ICARUS and DARIUS approaches towards interoperability

Two complementary projects that cover the full spectrum of interoperability issues for the integration of unmanned platforms in Search and Rescue operations

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***Abstract*— The two FP7 projects ICARUS and DARIUS share a common objective which is to integrate the unmanned platforms in Search and Rescue operations and assess their added value through the development of an integrated system that will be tested in realistic conditions on the field. This paper describes the concept of both projects towards an optimized interoperability level in the three dimensions: organizational, procedural and technical interoperability, describing the system components and illustrating the results of the trials already performed.**

***Keywords*— Search and Rescue; Unmanned Systems, Interoperability**

I. INTRODUCTION

The two FP7 projects ICARUS and DARIUS share a common objective which is to integrate the unmanned platforms in Search and Rescue operations and assess their added value through the development of an integrated system that will be tested in realistic conditions on the field.

Both projects have the same priorities which are, in the order of importance: 1. The seamless integration of heterogeneous unmanned platforms in the command and control systems of the end-users and 2. The assessment of the operational capabilities of unmanned platforms.

DARIUS answers to these priorities with the development of a highly matured integrated system covering the whole chain from strategic to operation level and with a strong emphasis on operational and procedural interoperability. ICARUS answers with the adaptation of research prototypes to the specific requirements of assistive Search and Rescue operations, giving a higher flexibility to implement and test very innovative capabilities with a specific focus on the interoperability between platforms themselves and with the human-crisis manager. Both projects are user-driven and were or will be tested on similar operational scenarios (Earthquakes, Seveso accidents and Maritime SAR). The operational and technical evaluations done in collaboration with a large panel of civil protection agencies, military organisations and Maritime or Navy stakeholders will provide in the end a clear performance assessment and an instrumented roadmap for future developments in the domain.

The following sections will cover the concepts of the two projects towards an optimized interoperability level in the three dimensions (organizational, procedural and technical interoperability), and describe the system components and illustrate the concrete results of the trials already performed.

II. ICARUS: UNMANNED SEARCH AND RESCUE

A. Project description

The ICARUS project [1] deals with the development of a set of integrated components to assist search and rescue teams in dealing with the difficult and dangerous, but life-saving task of finding human survivors. The ICARUS tools consist of assistive unmanned air, ground and sea vehicles, equipped with victim detection sensors. The unmanned vehicles collaborate as a coordinated team, communicating via ad hoc cognitive radio networking. To ensure optimal human-robot collaboration, these tools are seamlessly integrated into the C4I equipment of human crisis managers and a set of training and support tools is provided to learn to use the ICARUS system. Real-life use case scenarios are foreseen as defined by the end-users: Belgian First Aid and Support Team (B-FAST) and CINAV (Portuguese Navy) (see Fig. 1):

- An earthquake similar to the one in Haiti will be simulated at Marche-en-Famenne, Belgium. An integrated team of ICARUS UAS and UGVs will work in close collaboration with the B-FAST response team.
- A shipwreck similar to the Costa Concordia disaster will be simulated near Lisbon, Portugal. A team of unmanned surface vehicles and unmanned aerial vehicles will help the crisis managers in locating and providing immediate support to human survivors.

Fig. 1. ICARUS integrated demonstration scenarios.

B. Approach to interoperability

Interoperability may be defined as the ability of robots to operate in synergy to the execution of assigned missions. Interoperability allows diverse systems and organizations to work together, sharing data, intelligence and resources.

ICARUS developments are heavily based on the end-users feedback, captured in the form of end-user requirements [2]. According to end-users, SAR teams are invariably faced with a massive overload of work, so “sacrificing” people to operate the robotic tools is not an easy compromise. As a general conclusion it can be noted that no more than two people should be required to operate all robotic tools [4]. A single standard Command, Control and Intelligent (C2I) system [5] shall be capable to operate the different robotics asset in a sector.

Fig. 2. The rugged and portable, Robot Command and Control station.

The C2I system of ICARUS consists of a central Mission Planning and Coordination System (MPCS), field portable Robot Command and Control (RC2) sub-systems (Fig. 2), a portable force feedback exoskeleton interface for robot arm tele-manipulation and field mobile devices.

To ensure interoperability, ICARUS proposes the standardization of the Command and Control and Payload interfaces. A standard for interoperability acts as the glue among the different robots within the team. In this context, a standard interface shall unambiguously define data types and messages, operation modes and optionally transport protocols. To ensure an appropriate level of development, ICARUS builds upon existing initiatives for standardization. There exist several predominant initiatives for interoperability of unmanned systems. Harmonization among them is not yet a fact. The ICARUS standard interface for interoperability of heterogeneous fleet is heavily based on the Joint Architecture for Unmanned Systems (JAUS) [2]. After analyzing the most relevant initiatives such as STANAG, MOOS and MAVLINK, to name some, JAUS was selected as the appropriate reference for standardization. It is fairly aligned with the ICARUS data model and provides the set of basic services required for multi-air, ground and sea vehicles operations.

