Key Initiatives for Interoperability through Standardization

– Applicability to Small Unmanned Vehicles –

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ABSTRACT

This paper intends to study the problem of standardizing the way small Unmanned Vehicles (UxV) are commanded and the way they report results. A particular focus is placed on multi-robot operations, where a team of unmanned air, ground and sea vehicles collaborate as a coordinated, seamlessly-integrated team. A strong effort shall be devoted to the integration of them as a heterogeneous fleet. The existing standards for interoperability of several unmanned vehicles are a mean to provide rules for the robots inner/outer communications. To ensure an appropriate level of development, advantage should be taken from these existing standardization approaches while avoiding the risk of inheriting undesirable or restrictive complexity. Therefore, the purpose of this report is to critically appraise some of the existing initiatives in terms interoperability of unmanned platforms.

1.0 INTRODUCTION

Currently there are many and very heterogeneous Unmanned Air, Ground, Surface, and Underwater Systems (UxS) in use by NATO forces. In the foreseeable future that number will certainly increase significantly. There is also a tendency to increase the interactions between these systems, making them aware of each other, executing tasks that require cooperation (both by design and by self-organization), and finally implementing flock or swarm behaviours.

Although many standards have been proposed, most of these systems have their own command and reporting protocols, and consequently require their own ground control stations. This profusion of protocols makes it very difficult to implement cooperation between systems. Their operation and maintenance, in multiple vehicle environments, also poses an unnecessary burden due to lack of unified standards.

A common solution is to develop wrappers and gateways from one system to another. This solution is generally sub-optimal in characteristics, and computationally inefficient. Previous NATO standards are not easily implemented in small systems, and were not developed with these systems in mind. There has been a lot of development in this area, and many different frameworks and standards have emerged to address various needs that developers have felt. However, there is sometimes little awareness of existing standards, and it is probably time for NATO to raise awareness of those protocols, and probably recommend the adoption of some of these for use in alliance forces, possibly by approving some new STANAGs.

If researchers and developers were more familiar with existing standards, it would be easier to adopt them from the outset, thus simplifying later efforts to promote cooperation. This could lead to a qualitative change in the way we use UxS, by enabling the implementation of new concepts of operation for multi-UxS scenarios, and a greater integrations of these systems. The previous experience indicates that this is a pressing issue that should be addressed as soon as possible, and thus this paper introduces the key initiatives for interoperability.

2.0 INTEROPERABILITY NEEDS

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

A method to ensure interoperability is the adaptation of the different previously existing technologies to a unique standard interface. ISO defines a standard as a set of "requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose" [1]. In the context of interoperability, a standard shall unambiguously define data and message types, operation modes and optionally transport protocols. A standard for interoperability acts as the glue among the different robots within the team.

Nowadays, there exist multitude robotic platforms, software frameworks and protocols. The integration of several robots as a single integrated team requires a strong effort. Interoperability standards provide a common framework for unmanned systems. They minimize the integration time and development costs by avoiding custom implementations. The ultimate goal of the standardization is to consolidate a common interface to be agreed and adopted by all robotics platforms and Control Ground Stations (CGS) involved in a system.

There are other advantages of using interoperability standards. A common interface helps to easily integrate new technologies with minor or no modifications to the existing systems, therefore, technology insertion on the field becomes easier. Another advantage of the use of standards is that it will facilitate the compatibility between existing and future platforms and CGS from different providers.

In order to evaluate an existing initiative, an analysis of the interoperability needs is required. This may include the definition of the data model containing the required concepts (or messages) to describe the capabilities and services commonly found in unmanned systems.

Some standardization initiatives define also key concepts to facilitate the interoperability between systems, for instance, the Levels of Interoperability (LOI) depending on the platform level of compliance with the standard interface [2].

