IARP Member and Observer Countries

Australia	*Hugh Durrant-Whyte*
Austria	*P. Kopacek*
Belgium	*Y. Baudoin*
Brasil	*Liu Hsu*
Canada	*E. Dupuis*
China, P.R	*Qiang Huang*
European Commission (Observer)	*P.Karp* *Wolfgang Boch*
France	*Philippe Bidaud* *Etienne Dombre*
Germany	*R. Dillmann*
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Japan	*Kazuhito Yokoi*
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Poland	*A.Maslowski*
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Spain	*M. Armada*
United Kingdom	*G. Pegman*
USA	*Michael M. Reischman*

IARP Executive Committee

President :	*N. Caplan (USA)*
Vice-President	*G.Pegmann (UK)*
Executive Secretary :	*E.Dombre (FR)*
JCF 2011 Chair	*Mun-Sang Kim (KO)*

Time schedule

The contribution should focus on theories, principles and developments which have been explicitly developed for robots (terrestrial, aerial), and carried sensor systems for environmental surveillance, risky interventions, in the Humanitarian De-Mining in particular

An **abstract** of approximately 300 words (in English) should be received not later than ***.5 March 2012***

Electronic submissions of the abstracts (Word, PSF, PDF-files) should be e-mailed to:

nikola.pavkovic@ctro.hr **and**
Yvan.baudoin@rma.ac.be

- Final selection and invitation of participants: **March, 30, 2012**
- Receipt full ready **e-papers**: **April, 15, 2012**

Organization Committee

Workshop Co-Chair:
Prof. Yvan Baudoin, RMA, Brussels.
MSc Nikola Pavkovic, CROMAC-CTDT Director

Workshop inquiries to:

Workshop *HUDEM'2011'*
Prof Y.Baudoin
Royal Military Academy, Brussels, Belgium
Phone +32 2 742 6553 Fax: +32 2 742 6547

IARP International Advanced Robotics Programme

HCR CENTAR ZA TESTIRANJE, RAZVOJ I OBUKU d.o.o.

10th IARP Workshop

Robotics and Mechanical assistance in Humanitarian De-mining and Similar risky interventions

HUDEM'2012

24-26 April, 2012

Coupled with the
9th International Humanitarian Demining Symposium

Šibenik
Croatia
Call for Abstracts

Tiramisu

IARP
International Advanced Robotics Programme

TIRAMISU

Toolbox Implementation for Removal of Anti-personnel Mines, Submunitions and Uxo

SEVENTH FRAMEWORK PROGRAMME

REA

10th International IARP Workshop HUDEM'2012

Paper N°	Title	Author, Co-authors
1	**TIRAMISU: FP7 project developing a comprehensive toolbox for Removal of Anti-personnel Mines, sub-munitions and UXO**	**Vinciane Lacroix[1], et Al[2]** **[1]Royal Military Academy Brussels, Belgium** **[2]TIRAMISU Partners**
2	**IARP, International Program sustaining the Robotics for Humanitarian demining and Risky interventions**	**Yvan Baudoin[1], Manuel Armada[2], Andrzej Maslowski[3]** **[1]Royal Military Academy, Brussels, Belgium** **[2] Centre for Automation and Robotics – CAR (CSIC-UPM), Madrid, Spain** **[3] Institute of Systems and Robotics, University of Coimbra, Portugal** manuel.armada@csic.es a.maslowski@imm.org.pl
3	**TriDem- A Wheeled Mobile Robot for Humanitarian Mine Clearance**	**Yvan Baudoin[2], Ioan Doroftei[1]** **[1]Technical university GH Agashi of Iasi, Romania** **[2]Royal Military Academy, Brussels, Belgium** idorofte@mec.tuiasi.ro
4	**Bio-inspiration and Mine Detection**	**Maki K Habib, American university of Cairo, Egypt** **Maki@ieee.org**
5	**Complete coverage path planning of mobile robots for humanitarian demining**	**Marija Đakulović and Ivan Petrović** **University of Zagreb, Croatia** marija.dakulovic@fer.hr ivan.petrovic@fer.hr
6	**Extended Information Filtering and nonlinear control**	**Gerasimos Rigatos**

	for cooperating robot harvesters	**Harper Adams University College** grigat@ieee.org
7	**A robust, simple, low-cost autonomy enhancement module for LOCOSTRA, a remotely controlled demining machine**	**Michal Przybylko, Emanuela Elisa Cepolina, Gianni Polentes[1] and Matteo Zoppi[2]** **[1]Pierre Trattori snc, Silvano d'Orba, Italy** **[2]University of Genoa, Italy** mprzybylko@tlen.pl giovannipolentes@pierretra.com zoppi@dimec.unige.it patfordemining@gmail.com
8	**State of the art review on Mobile Robots and Manipulators for humanitarian demining**	**, M. Armada[2], R. Fernández[2], H. Montes[2] , L. Marques[1], A. T. de Almeida[1]Y.Baudoin[3]** **[1]University of Coimbra, Portugal** **[2] Centre for Automation and Robotics – CAR (CSIC-UPM), Madrid, Spain** **[3]Royal Military Academy, Belgium** lino@isr.uc.pt **manuel.armada@csis.es** roemi.fernandez@car.upm-csic.es hector.montes@csic.es adealmeida@isr.uc.pt
9	**Qualitative Spatio-temporal Representation and Reasoning Framework for Risky Intervention mobile robot's operator training Design**	**Janusz Będkowski[1], Paweł Musialik[1], Andrzej Masłowski[1], Yvan Baudoin[2]** **[1]Institute of Mathematical Machines, Warsaw, Poland** **[2]Royal Military Academy, Brussels** **Janusz.bedkowski@gmail.com** **amaslowski@imm.org.pl**
10	**Identification and classification of tools and missions needing e-training of Humanitarian Demining staff with use of computer simulation**	**Andrzej Kaczmarczyk, Marek Kacprzak, Andrzej Masłowski** m.kacprzak@imm.org.pl
11	**Sensors for close-in detection of explosive devices – current status and future prospects**	**Lino Marques[1], Giovanni Muscato[2], Yann Yvinec[3], Markus Peichl[4], Giovanni Alli[5], Graham Turnbull[6], Salvo Baglio[2], Anibal de Almeida[1]** **[1]University of Coimbra, Portugal** **[2]University of Catania, Italy** **[3]Royal Military Academy, Belgium** **[4]VALLON GmbH, Germany** **[5]IDS, Italy** **[6]USTAN, UK** gmuscato@diees.unict.it yann.yvinec@rma.ac.be lino@isr.uc.pt Holger.Wolfmayr@vallon.de g.alli@ids-spa.it gat@st-and.ac.uk
12	Robotic Complexes of integrated systems for environmental demining of minefields	**Marin Midilev** **Bulgaria** midilev@abv.bg
13	**Results of ESA's Space Assets for Demining Assistance Feasibility Studies**	**Dr. Michiel Kruijff** SERCO/ESA, Noordwijk, The Netherlands, michiel.kruijff@esa.int

		Dr. Daniel Eriksson Geneva International Center for Humanitarian Demining, Geneva, Switzerland, d.eriksson@gichd.org **Dr. Thomas Bouvet** European Space Agency (ESA), Noordwijk, The Netherlands, thomas.bouvet@esa.int **Mr. Alexander Griffiths** Swiss Foundation for Mine Action (FSD), Geneva, Switzerland, geneva@fsd.ch **Mr. Matthew Craig** Cranfield University, United Kingdom, m.p.s.craig@cranfield.ac.uk **Prof. Hichem Sahli** Vrije Universiteit Brussel, Brussels, Belgium, hichem.sahli@etro.vub.ac.be **Mr. Fernando Valcarce González-Rosón** INSA S.A., Madrid, Spain, fvalcarce@insa.org **Mr. Philippe Willekens** International Astronautical Federation, Paris, France, philippe.willekens@iafastro.org **Prof. Amnon Ginati** European Space Agency (ESA), Noordwijk, The Netherlands, amnon.ginati@esa.int
14	**Comparing different gradiometer configurations for underwater survey and demining**	**Yann Yvinec** Royal Military Academy, Brussels, Belgium Yann.yvinec@rma.ac.be
15	**Airborne wide area general assessment of the environment pollution due to the exploded ammunition storages**	**Milan Bajic** Scientific Committee of Centre for testing, development and training Ltd., Zagreb, Croatia milan.bajic@zg.t-com.hr
16	**Proposal for construction of demining machines and trailers for the transport of dangerous goods carried out within the project TIRAMISU**	**Marcin SZCZEPANIAK, PhD, Wiesław Jasiński** **WITI, Military Institute of Engineer Technology, Wrocław, Poland** szczepaniak@witi.wroc.pl
17	**First results: Robot mapping of sites contaminated by landmines and unexploded ordnance.**	**Kjeld Jensen[1], Leon B. Larsen[1], Kent S. Olsen[1], Jens Hansen[2], Rasmus N. Jørgensen[1]** [1]Institute of Chem-, Bio- and Environmental Technology, University of Southern Denmark Campusvej 55, 5230 Odense M, Denmark Phone: (+45) 27781926, email: kjen@kbm.sdu.dk [2]Lynex, Aalsøvej 2, 8240 Risskov, Denmark
18	**An overview of GIS-based Multi-Criteria Analysis of priority selection in humanitarian demining**	**Nenad Mladineo*, Snjezana Knezic* and Marko Mladineo**** University of Split, Faculty of Civil Engineering, Architecture and Geodesy E-mail: mladineo@gradst.hr ** University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, E-mail: marko.mladineo@fesb.hr

General Programme of the 9th International Symposium HUDEM: www.ctro.hr (not yet updated)

The schedule of both the symposium and the workshop IARP may slightly vary: definitive program on site

14.00 – 18.30 10th IARP WORKSHOP HUDEM'2012
Moderators: Yvan BAUDOIN (RMA),Andzej MASLOWSKI IMM), Manuel ARMADA (CSIC)

14.00 – 14.15 **Milan Bajic**: Airborne wide area general assessment of the environment pollution due to the exploded ammunition storages

14.15 – 14.30 Maki K Habib: Bio-inspiration and Mine Detection

14.30 – 14.45 Marija **Đaković and Ivan Petrović**: Motion Planning of Mobile robots for Humanitarian demining

14.45 – 15.00 **Lino Marques:** Sensors for close-in detection of explosive devices – current status and future prospects

15.00 – 15.15 Gerasimos G. Rigatos : Extended Information Filtering and nonlinear control for cooperating robot harvesters

15.15 - 15.30 **Michal Przybylko, Emanuela Elisa Cepolina, Gianni Polentes and Matteo Zoppi**: A robust, simple, low-cost autonomy enhancement module for LOCOSTRA, a remotely controlled demining machine

15.30 – 15.45 **L. Marques, A. T. de Almeida, M. Armada, R. Fernández, H. Montes , Y.Baudoin:** State of the art review on Mobile Robots and Manipulators for humanitarian demining

15.45 PAUSE

16.30 – 16.45 **Kjeld Jensen1, Leon B. Larsen, Kent S. Olsen1, Jens Hansen, Rasmus N. Jørgensen**
First results: Robot mapping of sites contaminated by landmines and unexploded ordnance.

16.45 – 17.00 **Janusz Będkowski, Paweł Musialik, Andrzej Masłowski, Yvan Baudoin**: Qualitative Spatio-Temporal Representation and Reasoning Framework for RISE mobile robot's operator training Design

17.00 – 17.15 **Andrzej Kaczmarczyk, Marek Kacprzak, Andrzej Masłowski**: Identification and classification of tools and missions needing e-training of Humanitarian Demining staff with use of computer simulation

17.15 - 17.30 **Marcin Szcepaniak:** Proposal for construction of demining machines and trailers for the transport of dangerous goods carried out within the project TIRAMISU

17.30 – 17.45 **Nenad Mladineo*, Snjezana Knezic* and Marko Mladineo:** An overview of GIS-based Multi-Criteria Analysis of priority selection in humanitarian demining

17.45 – 18.00 **Marin Midilev** : Robotic Complexes of integrated systems for environmental demining of minefields

18.00 – 18.15**: Y.Baudoin,I.Doroftei** : TriDem- A Wheeled Mobile Robot for Humanitarian Mine Clearance

Background

Robotics solutions properly sized with suitable modularized mechanized structure and well adapted to local conditions of dangerous unstructured areas can greatly improve the safety of personnel as well as the work efficiency, productivity and flexibility. Solving this problem presents challenges in robotic mechanics and mobility, sensors and sensor fusion, autonomous or semi autonomous navigation and machine intelligence.
The workshop will review and discuss the available technologies, their limitations, their adaptability to different environmental natural or artificial calamities (humanitarian demining (OTTAWA convention, OSLO convention including the detection of sub-munitions) and discusses the development efforts to automate tasks related to detection / interventions processes wherever possible through the use of Robotics Systems and other technologies. The FP7 project TIRAMISU will be introduced.

Scope and Topics

Specific topics include but are not limited to:

- Tele-operations
- Mobile Robotics Systems (Design, control, command) for unstructured environments (UGV,UAV, multi-robotics cooperation)
- Conventional and Autonomous Hybrid Vehicles
- Sensors and sensor fusion for detection as well as for robot localization
- Demonstrators – Tests Results
- Human Machine Interface

The workshop will also review and discuss the available risky intervention/environmental surveillance technologies along with their limitations and discusses the development efforts to automate tasks related to detection / decontamination / neutralization process wherever possible through robotization. Other Specific topics thus include but are not limited to:

- Inspection of fire or crisis grounds
- CBRN-E threats
- Map building and reconstruction
- Networked crisis management tools
- Remote controlled, semi-autonomous, autonomous robot navigation
- Victim Detection
- Swarm of robots
- Crisis Management Information Systems

IARP Sponsoring countries

Belgium,Canada, Korea, Poland, Russia, Spain

IARP WG HUDEM IPC

M.Armada
R.Babajko
A.Benkhalifa
K. Benkhalifa
M.H.Bedoui
K.Berns
P.Bidaud

E.Cepolina
R.Chesnay
F.G.Cordova
J.L.Coronado
J.Dai
A.T.de Almeida
K.Debruyn
R.Dillmann
P.Drews
R.Fathallah
F.Gamaoun
P.Gonzales de Santos
M.K.Habib
J.Hewit
W.Khalil
K.R.Kozlowski
D.Lefeber
Man Wook Han
M. Chaaban
A. Maslowski

R.Molfino
C.Morconi
K.Munsang
K.Nonami
A.Pajaziti
C.Parra
M.D.Penny
N. Perić
I.Petrovic
L.Romhdane
A.Rao
A.Safiotti
H.Sahli
J.C.Samin
U.Schmucker
L.Seneviratne
L.Steinicke
O.Tokhi
S.Tzafestas
L.Vatja
H.Van Brussel
J.C.van den Heuvel
D.van Zwynsvoorde
F.Verhaege
N.Vincent
G.S.Virk

Venue

The workshop will take place in ***Šibenik***

By establishing the mine action system in Croatia, the Croatian Mine Action Center (CROMAC) created preconditions to engage in research and development and improvement of mine action techniques, technology and methods, testing of machines, mine detection dogs and handlers, testing and field evaluation of modern technologies, education and expert assistance to the countries in the Region and wider

TIRAMISU
Toolbox Implementation for Removal of Anti-personnel Mines, Sub-munitions and UXO

Dr Ir Vinciane Lacroix
Royal Military Academy, Brussels, Belgium
Vinciane lacroix@rma.ac.be
www.fp7-tiramisu.eu

OBJECTIVE

The goal of the FP7 Project TIRAMISU project is to prepare a series of cost-effective **tools integrated in a comprehensive modular toolbox** for Humanitarian Demining, explosive remnants of war (ERW) and unexploded ordnance (UXO) removal tasks and a related operational implementation of services, including standardization actions.

As every situation is different, it is impossible to provide one solution for Humanitarian Demining that fits all needs. The TIRAMISU project will concentrate on developing components or building blocks, which can be directly used by the Demining managers when planning Mine Actions, from area reduction to effective mine-clearance.

This objective will cover the following Mine Action Processes :

1. The **Land impact survey** by developing tools to enable the prioritization on the most threatening and the most useful areas to the society.
2. The **Non-technical survey** (Area Reduction) by developing tools for collecting and analysing information about a hazardous area in order to establish the perimeter of the actual hazardous areas without physical intervention.
3. The **Technical Survey** (Area Reduction) by developing tools to get indicators of absence of mines
4. The **Clearance** by developing tools reducing the cost and increasing the speed of (full) clearance, which includes close-in-detection and neutralisation

Taking into account the **end-user's needs**, as they are currently known, and their associated challenges, the TIRAMISU toolbox will be structured into modules. Each module is a set of tools **aimed at the solution of a specific activity or issue related to** Mine Action. The concept of Tool used here, is a generic expression to define a **service** (analysis/software/hardware), a **method**, **equipment** (sensor, platform, protective device, etc.), a **GIS product**, among others

Besides the modules dedicated to the above list of mine action processes, the toolbox will also include a Mine Risk Education module and a personnel equipment module.

OPERATIONAL IMPLEMENTATION

The TIRAMISU toolbox will contain modules based on improved, and possibly standardized or certified, tools associated with their training tools. Moreover, the tools will be validated by end-users in mine-contaminated countries when necessary.

The TIRAMISU toolbox will not duplicate tools that already exist although it will refer to them

The philosophy of the TIRAMISU project is to concentrate most of its efforts on the most mature technologies and methods while still investigating promising and innovating even solutions

The TIRAMISU toolbox will address the operational needs of tools for mine actions in world-wide civilian contexts. A number of scenarios will be selected for their diversity with respect to conflict type, time passed after conflict resolution, climate type, and socio-economic situation. The tools will be defined by the consortium with the help of a large panel of end-users (EUB) involved in the considered scenarios.

A Project Advisory board made of experts (consultants in MA, specialists in conflict/post-conflict analysis, etc.) will provide advice and guidance to the project staff concerning the Project's overall content, direction, priorities, methods and dissemination.

NORMALISATION

The work done in TIRAMISU will naturally lead to standardization through two processes:

- When specifications written for some TIRAMISU tools have a larger benefit to the mine action community, they will form the basis for a new standard;
- Test and evaluation protocols that will be written to evaluate some of the tools can also benefit the mine action community and, when they do, they will serve as starting points for new standards;

INTEGRATION

The integration of the TIRAMISU toolbox will be made through two different means: a TIRAMISU website toolbox the TIRAMISU Information Management and Analysis System (T-IMS)

The TIRAMISU toolbox Website will be set up at the beginning of the TIRAMISU project and will be fed throughout the project."

Six months after the kick-off meeting, the site should already contain detailed information on the state of the art. After the project, the site would be transferred to the Geneva International Centre for Humanitarian demining.

USERS

The toolbox will be designed to provide useful information to three different kinds of end-users:

- Mine Action Centres, who will find details on:

    - "Ready-to-take" tools and other tools (e.g, metal detectors, mechanical devices with their tests and evaluation reports, and training)
    - information about companies offering services for Impact Survey, Technical Survey, or information services subject to agreement with a TIRAMISU partner (for example sensors data)

- Any contracting company involved in Mine Action will find information useful for providing services to NMAA/MAC (such as prioritization tools, GIS dedicated to mine action, guidelines to perform Impact Surveys, access to Earth Observation (EO) and non EO data), list of modules given a specific scenario, etc.)
- Industrial or software companies will find details on tested prototypes and demonstrated methods in order to commercialize tools not developed by the industrial partners of the TIRAMISU consortium

For each tool, the point of contact, descriptive sheets, cost information, training tools, and all other relevant information will be available and accessible externally.

The TIRAMISU toolboxWebsite will include a service gateway that will provide end-users with a user-friendly interface (interactive Website, including Web-GIS tools) for information and services access.

Any sequence of TIRAMISU modules used in a given scenario will be integrated in the sense that the output data of one module will be compatible with the input of the next one. The T-IMS will guarantee this compatibility.

Many of the tools that are a part of TIRAMISU already exist in some form (prototype, first release or mature system). This would most likely lead to some problems if the TIRAMISU project would aim at a complete integration into a common application framework and a unified user interface.
In order to avoid unnecessary costs the project will focus on a loose integration based on a common data exchange format (tsuXML). The data exchange format will cover all data structures and elements that are needed through the TIRAMISU workflow (raw data like imagery is not covered by the xml scheme and will be exchanged as separate files). Each data transmission between two tools may use the parts of tsuXML that are necessary to perform the next task.

The T-IMS will have an internal data structure that is capable of storing the complete dataset used in the TIRAMISU workflow.

Ref: FP7 GA 284747 (www.cordis.eu)

IARP

International Advanced Robotics Programme

G8 Initiative

2012 Status: www.iarp-robotics.org

AIM: FOSTER INTERNATIONAL COOPERATION in the development of ADVANCED ROBOTICS SYSTEMS able to dispense with human exposure to difficult activities in harsh, demanding or dangerous conditions or environments

US-UK-FRA-CDN-JPN-CHINA-SKOREA-RUSSIA-HUN-POL-BEL-NZEEL-AUSTRIA-ITA-SPAIN-GER-EUR COM

IARP
International Advanced Robotics Programme

One JCF per year – WARSAW in 2012
Objectives of the Joint Committee Forum:

- to get an updated information on the member’s programmes in Advanced Robotics
- to get an updated information on the yearly activities of the mandated working groups
- to plan IARP workshops on topics proposed by the Members
- to inform the European commission on the above mentioned programmes and get information on the EC planning in Robotics and related technologies

Working Groups

SSRR	Security, Safety, Rescue Robotics	Coord: USA …JPN
HUDEM	Robotics for Humanitarian De-mining	Coord: BEL (Y.Baudoin)
DEPEND	Dependability of Robotics Systems	Coord: FRA
RISE	Robotics for Risky Interventions and Surveillance of the Environment	Coord: BEL-GER (Y.Baudoin – R.Dillman)
ASSIST	Assisted Living Quality of Life	Coord: UK, USA
ULTRA	Medical Robotics and UltraOperations	Coord: USA

WG Tasks

- Define a Technical Activity Program (TAP)
- Yearly report on existing Programs/projects and related funds/IARP country
- Yearly formulate according recommendations towards National and International Funding Authorities (updated related roadmap)
- Periodically inform the official members of the IARP on progresses, projects, relevant events, proposal-calls, etc
- Yearly organise a dedicated IARP Workshop
- Inform on and update the list of the members of the WG
- Update a page on the Website http://iarp.isir.upmc.fr

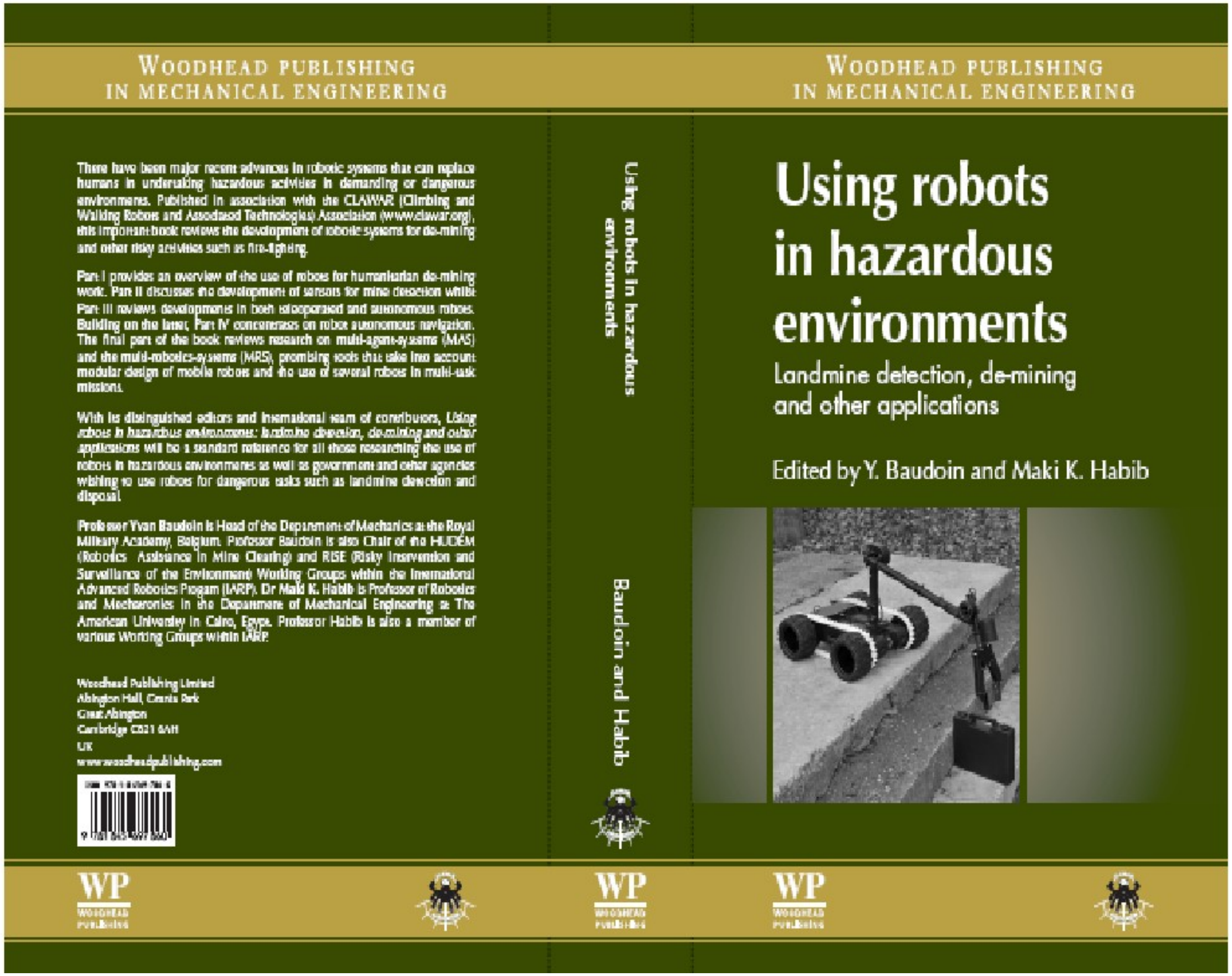
WG HUDEM

Working Group	HUDEM
Title:	Robotics for humanitarian de-mining
Description:	Establishment of detailed minimal requirements, design concepts, standards and procedures for the implementation of robotics systems for humanitarian de-mining
Aim:	Organization of a (bi-) yearly workshop
Request:	IARP
Category:	Robotics Assistance, Multi-robotics, Sensor Systems (detection)
Type:	R&D results exchange of information *R&D results sent to the ITEP (International Testing Evaluation Programme) www.itep.ws (now GICHD)*
Equipment:	N/A
Development:	N/A
Time Frame:	1998-2012
Coordination Place:	Belgium, Royal Military Academy (RMA)
Lead Nation(s)	Belgium
Partners:	IARP, EURON, CLAWAR Association, , a.o.
Point of contact:	Yvan Baudoin
E-mail:	Yvan.baudoin@rma.ac.be
Status:	Ongoing
Web site:	ww w.itep.ws (now GICHD) – http://mecatron.rma.ac.be
Comments:	•Ten IARP workshops have been organized to date: six scientific workshops (Toulouse 98, Vienna 02, Brusse 04, Tokyo 05, Cairo 08, Sousse 10) and two on-site workshops (Zimbabwe/Mozambique 00, Prishtina 02). Proceedings of the Workshops are available at the above-mentioned website. •Actualised Repertory of current projects available on request POC

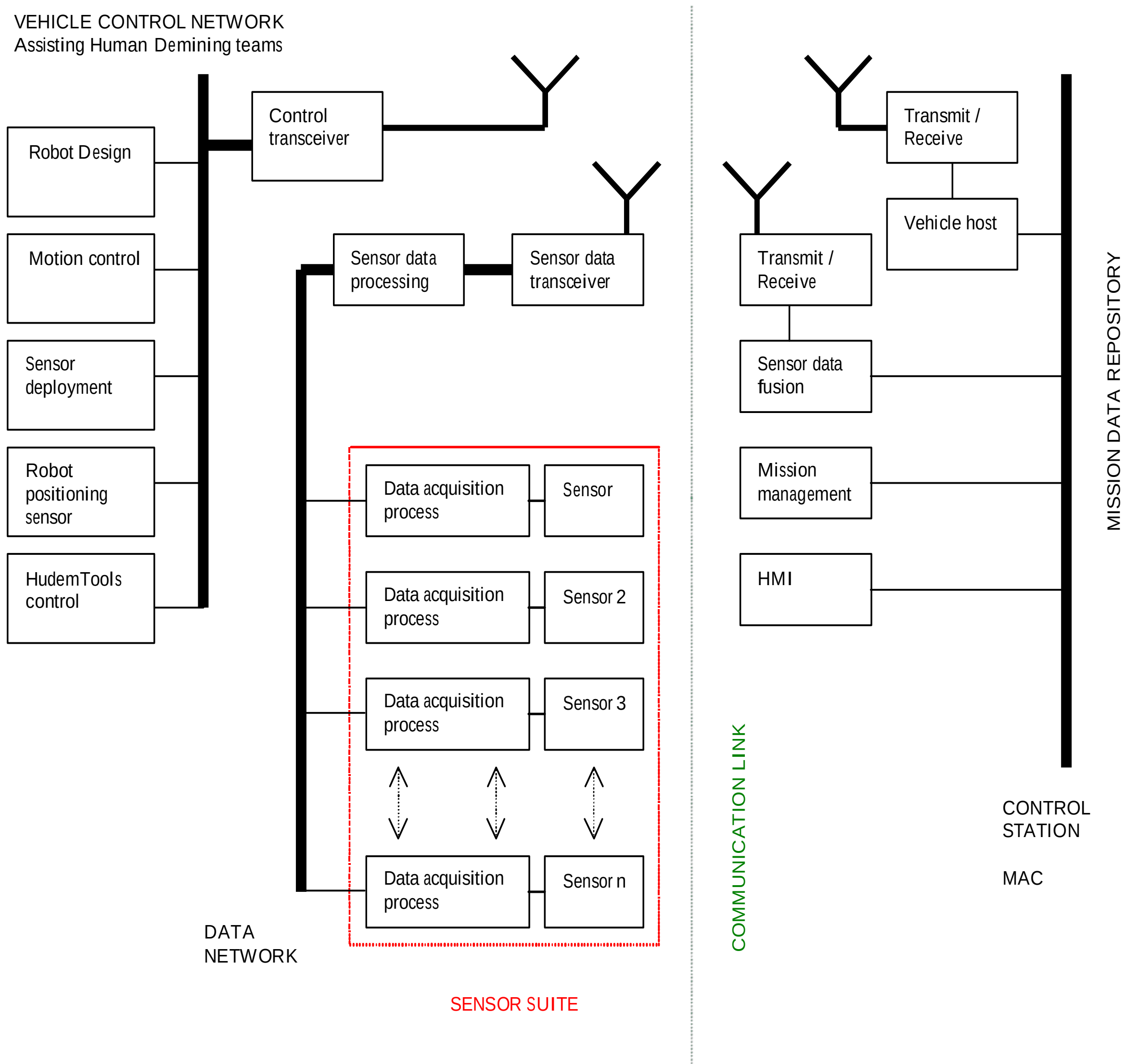
WG HUDEM

Roadmap	1.Collect the End-users Requirements (Ottawa, Oslo, Field) 2.Define the System Requirements (IARP Workshops) 3.Define the Platform requirements 4.Define the Testing procedures (RTO, (ELROB) a.o.) 5.Build or negotiate Test facilities (DOVO, Belgium) 6.Edit first repertory of UGV for Close-in detection 7.Edit a handbook on robotics and sensor technologies 8.Disseminate the Handbook (cooperation CLAWAR) 9.Introduce proposals through FP7-SEC topics 10.introduce other projects through Eureka, bilateral contacts, etc
Next action:	Although robots are promising systems some detection tasks, only prototypes were and a currently in development and partial on-site tests (described in the proceedings of the IAR WS and on the ITEP Site) have been done. This application, extended to the sub-munitions (OSLO Convention) remains interesting a will be pursued through - FP7-SEC proposals (TIRAMISU) -Actualized Handbooks and workshops (11th in Sibenic April 2013)

First Handbook (2011)



1st and 2nd WS (Zimbabwe, Toulouse) : Definition of the modules to develop by RS



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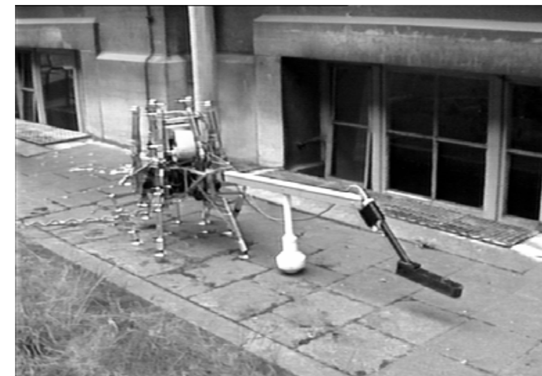
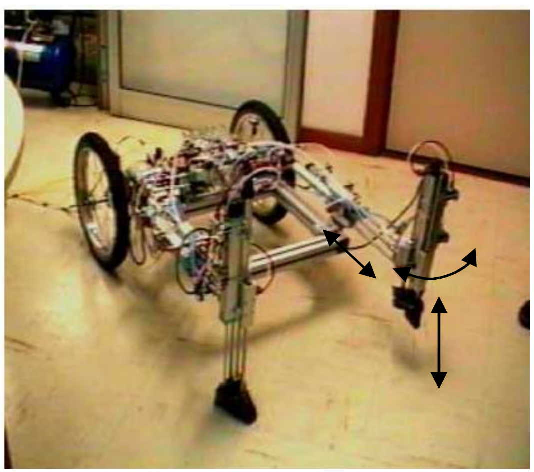
3-4-5th IARP WS HUDEM (Vienna-Pristhina-Brussels) – Description of <u>first</u> prototypes

(support: European CLAWAR Network – multi-legged robots)(EOD robots)



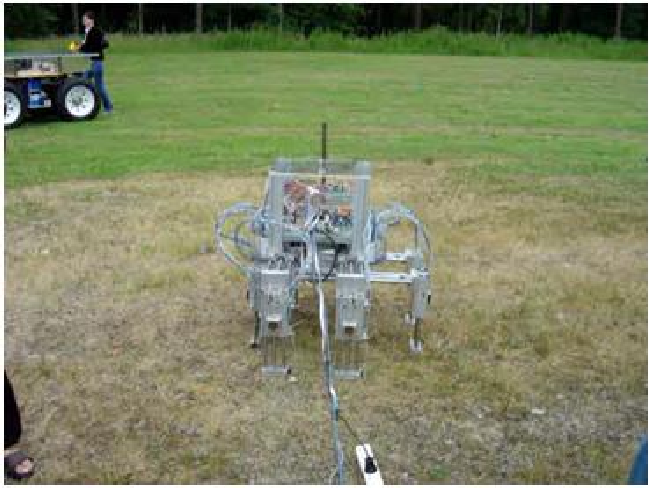


3-4-5th IARP WS HUDEM (Vienna-Pristina-Brussels – minimal requirements

- **High Mechanical Reliability**: robust material and electronics to support high humidity, high temperature, dust, sand, rain, etc.
- Good resistance to accidental explosions: a protection shield could be a solution.
- **Easy to use**: A simple man-machine interface must be provided in order to allow a non-robotic expert operator to control the robot.
- Easy to repair: A modular construction can help to repair the robot easily and efficiently. Legs/feet, as the devices more in danger on an accidental explosion should be simple and modular and able to be re-constructed with simple materials.
- **Low cost**: In general all the parts should be based in systems spread all over the world. Mechanical parts could be based on very simple designs

(simple rods, etc). Electronics and computers based in PC technologies, etc.

- **Autonomy**: At least half a day of autonomy is required. In electrical robots this can also be accomplished using petrol engine onboard or using tethers for supplying the power from outside the robot. The handle of the tether can be a great problem to be solved



IARP International Advanced Robotics Programme

3-4-5th WS Vienna, Kosovo - Usefulness

- Improvement of the safety in very dense minefields or fields containing a high percentage of iron (1/3 of the areas treated in Cambodia, for instance): a precise scanning, according to well- drilled motion-procedures, could allow the mapping (terrain modelling AND mine localisation) of unstructured areas with the same (or better) effectiveness (than this one of the Human deminers) and improved safety.
- Improvement of the 'productivity' of Human Deminers
- Progressive implementation of High-Level/Low-Level Scanning procedures (unmanned aerial/ground vehicles cooperation)
- Multi-Tooling of a mobile robot
- Quality Assurance (post-demining inspection)
- Dual-Use:

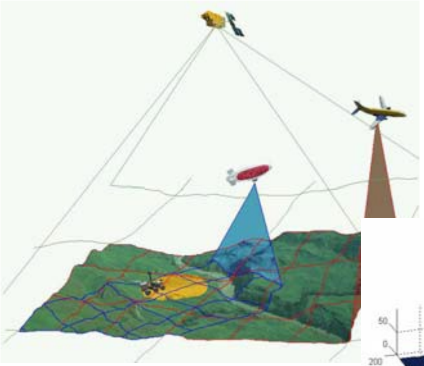
- Systematic inspection of dangerous areas after earthquakes

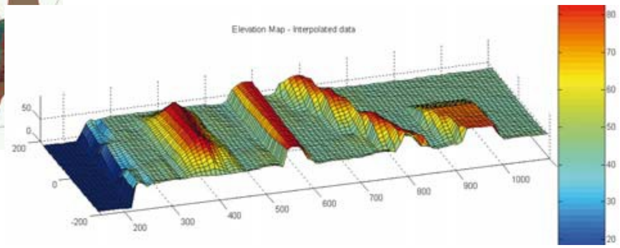
- Systematic inspection of dangerous areas after Nuclear/Chemical accidents

- Space applications (March Rover…)

-Survey of forests and prevention of Fires

-Military Robotics (including the Mine-clearing Ops during Peace-keeping/maintaining missions





IARP
International Advanced Robotics Programme

6-7-8thh IARP WS HUDEM (Tokyo-Cairo-Sousse))

Improvement and testing of Robots/Sensors

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DYLEMA- CSIC (MD-GPR)

SCARA ALYS, Prof Nonami Shigeo JPN

GRYPHON Prof Ishikawa Tokyo JPN

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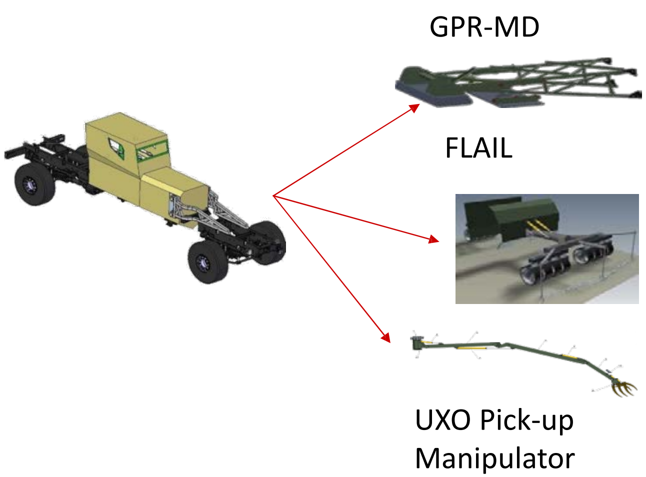
IARP International Advanced Robotics Programme

9-10th WS – Sibenic : Technical Survey – Close-in-detection – clearance – Control - Training

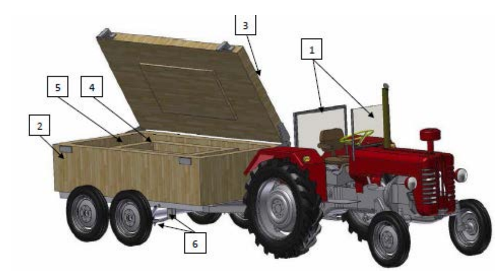
2011: LOCOSTRA Test in Jordan
(SNAIL-AID, PIERRE)

2012: A robust, simple, low-cost autonomy enhancement module for LOCOSTRA, a remotely controlled demining machine: Michal Przybylko, Emanuela Elisa Cepolina, Gianni Polentes[1] and Matteo Zoppi[2] (DIMEC, PIERRE)



2011: Concept, MILITARY INSTITUTE OF ENGINEER TECHNOLOGY

2012: Proposal for construction of demining machines and trailers for the transport of dangerous goods carried out within the project TIRAMISU: Marcin SZCZEPANIAK, PhD, Wiesław Jasiński, (WITI)



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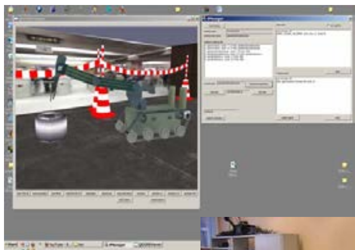

2011: Training with Robots

2012: Identification and classification of tools and missions needing e-training of Humanitarian Demining staff with use of computer simulation: Andrzej Kaczmarczyk, Marek Kacprzak, Andrzej Masłowski (IMM)

2012: Qualitative Spatio-temporal Representation and Reasoning Framework for Risky Intervention mobile robot's operator training Design:Janusz Będkowski[1], Paweł Musialik[1], Andrzej Masłowski[1], Yvan Baudoin[2] (IMM, RMA)

2011: ROBUDEM, BBN of RC Sensor carrier (RMA)

2012: TRIDEM, project of teleoperated dog-like post-scanner for QA: Y.Baudoin, I.Doroftei (RMA-TUI)

2012: State of the art review on Mobile Robots and Manipulators for humanitarian demining:L. Marques[1], A. T. de Almeida[1], M. Armada[2], R. Fernández[2], H. Montes[2] , Y.Baudoin[3] (ISR-UC, CSIC-CAR, RMA)

2012: Robot mapping of sites contaminated by landmines and unexploded ordnance. Kjeld Jensen, Leon B. Larsen, Kent S. Olsen, Jens Hansen, Rasmus N. Jørgensen (*University of Southern Denmark Campusvej*)

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9-10th WS – Sibenic : Technical Survey – Close-in-detection – clearance – Control - Training

2012: Sensors for close-in detection of explosive devices – current status and future prospects: Lino Marques[1], Giovanni Muscato[2], Yann Yvinec[3],Salvo (ISR-UC, UNICT, RMA,VALLON, USTAN)

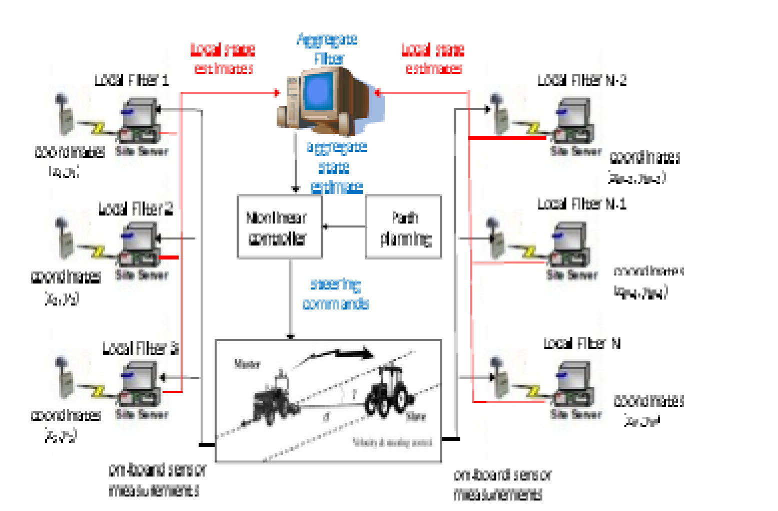
2012: Bio-inspiration and Mine Detection: M.K.Habib, UN CAIRO

Efforts were focusing to determine whether trained foraging bees can reliably and inexpensively search wide areas for the presence of landmine chemical signatures, such as TNT, at very low concentration, and possibly other explosive materials in bombs and landmines, as well as other chemicals of interest,

including drugs and even decomposing bodies.

ISR-UC S-O ground detection (L.Marques)

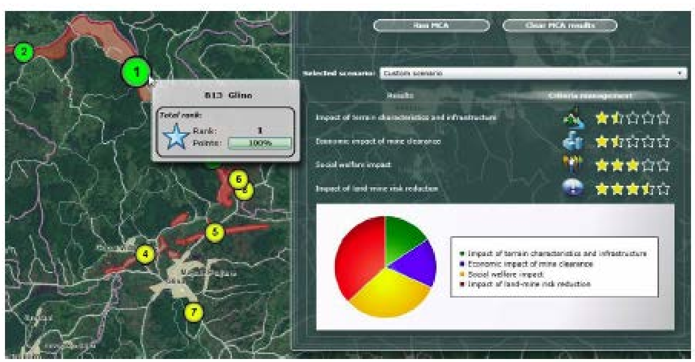
9-10th IARP WS SIBENIC



2012: Extended Information Filtering and nonlinear control for cooperating robot harvesters (G.C. Rigatos)

2012: Complete coverage path planning of mobile robots for humanitarian demining: Marija Đakulović and Ivan Petrović University of Zagreb, Croatia

2012: Airborne wide area general assessment of the environment pollution due to the exploded ammunition storages: Milan Bajic, Croatia



2012: An overview of GIS-based Multi-Criteria Analysis of priority selection in humanitarian demining : Nenad Mladineo, Snjezana Knezic, Marko Mladineo

Figure 1. The ammunition storage Padjene: a) before the explosion, shown on the satellite IKONOS image 29.03.2006 (Google Earth Pro); b) one month after the explosion shown on the aerial photography 13.10.2011.

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TIRAMISU

Toolbox Implementation for Removal of Anti-personnel Mines, Submunitions and Uxo

Towards a Network of End Users: contact Yann Yvinec@rma.ac.be

•We thank Nikola Pavkovic, Milan Bajic, Sanja Vakula and their colleagues for having hosted the 10th IARP WS HUDEM

•We thank CTDT, FGUNIZ, CROMAC, ITF for their active support by the preparation of the TIRAMISU proposal, hoping we may further cooperate to reach the objectives of the OTTAWA and OSLO threaties

•We thank GICHD for his support through our Project Advisory Board and the Belgian DOVO for the sharing of his large experience over the world

We thank all of you, and particularly the IARP WS attendees for your kind company

Yvan Baudoin, Ioan Doroftei

TriDem - A Wheeled Mobile Robot for Humanitarian Mine Clearance

***Abstract*—There are millions of lethal land-mines that have been left in many countries after a conflict. They represent a particularly acute problem in developing countries and nations already economically hard hit by war. The problem of unexploded mines has become a serious international issue, with many people striving to find a solution. This paper will discuss a wheeled mobile robot developed at the Royal Military Academy of Brussels in collaboration with Free University of Brussels, Belgium, in the framework of Humanitarian Demining Project (HUDEM).**

I. INTRODUCTION

MORE than 100 million of unrecovered anti-personnel and anti-tank mines can be found in more than 50 countries. It is estimated than mines hill or mutilate tens of people every day. In countries where the presence of landmines became a part of the everyday life, the consequences of landmines problem on humanitarian and environmental levels are very high (Colon *et al*., 1998; Habib, 2007; Habib, 2008).

There is an essential difference between military and humanitarian mine clearance operations in the Clearance Efficiency (CE). Military troops generally open a breach through a minefield while for humanitarian demining a high CE is required (99.6% according to UNO standards). This can only be achieved through a keen carding of the terrain and an accurate scanning of the infested areas, what implies the use of sensitive sensors and their slow systematic displacement, according to well-defined procedures on the minefields. This is where robots, carrying mine detectors, can play an important role (Colon *et al*., 2007).