To comply with the ICARUS interface, a system may directly integrate this interface (native support). However, most robotics systems nowadays are based on existing proprietary or open-source middleware. To accommodate these systems into an ICARUS compliant network, an alternative is to implement and adapter to the robot-specific middleware (translator-based support). Fig. 3 illustrates both cases: robot C shows a native integration while robots A and B are using existing middleware and interfacing the ICARUS network through an adapter. The ICARUS project has validated the interoperability standard for the context of Search and Rescue missions. A sequence of trials were carried out to evaluate the most relevant collaborations at task and mission level within the ICARUS team.

An initial laboratory integration of each unmanned platform and the C2I served as a benchmark for verification of the ICARUS standard interface. These set of tests have mostly been done in a laboratory, by means of logged data and simulations. The purpose of this phase is to ensure that the proposed ICARUS interface can ensure interoperability of the ICARUS platforms when operating in synergy on a Search and Rescue scenario.

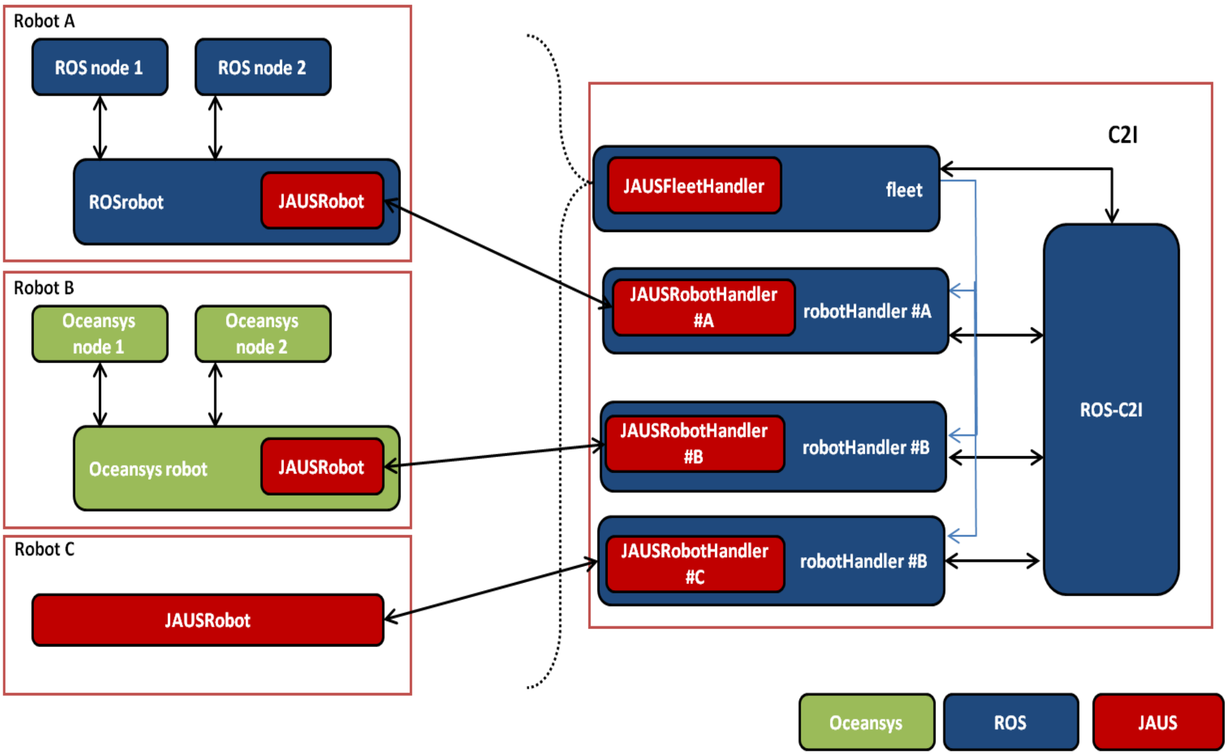

Fig. 3. ICARUS robots adaptation strategy

C. Trials: UAV-UGV trials

The multiple air vehicle tests were organized by ASCAMM in the CATUAV Test Center (CTC) in Barcelona (Spain), from the 19th to the 26th July 2014. The scenario focused on the collaboration between the ETHZ Atlantik Solar and ASCAMM outdoors quadrotor.

Fig. 4. ICARUS Solar aeroplane UAS by ETH

Fig. 5. ICARUS outdoors multirotor by ASCAMM

The outdoor aerial platforms collaborate to generate an enhanced situational awareness following a multi-stage approach. The ICARUS C2I was used to plan and monitor the multi-robot operations through the standard interface. Live images were available at the C2I to assess the disaster area. Post-processing these images, an initial map illustrated in Fig. 6 was available to the coordinator of the operations. To enhance the situational awareness at the Base of Operations, the map is classified. Examples of regions of interest in this map are paths, roads, vegetation, waters and buildings. This information allows the definition of safe Forward Base of Operations (relatively flat ground close to some road).

