Robotics Assistance by Risky Interventions: Needs and Realistic Solutions

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1. Introduction

According to the International Advanced Robotics Program (IARP– www.iarp-robotics.org), the Advanced Robots, while somewhat difficult to define precisely, have one or more of the following characteristics: to be able to sense and adapt to their environment , to be mobile , to operate in harsh, demanding or dangerous conditions or environments, to operate in non-manufacturing applications such as space, underwater, nuclear, tunnels, agriculture, medical and healthcare, civil engineering and construction, intelligent manufacturing, fire fighting and emergency rescue operations, services, domestic applications and personal robotics.

Navigating intelligently in an unstructured unknown environment while accomplishing useful tasks is not a trivial problem and many aspects have not been completely solved by the scientific community. A complex mission cannot be simply solved by assembling disparate components and hoping that they will seamlessly cooperate to achieve the mission.

Two risky applications have been considered in the Robotics activities of the RMA: the Fire-fighting operations when dangerous products may affect the safe work of fire-fighters, through the participation to a European project called 'View-Finder' (https://www.view-finder-project.eu) , the CBRN-E threats (including the de-mining operations on fields where AP-mines or sub-munitions have been laid or buried.

2. Objectives and requirements

2.1. CBRN-E

The scenario of a terror attack using mass destruction and non conventional warheads is today a major concern of Europe. A device including CBRN-E (Chemical, Biological, Radiological, Nuclear agents and Explosives) agents may be found before its activation. It is widely accepted that such a scenario will be possible in the near future. In such a scenario it may happen that the device is not yet activated and Special Forces are required to give an immediate response**.** Most of these devices will contain only explosive warheads, but some chemical projectiles, which were left during and after WWI are still around in Middle Europe countries. The current technology of neutralization of munitions is based on remote manual operation, which is a very demanding and dangerous activity, since the human operator is assumed to remember technical details of thousands of possible treats. The innovative technologies should thus include a computer based device localization and identification, the development of an intelligent Command, Communication and Control station, where new sensors and human supervised autonomous control enables a distant intelligent robot to perform its task with maximum available knowledge; precise manipulation and world wide technical support in order to maximize the probabilities to successfully complete the task to neutralize a terrifying device. Some described activities are realized with the volunteered support of the Belgian relevant expert units (DOVO and DLD).

The next figure illustrates the missions devoted to the DOVO (Defense Unit for EOD Explosive ordnance disposal, IEDD, Improvised explosive device detection), including humanitarian de-mining operations, over the world:

MISSIONS ABROAD

BELBAT : 92 - 97
UNTAES : 96 - 98

PROVIDE COMFORT : 91

BOSNIA ROAD : 92 - 94
BELBOS : 94 - 94
BELUGA : 96 - 97
BELU BG : 98 - 00
Explosive winter : 03
Armadillo : 04

LAOS : 98 – 2005
1 Offr + 1 NCO

CMAC : 94 – 2004

KOSOVO : 99 - ...
2NCO + 1 B4

AFOR : 99

AFGHANISTAN : 08/04 – 02/05

GENIMED : 01

RESTORE HOPE / UNOSOM : 92 - 93

GREEN STREAM : 97

KIGALI : 86 – 86
UNAMIR : 93 - 94

AVENIR : 04

2.2. Fire-fighting

The objective of the 'View-Finder' project is to develop and use advanced robotics systems, equipped with a wide array of sensors and cameras, to explore a crisis ground in order to understand and reconstruct the investigated scene and thus to improve the decision making. To reach its goals, the project should define and develop an open, flexible and generic information tool which will allow the decision makers and the emergency workers in the field to take the right decisions in an efficient and effective way.

The entire View-Finder system should be a complete semi-autonomous organism, composed of two on place high level conceptual entities communicating with each other: the robots and the Control Operation Centre (COC).

The key appliances of the system are the robots which are designed to navigate on an individual or cooperative but semi-autonomously base within a crisis area. The purpose is to gather chemical and visual data of a zone which might be inaccessible for men. The COC is the local operations centre, located nearby the emergency ground, and can be considered as a decentralized command post of the permanent crisis centre. It is staffed with crisis managers

and technicians and combines : (1) a Base Station (BS) The BS is the main control station from which operators, which are specialists in robot control, manage the robots by giving them high-level instructions. By doing this, they monitor the intervention of the robots. This means that they can renew task assignments or detail tasks of an individual robot.

Besides the monitoring duty, the operators will also be trained to interpret the raw data gathered from the sensors, which they will send to the COC; (2) a Crisis Management Information System (CMIS) The CMIS is the nerve centre of the COC. It is a local access point of information to the crisis coordination services in the COC, enabling real-time coordination of the View-Finder robot data with higher level information and

crisis coordination decisions, coming from the Permanent Coordination Centre, which can be found on a national or either regional level.The next figure summarizes the global system:
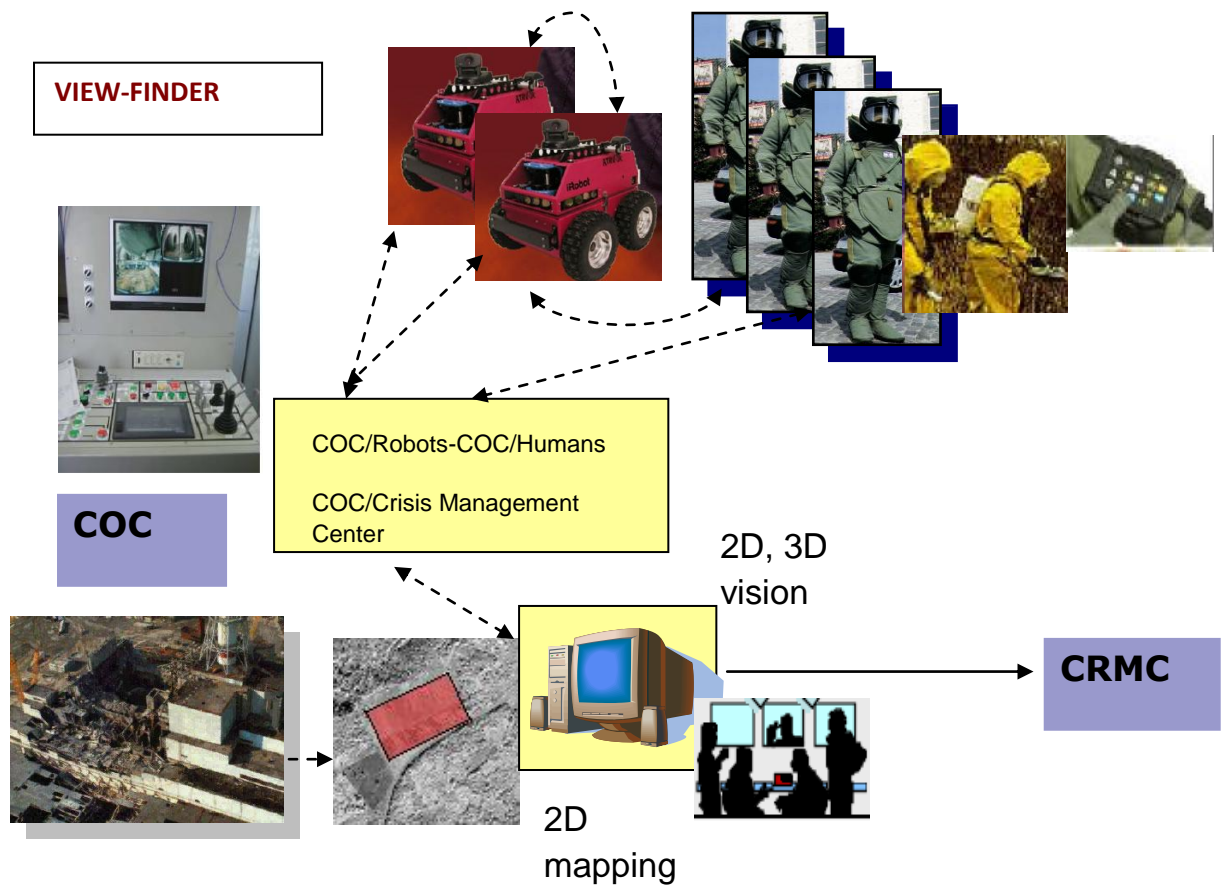
2.3. Humanitarian De-mining