It has been recognized that developing modular and cheap robotic systems that could offer reliable, cheap and fast solutions for the demining operations is an important challenge. The development and implementation of robotics in mine clearance is attractive and it is building up momentum to spare human lives and enhance safety by avoiding physical contact with the source of danger in mined area, improve accuracy, help in mined area reduction, increase productivity and enhance effectiveness of repetitive tasks, necessary in the demining process (Habib, 2008). Solving this problem presents challenges in robotic mechanics and mobility, sensors and sensor fusion, autonomous or semi autonomous navigation and machine intelligence.

Even if there are some reported researches into individual, mine-seeking robots is still at the early stages (Colon *et al*., 2002; Debenest *et. al*, 2003; Freese *et al*., 2006; Furihata and Hirose, 2005; Habumuremyi and Doroftei, 2001; Hirose and Kato, 1998; Hirose *et al*., 2005; Nonami et al., 2000; Tojo et al. 2004). In their current status, they lack flexibility and yet they represent a costly solution for mine clearance operation. But, if designed and applied at the right place for the right task, they can be effective solutions.

The automation of an application such as the detection and removal of antipersonnel mines implies the use of autonomous or teleoperated mobile robots. These robots follow a predefined path, send the recorded data to their expert-system (in charge of processing the collected data), mark the ground when a mine is detected with a probability of predefined level and possibly remove the detected mine.

The Belgian project HUDEM, which was focused on the detection, comprises three groups, each group dealing with one aspect of the problem. The first group was in charge of studying, evaluating and improving existing sensors, the second group developed algorithms to improve detection and the third one was responsible for robotics aspects. The Robotics Work Group was focused on: studying sustainable mechanical solutions for humanitarian mine clearance, developing of modular low-cost mobile platforms and developing of control algorithms using images of the environment and data coming from the mine sensors.

In this paper, the design of a simple, modular and cheap solution of wheeled mobile robot for humanitarian demining purposes will be described.

II. ROBOTIC SYSTEMS OVERVIEW AND REQUIREMENTS

Basically, the robotic systems for mine clearance are composed of the following elements: a vehicle, visual tracking and positioning systems, a control station with the Human Machine Interface.

The robotic systems for humanitarian demining can be divided into two categories: the ones having a scanning device that can be equipped with different sensors and the ones that can simply carry a single sensor. In this case, the scanning of an area can be obtained by moving the robot body itself. It is the case of our mobile robot described here.

Based on a state-of-the-art survey, we have defined some general requirements that a mechanical system for mines detection should meet and the possible solutions (see Table 1).

Reading the requirements, we will immediately find some contradictions: if we want to protect the vehicle and increase the autonomy, we also increase the weight; if we want to reduce the price, we have to use low cost, off-the-self components that do not resist very well to extreme conditions. We also have to limit electronic components, but these are essential to automate the mines detection and the motion control of the vehicle.

The best vehicle will result from a compromise between all these requirements. It is totally utopian to develop a vehicle that could be used in all circumstances: desert, wood,

TABLE I
REQUIREMENTS OF A ROBOTIC SYSTEM AND POSSIBLE SOLUTIONS

Requirements	**Possible solutions**
Low cost	Off-the-self technologies, large series
High mechanical reliability	Robust mechanics and electronics
Easy to service and repair	Modular design
Good resistance to explosions	Robust construction, a protection shield
Easy to deploy	Apparent limited command system
Easy to use	Simple Man Machine Interface
Easy transportable by a light vehicle	Light weight (Light materials)
Good autonomy	On board gas engine (stand alone or to produce electricity)
Water, sand, temperature and humidity resistant	Corrosion resistant material, high tech electronics

bush, hot or cold, wet or dry weather, etc. Furthermore, the characteristics of the vehicle will also depend on the way we will use it as explained in the next paragraph.

III. MINES DETECTION STRATEGY

Robotic systems could be used in different ways to help human deminers. Based on mine clearance teams' experience, the following scenario has been considered. Small autonomous vehicles equipped with different sensors run around to delimit the area of an assigned place that is really polluted with mines. This phase when done manually is one of the most dangerous one because deminers are working faster and are taking more risks than during a systematic detection. The mobile robot discussed here, named TriDem has been developed to study this first aspect.

Once the actual mined area is delimited, a systematic scanning process can begin. It has been proved that the use of different sensors could drastically improve the detection efficiency and reliability. However, the data fusion process requires the registration of the data acquired by the different sensors.

Our purpose is to develop systems to detect mines and not to destroy them. Based on this fact, we have also chosen to follow the existing demining procedures. When a mine has been discovered, its position is indicated with a beacon and the operation goes on in another corridor. Mines will be destroyed at the end of the day (or half of the day).

Different scenarios can be considered when replacing the man by machine. In the first scenario, we accept to sacrifice the robot; in this case we take the risk to roll over a mine and the vehicle must be disposable. In this case the sensors can be fixed everywhere on the robot.

The second scenario tries to preserve the robot. In this case, we cannot simply replace the man by a robot, because we will have to stop the robot each time when something has been detected and to go backwards and to maneuver to start in a new area. We also suppose that the mine zone is bordered by an area free of mines. The robot will follow the mine field while scan the ground laterally. Doing so, we do not have to stop the robot each time when a mine has been detected.

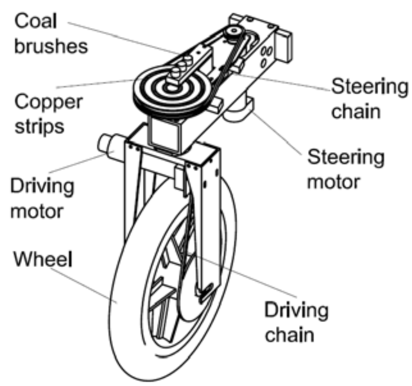
As everyone can imagine, the performance of a robotic system for humanitarian demining will rely principally on the quality of the detection system.

IV. TRIDEM MOBILE ROBOT

Based on the requirements discussed in Table 1, we have designed a modular wheeled robot where each wheel module is equipped with a driving and a steering motor. Thanks to the three steered standard wheels, the robot has omni-directional capabilities.

A. *Wheel architecture*

The wheel module architecture is shown in Fig. 1. There are two motors connected to each wheel, one for steering and the other for driving. Therefore, each wheel has the capability of steering and driving independently. In order to prevent wires from becoming entangled, the power is transmitted to the driving motors using coal brushes and copper strips. This will give to the wheel a 360º rotation for steering motion.



(a)

(b)

Fig. 1. Wheel module: a) 3D design; b) Real picture.

The speed of each motor is reduced by using chain transmissions. To avoid cumulative mechanical errors of wheels in the mobile robot, the wheel alignment process is implemented. This process enables all three wheels to align, making it easier for the mobile robot to navigate. The wheel alignment process is made possible by a luminary point marked on the circular copper strips plate and a photo sensor.

B. *Robot architecture*

A construction using three wheels insures a permanent contact with the ground without adding any suspension. The repairing requirements lead us to a modular design of our robot: three similar units of driving and steering wheels are fixed on the main frame (see Figure 2). The fastening and the connections of the units to the frame should be as simple as possible to allow a quick removal. In case of breakdown or damage a module can be easily replaced by a new one. The defective unit will either be repaired locally or returned to the factory for more important repair, or thrown away if it is badly damaged.

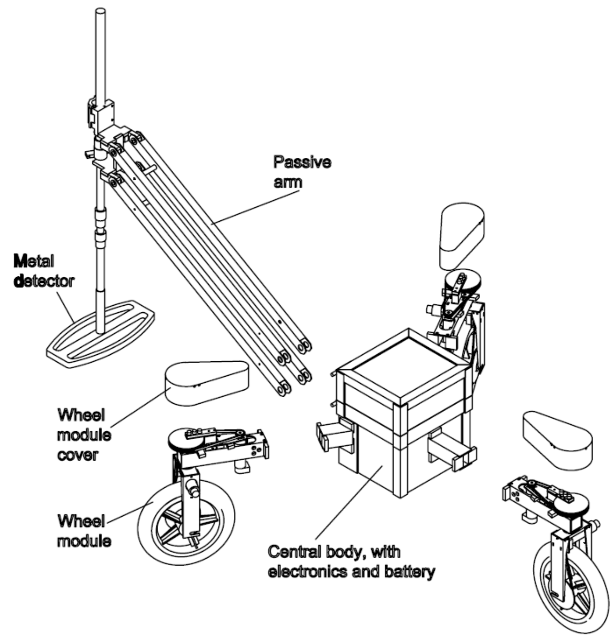


Fig. 2. Exploded view of the TriDem robot.

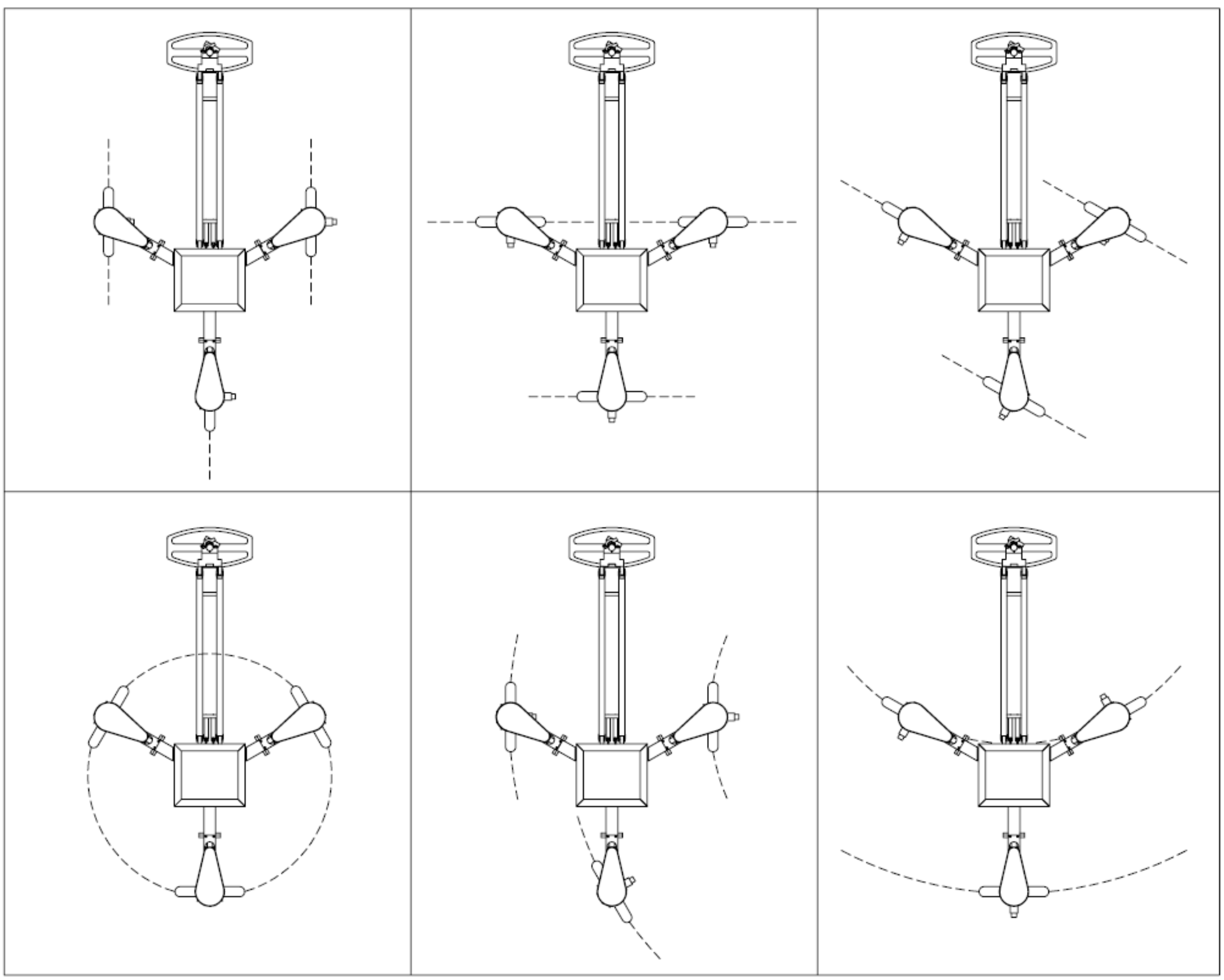


Fig. 3. Possible trajectories of the platform.

The wheels can be removed and replaced very easily because of the modular conception. All the wheel modules are identical and they are fastened to the robot frame with fast screw connections. The wires (signal and power transmission) of each wheel module are connected to the electronic board, placed in the central robot frame, via some standard connectors (DB15).

Thanks to the three steered standard wheels, we get an omni-directional mobile robot. It can perform a linear motion in any direction relative to its body; follow circular trajectories in different configuration or turn around its center (Figure 3). In contrast, a robot with synchronous drive can only perform linear motion. This means that a synchronous drive robot cannot follow smooth circular trajectories and cannot turn in place.

As drawbacks of this robot architecture, we can mention: the wheels should be very well aligned in order to avoid wheels slippage; when turning the wheels in place, on a surface with vegetation, it is happen with a high friction.

This platform can be used to locate minefields in areas that human deminers have difficulties to reach. For this reason, it has also been equipped with a spring articulated arm (with two parallelogram mechanisms) to carry light sensors. Springs are used to compensate the effect of gravity. This mechanism has one degree of freedom that allows the detector to move vertically in order to glide over obstacles. Thanks to this mechanism, the vertical axes of the robot and the one of the detector are permanently parallel.

C. Robot control

TriDem mobile robot can be controlled by a wired joystick, a remote control or a computer via serial communication. Communication between the remote computer and the onboard microcontroller is assumed by a Radio link RS232.

The robot has been tested on dummy minefields and it performs well on gravels and grass but not on sand due to the limited size of the tires. As it was mentioned before, on the grass, the wheels turn in place with difficulties. It can clear small positive and negative obstacles (5 to 10 cm) with the detector still following the ground.

The robot frame supports holding the control electronics and the batteries. TriDem has been designed to have a 20-kg payload and a speed of 0.1 m/sec.

Figure 4 illustrates a 3D view of TriDem robot and different pictures during the real test on different surfaces.

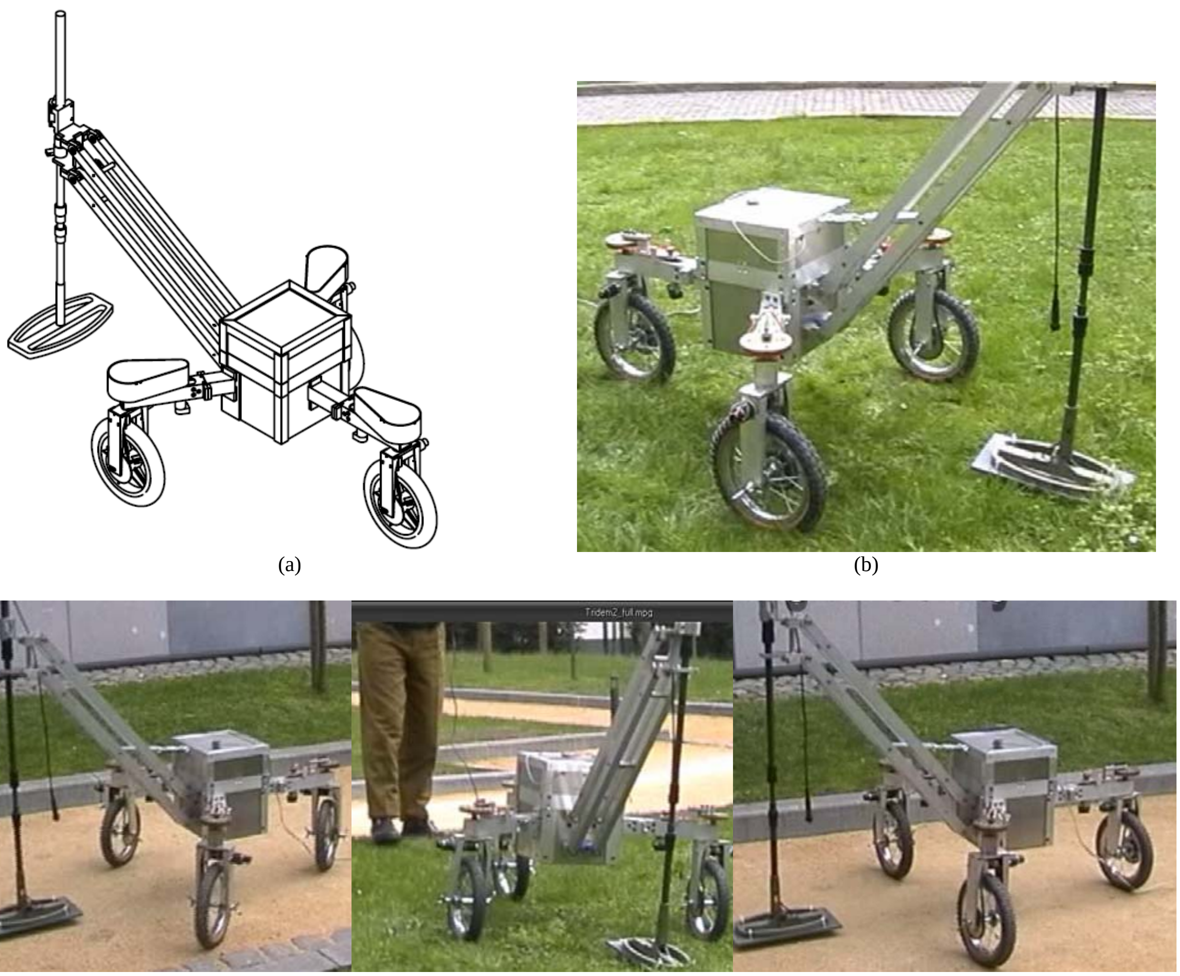


Fig. 4. TriDem wheeled robot: a) 3D design; b-e) real pictures during tests.

D. Robot kinematics

This section deals with the geometric kinematics modeling of TriDem omni-directional mobile robot. The kinematics modeling is divided into two parts, inverse kinematics and forward kinematics. Inverse kinematics is used to solve the angular velocities, ω_{w_i}, and steering angles, θ_{s_i}, of each wheel. Forward kinematics will estimate the position and heading angle of the mobile robot using the wheel measurement from the encoder.

It is assumed that there is no wheel slippage during the movement of the mobile robot.

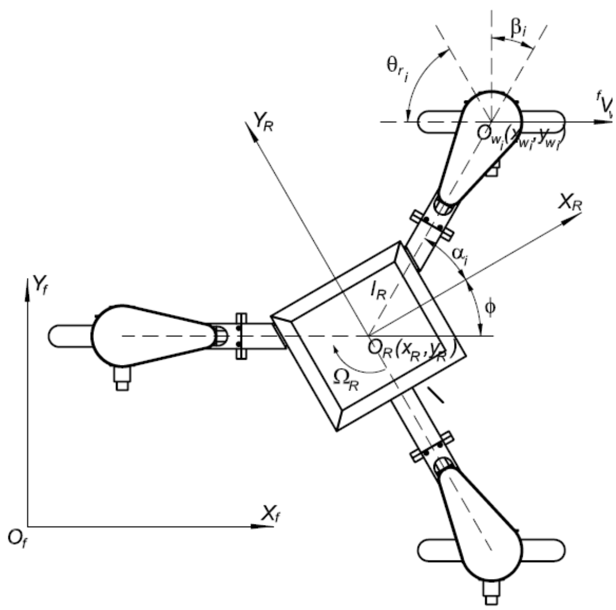


Fig. 5. Robot kinematics.

E. Inverse kinematics

We suppose to know: the linear velocities of the mobile robot in X and Y directions, ${}^{f}V_{l_x}$ and ${}^{f}V_{l_y}$, the angular velocity of the mobile robot, Ω_R, and the iteration number. Three coordinate systems are used in inverse kinematics: the floor coordinate system, $X_f Y_f$; the mobile robot coordinate system with its origin at the center of the platform, $X_R Y_R$; and, the wheel coordinate system with its origin at the center of each wheel, $X_w Y_w$. Each coordinate system consists solely of translation components, with no rotation components. A wheeled mobile robot's motion can be expressed in terms of translational and rotational motion. The translational component is the displacement of the mobile robot center, and the rotational component is the rotational movement of the axis of each wheel. Rotational components are expressed as follows:

$$\theta_{r_i} = \tan^{-1}\left(\frac{y_{w_i} - y_R}{x_{w_i} - x_R}\right) = \alpha_i + \beta_i\,, \tag{1}$$

where θ_{r_i} is the angle between the direction of translational speed of the i wheel and the Y_R axis; x_R, y_R and x_{w_i}, y_{w_i} are the coordinates of the mobile robot's center and each wheel's center with respect to the origin of the floor coordinate system; $i = 1 \div 3$.

The rotational velocity of each wheel with respect to axes of the floor coordinate system, ${}^{f}(V_{rx})_i$ and ${}^{f}(V_{ry})_i$, can be calculated as follows:

$$\begin{cases} \left({}^{f}V_{rx}\right)_i = \Omega_R \cdot l_R \cdot \sin(\alpha_i + \beta_i) \\ \left({}^{f}V_{ry}\right)_i = \Omega_R \cdot l_R \cdot \cos(\alpha_i + \beta_i) \end{cases}, \tag{2}$$

where l_R is the radial distance between the robot body center and the wheel center.

If we combine the known linear velocities of the robot with the rotational components (2), we get the linear velocity of each wheel:

$$\begin{cases} \left({}^{f}V_{wx}\right)_i = {}^{f}V_{lx} + \Omega_R \cdot l_R \cdot \sin(\alpha_i + \beta_i) \\ \left({}^{f}V_{wy}\right)_i = {}^{f}V_{ly} + \Omega_R \cdot l_R \cdot \cos(\alpha_i + \beta_i) \end{cases}. \tag{3}$$

In these conditions, the steering angle of each wheel is

$$\theta_{s_i} = -\tan^{-1}\left(\frac{{}^{f}V_{lx} + \Omega_R \cdot l_R \cdot \sin(\alpha_i + \beta_i)}{{}^{f}V_{ly} + \Omega_R \cdot l_R \cdot \cos(\alpha_i + \beta_i)}\right) + \Omega_R \cdot t_s\,, \tag{4}$$

where t_s is the steering time, and the total linear velocity of each wheel will be as follows:

$${}^{f}V_{w_i} = \sqrt{\begin{aligned} &\left[{}^{f}V_{lx} + \Omega_R \cdot l_R \cdot \sin(\alpha_i + \beta_i)\right]^2 + \\ &+ \left[{}^{f}V_{ly} + \Omega_R \cdot l_R \cdot \cos(\alpha_i + \beta_i)\right]^2 \end{aligned}}\,. \tag{5}$$

Once the velocity of the wheels is calculated, angular velocities of the each wheel can be found,

$$\omega_{w_i} = \frac{{}^{f}V_{w_i}}{r_w}\,, \tag{6}$$

where r_w is the wheel radius.

F. Forward kinematics

Forward kinematics is used to estimate the position and heading angle of the mobile robot using the angular increments of each wheel, measured with encoders. Firstly, the rotational and steering values of the wheels are measured and obtained from translational and rotational components at the mobile robot center. Velocity components of each wheel, measured with respect to the robot coordinate system are given as

$$\begin{cases} \left({}^f V_{wx}\right)_i^m = -\left({}^f V_w\right)_i^m \cdot \sin\left[\left({}^f \theta_{s_i}\right)^m + {}^R\Omega_R^m(k-1)\cdot t_s\right] \\ \left({}^f V_{wy}\right)_i^m = -\left({}^f V_w\right)_i^m \cdot \cos\left[\left({}^f \theta_{s_i}\right)^m + \Omega_R^m(k-1)\cdot t_s\right] \end{cases}. \quad (7)$$

Using the property that the rotational components are canceled if the velocities of the three wheels are added together, the translational components of the robot velocity are obtained as:

$$\begin{cases} \left({}^f V_{lx}\right)^m = \sum_{i=1}^{3} \frac{\left({}^f V_{wx}\right)_i^m}{3} \\ \left({}^f V_{ly}\right)^m = \sum_{i=1}^{3} \frac{\left({}^f V_{wy}\right)_i^m}{3} \end{cases}. \quad (8)$$

Using eq. (6)-(8), the coordinates of the mobile robot's center and each wheel's center are obtained as follows, with respect to the origin of the floor coordinate system:

$$\begin{cases} x_R(k) = \left({}^f V_{lx}\right)^m \cdot t_s + x_R(k-1) \\ y_R(k) = \left({}^f V_{ly}\right)^m \cdot t_s + y_R(k-1) \end{cases}, \quad (9)$$

$$\begin{bmatrix} x_{w_i}(k) \\ y_{w_i}(k) \end{bmatrix} = \begin{bmatrix} \cos\Phi & -\sin\Phi \\ \sin\Phi & \cos\Phi \end{bmatrix} \cdot \begin{bmatrix} x_{w_i}(k-1) - x_R(k-1) \\ y_{w_i}(k-1) - y_R(k-1) \end{bmatrix} + \begin{bmatrix} x_R \\ y_R \end{bmatrix}. \quad (10)$$

The angular velocity of the mobile robot is obtained from the amplitude and its directions as follows:

$$\Omega_R^m = \frac{\sqrt{\left[\left({}^f V_{rx}\right)_i^m\right]^2 + \left[\left({}^f V_{ry}\right)_i^m\right]^2}}{r_w}, \quad (11)$$

where

$$\begin{cases} \left({}^f V_{rx}\right)_i^m = \left({}^f V_{wx}\right)_i^m - \left({}^f V_{lx}\right)^m \\ \left({}^f V_{ry}\right)_i^m = \left({}^f V_{wy}\right)_i^m - \left({}^f V_{ly}\right)^m \end{cases}. \quad (12)$$

In this case, the direction of the angular velocity should be determined considering positions of each wheel by the mobile robot's coordinate system.

V. CONCLUSION

The robot we are developing demonstrates a great potential for humanitarian demining application. Its simplicity, modular architecture and low cost make the robot a real candidate for such applications. It is sure that we did not solve the anti-personnel mines problem with this preliminary project, and perhaps our efforts are like a drop in the ocean, but we know that many people all over the world are working in the same direction. So, we are sure that, together, we may give some positive results in a near future.

ACKNOWLEDGMENT

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Bio-Inspiration and Mine Detection

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Abstract- There are many methods to detect explosives and landmines. However, most of them are limited by sensitivity and/or operational complexities due to type of terrain and soil composition, climatic variables, and ground clutter, such as, shrapnel and stray metal fragments that produce great number of false positive signals and slow down detection rates to unacceptable levels. Other methods are focusing on the detection of explosives itself since small amount of explosives routinely leak over time from landmines and can be found on surrounding ground and plant life. Hence, the robust primary indicator of a landmine is the explosive itself since the vapor of explosives signature such as TNT, DNT and RDX, as well as vapor from their casing materials of various types of plastics, metal, wood, or paint, can be checked in the air above or near buried mines or UXOs. Typically, humidity and temperature are key factors affecting vapor availability. The increase of temperature significantly increases the vapor availability above a given substance. In addition, signature scent above the soil is complex and can vary according to the amount of buried time. New approaches to landmine detection are being studied to improve the detection rates and to reduce the false alarm rate of the existing detection techniques. Developing efficient techniques and tools to identify explosives residue in mined areas represents an attractive approach. This paper aims to present, discuss and evaluate the potential and the of research development in the area of bio-inspiration and landmine detection from the prospect of humanitarian demining.

Keywords:
Mine detection, Humanitarian demining, Biomimetic, Biosensors, Landmines, Genetically Engineered bio-systems.

I. INTRODUCTION

Mine detection represents the most important step of the demining process, and the quality of mine detector affects the efficiency and safety of this process. The main objective of mine detection is to achieve a high probability of detection rate while maintaining low probability of false alarm. The probability of false alarm rate is directly proportional to the time and cost of demining by a large factor. Hence, it is important to develop effective detection technology that speed up the detection process, maximize detection reliability and accuracy, reduce false alarm rate, improve the ability to positively discriminate landmines from other buried dummy objects and metallic debris, and enhance safety and protection for deminers. In addition, there is a need to have simple, flexible and friendly user interaction that allows safe operation without the need for extensive training. Such approach needs to incorporate the strength of sensing technologies with efficient mathematical, theoretic approaches and techniques for analyzing complex incoming signals from mine detectors to improve mine detectability. This leads to maximize the performance of the equipment through the optimization of signal processing and operational procedures. Furthermore, careful study of the limitations of any detection device and technology with regard to the location, climate, and soil composition is critically important besides preparing the required operational and maintenance skills. It is important to keep in mind that not all high-tech solutions may be workable in different soil and environmental conditions. The detection technologies are presently in varying stages of development. Each has its own strength and weaknesses. The development phase of new technologies requires a well-established set of testing facilities at the laboratory level that carried out in conditions closely follow those of the mine affected area. In addition, the verification test should be carried out at the real minefield site. This should be followed by extensive field trails in real scenarios to validate the new technologies under actual field conditions for the purpose to specify benefits and limitations of different methods while fulfilling certain benchmark requirements. The work must be performed in close cooperation with end-users of the equipment while real deminers should carry out the test at a real site, in order to ensure that the developments are consistent with the practical operational procedures in the context of humanitarian demining, and that it is fulfilling user requirements. In addition, there is a need to have reliable process of global standard for assessing the availability, suitability, and affordability of technology with enabling technology represented by common information tools that enable these assessments and evaluations. The benchmarking is going to enhance the performance levels that enable the development of reliable and accurate equipment, systems and algorithms [2, 9, 10].

. The current mine detection process represents the slowest and the most dangerous step within the demining process. The quality of mine detection affects the efficiency and safety of this process. Many methods and techniques have been developed to detect explosives and landmines [2, 9, 10]. However, the performance of the available mine detection technologies are limited by sensitivity and/or operational complexities due to type of terrain and soil composition, vegetation, mine size and composition, climatic variables, burial depth, grazing angle, and ground clutter, such as, shrapnel and stray metal fragments that produce great number of false positive signals and slow down detection rates to unacceptable levels [1-3, 9-11]. New approaches to landmine detection are being studied to improve the detection rates and reducing false alarm rates of existing detection techniques. In addition, it is important and would be efficient to have sensing technology that can facilitate fast mined-area reduction. The robust primary indicator of a landmine is the explosive itself since the vapor of explosives signature such as TNT, DNT and RDX, as well as vapor from their casing materials of various types of plastics, metal, wood, or paint, can be checked in the air above or near buried mines or UXOs.

Researchers are studying wide range of bio-systems and are trying to mimic (not necessary duplicating 100%) certain natural capabilities particularly where the performance of bio-systems exceeds the available artificial systems and technologies. However, many research questions remain to be answered and further research still needed.

II. BIOLOGICAL AND BIO-INSPIRED APPROACHES FOR LANDMINES DETECTION

Four categories of research directions can be recognized in relation to the biological and bio-inspired approaches for the detection of landmines, explosives and other chemical residues. The main research directions can be categorized as follow:

(a) Bio-hybrid systems. This category focuses on the possibility to integrate a suitable technology with a bio-system to boost its natural abilities.
This category focuses on studying and understanding the full range of species combined with creative thinking, design and innovative technology in association with possible and relevant applications. Bio-hybrid systems aim to boost the natural capabilities of selected biological systems to support certain applications and solutions that are more than just learning from nature.

(b) Bio-systems. The research within the category aims to understand and conclude how existing bio-systems can be trained and used efficiently as a stand detection tools.

(c) Genetically engineered bio-systems. This may include animals, insects, bacteria and plants.
This category focuses on the development of biotechnology and genetically modified microbial techniques to help in environmental cleaning, waste management, detection of (bio-agents, explosives and landmines), etc.

(d) Biomimetic systems. Exploring technologies that exploit natural abilities of bio-systems and biological organisms to get new understanding and inspiration that lead to build new systems and hardware.

This category is based on biological inspiration and attempts to produce engineered systems that possess characteristics, and resemble or function like living systems, i.e., new technologies can be developed from nature. Biomimetic systems can be designed by extraction of the biological principles that govern them, which is possible only by a synergy of the basic and applied sciences. Biomimetics has been utilized as a mechanism for technological advancement in an attempt to facilitate the realization of the novel features in nature. There is a growing awareness among scientists and engineers that biological systems can be a valuable source of inspiration for man-made materials and systems by mimicking novel aspects of biological systems. Scientists mimic everything from worm brains to fish jaws to create better technologies.

III. EXAMPLES ON BIO-SYSTEMS AND GENETICALLY ENGINEERED BIO-SYSTEMS FOR LANDMINES DETECTION

Animals and other species have senses more acute than those of humans. Biological systems offer excellent examples of highly sensitive, versatile, and robust sensors. Researchers are studying wide range of bio-systems while at the same time they are trying to mimic certain natural capabilities particularly where the performance of bio-systems exceeds the available artificial systems and technologies. Examples may include invertebrate-inspired sensory-motors systems, olfactory in dogs and insects where odors play a vital role in all aspects of life, locomotive skills of a cockroach to move easily over rough terrain, etc. In addition, there is no doubt that understanding animals' locomotive capabilities can help to apply such knowledge in developing new generation sensors and other intelligent mechanism.

Artificial vapor detection has the potential to compete with or be used in conjunction with animals. However, dogs, rats, bees and pigs are still far better vapor detectors than any currently available technology. Furthermore, animals are sensitive to many different scents concurrently, a property that has proven difficult to replicate artificially. Current examples of natural biosensors are dogs, honeybees, bacteria and microbes, plants, etc.

A. Dogs

The odor discrimination skills of dogs considerably exceed the abilities of laboratory equipment that are used to investigate those skills, and hence limiting the ability of researchers to study the capabilities of dogs for detection of mines. Dogs are considered so far the best detectors of explosives. Their sensitivity to the substances associated with landmines is estimated to be a factor of 10,000 higher than for a man made detector [4]. The availability of odor to dogs varies in complex ways with the environment in which the mine occurs. Influences include soil types, soil moisture, activity of micro-organisms, and climatic variables. Specially trained dogs are used to detect the characteristic smell of explosive residue emanating from mines regardless of their composition or how long they have been implanted.

Dogs are normally used is in the search mode. Mine detection dogs can work in almost all types of terrain. Trained dogs work best in clear open country with vegetation no higher than calf to knee height. They are easy to transport, highly reliable and can clear screening land up to five times faster than manual deminers. Success has been reported from South Africa and Afghanistan, more in locating the edges of minefields than in finding individual mines. In spite of that, dogs can get tired and distracted, and can be effectively used as little as only few hours a day. The presence of explosive vapor within the soil and vegetation is essential element for the dog to perform its detection duty. Dogs can be overwhelmed in areas with dense landmine contamination. Like their human handlers, they don't do well under extreme weather conditions. Dogs can become confused if they can smell explosive coming from several sources at once. Dogs and other sniffers have high ongoing expenses, are subject to fatigue, and can be fooled by masked scents. The effectiveness of the dogs depends entirely on their level of training, the skill of their handlers, and on using them in the right place at the right time.

B. African Giant Pouch Rats

African giant pouch rats have very poor eyesight and hence they depend on their senses of smell and hearing. They have a better sense of smell, cheaper to keep and maintain, small in size, and they are suited to African climate with more resistant to tropical disease. African giant pouch rats have a relatively long life span, weight up to 4 kg, and they required shorter training time than dogs. In addition, once taught, the rats tend to perform repetitive tasks [5, 6]. A Belgian company (Apopo) has begun training these rats to locate buried bombs and mines due to their good sense of smell and tractable personality for mine detection. When an area has been thoroughly swept by the rats a team with metal detectors goes in to check and detonates all the marked mines in the area. In addition, large areas can be swept by multiple rats before a detonation team goes in to explode/remove the detected mine/UXO. In case of dogs, each landmine must be detonated or removed as it is detected, to avoid detonating the marked landmines.

C. Honeybees

Efforts were focusing to determine whether trained foraging bees can reliably and inexpensively search wide areas for the presence of landmine chemical signatures, such as TNT, at very low concentration, and possibly other explosive materials in bombs and landmines, as well as other chemicals of interest, including drugs and even decomposing bodies. Bees are free-flying organisms and have an acute sense of smell. When properly conditioned, it has been found through a series of repeated trials conducted in 2001 and 2002 bees behaved like a fine-tuned detector at vapor levels higher than 10 parts per trillion (pptr) from 2.4-dinitrotoulene (2.4-DNT) mixed in sand with low probability (less than 2%) of either a false positive or negative [12]. Bees are analogous to dogs for mine clearance, except that thousands of bees can be trained within very short time to fly over and search a field for explosives. Honeybees inhale large quantities of air and bring back water for evaporative cooling of the hive. As such, bees sample all media (air, soil, water and vegetation) and all chemical forms (gaseous, liquid and particulate). A honeybee's body has branched hairs that develop a static electricity charge, making it an extremely effective collector of chemical and biological particles, including pollutants, biological warfare agents and explosives [13].

D. Biotechnology and Microbial Techniques for Mine Detection

A microbe can often sense environmental dangers before a human can. During few decades of environmental engineering progress, biologists and engineers have used the fact that common, naturally occurring bacteria consume chemical compounds in soils to accomplish hazardous chemical cleanup objectives. The field of bioremediation evolved from this understanding. The microbiologists were trying to detect the presence of explosives and other chemicals. The Microbial Mine Detection System (MMDS) is an example of a living system that responds to explosives and provides the operator with an identifiable signal [7]. Attractive methods in this area include chemical and biological approaches that involve naturally occurring microbes or genetically engineered soil bacteria to cause the bacteria to fluoresce under laser light when in contact with TNT. However, these approaches are less developed but hold promise and need further development and evaluation.

In 1975 it was discovered that the chromosomes in bacteria could be modified to make the bacteria glow in the presence of certain chemicals. ORNL took the advantage of such microscopic creatures to genetically engineer it for the possibility to apply it in waste management technologies [7, 8]. They found that such bacteria, when applied to soil, will glow if the soil is contaminated with solvents like toluene or xylene. TNT is closely related to these solvents chemically, so it was fairly simple to modify these bacteria to fluoresce in its presence. The plan is to spray a solution of genetically engineered pseudomonas over a minefield. When the pseudomonas contacts the explosives and starts metabolizing it, they will scavenge the compound as a food source activating the genes that produce the proteins needed to digest the TNT, and this triggers emitting extremely bright fluorescence when exposed to ultraviolet light. The fluorescent signals are mapped, and the area is examined for the source. The method has been tested mainly in lab environment with test over a simulated minefield where in both cases mines were located successfully, but real-world conditions may not be similar. In the field, this method could allow for searching hundreds of acres in a few hours, which is much faster than other techniques, and could be used for area reduction and on a variety of terrain types. While it needs more time to adequately test the technique in real minefield.

E. Plant Indicators

It may be possible to genetically manipulate plants to have them change their behavior in presence of TNT or other explosive material, for example changing color, growing up fast and high or display any other detectable sign. These signs need be visible to human; other signs such as changes in UV reflection are also usable and measurable by simple tools. In this case, the plants would aid demining by indicating the presence of mines through color change, and could either be shown from aircraft or visually by minefield deminers. Aresa Biodetection Company has developed a genetically modified weed that could help detect landmines. The weed has been coded to change color when its roots come in contact with nitrogen dioxide evaporating from explosives buried in soil. Within three to six weeks from being sowed over landmine infested areas, a Thale Cress plant (Arabidopsis thaliana, it is a small flowering plant related to cabbage and mustard), will turn a warning red when close to a landmine. Aresa has succeeded at the laboratory level in growing the plant by using a combination of natural mutations and genetic manipulation.

However, because nitrous oxide can also be formed by denitrifying bacteria, there is some risk of generating false indicators through the use of this technique. In addition, no reported study has been conducted with actual landmines, though successful studies have been done in greenhouses [19]. Some scientists raised their concern that such bioengineered plants could escape into the wild and confer undesirable traits on wild plants. Genetically altered plants may be transplanted via planes, on roads or pathways, or by a number of other methods. Proper consideration should be given to water requirements and pollution issues.

IV. Artificial Protein and Synthetic Biology

Computational method has been developed to engineer proteins that can specifically detect a wide array of chemicals from TNT to brain chemicals involved in neurological disorders. This may constitutes an important step toward a new technology of synthetic biology, in which scientists will be in position to construct tailor-made organisms for a variety of tasks. Scientists at Duke University recognize the feasibility of this approach over the long term using computational design to create sensor proteins. Such sensor proteins can be re-incorporated into cells to activate cellular signaling and genetic pathways. The research team was able to establish control over molecular recognition of small molecules in biology. The researchers have demonstrated that it is not only possible to design highly specific receptors, but also to put them into biological systems and control them. It would be possible with this technique to develop TNT-sensing protein to provide free-roaming underwater and land robots with the capability of sniffing a plume of TNT emanating from unexploded ordnance, tracking it to its source, and help to clean up.

V. Conclusions

The presented techniques are promising approaches to help detect individual landmines and support area reduction, but some of the presented research are still years away to be effectively applicable in a real minefields. These techniques take advantage of the fact that all munitions will leak small amounts of their chemical constituents as vapors that can be found on the surrounding ground and plant life. Even very slow, low concentration, vapor emissions will be sufficient to allow interception and identification. Being conditioned on explosives, they will also pick up the scent from UXO. Landmines that might be manufactured to be completely sealed (which are not currently the case) cannot be detected by any of the methods listed in this paper. Important care should be applied in relation to safety, health and environmental concerns when developing genetically engineered bio-systems. It is a huge challenge to seek and optimize new technology and to make a meaningful difference in the elimination of landmines threat.

Although many studies have been conducted with promising results, and while there are additional studies are underway, there are still many more remain to be done in this area to,

(a) Have better understanding about the natural capabilities of bio-systems. This will lead, to enhance the development at the other three categories.
(b) Coordinate and develop efficient interdisciplinary research teams.
(c) Create new ideas and innovative technologies to boost the performance of already available techniques and new approaches as well.
(d) Fulfill the high level of interest in the detection of low-level concentrations of explosives such as TNT and RDX.
(e) Have better understanding the key features that identify the specificity of explosive and chemical signatures, and study the effect of humidity, temperature and other climatic parameters on them.
(f) Improving the sensitivity and fine resolution of sensors because it has a direct effect to determine what can be detected, at what location, and how quickly.

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Complete coverage path planning of mobile robots for humanitarian demining

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Abstract— **The paper presents a path planning algorithm for a non-circular shaped mobile robot to autonomously navigate in an unknown area for humanitarian demining. For that purpose the path planning problem comes down to planning a path from some starting location to a final location in an area so that the robot covers all the reachable positions in the area while following the planned path. Based on our previous complete coverage algorithm of known areas we have developed a complete coverage algorithm capable of operating in unknown areas with known border dimensions. The proposed algorithm uses occupancy grid map representation of the area. Every free cell represents a node in the graph being searched to find the complete coverage path. The proposed algorithm finds the complete coverage path in the graph accounting for the dimensions of the mobile robot, where non-circular shaped robots can be easily included. The algorithm is implemented under the ROS (robot operating system) and tested in the stage 3D simulator for mobile robots.**

Index Terms— **autonomous mobile robots, path planning, coverage path planning, exploration**

I. INTRODUCTION

The path planning problem of a mobile robot for humanitarian demining application comes down to planning a path from a start position to a final position in an area so that the robot inspects all the reachable positions (nodes in a graph) while following the planned path. The problem of finding the path that visits all nodes in a graph is called the complete coverage path planning [7]. Finding an optimal path that visits every node in a graph exactly once is NP-hard problem known as the traveling salesman problem. Therefore, approximate or even heuristic solutions are used for the complete coverage path planning task.

A common approach to complete coverage planning is decomposing the environment into subregions [6], selecting a sequence of those subregions, and then generating a path that covers each subregion in turn. Most methods assume convex polygonal environments and perform exact cell decomposition [5], [1], [11], which can be very time consuming in changing environments. Methods based on the approximate cell decomposition (i.e. grid maps) are less time consuming, but suppose that the mobile robot has the dimensions of exactly one cell within the grid map [4], [12].

Most complete coverage planning algorithms assume circular shaped mobile robot, and there is little work reported for complex non-circular shaped mobile robots. This paper presents a new complete coverage path planning algorithm for complex shaped mobile robot and is capable of operating in unknown areas of known border dimensions for the application of humanitarian demining. The algorithm is an extension of our previous complete coverage D* algorithm (CCD*) developed for circular shaped robots operating in known indoor environments with moving obstacles [2]. The proposed algorithm uses decomposition of the unknown area into squared cells of equal size and finds the complete coverage path that covers all reachable cells. The complete coverage path is integrated with the dynamic window obstacle avoidance algorithm [3] to produce smooth robot trajectory considering robot's kinematic and dynamic constraints.

The rest of the paper is organized as follows. Section II describes robot and environment representation for the humanitarian demining. Section III presents the proposed complete coverage planning algorithm. Test results are given in Section IV and conclusion in Section V.

II. ROBOT AND ENVIRONMENT REPRESENTATION

A. The robot

In this paper, we assume usage of the humanitarian demining mobile robot MV-4 of DOK-ING company (Fig. 1), although developed algorithm is generally applicable to other robots. The dimensions of the prime mover together with the attached flail tool for activating mines are given in Table I (taken from `www.dok-ing.hr`). The simulation setup with the robot model is shown in Fig. 2. The simulated robot has on-board laser range sensor with 360° field of view. The maximal range used for mapping of unknown obstacles are set to 8 m, although outdoor laser range sensors provides much higher ranges (e.g. 30 m). The limitation of only 8 m ranges data assure more reliable map update especially in an uneven terrains (detecting of the ground). The robot has differential drive, i.e., it can rotate in place, and can move in forward and backward direction.

TABLE I

TECHNICAL DATA FOR THE MV-4 MINE CLEARANCE SYSTEM.

Dimensions	(Length x Width x Height) mm
Prime Mover	3005 x 1530 x 1470 mm
Prime Mover With Flail (Clearing arm pulled in)	4455 x 2015 x 1470 mm
Prime Mover With Flail (Clearing arm extended)	5145 x 2015 x 1470 mm

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Fig. 1. The MV-4 mine clearance system. Courtesy of DOK-ING company `www.dok-ing.hr`.

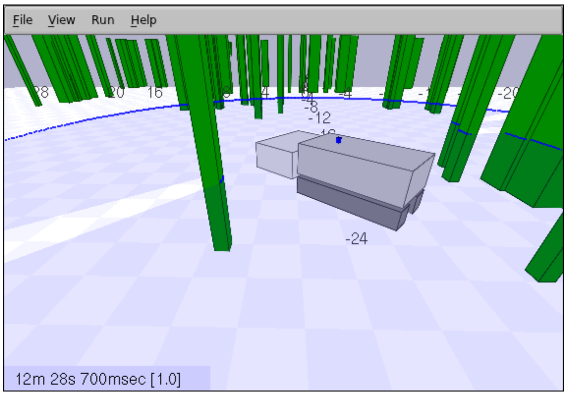

Fig. 2. The simulation setup in the Stage simulator – 3D view of the robot model and the part of the random environment.

B. The occupancy grid map

Two-dimensional (2D) occupancy grid maps are usually used to represent a continuous environment by an equally-spaced grid of discrete points [10]. The whole unknown area with known borders is divided into squared cells of equal size. Each cell contains occupancy information of the part of the environment that it covers, which is continuously updated as the robot detects obstacles within the corresponding cells.