Fig. 6. Point cloud of the CTC Test enter using AtlantikSolar UAV by ETH

The next step in the integrations of multiple ICARUS robots was the multiple air and ground vehicle tests. They were organized by RMA in the Military base of Marche-en-Famenne (Camp Roi Albert) in Belgium. The tests were carried out from the 5th to the 13th September 2014. The trial site consists of two main locations, a rubble field simulating a demolished block of apartments and a city with skeleton houses.

Fig. 7. Marche-en-Famenne testing site: skeleton houses

Fig. 8. Marche-en-Famenne testing site: the rubble field

All ICARUS UAS and UGV intervened in the operations. Together with the systems shown in Fig. 4 and Fig. 5, the following platforms intervened in these trials:

Fig. 9. ICARUS large UGV by Mettaliance

Fig. 10. ICARUS small UGV by Allen Vanguard

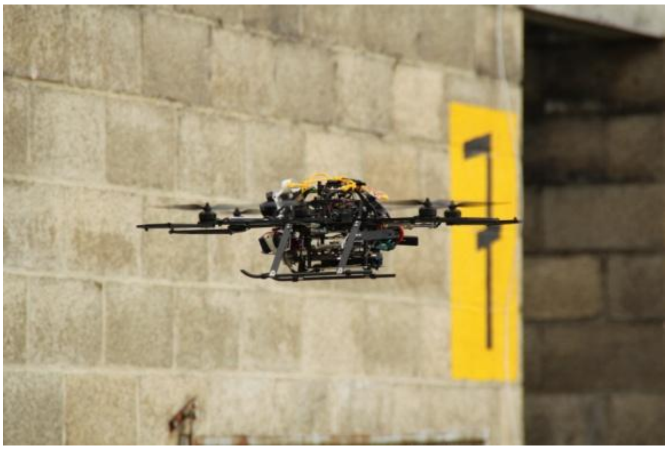

Fig. 11. ICARUS indoor multirotor by Skybotix

Once the Forward Base of Operations has been established, sectorization of the disaster area takes place. On the first sector, the outdoor quadrotor is required to perform a closer inspection to assess the status of the structure. The following results are obtained after post-processing:

Fig. 12. 3D map of the skeleton houses(Software used: Agisoft Photoscan)

During the exercise, the team explored the potentialities shown by these two platforms to detect victims. Several flights were performed at different altitudes, on different areas.

Outdoor victim search on ground was mostly conducted by the large ground vehicle in cooperation with the other vehicles. To allow for a visual inspection of a blocked house entrance, the jackhammer of the large vehicle was used to open a small hole inside the blocking concrete plate. Afterwards the gripper was used to clear a window of that house from rubble, so that it was possible to enter with a small indoor multicopter.

The Indoor Victim Search operation, the Small Ground Robot (SUGV) cooperated with Skybotix Multirotor in a damaged building. The SUGV uses the information provided by the Multirotor (Fig. 11) to navigate towards the victim. During the exploration flight in the building, two live video streams (standard & thermal) are used to locate victims. In the end, the resulting obstacle avoidance map allowed to assess the completeness of the search within the building.

Fig. 13. Collaborative indoor victim search

The complete data-set from some of the platforms can be accessed and freely downloaded here:

http://projects.asl.ethz.ch/datasets/doku.php?id=jfricarus.

D. Trials: UAV-USV trials

An integration test for the USV was performed in Lisbon at the REX exercises, from 30 June to 4th of July of 2014. The field trials were conducted in the Tagus river basin, in an area where multiple ferry lines operate. This area was chosen since it is a viable and possible scenario of a large-scale disaster at sea due to the ferry traffic, currents and large area in the Tagus estuary.

ICARUS Unmanned Maritime Vehicles (USV) (Fig. 14 to Fig. 16) are critical for the SAR operations in water. They are capable of transporting search equipment and deploying first assistance devices, reducing the arrival time at the incident area of basic life support equipment. ICARUS USV comprises the U-Ranger by Calzoni and the ROAZ II by INESC [7]. These systems are complemented by a Rescue Capsule, an instrumented survival capsule capable to navigate towards survivors.

Fig. 14. ICARUS U-Ranger USV by Calzoni/CMRE

Fig. 15. ICARUS ROAZ II USV by INESC

Fig. 16. ICARUS Rescue Capsule by INESC

Victim in the water detection tests were conducted with the ROAZ USV, using vision and thermal imagery. In addition, data was collected from radar and LIDAR sensors in order to validate the environment perception capabilities of the team.

During the REX 2014 trials, conditions with multiple victims on the water were tested along with additional USV vehicles.