The focus of this paper is placed on operations involving a team of unmanned air, ground and sea vehicles that collaborate as a coordinated, seamlessly-integrated team. In such a context, the interoperability between the systems is crucial to allow the effective collaboration between the heterogeneous vehicles. An heterogeneous team usually contains a set of vehicles with very diverse capabilities and that can play different roles. Different strategies for the coordination are feasible and depending on the strategy, different requirements may be placed on the interface. Concepts such as roles, responsibilities, modes of operations and tasks may be part of the standard to support this fleet management.

An effective heterogeneous team management requires *reasoning* about the mission goals, given the robots capabilities and constraints. To support these activities, some other aspects which are critical to ensure interoperability is the robust definition and specification of roles and tasks in the system, modes of operations and the adjustable level of automation.

3.0 LEVELS OF INTEROPERABILITY

A major challenge for interoperability is the need to account for very diverse platforms technologies. The definition of different Levels of Interoperability (LOI) is a STANAG 4586 concept [2]. It is defined as the platform, subsystem or sensor ability to be interoperable for basic types of functions related to unmanned systems.

These levels show a degree of control that a user has over the vehicle, payload or both. This concept becomes crucial when focusing on small UxS since these systems are limited in terms of resources and may not be able to integrate the equipment required to fully comply with a given standard.

The Levels of Interoperability are defined as:

- Level 1: Indirect receipt/transmission of UxV metadata and payload data. The RC2 receives the communication from another RC2 or other communication channel (web-server, storage, etc).
- Level 2: Direct receipt/transmission of UxV metadata and payload data. The RC2 has direct communication with the platform, but does not control it.
- Level 3: Control and monitoring of the UxV payload, not the unit, in addition to LOI2.
- Level 4: Control and monitoring of the UxV without launch and recovery (unless specified as monitor only)
- Level 5: Control and monitoring of the UxV including launch and recovery (unless specified as monitor only)

These interoperability levels are enabled through compliance with standard interfaces such as:

- A data link system(s) that provides connectivity and interoperability between the Ground Control Station and the UxV.
- Messages types and format definition for command/control data.
- Messages types and format definition for payload/sensor data for transmission to the GCS via the data link and/or for recording on the on-board recording device.

4.0 ADJUSTABLE AUTOMATION

Adjustable Automation (AA), in general, is the ability of a robot to behave autonomously and, dynamically, change its level of independence, intelligence and controllability [10]. AA becomes also an asset when dealing with communication delays, human workload and safety [11].

The automation of a robot is related to the degree of intervention of the human operator and other robots in the decision process. However, the fact that a robot is autonomous does not imply that it has to make all its decisions by itself. Different levels of automation and classifications have been described in the literature [12]. For instance, Lacroix et Al. in [13] define five levels of automation according to the robot responsibilities towards the fleet (tasks allocation, mission coordination, etc), which is mostly relevant for tightly coupled coordination.

To ensure an effective fleet management, the interoperability standard shall provide the means to support this mission planning and coordination at different level of automation for each of the platfoms. As mentioned before, the concept of adjustable autonomy implies the ability to adapt and dynamically change between these levels of autonomy depending on situational changes

5.0 KEY INITIATIVES FOR INTEROPERABILITY FOR SMALL UXV

NATO Standardisation Agreement (STANAG)

The STANAG (Standardisation Agreement) standards are published by NATO to provide common military or technical procedures for NATO members. They define processes, procedures, terms, and conditions for common procedures or equipment between the member countries of the alliance. STANAGs also form the basis for technical interoperability between a wide variety of communication and information systems (CIS). Some are publicly available in NATO's online library.

These standardization agreements have in common a hierarchical structure and a functional or platform approach. A specific objective is the standardization of three key interfaces:

- Data Link Interface (DLI)
- Command and Control Link (CCI)
- Human Control Interface (HCI)

Among the hundreds of standardization agreements (current total is just short of 1300) are those that may be relevant for the interoperability across UxS . This table lists the three most relevant:

Table 1: STANAG related standards.