The real shape of the robot represented in the grid map is shown in Fig. 3. It is usually assumed that the robot shape can be approximated by the circle, which position coordinates are planned. In order to avoid robot orientation planning, in this paper we assume that the real shape of the robot can be approximated by two circles. One circle covers the robot's vehicle (prime mover), and another circle covers the robot's flail tool for demining. By introducing the two circles and with certain adaptation of the obstacle avoidance module it is sufficient to plan only position coordinates. The larger circle (R_1 in Fig. 3) is used for obstacle enlargement. The robot's position is considered to be in the center of the prime mover. For the path planning it is assumed that the robot needs to inspect the whole area by its tool and not by its mask. Further, it is assumed that the visited nodes are within the approximated squared shape of

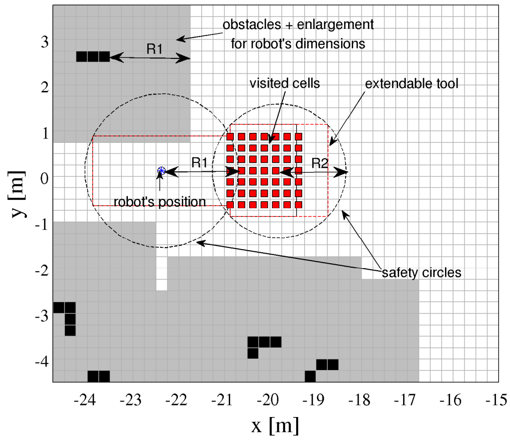

Fig. 3. The occupancy grid map with the robot real shape. The size of the cell is $e_{\text{cell}} = 0.25$ m.

the tool, which is a little bit narrower than the real tool dimensions. On the other hand, while following the planned path, nodes that are visited are determined conservatively, i.e., the ones that are covered with the real shape of the robot.

III. The Complete Coverage Planning for Humanitarian Demining

The proposed complete coverage planning algorithm for humanitarian demining is actually a modified version of our original complete coverage D* algorithm [2]. While original CCD* algorithm is limited to path planning of circular shaped robots in known area, introduced modifications enables path planning of non-circular shaped robots in unknown areas.

A. The CCD* algorithm's modifications

Modifications of the CCD* algorithm, which enable path planning for complex robot's shape, include first planning the coverage path for the tool's center, i.e., the node in the center of the tool's squared shape (see Fig. 3), and afterwards deriving for the robot's position. The first node in the coverage tool's path is the tool's center point when the robot is in the start position, and the first node in the coverage robot's path is the start node. The tool's center point is displaced from the robot's center point. The CCD* algorithm is called for the tool's position T and the path $\mathcal{P}_T$ is determined. Afterwards, by performing certain coordinate transformation the path of the robot's center point $\mathcal{P}_R$ is determined.

When an on-board range sensor detects obstacles, corresponding cells become occupied. Additionally, cells between the robot and the detected obstacles become free. Afterwards, the path replanning process is initiated and certain parts of the area are included or removed from the path. To track which cells are visited by the robot while following the complete coverage path, functions $\textbf{visited}_R(n) = \{0, 1\}$ and

overlapped$_R(n) = \{0, 1\}$ are used. Before each execution of the complete coverage path calculation values of functions **visited**(n) and **overlapped**(n) are rewritten by the new ones **visited**$_R(n)$ and **overlapped**$_R(n)$, respectively. The new coverage path is recalculated by the same procedure but with smaller number of non-visited nodes in the graph.

B. Illustration of algorithm's iterations

First, the D* search [9] is performed from the start node S to calculate the cost values g for every reachable node. The first node in the coverage tool's path is the tool's center point, and the first node in the coverage robot's path is the start node. The tool's center point is distanced from the robot's position for the fixed length l_T along the x-axis of the robot's local reference frame (robot's direction of moving forward). In the path planning step, smaller mask of squared shape (inner part of the real tool shape) is used for determining visited nodes (see Fig. 3), as opposed to the path following step where all cells that are covered by the real shape of the robot are used. Only for the first step of the algorithm visited and overlapped values are determined for complete robot mask. In all other steps those values are determined only for the tool.

The next node in the coverage tool's path is chosen from the candidate nodes in the same way as in the original CCD* algorithm for the robot's path. The candidate nodes are defined to be non-overlapped nodes that are reachable and distanced from the previous node in the coverage tool's path for the tool square size in four straight directions through the grid. The next node is the one with the smallest cost value g. An example of the first iteration of producing the coverage path is shown in Fig. 4.

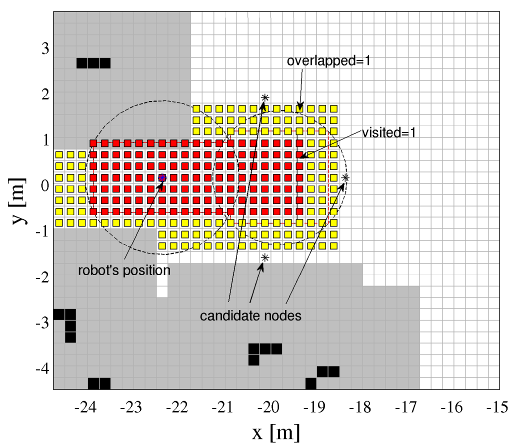

Fig. 4. The first iteration of the coverage path – assigning the visited and overlapped nodes and determining the candidate nodes.

When each node in the tool's path is determined, for example the i-th node of the tool's path, the i-th node of the robot's path is calculated to account for displacement between the robot's position and the tool's position. The point in the tool's path is translated backwards for the length l_T along the connection line between the $(i-1)$-th point in the robot's path and i-th point in the tool's path. If the length of the connection line is smaller than the displacement length l_T, then the i-th point in the robot's path gets repeated its previous $(i-1)$-th point. By this procedure the robot's path is smoothed and becomes more appropriate to follow by the path following module. An example of this procedure is shown for the third iteration of the algorithm in Fig. 5. Described iterations continue until there is no

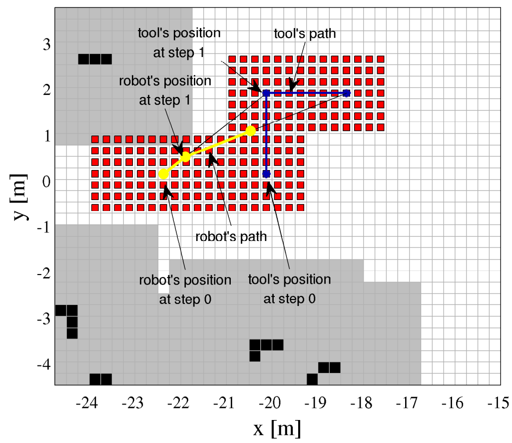

Fig. 5. The third iteration of the coverage path – determining the robot's path from the tool's path.

surrounding candidate nodes. Then, like in the CCD* algorithm, another search is performed from the last node of the tool's path to find the closest non-visited node. Algorithm stops when there are no non-visited node left.

IV. Test results

The proposed algorithm was implemented in ROS (the robot operating system and the Stage simulator www.ros.org) with the MV4 robot model described in section II. The AMCL algorithm (Adaptive Monte Carlo Localization) was used for robot localization. For path following a dynamic window based algorithm, described in our previous work was used [8] with certain adaptations for two circle shaped robot. The robot was allowed to go backwards in some deadlock scenarios. A randomly generated map was used with dimensions 50 m x 50 m as the simulation map of an unknown area, see Fig. 2. The laser range readings used in the simulation has full field of view (360 degrees) and was limited to 8 meters to cope only with obstacles in local vicinity of the robot. While the robot was moving, it detected unknown obstacles and replanned the complete coverage path.

Figure 6 shows three of many replannings while moving through the unknown area. The first one (left)

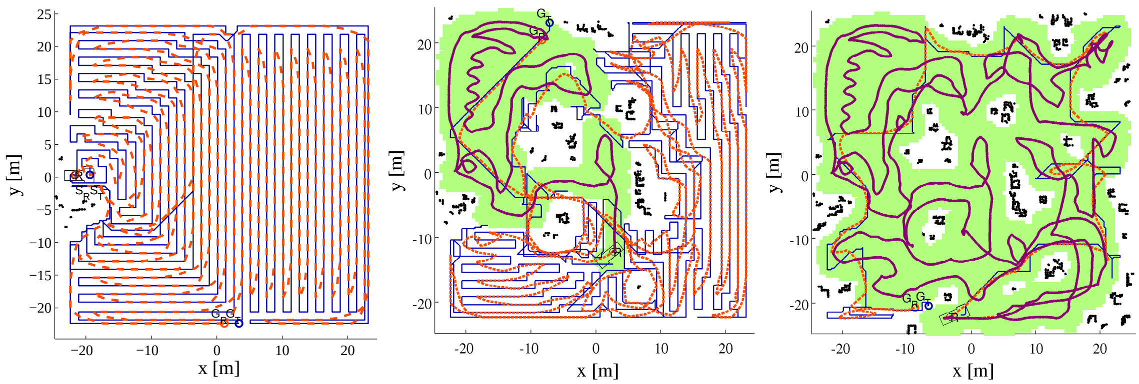

Fig. 6. Three snapshots of (many) replanning steps while the robot is moving through the unknown area and detecting unexplored obstacles – visited area is colored green, the new tool's path is noted by solid line, the new robot's path is noted by dashed line, and driven trajectory is bolder curve.

is the initial planning. End nodes of the tool's path and the robot's path are noted by G_T and G_R, respectively. The path was changing at each replanning step and had more path direction changes with more obstacles detected. Due to non-perfect path following some parts of the area remind non-visited. Those parts were included in the new complete coverage path with the next replanning step. However, some cells were very hard to visit due to complex shape of the robot and rotation on the spot near certain obstacle configuration was not admissible by the dynamic window algorithm. Total time needed to visit green area in the snapshot 3 took about 80 minutes, and for the final covering it took 110 minutes. The robot was traveling with average speed of 135 mm/s. Maximal allowed speed was 500 mm/s for forward motion and 100 mm/s for backward motion. Maximal orientation speed was limited to 100 °/s. From snapshot 3 the robot tried to visit cells near the border of obstacles, which was not successful in all cases since the robot needed also to rotate in place to reach the non-visited cells, which was not planned by the algorithm. Finally, the robot covered total number of 30712 cells (1919.5 m^2) of the total number of 30718 reachable cells, i.e., only 6 cells remained non-visited. The total length of the robot's driven trajectory was 938.4 m.

V. Conclusions

In this paper a new complete coverage path planning algorithm for humanitarian demining has been proposed. It was shown that it effectively plans the robot's path ensuring that the flail tool visits all reachable regions (cells) of the inspected area. The test results of the proposed algorithm have shown satisfactory behavior of the algorithm in the environment populated with unknown static obstacles. A few cells have stayed non-visited due to non-perfect path following. In our future work, a better path following algorithm will be developed and additional constraints will be included in the planning algorithm such as the minimization of the number of path direction changes and planning also orientations for certain points near the obstacles.

Acknowledgement

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Extended Information Filtering and nonlinear control for cooperating robot harvesters

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***Abstract*—A method for autonomous navigation of agricultural robots under a master-slave scheme is developed. The method uses: (i) a nonlinear controller that makes the robots track with precision the desirable trajectories, (ii) a distributed filtering scheme (Extended Information Filter) for estimating the motion characteristics of the vehicles through the fusion of measurements coming from on-board sensors, as well as measurements about the vehicles' coordinates coming from multiple position sensors (e.g. multiple GPS devices). The autonomous navigation of the cooperating agricultural robots is finally implemented through state estimation-based control. The nonlinear controller uses the estimated state vector of the robots, as provided by an Extended Information Filter. In this manner, the control signal that defines the robots speed and heading angle is generated.**

I. Introduction

There are many types of field operations that are performed by cooperating tractors. The need for collaborating farming robots that will be able to carry out complicated tasks under synchronization and within desirable precision levels is anticipated to grow in the following years [1]. In several applications a master-slave scheme is required for the robots coordination, which means that a master tractor generates a reference path and the motion characteristics (velocity, acceleration, orientation) that the slave tractor has to follow. When harvesting hay on grassland, it is customary for one dump truck and one tractor with a hayfork to be used. When harvesting corn, a combination of one harvester and one tractor with trailer is generally adopted. Therefore, a master-slave system, which uses two vehicles, can be very useful in actual field operations.

In this paper, a method for autonomous navigation of agricultural robots under a master-slave scheme is developed. The method comprises the following elements: (i) a nonlinear controller that makes the robots track with precision the desirable trajectories, (ii) a distributed filtering scheme (Extended Information Filter) for estimating the motion characteristics of the vehicles through the fusion of measurements coming from on-board sensors, as well as measurements about the vehicles' coordinates coming from multiple position sensors (e.g. multiple GPS devices). The integrated navigation system for the agricultural vehicles also includes a path planner for generating automatically the trajectory that has to be followed by the cooperating agricultural robots, The autonomous navigation of the cooperating agricultural robots is finally implemented through state estimation-based control where the nonlinear controller uses the estimated state vector of the robots, as provided by distributed filtering, so as to generate the control signal that defines the robots speed and heading angle (see Fig. 1).

The proposed robotic system performs distributed information processing for estimating the position and motion characteristics of the vehicles. At a first stage, measurements from on board sensors are combined with measurements from multiple position sensors (e.g. GPS devices) and are initially processed by local filters to provide local state vector estimates. At a second stage, the local state estimates for the robotic vehicles are fused using a distributed filtering algorithm. Thus an aggregate state vector of the robotic harvesters is obtained (see Fig. 1). Such a filtering approach has several advantages: (i) it is fault tolerant: if a local information processing unit is subject to a fault then state estimation is still possible, (ii) the information processing scheme is scalable and can be expanded with the inclusion of more local information processing units (local filters), (iii) the bandwidth for the exchange of information between the local units and the aggregate filter remains limited since there is no transmission of raw measurements but only transmission of local state estimates and of the associated covariance matrices.

Under the assumption of a Gaussian measurement model, a solution to distributed information fusion for the robotic harvesters can be obtained with the use of distributed Kalman Filtering [2-7]. Distributed state estimation in the case of non-Gaussian models has been also studied in several other research works [8-10]. In this paper, a solution for the problem of distributed state estimation will be attempted with the use of the Extended Information Filter, which is actually an approach for fusing state estimates provided by local Extended Kalman Filters [11-12].

Another issue that has to be taken into account for the autonomous functioning of the robotic harvesters is nonlinear control for precise tracking of desirable trajectories. The paper proposes flatness-based control for steering the robot harvesters along the reference paths. Flatness-based control

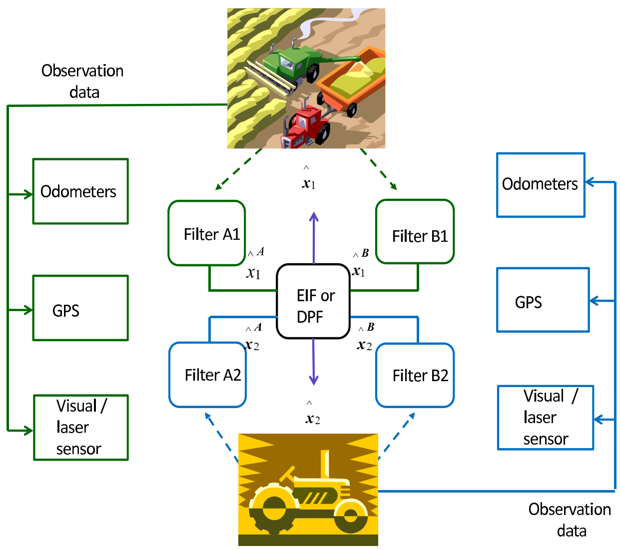


Fig. 1. Sensor fusion at the local filters for obtaining local state estimates

is currently a main direction in the design of nonlinear control systems [12]. To find out if a dynamical system is differentially flat, the following should be examined: (i) the existence of the so-called flat output, i.e. a new variable which is expressed as a function of the system's state variables. It should hold that the flat output and its derivatives should not be coupled in the form of an ordinary differential equation, (ii) the components of the system (i.e. state variables and control input) should be expressed as functions of the flat output and its derivatives [13]. Expressing all system variables as functions of the flat output and its derivatives enables transformation of the robotic vehicle model to a linearized form for which the design of the controller becomes easier.

The structure of the paper is as follows: in Section II the Extended Information Filter (Distributed Extended Kalman Filter) is studied. In Section III nonlinear control (flatness-based control) is proposed for succeeding trajectory tracking by the robotic vehicles. In Section IV simulation experiments are provided about the autonomous navigation of the robotic harvesters using the Extended Information Filter and flatness-based control. The test case is concerned with 2 autonomous tractors cooperating within a master-slave scheme. By fusing the outcome of the distributed filters with the use of the Extended Information Filter, state estimates of the robotic harvesters are obtained. These in turn are used by local nonlinear controllers for succeeding trajectory tracking. Finally in Section V concluding remarks are be provided.

II. Distributed state estimation using the Extended Information Filter

A. Kalman and Extended Kalman Filtering

In distributed filtering an aggregate state vector is produced through the fusion of the state estimates provided by local filters (e.g. KF or EKF). In the discrete-time case a dynamical system is assumed to be expressed in the form of a discrete-time state model:

$$\begin{aligned} x(k+1) &= A(k)x(k) + B(k)u(k) + w(k) \\ z(k) &= Cx(k) + v(k) \end{aligned} \tag{1}$$

where the state $x(k)$ is a m-vector, $w(k)$ is a m-element process noise vector and A is a $m \times m$ real matrix. Moreover the output measurement $z(k)$ is a p-vector, C is an $p{\times}m$-matrix of real numbers, and $v(k)$ is the measurement noise. It is assumed that the process noise $w(k)$ and the measurement noise $v(k)$ are uncorrelated. The process and measurement noise covariance matrices are denoted as $Q(k)$ and $R(k)$, respectively. Now the problem is to estimate the state $x(k)$ based on the measurements $z(1), z(2), \cdots, z(k)$. This can be done with the use of Kalman Filtering. The discrete-time Kalman filter can be decomposed into two parts: i) time update (prediction stage), and ii) measurement update (correction stage).

measurement update:

$$\begin{aligned} K(k) &= P^-(k)C^T[C{\cdot}P^-(k)C^T + R]^{-1} \\ \hat{x}(k) &= \hat{x}^-(k) + K(k)[z(k) - C\hat{x}^-(k)] \\ P(k) &= P^-(k) - K(k)CP^-(k) \end{aligned} \tag{2}$$

time update:

$$\begin{aligned} P^-(k+1) &= A(k)P(k)A^T(k) + Q(k) \\ \hat{x}^-(k+1) &= A(k)\hat{x}(k) + B(k)u(k) \end{aligned} \tag{3}$$

Next, the following nonlinear state-space model is considered:

$$\begin{aligned} x(k+1) &= \phi(x(k)) + L(k)u(k) + w(k) \\ z(k) &= \gamma(x(k)) + v(k) \end{aligned} \tag{4}$$

The operators $\phi(x)$ and $\gamma(x)$ are

$$\begin{aligned} \phi(x) &= [\phi_1(x), \phi_2(x), \cdots, \phi_m(x)]^T \\ \gamma(x) &= [\gamma_1(x), \gamma_2(x), \cdots, \gamma_p(x)]^T \end{aligned} \tag{5}$$

It is assumed that ϕ and γ are sufficiently smooth in x so that each one has a valid series Taylor expansion. Following a linearization procedure, about the current state vector estimate $\hat{x}(k)$ the linearized version of the system is obtained:

$$x(k+1) = \phi(\hat{x}(k)) + J_\phi(\hat{x}(k))[x(k) - \hat{x}(k)] + w(k),$$
$$z(k) = \gamma(\hat{x}^-(k)) + J_\gamma(\hat{x}^-(k))[x(k) - \hat{x}^-(k)] + v(k),$$

where $J_\phi(\hat{x}(k))$ and $J_\gamma(\hat{x}(k))$ are the associated Jacobian matrices of ϕ and γ respectively. Now, the EKF recursion is as follows [12]:

Measurement update. Acquire $z(k)$ and compute:

$$\begin{array}{c} K(k) = P^-(k) J_\gamma^T(\hat{x}^-(k)) \cdot \\ \cdot [J_\gamma(\hat{x}^-(k)) P^-(k) J_\gamma^T(\hat{x}^-(k)) + R(k)]^{-1} \\ \hat{x}(k) = \hat{x}^-(k) + K(k)[z(k) - \gamma(\hat{x}^-(k))] \\ P(k) = P^-(k) - K(k) J_\gamma(\hat{x}^-(k)) P^-(k) \end{array} \quad (6)$$

Time update. Compute:

$$\begin{array}{c} P^-(k+1) = J_\phi(\hat{x}(k)) P(k) J_\phi^T(\hat{x}(k)) + Q(k) \\ \hat{x}^-(k+1) = \phi(\hat{x}(k)) + L(k) u(k) \end{array} \quad (7)$$

B. Fusing estimations from local distributed filters

Again, the discrete-time nonlinear system of Eq. (4) is considered. The Extended Information Filter (EIF) performs fusion of the local state vector estimates which are provided by the local Extended Kalman Filters, using the *Information matrix* and the *Information state vector* [11]. The Information Matrix is the inverse of the state vector covariance matrix, and can be also associated to the Fisher Information matrix [14]. The Information state vector is the product between the Information matrix and the local state vector estimate

$$\begin{array}{c} Y(k) = P^{-1}(k) = I(k) \\ \hat{y}(k) = P^-(k)^{-1} \hat{x}(k) = Y(k) \hat{x}(k) \end{array} \quad (8)$$

The update equation for the Information Matrix and the Information state vector are given by

$Y(k) = P^-(k)^{-1} + J_\gamma^T(k) R^{-1}(k) J_\gamma(k) = Y^-(k) + I(k)$ and $\hat{y}(k) = \hat{y}^-(k) + J_\gamma^T R(k)^{-1}[z(k) - \gamma(x(k)) + J_\gamma(k)\hat{x}^-(k)] = \hat{y}^-(k) + i(k)$,

where $I(k) = J_\gamma^T(k) R(^k)^{-1} J_\gamma(k)$ is the associated information matrix and, $i(k) = J_\gamma^T(k) R(^k)^{-1}[(z(k) - \gamma(x(k))) + J_\gamma \hat{x}^-(k)]$ is the information state contribution. The predicted information state vector and Information matrix are obtained from

$\hat{y}^-(k)= P^-(k)^{-1} \hat{x}^-(k)$, and $Y^-(k) = P^-(k)^{-1} = [J_\phi(k) P^-(k) J_\phi(k)^T + Q(k)]^{-1}$.

It is assumed that an observation vector $z^i(k)$ is available for the N different sensor sites (e.g. GPS measurement nodes) $i = 1, 2, \cdots, N$ and each GPS node observes the vehicle according to the local observation model, expressed by $z^i(k) = \gamma(x(k)) + v^i(k), \ i = 1, 2, \cdots, N$, where the local noise vector $v^i(k) \sim N(0, R^i)$ is assumed to be white Gaussian and uncorrelated between sensors. The variance of a composite observation noise vector v_k is expressed in terms of the block diagonal matrix $R(k) = diag[R(k)^1, \cdots, R^N(k)]^T$. The information contribution can be expressed by a linear combination of each local information state contribution i^i and the associated information matrix I^i at the i-th sensor site

$i(k) = \sum_{i=1}^N {J_\gamma^i}^T(k) R^i(k)^{-1}[z^i(k) - \gamma^i(x(k)) + J_\gamma^i(k)\hat{x}^-(k)]$, $I(k) = \sum_{i=1}^N {J_\gamma^i}^T(k) R^i(k)^{-1} J_\gamma^i(k)$. Thus, the update equations for fusing the local state estimates is

$\hat{y}(k) = \hat{y}^-(k) + \sum_{i=1}^N {J_\gamma^i}^T(k) R^i(k)^{-1}[z^i(k) - \gamma^i(x(k)) + J_\gamma^i(k)\hat{x}^-(k)]$, and $Y(k) = Y^-(k) + \sum_{i=1}^N {J_\gamma^i}^T(k) R^i(k)^{-1} J_\gamma^i(k)$.

At a second stage, in the Extended Information Filter an aggregation (master) fusion filter produces a global estimate by using the local sensor information provided by each local filter. As in the case of the Extended Kalman Filter the local filters which constitute the Extended information Filter can be written in terms of *time update* and *measurement update* equations.

Measurement update: Acquire $z(k)$ and compute

$$\begin{array}{c} Y(k) = P^-(k)^{-1} + J_\gamma^T(k) R(k)^{-1} J_\gamma(k) \text{ or} \\ Y(k) = Y^-(k) + I(k) \\ \text{where } I(k) = J_\gamma^T(k) R^{-1}(k) J_\gamma(k), \text{and} \end{array}$$

$$\begin{array}{c} \hat{y}(k) = \hat{y}^-(k) + J_\gamma^T(k) R(k)^{-1}[z(k) - \gamma(\hat{x}(k)) + J_\gamma \hat{x}^-(k)] \\ \text{or } \hat{y}(k) = \hat{y}^-(k) + i(k) \end{array} \quad (9)$$

Time update: Compute:

$$\begin{array}{c} Y^-(k+1) = P^-(k+1)^{-1} = [J_\phi(k) P(k) J_\phi(k)^T + Q(k)]^{-1} \\ \text{and } y^-(k+1) = P^-(k+1)^{-1} \hat{x}^-(k+1). \end{array} \quad (10)$$

C. Calculation of the aggregate state estimation

The outputs of the local filters are treated as measurements which are fed into the aggregation fusion filter (see Fig. 1) [11]. Then each local filter is expressed by its respective error covariance and estimate in terms of information contributions and is described by

${P_i}^{-1}(k) = P_i^-(k)^{-1} + J_\gamma^T(k) R(k)^{-1} J_\gamma(k) \hat{x}_i(k) = P_i(k)(P_i^-(k)^{-1} \hat{x}_i^-(k)) + J_\gamma^T(k) R(k)^{-1}[z^i(k) - \gamma^i(x(k)) + J_\gamma^i(k) \hat{x}_i^-(k)]$.

The global estimate and the associated error covariance for the aggregate fusion filter can be rewritten in terms of the computed estimates and covariances from the local filters using the relations

$J_\gamma^T(k) R(k)^{-1} J_\gamma(k) = P_i(k)^{-1} - P_i^-(k)^{-1}$, and $J_\gamma^T(k) R(k)^{-1}[z^i(k) - \gamma^i(x(k)) + J_\gamma^i(k)\hat{x}^-(k)] = P_i(k)^{-1} \hat{x}_i(k) - P_i(k)^{-1} \hat{x}_i(k-1)$.

For the general case of N local filters $i = 1, \cdots, N$, the distributed filtering architecture is described by

$$\begin{array}{l} P(k)^{-1} = P^-(k)^{-1} + \sum_{i=1}^N [P_i(k)^{-1} - P_i^-(k)^{-1}] \\ \hat{x}(k) = P(k)[P^-(k)^{-1} \hat{x}^-(k) + \\ + \sum_{i=1}^N (P_i(k)^{-1} \hat{x}_i(k) - P_i^-(k)^{-1} \hat{x}_i^-(k))] \end{array} \quad (11)$$

The global state update equation in the above distributed filter can be written in terms of the information state vector and of the information matrix, i.e.

$$\begin{array}{c}\hat{y}(k)=\hat{y}^{-}(k)+\sum_{i=1}^{N}(\hat{y}_i(k)-\hat{y}_i^{-}(k)) \\ \hat{Y}(k)=\hat{Y}^{-}(k)+\sum_{i=1}^{N}(\hat{Y}_i(k)-\hat{Y}_i^{-}(k))\end{array} \tag{12}$$

From Eq. (11) it can be seen that if a local filter (processing station) fails, then the local covariance matrices and the local state estimates provided by the rest of the filters will enable an accurate computation of the vehicle's state vector.

III. Differential flatness for nonlinear dynamical systems

A. Definition of differentially flat systems

Each agricultural vehicle participating in the multi-vehicle system is steered along the desirable paths with the use of a flatness-based controller. The main principles of flatness-based control are as follows [13]: a finite dimensional system is considered. This can be written in the general form of an ordinary differential equation (ODE), i.e. $S_i(w,\dot{w},\ddot{w},\cdots,w^{(i)}),\quad i=1,2,\cdots,q$. The quantity w denotes the system variables (these variables are for instance the elements of the system's state vector and the control input) while $w^{(i)}$, $i=1,2,\cdots,q$ are the associated derivatives. Such a system is said to be differentially flat if there is a collection of m functions $y=(y_1,\cdots,y_m)$ of the system variables and of their time-derivatives, i.e. $y_i=\phi(w,\dot{w},\ddot{w},\cdots,w^{(\alpha_i)}),\ i=1,\cdots,m$ satisfying the following two conditions [12],[13]:

1) There does not exist any differential relation of the form $R(y,\dot{y},\cdots,y^{(\beta)})=0$ which implies that the derivatives of the flat output are not coupled in the sense of an ODE, or equivalently it can be said that the flat output is differentially independent

2) All system variables (i.e. the elements of the system's state vector w and the control input) can be expressed using only the flat output y and its time derivatives $w_i=\psi_i(y,\dot{y},\cdots,y^{(\gamma_i)}),\ i=1,\cdots,s$.

B. Controller design for agricultural robots

The kinematic model of the agricultural robot is considered. This is given by

$$\begin{array}{c}\dot{x}=vcos(\theta) \\ \dot{y}=vsin(\theta) \\ \dot{\theta}=\omega=\frac{v}{L}tan(\phi)\end{array} \tag{13}$$

where $v(t)$ is the velocity of the vehicle, L is the distance between the front and the rear wheel axis of the vehicle, θ is the angle between the transversal axis of the vehicle and axis OX, and ϕ is the angle of the steering wheel with respect to the transversal axis of the vehicle (Fig. 2). The position of such a vehicle is described by the coordinates (x,y) of the center of its rear axis and its orientation is given by the angle θ between the x-axis and the axis of the direction of the vehicle. The steering angle ϕ (or equivalently the rate of change of the vehicle's heading $\dot{\theta}=\omega$) and the speed v are considered to be the inputs of the system.

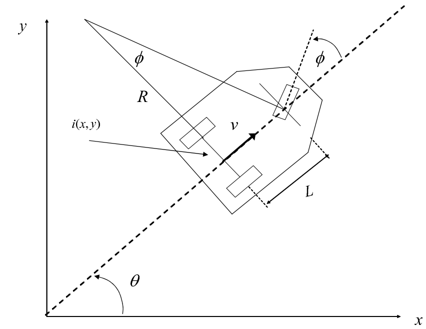


Fig. 2. The model of the autonomous agricultural vehicle (cart-like vehicle)

Flatness-based control can be used for steering the vehicle along a desirable trajectory. In the case of the autonomous vehicle of Eq. (13) the flat output is the cartesian position of the center of the wheel axis, denoted as $\eta=(x,y)$, while the other model parameters can be written as:

$$v=\pm||\dot{\eta}|| \quad \begin{pmatrix}cos(\theta)\\ sin(\theta)\end{pmatrix}=\frac{\dot{\eta}}{v} \quad tan(\phi)=ldet(\dot{\eta}\ddot{\eta})/v^3 \tag{14}$$

These formulas show simply that θ is the tangent angle of the curve and $tan(\phi)$ is the associated curvature. One then proceeds by successively differentiating the output until the input appears in a non-singular way. If the sum of the output differentiation orders equals the dimension $n+v$ of the extended state space, full input-state-output linearization is obtained. The closed-loop system is then equivalent to a set of decoupled input-output chains of integrators from u_i to η_i. The exact linearization procedure is illustrated for the unicycle model of Eq. (21). As flat output $\eta=(x,y)$ the coordinates of the center of the wheel axis is considered . Differentiation with respect to time then yields [15]

$$\dot{\eta}=\begin{pmatrix}\dot{x}\\ \dot{y}\end{pmatrix}=\begin{pmatrix}cos(\theta) & 0\\ sin(\theta) & 0\end{pmatrix}\cdot\begin{pmatrix}v\\ \omega\end{pmatrix} \tag{15}$$

showing that only v affects $\dot{\eta}$, while the angular velocity ω cannot be recovered from this first-order differential information. To proceed, one needs to add an integrator (whose state is denoted by ξ) on the linear velocity input $v=\xi$, $\dot{\xi}=\alpha\Rightarrow\dot{\eta}=\xi[cos(\theta),sin(\theta)]^T$, where α denotes the linear acceleration of the vehicle. Differentiating further one obtains

$$\begin{array}{c}\ddot{\eta}=\dot{\xi}\begin{pmatrix}cos(\theta)\\ sin(\theta)\end{pmatrix}+\xi\dot{\theta}\begin{pmatrix}sin(\theta)\\ cos(\theta)\end{pmatrix}= \\ =\begin{pmatrix}cos(\theta) & -\xi sin(\theta)\\ sin(\theta) & \xi cos(\theta)\end{pmatrix}\begin{pmatrix}\alpha\\ \omega\end{pmatrix}\end{array} \tag{16}$$

and the matrix multiplying the modified input (α, ω) is non-singular if $\xi \neq 0$. Under this assumption one defines

$$\begin{pmatrix} \alpha \\ \omega \end{pmatrix} = \begin{pmatrix} cos(\theta) & -\xi sin(\theta) \\ sin(\theta) & \xi cos(\theta) \end{pmatrix}^{-1} \cdot \begin{pmatrix} u_1 \\ u_2 \end{pmatrix} \tag{17}$$

and $\ddot{\eta}$ is denoted as

$$\ddot{\eta} = \begin{pmatrix} \ddot{\eta}_1 \\ \ddot{\eta}_2 \end{pmatrix} = \begin{pmatrix} u_1 \\ u_2 \end{pmatrix} = u \tag{18}$$

which means that the desirable linear acceleration and the desirable angular velocity can be expressed using the transformed control inputs u_1 and u_2. Then, the resulting dynamic compensator is (return to the initial control inputs v and ω)

$$\begin{gathered} \dot{\xi} = u_1 cos(\theta) + u_2 sin(\theta) \\ v = \xi \\ \omega = \frac{u_2 cos(\theta) - u_1 sin(\theta)}{\xi} \end{gathered} \tag{19}$$

Being $\xi \in R$, it is $n + v = 3 + 1 = 4$, equal to the output differentiation order in Eq. (18). In the new coordinates

$$\begin{gathered} z_1 = x \\ z_2 = y \\ z_3 = \dot{x} = \xi cos(\theta) \\ z_4 = \dot{y} = \xi sin(\theta) \end{gathered} \tag{20}$$

The extended system is thus fully linearized and described by the chains of integrators, in Eq. (18), and can be rewritten as

$$\ddot{z}_1 = u_1, \quad \ddot{z}_2 = u_2 \tag{21}$$

The dynamic compensator of Eq. (19) has a potential singularity at $\xi = v = 0$, i.e. when the vehicle is not moving, which is a case not met while executing the trajectory tracking. It is noted however, that the occurrence of such a singularity is structural for non-holonomic systems.

A nonlinear controller for output trajectory tracking, based on dynamic feedback linearization, is easily derived. Assume that the autonomous vehicle must follow a smooth trajectory $(x_d(t), y_d(t))$ which is persistent, i.e. for which the nominal velocity $v_d = (\dot{x}_d^2 + \dot{y}_d^2)^{\frac{1}{2}}$ along the trajectory never goes to zero (and thus singularities are avoided). On the equivalent and decoupled system of Eq. (21), one can easily design an exponentially stabilizing feedback for the desired trajectory, which has the form

$$\begin{gathered} u_1 = \ddot{x}_d + k_{p_1}(x_d - x) + k_{d_1}(\dot{x}_d - \dot{x}) \\ u_2 = \ddot{y}_d + k_{p_2}(y_d - y) + k_{d_2}(\dot{y}_d - \dot{y}) \end{gathered} \tag{22}$$

and which results in the following error dynamics for the closed-loop system

$$\begin{gathered} \ddot{e}_x + k_{d_1}\dot{e}_x + k_{p_1}e_x = 0 \\ \ddot{e}_y + k_{d_2}\dot{e}_y + k_{p_2}e_y = 0 \end{gathered} \tag{23}$$

where $e_x = x - x_d$ and $e_y = y - y_d$. The proportional-derivative gains are chosen as $k_{p_1} > 0$ and $k_{d_1} > 0$ for $i = 1, 2$. Knowing the control inputs u_1, u_2, for the linearized system one can calculate the control inputs v and ω applied to the vehicle, using Eq. (19). In the general case of design of flatness-based controllers, the avoidance of singularities in the proposed control law can be assured [15].

When the estimated state vector of the vehicle $[\hat{x}, \hat{y}, \hat{\theta}]^T$, as computed by the Extended Information Filter algorithm, is used in the control loop, the control input for steering the vehicle becomes

$$\begin{gathered} u_1 = \ddot{x}_d + k_{p_1}(x_d - \hat{x}) + k_{d_1}(\dot{x}_d - \dot{\hat{x}}) \\ u_2 = \ddot{y}_d + k_{p_2}(y_d - \hat{y}) + k_{d_2}(\dot{y}_d - \dot{\hat{y}}) \end{gathered} \tag{24}$$

and consequently from Eq. 19 one has

$$\begin{gathered} \dot{v} = u_1 cos(\hat{\theta}) + u_2 sin(\hat{\theta}) \\ \omega = \frac{u_2 cos(\hat{\theta}) - u_1 sin(\hat{\theta})}{v} \end{gathered} \tag{25}$$

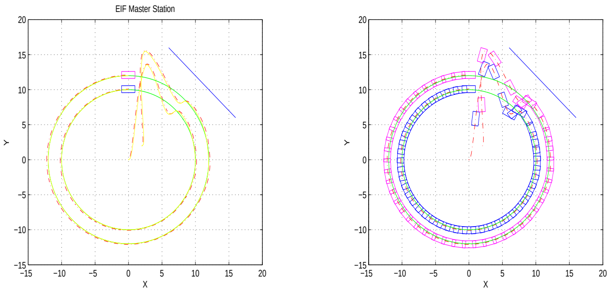
IV. Simulation tests

Master-slave cooperation of two agricultural robots was considered (see Fig. 1). The master tractor generates a reference path and the motion characteristics (velocity, acceleration, orientation) that the slave tractor has to follow. It was assumed that measurements of the xy coordinates of the vehicles could be obtained through multiple GPS units (localization of moderate accuracy), or multiple local RTK-GPS stations (localization of higher accuracy). Moreover, localization of the vehicles could be performed using measurements of their distance from a reference surface. This distance can be measured with the use of different on-board sensors, e.g. laser, sonar or vision sensors. The measurements from the GPS were combined with the distance sensor measurements and were initially processed by local filters to provide local state vector estimates. At a second stage the local state estimates for the robotic vehicles were fused using the Extended Information Filter. Using the outcome of the Extended Information Filter state estimation-based control was implemented.

Indicative results about tracking of various trajectories (e.g. reference paths followed by the vehicles to perform harvesting) with use of the Extended Information Filter are shown in Fig. 3 to Fig. 6. It can be noticed that the Extended Information Filter provides accurate estimates of the vehicle's state vector thus also resulting in efficient tracking of the reference trajectories. Finally, it is noted that the paper's approach can be applied also to various types of 4WD agricultural vehicles.

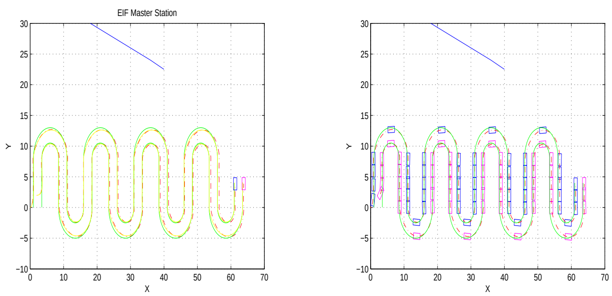
V. Conclusions

The Extended Information Filter has been introduced and applied to autonomous agricultural robots. The method is also suitable for filtering and state estimation-based control of a generic class of robotic vehicles. Thus apart from agricultural robots the method can be applied to autonomous navigation of service or surveillance robots. Two robotic vehicles were considered navigating autonomously within a master-slave cooperation scheme. Local Extended Kalman Filters provided



(a) (b)

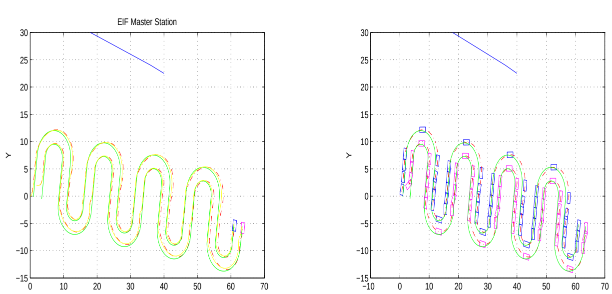
Fig. 3. Extended Information Filtering and flatness-based control for cooperating robot harvesters: (a) synchronized tracking of reference path 1 (b) position of the synchronized vehicles every 100 sampling periods



(a) (b)

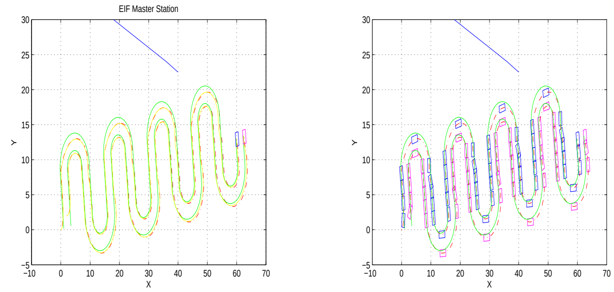
Fig. 4. Extended Information Filtering and flatness-based control for cooperating robot harvesters: (a) synchronized tracking of reference path 2 (b) position of the synchronized vehicles every 100 sampling periods

local state estimates for the vehicles which were finally fused into aggregate state estimates using the Extended Information Filter. Next, the estimated state vectors describing the motion characteristics of the vehicles were used in a nonlinear control loop which generated steering commands for guiding the vehicles along desirable trajectories. The nonlinear controller was designed according to differential flatness theory. The proposed state estimation-based control for autonomous navigation of agricultural robots was tested through simulation experiments.



(a) (b)

Fig. 5. Extended Information Filtering and flatness-based control for cooperating robot harvesters: (a) synchronized tracking of reference path 3 (b) position of the synchronized vehicles every 100 sampling periods



(a) (b)

Fig. 6. Extended Information Filtering and flatness-based control for cooperating robot harvesters: (a) synchronized tracking of reference path 4 (b) detailed motion of the synchronized vehicles

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A robust, simple, low-cost autonomy enhancement module for LOCOSTRA, a remotely controlled demining machine

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Abstract

The paper gives a short description of LOCOSTRA project and introduces the most recent work done within the project – the robust, simple, low-cost autonomy enhancement module. LOCOSTRA (LOw-COst TRActor for Humanitarian Demining), a remotely controlled, armoured demining machine[5] is the output of an eighteen months project co-funded by the Italian Ministry of Economic Development and the Italian Institute for Foreign Trade and coordinated by the University of Genova. The autonomy enhancement module is part of a recent work undertaken in order to upgrade the LOCOSTRA remote control system. Using easy available components we have created a fully operating system which satisfies the principal requirements of reliability, low cost, and ease of future upgrade. The autonomy enhancement module introduces new important functions to the control system such as the supervision of the safety of the machine's operations and remote control assistance and provides a suitable base for further development of the remote control system.

1. Introduction

Most countries affected by landmines have suffered protracted conflict and Humanitarian Mine Action occurs alongside post conflict reconstruction and development within the constraints of a weak economy. Removing all Explosive Remnants of War (ERW) from a country can take decades and the national economy is often unable to finance such a long-term commitment. The need for the adoption of sustainable demining procedures and tools, and the need to transfer of demining and managing skills to local entities, is now widely acknowledged throughout the HMA community.

In many cases, high purchase and maintenance costs prevent demining organisations from using machines to assist their manual demining endeavours. Sometimes machines are donated by governments but there are many cases of such machines being underutilised because of the lack of spare parts and expertise needed to keep them running. Many were also not designed for practical use in the field.

The use of machines to assist manual demining and make it safer is limited by the following factors:

- High purchase price;
- High running costs (in terms of fuel and fluids);
- High cost of spare parts;
- Limited availability of spare parts;
- High complexity of maintenance and operation.

Exceptions occur when mature agricultural or plant machinery is adapted using locally available materials in a local workshop. In Angola, Sri Lanka, Cambodia and Georgia there are examples of plant and agricultural machinery that has been adapted for use in HMA and that can be both operated and maintained using skills that are available in-country.

As their job is to process the ground, agricultural machines originally conceived to work the soil could be efficiently employed. Agricultural technologies are largely available everywhere and in different sizes. Where they are not already available their presence might be desirable to increase the capability to produce food by farm mechanization. As mine affected countries are traditionally agricultural countries where a great proportion of the gross national product comes from fruits of the land, some agricultural resources are already available [1].

Agricultural technologies are mature and simple, easy repairable in every developing country in local, not specialized workshops. The modularity of agricultural technologies is another advantage; same tools can be mounted on different tractors units and replaced by dedicated agricultural tools when demining operations are over. Moreover, involving local technicians into the re-design of new or improved technology helps reducing dependency of local communities from donor's help as well as facilitating local human development. Empowerment is an integral part of many poverty reduction programs [2]. It is seen as essential to promote human development and

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[5] According to International Mine Action Standards (IMAS) 04.10 Glossary of mine action terms, definitions and abbreviation, the term demining machine refers to a unit of mechanical equipment used in demining operations.

human freedom to help individuals and communities to function as agents for the improvement of their own wellbeing. The handover of all mine action activities to local entities who can perform the majority of the work and can gain skills while participating to the creation and maintenance of new agricultural technology for area reduction is desirable and necessary.

2. LOCOSTRA project

LOCOSTRA, whose name stands for LOw-COst TRActor for Humanitarian Demining, is an agricultural tractor adapted to be used in demining activities (Figure 1). The tractor is armoured and equipped with blast resistant wheels. By employing an industrial transmitter and receiver coupled with electro-hydraulic valves we made it suitable to be controlled remotely as an alternative option to the traditional on board control.

LOCOSTRA has been specifically designed to be used as verification asset for technical survey and can be equipped with many different commercial off the shelf (COTS) tools:

- a mulcher (Figure 2) that allows vegetation to be cut and a visual inspection to be done either by a person on a small tower, by a camera on a balloon, or a video camera on board, or
- with an agricultural derived tool for removing/destroying landmines (Figure 3), or
- with an array of metal detector or a large loop detector to check for the presence of metallic parts of buried mines (Figure 4).

According to the tool with which the tractor is equipped LOCOSTRA machine can be classified as ground preparing machine, ground processing machine or mine protected vehicle (used as a platform for a detection system in a Suspected Hazardous Area (SHA)). LOCOSTRA is an intrusive, semi-autonomous machine. Being the overall weight of the tractor and the blast resistant wheels approximately 3000 kg, the machine can be classified as light.

LOCOSTRA is built around the P796V tractor produced by Pierre Trattori, a small, lightweight, four wheel drive, agricultural mini-tractor with 79hp, designed to be equipped with one or more of a range of proven agricultural tools. Power to the attachments is drawn from a power-take-off (PTO) at the rear of the vehicle. The frame being reversible, i.e. the driving position invertible, the same power-take-off can be used to carry tools such as cutting bars at the front to cut vegetation in front of the machine. The steel frame allows the use of relatively heavy attachments and leaves the potential to add dedicate robotic devices if a need to move ERW is required. A standard, category one three point linkage attachment at the rear allows hydraulic lifting and positioning of many off-the-shelf agricultural tools.

The machine is designed to be easily transported over unimproved terrain without the need for a dedicated transporter. The innovative blast resistant wheels and the relatively high travel speed (20km/h) allow self movement, easy also on uneven terrain, while the overall vehicle weight and dimensions allow it to load into a truck bad, when long distances will have to be covered. When medium long distances have to be covered, the tractor can be equipped with traditional pneumatic wheels, which will be provided together with a set of blast resistant wheels.