Fig. 17. Multiple victims in the water tests at REX2014

Collaborative USV operations were also performed, in particular the deployment of the Rescue Capsule from ROAZ USV. The adaptation of the platforms to the ICARUS interface resulted in the possibility to supervise the entire operation from the ICARUS C2I successfully.

A second step in the integration of the maritime vehicles in an ICARUS team was carried out in October 2014 at CMRE, Italy. All ICARUS sea vehicles and a representative of the UAS were involved in these exercises to explore and validate the air and sea collaboration. Collaborative navigation between the UAS and the USV was performed. Fig. 18 shows a bird-eye view on the thermal and grayscale cameras onboard the ASCAMM Quadrotor.

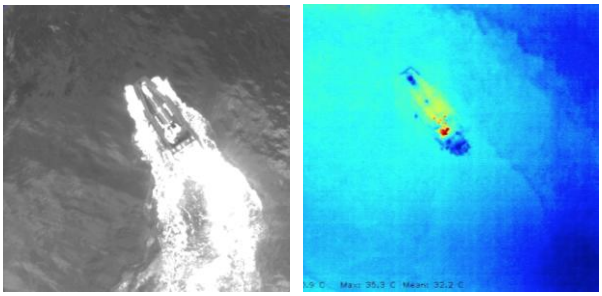

Fig. 18. UAS bird-eye view of the mission on thermal and gray scale images

Collaborative victim-search was also experimented. ASCAMM quadrotor automatically explored the disaster area and reported the location of the victim to the USV (Fig. 19) . The URanger will travel towards the location of the person and deploy the Rescue Capsule, which at the same time, will navigate towards the victim.

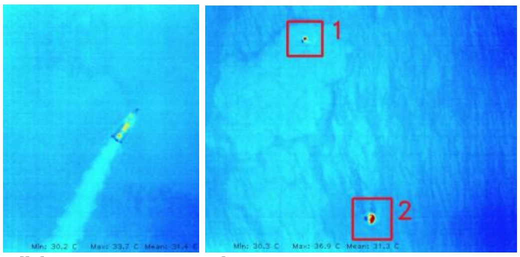

Fig. 19. Collaborative victim-search

The overall objective of these trials was the integration of all ICARUS assets on the C2I system. The adaptation of the platforms to the ICARUS standard interface allows the interoperability of the different systems, enabling their ability to collaborate in synergy towards the supportive intervention in the ICARUS Search and Rescue concept of operations.

III. Darius

A. *Project description*

DARIUS considers various SAR scenarios where the operations require the intervention of multiple agencies in a multi-national context. The operational organisation consists of three levels:

- ***Coordination level*** responsible for the planning function in the Command and Control (C2) cycle (choosing pre-established plans, refining them and updating them where needed), involving agencies at operative level (civil protection, police, etc.), and planning in a collaborative manner;
- ***Tactical level*** responsible for tasking (allocating missions to units) and actual operations monitoring. The main Tactical Command Post (hosting the tactical level) may be a mobile unit and can be supported by additional mobile Forward Command Posts that are placed closer to the events. It is in direct relation with the deployed C2I or information systems from the other agencies;
- ***Execution level***: are the teams on the field (first responders and support).

Within DARIUS, the coordination level and tactical level are the C2I/C4I nodes, whereas unmanned systems are operated at execution level (for local operations), at tactical level (for situation assessment) and in some cases at coordination level for wide range operations (High Altitude, Long Endurance (HALE) or Medium Altitude Long Endurance (MALE) unmanned airborne systems). These assets are used for overall situation monitoring or preliminary damage assessment.

Most SAR operations involve a combination of unmanned and manned systems, so DARIUS considers a system of systems where these two operate at the same level. DARIUS studied and developed the systems components aiming to integrate the unmanned platforms in the overall system of systems.

In order to be able to evaluate the real achievements of the project, DARIUS used three scenarios designed and validated in close cooperation with the end users of the consortium.

These scenarios have been designed not only to describe exceptional (and rare) large scale events, but also to integrate day-to-day requirements and concerns of SAR professionals and investigate operational limitations. These scenarios played on simulation platform for the training of the end-users and the preparation of the field trials, as well as in the field with a maximum use of real assets and data.The three scenarios where DARIUS system and its components were tested are:

1. **Urban/indoor scenario corresponding to earthquake urban destruction and Seveso-like plant accidents (played for real in Bollene and Sorgues in Southern France, in collaboration with the Region of Vaucluse and the French Fire Brigades)**;
2. **Forest fire scenario integrating explosion hazards (played for real in the area of Anavyssos in Greece in cooperation with the Greek Fire Service, Hellenic Police and Local Authorities);**
3. **Maritime SAR (prepared in NMCI simulation and played for real in La Ciotat, Francein cooperation with French Coast Guards and the volunteers' organization SNSM).**

The three scenarios covered most of the possible use cases as they involved different types of unmanned platforms with specific requirements and constraints. Simulations only covered systems that are too costly to be integrated in the trials (HALE, MALE), and for the general story of the disasters. Numerous real assets were used during the field trials in order to prove the integration capabilities and limitations while testing the interoperability challenges at the same time.