The mines have been used for the first time during the American Civil War in the United States (1861-1865). Antitank (ATK) mines were later ameliorated and laid on the battlefields of the First World War: the mine-clearing operations didn't pose major problems with those visible or easy-to-detect ATK-mines, reason why Anti-personal mines have been conceived and systematically used on the ATK minefields during the Second World War: such mines prevented the enemy from easy de-mining of the defence system. But the Anti-personal mines are today more and more used as offensive weapons and for sowing the terror among the civilian population of a country affected by guerrilla war: the marking of the minefield does no more exist and the Anti-personal mines, often buried in the ground, remain active after the war: about 60 millions AP-mines infest today 70 countries all over the world, two-third of them in Africa and South-East Asia...AP mines of the Second World War still exist in all the countries of Europe...45 countries are today assisted by the above mentioned European Assistance, namely Afghanistan, Albania, Angola, Armenia, Azerbaijan, Belarus, Burundi, Cambodia,Chile, Colombia, Croatia, Cyprus, DRC, Ecuador, Eritrea, Ethiopia, Georgia, Guinea-Bissau, Honduras, Indonesia, Iraq, Jordan, Kosovo, Kyrgyzstan, Laos, Lebanon, Mozambique, Myanmar, Nepal, Nicaragua, Peru, Russia, Senegal, Serbia, Somalia, Sri Lanka, Sudan, Tajikistan, Tunisia, Uganda, Ukraine, Venezuela, Vietnam, Yemen. This list obviously evolves with new signing parties

Mines dans le monde
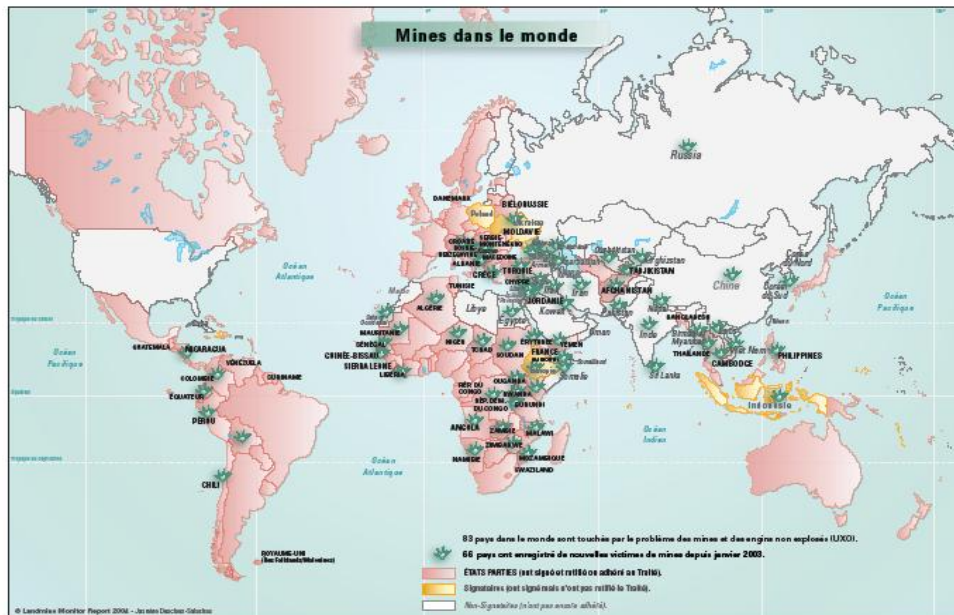
Two definitions coexist: according to the military standards, an AP-mine is a pyrotechnic instrument developed for being activated by an involuntary action of the enemy in order to set him out-of-fighting. According to the Civil Right, an AP-mine is some object placed on or under the ground or any surface, conceived for exploding by the simple fact of the presence, the proximity or the contact of a person or a vehicle. On a general way, two models of mines exist: the blasting mines and the fragmenting ones: more then 700 known types of mines have been produced in about 55 countries, varying each from other by the explosive-load, the activation mean, the action-range, the effects they have on the human body, etc. The next Figure shows a sample of AP mines

Since 1975, the mines have killed more than one million people, essentially civilian people and children: about 70 victims per day or 26.000 victims per year, about 300.000 severely disabled children. The people affected by this plague are these ones who less support the medical, social and economical consequences: the ICRC (International Committee of the Red Cross) estimates that 2/3 of the surviving victims must get into debt for life, a life expanse reduced to 40 to 50 year: they will need about 20 prosthesis's and will pay about 120 euros each , that in countries where the individual mean income varies from 10 to 25 euros per month: crutches are often the only tool they may pay for walking

2.4. Requirements

The requirements defined in the above projects require many advanced capabilities. The robot has to autonomously travel between assigned waypoints while collecting information with a gas or a CBRN-E detection sensor. While the goal appears simple it is not and actually requires following capabilities:

2.4.1. CBRN-E and Fire-Fighting Assistance:

Reliable self location estimation
The estimation of the robot position is realized by a Visual Simultaneous Location and Mapping system that integrates data from several sensors: GPS, Inertial Navigation System, odometer and images from a monocular camera. This solution provides accuracy and reliability by combining information from different sources.