The remote control allows the tractor to be driven from a safe distance of up to 100m. No manual controls have been removed, so leaving manual drive with the operator on board possible when the machine is brought to the work place and when it is used in traditional agricultural activities after demining operations are over.

Intended for use in areas where there is a risk from explosive devices, its wheels are designed to withstand the detonation of 500g of TNT without damage that would halt operations. The same blast resistant wheels are mounted at the front and rear.

To maintain a low weight, the minimal armouring required is a composite of ballistic polyamides and polycarbonate with critical areas further protected by steel plate. The armouring can be easily removed for servicing and when working in extreme temperatures (over 40°C).

The machine is too small and light to allow any significant protection against large explosive threats (such as AT mines) and no effort has been made to provide this. The machine is designed for use in areas with an AP mine threat.

The machine has been proven with a vegetation cutting attachment. Other attachments able to prepare the ground surface have been used, but the ground conditions so affect performance that the effectiveness of ground-processing implements in a mined environment must be determined on a case-by-case basis or by reference to a data-pool gained by real field experience. Vegetation cutting is of proven advantage to demining operations from survey to clearance of defined hazardous areas. It allows visual assessment of the ground to be conducted and removes the need for deminers to cautiously remove undergrowth as they advance during clearance procedures. Ground processing can be used for “proving” or confidence building over small or wide areas, but LOCOSTRA is intended to be used as a ground-processor in advance of manual excavation clearance methods widely used in Asia.

According to one of the most important requirements the final purchase price is equal to € 50,000 per unit, with operating costs comparable to that of a road vehicle.

The only components added to the original tractor are:

- Innovative blast resistant wheels, designed to resist several explosions (at least 5) while protecting the tractor from damages caused by the explosions. Wheels are essentially built around a COTS solid rubber wheel embedded in an outer steel structure providing ventilation and protection.
- Remote control system, designed to allow driving the tractor from the safe distance of 100m. It consists of the industrial transmitter/receiver coupled with electro-hydraulic valves. Only essential commands are actuated remotely by electro-hydraulic valves mounted in parallel to hydraulic valves that were on board in the original tractor. Therefore LOCOSTRA can be driven both on board with traditional commands and remotely by the transmitter.
- Autonomy enhancement module, designed to allow an easier remote control of the machine by embedding several more sensors than the basic remote control, an industrial programmable logic controller (PLC), the communication module and a video camera, to help driving the machine remotely in difficult environments such as areas covered by thick vegetation and allowing the machine to be used in more complex agricultural tasks.
- Armouring, designed to be simple and easy to be removed during maintenance. It is constituted by appropriately shaped covers of 3mm thick mild steel mounted to protect delicate parts and easy removable ballistic fabric shields protecting hydraulic hoses and separating the active tool from the machine main chassis.

3. The autonomy enhancement module

The main idea of LOCOSTRA project is to provide a robust, simple, easy to maintain and low-cost solution to ground processing, vegetation cutting and quality control in mine action. On the basis of these assumptions the autonomy enhancement module (AEM) for LOCOSTRA was designed as well.
The AEM for LOCOSTRA was developed to upgrade the already existing remote control system. The autonomy enhancement module introduces new control system functions. It increases the safety of the machine operations during remote control thanks to the presence of additional sensors. Together with the IP (internet protocol) video camera, a video camera using internet protocol to send the captured images to the receiver, additionally mounted on the tractor, the AEM makes the remote driving of the machine easier.
Moreover the autonomy enhancement module can be reprogrammed allowing more features to be added to the control system and is a good base for a further development of the machine autonomy.
The core structure of the AEM and its arrangement on the machine are presented in Figure 5 and Figure 6, respectively. The module has four main components: the main control unit, the sensors, the communication module and the human machine interface (HMI).
The main control unit is basically a programmable logic controller (PLC) together with a block of electrical automotive relays. It is connected with the sensors installed on the tractor. The communication module is composed of wireless network components and is responsible for providing a communication bridge between the main control unit and the human machine interface. In our case the HMI is a notebook equipped with a wireless card.
Additionally to the main parts we installed an IP video camera to expend the functionality of the AEM.
The main control unit core component is a programmable logic controller (PLC). The PLC adds intelligence and some new functions to the control system. Because the PLC is connected to the electro-hydraulic valves in parallel to the remote control system's receiver, it is able to control most of the machine's functions. Coupled with additional installed sensors, it makes using the machine safer. The PLC can be remotely programmed trough the communication module using software (free and provided by the producer) installed on the HMI.
The elementary actions enabled by the PLC are: motor ignition, motor switch off, switch between steering axis (front/central), turn ON/OFF the Power Take-Off (PTO) clutch, turn ON/OFF the differential blockage system, and move up/down the three point linkage system.
The PLC is also used to monitor the state of the machine. Having access to the sensors and relays listed below the PLC can supervise operations done by the machine and send information about it to the HMI. Sensors and relays accessible for the PLC are: lack of oil sensor, low pressure of oil sensor, high temperature of oil sensor, double steering system sensors, double steering system relays, ignition relay, PTO clutch relay, differential blockage relay, three point linkage, up/down relays, velocity sensor.
The PLC model we chose provides 36 input and 24 output channels. The inputs and outputs are connected through the relays with sensors and electro-hydraulic valves, respectively. Currently only 20 input and 10 output channels are used, the remaining channels can be employed in future applications. The FATEK PLC was chosen because of its low price and because it is of industrial type, therefore, robust and reliable. Moreover it allows reprogramming and adding features to the control system in case of future upgrades.
The sensors added to the ones already installed onboard (oil pressure sensor, oil temperature sensor, velocity sensor) are inductive sensors used to supervise the driving system.
The communication module includes a RS232-to-IP converter used to convert a serial binary RS232 standard protocol to/from an internet protocol (IP), a wireless router coupled with a Wireless Local Area Network (WLAN) antenna working at the frequency of 2.4GHz, and a human machine interface, which in our case is notebook.

The router, like all the other components of the communication module, is available off the shelf everywhere in the world where Internet in used.
The task of the communication module is to provide a robust and reliable communication bridge between the main control unit (PLC) and other elements installed on the board of the tractor and the human machine interface. Apart from the communication module hardware we developed also the software which is an integral part of the communication module and the human machine interface. The software enables the user to control the PLC and, therefore, to control all the machine functionality provided by the PLC. Moreover, the software provides to the user images transmitted by the IP video camera mounted on board of the machine.
The communication between the PLC unit and the HMI works as follows. The PLC is linked with the wireless router through the RS232-to-IP converter. The notebook used as HMI connects wirelessly with the router which enables to communicate with all the other components linked to it. The network created allows the software installed on the HMI to access the PLC's communication port. All data sent from the PLC are converted (by the RS232-to-IP converter) from RS232 serial binary standard data to IP protocol packets which are readable by the HMI. In the next step, data is converted back to a serial asynchronous data form. This is performed by a virtual serial port driver, which enables to emulate a virtual RS232 serial port on the HMI operating system. Data provided to the virtual RS232 serial port is the data received from the PLC. The communication works in both ways, which means that data sent to the virtual RS232 serial port is delivered to the PLC's communication port. The communication bridge created by the communication module becomes transparent for the PLC and the software user giving an impression of a direct communication between them.
The last main part of the AEM is a standard notebook equipped with a WLAN card, used as Human Machine Interface.
To control the PLC the user handles a human machine interface software run on the notebook. This software consists of two components: graphical user interface (GUI) and OPC server, a software application that acts as a protocol converter. The GUI provides a user a graphical interface constituted by an application window with buttons and indicators and a window presenting images transmitted from the IP video camera. Through the GUI the user can control and supervise the work of the machine. The OPC server works as bidirectional protocol converter, it translates commands to the FACON-PLC communication protocol (a communication protocol used by the PLC) [3] sent from the GUI application to the PLC. By developing our own OPC server we increased the efficiency of the software and enabled a better setup of the communication channel which results in higher communication speed and more stable connection.
The communication module allows introducing some other components such as a global positioning system module and additional sensors, to the wireless communication bridge. The adoption of these new components will enhance the remote control system of the machine and will constitute a forward step toward an increased autonomy.
The autonomy enhancement module is completed by an IP video camera, connected to the communication module. The remote vision system created by connecting the IP video camera to the communication module makes driving the machine remotely easier by providing feedback images from on board the machine to the HMI (Figure 7).

4. Conclusions

Although, the amount of time spent at working on the module so far only allowed us to implement part of the functions foreseen, the current system already satisfies most of our expectations. It is robust, simple and low-cost, embedding only commercial off the shelf components. Moreover, it provides a suitable base for further development of the remote control system, because ready to host new components such as a global positioning system module and additional sensors.
The autonomy enhancement module introduces new important functions to the remote control system and makes LOCOSTRA a semi-autonomous machine suitable also to be used in agricultural activities by disabled people.
LOCOSTRA control system will be further improved within the framework of a European funded project called TIRAMISU (Toolbox Implementation for Removal of Antipersonnel Mines, Submunitions and UXO). LOCOSTRA machine has been included among the technologies for technical survey on which TIRAMISU research will be based.

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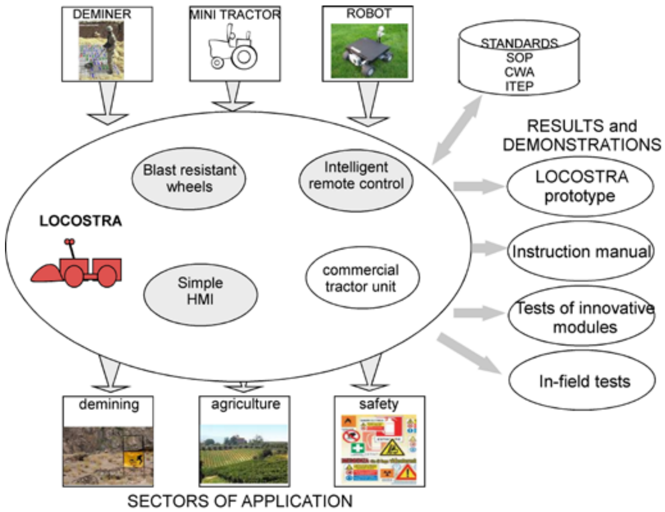

Fig.1. Idea of the LOCOSTRA project

Fig.2. LOCOSTRA machine equipped with COTS mulcher (produced by FAE – Advanced Shredding Technologies).

Fig.3. LOCOSTRA machine equipped with COTS ground processing tool (produced by F.lli Spedo).

Fig.4. LOCOSTRA machine equipped with COTS large loop detector (produced by Ebinger).

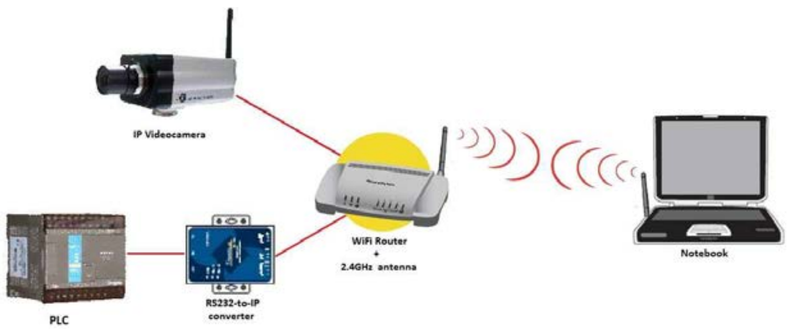

Fig.5. Communication module architecture

Fig.6. PIERRE P796V tractor with hardware installed onboard

Fig.7. Front and rear view from the IP video camera mounted on LOCOSTRA

State of the Art Review on Mobile Robots and Manipulators for Humanitarian Demining

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Abstract- **Robotics solutions properly sized with suitable modularized structure and well adapted to local conditions of dangerous unstructured areas can greatly improve the safety of personnel as well as the work efficiency, productivity and flexibility. In this sense, mobile systems equipped with manipulators for detecting and locating antipersonnel landmines are considered of most importance towards autonomous/semi-autonomous mine location in a proficient, reliable, safer and effective way. This paper reviews the most relevant literature and previous research activity regarding mobile robots and manipulators for humanitarian demining.**

I. INTRODUCTION

Detection and removal of antipersonnel landmines in infested fields is an important worldwide problem [1]. Landmines, cluster munitions, explosive remnants of war (ERW) and improvised explosive devices (IED) are an enduring legacy of conflict. These devices can remain active for decades, they are not aware of negotiation or peace treaties and do not distinguish between soldiers and civilians. AP mines and unexploded devices (UXO) of the Second World War still exist in all the countries of Europe and North-Africa [2]. In 2010, a total of 4191 new landmine casualties were reported, 5% more than in 2009, and a total of 72 states, as well as seven disputed areas, were confirmed or suspected to be mine-affected [3]. The problem of hidden IEDs has become especially worried. These homemade bombs came to prominence during the wars in Iraq and Afghanistan, but now these ghastly devices are proliferating around the world. The number of such bombing has increased from close to zero a decade ago to more than 4000 per year in Afghanistan alone [4]. A high mine-clearance rate can only be accomplished by using new technologies such as improved sensors, efficient manipulators and mobile robots. Mobile systems equipped with manipulators for detecting and locating antipersonnel landmines are considered of major relevance towards autonomous/semi-autonomous mine location in an efficient, reliable, safer and effective way. Robot mobility, manipulator dexterity and energy efficiency are some of the key points for future development. This paper reviews the most relevant literature and previous research activity [5-8] regarding mobile robots and manipulators for humanitarian demining being its main purpose to help outlining the main features, requirements and specifications, for the next generation of mobile robots to be developed in the frame of the TIRAMISU EC project (Grant Agreement n° 284747). The paper summarizes the information of the previous IARP workshops, complemented by some recent progresses achieved at the RMA, CSIC and ISR-UC.

II. THE PROBLEM

In 1994, the United Nations Mine Action Service (UNMAS) was founded, with as objectives the mine awareness and risk reduction education, the minefield survey, mapping, marking and clearance, the assistance to victims, the advocacy to support a total ban on AP-mines, and, in 1999, the treaty of Ottawa (the Convention on the Prohibition of the use, stockpiling, production and transfer of AP-mines and their destruction) entered into force.

The military de-mining operations accept low rates of Clearance Efficiency (CE). For these purposes it is often sufficient to punch a path through a mine field. But, for the humanitarian de-mining purposes, on the contrary, a high CE is required (a CE of 99.6% is required by UN). This can only be achieved through a 'keen carding of the terrain, an accurate scanning of the infested areas': that implies the use of sensitive sensors and their slow systematic displacement, according to well-defined procedures or drill rules, on the minefields. At present, hand-held detectors seem still to be the only and most efficient tools for identifying all unexploded ammunitions and mines, but this first step doesn't solve the problem: the removal task and/or the neutralisation and/or destruction task must follow, and those last two tasks are also very time-consuming actions. So the importance of fostering robotic technology advancements into the humanitarian demining context is considered of major interest in two main directions: improving operational performance and decreasing operational risks by means of demining task robotization and by separating as much as possible human operators from the direct exposure to threat.

III. MOBILE ROBOTS AND MANIPULATORS

A. Mobile robots

Conventional vehicle-mounted mine detector systems employ an array of sensor devices to achieve a detection swath typically 2~4m wide. Some systems employ more than one type of sensor technology. These systems, while being very useful are often expensive, unsafe, complex and inflexible [9-11]. Nevertheless, several IARP workshops [12-13] have on the contrary shown that the use of Robotics Systems could improve the safety and the clearance efficiency and that they may be considered as promising tools. However, the development of a Robotics System (RS) implies the design, the reliability and the cost-effectiveness of its modular components: those ones that appear in Figure 1.

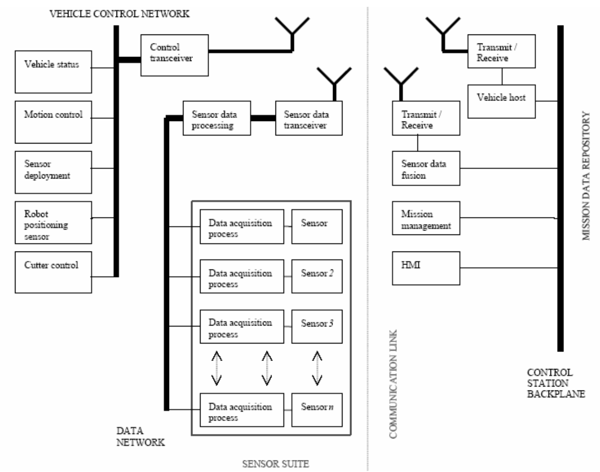


Fig. 1. Modular description of a Robotic System for the Detection of Explosive Devices

By other side, several mobile remote controlled platforms (with or without manipulators) have been described, some ones illustrated in Fig. 2.a to 2.h [for more information please refer to references: 1, 7, 10, 12, 13, 14, 15, 21, 27, 28, 29] where in most cases the motion control and the navigation sensory needs are highly sophisticated [16-24, 26].

General motion in difficult terrain needs advanced adaptive control, and closely controlled motion is required to deliver sensor packages to accurate positions when detection is in progress. The motion of the vehicle demands by far the highest power requirements. Whilst some scenarios allow the use of an umbilical, many need more autonomy so an on-board power supply is needed. Thus efficiency of motion is most important, requiring advanced control algorithms [25].

On the other hand, speed is unlikely to be paramount since detection will take time and will probably limit forward motion. The modes of operation need to be specified. Most requirements have a man-in-the-loop operation and there is a direct line of sight operation at a safe distance. This safe distance has to be specified and as is the method of ensuring that the safety restraints are carried out correctly. Typically, current methods for remote control from close in up to 1-2 km distance use Tele-operation.

Examples of the advantages of Tele-operation are that the task can be carried out by a single operator and that camera positions are easily selectable using a microwave link or fibre-optic for a line of sight video transmission from the machine to the remote command station. To carry out complex tasks, the numbers of cameras needed and their positions have to be considered. It is likely that at least two fixed or one rotational camera need to be fitted to the vehicle to give all round viewing during operation and allow the modelling of the ground. Recent developments with omnidirectional stereo tracking system have been reported [24].

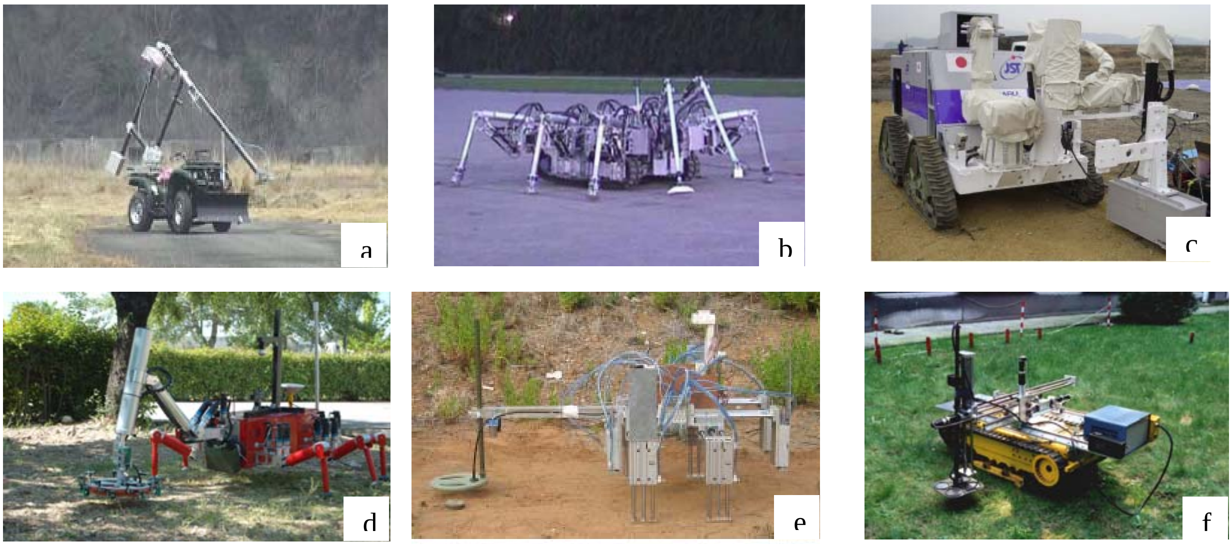
Operator control units can be fitted to display single or multi-image options. The communication link might be a 1.4 GHz video link. Fibre optic links that offer high bandwidth can be used but the trailing of cables can be a problem over long distances. A communications link to carry control and sensor feedback signals is also required.

In summary, machines to carry out de-mining activities in place of human de-miners are generally likely to be wheeled or tracked. However, there is a possibility that in certain terrain, walkers will add value [1, 5, 6-7, 14, 21, 28]. Such machines are likely to be light in weight. The control and communications system is likely to be of a nature which will facilitate the addition of higher order functionality such as sensor fusion, HMI, navigation, etc.

The complete system will need to integrate the vehicle control and navigation systems with a data fusion system that will discriminate, to a high degree of confidence, between mine and ‘no-mine’ conditions.

B. Manipulators for scanning/sensor handling

Manipulators are employed in many mobile robots [5, 6, 7, 9, 10, 12, 14, 21-23, 29] with the mission of handling sensors and to perform the sweeping/scanning of the interested surface. This is indeed a complex task. For example when using GPR (normally used in combination with a Metal detector), the signal is strongly affected by a ground surface. If it is not flat and even, a reaction from ground surface varies much stronger than that from landmines. In addition, this variation of reaction from a ground surface disturbs an imaging of landmine, occasionally cancels it out. It’s consequently mandatory to design an adaptive scanning of the ground surface to reduce the effect of a bad positioning on the useful reflection signal.



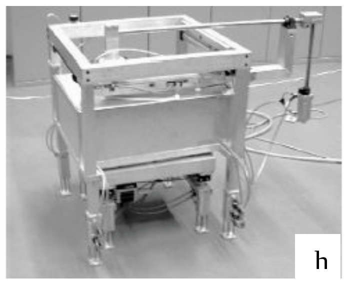


Fig 2: a) Gryphon-IV. Tokyo Institute of Technology, JP; b) COMET-III – Chiba University, JP; c) Mine Hunter Vehicle, with teleoperated hydraulic manipulator, Chiba University, JP; d) SILO6-DYLEMA, six-legged autonomous demining robot with 5 dof electrical manipulator, CSIC, ES; e) LADERO, pneumatic demining multi-sensor legged robot, ISR-UC, PT; f) Mine detection robot Hunter-ROBUDEM, Royal Military Academy, BE; g) 16-wheeled Sensing Vehicle, Tohoku University, JP; h) AMRU-4, eight-legged electro-pneumatic sliding robot, RMA, BE

Proximity sensors attached directly to the sensor head can be a very simple solution for a reflexive control scheme to automatically adjust the vertical distance of the sensor head to the terrain [10, 12, 13, 21, 26, 29]. However, although technically more complex and expensive, in order to make possible a more efficient mapping and scanning of wider areas in a minimal time, cameras and/or laser range finders have to be used.

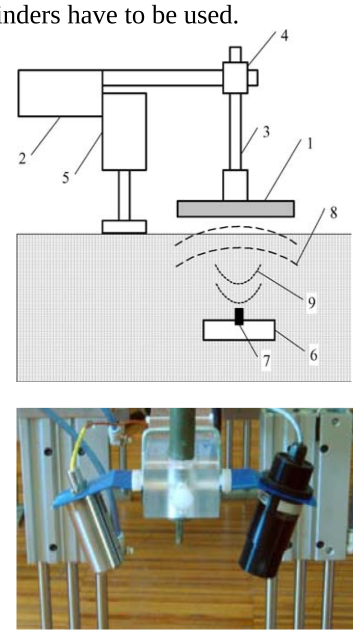


Fig. 3. Position of the metal detector on the robot. 1: metal detector, 2: robot platform, 3: support, 4: height adjusting unit, 5:pedipulator, 6: mine, 7: metal part of the mine, 8: transmit field, 9: receive field (top) and infrared sensor (down). ISR [30].

Figure 3 illustrates the use of IR sensor that together with computer vision was succesfully employed for terrain mapping [30].

The passive stereo system has been selected for the GRYPHON-IV (Fig 4.a,b), working in two steps: first the generation of a regular grid that will be overlapped to the terrain image, then the computation of the commands to the actuators of the 5-DOF manipulator carrying the multi-sensor-head. Mono system results obtained with RMA-Hunter are presented in Fig. 4c [11]. By other side the 5-dof manipulator on-board SILO-6 has been used for terrain mapping using a number of IR sensors placed around the MD (Fig. 4d) [26].

C. Robot positioning and tracking.

The ability to track the pose of a mobile robot, relative to its environment, while simultaneously building a map of the environment itself, is a critical factor for successful navigation in a partially or totally unknown environment. Simultaneous localization and map building (SLAM) has therefore been a highly active research topic during the last decade. While most existing approaches to SLAM make use of sonar or laser scanners, the use of vision sensors, both stereo and monocular, has also been studied, mainly because vision can yield a much richer information about the environment when compared to other kinds of range sensing devices. Omnidirectional stereo tracking system presents the advantage of full 360º view with mechanical simplicity of implementation [24].

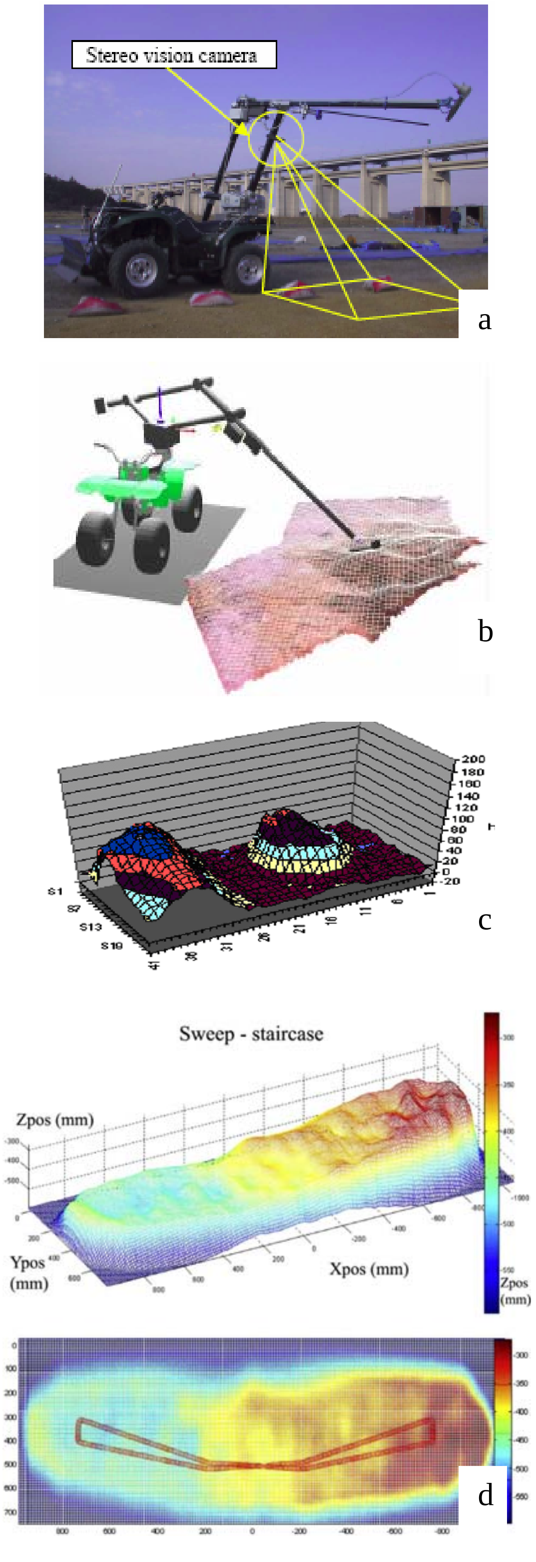


Fig. 4. .Stereo system results on GRIPHON-IV (a,b) [12], Mono system results on RMA-Hunter (c) [11], and validation of ground-surface-contour map generation with CSIC-SILO-6 (d) [26]

Finally, let us also mention that a good positioning accuracy can be obtained with commercial systems such as DGPS (Differential Global Positioning Systems) for so far the communications allow their use [27].

D. Robot control system

As previously mentioned, and as clearly pointed in the Fig.1, a Robotics System is not limited to a mobile platform, but includes proprioceptive and exteroceptive sensors allowing the precise actuation of the mechanical parts of the robot as well as the precise positioning of the robot self, and, in the case of Humanitarian de-mining, the detectors of the explosive devices. Furthermore, even if this solution may not be expected at short term, several robots may be used on the same minefield with dedicated de-mining tasks (brush-cutting, detection, removal, etc.). Computer systems are the backbones of all robotic applications. Since many years, searchers have developed ad-hoc programs for every new system. It is consequently difficult to build on existing systems and to reuse existing applications. There is a crucial need for reusable libraries, control framework and components. Efforts in this direction have focused on autonomous systems while we are also targeting Tele-operation. For example, the RMA chose this last base to develop COROBA, specific multi-robot-control software: such a control has to be based on robust communication libraries and to claim to be open it must subscribe as much as possible to existing standards. When considering communication libraries it appears that one communication middleware has been present for more than 10 years and has now reached its maturity, this middleware is CORBA. Beside the development of the architecture and to improve its capability, a simulator MoRoS3D written in Java already proved the consistency of the chosen middleware.

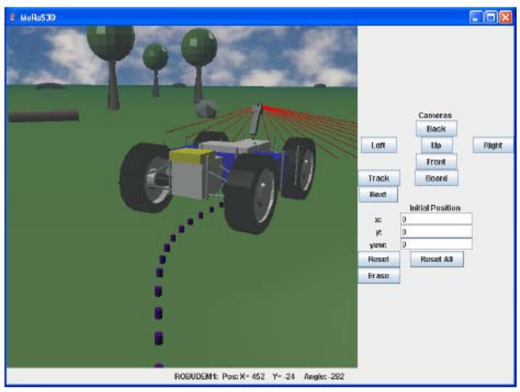


Fig.5. Virtual world

Figure 5 presents virtual world view on the treated scene. Tri-dimensional elements have been divided in different categories: robots, obstacles and terrain. Elements geometry can be read from files or directly created using Java code. At this stage, real implementations are realized on a outdoor robot ROBUDEM and an indoor one NOMAD.

IV. CONCLUSIONS

The development of a Robotics System not only depends on the technical aspects and modular components allowing the correct design of the remote controlled platform(s): the application related constraints have also to be carefully analysed in order to achieve the success of the whole system. Technically, the next scheme (proposed by the European Consortium CLAWAR) perfectly describes the hard- and software modules we have to focus on. The constraints related to the Humanitarian De-mining, and more generally to outdoor applications, may be summarised as follows: a high level of protection against the environmental conditions (dust, humidity, temperature, etc.), protection and resistance against vibration and mechanical shocks, long and continuous operation time between battery charging/changing or refuelling, wireless communication range depending on the terrain and minefield location, low cost, affordable prices by use of off-the-shelf components (typical constraint for HUDEM due to the lack of a real commercial market), high reliability, fail-safeness, easy maintenance, easy to use, application of matured technology. An ISO SC2 Technical Committee started the study of standards for mobile ROBOTICS (Catania, 23 Oct 2005 – final Clawar meeting). The paper is completed with next annexes, based on informations collected during the IARP workshops and allowed by their POCs, summarise the actual status of Robotics Systems. Test and Evaluation criteria are proposed as well, as result of WS discussions.

V. ACKNOWLEDGEMENTS

Prof. Baudoin want to mention that this paper includes the contribution of his colleagues from the CISS (Communication Information and Sensor Systems) department of the RMA [31, 32] and our researchers involved in the HUDEM (humanitarian de-mining) project [14, 17], as well as all the partners of our European funded projects (DG Education/OIC-R³-D², FW6-IST VIEW-FINDER, EDA/NMRS, MoD MB07). The authors also want to thank partners from the European Network CLAWAR (Climbing and Walking Robotics) and from the WG HUDEM of the IARP (International Advanced Robotics Programme). CSIC acknowledges DYLEMA/SILO-6 project, funded by the Spanish Ministry of Education and Science through grant DIP2004-05824. This work was supported in part by Consejería de Educación of Comunidad de Madrid under grant RoboCity2030 S-0505/DPI/0176. Dr. Montes acknowledges the support from the Technologial University of Panama. **The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 284747 (TIRAMISU).**

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ANNEXES

Important Note:

1. **The presented photos, robot data and drawings are drafts actually submitted by their authors. No reproduction is allowed without the written consent of them or of the IARP/WG Hudem Chairman (Yvan.baudoin@rma.ac.be)**
2. **New data may be added on request and are welcome (contact IARP/WG HUDEM) too**
3. **This data collection is adapted after each IARP WS HUDEM. The next one reflects the state of the art by end March 2012**

TITLE	COUNTRY
Introduction SOTA	**IARP - RMA**
HUNTER-ROBUDEM	**BELGIUM**
LADERO	**PORTUGAL**
DYLEMA/SILO-6	**SPAIN**
TRIDEM	**BELGIUM**
COMET II - III	**JAPAN**
AMS	**JAPAN**
GRYPHON IV	**JAPAN**
M HUNTER V	**JAPAN**
Other Robots, T&E criteria	**IARP WS Source**

TEST and EVALUATION

The next text will be adapted by mid 2011 to take into account with the current standards.
Two schemes have to be taken into account: the scheme of the figure 1 (Robotics System) and the modular specification defined in CLAWAR. Two major levels have to be considered when testing and evaluating a Robotics System, namely the system self, then the robot.
A robot may not be used in all possible circumstances and environmental conditions. It also has to be considered as a mechanical intelligent assistance that will be exploited if necessary. It's the reason why tests may not exceed the expectations of such a tool and why every robot belonging to this catalogue includes its actual capacities.
As an example, a large Tele-operated robot used in an agricultural zone will not have performances comparable with a multi-legged robot intended for assistance of some de-mining teams in a woody area.
Both systems will be quite different in size, locomotion, power, speed, etc.
First, in general, the robotics system should be tested at system level (figure 1) unless it can be shown that system integrity does not contribute to the specific results. The criteria Si (table 1 below) have to be verified if they correspond to the environmental conditions wherefore the system is proposed. Only some requirements have to be satisfied whatever the envisaged use of the RS.

SYSTEM LEVEL REQUIREMENT

The basic performance, at the Robotics System level, lies obviously in the correct (precise) mapping/detection of (a) pre-defined dummy minefield (s). All the modules (figure 1) aiming the working of the robotics system has to be evaluated during the trials. The minimal performance is fixed by this one obtained by a manual team in same circumstances. The next table only focuses on the use of a mobile Ground Robot carrying detection sensors.

S1	Map points (identified locations of mines from the mapping procedure) shall be accurate to within 50x50 cm² area, at least
S2	Control, communications and mine detection electronics should be insensitive to occasional explosions, shocks during the transportation and operator errors
S3	The system shall operate within the geographical (local) temperature range
S4	The system shall operate within the local humidity range
S5	The system shall be capable of detecting all mine types in *all- local* environments
S6	All components of the system shall communicate with a central controller, with progress information
S7	Communications equipment shall not interfere with the detection process
S8	Communications equipment shall not cause the detonation of any mines
S9	All sensor and electronic sub-systems shall be integrated without interference
S10	General safety/security related ISO have to be applied.

Table 1. ***SYSTEM LEVEL REQUIREMENT***

R1	Each robot shall be small enough to be portable (by manned ground transportation to access the minefield or to be removed from the minefield in case of failure), easy to transport and deploy
R2	Each robot shall have a mean-time between failures of , at least, 1 month
R3	Each robot shall be fail-safe on the minefield; it should have suitable mechanism for self-

	recovery for some levels of the problems that may face during it works
R4	Each robot shall have navigation capabilities allowing him to navigate to a map-point of a mine. It must have a localisation capability of its sensors.
R5	There shall be scanning equipment on the robot(s) to scan for dangerous terrain in front and behind the vehicle when it is been located at a specific map-point
R6	The robot shall be 100% reliable in clearing (detecting) mines
R7	The robot shall move effectively over longitudinal slopes of up to 25 %
R8	The robot shall move effectively over lateral slopes of up to 15%
R9	Sensor deployment will be such that Mine detection sensors shall identify mines down to depths specified at varying orientations in varying soil and vegetation conditions
R10	A de-mining robot should be self-contained (i.e.no ombilicus)
R11	All robots shall carry a marking system on board
R12	All robots shall be capable of operating for at least four hours of land-mine clearance before being refueled (recharged)
R13	The robot navigation systems shall be provably correct and convergent
R14	The robot control system shall be provably stable
R15	The robot shall traverse a variety of terrains: slippery surfaces, soft soil, hard core
R16	Operator safety should be guaranteed
R17	It should be capable of withstanding explosive blast without suffering major damage. At the minimum, the High Tech parts of the robot that can not be replaced locally should be well protected
R18	The man-machine interfaces including the ergonomic of lightweight portable control stations, friendly users
R19	The platform should not, through its design, limit the potential of the sensors. The operational conditions should be limited only by the detectors'capabilities
R20	The mechanical and electrical design should be modular, and the control architecture should include a high level application programming interface permitting upgrades and placements to sensor payloads throughout operational lifetime

Table 2. ***ROBOT LEVEL REQUIREMENTS***

With those minimal requirements in mind, Procedures suggested by the STANAG 4587 and the NATO RTO SCI-133 working group on "Countermine Technologies" may be adopted as well, and in particular:

(i) For the robot considered as a mobile platform:

- Mobility Testing
    - Transportability
    - Mobility to operations site
    - Mobility on off-road slopes (climb, descend, cross-slope)
    - area scanned in given period of time.
- System Robustness
    - Number of equipment breakdowns
    - Man-hours and parts to repair
    - Equipment modification recommendations
    - Blast effects on platform structure and mobility
- Logistic Support (POL and spare parts)
    - Daily POL/ELEC logs (oil, batteries, etc)
    - Operating hour consumption rates
- Maintenance
    - Scheduled, including daily, maintenance actions, time and parts
    - Unscheduled maintenance actions, time and parts
    - Percent of test time devoted to scheduled and unscheduled maintenance
    - Available manufacturer, dealership support
- Required Facilities
    - Storage facilities
    - Maintenance facilities
- Support Staffing and Associated Training
    - Unique mechanical maintenance
    - Unique electronic equipment maintenance
    - COTS equipment support

(ii) For the robot considered as a remote controlled platform

- Human Factors and Operator Comments
    - Visual, audio issues, communications (HMI)
    - Navigation issues
    - Tracking/positioning precision
    - Ease of updating the software control system
    - Ease of maintaining the hardware control system
- Blast/fragmentation Survivability Tests / module Fig 5 excluding detection sensors and mechanical structure)
    - Direct blast and bounding mine blast tests
    - Equipment survivability
    - Field reparability of blast damage
    - Time and parts to repair

(iii) For the robot considered as a mechanical sensor-carryer

- Blast/fragmentation Survivability Tests / module Fig 5 detection sensors)
    - Direct blast and bounding mine blast tests
    - Equipment survivability
    - Field reparability of blast damage
    - Time and parts to repair
- Sensor data transmission/processing
    - Reliability of transmitted data
    - Interpretation
    - Area cleared / hour (including the reaction/action times by each detection)

Qualitative Spatio-Temporal Representation and Reasoning Framework for RISE mobile robot's operator training planning

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Abstract

In this paper we proposed new methodology for RISE (Risky Intervention and Surveillance Environment) mobile robot's operator training planning. For this task Qualitative Spatio-Temporal Representation and Reasoning Framework called Semantic Simulation Engine is used. The core concept is connected with development of Mobile Spatial Assistance System capable of building a semantic model of the environment based on observations. The goal is to support operator's training planning by using information gathered from real tasks execution. This can drastically increase the effectiveness of the training process by providing realistic scenarios without the need for time-consuming development of complex and sophisticated artificial environments.

Keywords: semantic model, robotic system, operator training, qualitative representation and reasoning

Introduction

In the paper the framework for RISE (Risky Intervention and Environmental Surveillance) mobile robot's operator training planning is presented. The basic idea behind the framework is to provide software tools for mobile robot simulation. Created simulations may then be used in operator training. To achieve realistic rigid body simulation and realistic rendering NVIDIA PhysX engine and OGRE (Open Graphic Rendering Engine) are used. To provide realistic visual representation of the environment we use CAD models. The compatibility between modeling tools, such as SolidWorks, an the framework is assured by using COLLADA format. The simulator has motion models of several types of robots such as caterpillar or wheeled. The simulated robot can be operated from real control station.

The main feature of presented framework is the idea of automatically generated semantic model of the environment, in a way so that the model could easily be used for operator training. We believe that in the near future it will be possible to model complex training scenarios based on robot's observation of real task execution. The work is related with Spatial Assistance System (SAS)[1]. For this paper our focus is on Mobile Spatial Assistance System (MSAS) that is the agent for gathering information and creating semantic model of the environment. The model can be used for designing training levels in virtual environment, that can be used for operator's examination.

The paper is organized as follows: the next section QSTRR (Qualitative Spatio-Temporal Representation and Reasoning) Framework demonstrates the ontological approach to semantic modeling used in training planning, section named Training Design explains the integration issues with existing training platform, final section Conclusions and Future Work points out the advantages of proposed approach and direction of future research.

QSTRR (Qualitative Spatio-Temporal Representation and Reasoning) Framework for training planning

Work[2] is a good overview of computer simulators of unmanned vehicles. In [3] a comparison of modern real-time physics simulation systems is given, along with qualitative evaluation of number of free publicly available physics engines. Apart from that, several frameworks are available that can, partially, support mobile robot's simulation examples being: USARSim [4] [5] [6], Stage, Gazebo [7], Webots [8] and MRDS [9] [10]. Interesting simulator classification system is proposed in [11]. The system provides means for grading existing simulators on the basis of their functionality. An interesting simulation engine - the Search and Rescue Game Environment (SARGE), which is a distributed multi-player robot operator training game, is described in [12]. Unfortunately presented systems do not provide means for creating semantic models from information gathered during real task execution. Our aim is for Mobile Spatial Assistant System to explore the environment and generate it's semantic model. Afterwards we can define semantic events related to specific training task. After this steps training planning is complete.

Ontology of training

The concept of using Spatio-Temporal Representation and Reasoning, in automatically generated semantic models of the environment for robot operator training, is a fresh approach. In our framework internal information sharing is accomplished by encoding domain knowledge using a standard vocabulary based on an ontology. An example of such approach is a declarative Spatial Reasoning Framework (SRF) [13] capable of representing and reasoning in a high-level, qualitative way based on spatial knowledge about the world. Ontology, as a representation vocabulary, proposed in this paper is dedicated for the domain of physical/functional entities in real structured environment. An ontology (O) is composed of several entities: { a set of concepts (C), a set of relations (R), a set of axioms (A) (e.g. transitivity, reflexivity, symmetry of relations), a concepts' hierarchy (CH), a relations' hierarchy (RH), a set of spatio-temporal events (Est) }. what can be formulated as following definition:

$$O = \{C, R, A, CH, RH, Est\}$$

An ontology is supposed to support reasoning mechanisms. Concept is defined as a primitive spatial entity described by a shape (S), composed of polygons in 3D space, associated with a semantic label (SL). Shape is perhaps one of the most important characteristics of an object, and particularly difficult to describe qualitatively. Ontology distinguishes two different types of attributes that can be assigned to a concept, quantitative (Aqn) and qualitative (Aql). Five values of qualitative attribute (entity function) are listed: {real physical object, empty space, functional space, operational space, range space}. Functional, operational and range spaces are connected with spatial artifacts, more information can be found in [1], [14], [15]. Quantitative attributes are connected with physical properties of spatial entities and are as follows: {location, mass, center of mass, moment of inertia (how resistant is the object to changing the orientation about an axis), material (friction, restitution)}. Therefore, the definition of the concept (C) can be formulated:

$$C = \{S, Aqn, Aql, SL\}$$

The set of relations (R) is composed of quantitative and qualitative spatial connections. For topological spatial relations (qualitative) the Region Connected Calculus (RCC) [16] is proposed. RCC is a formalism for spatial reasoning that takes regions of space (shapes) instead of points of classical geometry as primitives. One particular prominent reasoning system is a system of topological relations called RCC-8 [17] (the relations of RCC-8 calculus and conceptual neighborhood is shown on figure 1), in which the ontology includes eight different topological relations between two regions (in our case shapes): {disconnected (DC), externally connected (EC), partial overlap (PO), equal (EQ), tangential proper part (TPP) and its inverse (TPPi), non-tangential proper part (NTPP) and its inverse (NTPPi)}. Quantitative spatial relations are a way to constrain entities movement relative to each other. Ontology defines following constraints: {origins locked, orientations locked; origins locked, orientations free; free rotation around one axis; sliding}. Quantitative attributes and relations can be used to build a quantitative model in COLLADA (COLLAborative Design Activity) format. COLLADA is used as an interchange file format for interactive 3D applications. Qualitative attributes and relations can be used, for example, to build a qualitative model for Spatial Reasoning Framework (SRF) [13].

An important aspect and, at the same time, difficult to implement is qualitative spatio-temporal representation. Ontology should provide mechanism of building world models, that assume spatio-temporal relations in different time intervals (in other words: world models that can integrate changes), for representing the knowledge used for spatiotemporal reasoning. Chosen temporal representation takes temporal intervals as a primitive [18], therefore ontology defines qualitative spatio-temporal events (Est) related with topological spatial relations TSR_{RCC-8}: { onEnter (DC->EC->PO), onLeave (PO->EC->DC), onStartInside (PO->TPP->NTPP), onStopInside (NTPP->TPP->PO)}. These four qualitative spatio-temporal events can be used to represent most important relations between two concepts in different intervals of time. Spatio-temporal events are also associated with time stamp, therefore we can define Est as:

$$Est_T=\{C_A, C_B, TSR_{RCC-8}, T\}$$

where: C_A,C_B concepts, TSR_{RCC-8} topological spatio-temporal relations using RCC-8, T timestamp. Ontology defines a TASK as a set of spatio-temporal events connected via temporal relations Est_T:

$$TASK = \{Est_{T1}, Est_{T2}, Est_{T3}, \ldots Est_{TN}\}, T1<T2<T3<\ldots<TN$$

MISSION is defined as set of pairs - independent tasks related with a goal assigned quantitatively an amount of points.

$$MISSION = \{ (TASK_1, GOAL_1), (TASK_2, GOAL_2), (TASK_3, GOAL_3), \ldots , (TASK_N, GOAL_N)\}$$

TRAINING is defined as a directed graph where nodes are defined as pairs (MISSION, tasks' sum of points) and edges correspond to the conditions for advancing into the next MISSIONS checked using the amount of points acquired during previous tasks' execution. To store the instances of ontology-based training elements (defined on the conceptual level) an instance base (IB^O) is defined:

$$IB^O = \{I^O_C , I^O_R , I^O_{Est}, I^O_{TASK}, I^O_{MISSION}, I^O_{TRAINING} \}$$

where: I^O_C contains instances of concepts C, I^O_R contains instances of relations R, I^O_{Est} contains instances of spatio-temporal events E_{st}, I^O_{TASK} contains instances of training tasks, $I^O_{MISSION}$

contains instances of missions, $I^{O}_{TRAINING}$ contains instance of training. Semantic model of the training is defined as a pair:

$$SM_{TRAINING} = \{O, I_B^{O}\}$$

where: O is an ontology and I_B^{O} is an instance base related to ontology O. Ontology is known a-priori but instance base is being updated during training planning process.