The system considered by DARIUS encompasses the following segments:

- ***The C4I segment***: this segment consists of the Command and Control systems (each agency may have its own and this is one of the options that DARIUS used to study the interoperability and collaboration issues). The C4I segment is implemented in:
  - The Coordination Centre: a fixed control room with computers, displays and access to the infrastructure communication networks. This is the planning level of the Command and Control system;
  - The Tactical Command Post (TCP) which consists of a mobile or deployable structure (truck, shelter, tents, etc.) that is equipped with computers where the tactical functions of the C4I are implemented (i.e. tasking and current operations monitoring). The TCP can access the infrastructure communications and the wireless tactical communications. It can be composed of several elements (each agency can have its own command post that will be coordinated by the main tactical command post) and several mobile forward command posts (in trucks, cars, helicopters, planes) that operate under the control of the main command post. The TCP is in permanent communication with the C2I and information systems deployed by different agencies;
  - The execution level are equipped with terminals (laptops, PMR, etc.) that enable them to report to the C4I (tactical level).
- **The Communication segment**: which is generally a heterogeneous segment that groups:
  - Infrastructure communication segment (fixed + mobile) that generally supports the exchanges between coordination level and tactical level and can also be used at tactical and execution level;
  - Tactical data links (Ground-Air-Ground): wireless segment between the C4I and the unmanned systems. For the control of unmanned systems, the Tactical Data Link links generally the Ground Control Station (GCS) to the air, ground or maritime platforms. This is the uplink to control the platforms and their sensors, and the downlink to transmit the data gathered by the unmanned platforms to the GCS;
  - The wireless bubble: an ad-hoc deployable communication network set-up to provide the deployed systems and units with the necessary communication means, in areas where no network is available or where the available networks cannot guarantee the necessary availability and confidentiality.
- **The Ground Control Stations** (GCS) segment: as described in DARIUS concept, this segment is composed of:
  - The Generic Ground Station (GGS) that will have capability of tasking any of the unmanned systems and exploiting all the data received. This is a concept supporting technical and operational interoperabilityas well as a real component developed within DARIUS.;
  - The specific Ground Control Station (GCS) associated to each unmanned system integrated to DARIUS. Each GCS is composed of 2 parts: the control module (to control the platform and the sensors) and the exploitation module (data management) to exploit the data, display them and exchange them with the C4I segment.
- **The platforms**: are the unmanned vehicles, their navigation and communication systems and the payloads (sensors and others). In DARIUS, four main types of platforms are considered:
  - Unmanned Air Vehicles: HALE (simulated), MALE (simulated), Tactical fixed wings (TANAN system from CASS), Tactical X-wings (1 helicopter, 90 kg, from ONERA);
  - Ground Robots: CAMELEON unmanned ground system from ECA that can carry sensors and communications relay and also transport first aid kits, and the ROBOVOLC system from BAES;
  - Maritime Platforms: a small SAR platform equipped with big engines to be quickly on station (INSPECTOR system from ECA);

- Underwater Platform: Underwater unmanned vehicle (simulated by NMCI)

- **The sensors**: typically cameras, audio or radars, and chemical sensors are considered in SAR operations. DARIUS focused to develop and test chemical sensors for detecting toxic gas concentrations in SAR operation scenes, a gsm localization module and video and IR sensors on board of ground and aerial platforms.
- **The other payloads**: the proposed DARIUS scenarios call for 4 other types of payloads to be installed and operated on the unmanned platforms:
  - First aid-kits (transportation and delivery capabilities);
  - Cables to attach crippled boats or dinghies;
  - Medical sensors (bracelets to be brought to the victims);
  - WiMAX relays: so the unmanned platforms can automatically deploy the communications infrastructure in difficult areas.

The DARIUS system general layout is presented in the following picture:

