Interoperability of armed forces unmanned systems – the INTERACT project

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ABSTRACT

The INTERACT Project, funded by the DG-DEFIS of the European Commission and managed by the European Defence Agency (EDA), aims at enhancing the capabilities of European armed forces to safely, effectively and flexibly operate unmanned and manned systems in joint or combined operations. The challenge to achieve this lies in creating overarching interoperability concepts for defence systems in general and unmanned systems in particular.

INTERACT proposes to use selected NATO STANAGs to engender compatibility for military systems. But the lack of a promulgated STANAG for UxS (Unmanned Systems) control in an all-domain context is identified as a major gap regarding this endeavour.

As a response the INTERACT project is elaborating a set of interoperability concepts and standardisation proposals, which will enable the coordinated deployment of multiple and potential heterogeneous platforms by a single, standardised control station as well as the controlled hand-over of platforms between INTERACT compliant control nodes.

The INTERACT solution creates a holistic approach and includes the proposal for concepts and design of a set of interoperable standardized interfaces between subsystems and payloads within an unmanned system (intra-system interoperability) to ease the upgrade and adoption of novel payloads and maintaining and upgrading equipment and components to the state-of-the-art, as well as the proposal for inter-system interface standardization in order to pave the way for future operational concepts where autonomous assets will flexibly operate together in organized heterogeneous UxS teams.

Beneath the system interoperability INTERACT will also address the human-machine interaction by proposing a common design solution for standardisable user interfaces.

The INTERACT consortium consists of 4 major European RTOs as a core team supported by a strong alliance of 15 representative European defence industries, SMEs and RTOs from 11 different nations.

Keywords: unmanned systems, interoperability, standards, open architecture

1. INTRODUCTION

As UxSs increasingly become a key instrument in civilian and defense operations, the necessity for interoperability support is more pressing than ever before. Multiple aspects are to be considered, such as piloting, controlling multiple UxS by a single control station, exchange of data collected during a mission and data link interoperability.

NATO Standardization Agreements (STANAGs) are commonly used for existing systems, and are widely adopted in the defense industry. However, for the complete UxS area considering all the involved domains (ground, maritime, air) no STANAG has been promulgated (NATO STANAG 4817 - Multi-Domain Control Station is under development and not publicly available yet).

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In response to these challenges, INTERACT provided a set of interoperability solutions and standardisation proposals, which will enable the coordinated use of multiple platforms by a single, standardised control station and the controlled hand-over of platforms to other control stations. This coordinated use of multiple platforms and the hand-over possibility together with an envisioned standard proposal for an interoperable data link including standardized security will enable the deployment of complex UxS platforms in a network-centric environment within future multi-national operations. In addition to this inter-system interoperability and in order to ease the upgrade and adoption of novel payloads and maintaining and upgrading equipment and components to the state-of-the-art, INTERACT also designed and proposes as standard a set of interoperable interfaces between the subsystems and payloads within an unmanned system (intra-system interoperability). These standard interfaces will lead to plug-and-play connection capabilities, making it thus easy to install new mission payloads or change them on demand. This will enable the adaptability of unmanned systems to specific mission requirements. INTERACT also addresses the human-machine interaction and teaming aspects of manned systems and UxS by proposing a common design solution for standardisable user interfaces and proposing it as a standard. This would increase multi-national and cross-national domain interoperability, making it easier to operate various UxS. In addition, the human-machine interaction solutions will allow the mixed initiative planning and management of tasks, smooth transitions and hand-overs in human-machine transfer of control and changes between interaction modes, diversity of strategies for human control of unmanned systems with varying degrees of automation.

Specifically, INTERACT defined concepts and proposed standards to be used for ensuring interoperability of payloads and carriers, defined the functionality needed for implementing an interoperable control station, capable of simultaneously controlling multiple heterogeneous UxS as well as responding flexibly to changes and requirements in relation to other control units, proposed the use of standards and defined requirements at functional level of future communication needs, including their adaptability to future environments and high-data rate exchanges. INTERACT also define the means to enable the use of heterogeneous unmanned systems in a variety of combinations, including their usage as an autonomously acting team. In addition, INTERACT developed an Interoperability Open Architecture of interoperable UxS and control stations.