Conceptualization

An important part of the framework is development of semantic object identification and transformation into concepts with accordance to the ontology presented in previous section. Instead of wall, door, ceiling and door identification proposed in [21] we focus on human detection and Delaunay triangulation [22] for complex planar 3D shapes modeling.

Human detection

The method used for human detection we use is Histogram of Oriented Gradients (HOG) [19]. We chose it because it proved to be effective in detecting objects of characteristic shapes(humanoid shape in case of people detection). For the purpose of basic framework development we use the OpenCV library package [20]. In the final version we want to use a GPU supported version of the algorithm. For the conceptualization purpose we decided to use the default detection descriptor provided be OpenCV. In preliminary experiments it proved to be reasonably robust achieving up to 90 percent positive detections. To get the images necessary for detection we use the KINECT device. It was chosen because of good video quality and most importantly, automatic stabilization of images, which is extremely important for data acquisition during motion. For the purpose of detection, information from both the RBG camera and depth camera are used. HOG provided potential areas of detection and ,based on depth information, rough size of detected object is calculated. This allows to filter most of the false positives, as commonly they are much smaller or much larger than average human. Figure 2 demonstrates the result: detected human and visualization of automatically generated concept.

Wall detection

Apart from wall, door, ceiling and door identification proposed in [21] we proposed a new approach that uses Delaunay triangulation [22] for complex 3D shapes modeling. It provides one of the possible solutions for extracting triangles from the given projected 3D cloud of points onto a plane. Triangulation of a planar set of points connects them by edges in such a way that no edges intersect each other. The assumption is that no edges can be added that break this condition. Delaunay triangulation maximizes minimal angle of all the triangles in the triangulation. Thus it tends to produce least possible amount of thin triangles which is beneficial for our application. We expect, that solid large obstacles such as walls will be represented as large triangles, which will allow to minimize the computation effort for further 3D RCC8 analyses. There is a number of algorithms for building Delaunay triangulation and corresponding Voronoi subdivisions. For basic framework purpose we are using implementation coming with the OpenCV library [23]. This implementation provides a sufficient performance for most practical purposes where the number of nodes is not too high.

Robot path in INDOOR environment (room detection)

We demonstrate an illustrative example of automatic semantic model generation performed by mobile assistant during INDOOR environment exploration. The 3D data were collected in

Royal Military Academy (Brussels, Belgium) building with the prototype of MSAS (Mobile Spatial Assistance System). The goal is to provide semantic model of a room based on proposed ontology, where each concept is connected with a shape. Figure 4 shows an example of this approach. Room is composed of several shapes in relation PO (Partially Overlapped) to neighboring shapes. Each shape has assigned semantic label describing its function or a role in the environment, for example door shape is an operational shape. If there is a semantic connectivity between two neighboring doors via empty spaces in relation PO, we consider that this set of shapes can be labeled as a room-concept. A room-concept can be used as a training environment.

Training design

After automatically generating semantic models of an INDOOR environment (previous section) we are able to plan the training using developed software tools that integrate semantic model of a robot with the semantic model of the environment. More details can be found in[24].

Semantic model of a robot

Semantic model of a robot is shown in figure 5. The model is a composition of concepts: real robot parts connected via quantitative relations describing joints, cameras and lights that are modeled by shapes with qualitative attribute: range space. Such semantic model may be used in training simulation. Based on spatio-temporal reasoning we can observe possible mistakes of the operator, for example an intersection between robot's arm and robot's chassis will be marked with negative points.

Semantic model of an environment

Example semantic models of an OUTDOOR and INDOOR environments are shown in figures 6 and 7. These semantic models compose of crucial concepts needed to perform a mission, that is hazardous material transportation from given location into defined location of neutralization. Hazardous material detection by operator is monitored based on PO (Partailly Overlap) qualitative relationship, and spatio-temporal event onEnter between operation shape: camera and physical shape: hazardous material. The success or failure of the mission is decided based on the spatio-temporal event onEnter between physical shape: hazardous material and empty space: location of neutralization. Operator is punished each time when the shape: hazardous material is in qualitative relation PO (Partially Overlap) with defined concepts: real physical shapes.

Conclusion and future work

In this paper we proposed new methodology for RISE (Risky Intervention and Surveillance Environment) mobile robot's operator training planning. The planning process is performed using Qualitative Spatio-Temporal Representation and Reasoning Framework called Semantic Simulation Engine. The core concept is related to the development of a Mobile Spatial Assistance System that can build a semantic model of a training based on environment's observation, which is considered as the main advantage of proposed approach. We believe that in near future such approach will replace SoA techniques as it will be possible to model the real task scenarios based on robot' observation. Our mobile assistant serves the informational and computational functionality of spatial assistance system that is intended to provide intelligent spatial decision-making capabilities for training design purpose. The goal is to support operator's training planning by using information derived from real task execution. This can drastically improve the training process by providing realistic scenarios without the need of time-consuming manual development of complex and sophisticated virtual artificial environments.

Acknowledgement

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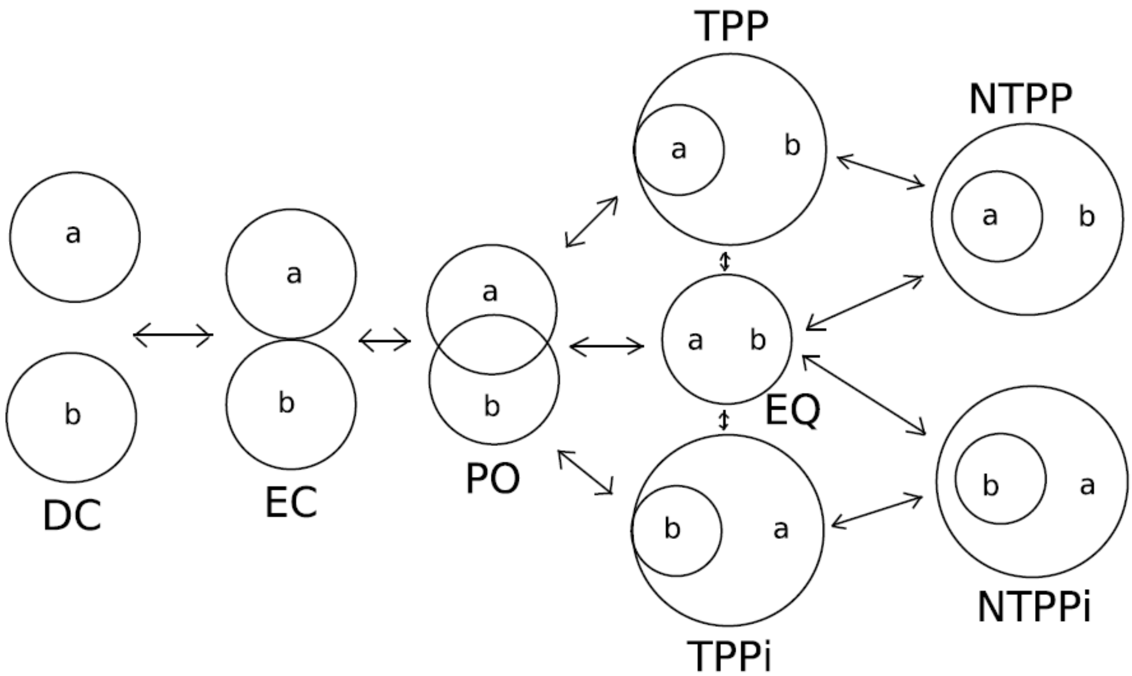

Figure 1: The relations of RCC-8 calculus (conceptual neighborhood).

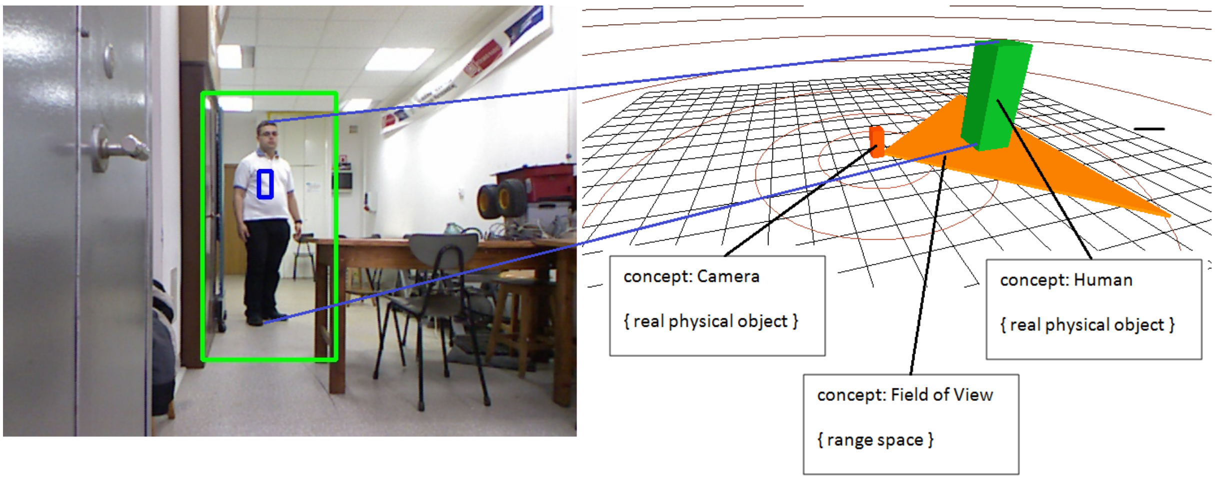

Figure 2: Conceptualization of human detected by the mobile robot equipped with KINECT sensor.

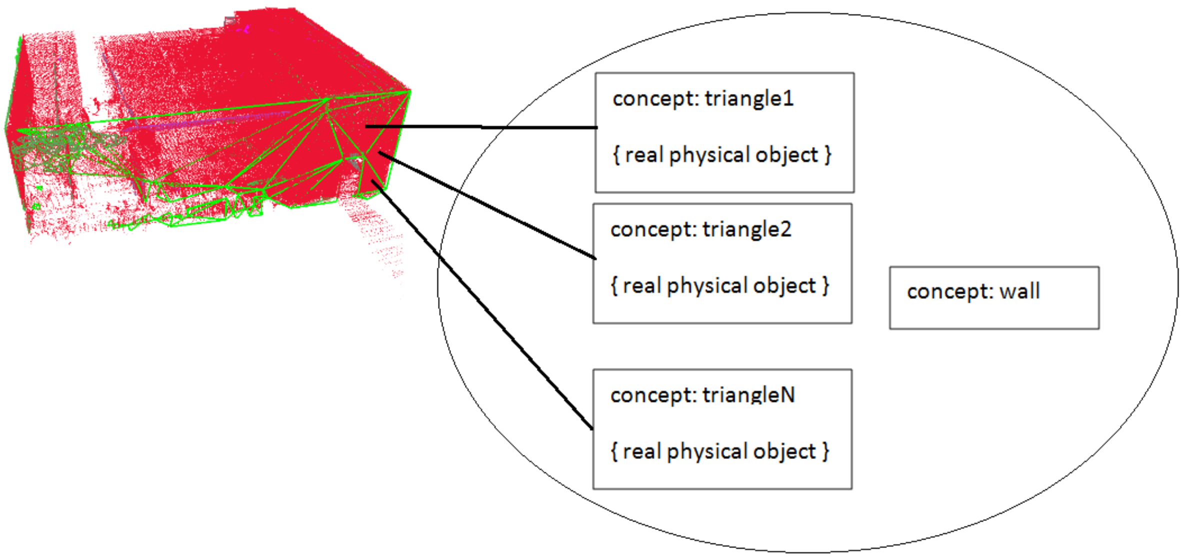

Figure 3: Extracted triangles for given 3D cloud of points using Delaunay triangulation technique. The concept of wall is a set of concepts: triangles.

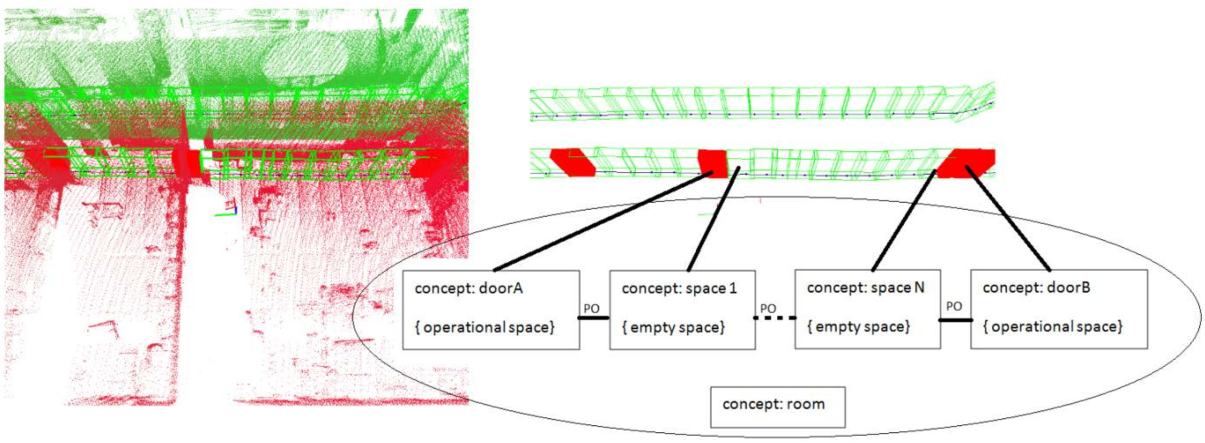

Figure 4: Semantic model of a room automatically build from 3D cloud of points using qualitative representation. PO - RCC8 relationship Partially Overlap.

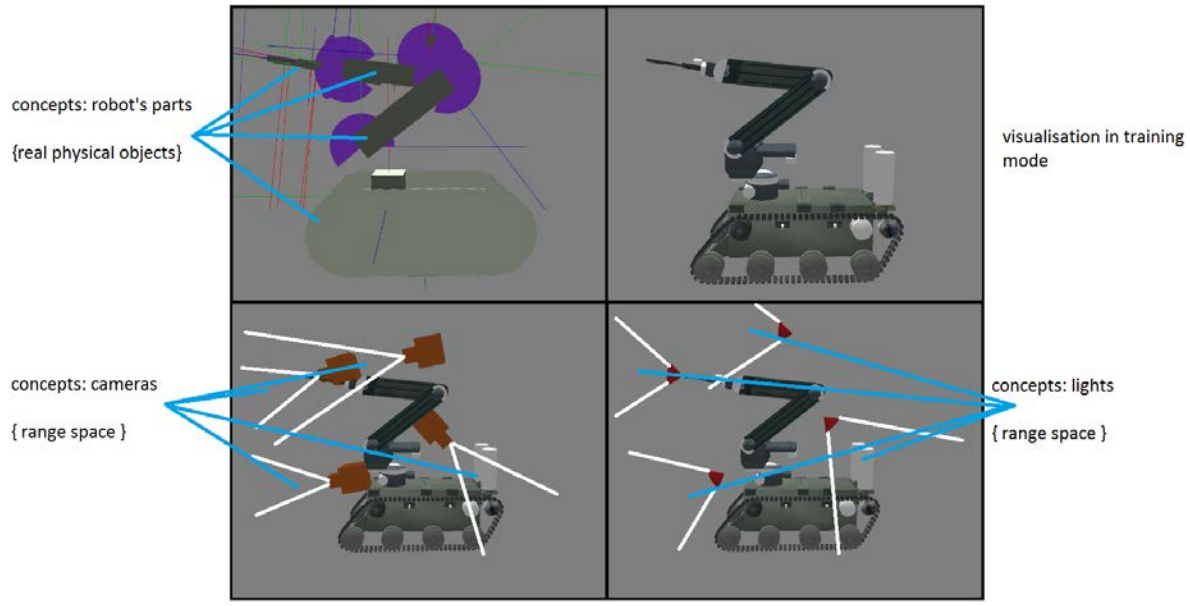

Figure 5: Semantic model of a robot.

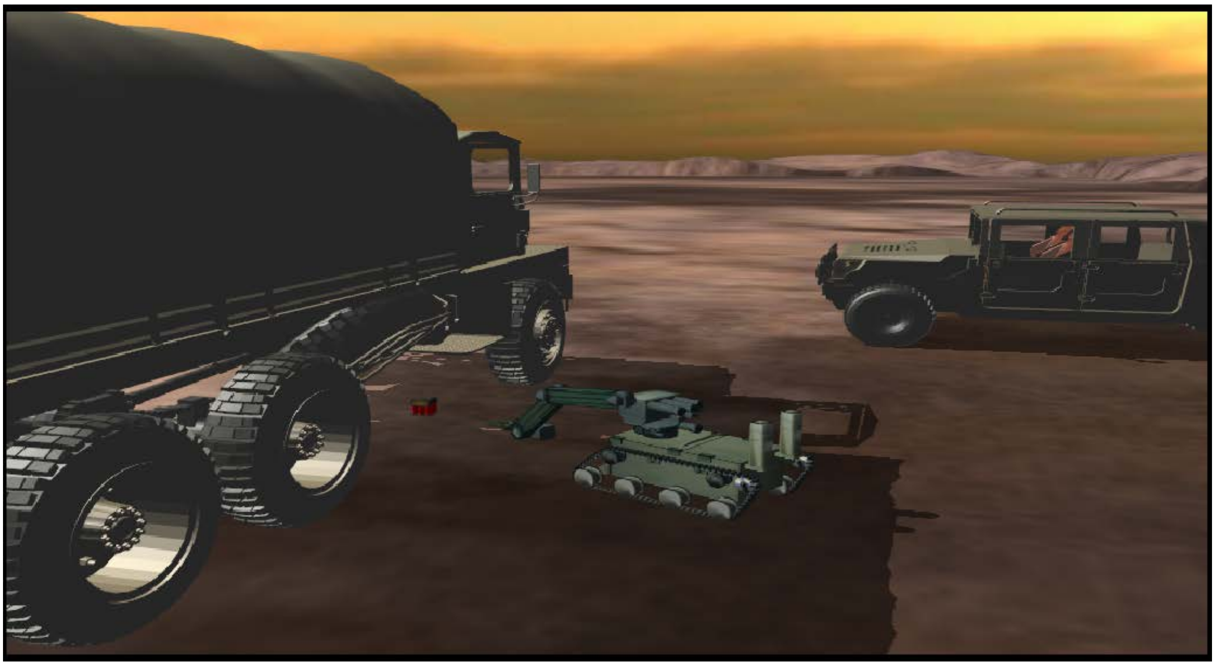
Figure 6: Visualization of a semantic model of a mission in OUTDOOR environment.


Figure 7. Visualization of a semantic model of a mission in INDOOR environment.

Identification and classification of tools and missions needing e-training of Humanitarian Demining staff with use of computer simulation

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ABSTRACT

Classification of computer-assisted training activities related to humanitarian demining are considered in the article. Two classification schemes postulated for e-training in the TIRAMISU project are presented, one of them for simulation-type training of unmanned ground vehicle operators, and second for game-type training of management staff. An assumption is made that these schemes can be treated as an example-pattern for classification on wider humanitarian demining field.

1. INTRODUCTION

During initial works on TIRAMISU humanitarian demining project [1] it turned out that some systematization and classification of information about training as a part of the project is helpful.

As an example-pattern, such classification related to computer-assisted training was considered and is presented in this article. Two classification schemes are particular subject of interest. One of them relates to simulation-type training of unmanned ground vehicle operators, and second to game-type training of management staff. Three-dimensional classification spaces are applied in both schemes. Dimensions, representing particular views of training, determine classification frameworks. Instances of views-dimensions determine crates of individual types of training, being atomic cells of classification, having individual addresses. In these crates detailed characteristics of training types can be placed.

The authors are of the opinion that similar approach to classification could be helpful also in wider field of humanitarian demining.

2. TERMS

Terminology used in the paper is mainly based on IMAS standards [2, 3, 4 ,5]. Humanitarian demining process is understood as a set of activities which lead to the removal of mine and ERW (Explosive Remnants of War) hazards, including survey, mapping, clearance, post-clearance documentation, and the handover of cleared land. The notion ERW covers mines and ordnance whether fuzzed, fired or otherwise, and all explosive devices whether mass-produced or improvised [6]. Demining mission (process) consists of 4 steps: planning, preparation, clearance and post-clearance. Typical demining action is performed by deminers and operators of demining machines, acting under supervision of section commander, which in turn is subordinated to team leader. Mine Action Centre (MAC) is an organisation that conducts reconnaissance of hazardous areas, collection and centralisation of mine data, coordinates local (mine action) plans with the activities of external agencies and carries out mine risk education training.

3. IDENTIFICATION AND CLASSIFICATION OF TOOLS NEEDING E-TRAINING

Unmanned ground vehicles (UGV) to be used in humanitarian demining are of rather narrow autonomy and need to be driven by skilled operators. Training of UGV operators should be conducted in accordance with the methodology of multi-level training with use of computer trainers (simulators) of different grade of perfection, taking advantages of technologies of virtual reality (VR) and augmented reality (AR) [7, 8, 9]. The following types of trainers are to be used:

- Trainers of the Level 1 – built with use of typical PCs. VR technology is applied. UGV, its environment and control console are simulated.
- Trainers of the Level 2 – built with use of PCs with real UGV control consoles connected. VR technology is applied. UGV and its environment are simulated.
- Trainers of the Level 3 – trainers of the Level 1 or 2 with application of AR technology – real UGV in the real environment with simulated elements added. A trainee uses special helmet.

In the case of use of trainers of the Level 1 and 2, the performance of training via Internet is possible (trainers of the Level 2 should be equipped with simplified control consoles, e.g. typical consoles for computer games). Training with use of computer trainers, both used locally and via Internet, is named as *e-training*. E-training is understood as an extension of e-learning: e-learning concerns obtaining of knowledge, whereas e-training concerns obtaining of operation skills.

E-training consists in realization by a trainee his/her individual *program of training.* Every program of training is a sequence of *training tasks*. An exemplary training task for UGV operator is lifting, with use of the UGV's gripper, of a certain object, and putting it in a certain container. At the beginning of the training session the trainee is informed on the task to perform, as well as on time limits, grading scale, and penalty points for causing wrong events (e.g. collisions of UGV with objects in its environment). The trainee, using virtual or real control console, performs training tasks of the character of a computer game, and after finishing them is informed about the score obtained. During execution of training tasks, the knowledge about trainee's progress is gathered, and on this basis a choice of the next task, or decision on the end of training is made. The detailed description of training methodology of RISE (Robotics for Risky Interventions and Environmental Surveillance) systems' operators is described in the paper [10].

With reference to TIRAMISU project a proposed classification of tools needing e-training is based on three parameters: type of a task do be performed by a UGV, type of an UGV, type of an environment. Dimensions-views of the framework and their instances are the following:
The dimension *Goal of a training* has instances: *Inspection (pre and post-removal), Close-in detection, Removal activities,* and *Mine transport.*
The dimension *Vehicle* has instances: *Semi-autonomous mobile robot, Unmanned ground vehicle adapted for demining tasks, Remote-controlled mine-clearer*, and *Mine transport trailer.*
The dimension *Environment* has instances: *Natural, Artificial,* and *Unknown.*
Graphical representation of the proposed classification is presented in Fig. 1.

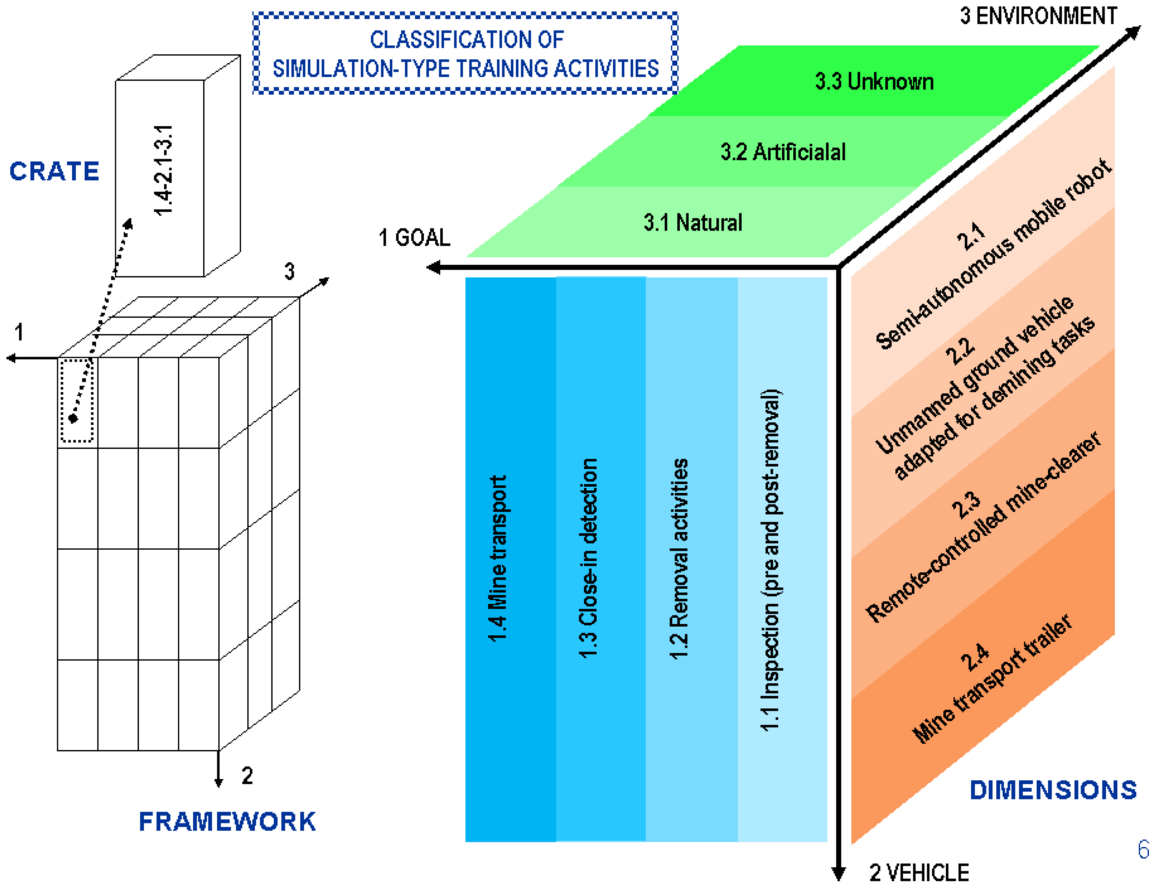

Fig. 1. Classification of tools needing e-training

An example of a crate content that is supposed to be considered within TIRAMISU project is:
CRATE 1.4-2.1-3.1
<u>Training mission No XXX</u>
Mine transport – Semi-autonomous mobile robot – Natural environment
Description: Operation of transporting of previously pulled ERW into defined place of disposal.

4. IDENTIFICATION AND CLASSIFICATION OF MISSIONS NEEDING E-TRAINING

In a case when a given demining mission is performed by more then one human and when activities of the people involved should be coordinated somehow, then a *collective computer trainer* should be applied for training. (This is in contrast to *an individual computer trainer* described in point 3, which may be applied to the training of only one operator at a given point of time).

The simplest implementation of a collective computer trainer it is a set of computers connected via local area network. Nodes of the network may be individual computer trainers accustomed to needs of training both of operators of UGV used and members of managing staff as well. Through the network any kind of data may be transmitted, including voice and video.

Training based on collective computer trainers has a form of network computer game. Depending on the need different type games may be applied: simple simulation games, adventure games with interactive scenarios, role-playing games (with use of avatars). Strategy games with management of resources (of MONOPOLY-type) seems to be out of the scope of TIRAMISU, but purposefulness of modelling of some functions performed by MAC (associations with police, medical services, fire department, local authorities, among others) is to be considered.

Specific methodology of training is to be elaborated for training with use of collective computer trainers.

In TIRAMISU project a proposed classification of missions needing e-training is based on three parameters: goal of a training, action type performed, structure of managed forces.
Dimensions-views of the framework of missions needing game-type training of the HD staff, and their instances are the following:
The dimension *Goal of training* has instances: *Action planning,* and *Operation Management.*
The dimension *Action type performed* has instances: *Non-technical survey, Technical survey, Ground-based close-in detection, Stand-off detection, Removal action,* and *Combined.*
The dimension *Managed forces structure* has instances: *Uniform group, Joint task force,* and *Aggregate with vertical and horizontal connectivity.*
Graphical representation of the proposed classification is presented in Fig. 2.

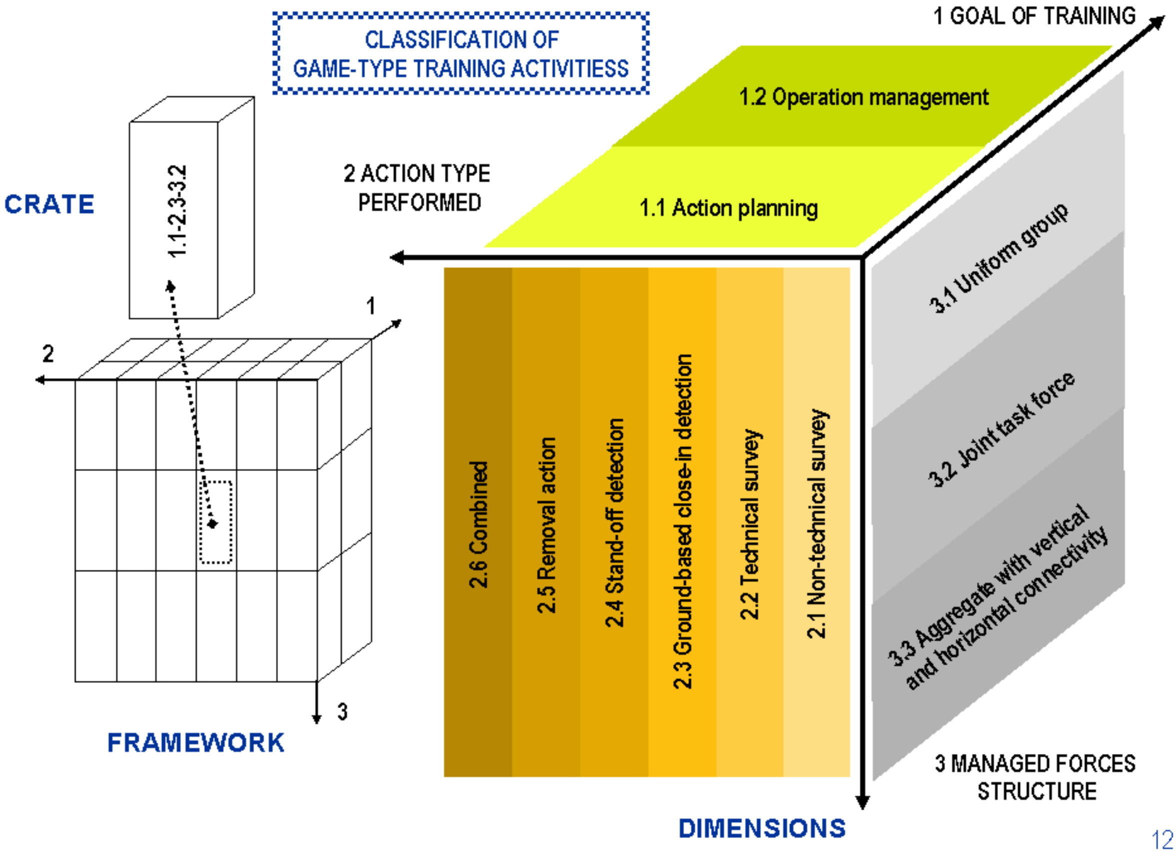

Fig. 2. Classification of missions needing e-training
An example of a crate content that is supposed to be considered within TIRAMISU project is:

CRATE 1.2-2.3-3.2

Training mission No YYY

Operation management – Ground-based close-in detection – Joint task force

Description: Manual and mechanical demining combined operation in confirmed hazardous area.

Use of the following TIRAMISU tools:

- Ground penetrating radar array
- Chemical sensor
- Remotely controlled platforms for inspection
- Low-cost agricultural derived assistance
- Intelligent prodder
- Innovative metal detector array
- Real-time location and communication system

5. CONCLUSION

Computer-assisted training, both in the form of trainers-simulators and computer games, becomes more and more popular in many sectors of human activity. Demining in general, and humanitarian demining particularly, seem to belong to the sector of very high demand for such training. So, many computer training tools and applications will appear here. Therefore their identification and classification can be an important problem. An approach to this problem presented in connection with TIRAMISU matter maybe will turn to be useful on the whole HD field, and of course more-than-three dimensional classification space can be applied for this. **REFERENCES**

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Sensors for close-in detection of explosive devices

Current status and future prospects

***Abstract*—This paper presents a brief overview of sensor technologies for close-in detection of buried explosive devices and describes the research and development activities planed to be carried-out in the framework of FP7/SEC-2011/TIRAMISU project to advance the state of the art in this area.**

I. Introduction

Landmines are used as tactical weapons during wars. To be effective, landmines should be hidden (usually buried) turning difficult its detection by potential targets. Just like landmines, a large amount of other explosive devices, such as cluster munitions, explosive remnants of war (ERW) and improvised explosive devices (IED) are left on field after conflicts, causing victims and restricting land usage in dozens of developing countries with scarce resources. Cleaning post-conflict areas has for long time been identified as one of the most serious and urgent humanitarian problems to be solved by humanity, but the large amount of affected areas, sometimes of difficult access, and the lack of efficient sensing technologies are major difficulties to solve this problem effectively.

The detection and localization of a specific explosive device (ED) is usually done at short distance, by a process called close-in detection (CID). Tools currently used to perform close-in detection include metal detectors (MD), either hand-held or vehicle-mounted, vehicle-mounted ground-penetrating radars (GPR), hand-held detectors combining metal detectors and ground-penetrating radars, and vapor detection methods with or without animals. Sweeping a handheld metal detector and prodding manually a suspected area is still the most frequent technique employed by deminers. This is a trusted, but very slow procedure, since metal detectors are prone to provide a very high false alarm rate – on one hand post conflict areas may contain large quantities of metal debris generating frequent alarms by metal detectors, on the other hand stones can provide a prodding response similar to potential landmines.

According to the Geneva International Center for Humanitarian Demining (GICHD) an area can only be considered clean when all ED have been removed and destroyed – this requires a detection rate of 100%. The United Nations (UN) set a less ambitious, although still difficult to achieve detection target of 99.6%. All above detection tools exploit some kind of signature provided by the ED (e.g., metal content, dielectric discontinuity, explosive trace vapors, shape, etc.), but on one hand these signatures can also be found in non-explosive devices giving rise to a potentially high false alarm rate (FAR), on the other hand, the searched signature provided by some ED may be too weak to be detected by the CID tool, giving rise to a lower than unity probability of detection (POD).

Addressing these problems require better sensors and/or using multiple sensors simultaneously and fusing their output in order to obtain higher POD and lower FAR. The efficiency of CID tools can additionally be increased through the use of large arrays with high detection width, able to cover wider areas in the same or lower cost (be it time, involved persons or resources in general).

The remaining sections of this paper describe and analyze the conventional close-in detection techniques and commercial systems currently employed by humanitarian demining teams and surveys the latest advances in sensor technologies, still in an early research phase or being tested through prototypes. Particular emphasis will be devoted to sensing technologies developed in the framework of the TIRAMISU project, namely intelligent prodders, capable to automatically and safely detect and recognize the material in contact, chemical sensors for explosive vapours, advanced metal detector arrays, capable to identify the type of detected metal, and GPR arrays, for close-in detection and identification of buried explosive devices. A detailed survey is out-of-scope of this paper. For deeper treatment on the subject the readers are invited to check the following references [Robledo 2009, Kasban 2010].

II. Metal detectors

The metal detector is the main tool used in manual humanitarian demining. This technology, invented during World War II, was very effective when the landmines contained large amounts of metal (e.g., a metal case), but modern landmines may contain only fractions of a gram, which significantly complicates their detection.

Conventional metal detectors employ the principle of electromagnetic induction, using a secondary coil to detect the disturbances produced by metallic or conductive objects in the continuous wave field generated by a primary coil. In

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modern metal detectors this basic principle may be implemented in different ways (e.g., pulse induction). A comprehensive overview of metal detectors technology and their use for humanitarian demining can be found in [Guelle 2003].

Metal detectors come from many different manufacturers. They may include features such as soil compensation algorithms (to reduce the influence of soil on detection) or discrimination features (to make the difference between different types of metal). Although being the tool of choice they do have some limitations. A heavy concentration of metal scraps can create a lot of unwanted alarm indications. Magnetic soils can reduce their detection. Soil with high concentration of salt and with high soil moisture, such as at sea beaches, can have a high conductivity which makes detection difficult because of additional alarm indications. Techniques implemented within metal detectors to compensate for the effect of soil may reduce sensitivity. High electromagnetic fields, such as what can be found near power lines, can create interference. In addition, some operators do not know that the sensitive area of a metal detector decreases with depth. [GICHD 2006].

A. *Metal detector array*

The use of double balanced receiving coils provide several advantages in terms of detection, namely the ability to cancel the background effect of the soil and the ability to identify the type of metal. TIRAMISU partner Vallon will investigate this metal discrimination ability with a metal detector array. This partner will develop lightweight modular system, containing from 2 to 16 coils, adaptable to the width of mobile robots and other mobile platforms.

III. Ground Penetrating Radars

GPR is a geophysical technology widely used for subsurface imaging. This method is based on the following principle: 1. A transmitting antenna emits short pulses of high-frequency electromagnetic waves. 2. The electromagnetic pulse is reflected from a buried object or a boundary with different dielectric constants. The reflected signals arrive back to the receiving antenna at different times, which depend on the depth of reflection. 3. The receiving antenna records samples of the time varying reflected signal providing a scan, called A-scan. 4. The A-scan provides information about variation of dielectric properties at different times of reflection. The time of reflection roughly represents the depth of reflection. However, there is no exact transformation due to the unknown properties of the materials where the signal is propagating. The frequency of the transmitted radio pulse determines its penetration depth. For the purpose of humanitarian demining GPR antennas with frequencies around 1-2 GHz are normally used. This allows detecting antipersonnel landmines up to the depth of around 30 cm. GPR data use to contain clear signatures of landmines or other man-made objects buried in clean soil. However, GPR is also sensitive to a large amount of clutter objects and any dielectric heterogeneity of the soil.

A. *Ground Penetrating Radar array*

A densely sampled GPR imaging approach to detection of small AP mines has been recently demonstrated by Prof. M. Sato (Tohoku University, Japan) in the development of the ALIS hand held combined GPR and MD sensor by CEIA [Sato 2008]. However, the ALIS GPR can only explore/image a very small area around the mine (e.g. 40x40 cm) and uses a simple threshold detection mechanism to declare the alarm.

TIRAMISU’s partner IDS aims to extend the advantages of GPR imaging arrays, now proven in state of the art military systems, to a wider variety of targets (i.e., AP mines and small UXOs) and terrains while improving the automatic detection capabilities so that no operator interpretation skills will be required.

B. *Dual sensor systems*

A limited number of teams currently use dual sensors combining a metal detector and a ground-penetrating radar [Doheny 2005, Daniels 2005, Ishikawa 2009]. The detection range of ground-penetrating radars is reduced by certain types of conductive soils such as clay. Soil moisture has two effects on detection. On one hand it decreases the detection range into the ground by attenuating the microwave propagation, but on the other hand it increases the contrast between the mine and the surrounding soil, making the mine easier to detect. It is not clear which of this effect is preponderant in a given situation. Soil inhomogeneities, such as roots, rocks, and very uneven ground surfaces can create additional alarm indications. Since ground-penetrating radars are often used to discard an object based on its small size, detecting small mines can be a challenge. [GICHD 2006].

IV. Imaging Radars for Landmine Detection

Ultra-wideband (UWB), ground penetrating radar (GPR) radiates a short pulse, pseudo-random coded sequence or frequency modulated burst of electromagnetic energy into the ground and detects the backscattered energy from the buried target. The radiated pulse is typically a wavelet of several nanoseconds duration and in the frequency domain, covers a wide range of frequencies in the region of a few hundred MHz to several GHz. Typically the spectral characteristics of the pulse consist of a series of individual frequencies whose spacing is related to the pulse repetition interval and whose envelope is related to the temporal characteristics of the wavelet. The power radiated per spectral line is in the order of a few nanowatts. For close-in systems the radar antenna beam is moved in a known pattern over the surface of the ground and an image of the ground can be generated, in real time, on a display either in gray scale or in colour. The image can be a cross-section or a plan view. The radar image is not identical to an optical image because the wavelengths of the illuminating radiation are similar in dimension to the target. This results in a much lower definition in the radar image and one that is highly dependent on the propagation characteristics of the ground. In addition the beam pattern of the antenna is widely spread and this degrades the spatial resolution of the image, unless corrected. For longer-range systems where the objective is to detect surface laid or very shallowly buried mines, synthetic aperture techniques are used. Radar systems may be hand held, vehicle mounted or airborne [Daniels 2002].

Since for close-in scanning GPR the radar antenna is typically moved mechanically in close distance to the ground following a horizontal scan pattern, the lateral spatial resolution is limited to the average antenna footprint at a certain depth, but the depth resolution can be high due to the UWB signal character. A three-dimensional image can be formed by stringing together the lateral (horizontal) samples to form a two-dimensional image, and the third dimension is given by the vertical range profile for each lateral sample. For larger stand-off distances to the ground (several meters or even much more) the technique of synthetic aperture radar (SAR) can be combined with the use of UWB signals. The SAR principle requires a side-looking geometry for a moving radar, since the across-track image dimension and resolution are determined by the across-track antenna beam width and pulse length, and the signal bandwidth. The along-track image dimension and resolution are given by the length of motion and the along-track beam width of the antenna, and produced by coherent processing of the sampled signals. Hence in both horizontal dimensions a very high resolution can be achieved. The depth information as the vertical dimension is connected to the across-track or range information and cannot be unambiguously retrieved when only one antenna or antenna pair for transmit and receive is used.

Both imaging methods (close-in and stand-off) have been already extensively analyzed in the past for landmine or UXO detection and big progress has been achieved. However, the buried object detection still is a challenging problem due its enormous complexity, being expressed in the specific soil and target conditions, the background clutter, the resolution and sensitivity constraints, and the ambiguity impacts due to limited sampling and multipath effects. Furthermore the clear discrimination between a true threat and a false alarm is difficult, making the threat detection process very inefficient. Those problems can only be overcome by increasing as well the complexity of the radar sensors by using polarimetric information, multiple antenna systems and multi-static imaging geometries, and well-adapted waveform designs and signal processing methods. Work in that direction was and is done, but there is still a large requirement for further research and development.

A. *TIRAMI-SAR*

TIRAMISU's partner DLR HR-AS aims to develop high-resolution, high-sensitivity, ground penetrating imaging microwave radars (TIRAMI-SAR) following advanced Synthetic Aperture Radar (SAR) principles. The development shall consider suitable processing algorithms to be used for close-in stand-off ground penetrating radar to be installed on a moving vehicle.

V. VAPOR DETECTION

When EDs are deployed in the field, continuous release of trace vapours occur. These vapours, usually nitroaromatics like TNT or DNT, are signatures that can be used to identify dangerous fields or to localize approximately the corresponding ED. Some of the important and critical factors for this application are very low-detection limits (ppt), short-detector response time for operations, involving moving platforms, good baseline stability, and minimum interferences from environmental species and conditions.

A. *Animal smell*

Dogs can be used in different ways to detect explosives. The dog handler can stay at the border of the minefield and the dog walks in a lane through the minefield. This method is called the long-leash method. In another method the dog handler walks along the border on the minefield with the dog at his or her side but inside the minefield. This is called the short-leash method. In a third method the dog handler shows the locations to explore with a wooden stick and the dog studies that area. Training and operational procedures seem to be important to have an efficient detection. Dogs are said to be better for area reduction and delineation of minefield boundaries, mine and ERW verification, clearance of roads, quality assurance. There is a large influence of environmental parameters and target history on the explosive vapour and particle concentration. Weather and soil conditions can lead to samples not being reproducible. Direct vapour detection seems to be more difficult in arid areas. Cross-contamination and handling issues are of great importance. There are also possible problems due to interfering chemicals, and explosive residues due to devices that have detonated.

B. *Chemical sensors*

For chemical vapour detection, several techniques have previously been employed including electrochemical sensors, metal oxide sensors, laser Raman detection and fluorescence based sensors. When special class of plastic electronic materials is illuminated by UV or blue light, it absorbs the light and emits fluorescence [Thomas 2007]. If the film then comes into contact with very dilute vapors of TNT or a similar nitro-aromatic compound, some molecules of the vapor will adhere to the surface of the film and may penetrate deeper into the polymer. These TNT molecules act to quench the light emission through an electron-transfer process. The process is reversible and light emission returns when the sensor is isolated from the vapours. Such fluorescence sensing has been studied in laboratory conditions by several groups [Thomas 2007, Toal 2006] in the field as the Fido product by ICx Technologies. It was recently discovered that greater sensitivity is possible by using laser light from the polymer rather than fluorescence to detect explosives [Rose 2005].

C. *Polymer laser sensors*

The organic Semiconductor Centre of the University of St Andrews (USTAN) is internationally recognised for their development of organic semiconductor lasers [Turnbull 2007] demonstrated laboratory prototype sensors for nitroaromatic explosive vapors, using plastic lasers based on the blue light-emitting materials polyfluorene [Yang 2010] and bisfluorene dendrimers [Richardson 2009] and will now work with the University of Coimbra to improve the prototype in on-the-(mine)field conditions. The majority of the research on light-emitting polymer chemical sensors to date has been laboratory based and materials oriented, while there are only a few examples of polymer laser based sensors. The work in the TIRAMISU project will make a step-change in progress beyond the state-of-the-art. It will advance the use of polymer laser sensors to on-the-mine-field detection conditions and will establish the feasibility for new modes of application of laser and fluorescence sensors in mine absence sensing for technical surveys.

VI. MECHANICAL PRODDERS

According to [GICHD 2005] the most dangerous action for a deminer is prodding from the surface of the ground.

Usually very simple tools are used to probe the ground until a solid object is contacted. Then the material surrounding the buried object is carefully removed and the identification can be made. The process is repeated for each buried object until the area is cleared. Many attempts have been done to improve a classical prodder into a more complex sensors capable to safely detect and recognize the material in contact. Examples are the SmartProbe by DEW Engineering and Development Ltd., developed at Defence R&D Canada, using acoustic pulses to recognize the material. However After extensive field testing, it was concluded that the SmartProbe did not function as advertised and DEW discontinued the product [Melville 1999]. In 2001 HF Research Inc. improved the SmartProbe combining the acoustic pulse with a force feedback system [HF Research, 2002]. TNO-FEL conducted in 2003 extensive tests of the Instrumented Prodder, concluding that even if material identification of buried objects is feasible with the implemented technology, however it is not reliable [Schoolderman 2003]. Other works involved the development of rotary prodders to improve penetration into the soil, or prodder equipped via a microphone to give feedback of the contact sound to the operator [Gasser 1998]. In [Schade 2004] and in [Bohling 2006] preliminary results on the adoption of Laser-induced breakdown spectroscopy (LIBS) in combination with a conventional mine prodder for remote detection of explosives and mine housing materials are described. Fiber optics are used for guiding the laser pulses to the end of a modified conventional mine prodder and the LIBS signal back to the detector. In [Furihata 2005] two mechanical master-slave hands, named Mine Hand 1 and 2, to remotely prod to detect and to remove landmines and UXOs are proposed and experimentally tested. The University of Catania conducted intensive research activity in the development of tactile Measuring Systems for the Recognition of Unknown Surfaces [Baglio 2002, 2003]. In this work a novel smart tactile sensor that recognizes the nature of the surfaces was developed. The approach is based on the idea of analyzing the signal produced when the sensor touches and stimulates the surface. An "intelligent probing" system for material recognition has been developed. It is based on the use of bimorph piezo-ceramic actuators and sensors that allow the unknown surface to be stimulated and the response signal sensed. Two different experimental prototypes of the tactile sensing system have been realized and their performance has been characterized. Several interesting applications have been considered with particular emphasis on the problems of "humanitarian demining" and automatic waste material recycling. Experimental results are given to show the efficiency of the smart measuring system.