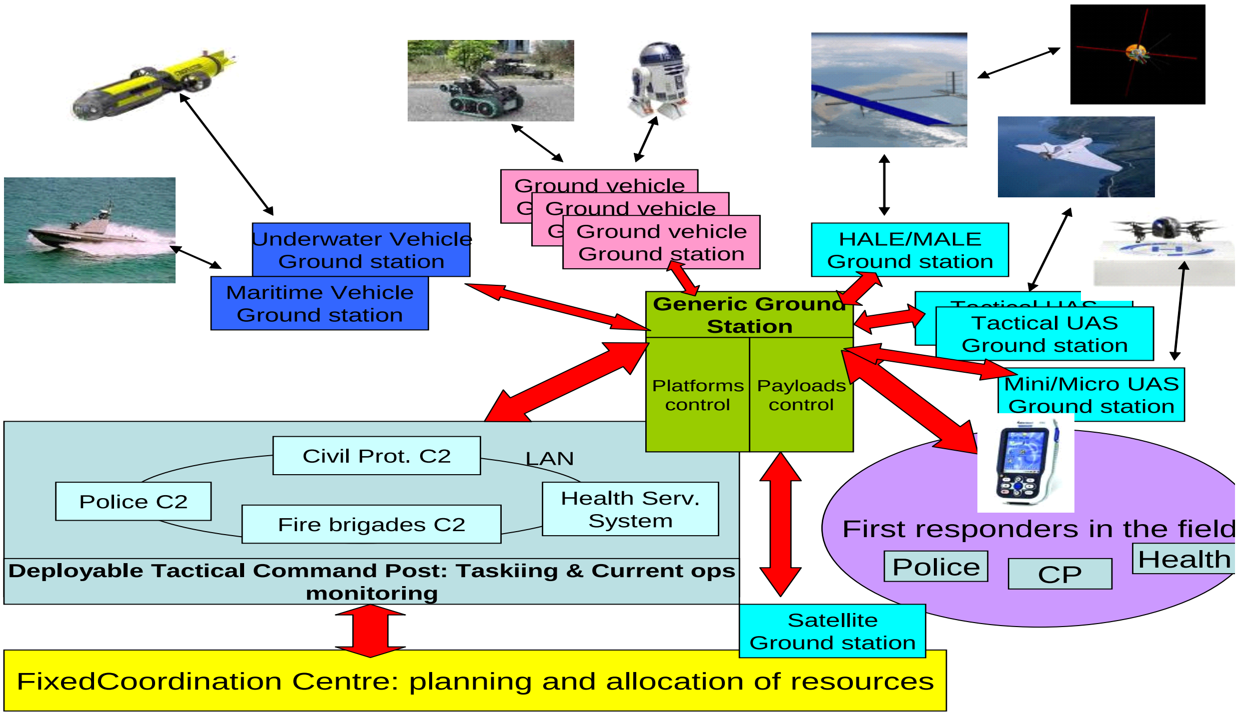

Fig. 20. DARIUS general system layout

B. Unmanned platforms involved

The prototype DARIUS system of systems integrated several types of unmanned platforms that correspond to different and complementary usages during the whole SAR operation cycle.

More specifically three types have of unmanned platforms have been considered:

- A HALE/MALE (High/Medium Altitude Long Endurance) capability that is mainly dedicated to elaborate and to maintain the large area situation awareness during the whole operation. It can also be use as a communication relay. This capability was simulated in DARIUS as the cost and authorisations were beyond the project capabilities.
- Tactical UAVs: 2 types were used. 1. A fixed wing that can be launched by catapult (DFRC 2000) and a helicopter (Copter 4). The fixed wing UAV is more adapted to medium area monitoring whereas the helicopter can better monitor hotspot and drop first aid kits.

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Fig. 21. DVF 2000 fixed wing UAV by Survey Copter

Fig. 22. Copter 4 UAV by Survey Copter

- Mini-UAV: it can be used outdoor (calm weather) or indoor to spot victims and monitor/guide the UGVs.

Fig. 23. Micro UAV by DFRC

DARIUS integrates two different UGVs:

- ROBOVOLC by BAES. The six-wheel UGV is big and can navigate in all terrain conditions.

Fig. 24. ROBOVOLC by BAES

- CAMELEON by ECA. This UGV is smaller and is on tracks. It has good navigation capabilities in structured environment.

Fig. 25. CAMELEON by ECA with Chemical sensor on top

For the maritime SAR operation, DARIUS integrated two platforms:

- An Unmanned Surface Vehicle, the INSPECTOR by ECA.

Fig. 26. INSPECTOR by ECA towing automatically a crippled boat

- An undersurface ROV by the University of Limerick that was used during the lab trials in Cork.

All platforms used in DARIUS systems are equipped with one of several cameras in addition with the navigation sensors. A chemical sensor was adapted and can be carried either on ROBOVOLC or on CAMELEON to analyse chemical threats.

C. Approach to interoperability

DARIUS ambition is to manage the interoperability at organisational, procedural and technical level with a clear traceability between these aspects.

For the organisational interoperability, DARIUS system covers the whole C2 chain from strategic (coordination level) to the fieldgoing through the various instances of the tactical level. DARIUS made the choice to use a simple yet complete C2I, IMP@CT from ADS, to configure it into several avatars representing Civil Protection, Firemen, Health Services and Army C2. For each of the trials, the potential organisational interoperability issues were identified and the C2 was adapted to address the respective requirements.

For procedural interoperability, as also a follow-on of previous projects, DARIUS focussed on existing interoperability solutions developed starting from Military standards or de facto standards between Civil Protection organisations. For each domain of procedural interoperability that could raise issues, studies were performed to determine if it was more effective to impose standards or to develop rapid translation/transformation mechanisms. In symbology and languages issues in particular, it appeared more realistic and efficient to develop "translating devices" rather than oblige all the systems to comply with one universal standard.