This paper presents the results regarding the interoperability of payloads and carriers, concepts for autonomous unmanned systems working as a team, and the proposed solutions for interoperable control stations.

The rest of the paper is structured as follows: Section 2 provides the concepts and proposed standards for payload-carrier interoperability. In section 3 the command and control concepts for exchangeable payloads are described and in section 4 the design of an interoperable control station is provided. The paper concludes with a conclusion and an outlook of the future work of INTGERACT.

2. PAYLOAD-CARRIER INTEROPERABILITY

Based on a state-of-the-art analysis performed at the beginning of the INTERACT project, the Sensor Open Systems Architecture (SOSA) standard [1] is proposed by INTERACT as a candidate for payload-carrier interoperability.

The SOSA standardizes hard-, firm- and software of a SOSA sensor. The main outcomes of the work of the SOSA working groups are these three documents:

- Technical Standard for SOSA™ Reference Architecture, Edition 1.0 (September 2021)
- Technical Standard for SOSA™ Reference Architecture, Edition 1.0: SOSA Domain-Specific Data Model
- SOSA™ Business Guide Version 0.8

SOSA adopts the most appropriate subsets of existing open standards to form a multipurpose backbone of building blocks for current and future embedded systems for the five sensor types Radar, EO/IR, SIGINT, EW, and communications. SOSA is/will be developed as a standard of standards (currently SOSA references 96 other standards!).

SOSA objectives include vendor agnostic (with the implication of higher market competition and lower costs), lower procurement (e.g. development & integration) costs, easier technology upgrades (e.g. through modularity), quicker reaction to new requirements (e.g. fielding a new sensor) and longer life cycles (e.g. through re-use).

The SOSA Architecture was documented using the DoDAF, Version 2.02 Viewpoint Models.

The SOSA Reference Architecture follows the grey box design, that is, it describes what SOSA elements are doing and specifies the interfaces. The SOSA Reference Architecture does not describe how functions are (to be) implemented, that lies in the responsibility of the manufacturer of the components to be able to protect their intellectual property.

In the SV-1 (System View 1 system interface description) the physical/hardware elements of a SOSA Sensor and the SOSA Host and their interconnections are depicted. A SOSA Host is either the platform (i.e. the carrier) itself or a pod, which is mounted on/in the carrier. The interconnections are physical mountings, cooling, power, analogue & digital and the respective connectors. A SOSA sensor may have several SOSA (hardware) elements, which are connected via the SOSA internal interfaces. Connections crossing the system boundary of a SOSA Sensor realizes the SOSA external interfaces to the SOSA Host.

A SOSA hardware element consists of an aperture, which can be an antenna, packaged antenna or imaging array or an imaging turret as well as a hardware enclosure (i.e. a chassis) with Plug-In Cards (PICs) connected to a backplane.

The SOSA Host Platform is the physical entity (i.e. the carrier) to which the SOSA sensor is mounted. It can be a vehicle, a building or one or more pods. The host platform provides power, cooling, platform navigation information, reference signals, network connection and connections to analogue & digital interfaces. The host platform may contain external processing capabilities using the sensor products and provides the sensor with its tasking information.

Figure 1 shows the services context diagram (Service View 1 in DoDAF) of a SOSA sensor, the relevant modules with parts of the descriptions for the coverage of the refined requirements are described in Table 1. The modules in Figure 1 are the main building blocks of the SOSA architecture, whereby it is not mandatory for a system to realize all of these modules at once to be conformant. The architecture is built in three main layers: Sensor Management (main index 1), Processing Chain & Data Path (main indices 2 through 5) and the Supporting Services (main index 6).