A. Smart prodder

The University of Catania will develop innovative prodders by the incorporation of new concepts and algorithms based both in ultrasound technology and in active prodding combined with force feedback, both containing touch sensors. This prodders will be able to be employed either by a human deminer or adapted to automatic demining systems and they will provide enhanced perception abilities about the kind of material that is being touched inside the ground as well as required penetration forces by keeping them within required safety margins. The advanced feedback provided by the smart prodder will be explored by CSIC to develop a haptic prodding interface.

VII. CONCLUSIONS

This paper discussed the established technologies for close-in detection of hidden explosive devices, namely metal detection, ground penetrating radar, vapour detection, and mechanical probing, and described the foreseen advances of these technologies in the framework of TIRAMISU project.

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Robotic Complexes of integrated systems for environmental demining of minefields

Abstract— On condition that the mines from a mine field can be laid on production line every industrial robotics team of engineers will be able to construct automated deactivation and disassembly of mines. This is attainable with the help of auxiliary means - robots – a method which has not been used by now. This is a modern mode of operation set in the Robotic Complexes. It complements the demining procedures. Robotic Complexes will be designed according to the type of mines, the type of soil, the relief and the plant cover of the minefield. The purpose is the least time to be spent clearing a minefield with minimum energy consumption.

SHORT PRESENTATION

In order demining actions to be more effective it is necessary to have complete information about each mine from the minefield: X, Y, Z coordinates, azimuth fuses of mines and three-dimensional image. This is possible with the combination of well known method for detection. At least three methods are needed to be used: explosives detector, metal detector and thermal detector (with a thermal camera), which is rejected as ineffective. X, Y coordinates of each mine will be found with the first two methods. The opportunity lies in the following. In a circle of defined dimensions above the mine, vegetation is destroyed by carrying defoliants. After the destruction of the vegetation, the zone above the mine is being poured on with chilled water. In that way an artificial distinction between the temperatures of the mine body and the soil around and above it is created because of the different heat conductivity. The needed three-dimensional image of the mine is received by the synchronized work of the two thermal cameras. This is the way to create artificial conductions for thermal scanning when it is necessary. Natural conditions for thermal scanning occur after rainfall. Low temperature difference appears in the morning after sunrise and in the evening after sunset. All methods are described in “Guidebook on Detection Technologies and Systems for Humanitarian Demining”, 2006. Technologies and systems are carried mainly by an operator or vehicle. Technologies have been improved with reduced weight by now. Based on existing and improving air drones such as quadrocopters, hexacopters, etc technologies can be carried by air. Tonnage is about 1.5 kg, flight time is 70 minutes. There are experimental technologies with capacity up to 10 kg. Efficiency based on the own weight and tonnage is very high. The idea is the active use of air drones while clearing the minefield. Mines will be cleared with a "system of packing and removal of mines." Mines will be packed up together with the surrounding ground. Packed mines will be removed and stored in so-called stacks. Packing will be done by digging a solid like a tube into the ground around the minefield – “Packing Cylinder”. The digging in is done by a combination of rotary and reciprocating motion. “Packing Cylinder” is an analogy of pine crowns. There are cutting devices at the bottom of the “packing cylinder”. The digging of the “packing cylinder” stops at a certain level under the bottom of the mine. “Packing cylinder” is able to cut the soil layers under the mine floor and to create a solid wall. "Packing cylinder" can be of poly carbonate plastic, bakelite or any other material with a small specific gravity, which have the necessary strength. It is preferable the “packing cylinder” to be disposable. There are various design solutions in addition to the logical solution or modifying it. The basis for the logical solution is a combination of mini-ML-7 with PMN, as well as other types of mines liable to destruction because they could not be disabled. The so called “packing system and removal of mines” can be developed in the following three types of shifting, positioning and usage:

1) By hand with the participation of engineer operator
2) By vehicle or auto drone
3) By air drone

In order to make the minefield safe from mines mini PROM, OMZ, Valmara, S mines, POMZ, M-16 before using the “packing cylinder” it is necessary to cut the cable (cord, rope, wire, etc.) used for activation. The method of cutting by air drone will be the following: The air drone has a video camera and a robot carrying cutting device. The azimuth of the cable is fixed. The air drone lands above the mine. The cable is cut as close as it is possible to the mine. Mine is ready for packing by the “packing cylinder”. Every air drone (quadrocopter or hexacopter) will have a mobile platform for arrival, departure and servicing. The servicing consists in changing the storage batteries, loading and unloading – empty and full packing cylinders, etc. Mobile platforms are mounted on auto drones. With the increasing distance from the module for disable and disassembly, mobile platforms will be moved to a suitable distance from the module. Transportation of the module for disable and disassembly is done by transport trucks like auto drones. Trucks can have 3, 4, 6 or 8 wheels. Every wheel is powered by own electric motor. This allows a movement at an angle of 90° and a turn of 180° on the spot. Transport trucks will serve aero drones. They will work as a temporary storage of the empty stacks, stacks with full packing materials and devices of assistance in the demining operations. The module for disable and disassembly is an element of the Demining complex. The demining complex will have station for supplying charge for the storage batteries of the drones, photovoltaic power, communication devices, technology for destructing mines and fuses, which are not liable to disable and etc.
The Complex for Robotic Demining of minefields is supposed to be integrated with INSA, SADA, SAFEDEM - Space Assets for Enhanced DEMining (SADA), IMSMA (Information Management System for Mine Action) and other technologies for detecting mines in minefields.

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Space Assets for Demining Assistance

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Populations emerging from armed conflicts often remain threatened by landmines and Explosive Remnants of War. The international Mine Action community is concerned with the relief of this threat. The Space Assets for Demining Assistance (SADA) undertaking is a set of projects that aims at developing new services to improve the socio-economic impact of mine action activities, primarily focused on the release of land thought to be contaminated, a process described as Land Release. SADA was originally initiated by the International Astronautical Federation (IAF). It is now being implemented under the Integrated Applications Promotion (IAP) programme of the European Space Agency (ESA).

Land Release in Mine Action is the process whereby the demining community identifies, surveys and prioritizes suspected hazardous areas for more detailed investigation, which eventually results in the clearance of landmines and other explosives, thereby releasing land to the local population. SADA has a broad scope, covering activities such as planning (risk and impact analysis, prioritization, resource management), field operations and reporting.

SADA services are developed in two phases: feasibility studies followed by demonstration projects. Three parallel feasibility studies are currently ongoing. They aim at defining an integrated set of space enabled services to support the Land Release process in Mine Action, and at analysing their added value, viability and sustainability. The needs of the Mine Action sector have been assessed and the potential contribution of space assets has been identified. Support services are now being designed. To test their fieldability, proofs of concept involving mine action end users in various operational field settings are also under preparation by each of the study team. The economic viability will then be assessed.

Whenever relevant and cost effective, SADA aims at integrating Earth Observation data, GNSS navigation and SatCom technologies with existing Mine Action tools and procedures, as well as with novel aerial survey technologies. Such conformity with existing user processes, as well as available budgets and appropriateness of technology based solutions given the field level operational setting are important conditions for success. The studies have already demonstrated that Earth Observation data, Satellite Communication and Navigation indeed provide added value in Mine Action activities. Such added value for example includes the benefits of easy and sustained access to Earth Observation data that can satisfy the ubiquitous needs for general purpose mapping, as well as the value of data fusion algorithms which can be applied to relevant datasets to quantify risks and socio-economic impact for prioritization and planning purposes in order to justify land release. The environment of a hazardous area can also be characterized to support the land release process including detailed survey and clearance. Satellite Communication can help to provide relevant data to remote locations and in some cases can help to integrate field data and reporting with national or international databases. Finally, Satellite Navigation can support more precise non-technical surveys as well as aerial observation with small planes or hand-launched UAV's.

To ensure the activity is genuinely user driven, the Geneva International Centre for Humanitarian Demining (GICHD) plays an important role as ESA's external advisor. ESA is furthermore supported by a representative field operator, the Swiss Foundation of Mine Action (FSD), providing ESA with a direct connection to the field level end users. Specifically FSD has provided a shared user needs baseline to the three study teams. To ensure solutions meet with end user requirements, the study teams themselves include Mine Action representatives and interact closely with their pre-existing and newly established contacts within the Mine Action community.

I. SADA AND ESA'S INTEGRATED APPLICATIONS PROGRAMME

Space Assets for Demining Assistance is a set of projects of the Integrated Applications Program (IAP) of the European Space Agency (ESA).

ESA's Agenda 2011 contains a key objective: "*Development and Promotion of integrated applications (space & non-space) and integration of security in the European Space Policy. New concepts, new capabilities and a new culture have to be developed in order to respond to a multitude of needs from users who are not yet familiar with space systems*." Responding to this objective are the Integrated Applications Programme (IAP), also known as ESA's ARTES 20 element (user-driven applications), as well as the ARTES 3-4 Telecommunications Applications element (product-driven applications). These elements are dedicated to development, implementation and pilot operations, utilising not only Telecommunications satellites, but also combining the use of different types of space assets, including Earth Observation and Navigation, as well as Human Spaceflight technologies.

The overall goal of the IAP program is the *"the development of operational services for a wide range of users through the combination of different systems"*. The goal is to incubate sustainable services for the benefit of society that obtain their added value from the innovative integration of existing terrestrial technologies with space assets, such as Telecommunications, Earth Observation, Navigation, and Human Spaceflight technologies. "*Sustainable*" means here: triggered by, responsive to and sustained by real user demand, while taking into account financial (e.g. commercial) and non-financial (e.g. environmental, legal, adoptability) constraints. The provision of commercial *services* (rather than of mere products) is seen as a key outcome - one that offers flexibility and increases sustainability of demand, supply, and indirectly, up the value chain, also of space assets. In this way, "our satellites help to do better the daily work of society".

Such services are to be incubated through two steps or levels of ESA IAP activities:

1. Basic activities, which aim at generating, assessing and studying ideas for projects. Feasibility Studies provide the preparatory framework to identify, analyse and define new potentially sustainable activities.

2. Demonstration activities which aim at development and demonstration of the novel services identified in the first element, until an operational maturity is achieved that is satisfactory to the users.

IAP activities cover a wide range of themes, including Health, Transport, Energy, Environment, Development, Safety, Agriculture and Fisheries.

In January of 2011, within the theme of Safety, three parallel Feasibility Studies regarding Space Assets for Demining Assistance have been initiated that intend to conclude by early 2012. One or more Demonstration Projects are then likely to follow to demonstrate the SADA services to the key mine action end users.

II. DEMINING

II.1 Challenges for Mine Action Land Release

Landmines and Explosive Remnants of War (ERW) still kill or maim civilians every day, even long after conflicts are over. For landmines alone, an estimated 110 million live units have been scattered in about 70 countries since 1960[1]. At the current rate of clearance of about 500.000 mines per year[2] and assuming no additional mines are laid from now on, it could still take hundreds of years to find and clear all the landmines around the world. Each year the remaining units claim between 15,000 and 20,000 new victims. In addition, landmines and ERW dramatically hinder the recovery of economies wounded by a conflict, because resources located within areas such as arable land, infrastructure and water suspected of mine contamination cannot be exploited.

The 1997 Mine Ban Treaty aims to provide momentum to demining activities and targets clearance of mine affected areas within 10 years after ratification. Landmine Monitor estimates that as of August 2009 there may be left, worldwide, less than 3,000 km2 of contaminated land, in which the vast majority of the remaining mines are concentrated[2]. However, of all the land that has been subjected to meticulous landmine clearance activities, in retrospect only about 2.5-10% was found to be contaminated - the remainder could as well have been released without clearance effort[3]. This fact represents a major and unnecessary cost factor, considering that the average cost of clearance is around $\$1/m^2$, whereas well-informed land release (without such clearance efforts) costs only $\$0.02$-$\$0.05/m^2$, see [4].

Such statistical analysis results in a need for the Mine Action community to focus their efforts in three ways:

1. *Target with priority those minefields that are most threatening and costly to society.*
2. *Avoid the unnecessary deployment of clearance activities in non-contaminated areas.*
3. *Reduce the cost of detection and clearance per unit of land area.*

With the help of new methodologies and technologies it should thus be feasible to resolve most of the (historic) landmine problem within the next few decades.

At the same time, the problem of ERW remains and even increases, in particular considering submunitions. Cluster bombs spread out many highly explosive units (the submunitions) over the surface of targeted areas, where a significant percentage does not detonate as intended (ranging from 4-50%) and thus presents a real danger to the population. The first major use of cluster bombs was in South East Asia in the 60s and 70s. Widespread usage continues to this day. As an example of the scale of the problem, in Laos alone up to 27 million submunitions remain[5].

The combined issue of landmines and ERW calls for cost-effective innovations that improve the land release process and thus increase the socio-economic benefit of often scarce mine action activities.

II.2 Current practice of mine action land release

The process of Mine Action land release involves a significant amount of preparatory activities before mines and ERW can be located and actually cleared. Although the cost per unit of land area for these preparations is much lower than the cost for clearance, the volume of land to be investigated in the preparatory stages is generally much larger. A recommended methodology for land release is presented in Figure 7 [3,4,6,7]. This methodology serves as a guide for the remainder of this document, although it should be noted that it is not the only methodology and has not been implemented universally. See Figure 1 for a representation of definitions used in this listing. Figure 3 shows an example of a real world map of the areas explained here.

a. The first step is the **General Assessment** (General Mine Action Assessment or Land Impact Survey). A high level analysis is made of risk factors and socio-economic interests to identify and prioritize the Suspected Hazardous Areas (**SHA**) for investigation.
b. Typically a **Non-Technical Survey** will then be conducted which can consist of a range of information sources including local interviews, incident reports, and analysis of historical conflict information. In some cases, accurate and reliable records of mine locations exist which results in a significant reduction in the amount of time to clear. More typically however only a very limited amount of suspected land can then be cancelled so that it can be used by local communities or for national and local development, whilst the remainder will then be demarcated as a Confirmed Hazardous Area (**CHA**) for subsequent Technical Survey and clearance.
c. Through a **Technical Survey** most of the CHA will be investigated further in order to identify what areas require clearance, and which can be released without full mine clearance. This is usually conducted through lane clearance involving mine detectors and probing, visual inspection and other on-site activities. Patterns and other evidence is used to determine the Defined Hazardous Area (**DHA**) which subsequently requires clearance.
d. Only at this time the **close-in mine and ERW detection and clearance** will take place, in the DHA. Clearance is conducted, detected contamination is removed, and the land is thereby ready for hand over to impacted communities for effective use.

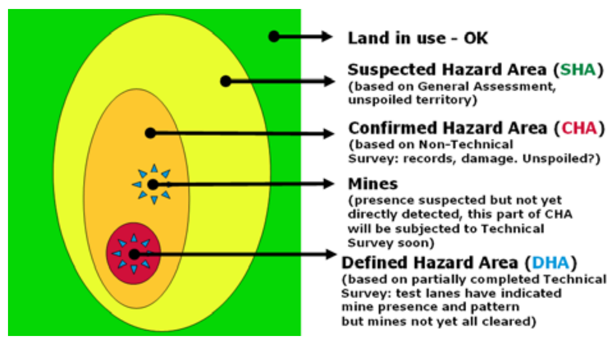

Figure 1. Schematic definitions for hazard classification in Land Release.

The final step of demining, involving mine detection and clearance remains a painstakingly slow process. Humanitarian demining requires a near perfect detection (a near 100% mine detection probability) in the sense that mines shall not be missed. So-called false negatives can not be accepted. For this reason, detection equipment must be tuned to respond even to low signals, which often causes the equipment to provide a false positive reading for objects and disturbances in the ground that are neither mines nor ERW. In fact, such false alarms routinely outnumber the actual detections of mines by hundreds to one and thus become primary drivers of the clearance cost.

Trained animals such as dogs (and rats) currently provide the most sensitive chemical tracing of mines and produce few false alarms. Though, in optimal ground, dogs detect mines in no more than about 95% of the cases. Such detection probability is therefore only sufficient for confirmation purposes. For some environments demining machines can be very suitable[8], though they are often costly to acquire, to deploy, and to maintain.

The primary method for obtaining sufficient detection probability of buried explosive ordinance is still a manual based process that involves close inspection of the soil by trained personnel equipped with individual prodders and metal detectors. On average a trained deminer processes a mere 35-50 m^2 per day.

The development of novel mine and ERW detection technologies is hampered by the multi-faceted nature of the problem. Mines, ERW and minefields can appear in a wide range of scenarios with varied characteristics including the type of terrain, type and conditions of the soil, type of minefield, type of mine or ERW, range of depth and orientation, and varied obstacles that impact upon the effective detection such as vegetation or metal contamination.

A large variety of innovative technologies for mine and ERW close-in detection are effective in laboratory conditions, e.g. Ground Penetrating Radar (GPR, Figure 2) and acoustic sensing. Each method has its own strengths and weaknesses. For example, GPR in combination with a metal detector for example works well for shallow mines in dry soil[9], whereas mine detection dogs do better in wet soil, but not on steep slopes, etc. However so far, no single innovative technology has provided an adequate solution covering the full range of contamination and field conditions[8,10,11].

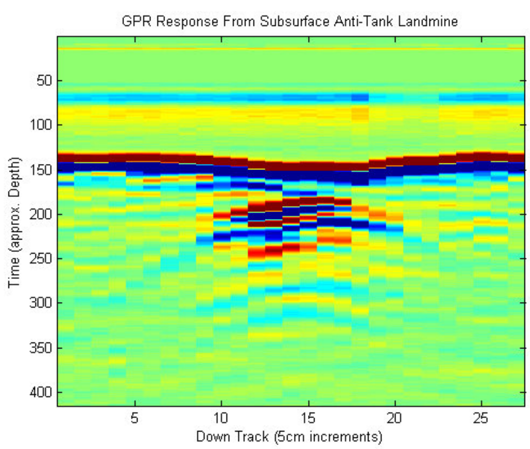

Figure 2. Ground Penetrating Radar result example for an anti-tank mine.

Stand-off detection systems have also been studied recently for the purpose of individual mine and ERW detection. Although it would be highly desirable to reliably detect individual buried landmines from a remote standpoint, a solution is considered by mine action experts and the technology sector not to be available in the near term.

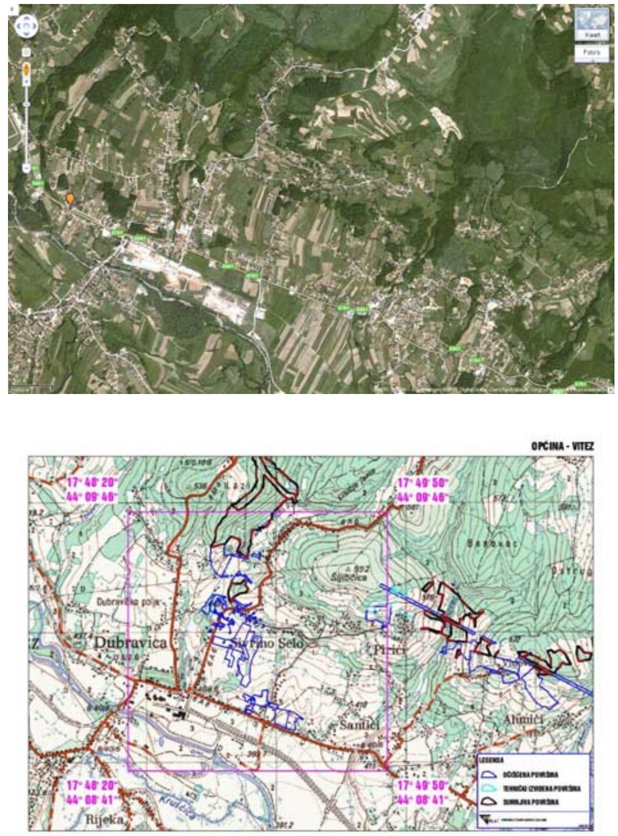

Figure 3. Example of maps indicating SHA (red/black), CHA (blue) and cleared areas (light blue) vs. Google Earth image, courtesy of BHMAC.

II.2 User segments

Within the complex arena of stakeholders (Figure 4)[12], users of humanitarian (non-military) land release services based on space assets can be divided over principally three segments: decision makers, operators and donors.

1. **Decision makers** in this context are the entities that decide on prioritization of regions for Non Technical Survey, Technical Survey and clearance. They may be National Mine Action Authorities (NMAA), or in their absence, UN bodies such as UNMAS or government authorities supported by UNDP. Such decision makers need socio-economic impact information to make reliable estimates of the mine/ERW problem in their country, as well as an overview of the resources and difficulties involved in implementing mine action activities. At the national operational level, National Mine Action Centers (NMAC), often assisted by NGO’s or

UNMAS, coordinate the regional activities of demining organizations.

2. The regional **field operators** may be NGO's, military, commercial demining companies, typically employing local people trained for mine action activities. They need services to support operational planning and the demining operations themselves.
3. **Donors** are unlikely to be direct customers of SADA services, but are influential, as they will want to have access to a reliable indicator of the progress of mine action activities and receive quantitative information to support investment decisions in particular equipments or methodologies. They often have particular constraints with respect to the activities they fund, e.g. limited to a particular region or type of activity (e.g. mine education, landmine clearance).

In some cases, demining activities are initiated by corporations with localized commercial exploitation needs, e.g. to provide access to resources or infrastructure. Such **corporate users** can be seen as a fourth group of users within the scope of SADA.

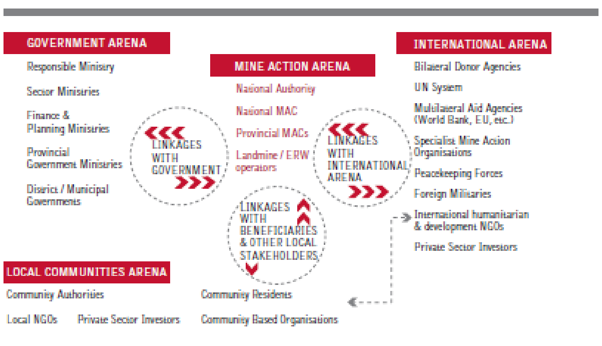

Figure 4. Mine Action stakeholders, source: GICHD.org

II.3 Users' drivers and constraints

Mine Action users have clear needs and will accept innovations only if certain conditions are met (see also [4,13]), including:

- **The cost/benefit ratio is a major driver.** Funding for research and investment is limited as budgets are often earmarked for specific identified mine or ERW clearance work. Donors may however be more willing to invest if non technical effectiveness can be traced clearly in a quantified, visual and objective manner. The cost/benefit ratio at a given budget can further be improved at the level of the General Assessment by maximizing the socio-economic impact of a given land release effort. For this, strategic planning tools are necessary, which could be based on an integration of remote sensing data with existing databases. At the level of the Non-Technical Survey, significant costs could be saved by more efficient collection and integration of field level data. Improvement of the Technical Survey which distinguishes contaminated zones from mine/ERW-free zones could lead to a more accurate focus for scarce mine action clearance resources and could thus reduce the amount of unnecessary fieldwork. According to a 2004 study on landmine clearing over 15 countries an average of 97.5% of cleared land proved to be uncontaminated[3].

- **Innovations (technologies and methods) should be easily deployable and generate immediate increase in land release efficiency.** To this end they should be easy to use and in line with existing procedures. In fact any deviation would require significant additional implementation and training costs. This necessary "fieldability" of the system also includes also includes ease of use by operators, appropriate technology and interoperability with existing tools (such as the Information Management System for Mine Action, IMSMA, as detailed below[14]).

- **Overall detection performance of the technology is imperative**. Performance does not necessarily have to be obtained by a single detection technology. A toolbox of innovative and complementary detection technologies could be utilized, each with its own strengths under certain known scenarios, surface and weather conditions. A reliable method would then be required to characterize the scenario present at a given time and for a given geographical area, and thus select which of the available detection technologies should be deployed for optimal performance and cost.
  Performance parameters include sensitivity or detection probability (high value reduces the risk of releasing land that still contains mines or ERW) and the Positive Predictive Value (PPV) of the detection or discriminatory ability (with high value, few false alarms are generated).

- **Assistance to access, demarcate and navigate the zone to be cleared**, for more automated reporting, data sharing, for secure communication and data relay in remote areas, etc.

II.4 Recent developments

Maturing technologies and procedures could make a real positive impact to Mine Action land release activities if properly integrated into an efficient seamless service and methodology.

Advances have been made on the organizational level. In 2009, standards for Land Release processes have been added to the International Mine Action Standards (IMAS 08.20-08.22)[15,16]. These standards also serve to avoid inflation of the mine problem, and discourage the assignment of large amounts of resources to areas that have only low impact or a weak case for being contaminated.

The Geneva International Center for Humanitarian Demining (GICHD)[3] has developed and is promoting the widespread use of the Information Management System for Mine Action (IMSMA), originally released in 1999[17]. It is supported by a definition of best practices and standards for usage and marking of maps in Mine Action related Geospatial Information Systems (GIS). IMSMA includes a database with an intuitive graphical user interface (GUI) and GIS that can be used for planning, prioritizing, managing, reporting and mapping the results of Mine Action surveys and clearance activities. It is in use in more than 80% of mine action programmes around the world.

Stand-off detection, even if it does not provide sufficient overall detection performance to proceed directly to clearance activities can provide important complementary inputs to Technical Survey and can assist with the discrimination between mine/ERW-free and contaminated field based locations significantly reducing land area for close-in detection[18,19] (Figure 6).

The so-called SMART approach (Space and Airborne Mined Area Reduction Tools[20]) and related approaches such as the Decision Support System (DSS)[21,22], the Airborne Minefield Area Reduction (ARC)[23,24] and its spin-off "General Aerial Survey"[10] have been recognized to offer support to the efforts in area prioritization and hazard confirmation.

These methodologies focus on indicators of landmine presence. It must be stressed that they are not a mine detection technology, but rather a methodology that integrates a variety of geographical data. They output maps of danger, based on indicators of mine presence, obtained from contextual information, such as spaceborne and airborne data, combined with Mine Action information, such as accidents, mine field records, historical events. Tests on actual minefields have demonstrated that these approaches provide a good indication of mine presence and produces a useful recommendation for demining action. In addition, they are able to reliably identify some of the suspected contaminated areas as uncontaminated, based on evidence of human activities. Although costs are relatively high and specific expertise is required to support the interpretation of the acquired stand-off data, the DSS has been successfully operated on extended yet remote (so-called "Class-III") areas in Croatia that otherwise could not be cost-effectively released.

Such approaches that fuse space, airborne and geo-spatial data are able to deal with innovative inputs, as they aggregate all available evidence (indicative of mine absence or mine presence) into a consolidated index of mine presence or absence. There is thus a flexible potential for enhancements, such as inclusion of remote sensing technologies and data for detection of evidence of mine laying activity or submunitions damage but also for a more direct detection of (individual) mines and ERW.

Evidence for mine laying or bombing activity may be gathered by analysis of historical data sets. Regular comparison of optical or radiometric imagery in conflict areas may reveal mine fields or locations as soon as the mines/ERW are deployed, based e.g. on temporary changes in the soil and vegetation structure. This comparative analysis may also be applied to past conflicts. To this end, an inventory of relevant available spaceborne/airborne imagery may provide support.

Preliminary testing and service operations in Israel and Angola have suggested that plants and microbes growing in a contaminated field could be subject for identification from satellite hyperspectral imagery[25,26]. Such a technology could provide valuable complementary information for a range of mine action programs that face particular difficulties that conventional methods can only handle at very high cost (**Figure 5**).

There are various concepts for direct mine and ERW detection, which are not yet available at operational level, that could be enhanced by stand-off technologies, such as:

- Objects on the surface such as submunitions can be detected in various ways including optical and multispectral sensing.
- Objects just under the surface could be detected through day-night effects unique to explosives locations by diurnal comparison of stand-off detection data, using infrared sensing or radiometry[27].
- Various airborne detection systems for individual buried mines or ERW are under development, which make use of a combination of ground penetrating radar and InSAR-type algorithms.
- A proposed detection method for individual mines or ERW uses biomarkers like microbes emitting fluorescent light when in contact with explosives which can be excited by laser light (close-in technology) for detection from a stand-off location[28].
- In some cases, aerial magnetic field sensing can be used e.g. to detect patterns of metal anti-tank mines.
- Change detection could be suitable for delineation of potential mine or ERW areas.

The stand-off detection methods that detect individual mines and ERW, even if limited in detection probability, typically promise relatively low false alarm rates. Thus, they could help to recognize patterns in mine-laying or submunitions clustering and to define tighter boundaries for resource intensive close-in detection and clearance work. The extent to which such a reduction of close-in detection effort is accepted is a matter of risk management and will generally depend on an individual national authority.

Other developments cover field and reporting activities of all types that may well be streamlined by user friendly satellite navigation and communication applications. For example, current navigation methodologies for the demarcation of mine/ERW fields are based on bearing and distance measurements, but could be improved by augmented satellite navigation technologies providing the required accuracy to allow operating under vegetation canopy or other challenging environments.

Sustainability relevance		Afghanistan	Bosnia	Cambodia	Colombia	Congo	Cyprus	Ecuador	Egypt	Iraq	Laos	Mozambique	Sudan	Zambia
1	Cluster ammunition	4	0	4	0	0	0	0	0	4	4	0	0	0
2	Commercial operations	4	4	0	0	0	0	0	0	4	0	0	4	0
3	Large area	4	4	3	3	0	0	0	0	4	0	2	0	4
4	Vegetation (TBC)	1	3	3	3	0	0	3	0	1	0	2	0	0
5	Difficult access	4	3	4	0	0	0	3	0	4	0	2	0	0
6	Disturbed minefields	0	4	0	4	0	0	0	0	4	0	2	0	0
	Other	0	0	3	0	2	0	0	2	0	0	0	2	0

Figure 5. Potential countries suitable for hyperspectral detection of vegetation contaminated with traces of explosives, following user interest expression in ESA survey. High interest = 1, very high interest = 4. The scoring is a combined value, relative not only to other countries but also to other (not-listed) services. The "sustainability relevance" ranking of the selection criteria is based on the level of interest as expressed by the mine action community as a whole.

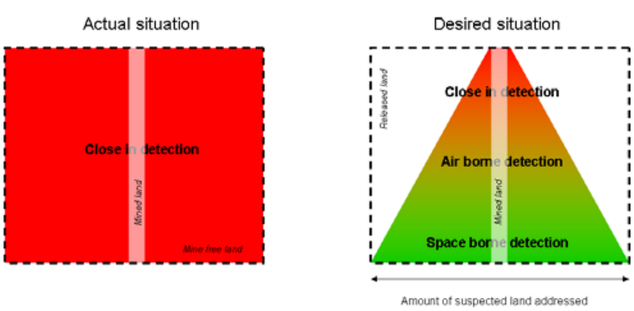

Figure 6. Targeted benefits of land release by stand-off detection

II.3 Space assets for mine action

A non-exhaustive list of potential services relying on space assets is described here referring also to the methodology presented in Figure 7.

At the level of General Assessment, Earth observation can provide beneficial support. The starting point for General Assessment could be existing map material and data such as digital terrain models and land use maps. If these are not considered to be sufficient, additional new satellite imagery could complete the mapping information. EO data of suspected contaminated areas could be used to indicate risk factors of mine presence (such as strategic position) as well as socio-economic impact (e.g. fertility of the land). By integrating demographic and topographic maps, areas of high density of human activity, heavily used access pathways, living areas and grounds used for sports and other activities could be identified. This information could be combined to produce impact maps for decision makers to define priority zones and to plan activities for maximum impact within a given budget and timeframe (Service 1 in Figure 7).

For the Non-Technical Survey, GIS and Earth Observation data combined with GNSS could be used to georeference reports and identify and mark suspect locations (Service 2 in Figure 7).

For the Technical Survey, various space assets could contribute to the detection of minefields and ERW-contaminated areas. These tasks will then require less field work (the stand-off detection perhaps fitting better the non-intrusive definition of Non-Technical Survey).

Minefields may have a different signature from space/air over various frequencies compared to surrounding fields or the same fields before mining (Service 3 in Figure 7). Specifically, if historical data is present or alternatively captured at the beginning of conflicts, identifying such changes can be a viable approach. Spaceborne Earth Observation data could help increase the overall performance level of the aerial and close-in detection by generating recommendations for sensing methods and timing which depend heavily on the scenario including topography, weather, vegetation state, as well as existing knowledge. Soil moisture data and vegetation density dynamics derived from multi-spectral infrared/optical sensors could provide insight into vegetation levels and seasonal patterns. Combined with surface slope mapping and weather forecasts, the best technology selection and the best times in the year to operate the stand-off or close-in detection could be determined. In particular planning of demining activities could be improved and costs could be better estimated (Service 4 in Figure 7).

Satellite navigation provides the means to optimize the routing of sensing aircraft/UAV over zones of investigation, reducing overlap and time to get full coverage, and thereby the cost of fuel, manpower and maintenance. Low-cost 2D/3D mapping technologies using hand-launched UAV's are currently available[29,30].

Precise navigation is also required to geo-reference remote sensing data to the observed position on the ground (Service 5 in Figure 7).

Satellite navigation technology could be used to unambiguously and efficiently fence off danger zones and mark released areas, and reduce costly unnecessary safety margins due to inaccurate information, common as a result of conventional distance-bearing methods. Future Galileo GPS navigation signals and Satellite Based Augmentation Systems such as EGNOS can be combined to improve not only accuracy but also to significantly improve signal integrity and availability in case of obstruction, such as under vegetation canopy or in mountain valleys[31] (Service 7 in Figure 7). Terrestrial relative positioning systems based on satellite navigation allow position accuracy well below one meter (differential GPS), and if required, centimetre level (RTK network). The latter will be much more costly to install, but may have additional benefits such as for agriculture, thus requiring careful trade-off. Such precision may be relevant for site marking and guidance purposes (Service 8 in Figure 7).

Communication is obviously critical in Mine Action, and is required between national and often remote regional mine action centers, as well as for national and international coordination (such as involving operators' main offices, UN bodies, GICHD for IMSMA software, and international conferences). In addition, the SADA services themselves may require reliable communication links for delivery of maps.

Mine Action communications are generally not considered highly time-critical and given the absence, degradation, or break-down of terrestrial infrastructure, solutions are almost always available (incl. satellite phone back-up, manual file transfer, or sheer patience). However, Satellite Communication may well have a more constructive role to play. Broadband Satellite Communication (e.g. BGAN or possibly VSAT based) can enable cost-efficient and reliable provision of EO services (map delivery) as previously mentioned to remote mine action centers. These communication infrastructures could then also be used for reliable communication, reporting, conferencing, as well as software updates. A more coherent and reliable communication solution which reduces delays and interruptions is likely to improve adherence to reporting procedures, which will benefit of traceability and quality management of mine action activities (Service 6 in Figure 7).

Finally, following the release of contaminated land, donors can be provided with impact maps overlaid with land release data, base on integration of GIS technology with Satellite Navigation and Earth Observation data as an insightful means of quantifying progress (Service 9 in Figure 7).

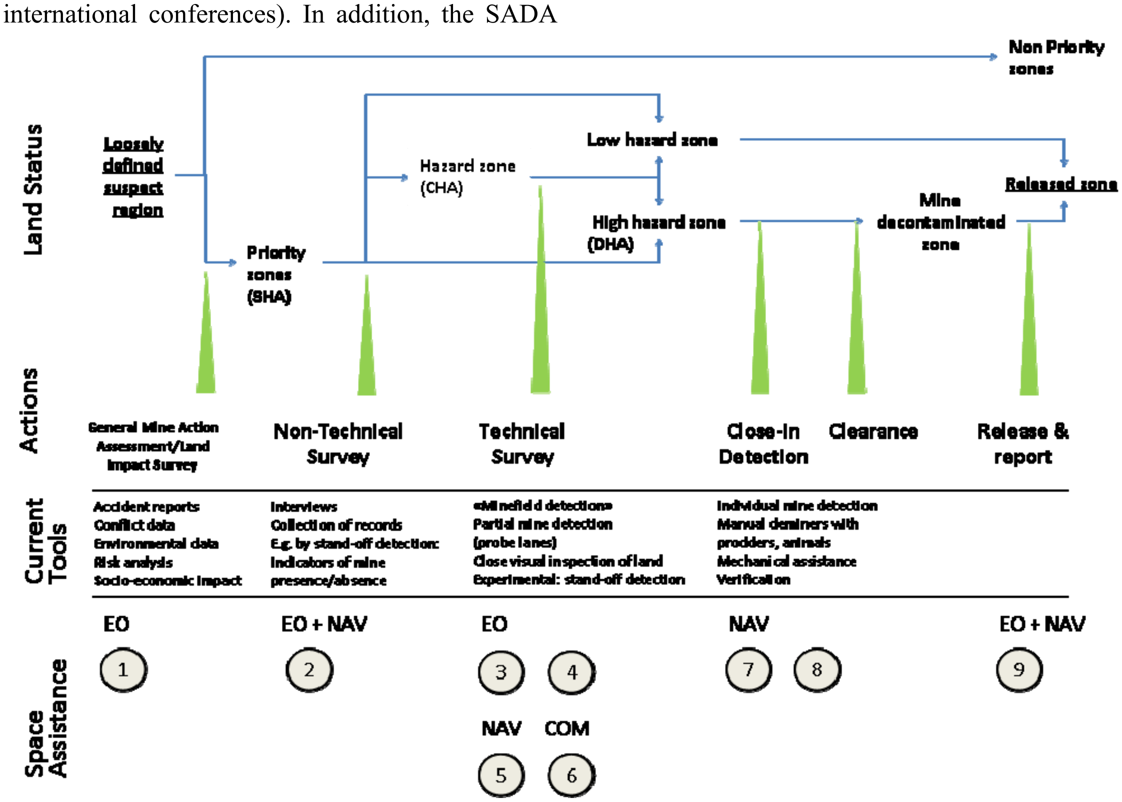

Figure 7. Recommended process for Land Release. Potential for Space Assets is indicated.

II.4 The SADA Project

In order to maximize impact on socio-economic development of landmine and ERW impacted countries, the SADA Feasibility Studies aim to assess the feasibility and viability of innovative integration of existing terrestrial methodologies and technologies with space enabled services to improve and optimize the planning, preparation, efficiency and impact of land release activities in Mine Action in order to answer the following questions:

- What added value can space assets provide in:
  - increasing the socio-economic benefit of mine action as a result of better prioritization,
  - improving non-technical survey work,
  - confirming and defining hazardous areas (incl. minefield detection) as well as land cancellation and release,
  - enhancing the mine and ERW detection effort by using stand-off imaging to better plan the use of close-in technologies,
  - supporting field work (incl. clearance)
  - reporting of results and interfacing with databases.
- How can this added value be improved by integration of space enabled technologies with existing accepted procedures, systems and services?
- What should an integrated system and service look like taking into account the current modus operandi, interests, constraints and concerns of mine action stakeholders?
- What sustainable services can be realistically provided considering currently available space assets, as well as technical and commercial viability?
- Can a service provider(s) and user(s) be identified to take part in and co-fund a potential follow-on demonstration project?
- Which are the capability gaps that cannot be overcome with existing assets?

II.5 The Study Teams

Three consortia, each with complementary capabilities and user representation, are undertaking the SADA Feasibility Studies in parallel. They are led respectively by Infoterra (UK), Radiolabs (IT) and INSA (E). ESA is supported in its management of these activities by the GICHD, which acts as a neutral observer. GICHD and the participating users and consortia are further introduced below.

GICHD

The GICHD is an international non-profit organization based in Switzerland which is staffed by mine action experts. The GICHD, in partnership with others, strives to provide capacity development support, undertake applied research, and develop standards, aimed at increasing the performance and professionalism of mine action. In addition, the GICHD supports the implementation of relevant instruments of international law, and manages the development and review of the IMAS standards on behalf of UNMAS to guide the planning, implementation and management of mine action programmes [15].

The GICHD role in SADA is to ensure the relevance and applicability of the results from the feasibility studies, and to coordinate the studies with other mine action developments. For this reason GICHD has supported the project definition, participates in project reviews, and has hosted a SADA discussion with the consortia and user community during the 14th International Meeting of National Mine Action Programme Directors and UN Advisors (March 2011).

SADA leverages on GICHD experience and ongoing research. For example, in August 2011, GICHD hosted a training workshop for the SADA consortia in order to allow them to develop effective interfaces between SADA services and IMSMA[17].

Figure 8. SADA-IMSMA interface workshop at GICHD

User involvement

Beyond the support of GICHD, the Mine Action community is broadly represented in SADA:

- Both during and following the 14th International Meeting of National Mine Action Programme

Directors and UN Advisors in Geneva in early 2011, ESA and the SADA consortia have extensively discussed mine action needs and concerns with a broad range of users. Part of the results which covering 37 contributors have been documented through an ESA User Survey (see Section III.1).

- Each of the consortia has representative Mine Action users (NGO’s, commercial operators, national authorities) directly involved in their study teams.
- The consortia have held their own workshops and conducted individual user surveys to collect and analyse mine action user needs and concerns.
- Each consortium will hold a proof of concept supported by a relevant Mine Action programme (including Afghanistan, Bosnia i Herzegovina, and Chile).
- ESA is supported in particular by a representative field operator, the Swiss Foundation of Mine Action (FSD), an NGO providing ESA and individual consortia with a direct connection to mine action field operators. FSD is active in Lao, Tajikistan, Lebanon, Afghanistan, and Armenia, and provides ESA with user needs and feedback based on the work of the consortia, as well as hosting a field visit to Tajikistan for the benefit of the SADA consortia.

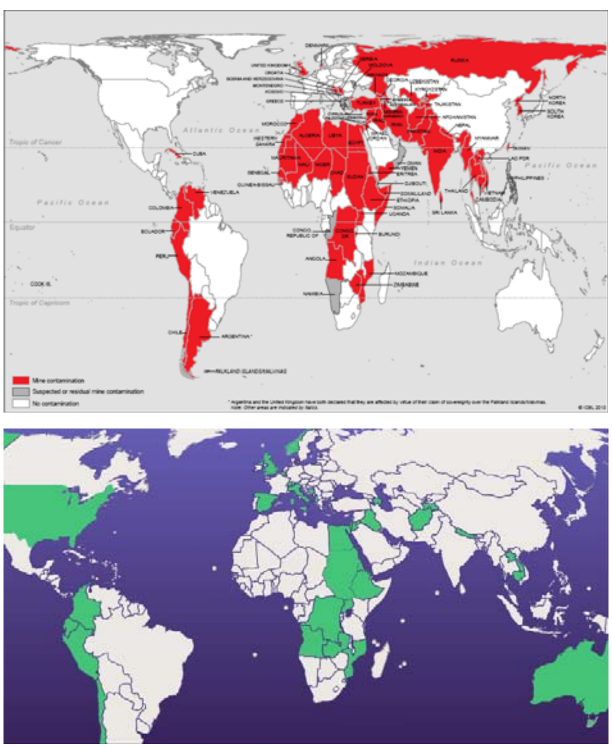

Figure 9. Mine affected countries vs. nations so far that have representatives participating in SADA.

Figure 9 provides an overview of the mine affected countries as well as of the contributors to the SADA projects so far.

Consortia

- **Infoterra (UK)**. The Infoterra consortium consisting also of Cranfield Mine Action (Cranfield University) and BAE Systems provides a unique combination of experience of space enabled solutions to benefit a wide range of sectors, extensive expertise on state of the art sensor technology, and extensive experience of the mine action sector through experience of close collaboration with over 30 mine action programmes as well as national and international non governmental organisations, national authorities and mine action centres, as well as commercial mine action companies. The consortium benefits greatly from the direct involvement of MAG, and MineTech International, as well as representative members of the national mine action programmes in Sudan and Afghanistan (two of the largest mine action programmes in the world).

- **Radiolabs (IT)**, an international consortium with Università di Roma “Sapienza” (IT), MEEO (IT), Vrije Universiteit Brussel (B), Aurensis (E), and domain experts GTD – Sistemas de Informacion (E), Agenzia Industrie Difesa (IT) and Appalti Bonifiche Costruzione (IT). This “SAFEDEM” consortium is active in all the phases of the development lifecycle with expertise covering Earth observation and mapping, unmanned aerial vehicles, satellite navigation, (satellite) communications, Mine Action applications based on IT (Information Management, Geographic Information Systems, Data Mining, Geospatial and Risk Analysis), artificial intelligence and data processing.

- **INSA (E)**, an all-Spanish consortium with Hispasat (E) and domain expert EXPAL. The consortium combines expertise in remote sensing products provision and operational systems development, satellite communications provision, knowledge of the military mine action market and mine land release expertise.

III. SADA INTERMEDIATE RESULTS AND STATUS

III.1 User Needs

Shared User Baseline

The FSD "Shared User Baseline" produced for the the SADA studies details the peculiarities of demining and land release in Mine Action. Following a conflict, risks, benefits and hence Mine Action priorities typically shift significantly over time (Figure 11). Threats within a post-conflict area often occur in a mix of various scenarios, in terms of contamination (patterned, non-patterned minefields, and/or ERW), as well as physical environment (such as mountains, deserts, grass, bush etc.). As no single "silver bullet" solution exists covering all scenarios, it is not easy to define a specialized service that meets the majority of user needs even within a single country or mine action programme.

Services must therefore be flexible, generic and be capable of integrating different inputs. The use of IMSMA is one of the few common factors within the sector, and general purpose mapping has been identified as the most common need. FSD also confirms there is a general need for access to reliable information that does not require field based access to suspected hazardous areas, and for methodology and technology to better reduce (cancel or release) non-affected land, and to provide better reports/rationale to donors. There is *no* need for better clearance (destruction) technology as current approaches are widely considered to be satisfactory.

Solutions should therefore be robust and based on incremental innovation, be built on or interoperable with existing tools & systems (such as with VHF/HF/mobile phone, (D)GPS etc), and be operable and maintainable by local staff who require minimal infrastructure and training.

Requirements analysis has indicated that costs should be in keeping with individual donor priorities and budgets, and there should not be an expectation that cost for a service/solution will be borne by the host country. As most high impact, easy access and well-documented minefields have been cleared, funding for Mine Action is currently levelling off despite the abundance of remaining ERW and more challenging minefields. The priority is to integrate mine action into other types of development, such as traditional development, reconstruction, recovery, peace and security. To obtain and maintain donor support, results should be quantifiable not only in terms of socioeconomic benefit, but also in relation to development goals (such as agriculture & food security, infrastructure, health, and stabilisation of populations).

ESA User Survey

The ESA User Survey was a crude survey among the mine action community to map the level of interest in services and improvements that may be supported by space assets. The survey covered 37 respondents from 20 mine affected countries and areas, as well as various UN and NGO representatives. An overview of intermediate results (30 respondents, 15 affected countries/areas) are presented in Figure 15.

Participants were asked to judge an item as "Relevant" if it relates to:

- a core activity for their organisation,
- an issue of high urgency or high impact for the region,
- a difficult issue to deal with, i.e. many resources would be required on a daily basis to deal with this issue to your full satisfaction,
- a large scale issue, in terms of area affected or total level of contamination, or
- a chronic issue.

Most services listed were considered to be highly relevant. In order to identify confirmation bias or bias by selectivity of the respondents (**Figure 14**), a rescaling was performed, from which confirmation bias was found not to be too significant however the relatively large fraction of information management professionals was noted to have raised the relative relevance of technical and information related services.