For technical interoperability, DARIUS based on two major concepts:

- The GGS (Generic Ground Station). The GGS is the unique interface between the C2I and the unmanned systems (through their Ground Control Stations). The GGS that propose an interoperability protocol in terms of standardised messages both in the domain of Command and Control and in the domain of tactical situation and video exchanges is therefore a powerful integration tool that enables to integrate heterogeneous (from origin and technically) unmanned platforms.
- The Coalition Shared data base (CSDB) mechanism: developed initially by NATO, this concept has been adapted for DARIUS. Whereas the GGS concept is largely centralised to limit the number of adaptations requested to integrate new unmanned platforms, the CSDB concept acknowledge that each unmanned system will manage the majority of the data it produces and that it would not really be effective to store all the data at GCS level. So CSDB is the distributed data concept with the capability to access any data from anywhere in respect of the security and confidentiality issues.

Technically speaking, DARIUS also provides a deployable communication solution developed by FINT. The idea is to federate all the components of the systems inside a wireless communication bubble (WIMAX for DARIUS trials) so that the physical connections are completely consistent. These connections are either intrusive via a dongle or not via an interface PC, reflecting thus the level of control that can be given by each organisation on its systems. This deployable bubble is a powerful tool that supports the DARIUS technical interoperability solution. A picture of DARIUS communication network is provided here below:

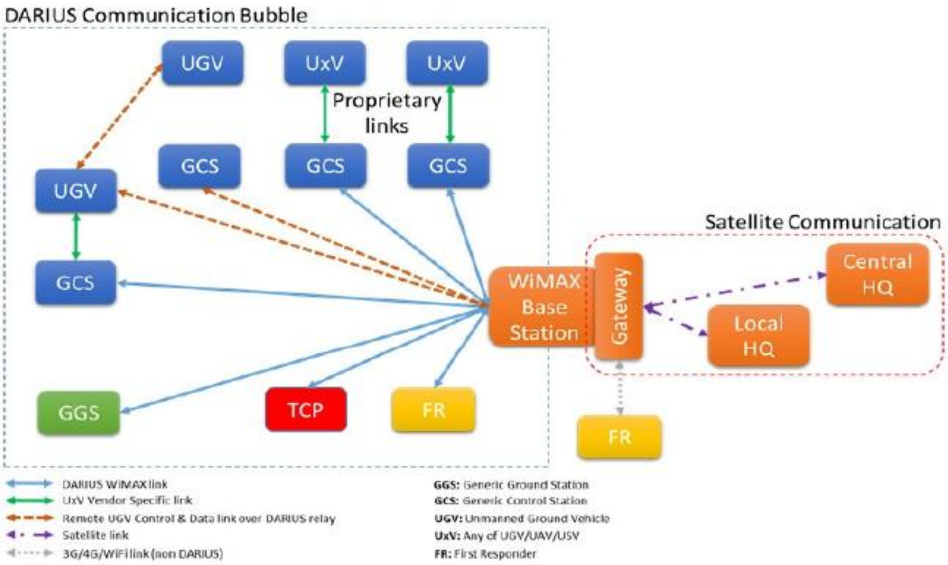

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Fig. 27. DARIUS network topologyTrials

Finally, to enhance the interoperability between the platforms and to some limit their inter-exchangeability, DARIUS has also implemented as far as possible the existing standards in the domains of sensor integration from OGC and the sensor data exchange defined by NATO.

D. Trials

DARIUS trials have been structured in 3 campaigns:

- Maritime SAR,
- Earthquake and Seveso,
- Forest fires.

Maritime trials were performed in two phases: a simulated part in National Maritime College of Ireland in Cork (June 2013), focussing essentially on a first factory demo of the GGS capability with the integration of the GCSs from the TANAN UAV, the INSPECTOR USV; the micro UAV and the ROV. The real Maritime trials took place in La Ciotat, France in December 2013. The end-user (SNSM, French charity Maritime SAR organisation) provided the rescue boat and the various “targets” (small boats and people in the sea) whereas DARIUS provided the Maritime C2 (SPATIONAV), the GGS and the GCS of the TANAN UAV (emulated by a piloted aircraft) and the INSPECTOR USV. The Maritime trials in La Ciotat demonstrated the capability of DARIUS concept for the legacy systems integration and the potential interoperability between platforms and organisations.

Fig. 28. SNSM lifeboat in La Ciotat Bay with the INSPECTOR USV behind

Earthquake and Seveso trials: they took place both in the Department of Vaucluse (Bollène and Sorgues) in Southern France) in May 2014. The trials were supported by the French Fire Brigades and gave the opportunity to test DARIUS in a Civil Protection type of ground operations including collapsed buildings, subterranean structures and land components. The deployed system was composed of the C2I component (Strategic and Tactical, with additional tablets), the GGS, RESSAC and City Copter unmanned helicopters and micro drones (UAVs), ROBOVOLC UGV and CAMELEON UGV. These trials enabled the validation of DARIUS solution in a fully autonomous deployed configuration.