Standard	Title
STANAG 4586	Standard interfaces of UAV control system for NATO UAV interoperability types
STANAG 7023	Air Reconnaissance Primary Imagery Data Standard
STANAG 4545	NATO Secondary Imagery Format (NSIF)
STANAG 7085	Interoperable Data Links for Imaging Systems

A drawback for the application of this standard is that some of them may be geographically constrained to NATO member states and may become a limitation to intervene in non-NATO countries. For instance, STANAG 4586 is NATO "UNCLASSIFIED". This may become a barrier to many global suppliers & non-traditional innovators from non-NATO countries such as robotics leaders in Japan. [3]

Joint Architecture for Unmanned Systems (JAUS)

The main goal of JAUS is to structure communication and interoperation of unmanned systems within a network. A JAUS system is made up of subsystems connected to a common data network. A Subsystem typically represents a physical entity in the system network, such as an unmanned vehicle or operator control unit.

The JAUS network is further subdivided into hierarchical layers. Subsystems are divided into Nodes, which represent a physical computing end-point in the system. For example, a Node might be a computer or microcontroller within a Subsystem.

Nodes can then host one or more Components, which are commonly applications or threads running on the Node. Finally, Components are made up of one or more Services.

The JAUS services are grouped in Sets and published as related but separate documents. They described generic concepts commonly found in unmanned systems. The following table lists the most relevant ones:

JAUS Standards	Date	Content
JAUS Core Service Set (SAE AS5710A)	2010.08	Low level services such as transport and discovery to enable basic interoperation
JAUS Mobility Service Set (SAE AS6009)	2009.04	Common mobility services such as global positioning and vehicle platform control by defining abstract services that are agnostic to specific vehicle mobility types (ground vehicles, aircraft, etc.)
JAUS Environment Sensing Service Set (SAE AS6060)	2010.11	Environment sensing capabilities commonly found across all domains and types of unmanned systems in a platform-independent manner (range, visual, video, etc).
JAUS Manipulator Service Set (SAE AS6057)	2011.03	Service definitions for controlling robotic manipulators. Messages are defined generically so they can be applied to many different types of manipulators (arms, grippers, pan/tilt, etc.).
JAUS HMI Service Set (SAE AS6040)	2010.11	Service definitions for HMI interaction that includes drawing, keyboard input, pointing device input, analog and digital user controls.
JAUS Mission Spooling Service Set (SAE AS6062)	2010.07	Services definition to store mission plans, coordinate mission plans, and parcel out elements of the mission plan for execution
JAUS Unmanned Ground Vehicle Service Set (SAE AS6091)	2014.07	Represent the platform-specific capabilities commonly found in UGVs, and augment the Mobilty Service Set [AS6009] which is platform-agnostic.

Battle Management Language (BML)

Battle Management Language (BML) is an unambiguous language used to command and control forces and equipment conducting military operations and to provide for situational awareness and a shared, common operational picture (COP). It is particularly relevant in a network centric environment for enabling mutual understanding and focused in the battle management.

BML is being developed as an open standard that unambiguously specifies Command and Control information, including orders and reports built upon precise representations of tasks. BML is both a methodology and a language specification, based on doctrine and consistent with Coalition standards.

Multi-Sensor Aerospace-Ground Joint Intel. Interoperability Coalition (MAJIIC)

Multi-Sensor Aerospace-Ground Joint Intelligence Interoperability Coalition (MAJIIC) is another multinational effort to maximise the military utility of surveillance and reconnaissance resources through the development and evaluation of operational and technical means for interoperability of a wide range of ISR assets.

The primary aim of the MAJIIC project is to improve the commanders' situation awareness through collaborative employment and use of interoperable ISR sensor and exploitation capabilities. MAJIIC will address interoperability in a flexible and wide-reaching manner, ranging from small tactical systems usually assigned to tactical commands and all the way up to highly capable strategic multi-user systems. MAJIIC is well suited to act as documentation management system due to its client-server architecture and the publishing and subscription policy to access to data, but it was not designed to manage C2I and C4I.