Consortia Users

The consortia took these initial ESA survey results into account in subsequent discussions with mine action end users, through web surveys, interviews and workshops. Subsequent identified consortia needs were largely in line with the ESA survey results, though have been more specific in the detail of needs, requirements, constraints and success criteria in order to define commercially viable services.

Top relevance	
19	Planning & prioritization of mine action activities
19	Land release to enable access and repopulation
17	Information to maximise release of land with high socio-economic impact
16	Information to improve land release without technical survey and more objective SHA delimitation
16	Land release to enable agriculture/farming
15	Collecting & combining indicators of presence or absence of contamination
15	Detailed hazard mapping (from historical data, field reports, feature recognition, geographical, climatic indicators, ordnance footprint estimation)
Not so relevant	
13	Improved capacity building and risk education in absence of on-site experts
11	Land release for other purposes (tourism, Art. 5 obligation, ...)
11	Demining assistance for terrain with difficult access or challenging conditions for dogs and machines
09	Assessing impact of floods, landslides and other events that affect mine/ERW distribution

Table 1. Relevant services with potential space asset contribution as ranked by the survey respondents (ad hoc scorings)

III.2 SADA High Level Concepts and Next Steps

Infoterra Consortium

The Infoterra consortium has identified a wide range of user needs and requirements relative to the provision of space enabled solutions (Figure 10). The key challenge that they have identified relates to the cost effectiveness of such solutions, a factor that has limited the adoption of previous similar technologies at both a national and global level. The consortium has defined two fundamental yet flexible, and integrated services:

(i) *Decision Support Service*
Based primarily on Earth Observation data processing chain, prepared to take in other geographical data sources.

(ii) *Field Support Service*
With the intention to support field teams with mapping, communication, navigation and GIS functionalities.

The consortium is working closely with their representative end users in the preparation of a proof of concept which will trial their proposed two-pronged space enabled integrated service in order to directly benefit the mine action sector, and look forward to further refining their proposed service based on important feedback from end users.

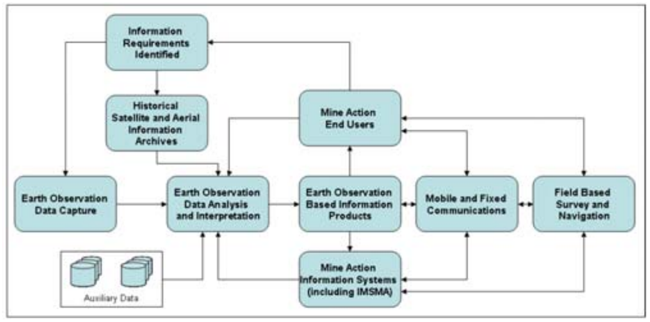

Figure 10. Infoterra high level functional SADA concept.

Radiolabs Consortium (SAFEDEM)

Having finalised the user requirements and needs phase, the focus of the Radiolabs Consortium "SAFEDEM" concept is *Data Acquisition* and *Data Exploitation*, aiming to provide operational and decision support for Mine Action Land Release process, mainly in the context the activities of the General Assessment, the Non-Technical Survey and the Technical Survey, described in Section II.2. New tools will be designed in the form of added-value services and/or plug-in applications to IMSMA with direct interfacing to it. The SAFEDEM concept combines thus two elements:

1. SAFEDEM Data Acquisition Services

- A pyramidal remote sensing imagery acquisition (historical Low to high resolution Satellite images, combined with very High unmanned aerial vehicle (UAV) images),
- Thematic maps production, including but not limited to, topographic, land cover, land cover change, Digital Terrain Models (DTM), soil, mine and mine field indicators maps, and GIS layers production,
- Field Mobile Service at the intersection of GIS, Navigation systems and Telecommunications implementing the so-called 'telegeoprocessing' technologies such as: Integration of mobile computing, data acquisition and GIS (Mobile geoprocessing)

2. SAFEDEM Data Exploitation Services
These services are Geospatial Decision Support and advanced on-line reporting, analytics, dashboard – Business Intelligence Services Platform, to sustain the workflow of the above considered Mine Action Activities, in particular the following survey process phases:
(i) planning and preparation,
(ii) data collection,
(iii) analysis, integration and interpretation,
(iv) risk and impact assessment, and
reporting & dissemination.

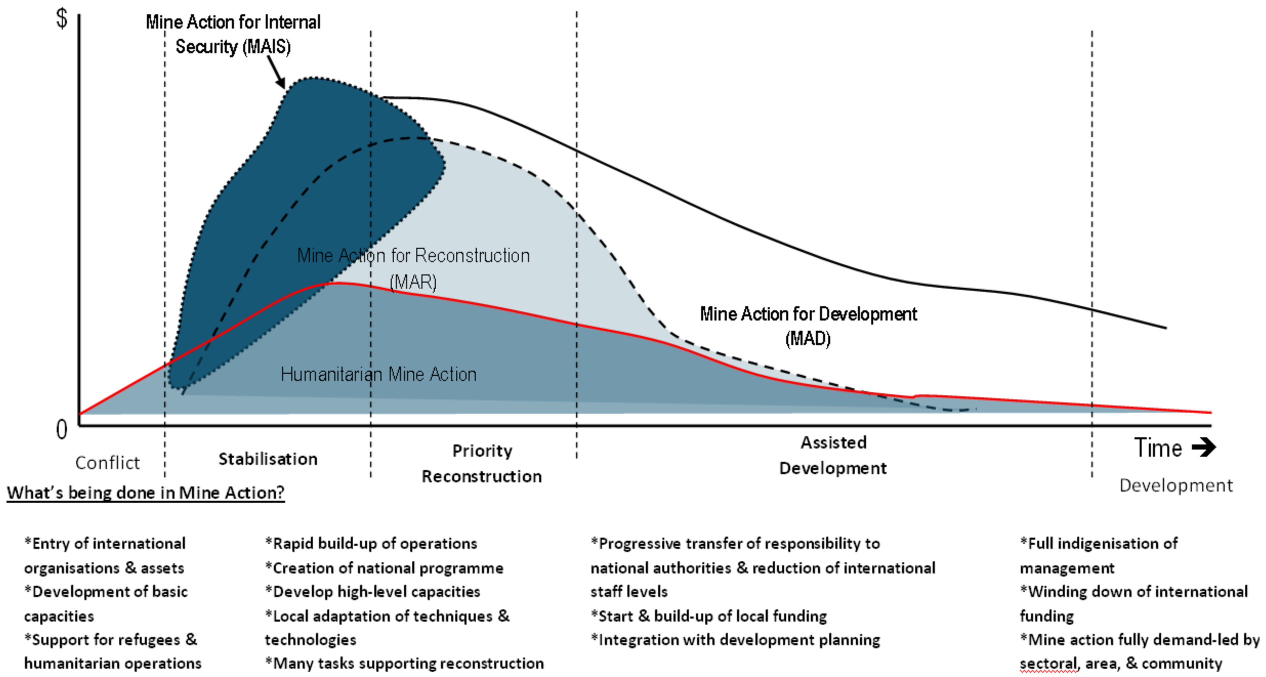

Figure 11. Mine Action Life Cycle

The SAFEDEM consortium is closely collaborating with the Bosnia and Herzegovina Mine Action Center, the Tajikistan Mine Action Centre-United Nations Development Programme, and the United Nations Mine Action Office in Sudan, in refining user requirements and user needs assessment with respect to operational scenarios and stakeholders characterisation, and scenarios proposal for the proof of concept. The overall planes of the proof of concept are to demonstrate the feasibility of SAFEDEM Services to assess their usefulness in the above process phases (i) and (ii), these will comprise also aspects of process phase (iii) analysis, integration and interpretation, as well partly (iv) risk and impact assessment. It should be noted that the scenarios for the proof of concept are also being discussed with other Mine Action Centres and Mine Action Operators (NGO's and Commercial) to get a broader feedback in the user needs assessment as well as the development of the business model required by the SADA terms of reference.

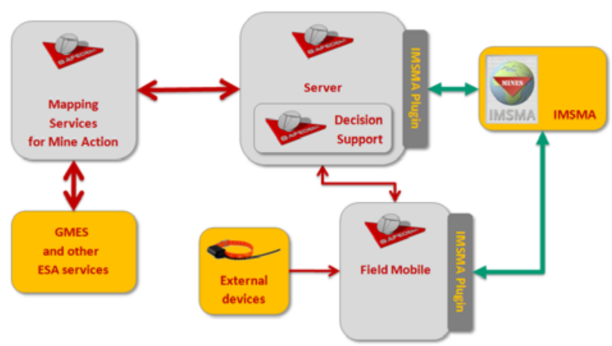

Figure 12. SAFEDEM high level SADA concept.

INSA Consortium

INSA Services proposed

Services proposed are classified in four categories or groups related to the phases of the mine action activities:

- ***General Assessment***: a complete service providing strategic information for planning and prioritization of mine action activities is defined for this stage of the land release process, including information about real contaminated areas (better SHA delimitation), socioeconomic impact information and cartography support, which will be an advantage for the planning tasks and Land Impact Survey (LIS) activities.

- ***Non Technical Survey***: two services are defined for this phase, with the main objective of providing confidence data about the evidence of mine/ERW presence and absence in a specific region or area. The first service focuses on the detection of visible craters, destroyed bridges, destroyed infrastructures/buildings, etc. (evidence of mine/ERW presence) and the second one focuses on the detection of land use changes on a yearly basis to indentify which lands can be released (evidence of mine/ERW absence).

- ***Technical Survey***: for the technical survey phase the SADA system will provide a service describing and classifying in detail the vegetation and the soil type presented in a specific region or area, which will improve the technical survey planning tasks achieving a more efficient deployment of the technical assets in the field.

- ***Post-clearance and report:*** once the demining activities are finished the user demands a monitoring tool in a long term basis to provide donors verification of the invested donations by providing information about the use of the released lands. There is also a need of a monitoring service showing the evolution of the demining activities. These two factors will be provided in the service defined for this phase.

Communication and navigation support services will also be provided for field site operations. It is assumed that any of the previous phases may involve field deployment, so there will be support for all the phases of the land release process. The main communication service to be provided is voice communication between the field offices and working sites located in remote areas where the existing telecommunications infrastructure does not provide coverage. Navigation support service will be provided with different degrees of accuracy for the different phases of the land release. It is understood that Technical Survey (TS) teams may need high accuracy positioning data unlike LIS or non-TS teams, and this fact must be considered.

INSA Concept description

The concept definition takes into account at least the Information Management System for Mine Action (IMSMA), a tool that is already well-established in the community. It is integrated into the architecture for the services provision. Space assets are a key part of the architecture, helping to fill the gaps identified with the already used technologies. The main blocks composing the SADA system are depicted in Figure 10.

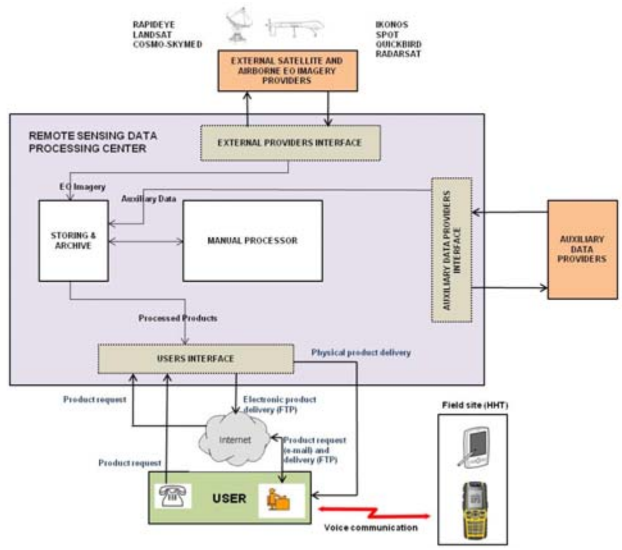

Figure 13: INSA SADA system main blocks

The Remote Sensing Data Processing Center (RSDPC) will be in charge of processing the remote sensing data and making the resulting products available to the users. Therefore, it will carry out the generation of the different products demanded by the users and the delivery to them. The RSDPC is also a front-end interface to the remote sensing and auxiliary data suppliers (through the mentioned interfaces) and will be in charge of products distribution to the users.

Within the RSDPC, The Processing block will prepare all remote sensing data acquired by the existing airborne, satellite sensors, and auxiliary products and generate the different products and related metadata. Finally a Database Manager is needed in order to facilitate the integration of the indicators of the different products, and to provide storing and archive capability (geospatial database of the products and user information classification).

The “User Community” has been included in a single box to state that the user of the system can be any organization related to the mine action community: a decision maker, mine action center, NGO, commercial company, military, etc.

Finally field demining sites are depicted in order to consider the fact that a subset of the services to be provided by the SADA system will apply exclusively to these field sites (namely the Handheld Terminals), specially navigation and communication services.

INSA Proof of concept

The INSA proof of concept shall be the opportunity to validate the system and service design. Users from Mine Action Coordination centre of Afghanistan

(MACCA) and Bosnia Herzegovina Mine action centre (BHMAC) shall be receiving the products generated by the consortium for their validation. This will be a good opportunity to test the critical technologies against user data and requirements and create user awareness about the integrated technologies capacity.

Some examples included in the PoC shall be the suspect area reduction using a non-technical method and provision of non-biased information of results and socioeconomic impact achieved after the mine action activities.

V. CONCLUSION

Land Release in Mine Action is a process involving a multitude of possible scenarios and technologies. There is a clear need for an end-to-end assistance service for enabling Mine Action land release. the service should support planning, categorization and prioritization of geographical areas and scenarios to be dealt with for realising maximum socio-economic benefit. Field data collection and reporting should be improved. All services should be in line with the already ubiquitous IMSMA software.

Stand-off detection could be used at various levels of the land release process to support risk mapping, impact mapping, minefield and ERW-contaminated area detection and eventually to help to couple the most appropriate detection technology to meet field conditions.

As far as detection of individual mines or ERW itself is concerned, the main driver is the need for near flawless detection probability, requiring sensitive detection methods that offer a reduced false alarm rate. To make a difference, Minefield, ERW and mine detection technologies should be fieldable, cost effective, reliable, and discriminatory. In many cases, multiple detection technologies may be employed and the true benefit may come from their optimal combination and fusion of data.

The land release process is expected to be improved by space enabled services currently being defined by the three SADA consortia. Proof of Concepts are currently being initiated, and, if successful, commercial services will be developed as part of one or more Demonstration Projects.

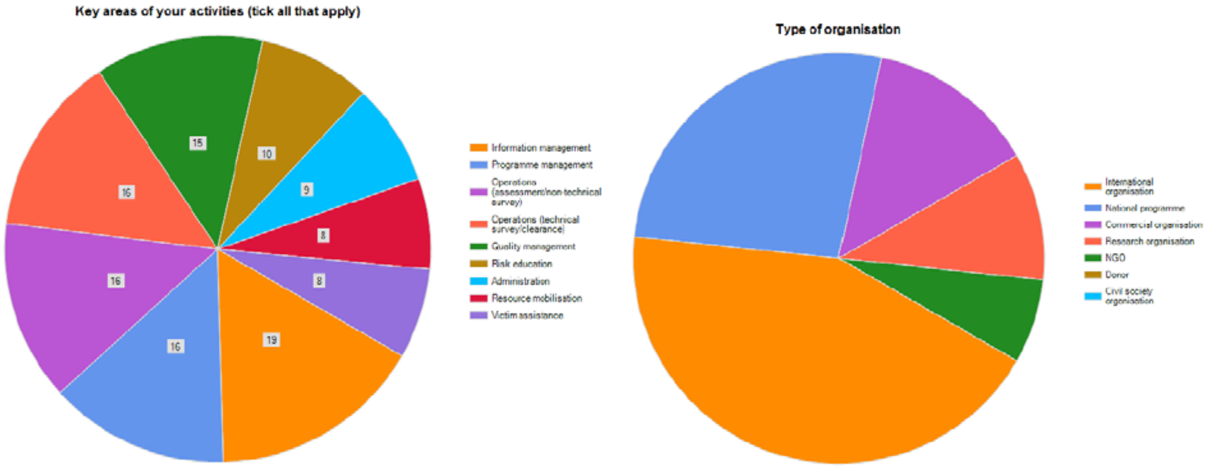

Figure 14. ESA survey respondents analysis.

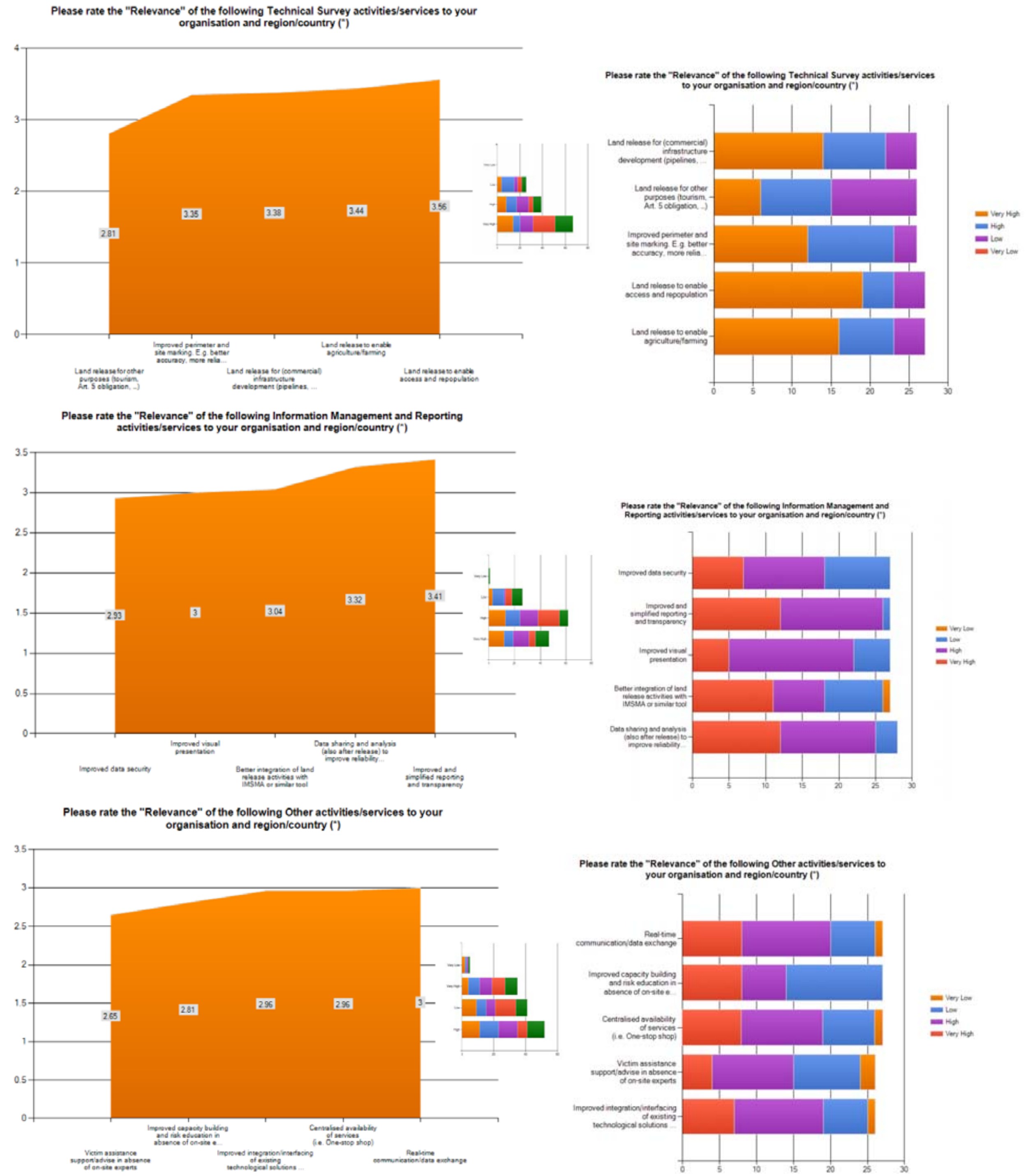

Figure 15. ESA survey results of Mine Action user interest in services with space asset elements (30 responses intermediate result).

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Comparing different gradiometer configurations for underwater survey and demining

Yann Yvinec[1]

Abstract

This paper compares the simulation of the use of gradiometers made of two, three of four magnetometers in estimating the three components of the gradient of the intensity of the magnetic field. The simulations take into account the sensor characteristics (measurement frequency, etc.), the target's magnetic properties (magnetic moment dipole) and the description of a survey where the gradiometer is towed behind a ship (ship speed, sensor depth, track inter-distance, etc.)

The simulations show quantitatively that, if the vertical gradient can theoretically be reconstructed from the measurements of two magnetometers, in practice the estimation may be very noisy. A more precise, direct measurement can be obtained by a third magnetometer. A four magnetometer can be used to increase the precision of the estimation of the gradient along-track.

1. Objectives

Mines and any large mass of ferromagnetic metal locally modify the ambient magnetic field. Measuring the intensity of the magnetic field can therefore be used to detect mines underwater even if they are buried. Measuring the gradient of the magnetic field (rather that the magnetic field itself) can help distinguish two metal objects close to each other. Each of the three components of the gradient can be either measured directly by using the difference of the measurements of two different magnetometers used together, or reconstructed from the different measurements of a single magnetometer along a survey.

This leads to different possible configurations for a gradiometer depending on the number and relative locations of the magnetometers [1][3][4]. In this paper we will consider three configurations. One is a gradiometer composed of two magnetometers located laterally with respect to the movement direction: one on port and one on starboard. Then the across-track gradient can be estimated directly. The along-track gradient can be recovered by difference of measurements along the track, and the vertical gradient can be estimated from the two components of the horizontal gradient. The second configuration is when a third magnetometer is added on top or below the first two. This allows the vertical gradient to be measured directly. And finally the third configuration is when a fourth magnetometer is added behind the first two. Then all three components of the gradient can be estimated at each time.

In this paper the following conventions will apply. When a gradient is computed by combing measurements collected at the same time, the gradient will be said to be *measured*. If it is computed from data collected over time, it will be said to be *estimated*.

Measuring the gradient is better than estimating it [2]. The objective of the paper is to confirm and quantify this improvement.

In the simulations described below, the magnetometers will have an acquisition frequency of 1 Hz.

2. The added value of the third magnetometer

In order to analyse the added value of the third magnetometer, a simulation was done with a simulator described in [5].

The parameters of the simulation are as follows:

- The gradiometer is towed behind a ship.
- We assume the Earth's magnetic field to be close to what it is in the North Sea.
- We assume that the magnetic moment of the target is in the direction of the Earth's magnetic field with an intensity of 10 Am^2.

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- The ship's trajectory consists of 60 tracks back and forth, in the North-South direction, two metres apart; the speed is 5 knots.
- The gradiometer is 10 metres above the sea ground.
- A uniform noise is added to the gradiometer locations with a largest value varying from 0 cm to 50 cm.
- Magnetic maps are built from the data collected from this survey.
- The theoretical vertical gradient is computed.
- The vertical gradient estimated from the data of two horizontal magnetometers is simulated.
- The vertical gradient as measured by the three magnetometers is simulated.
- For each configuration the relative error with the theoretical gradient is computed.

The estimation of the vertical gradient from the horizontal gradient is theoretically correct if the horizontal gradient is known perfectly on an infinite surface. Therefore in practice it will be better if it is based on a large set of measurements, either by a finer grid or a lower speed. The above simulation is therefore only an example.

That being said, the results can be found in Figure 1

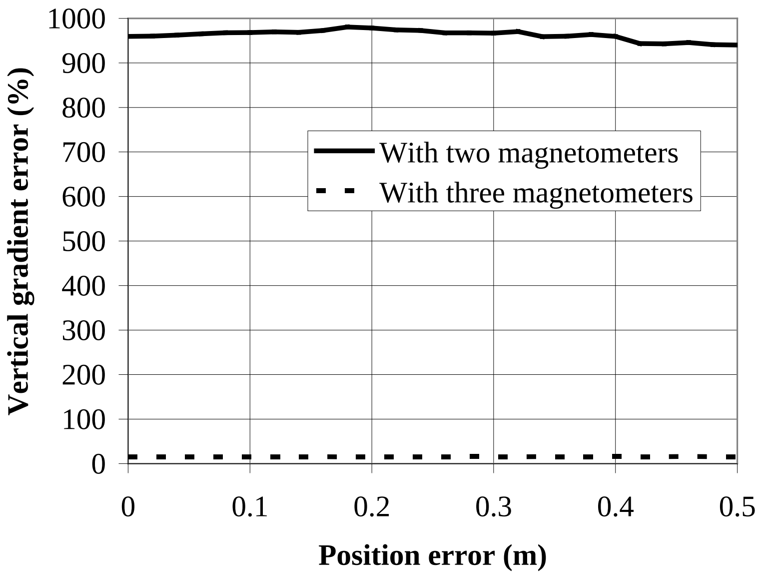

Figure 1—Vertical gradient errors when estimated with two magnetometers and measured with three magnetometers (1 Hz)

The estimation of the vertical gradient with only two magnetometers is far poorer than the direct measurement with three magnetometers.

Figure 2 shows the results if the magnetometers have an acquisition frequency of 10 Hz instead of 1 Hz. The estimation of the vertical gradient, although still noisy, is better.

It is theoretically possible to estimate the vertical gradient with measurements collected by two horizontal magnetometers, but the direct measurement with a third magnetometer is far better. With two horizontal magnetometers you can estimate the vertical gradient provided the horizontal gradient is known on an infinite surface. In practice the horizontal gradient is known only where measurements have been collected. This lack of data generates important errors when estimating the vertical gradient.

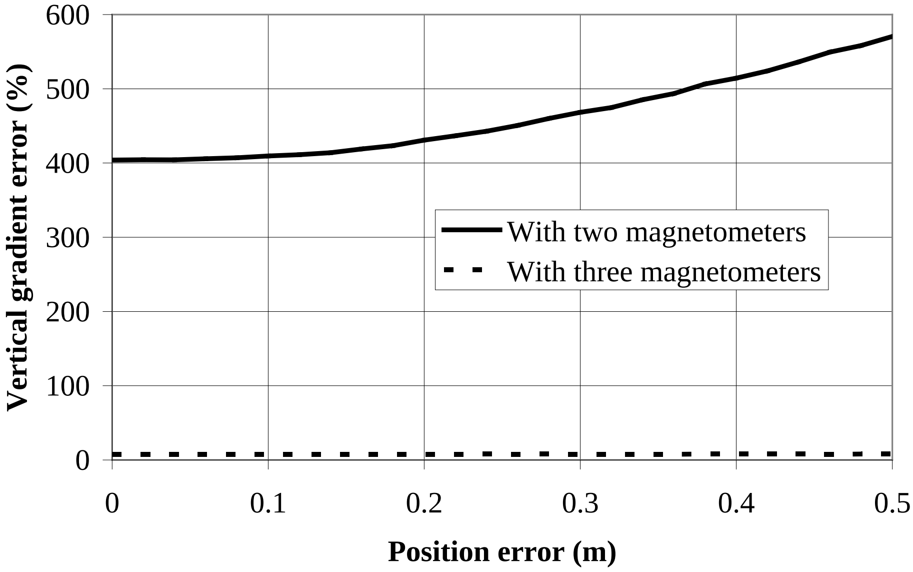

Figure 2—Vertical gradient errors when estimated with two magnetometers and measured with three magnetometers (10 Hz)

3. The added value of the fourth magnetometer

The fourth magnetometer allow the along-track gradient to be measured directly and not only estimated from data collected along the track.

In order to analyze the added value of the fourth magnetometer, a simulation is performed. The same parameters as above are used with the following differences.

- The theoretical along-track gradient is computed.
- The along-track gradient estimated from the data of three magnetometers is simulated.
- The along-track gradient as measured by the fourth magnetometers is simulated.
- For each configuration the relative error with the theoretical gradient is computed.

Results are shown in Figure 3.

It is possible to estimate the along-track gradient by combining the measurements along the track, but the direct measure of the gradient is better.

4. Conclusions

The following conclusions can be drawn:

1. It is theoretically possible to estimate the vertical gradient with only two horizontal gradient but the estimate is very noisy.
2. Measuring the vertical gradient with three magnetometers is better than estimating it with two.
3. Measuring the along-track gradient is better than estimating it.

This paper provides data to support quantitavely these conclusions.

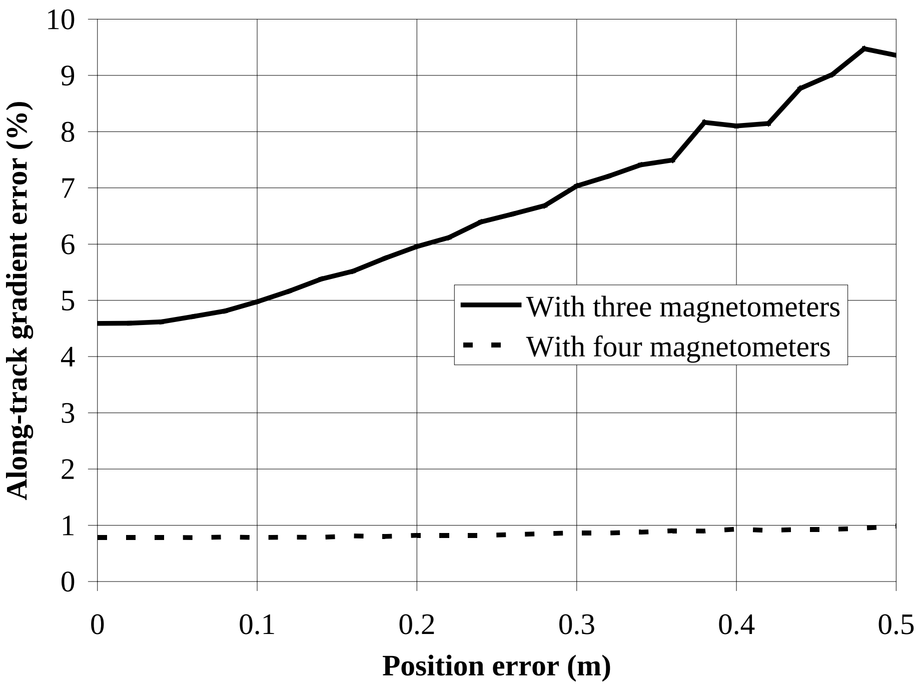

Figure 3—Along-track gradient errors when estimated with three magnetometers and measured with four magnetometers

Acknowledgment

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Milan Bajic

Airborne wide area general assessment of the environment pollution due to the exploded ammunition storages

Abstract - **The wide area assessment of military test ranges for training of airborne bombing, for testing the artillery, mortars and other weapons is mature technology, although it is mainly based on the magnetometers. The airborne multisensor imaging of test ranges was considered in several references, synthetic antenna radar (SAR) and hyper spectral airborne imaging were considered only in a few. The mentioned technologies are adequate for military test ranges and not for scattered unexploded ordnance after the explosion of the ammunition storage. The undesired explosions of the ammunition storages happens often and only visual and manual search is available for assessment of the contamination distribution. There is not available operationally effective technology for airborne wide area assessment of the unexploded ordnance litter at and around the storage. The success of the application of the airborne multisensor system (AI DSS) for the needs of the humanitarian demining, enables solution of the considered problem. In the case of the humanitarian demining the targets are remains of the war at the mine suspected area (trenches, shelters, bunkers, etc.), while in the case of ammunition storage explosion, the targets are smaller and there is the main problem to detect and locate them, recognize and describe. The key technology that could enable to perform all three functions combines airborne hyper spectral imaging and the imaging with several other electro optical sensors (multisensor imaging). The dimensions of the smallest target determine altitude above terrain which enables needed spatial resolution and required probability of the detection, recognizing and technical description in accordance to Johnson's criteria[1].**

I. Introduction

The ammunition storage Padjene (Croatia) exploded 13.09.2011., the cause was the wild forest fire. The Commander of Croatian Air Force and Air Defence suggested to apply hyper spectral and multisensor imaging of the ammunition storage Padjene, by the airborne system [1], [2]. Initiated by this event and suggestion, was derived 13.10.2011 first concept of the dedicated research project with following goal: develop, test, evaluate and operationally validate technology for the airborne hyper spectral & high spatial resolution multisensor assessment of the UXO litter at and around ammunition storage after undesired explosion, spectrally matched to UXOs and their litter, crude fuel and their litter at the considered terrain, soil and vegetation. Two objectives were defined also:

- Detect and locate UXO litter, produce thematic raster maps of UXO, their parts, in selected regions inside circular area centered at the ammunition storage Padjene.
- Assess the initial chemical contamination by airborne hyper spectral imaging of the ammunition storage Padjene after the undesired explosion.

II. Case Study Region Of Interest And Targets

The ammunition storage Padjene (44°04'27.20"N, 16° 08'11.29" E), Fig. 1, is locted near town Knin, Croatia. The explosion contaminated large area around the storage, Fig. 2. The UXO litter was scattered around the storage, the Task Force of Croatian Ministry of Defense started recovery action on September 14, 2011, inside radius 5 km (total area is 78,5 km^2), Fig. 2.

a

b

Figure 1. The ammunition storage Padjene: a) before the explosion, shown on the satellite IKONOS image 29.03.2006 (Google Earth Pro); b) one month after the explosion shown on the aerial photography 13.10.2011.

[1] J. Johnson, 1958, Analysis of Image Forming Systems, Proc. Image Intensifier Symposium, US Army Engineer Research and Development Laboratories, Fort Belvoir, Va., 6-7 Oct. 1958 (AD220160).

Croatian Ministry of Defense provided data and information about the ammunition storage Padjene, exploded on September 13, 2011.

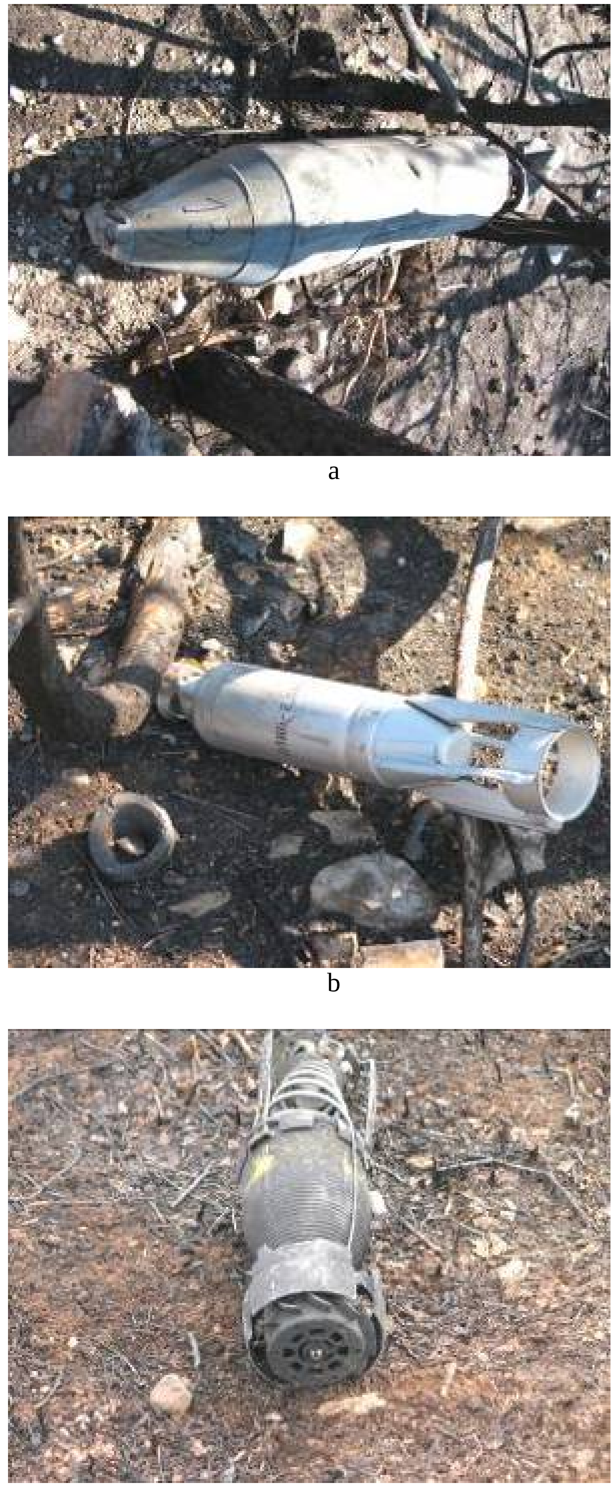
Figure 2. Region of interest is defined by circle having radius 5 km around the storage center. The circles with radius from 1 km to 5 km are shown in red. The satellite IKONOS image 29.03.2006, (Google Earth Pro).

The process of the recovery has several phases: the visual search, manual detection, marking, displacement or destroyment of detected unexploded ordnance, crude fuel and their parts, extraction of usable non explosive materials, assessment of the chemical contamination after the recovery, disposal. The Task force of Croatian Ministry of Defense for recovery, estimated density distribution of the scattered ammunition and parts, measuring from the center of the ammunition storage,

- inside radius 800 m – 70 %,
- from 800 to 1000 m – 20 %,
- from 1000 to 2000 m – 6 %,
- from 2000 to 3000 m – 3 %,
- from 3000 to 5000 m – 1 %.

and the varying from the uniform radial scattering of the explosion due to terrain and natural obstacles around the storage. The dimensions of the UXO vary from rifle ammunition to the airborne cluster bombs, examples at Fig. 3, where smallest are scattered inside of the ammunition storage and in small distance from it. With authorised officer was agreed that smallest diameter that research should consider is 40 mm.

Besides the UXO, the area of the ammunition storage is itself an important target, Fig. 1, Fig. 4. It is contaminated by all kinds of UXO, but also with the lead and the mercury. Similar chemical contamination with these heavy metals could be expected in nearest areas around the storage. The research should provide the starting assessment of the chemical contamination with mentioned heavy metals.



a

b

c

Figure 3. Examples of UXO dispersed around the storage due to explosion. Spectral samples of the UXO objects and litter, the soil and the vegetation shall be collected for the interpretation of the aerial hyper spectral images.

Figure 4. Detailed view of the part of the storage after the explosion.

III. Assement Of Explosion Danger Area

The undesired explosions of the ammunition storages happen often and only visual search and the manual detection are available for the assessment of the contamination distribution. There are several general references about the assessment of the status of the afflicted area after the undesired explosion, e.g. [3], [4], [5]. The wide area assessment for munitions response is considered in [6], bursting effect during detonation of explosive ordnances in [7], estimation of explosion danger areas in [8]. The principles and guidelines for the collection and destruction of collected ammunition are considered in [9], safety ammunition and explosives standards in [10], risk management principles and processes in [11]. Anyway, there is no available operationally applied airborne technology for wide area assessment of the unexploded ordnance litter at and around the storage after the explosion. The most similar problems, that have solution which could be interesting in our case are:

- the UXO detection at military test ranges, and
- the airborne hyper spectral assessment of the contamination with hazardous waste.

IV. Airborne Techniques For Detection Of Unexploded Ordnance In Military Test Ranges

The airborne wide area assessment of military test ranges, which were used for training the bombing, for testing the artillery, mortars and other weapons is a mature technology, although it is mainly based on the airborne magnetometers, Fig. 5, [12], [13], [14].

Figure 5. The sensitive magnetometer are used for UXO detection at the military test ranges from the helicopter flying very low.

Besides the magnetometers in the airborne methods are used LIDAR, stereo pairs of visible images for the detection craters of the explosion). The important issue are performance of statistical methods for UXO characterization and for wide area assessment, [13]. Since 2008 the airborne hyper spectral imaging sensors are in use, [16, pp. A-5 to A-6, A-11 to A12], [15, pp.3-37]. The airborne multisensor imaging was considered in several references, synthetic antenna radar (SAR) and hyper spectral airborne imaging were considered only in two or three references.

The browsing of the public references shows that there are no direct solutions for the considered problem: *the assessment of UXO litter distribution at and around the ammunition storage after the undesired explosion*. Among all relevant references about the airborne techniques for detection of unexploded ordnance and particulary of the detection by means of the hyper spectral remote sensing, two are the most suitable and usable, [12] and [15]. The difference of the spectral response between the targets (aerial bombs, cluster ammunition bombs, shells, mortar mines, missiles, their parts, crude fuel and its parts) and the soil and vegetation enables detection of the targets, Fig. 6. The receiver operating curve (ROC) of the airborne synthetic antenna radar data of UXO is improved if SAR data are fused with the hyper spectral data, [15].

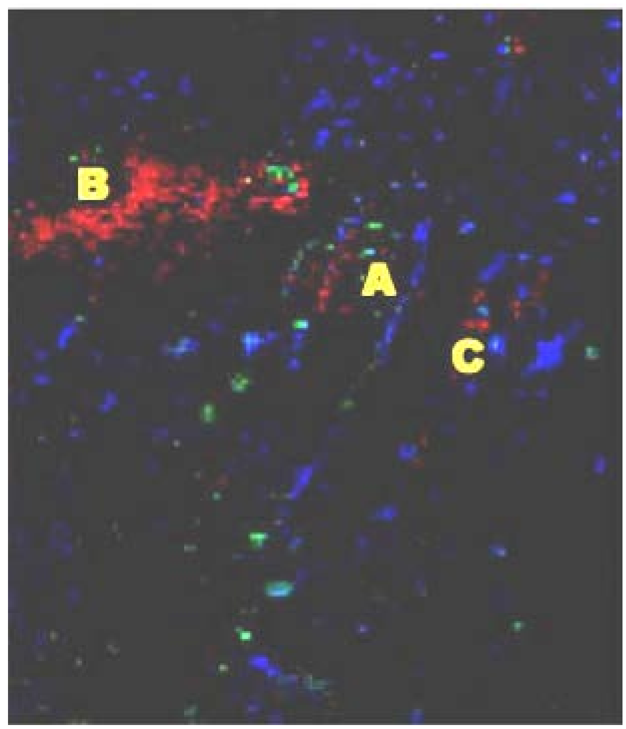


Figure 6. The spectral angle mapping classification of the hyper spectral images extracts: B – ferrous oxide, A – green vegetation, C – dry vegetation, [15, p. 21].

Besides civilian technology exist a military multisensor airborne system, MTADS, which provides detection of improvised explosive devices (IED) and UXO, [17].

V. Assessment Of Contamination By Hazardous Waste Through Airborne Hyperspectral Imagery

The assessment of the contamination by hazardous waste is developed technology in the USA, based on the16 airborne real-time cueing hyper spectral enhanced reconnaissance systems (ARCHER), [18], [19]. The hyper spectral aerial reconnaissance is applied in ARCHER also for search and rescue, disaster impact assessment and relief, and homeland security, besides for the hazardous waste assessment. The used hyper spectral technology is capable of detecting anomalies, and objects significantly different from the background in which they are located, can detect and find any object on the ground that match the spectral signature. This successful technology is very encouraging while it supports the basic assumption about possibility to assess spatial distribution of UXO litter after the explosion of the ammunition storage.

VI. Concept Of The Solution

HCR Center for testing, development and training Ltd Zagreb (www.ctro.hr) and Faculty of Geodesy University of Zagreb, Chair for Photogrammetry and Remote Sensing (www.geof.unizg.hr), Croatia, have the airborne hyper spectral and multisensor imagery acquisition system, [1], [2]. This system was developed and operationally used in humanitarian demining since 2008, due to very strong support of US Department of State via ITF[2], [20]. The experience from the humanitarian demining in Croatia (2008-2009), in Bosnia and Herzegovina (2009 – 2011) enables to match the system to the a new class of problems which appear in cases of undesired explosion of the ammunition storage. In the case of the humanitarian demining the targets are remains of the war at the mine suspected area (trenches, shelters, bunkers, etc.), and the fusion with contextual information, experts' knowledge is a key for the reconstruction of the mine field scene, [21]. The requirements in a case of the ammunition storage explosion is simpler, however the targets are smaller and the main problem is to provide high probability of the detection, locating, recognizing them. The technology that enables to perform new requirements combines [1]:

- very high spectral resolution (95 channels, from 430 nm to 900 nm) of the imaging hyper spectral sensor, with inertial positioning system and the parametric geocoding,
- very high spatial resolution, of the electro optical sensors (multisensor imaging) in the visible and in near infra red and in long wave infra red wavelengths.

The calibration of the radiometry of the hyper spectral imaging sensor has the crucial importance. Fig. 7 shows example of the pre-flight calibration, Fig. 8 shows objects used in the field to assist calibration. The reflection spectra measured in one airborne mission are shown on Fig. 9.

Figure 7. Pre-flight radiometric calibration. On the concrete surface is located Spectralon Multi-step target, SRT-MS-180[3].

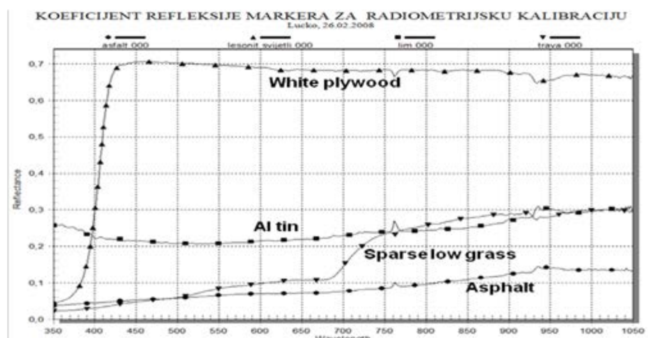


Figure 8. Spectral samples of the field objects measured on the ground by portable field spectro-radiometer FieldSpec®3 (ASD Inc., USA).

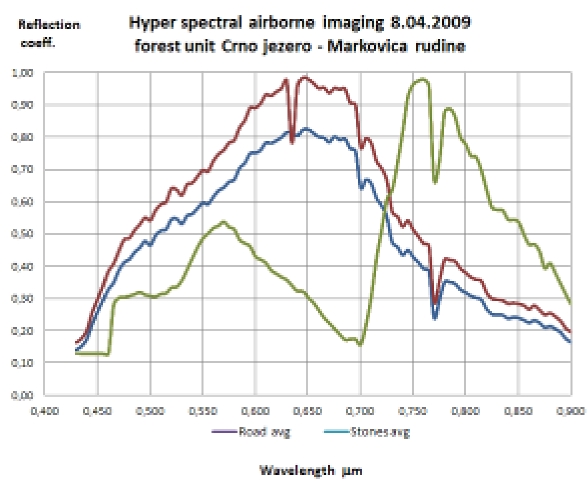


Figure 9. Spectral samples of stones, dirty road and the forest, measured 8.04.2009 from the airborne hyper spectral images.

[2] International Trust Fund to Enhance Human Security, www.itf-fund.si

[3] http://www.labsphere.com/products/reflectance-standards-and-targets/reflectance-targets/spectralon-targets.aspx

The spectral samples from Fig. 9 are used for spectral angle mapping (SAM) classification aimed to extract the dirty road and stones from the hyper spectral image of the forest unit named Crno jezero – Markovica rudine, near Gospic, Croatia. The dirty forest road is obscured by trees, the soil contains stones, nevertheless the spectra differ, Fig. 9, and it was detectd when the suitable treshold spectral angle was selected, Fig. 10.