Detection and avoidance of obstacles
The environment perception mainly relies on artificial vision. Several concurrent processing are based on images:
- Motion augmented stereo-vision that provides superior results compared to the classical method
- Terrain Traversability estimation to discriminate passable and non passable ground
- Fast automatic human victim detection.
- Possible neutralization, destruction or removal of a suspected package

Mixed control
The robot can be remotely controlled by an operator (normal procedure) or be tasked to automatically move between waypoints. The Behavior based control architecture integrates both control modes with automatic navigation and vision modules.

Integration of distributed processes
All the previous capabilities have been implemented with the CORBA based framework CoRoBA developed at the Royal Military Academy. Communication between processes running on board of the robot or on the Base Station is simplified by the architecture of this framework that has been explicitly tailored to Robotics applications [1]

Virtual environment for training and simulation
Operator's skill can be trained in a virtual environment that reproduces typical intervention scenario. A second advantage concerns mission debriefing and analyses. Offline processing of environment data collected during the missions allows the automatic reconstruction of the environment and the motions of a mission. This 3D reconstruction approach is based on dense structure from motion recovery from images. The 3D model can be imported in a 3D simulator for testing alternative procedures.

Disaster Management Action Plan and crisis management information system
In emergencies, crisis managers and emergency workers are very often faced with the information -paradox". Whilst information tends to be scarce in the early stages of a crisis, the responsible and intervening personnel will be overloaded with information during the latter stages. This state of duality can lead to information not being appropriately considered and analyzed, to poor distribution and integration of information, and consequently, to the risk of poor decision making.
Therefore, it is very important that, during each stage of a crisis, all involved managers and emergency workers dispose of the correct information at the right moment, so they can intervene in an efficient and effective manner. Consequently, one of the major challenges is adequate dissemination of information; top-down as much as bottom-up. [2]

2.4.2. Humanitarian de-mining

Several workshops, a.o. organised by the European Network CLAWAR (Climbing and Walking Robots and associated Technologies, now became the CLAWAR Association Ltd) and the IARP (International Advanced Robotics Programme) allowed discussions on the possible R&D activities for solving the problem(s): robotic systems are not (yet) felt today as the most promising solutions, due to their high cost, the use and maintenance difficulties, the varying (daily changing) terrain conditions, etc. However, specific tasks could be entrusted to mechanical mine disposal systems (or, if efficient, roboticized sensor-carriers):

1) the cutting of the vegetation : this is a mechanical (Tele-operated or not) assistance that doesn't need high level research activities, but adaptation of existing mobile cutters: one may consult the repertory of the GICHD
2) the mine-clearance of large agricultural areas: a detailed and recommended study has been managed by Håvard Bach, Head of Operational Methods Section (GICHD, 2004).
3) the detection tasks in very dense and dangerous areas (woody areas, mountain,..that constitute about 53 % of the infested areas) : such tasks could imply the realisation of specific robots, for instance multi-legged robots, a difficult long-term challenge
4) the delineation of the borders of a suspected area : task that could be entrusted to aerial tools : the EU encouraged several R&D projects focusing on this task
5) the systematic scanning of a zone : priority to the manual de-mining with enhanced multi-sensor-heads, but also assistance by mobile robotics systems on request (safety)
6) the inspection of an area after manual de-mining or mechanical clearance

More than or about 53 % of the minefields are un-structured (terrain) minefields in uneasy accessible areas: they are located in the South-East Asian Countries (Laos, Cambodia) and in South and Central Africa. Some of them are also located near destroyed villages or cities in European Countries (Kosovo, Bosnia) . Focusing on this kind of minefields (and thus avoiding the use of simple commercial vehicles (only road access or easy terrain) and avoiding the pure mechanical mine-clearance efficient in the other cases), we may underline some first advantages of light-weight modular low-cost robots:

1) **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, will allow the mapping (terrain modelling AND mine localisation) of large areas with the same (or better) efficiency (than this one of the Human de-miners) but improved safety. Dogs (and drawbacks of their use) may also be replaced by RMV (remote controled vehicles): the standard de-mining procedures would be applied with smaller intervalles between the scanned corridors (speed increase). The next picture illustrates the actual standard manual scanning procedure
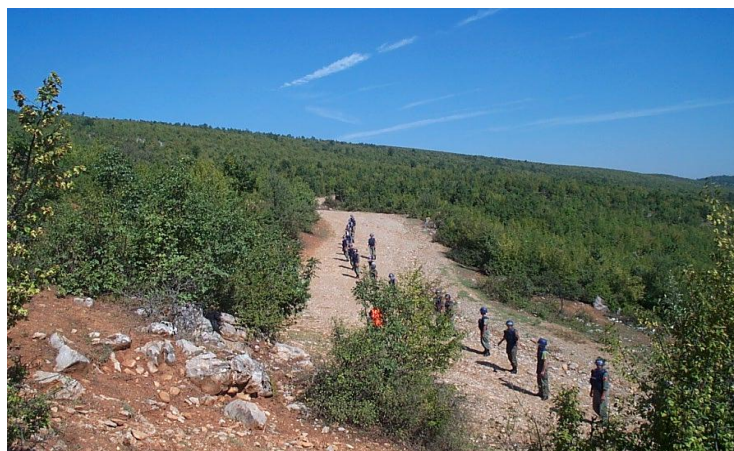
KPC Kosovo: parallel scanning with metal-detector

Corridor (1m large) Dulje Pas Area - Kosovo   *Area delineation Dulje Pas - Kosovo*

2) **improvement of the 'productivity' of Human De-miners** (example of better productivity: larger areas inspected with same number of H.D) Indeed, due to their (relative) inexperience, fatigue , lack of attention and fear, Human de-miners are progressing very slow (less than 100 m² in difficult areas) Replacing them by a sliding robot moving step by step (or another kind of robot according to the local constraints) could allow the reinforcement of other teams of Human De-miners, necessary where no any robot may access to)

3) **progressive implementation of High-Level/Low-Level Scanning procedures**. As long as aerial detections don't give precise and reliable information, the combination of aerial detection information and terrestrial scanning remain necessary: it is nevertheless excluded to ask human de-miners to take into account with the 'aerial maps' for changing their scanning drills (corridor per corridor) while a mobile robot (or better, several mobile robots) could 'navigate' according to well-known HL/LL strategies (path-planning methodes). Such navigations could increase the efficiency of the detection tasks.