Micro Aerial Vehicle Communication Protocol (MAVlink)

Micro Aerial Vehicle Communication protocol (MAVlink) [14] is a micro air vehicle marshalling and communications library specially focused into MAVs, it was developed in 2009 by Lornez Meier at the ETH Zürich. MAVlink is a library for lightweight communication between Micro Air Vehicles (swarm) and/or ground control stations. It serializes C-structs for serial channels and can be used with any type of radio modem. Messages definitions are created in XML, and then converted into C header files. MAVlink is employed in several UAV autopilots (pxIMU, ArduPilot Mega, SLUGS, among others) and also the Parrot AR.Drone where it serves as communication backbone for the MCU/IMU/on-board PC communications. MAVlink is also used for Linux inter-process, ground link communication, in several software packages (ROS, APM planner and more) and many projects (ArduPilot Mega, Aky-Drones, PIXHAWK and more).

The message set is organised around the object the message refers and each category is covered by the relevant instructions, reports and status messages. The framework architecture of MAVLink acts as a mechanism with a wide non filtered broadcast of messages that each component or sub-system can receive and read. At the same time, every component in the architecture can send messages to broadcast. The messages have a double CRC correction process with an extra byte for the second checksum. That improves the consistence of communications and the data package contents.

Other Ongoing Initiatives about Interoperability

There are definitely other groups currently working on standardization of command and control for unmanned systems.

The well estblished standardization committees are aware that previous standards were not developed with small systems in mind and therefore are not easily implemented in them. There have been new efforts to address this issue but mostly focused on specific needs or environments. For instance, European Defence Agency has commissioned a study on Unmanned Maritime Systems Standardisation Technologies (UMS-ST) aiming at the improvement of interoperability of European Unmanned Maritime Systems (UMS). The purpose of the study is to identify interfaces and propose optimal standards for these interfaces on two levels:

- Interfaces between UMS and other systems (including other UMS) and platforms;
- Interfaces within the UMS platform and its various subsystems in order to enable plug-and-play compatibility at subsystem level.

Another example is the FP7 project ICARUS and DARIUS that deal with developments to deploy unmanned systems in Search and Rescue operations. This project focuses on interoperability issues between unmanned systems, organizations or authorities

6.0 APPLICABILITY TO SMALL UXS HETEROGENEOUS TEAMS

In the context of these types of operations, the standards can be classified as fully operational standards and partially operational resources. The first group focuses on systems interoperability, providing a common communication framework between different agents. They provide all the basic functionality required for a multiplatform system. The second group includes initiatives that are, either very popular on specific fields, or designed specifically for some particular tasks. Most of them can ensure the interoperability between several platforms but not for all the possible type of platforms, systems and range of application.

The lack of a single standard of reference for interoperability of unmanned systems makes any choice difficult since it will have an impact one way or another on legacy platforms. However, some alternatives may fit better for a given set of requirements.

Harmonizing the existing standards, by combining them into one, or by proposing a brand new standard, would obviously solve most of the problems, but it would have serious implications both in industry and other programs that have adopted them as their standard [3]. This is clearly a crusade beyond the possibilities of this paper.

Along the studies, two candidates stood out from the rest, STANAGs related standards and JAUS. They both are stable, mature and complete. They are widely supported by many platforms. STANAG places a strong attention to the payload and ISR data while JAUS is instead more devoted to command and control interface of the platforms, robot navigation and perception. Each standard was created to address a specific requirement in different domains.

STANAG related standards are predominantly military and focused, even though they have been promoted for civil applications, their requirements are heavily demanding in terms of compliance. Likewise, it is mostly focused on UAVs, even though some other types of unmanned systems have been developed to meet the standard. For instance, certifying a small multirotor UAV for the STANAG 7085 Interoperable Data Links for Imaging Systems is costly and probably a barrier for small platforms providers. In this sense, STANAG is perhaps very relevant for the interoperability of military assets across the different NATO members, but it is hard to be adopted by civil or research platform without a strong investment. Furthermore, the geographical constraints (NATO only), the focus on bigger complex systems and the absence of open available implementation make this option less convenient.