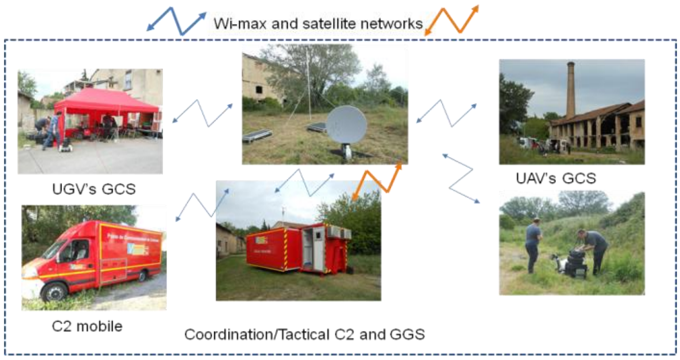

Fig. 29. Trials in Bollène

Forest Fire trials: they took place in Anavyssos (Greece, Attika) in October 2014. Differentlyfrom the trials in France, the Greek trials incorporated several organisations (Firemen, Police and Health Services) to demonstrate the interoperability solutions provided by DARIUS between different organisations that don’t have the same tasks, role and responsibility during SAR. In addition, the whole cycle of the operation was played, starting from the alert stage and followed by the system deployment under the coordination of the civil protection organization in charge (strategic level). During the trials, strong winds blew (Beaufort 6) which allowed to test the UAVs under harsh conditions.

IV. ICARUS AND DARIUS COMPLEMENTARITY

The ICARUS Command, Control and Intelligence (C2I) systems have local Geographical Information Systems (GIS) which host base maps from local and external sources in the form of vector and raster layers deriving from multiple sources: civilian and military authorities, Open Street Maps, NASA satellite imagery and low altitude aerial imagery. Custom defined layers are configured to store joint manned and unmanned SAR mission parameters such as points of interest, operational sectors, user notes etc. and robot sensor data such as images, videos, point clouds, trajectories, robot status etc. This data is accessed and rendered in the C2I map client that supports Open Geospatial Consortium (OGC) standards like WMS (Web Map Service), WFS (Web Feature Service) and WCS (Web Coverage Service).

The DARIUS Generic Ground Stations (GGS) [8] uses OGC services from the Sensor Web Enabled platform and the Catalogue Web Service platform to query and exchange sensor and mission specific data respectively with multiple Ground Control Stations (GCS). The Sensor Observation Service (SOS) is used by the GGS to query the GCS for a sensor capabilities list and this information is used to set up data streams between the two. The Web Feature Service (WFS) is used by all the ground stations to proliferate tactical mission features.

When heterogeneous SAR teams are operating in an area, it can be challenging to export or share data during the course of operations due to the use of ambivalent standards which render systems incompatible for exchanging data. This task is typically undertaken in the data post-processing phase after completion of operations. This gap between ICARUS and DARIUS interoperability can be bridged by first establishing a dedicated communication link via directional Wi-Fi antennas or a satellite link between the GGS and the MPCS. By adding new or using existing OGC standards that are already supported by both the central control centers, we propose the following approaches:

- WFS support at the DARIUS GGS can be leveraged to perform spatial queries to the ICARUS GIS to retrieve vectorial and raster information including mission plans and operations progress. This includes robot specific waypoints, trajectories, sensor data and temporal information which will enable the GGS to get an identical overview of MPCS mission layers. This improved situational awareness multiplies the capability of stake holders at the GGS for generating mission updates using the ICARUS team field information as a feedback. In this case, the MPCS can behave as an exporter of ongoing mission updates to similar systems in its vicinity.

- The OGC services supported at the MPCS can be augmented to include Catalog Web Service (CWS) queries to get the capabilities and records from a GGS to expose the list of GCS's within its ecosystem. With the inclusion of Sensor Observation Service (SOS), the MPCS can interrogate and request sensor observations from multiple GCS, enabling the MPCS to converge with some of the sensor data capture capabilities of a DARIUS-GGS. The mission planning layers configured in the GIS (in MPCS) can be adapted to incorporate GGS specific tactical mission features. Whenever the GGS triggers a dispatch to add or update mission specific features using WFS, the corresponding mission layer within the MPCS also gets updated and rendered in the map interface. Hence stake holders at the ICARUS-MPCS are passively exposed to mission updates from the GGS. Sensor observations can be acquired from the DARIUS-GGS on demand and rendered in the MPCS.

Data shared between these systems could experience time delays due to synchronization of large data sets using HTTP GET/POST requests with XML payloads over unreliable networks in disaster areas. The proposed latter approach will require significant software development effort to implement the DARIUS protocol within the MPCS, while a minimal effort is needed to adapt the GIS layers and the map rendering module at the MPCS.

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