4) **multi-Tooling of a mobile robot**: even if a performing hand-held multi-sensors could increase the efficiency of the detection by decreasing the FAR (false alarm ratio) , no doubt that the same de-miner cannot detect, mark and neutralize the mine at the same time: the 'manipulation of several tools' in a dangerous surface has already lead to accidents (loss of equilibrium, lack of protection during the pose of markers, etc..): a multi-tool arm may equip a robot allowing the cutting, the scanning, the laying of a marker or the spreading of a chemical neutralizer

5) **multi-robotics , multiple locomotion means**: in a same area, one can envisage the possibility to combine several kinds of robots according to the terrain: multi-legged, wheeled and tracked, working under supervision of Controllers while Human de-miners could focus on the unreachable areas.

6) **development of DUAL USE systems**: one of the problems of the HUDEM technologies lies in the fact that the development of specific systems (robots) are not industrially rentable: the development of techniques combining the sensory AND the robotics may be extrapolated to several applications and thus enhance the industrial interest. Examples are:
   - 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/holding missions)

Those technical challenges have defined the Research and Development activities of our Robotics Lab of the department of Mechanical Engineering. It was first necessary to correctly try to define the basic requirements of such developments (par 7). However, before designing mobile robots, a survey of the mechanical mine-clearers was also felt as necessary and our IARP workshops combined scientific lectures and on-the-field demonstrations. As an example, demonstrations have been organised by our Japanese colleagues during the 6th IARP Workshop in Tokyo, 2005

3. Behaviour based Robot control (View-finder Project)

The next figure illustrates the general robot control architecture [3]. The ROBUDEM robot used in this setup features 2 on-board processing stations, one for low-level motor control (SYNDEX Robot Controller), and another one for all the high-level functions. A remote robot control PC is used to control the robot and to visualize the robot measurements (color images, victim data) from a safe distance. All data transfer between modules occurs via TCP and UDP-based connections, relying on the CORBA and COROBA [1] protocols. The wireless link from the on-board high-level PC to the remote robot control PC is set up via a Wi-Fi connection. The robot is equipped with four main sensing abilities: a stereo vision system, a GPS system, an orientation sensor and a sonar array. All the modalities discussed above are encompassed in a behavior based framework. We will now discuss the structure of this global control architecture, depicted in the Figure, by explaining the different components from left to right.

To begin, the remote human operator disposes of a joystick controller, which enables him to steer the robot, when in Tele-operation mode. For safety reasons, the wireless connection of the robot to its base station is continuously polled by a connection checker. As such, the robot is ordered to stop or to return to the base station when the wireless connection has been lost.

The information coming from the sonar array is used by a fuzzy-logic based obstacle avoidance behavior which steers the robot away from obstacles detected by the ultrasonic sensors.
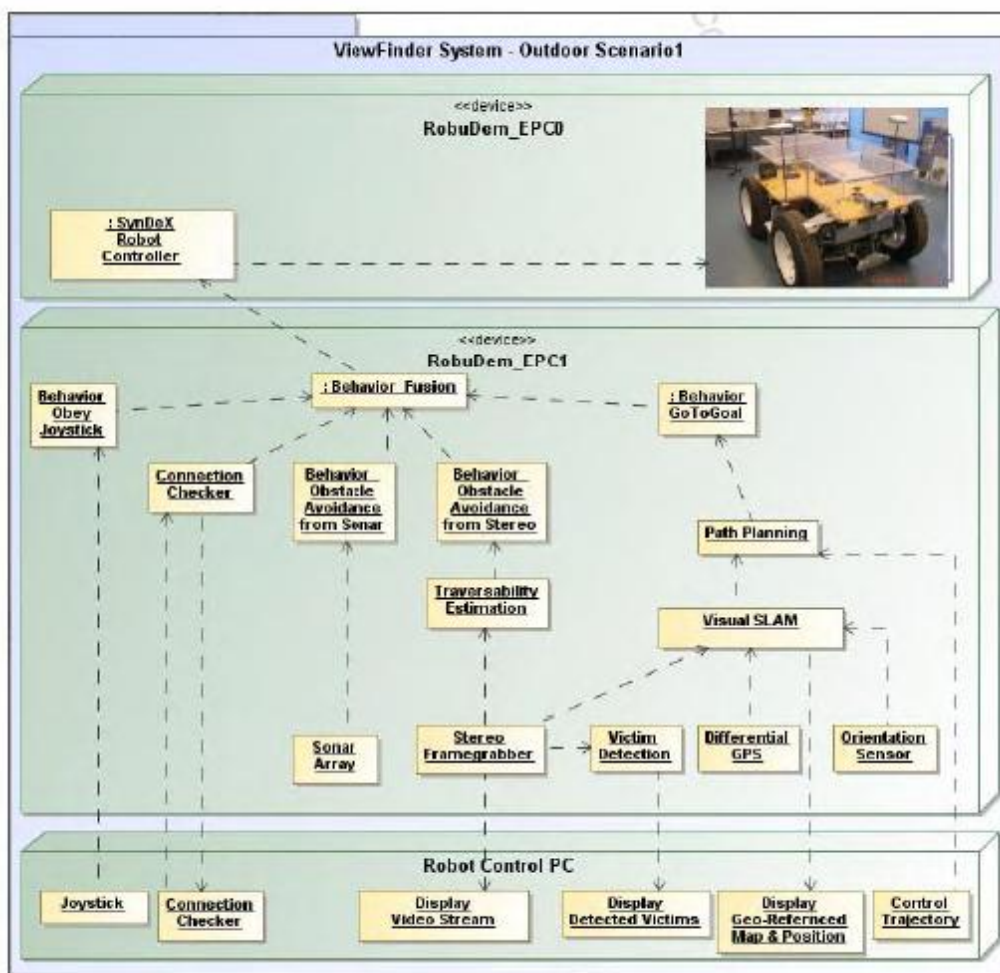
The information from the stereo vision system is used threefold:

1. The color images are sent over the wireless link, such that the human operator receives at all time a visual cue of the environment. This is absolutely necessary when the robot is operating under tele-operation mode.

2. The (left) color image is sent to a victim detection module. This module incorporates a vision-based human victim detector (adapted Viola-Jones algorithm [4] The victim detection module will report any detected human victims back to the human operator at the remote control station.

3. The calculated stereo disparity image is sent to a terrain Traversability estimation module. This module incorporates a stereo-based terrain Traversability analysis algorithm, generating a map of obstacles. From the obstacle map, a behavior is constructed to steer the robot away from these obstacles. [5]

A Visual Simultaneous Localization and Mapping processor takes as input information coming from different sensors: odometry, GPS, orientation sensor, prior map data (if present) and a color camera. From this information, the V-SLAM module builds a map of the environment while localizing itself in that map. This geo-referenced spatial information is sent to the remote station and is also used by a path planning module. From the robot control station, the human operator is able to compile a list of waypoints for the robot. The path planning module compares this list of waypoints with the robot position and calculates a trajectory to steer the robot to the goal positions in the list. The first point on this trajectory list is sent to a *GoToGoal* behavior module, which aims to steer the robot to this point, as such executing the trajectory defined by the path planner.