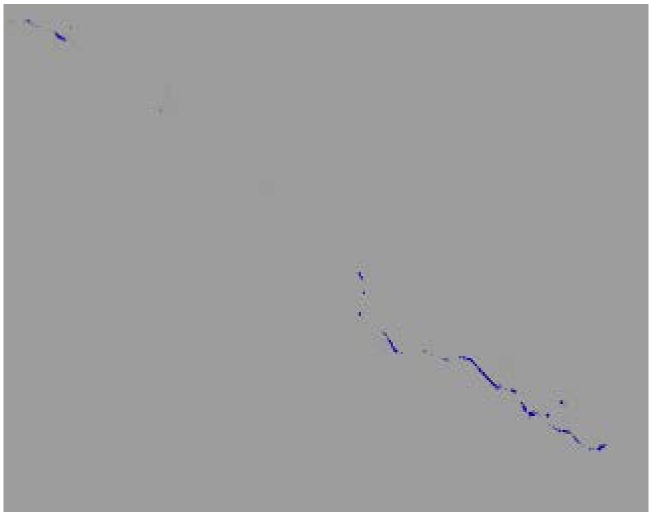


Figure 10. The dirty forest road (blue) was detected by 5,5 degrees angle threshold.

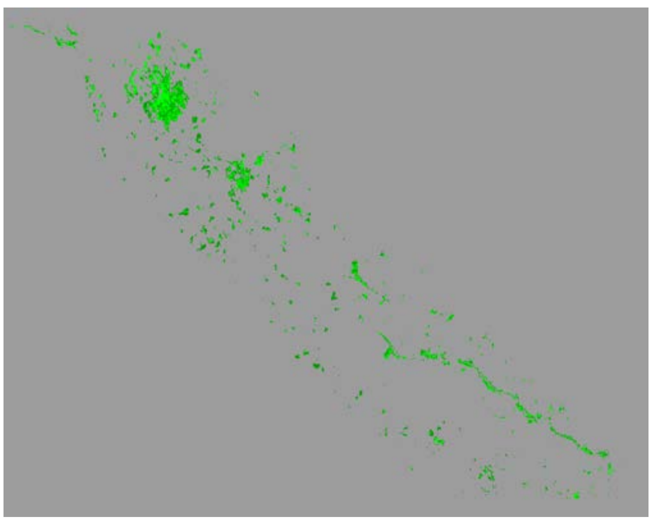


Figure 11. The stones (green) were detected by 7 degrees angle threshold.

Both, the layer of the dirty road and the layer of the stones were overlapped on the hyper spectral image Fig. 12. The image was visualized from following wavelengths: 760 nm – red, 650 nm – green, 570 nm – blue, usually named color infra red (CIR).

The ground resolving distance of the presented hyper spectral images was 1 m, while the spectral resolution was 4,9 nm. The spatial resolution for the survey of the exploded ammunition storage and its neighborhood should be changed.

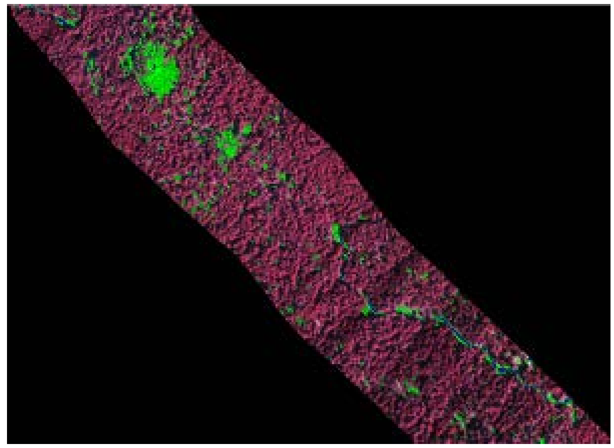


Figure 12. Layers of the dirty road and the stones shown on the CIR selection of the hyper spectral images.

The other sensors in the system are multispectral camera MS-4100, thermovision cameras (FLIR Photon, Agema THV-1000) and digital color camera. They acquire images in the same flight and conditions like the hyper spectral imaging sensor but with better spatial resolution. The dimensions of the smallest target determine altitude above terrain which enables imaging with needed spatial resolution and coverage, therefore the enabling required probability of the detection, recognizing in accordance to Johnson's criteria.

The multispectral sensor enables analysis of the vegetation stress due to the contamination and variety of indices can be derived and applied.

The high spectral resolution, the measured and collected spectral samples of the considered targets, soil, and vegetation, enable increase of the probability of the detection and recognizing. The fusion of the hyper spectral and multisensor imagery provides more then the sum of the results provided by each sensor separately.

VII. Plan Of Assumed Research

A. Phase 1 - Preparation

WP 1. Collecting the catalogue of photographies and data of unexploded ordnance (UXO), their parts, crude fuel and its parts, scattered due to the undesired explosion of the ammunition storage Padjene.
WP 2. Mesurement the representative spectral samples of UXO and remains, crude fuel and remains, at selected terrain, soil and vegetation locations.
WP 3. Matching the parameters of the airborne hyper spectral and multisensor imaging system to kinds of selected targets and their spectral samples.
WP 4. Training of the research team for technology of the airborne hyper spectral & multisensor assessment of the

UXO litter at and around ammunition storage after undesired explosion, spectrally matched to UXOs and their parts.

B. Phase 2 – Airborne and ground based data acquisition

WP 5. Prepare the samples of different UXO, their parts, crude fuel and parts, single samples and groups, for blind testing and the operational validation of the considered technology. Of course, the data and the locations shall be known only to commanding officer of Task force for recovery of Padjene.

WP 6. Airborne hyper spectral and multisensor imaging of the ammunition storage Padjene and the selected regions The triage and pre – processing of the acquired images, obligatory participation of the expert for the EOD.

C. Phase 3 – Processing, interpretation

WP 7. Processing and the interpretation of the acquired hyper spectral and multisensor imagery and calibrating data, while the satellite imagery could be useful.

WP 8. Analysis of the research results, evaluation of the achieved technical level of the considered technology. Operational validation of the technology by the blind test data. Obligatory participation of the expert for the EOD.

VIII. Testing, Evaluation, Operational Validation

The main goal of this research is to develop, test, evaluate and operationally validate technology for the airborne hyper spectral & multisensor assessment of the UXO litter at and around the ammunition storage after the undesired explosion, spectrally matched to UXOs and their parts, crude fuel and its parts at selected terrain, soil and vegetation.

The expected general result of the research should be technology for the wide area assessment of the UXO litter at and around ammunition storage after explosion, with determined operational parameters (smallest ammunition caliber, probability of detection, effectiveness of the hyper spectral imaging supported by spectral ground based samples, effectiveness of other electro-optical sensors, limiting influence of vegetation and soil). The airborne hyper spectral imaging should initially assess the chemical contamination at the area of the ammunition storage Padjene (the lead and mercury) and provide data for later correlation with ground based measurements after the recovery.

IX. Conclusion

The paper presents the basic background as it was prepared in October 2011 for the assumed research project.

Acknowledgment

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Proposal for construction of demining machines and trailers for the transport of dangerous goods carried out within the project TIRAMISU

Marcin Szczepaniak, Ph.D. Eng.; Wieslaw Jasiński MSc.

Abstract

The issue of work will be wide range and will cover both the destruction (by trawling), transport and storage of hazardous materials of various nature, including mines, unexploded ordnance, IEDs, ammunition and explosives. The proposed work will describe the issues related to hardware problems and the latest proposals of technical solutions related to the destruction, storage and transport of munitions. In the section on structural solutions will present information and ideas proposed two recent work related to the project TIRAMISU: modular demining machine, working by pressure, connected to a remote-controlled mobile support platform - for example: tractor of PIERRE and trailer for temporary storage and transport of explosives and munitions.

1. Family of Modular Vehicles for Road Reconnaissance and IED Disposal

Engagement of the Polish Armed Forces in stabilisation missions both in Afghanistan and in Iraq verifies the requirements of the post battlefield areas. One of the areas requiring equipment upgrade is the issue neutralizing and transport of antipersonel mines, UXO and submunition. That charges are characterized by diversified construction and using different explosives.

From 2010 year WITI leads a new project as System Modular Vehicles for Road Reconnaissance and IED Disposal.

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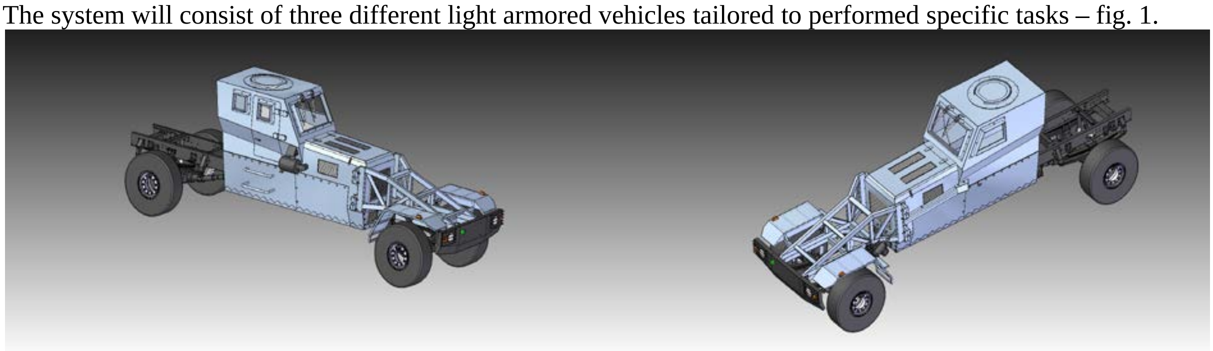

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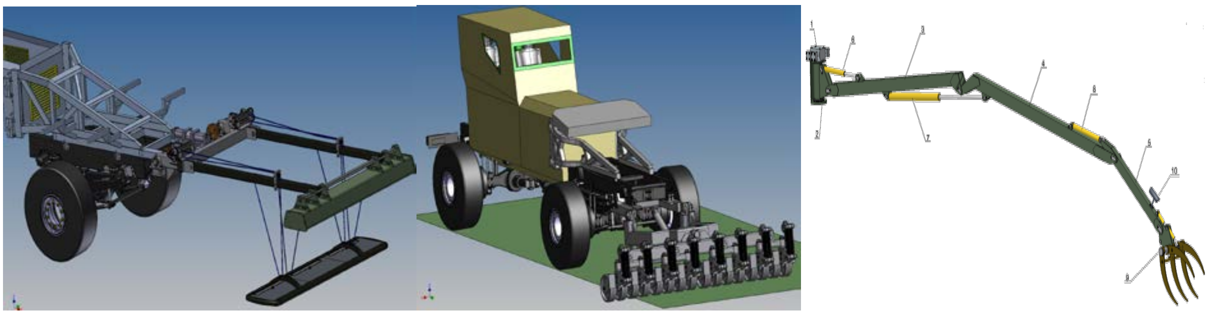

Fig.2. The equipment of a light vehicle: a multisensor detector (metal detector and GPR), a mine roller, an arm used to remove dangerous objects

Based on the experiences from construction of the system, we decided to create a new design of the modular demining machine, working by pressure, connected to a remote-controlled mobile support platform and trailer for temporary storage and transport of explosives and munitions

2. The modular demining machine

The Project is aimed at developing a state-of-the-art demining machine, working by pressure from polish national program, called SHIBA – fig.2. The modular demining machine, working by pressure, will be connected to a remote-controlled mobile support platform - for example: tractor of PIERRE.
Width of the device will be matched to the dimensions of the vehicle.

The modular demining machine – fig. 3, 4 – contains:

- protection kit (1, 2);
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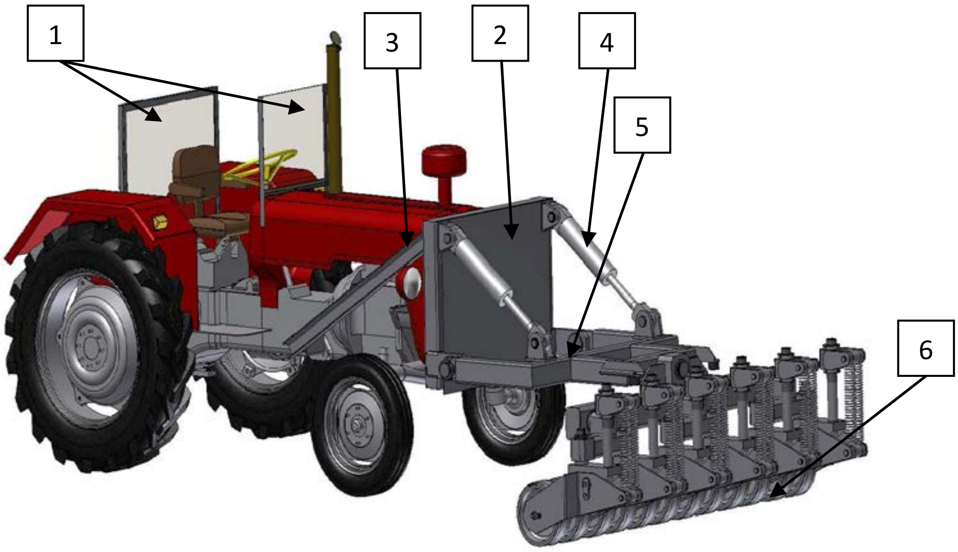

fig.3. The light modular demining machine, working by pressure with tractor – in working position

fig.4. The light modular demining machine, working by pressure with tractor – in transport

3. Trailer for temporary storage and transport of explosives and munitions

The aim of the project is to develop a idea storage and transport of explosives and munitions, extracted from areas at risk of post-war remnants – fig. 5, 6. The modular (demountable - exchangeable, composite structures

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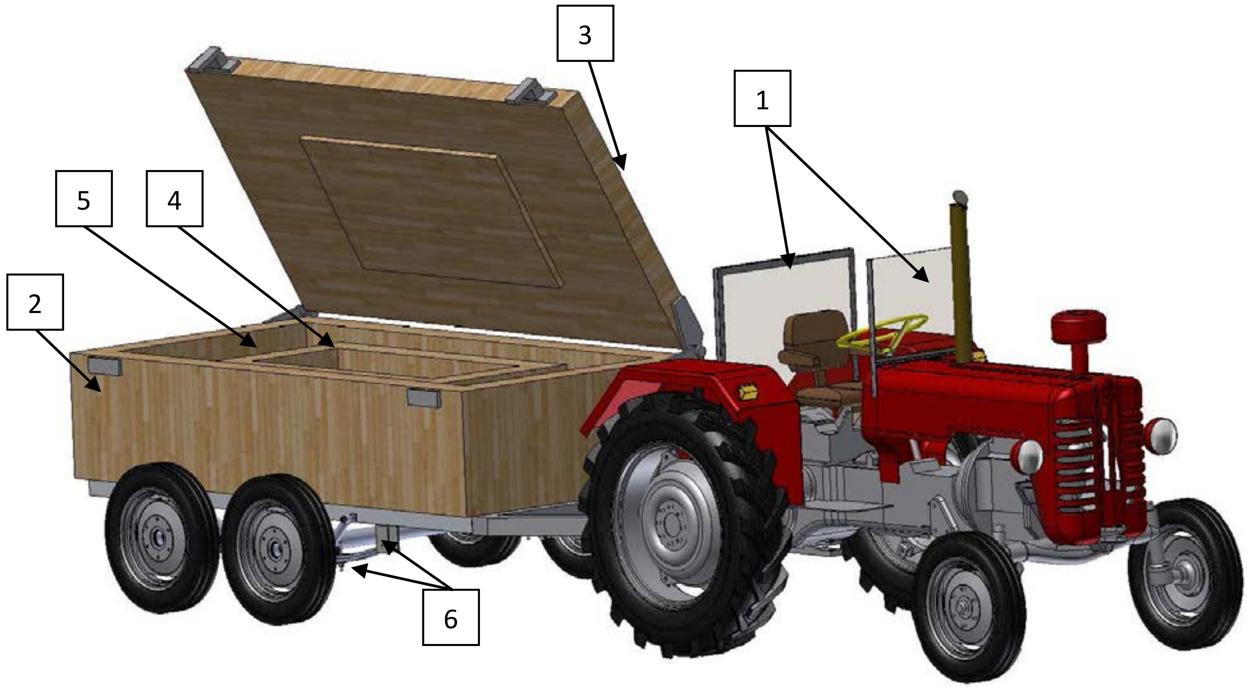


Fig.5. Trailer for temporary storage and transport of explosives and munitions – in open position

Fig.6. Trailer for temporary storage and transport of explosives and munitions – in closed position

4. The comprehensive set of trailer and demining machine

In order to maintain safe operation of the potential minefield is proposed to submit a set of two devices: the light modular demining machine and the trailer for temporary storage and transport of explosives – fig. 7, 8.

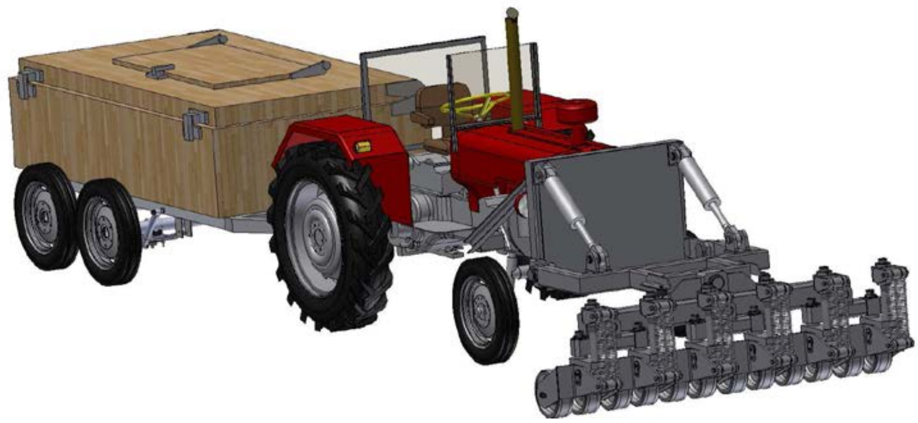
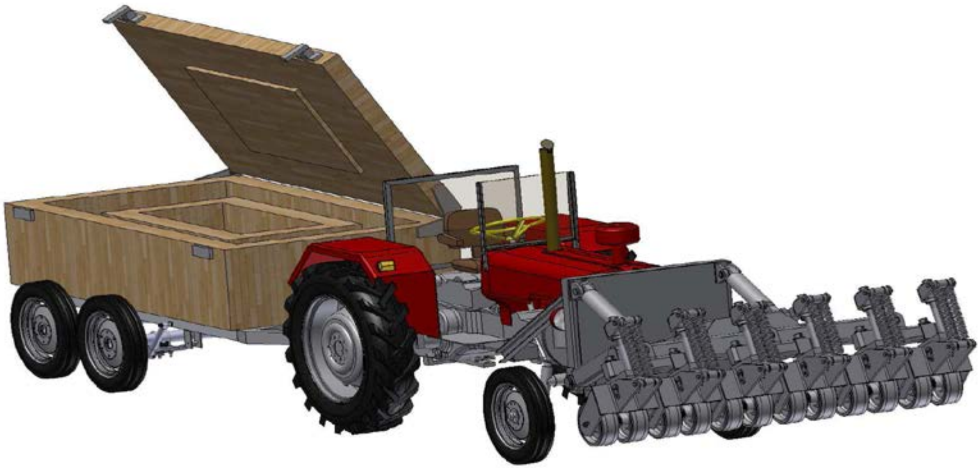


Fig.7. Trailer for temporary storage and transport of explosives with demining machine



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5. Conclusions

- In the project we'll establish the resistance of the demining machine to several hundred grams of explosive material (700 - 900 g).
- Weight at similar level assumes the maximum amount of explosive carried in the trailer for temporary storage and transport of explosives.
- In order to decrease of costs and increase of rebuilding the trailer after detonation of the explosive, barriers and housing are made of composite panels.

6. Acknowledgment

To the FP7 security Project TIRAMISU, GA 284747 which partially funds this research.

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Proposal for construction of demining machines and trailers for the transport of dangerous goods carried out within the project TIRAMISU

Marcin Szczepaniak, Ph.D. Eng.; Wieslaw Jasiński MSc.

Abstract

The issue of work will be wide range and will cover both the destruction (by trawling), transport and storage of hazardous materials of various nature, including mines, unexploded ordnance, IEDs, ammunition and explosives. The proposed work will describe the issues related to hardware problems and the latest proposals of technical solutions related to the destruction, storage and transport of munitions. In the section on structural solutions will present information and ideas proposed two recent work related to the project TIRAMISU: modular demining machine, working by pressure, connected to a remote-controlled mobile support platform - for example: tractor of PIERRE and trailer for temporary storage and transport of explosives and munitions.

1. Family of Modular Vehicles for Road Reconnaissance and IED Disposal

Engagement of the Polish Armed Forces in stabilisation missions both in Afghanistan and in Iraq verifies the requirements of the post battlefield areas. One of the areas requiring equipment upgrade is the issue neutralizing and transport of antipersonel mines, UXO and submunition. That charges are characterized by diversified construction and using different explosives.

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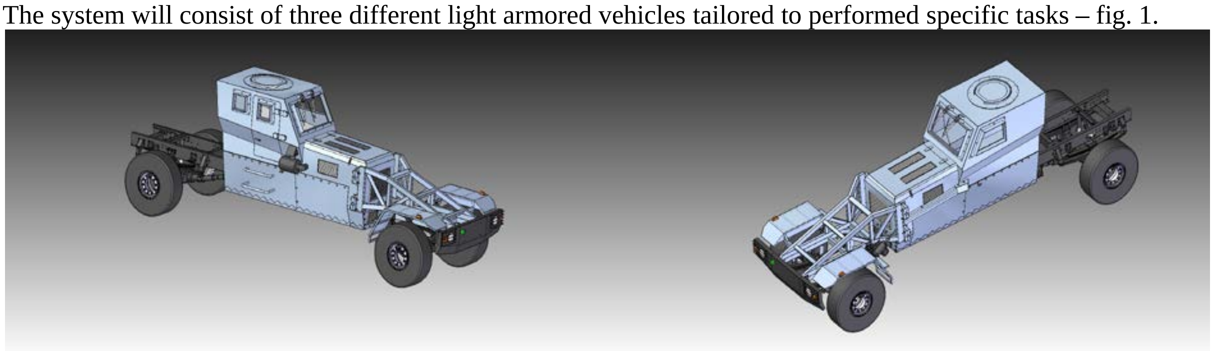
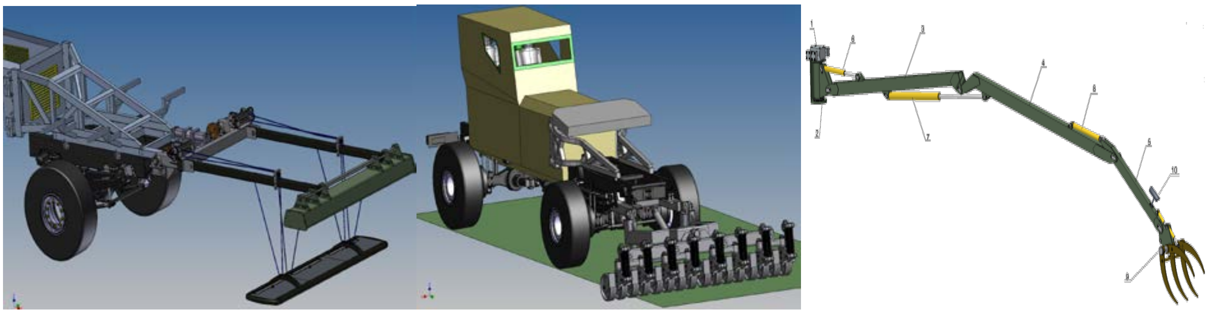


Fig.1. Light vehicle designed to specific tasks

The system allows detection, and most important: disposal and transport of mines, UXO, IEDs and explosive materials. Each vehicle of the system have its own dedicated equipment. The first in the group has a GPR [13] with metal detector, the second one – a mine flail, and the third one – a boom with manipulator to pick the detected object up – fig.2.



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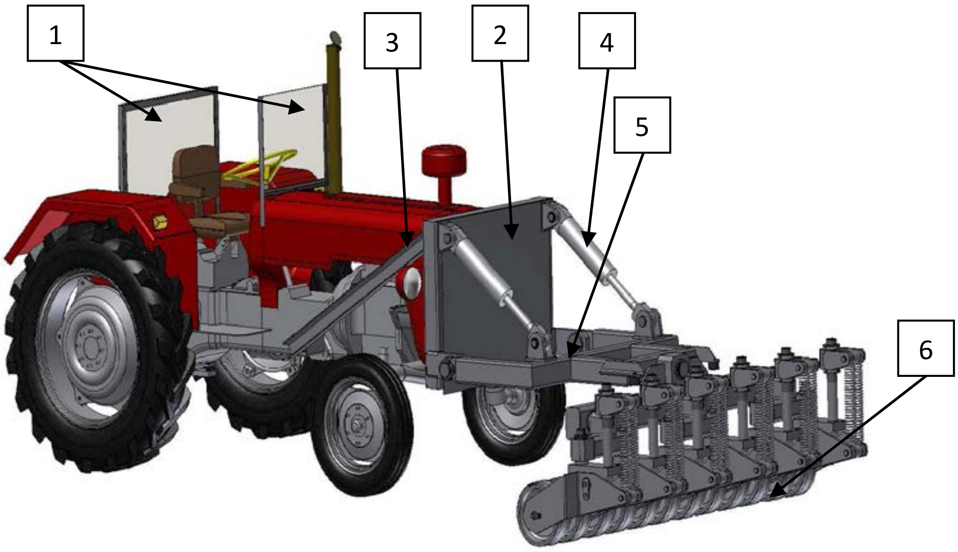

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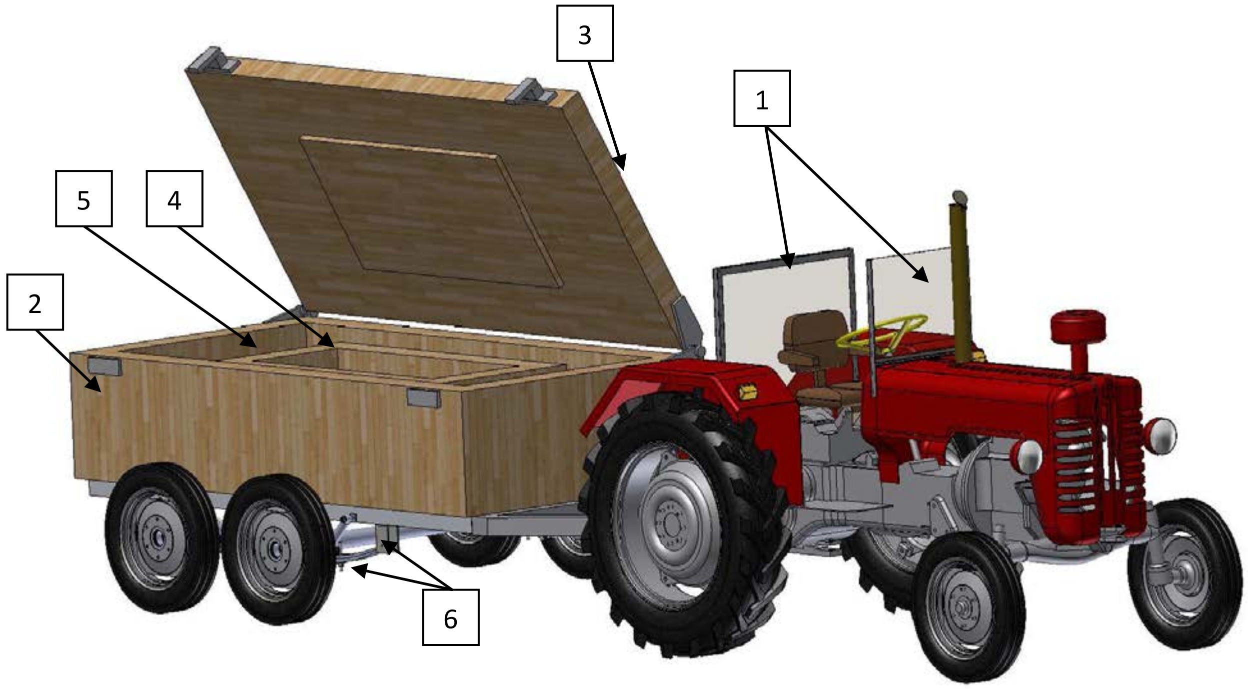

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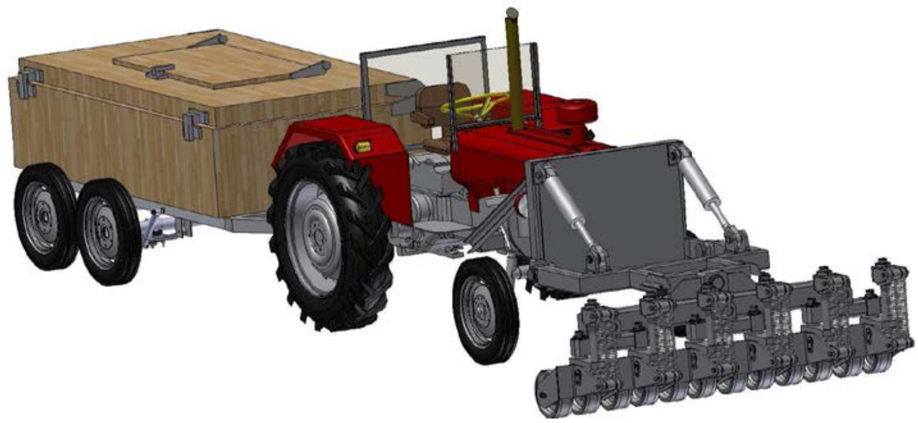

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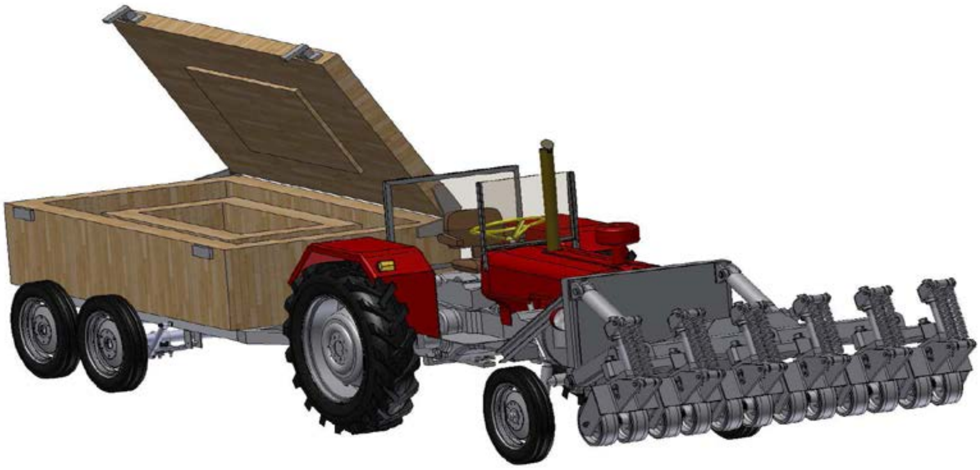

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First results: Robot mapping of sites contaminated by landmines and unexploded ordnance.

Kjeld Jensen[1], Leon B. Larsen[1], Kent S. Olsen[1], Jens Hansen[2], Rasmus N. Jørgensen[1]

Landmines and unexploded ordnance are a serious threat to the life and livelihood in post conflict areas in many parts of the world. In addition to the many casualties each year, the inaccessible roads and loss of cultivated areas have a significant impact on the local economy. Many organisations are running humanitarian demining projects to clear the contaminated sites. But progress is slow since mine clearance is a very time-consuming process, and there is no room for error since most existing techniques involves an operator on site. A number of research projects have demonstrated various mine detection robot prototypes during the past decade, yet robots do not seem to be utilized in practical humanitarian demining projects.

The Biosystems Engineering Group at the University of Southern Denmark collaborates with companies experienced in design of all-terrain vehicles and sensor technology to develop autonomous tool carriers for use in biological production applications. This article presents the first results applying this combined knowledge and experience to humanitarian demining.

The aim is to develop a low-cost, reliable, efficient and user-friendly robot capable of detecting and mapping landmines. It is hypothesized that with the exception of very inaccessible terrain an autonomous robot will be more efficient and reliable for mapping detected landmines than manual methods using the same sensor technology. At the same time it does not expose the operator to the risk of harm.

This paper presents the first results from the project. The existing robot platform design has been simplified to lower cost and allow repair in the field with limited tools and spare parts. The robot will be able to utilize various mine detection implements and support different detection methods simultaneously. The FroboMind architecture based on Robot Operating System (ROS) is used for robot control. Software components will be released as open-source for others to build upon.

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An overview of GIS-based Multi-Criteria Analysis of priority selection in humanitarian demining

Nenad Mladineo[1], **Snjezana Knezic**[2], **Marko Mladineo**[3]

Abstract

This paper demonstrates how an application of GIS-based Multi-Criteria Analysis could be efficiently used to support humanitarian demining operations and restoration of mine-contaminated areas. The financial shortage usually triggers a need for priority setting in the mine removal process. This overview validates GIS-based Multi Criteria Analysis (MCA) as capable tool for priority setting within mine action management. A combination of GIS analysis and a multicriteria method is applied to set humanitarian demining priorities in order to optimally reduce the risk caused by mines. GIS is outlined as a powerful tool for aggregation of information used in multicriteria analysis. It is also shown that coupled GIS-MCA model is very efficient tool for both functional connection between hierarchic decision levels and determination of the objective priorities. Besides GIS-based MCA for priority setting the paper will also demonstrate a development of Web&GIS-based MCA. By functional integration with web, priority setting process become fully transparent since stakeholders and donors are able to actively join decision making process using on-line web application.

1. Introduction

In Croatia, over the past ten years, a priority setting using Multi-Criteria Analysis (MCA) coupled with GIS has been deployed in mine-action management (Mladineo&Knezic, 2003). A multi-criteria approach gives an opportunity for stakeholders to express their needs and requirements through a set of criteria. Therefore, the methodology provides full transparency of decision data (Benini et al, 2003), visible to all stakeholders, so that anyone who is either directly involved in Mine Action process or affected by landmines could follow the process. Priority setting (Van Der Merwe, 2003) should be used to ensure that the limited resources of a mine action programme can have the greatest possible impact in each planning cycle on the socio-economic blockages caused by landmines. The application of MCA tools to the decision making process has been widely recognised (De Leeneer&Pastijin, 2002; Jankowski, 1995) for its utility in offering fundamental help for the decision maker in the presence of possibly conflicting targets.

While using MCA two problems have been noticed. The first one refers to the size and scope of either minefields or mine suspected areas, so they could be mutually comparable. A result from comparison process is priority rank for mine clearance. Each minefield is an action in MCA having its own rank in relation to defined criteria. Second problem relates to the fact that each decision level demands different criteria set, as well as to the fact that demining process on different land cover areas (water, woodlands, etc.) needs distinctive criteria. Experience in the application of MCA resulted in GIS-based Decision Support System (DSS) which comprehend different decision levels and land cover areas.

2. Methodology

The proposed GIS-based DSS for risk management in mine-affected supports multi-level approach (Knezic&Mladineo, 2006): for each problem level, a specific procedure for criteria and action (solution) evaluation is developed (Figure 1). At each decision level a separate set of actions (projects for humanitarian demining of socio-political entities, such as counties, municipalities, villages, mine fields, homogenous areas, etc.) is created by GIS, and evaluated by applying multicriteria analysis (Mladineo et al, 2003).

At strategic level counties, regions, districts or, alternatively, homogenous zones defined as parts of territories with common characteristics, make up a set of actions being evaluated by multicriteria analysis. Actions are ranked according to the humanitarian demining priorities. At the tactical level, the problem should be treated at regional level, so municipalities, urban areas or similar homogenous zones make up a logical set of actions. The criteria that could be concerned are assembled in four basic groups, as follows:

- Terrain characteristics and infrastructure
- Economic impact of mine clearance,
- Social welfare,
- Land-mine risk reduction.

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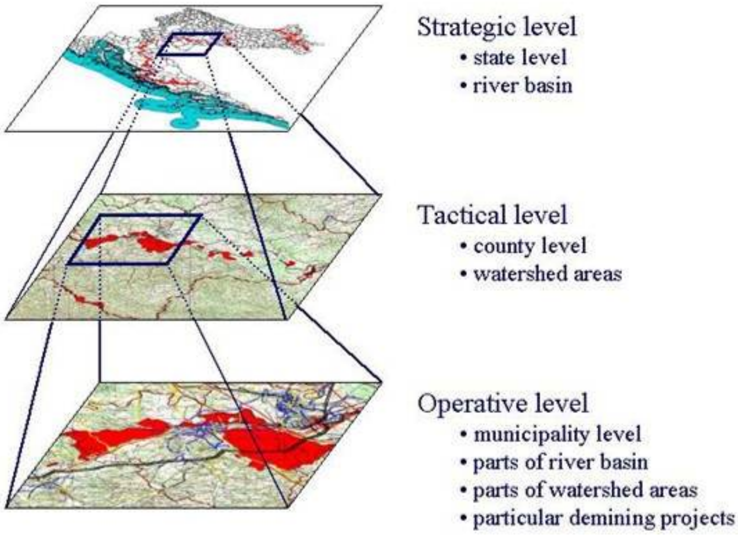

Figure 1: Hierarchic approach in humanitarian demining operations (example for water resources) (Knezic&Mladineo, 2006)

At the operational level, problems should be treated with respect to humanitarian demining projects, mine fields, selection of humanitarian demining company and technological support, etc., and particular criteria for each multicriteria evaluation has to be developed. For each decision level, a team of experts has to make the criteria set more detailed, by co-coordinating it with the demands characteristic of that particular level and with relevant stakeholders.

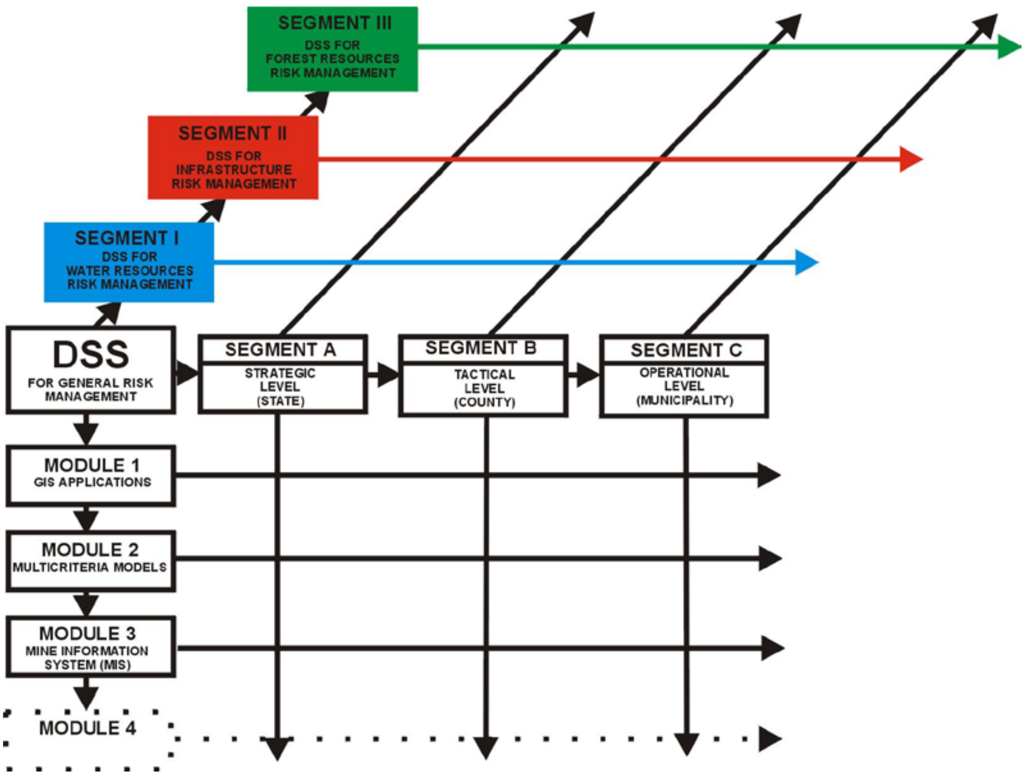

Figure 2: Structural layout of DSS for humanitarian demining operations (Knezic&Mladineo, 2006)

The hierarchic approach is very useful because, at each level, it makes distribution of money for the humanitarian demining of mine-affected counties easier by simulating results attained from multicriteria analysis.

Conceptualized DSS (Knezic&Mladineo, 2006) shown on Figure 2 consists of segments related to the hierarchic structure of DSS. Modules are related to both data and model bases. The database is based on GIS for general data, which contains topological, social, land-mine risk and economic data. In addition, the mine information system (MIS), functions as the central tool for mine risk-management. The model base, besides other models and various spatial operations, includes multicriteria models necessary for particular assessments and prioritizations. This approach avoids very expensive and sometimes imprecise terrain surveys, and at the same time enables very simple visual control of the parameters used.

3. Development of GIS-based MCA Web Application

Since several stakeholders, usually dislocated, are included in the priority setting process a new Web based GIS application has been developed. The application couples GIS thematic layers and MCA making it accessible via friendly user interface to different stakeholders. Consequently, priority setting has become fully transparent since stakeholders and donors are able to actively join decision making process using on-line web application.

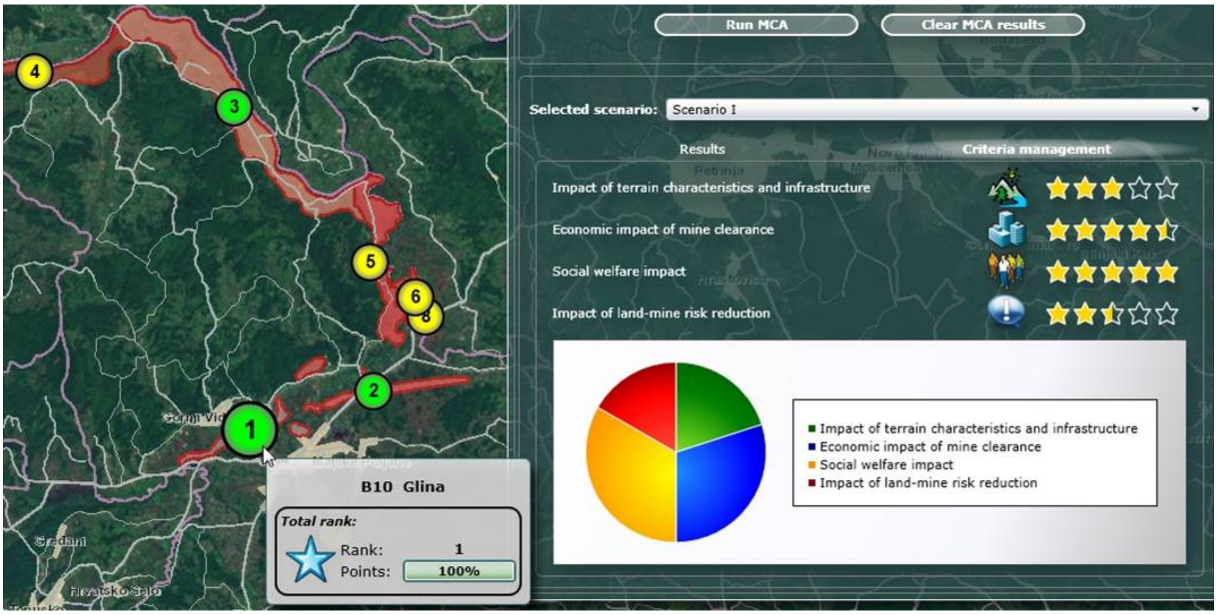

Figure 3: Display of results of Multicriteria Analysis for criteria weights predefined by "Scenario I"

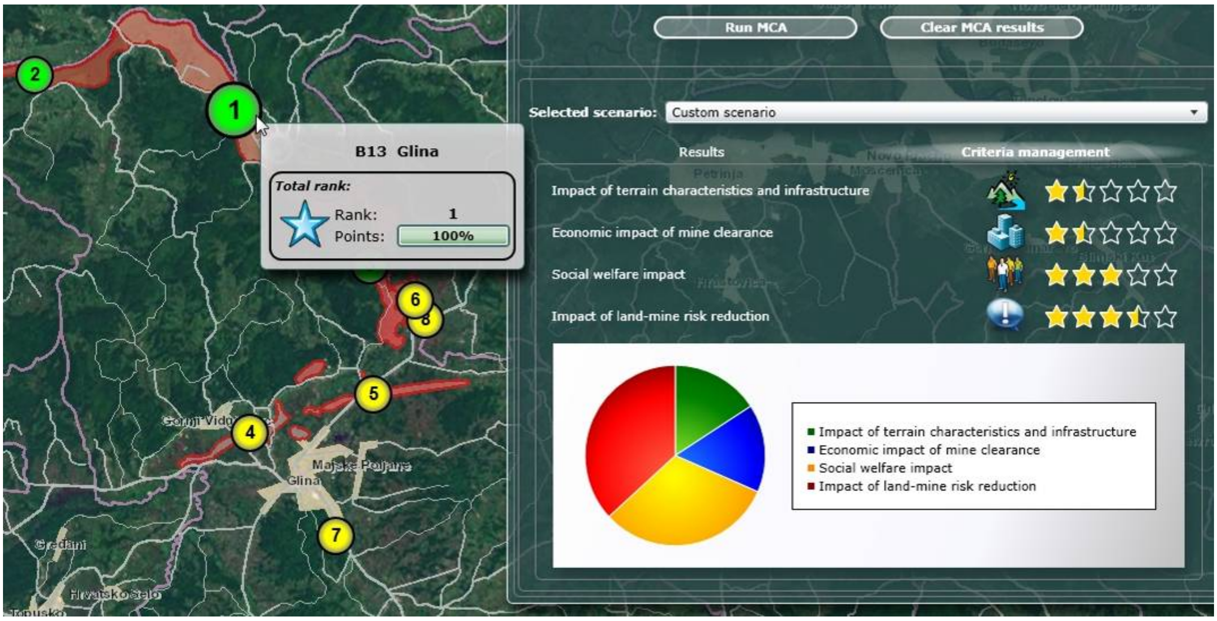

Figure 4: Display of results of Multicriteria Analysis for custom defined criteria weights ("Custom scenario")

Figures 3 and 4 show an example of priority setting in a municipality of Sisacko-moslavacka County. Weights of criteria groups could be easily changed on-line with automatic update of MCA results. The results of Multicriteria Analysis (MCA) are displayed in multiple ways: on a chart that represents PROMETHEE II output (Brans et al, 1984; Marinoni, 2005), on a map by placing a rank number on each suspected minefield, and on a suspected minefield 's "map tip" with details about each suspected minefield's rank.

By scenario selection a decision stakeholder attitude is transferred into MCA. On Figure 3 a predefined "Scenario I" has a greater weights of criteria groups "Social welfare" and "Economic impact of mine clearance". On Figure 4 a "Custom scenario" is used, in which greatest weight have criteria group "Land-mine risk reduction". Change of criteria weights affected ranks. Initially, 1st rank had suspected minefield "B10 Glina" (Figure 3), but after change of scenario 1st rank has suspected minefield "B13 Glina" (Figure 4). And the other ranks were also affected.

4. Conclusion

Mine action management often deals with limited funds, and thus requires efficient tools for the establishment of mine clearance priorities. Between the "small" farmers, whose backyards are contaminated, and county and community councils, forums and representatives, there are several levels that are directly or indirectly exposed to mine accident risks. All of them, more or less, expect that their problem should be treated as the priority one, so their involvement in the decision-making process lowers tensions and significantly reduces frustrations that may result from the prolongation of the problem solving process. This paper demonstrated how to easily include several stakeholders in decision process of priority selection in humanitarian demining. A new Web based GIS application has been developed. The application couples GIS thematic layers and MCA via friendly user interface. The further research will be based on defining of predefined scenarios and designing forms for MCA data input.

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