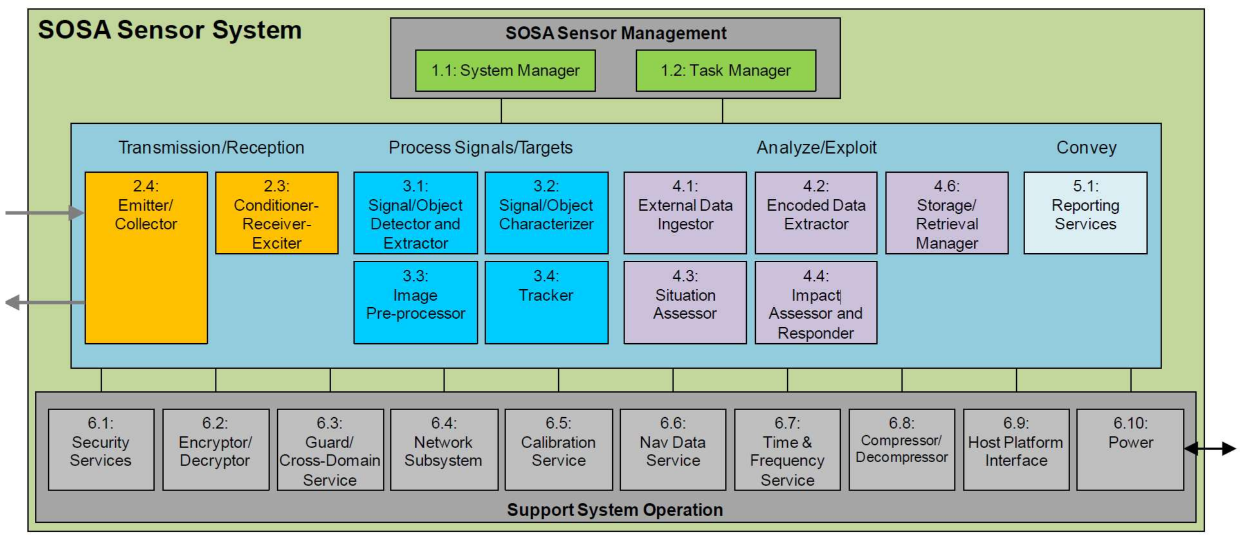


Figure 1: SvcV-1 Top-Level SOSA Services Context Description [1]

SOSA supports only RF sensors in version 1.0 of the reference architecture description. EO/IR sensors will be supported in future versions. The current version of the SOSA Technical Standard specifies the requirements for the transmission/reception modules when operating on RF signals in EW, Radar, and SIGINT modalities.

The flow of resources (e.g. control, status & sensor data) is depicted in Figure 2. The Host Platform Interface is the system boundary between the host platform (i.e. the carrier) and the SOSA sensor (i.e. the payload). Command & control information is crossing this boundary into the sensor and the sensor products are directed to the host platform (i.e. the carrier). This interface is mainly attached to the SOSA Sensor Management (System & Task Managers) and the processing chain, where operational relevant services generates higher value information i.e. by constituting data & information fusion functionalities (object detection -> situation assessor -> impact assessor) up to level 3 in the JDL information fusion model [2] from the raw sensor data. At the end of the chain the Reporting services are delivering the generated products (e.g. images, videos, tracks, contributions to operational picture).

Table 1: Relevant SOSA modules and their (shortened) description

SOSA sensor component	Relevant part of the Description
1.1 System Manager	System management functions include … Configuration (obtaining a detailed description of the sensor, its sensor components, and the security controls applied, reading and setting configuration parameters, and updating software packages), …, … provides “housekeeping” functions of the system … … takes care of the SOSA sensor itself so it can implement the mission.
1.2 Task Manager	The Task Manager module is responsible for coordinating all mission operations. External sensor tasking is accepted in the form of a request that contains information detailing when and where to collect data, the type of processing to be performed, and the required output products to be generated. The Task Manager module supports the tasking and control functions <u>but is not ready for publication in this version (version 1.0) of the standard.</u>
4.6 Storage/Retrieval Manager	The Storage/Retrieval Manager module provides the capability of storing a variety of data types in a persistent medium and allows it to be retrieved in bulk by authorized client entities.
5.1 Reporting Services	The Reporting Services module generates and disseminates reports. Specifically, the Reporting Services module is responsible for formatting, processing (as required by sensor type), packaging data for reporting, structuring data to match a selected format, and dissemination of data to intended recipients. Such data can include RF signal, image/video streams … The module is responsible for accepting/rejecting requests for existing data in storage,
6.4 Network Subsystem	The Network Subsystem module is the infrastructure responsible for … transferring data with the requested Quality of Service (QoS), and detecting intrusion …
6.7 Time & Frequency Service	The Time & Frequency Service module is responsible for providing time information and … The time information is a high precision time signal that is a higher precision than that typically provided by GPS although it may be synchronized with GPS …
6.9 Host Platform Interface	The Host Platform Interface (HPI) module is responsible for all communication with the host platform. Its primary function is data translation to/from formats and messages required by the host platform.