A Behavior Fusion processor takes as input the objective functions of the different behaviors and fuses this information to come to one consistent and globally optimal command to be executed by the robot. These objective functions are multi-dimensional functions which reflect the preference of each behavior for each type of possible actions.

The presented behavior-based control methodology was implemented on the robot, using the COROBA [1] software architecture platform. The experimental validation of the presented technique was performed by doing field tests, evaluating the performance of all subsystems and of the robotic system as a whole. The next figure shows the ROBUDEM robot during one of these field tests (post- aircraft- crash management – see Wikipedia video View-Finder)


4.   Dense Motion augmented stereo-vision (View-Finder project)

The next figure shows the results of our developed dense motion-augmented stereo estimation algorithm [5]. By comparing the disparity estimation result of the developed methodology, as presented by Figure (d) to the result of the classical stereo approach, without the presented augmentations, it becomes immediately evident that the proposed methodology outputs superior results compared to the classical method. The disparity map as estimated by our method presents no disturbing holes, the depth gradient of the ground plane is well-visible, the 2 obstacles on the ground can also be easily discerned on the disparity map, and even the building, which is very far away, can be distinguished on the disparity map of Figure (b). On the disparity map from pure stereo, as presented by Figure (c), on the other hand, there is only a very limited depth resolution, many holes are present in the disparity map, and only the big obstacle on the left can really be distinguished. It is thus clear that the presented methodology outputs disparity maps which are not only visually better, but also better suited for post processing, e.g. for terrain Traversability estimation.

The processing time required to estimate a dense depth map using the presented methodology is about 1 second, which is still reasonable for near-real time applications and it is to be expected that in the near future,

with the constant increase in processing power, the calculation time will go down substantially, allowing full real-time operation.

a) Left Image   b) Right Image

c) Disparity Map from Pure Stereo   d) Disparity Map from Dense Stereo + Motion
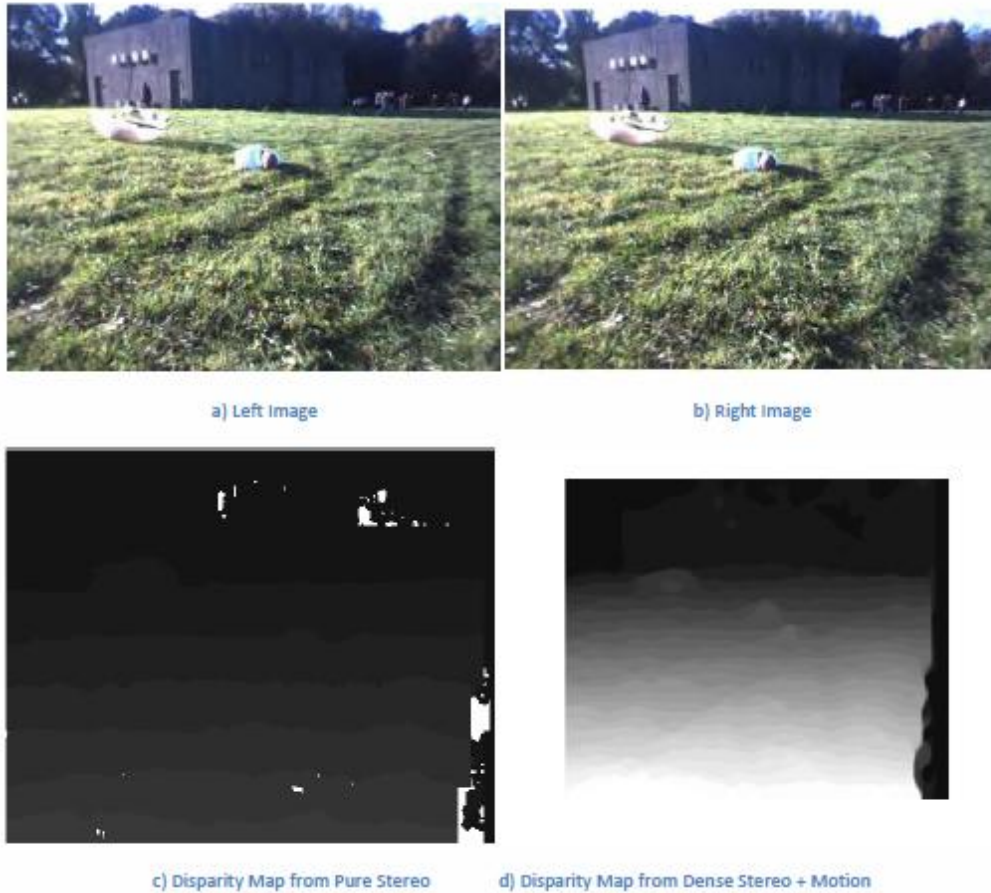
5. CBRN-E Project

Our project, derived from the results of the View-Finder one, also suggests developing a specially designed neutralization robot with mobility and manipulation capabilities that is controlled from a remote supervisor station. This robot will be able to identify suspicious terrorist devices in urban environments (streets, squares, gardens, train/metro stations, airports, etc). It is assumed that neutralization will be required in an urban scenario that may include some typical urban Traversability difficulties like stairs, slopes, debris, and similar objects [6]. However, it may require operating also in environments like power plants, storage tanks areas, etc. We ideally opt for an omni-directional robot [7]

This robotics system should include:

    a. Sensors for IED with CBR(N)-E content.
    b. Mobile platform carrying onboard sensor packages, robotic systems (manipulators, rovers), localization [8] and communication subsystems [1].
    c. Manipulators for data gathering and neutralizing effects in the Red Zone.
    d. (Mini)-Rovers that carry samples from the RED (danger) to the GREEN (safe) zone .
    e. The Command and Control station.

All these subsystems will continue to be subject to extensive research activities. The sensors packages for IED with CBRN-E content are major tools for neutralization of terrorist devices. They will reside inside a mechanical device which provides appropriate protection, have fast locking/unlocking connectors, and will be in a well defined position that is easy to reach by the operators. They will be handled by the operators to investigate the suspicious target. More sensors will be used to assess the overall neutralization task, to improve overall detection capabilities, to launch alarms, to control the robot subsystems and to monitor the whole system behavior. Project partners (DOVO and DLD) have extensive experience in sensors for IED with CBR(N)-E.