Likewise, Joint Architecture for Unmanned Systems (JAUS) was originally designed for UGVs. It is fair to say that JAUS has done great efforts to extend the coverage to any type of platform and currently considers any unmanned system a generic asset JAUS, on the other hand, is fairly aligned with the needs of small unmanned platforms in terms of interoperability. It seems to be quite direct traceability between these needs and the JAUS service sets. It is already compatible with popular transport protocols (TCP, UDP, serial) independently of the communication link beneath it. And it is already multi-environment (air, ground and maritime). There exist both commercial implementations, such as openJAUS, and open source alternatives, such as JAUS++, JAUSToolSet, etc. Unfortunately, there is a fee to access the JAUS documentation which may stop some providers from using it.

There are many other initiatives with strong support in different communities. However, most of them are essentially software framework and middleware rather than standards. They are really valuable and relevant for small unmanned systems development but they do not satisfy the interoperability requirements of the previous standards. They should remain at the platform level (subsystem level). For instance, some groups are using are using ROS and MOOS. It is the scope of the standardization to unify this heterogeneous nature into a single standardized system.

7.0 CASE EXAMPLE: INTEROPERABILITY IN ASSISTIVE ROBOTICS FOR SEARCH AND RESCUE, THE FP7 ICARUS PROJECT

The European research project ICARUS (*http://www.fp7-icarus.eu/*) develops a team of assistive robots to support human crisis manager. 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 for each objective, as defined by the end-users: Belgian First Aid and Support Team (B-FAST) and CINAV (Portuguese Navy).

Figure 1: Multi- small-UxV operation in the ICARUS project.

Having a multitude of robotic systems able to assist with disaster management operations will enhance the situational awareness, but if the interoperability between these heterogeneous agents is missing, then it will not help much in practical operational situations, where these robotic assets need to collaborate and share information. To ensure interoperability, ICARUS proposes the standardization of the Command and Control and Payload interfaces.

An ICARUS team is composed by complementary platforms in terms of capabilities. They play different roles and support one another towards the achievement of the common goals. During the project, the platforms in Figure 2 were adapted and integrated as a single standard team.

For the purpose of the ICARUS project, the analysis of the existing standards has been done with a special focus on Search and Rescue (SAR) operations. The role of ICARUS is therefore to actively contribute to these ongoing standardization initiatives by representing the needs of interoperability of assistive robots in Search and Rescue operations. The strategy followed has been to evaluate the correctness and completeness of the interface on real scenarios in order to identify possible improvements and recommendations.

Figure 2: ICARUS platforms: Atlantik Solar (ETHZ-ASL), Outdoors Quadrotor (ASCAMM), ROAZ II (INESC-TEC), UCAP (INESC-TEC), Indoors Multicopter (Skybotix) Small UGV (Allen Vanguard), Large UGV (Metalliance), USV (Calzoni).

ICARUS developments are heavily based on the end-users feedback, captured in the form of end-user requirements [6]. 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 [7]. Therefore, a single standard Command, Control and Intelligent (C2I) system [8] shall be capable to operate the different robotics asset in a sector.

The integration of several robots as a single integrated team is a major challenge. The C2I system of ICARUS consists of a central Mission Planning and Coordination System (MPCS), field portable Robot Command and Control (RC2) sub-systems, a portable force feedback exoskeleton interface for robot arm tele-manipulation and field mobile devices. The deployment of C2I sub-systems with their communication links for unmanned SAR operations is shown in Figure 3:

Figure 3: C2I deployment in ICARUS.

Figure 4: The rugged and portable, Robot Command and Control station.

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. The ultimate goal of the standardization is to consolidate a common interface to be agreed and adopted by all the robots involved to allow a single ground station to coordinate the team.