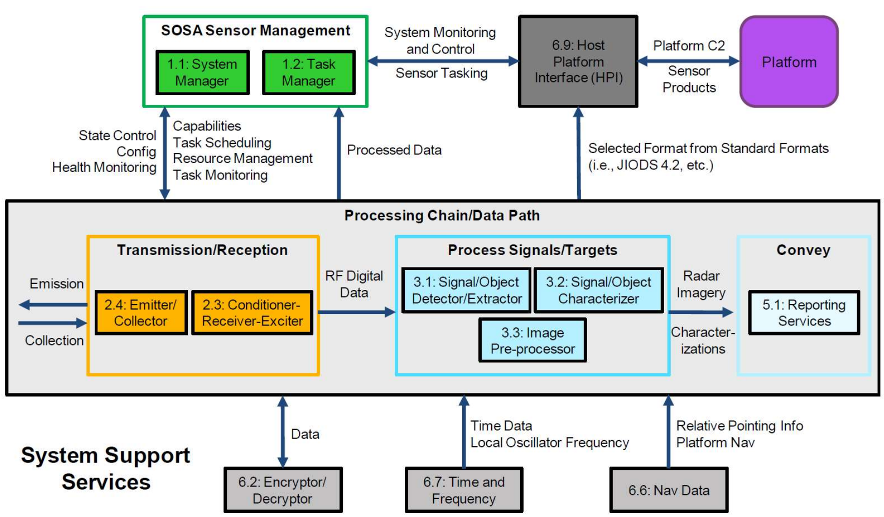


Figure 2: SvcV-2 Top-level SOSA service resource flow [1]

The Host Platform Interface (HPI) is detailed in Figure 3, showing the direct communication (interactions) with the System & Task Managers. These interactions represent a basic set of functionalities distilled from Universal Command & Control

Interface[1] (UCI), VICTORY[2], and STANAG 4586 [3], [4]. The Host Platform Interface translates command and control messages in the UCI, VICTORY, or STANAG 4586 format into the SOSA message format and vice versa. The HPI uses publish-subscribe (blunt end at the publisher side) and request-response (dotted line with diamond at the requestor side) interaction types.