The **mobile robot platform (MRP)** performs a major innovative neutralization task: it will permit remote IED and it will provide a safe envelope for the sensory heads and all other onboard equipments. All the samples of volatiles and dust particles, which were gathered by the special tools with the help of the operators, will be inserted into small containers and delivered to the green zone by means of the small rovers to be analyzed in a mobile lab. In general, onboard analysis will be avoided because this will increase the complexity and size of the MRP. Nevertheless, there will be "first alarm" sensors and even more complex ones (for example some biological, radiological and radioactive meters) when their size, technical characteristics and associated cost will allow it. The mobile robot platform will be able to move in urban environment covering all the required working positions. It will enable the operators to fulfill their tasks using manipulators capable of reaching their targets of interest. DGPS will allow fine positioning of the MRP [8]. A sufficient power will be necessary to all onboard subsystems and will allow greater autonomy at maximum performance than similar current systems. A third major subsystem comprises **a dual manipulator system** for gathering data and to perform neutralizing effects in the Red Zone. Each manipulator will be designed to handle the sensor payloads plus other necessary tools for demolishment of the device (laser, plasma or mechanical cutting, spraying nozzle for decontamination, grippers, etc.). Both Tele-operation and robotic modes (including playback of recorded sequences) could be used. Handling and reach capability of manipulators will be decided according to the weight of payloads and to the operational requirements and specifications. State-of-the-art force feedback capabilities will be incorporated to facilitate remote interaction and careful manipulation around sensible targets. Materials (first approach indicates stainless steel) and design (example using pressurized inert gas inside) of manipulators will allow external decontamination and re-usability of most components.
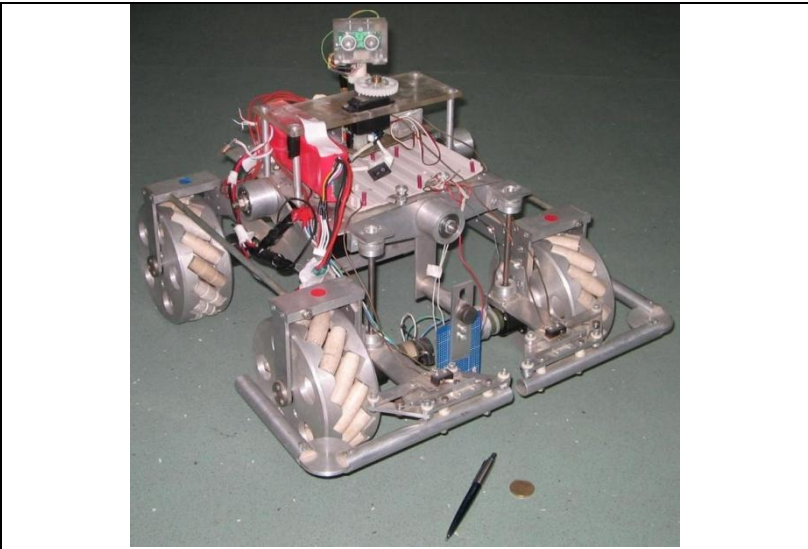
First Lab Omni-directional robot (Technical University of Iasi – I.Doroftei) for study of kinematical and dynamical properties

The fourth major subsystem of the proposed methodology consists in using **two small rovers (PIONNEER types)**. Their mission is to transfer samples from the red to the green zone across the Contamination Reduction Area (CRA). This will prevent the MRP to go back and forth between the red and the green areas. This optimizes its use and saves vital time. We shall consider use of at least two rovers to allow one of them to operate in the red zone while the other is transporting samples or is being decontaminated. Rovers will be powered by small size, low energy consumption batteries. For the project purposes, adaptation of existing rovers with the required new characteristics can be a good strategy. Remote control from the Command and Control Station will simplify its operation.

6. Robotics for Humanitarian de-mining Projects (1997-2007)

It is necessary to identify which are low key technologies and which are the higher ones, in order to take into account the development time scales required to bring to maturity the newer technologies - some of these may be up to ten years away from maturity.

The reliability of the equipment to detect and neutralise mines will need to be specified in Quality Assurance (QA) terms e.g 99.9% clearance guarantee. The European Joint Research Centre in Italy has first published some quantified standards against which application trials should be measured. The ITEP (International Test and Evaluation Program – www.itep.ws) pursues today the same objective through dedicated tasks. Measurement and pinpointing accuracy will need to be defined. It is suggested that the limit on this as a benchmark could be a quarter of the diameter of the smallest AP mine, say 10-15mm resolution. As a result the robot will need to be able to carry a marking work package and a means of communicating its position in the minefield. Accuracy of +/- 1 cm would be ideal.

The environment will play a large part in determining the attributes or characteristics of the Robotics equipment. In fact it is unlikely that a multi-purpose, single machine will be developed that will cope with all forms of environment. The environmental issues fall into various categories and equipment operation will need to be defined as desirable or mandatory under these conditions. Main environmental characteristics that need to be taken into account are:

- Weather eg temperature, snow, ice, frost, rain, wind, humidity .
- Terrain, e.g., urban - street, inside buildings; rural - desert, rocky, heavy vegetation, possible water scenarios.

Payload assessment must take into account two factors, expectations based on current engineering capability and those desired for the future, although the latter may be quite impractical at the present time. However, from knowledge of the various sensor systems being considered, a payload in the range 5-15kg is likely.

Various mechanism types are being considered. There is a need to concentrate on scenarios where tracked and wheeled vehicles will be unable to carry out the de-mining task. The likely configuration will therefore be a light-weight, articulated legged walker able to clamber over rough terrain, cross ditches, walk through heavy vegetation without disturbing it and hidden trip wires, climb steep slopes, etc. It will also have sufficient degrees of freedom of its body with respect to its legs to deliver sensor work packages and marking devices, probably on a boom or manipulator to difficult to access positions, accurately.

The actuation method is unclear. Electric motor driven joints seems the most likely although pneumatics should not be ruled out. Either way, the power requirements of the vehicle are likely to exceed significantly those of the work package. Use of an umbilical, although possible, will seriously degrade the operational scope of the vehicle so suitable on-board power devices may be required. The weight of battery packs or motors for producing compressed air is significant and a balance between functionality and mission length may be hard to achieve. Soft pneumatic muscle actuators may provide some solution since, weight-for-weight, they are able to provide much higher power for lower pressure than pneumatic cylinders. In the short term, the use of an umbilical may be necessary whilst suitable on-board power technology is found.