The outcome of this study was that JAUS is the best candidate for standardization in the context of this project. 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 middlewares. To accommodate these systems into an ICARUS compliant network, an alternative is to implement and adapter to the robot-specific middleware (translator-based support). Figure 5 illustrates both cases: robot C shows a native integration while robots A and B are using existing middlewares and interfacing the ICARUS network through an adapter:

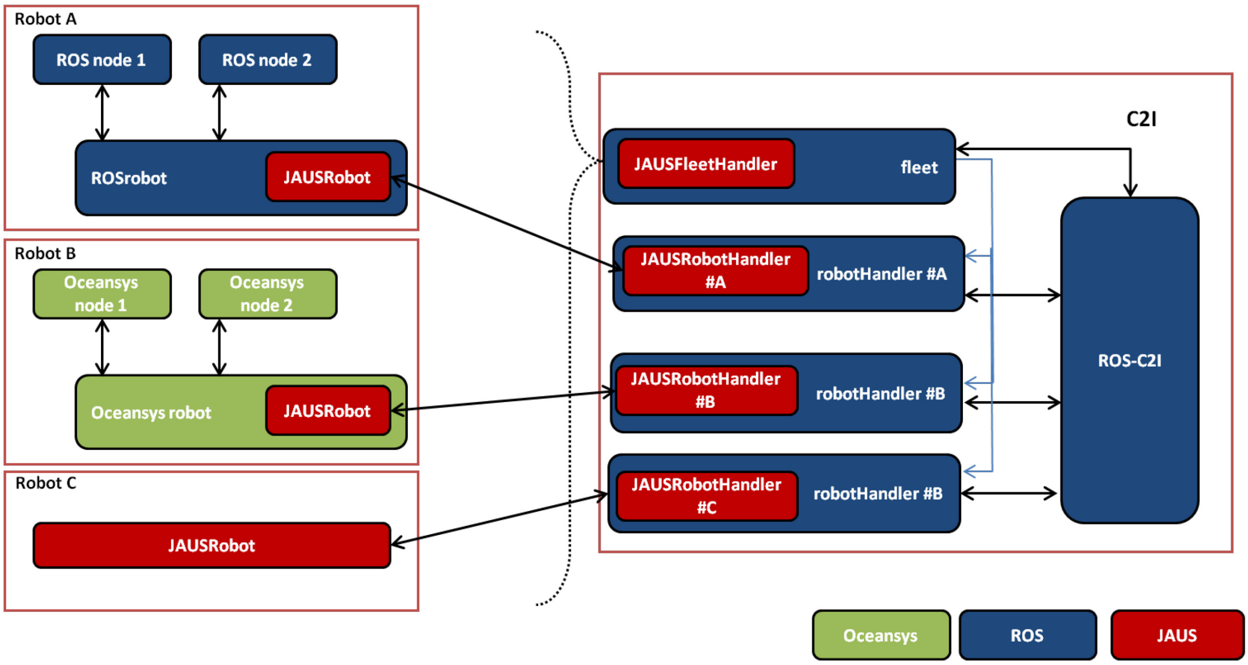

Figure 5: Adaptation of different technologies to the standard [5]

The ICARUS project has validated the interoperability standard through a sequence of trials where the different collaboration between the systems was tested at task and mission level within the ICARUS team. An initial 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.

During the verification of the ICARUS interface, some deviations were identified. A deviation may lead to a gap in the standard and, in such case; a recommendation for an extension may be required. But it may very well mean the opposite. As expected from a standardization activity, the set of messages provided by a each of the platform is generally bigger than the set of standard concepts on the ICARUS interface. A platform is generally able to provide some low level data that is not reflected in the standard for it is not abstract or common to all the platforms. In this case, no recommendation will be derived.

Table 2: Identified gaps.

Services	Platforms			
	Outdoor Quadrotors	***Indoor Quadrotors***	***Ground robots***	***Large sea vehicles***
Survival Kit deployment	X			
Rescue Capsule deployment				X
Platform-specific components enable/disable			X	
Platform extended status	X	X	X	X
Manipulator tool selection			X	
Voice transmission				X

JAUS standards are actively maintained. The current set of services focus on the common functionality of heterogeneous unmanned systems, but there are initiatives working on future service-sets focusing on the specific requirements of air, ground and sea platforms. These will be gradually released in the next years, and some of the new services may fill the gaps identified in here.

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