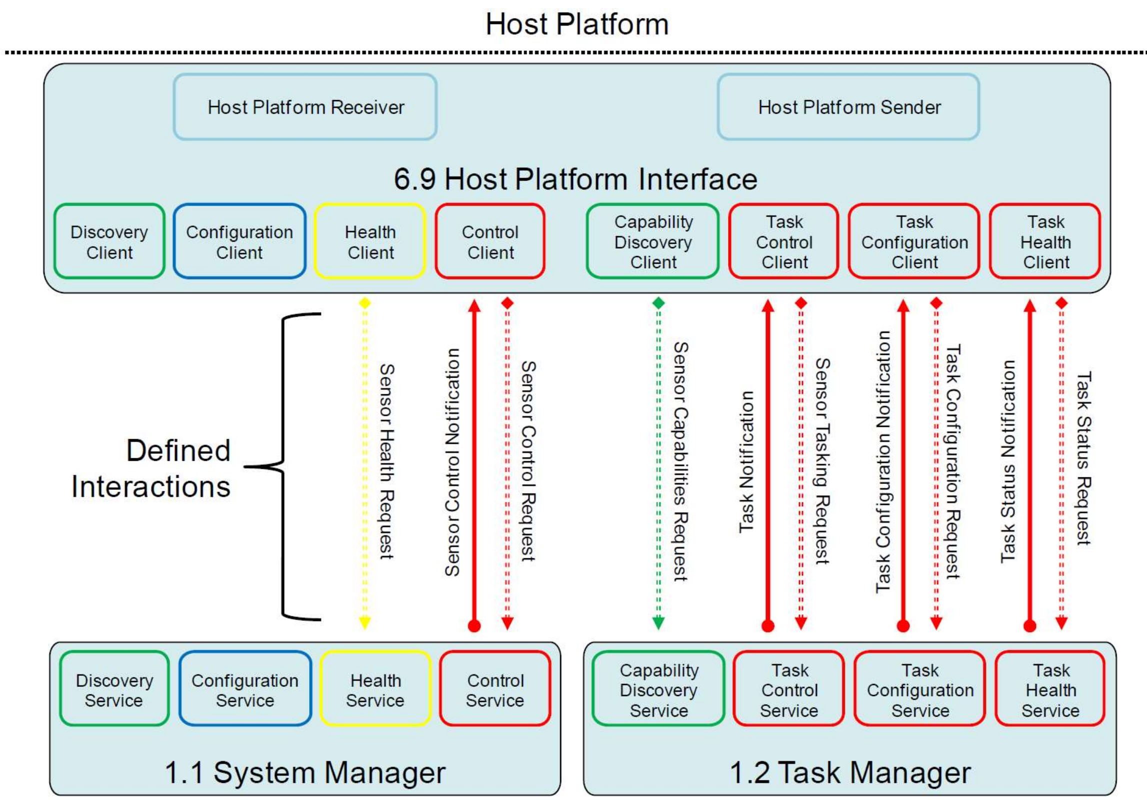


Figure 3: Host Platform Interface with interactions [1].

The relevant part of the HPI to translate between the outside world (i.e. the carrier) and the SOSA message world is the Task Manager component, which provides Capability Discovery, Task Control, Task Configuration and Task Health functions.

3. COMMAND AND CONTROL CONCEPTS FOR INTEROPERABLE (EXCHANGEABLE) PAYLOAD SYSTEMS

Payload control concept covers an approach how to deal with the different possible payload systems and regarding the feedback (status data), the configuration, but most importantly the control of the payload as well as the sensor via a unified or compatible protocol usable in a variety of different control stations (CS).

Based on a state-of-the-art analysis and review of existing standards performed at the beginning of the INTERACT project, three standards / approaches were identified as potential candidates for the command and control concepts for interoperable (exchangeable) payload systems:

[1] The Universal Command and Control Interface [formerly the Unmanned Aerospace Systems (UAS) Command and Control (C2) Standard Initiative] establishes a set of messages for machine-to-machine, mission-level command and control for airborne systems. The UCI vision is to decrease acquisition and operational costs of manned and unmanned systems and enable interoperability

2 The Vehicle Integration for C4ISR/EW Interoperability (VICTORY) standard was developed as a standard for U.S. Army vehicles

- JAUS

  As described in [5] the Joint Architecture for Unmanned Systems (JAUS) is an international standard that establishes a common set of message formats and communication protocols for supporting interoperability within and between unmanned vehicles and ground control stations. One aspect that needs to be covered is the command and control of the payload of unmanned systems. This is addressed with the JAUS Manipulator Service Set (SAE AS6057) [6] that contains the 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.).

- STANAG 4817 - Multi Domain Control Station (MDCS)

  STANAG 4817 has the goal to establishing a common framework for UxV control (Air, Sea, Underwater). Control and command concepts for multi domain payload systems are expected to be intensively covered by the STANAG 4817.

- STANAG 4586 - UAV Interoperability

  STANAG 4586 provides the definitions of the architecture and messages required for the interoperability of UAVs in complex NATO Combined/Joint Services Operational Environment. Essentially, it comprises the ‘rules’ that will allow an operator to have a defined level of control over any Unmanned Aerial Vehicle (UAV) that is standard compliant. At the same time, C4I systems will have access to UAV payload product [7]. A part of the STANAG 4586 definition is specifically dedicated to payload control. This subpart of the standard can be considered regarding the Command and Control Concepts for Interoperable (Exchangeable) Payload Systems

Since the development of the STANAG 4817 has been stopped during the INTERACT project duration and results of the STANAG 4817 are only preliminary and difficult to achieve, it has not been further analysed.