Motion control will need to be highly sophisticated. General motion in difficult terrain will need advanced adaptive gait control such as is being developed at present in various research centres. Closely controlled motion will be required to deliver sensor packages to accurate positions when detection is in progress. The motion of the vehicle will demand by far the highest power requirements. Whilst some scenarios will allow the use of an umbilical, many will need more autonomy so an on-board power supply will be needed. Thus efficiency of motion will be most important, requiring advanced control algorithms. 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 will have a man-in-the-loop operation and there will be a direct line of sight operation at a safe distance. This safe distance will have to be specified and as will 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 will have to be considered. It is likely that at least two fixed or one rotational camera will need to be fitted to the vehicle to give all round viewing during operation. Operator control units can be fitted to display single or multi-image options. The communication link might be a 1.4 GHz video link as used in the systems for Grand Prix F1 racing. 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 will also be 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. There is little likelihood that pure climbers will be required. Assuming that the friction of its feet to the ground is sufficient to provide the traction required, then provided the vehicle has the motive power to operate on steep inclines by modification of its gait, then a walker is sufficient. 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 walker will need to carry several kg of work packages; a selection from vision cameras, IR cameras, GPR, UWBR, metal detectors, chemical sensors and other more advanced detectors. Some may need to be held on a boom arm or manipulator. The machine will need to be able to traverse rough ground without operator intervention so a high degree of gait "intelligence" is required. Since ground conditions will vary considerably within mission, it will need to be able to sense ground condition and adjust its gait in-mission. It will need to be able to hold detectors in a pre-determined relationship to the ground contour and to control delicate prodding movements.

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.

Some such machines may need to be specified so that they can operate fully submerged in shallow seawater.

6.1. Our realistic solutions.

Conventional vehicle-mounted mine detector systems employ an array of sensors elements to achieve a detection swath typically 2~4m wide maximum . Some systems employ more than one type of sensor technology. These systems, while being very useful are often expensive, unsafe, complex and inflexible. The IARP workshops have on the contrary shown that the use of Robotics Systems (Remote controlled vehicles) 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 appear in next figures . (Nonami, 2005) (Fukushima, 2005) (Fukuda, 2005), (Dorofteï, 2007).

a. Gryphon-IV remote manoeuvring experiment., Tokyo Institute of technology, JP	b. Mine detection robot ROBUDEM – Royal Military Academy (RMA, BEL)	c. Mine Hunter Vehicle, equipped with a teleoperated hydraulic manipulator, Chiba University, JP

SLIDING ROBOT: a first strategy we suggested to start with consisted into the use of a step-by-step motion of a multi-legged electro-pneumatic sliding robot equipped with a 3D scanning device:, namely a metal-detector : the robot AMRU-4 was designed and demonstrated in 1997 on a dummy minefield laid at the RMA.

LEGGED ROBOT: the major drawback of this first sliding robot lies in the fact that it may not be used on irregular terrains. As a consequence, I decided to build an electrical six-legged robot. The first prototype was also ready by 1997, but again actuated by pneumatic linear and rotative cylinders and thus constrained by a feeding umbilicus (AMRU-2).
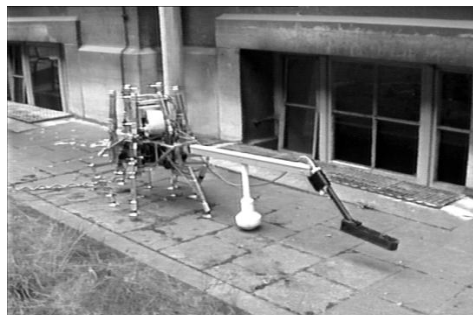
We then decided to build an electrical six-legged robot, AMRU-5.

Building a walking robot requires more expertise than a simple programming. The robot designers must own a compendium of basic skills from fields such as mechanical engineering, electrical engineering, computer science, automatic control and artificial intelligence. On the other hand, they must be able to identify the real needs, to create original ideas, to provide feasible designs, to consider environmental effects, and to come up with reliable devices, products, systems with expected performance and with reasonable costs. The main aim of these designers is to develop a machine that would satisfy at best the needs, would be economic, and would have the best technical and operational characteristics.
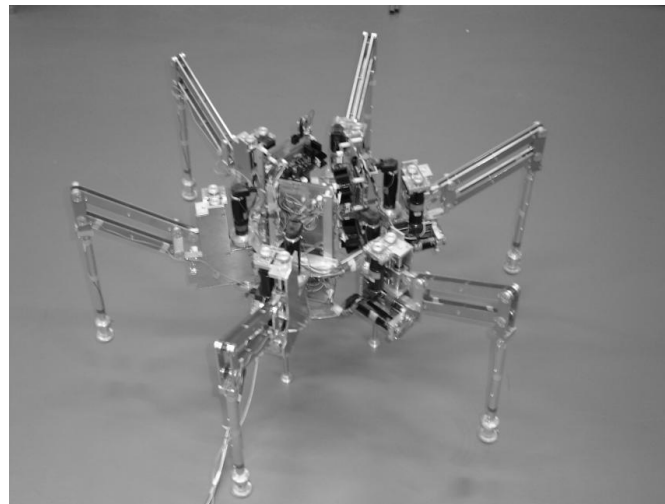

Very often, it is hard to reach requirements at the first attempt. Therefore, an iterative procedure has been continuously applied on our tentative design with the intention to reach these requirements.
Many walking robots are controlled using the hierarchical approach or a part of it except on robots where:

- A simple control ("bang-bang" or on-off control) is implemented and all possible sequences of the states of the robots are determined in advance. This was the case of the first previous described AMRU-4 and AMRU-2
- Alternative or advanced approaches are implemented such as the hybrid architecture (obtained by introducing reactive behaviors in a hierarchical approach).

Almost all proposed architectures based on the hierarchical control are the same. They differ in terms but the idea remains the same. We have considered the architecture shown in next Figure proposed by M.J. Randall and A.G. Pipe [10].
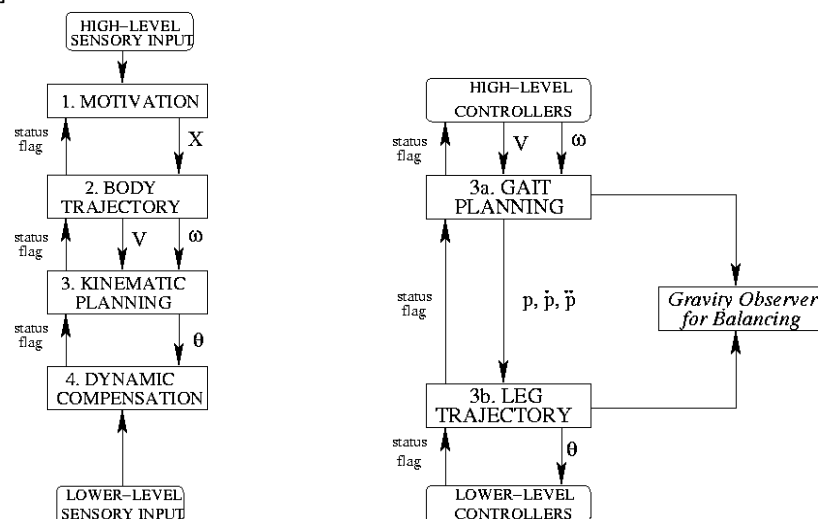
- The first and the highest level is the *motivation*. For a walking robot used in mine clearance, for example, the motivation could be "find a mine" by means of high level sensors such as metal detector, Ground Penetrating Radar (GPR), video images, etc.

- The second level is the *body route generation*. When the goal to attain is known, this level must establish an appropriate body centred trajectory. This is done by converting the high level command (find a mine, for example) into a velocity vector V and an angular velocity vector ω, for the body centred frame.

- The third level is the *kinematic planning* which involves two sub-levels namely the *gait planning* and the *leg trajectory generation* shown in Figure 6. The gait is a walking pattern and it can be defined by phase differences between the legs during their motion. At this level, the phases between the legs are determined, and also the stroke of the legs endpoint, are determined.

- At the fourth and the lowest level, named *dynamic compensation*, the target joint space vectors are turned into actuator signals. This level minimizes errors between the target vectors and the actual position of the joints.

TRACKED ROBOT: Beside the design of a multi-legged robot, we also started with the adaptation of an existing but 'obsolete' tracked EOD robot of the DOVO. First by equipping its manipulator with a frontal scanning metal-detector system controlled from an electric servomotor, then by designing a lateral 3D scanner controlled from 3 servomotors: the technical characteristics may be found in the repertory of the annexe 4 (HUNTER).

The next scheme illustrates the whole architecture of the Hunter. The HMI, called CORODE has been developed by Dr Eric Colon, and later extended to a COROBA framework [1]
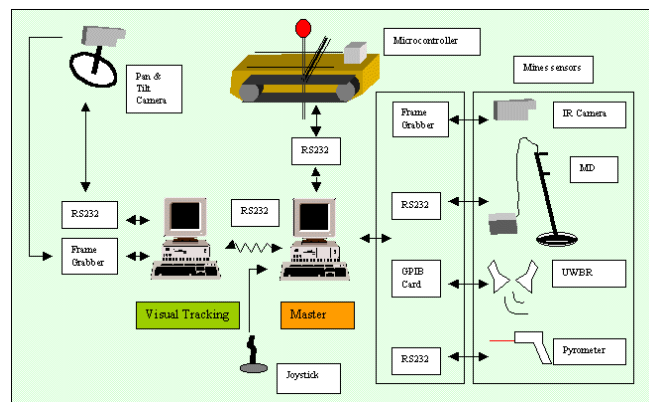
WHEELED ROBOT: a next vehicle has been developed, equipped with three independent driving/steering wheels for to obtain a very large mobility and modularity. The design of the TRIDEM has been entrusted to a researcher of the Free University of Brussels, while the control has been achieved by Dr Ir JC Habumuremyi.;

the robot is intended to be used for the 'Quality Assurance' of a de-mining task. After the mine-clearance, a last detection task could confirm the total absence of remaining Explosive devices.

COMMERCIAL WHEELED ROBOT: finally we opted for the se of a commercial platform (called ROBUDEM)

The ROBUDEM is a commercial platform delivered by the French Company ROBOSOFT and adapted by our UGV Centre:
- First with a 3D scanning system for Humanitarian mine detection tasks (next picture) (project HUDEM)
- Then with a set of sensors (DGPS, Inertial sensor, Stereo camera, Ultrasonic sensors and chemical sensor) for the robotics assistance to Fire-fighting services (project VIEW-FINDER)

The ROBUDEM has four wheels that are individually actuated by electrical motors. The two axles are steerable and are actuated by two linear electrical motors via an Ackerman mechanism. The following figures show the real robot and its 3D model.

The ROBUCAR of ROBOSOFT	The adapted ROBUDEM and its lateral scanner (D.Dorofteï, 2007)	The MODEL as simulation tool in the COROSIM software (E.Colon, 2005)

The control architecture describes the strategy to combine the three main capabilities of an intelligent mobile agent: sensing, reasoning (intelligence) and actuation. These three capabilities have to be integrated in a coherent framework in order for the mobile agent to perform a certain task adequately.

The working principle of the proposed control architecture is sketched on Figure 17. There are three distinctive modules to be discriminated: Navigation (on the right side), Mine Detection - Scanning (in the middle) and Metal Detection (on the left side). These three processes are controlled by a watchdog, the robot motion scheduler, which manages the execution of each module and decides on the commands to be sent to the robot actuators. This robot motion scheduler is explained more in detail in [11]
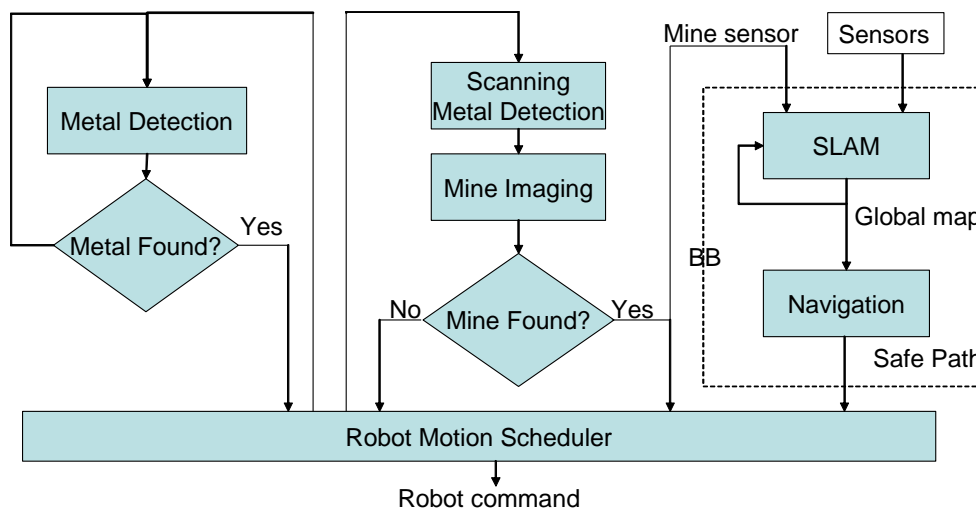
7.Conclusions

From the analysis of the realized [9] and proposed technical solutions, other related tasks that need intervention in a hazardous area may be envisaged (earthquake, Vulcan eruptions, Nuclear Explosion, SEVESO Accident, etc). This paper is a summary: readers interested by details may consult the View-Finder Website or our http://mecatron.rma.ac.be and, obviously, the references

8. Acknowledgments:

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