JAUS is a well-defined and comprehensively introduced standard, developed from quite a different viewpoint than e.g. STANAG 4586. The JAUS is very much focusing on the technical capabilities of ground vehicles and therefore has a strong dedication to functionalities relevant to the ground domain.

Although the JAUS approach is identified as a possible solution by the INTERACT consortium and capable of solving at least most of the interoperability issues regarding heterogeneous multi domain UxVs, it overemphasizes some technical (i.e. ground related) aspects (e.g. the manipulator control) and lacks some essential concepts at the same time (e.g. regarding more abstract payload control as waypoint indicated automatic payload actions or directing the payload to a given location (look-at-command)).

The STANAG 4586 provides the definitions of the architecture and messages etc. required for the interoperability of UAVs in complex NATO Combined/Joint Services Operational Environment. Essentially, it comprises the ‘rules’ that will allow an operator to have a defined level of control over any Unmanned Aerial Vehicle (UAV) that is standard compliant. At the same time, C4I systems will have full access to the UAV payload products [4].

The STANAG 4586 limits itself to the command and control of (single) Unmanned Aerial Vehicles and their payloads. It defines the data and command exchange format and regulates very radically the overall system design and architecture. It defines system modules, their functions and their interfaces up to the definition and design of the human device interface.

In order to be used for a wider group of unmanned assets, INTERACT analysed the STANAG 4586 message structure and provided proposals for extending or adapting existing fields in the messages in order to be fully applicable to the various domains. Especially with respect to the innovative functions required for centralized or decentralized, autonomous or semi-autonomous payload control, among others, in a UxV team, the respective messages have been identified and proposals for extending them have been provided. For example, the message #19700: Payload Operating Mode Command in the field 0201.06 should be supplemented by corresponding enumeration entries.

In addition, it is necessary to extend the messages, which are exclusively geared to aerial vehicles, to include corresponding payload types of other domains. For example, the specific limitation of STANAG 4586 to SAR, EO, and IR payloads is not up-to-date in the context of the different domains (INTERACT). A corresponding change should be set up to take also other payloads into account like: LIDAR, SONAR

To conclude, even if the STANAG 4586 is solely focusing on UAV / RPAS, it is widely accepted as a standard e.g. in European Armed Forces and it seems therefore legitimate to select the STANAG 4586 as a basis for UxV payload control commands and messages. Gaps in the existing solution have been identified and proposals are made how to close them.

4. CONTROL STATION INTEROPERABILITY

Via a control station an operator steers one or multiple unmanned vehicles (UxVs) and is thus responsible for accomplishing the mission goals. In order to enable this, a control station shall exhibit the following capabilities:

- Mission planning of heterogeneous UxVs
- Control of individual UxV either tele-operated or autonomous
- Progress monitoring of overall mission, individual UxVs, and teams
- Control handover of UxV platform and/or payload between control stations
- Collect and share payload data
- Collect and share status of platform and payload data
- Team operation by combining and controlling groups of autonomous UxVs

For providing these capabilities, INTERACT derived a set of high-level functions for control stations, addressing platform management, payload management, communication, mission planning, mission execution, and control station human-machine interface (HMI). Table 2 lists these functions.

Table 2: High-level functions of a control station

Function	**Description**
Platform Management	
operatePlatform	Control for platform movement (navigation e.g. course, speed or waypoints, autonomy) Display platform ownership and controller Control for handover of platform control
displayPlatformStatus	Display platform status (position, speed, remaining power, health status, autonomy status/mode)
operateTeam	Display task assignments and progress
Payload Management	
operatePayload	Control the payload directly (joystick, higher level commands, autonomy) Display payload ownership and controller Control for handover of payload control
displayPayloadData	Display payload data from UxVs (some may be controlled by another control station) Display payload data ownership and viewer
displayPayloadStatus	Display payload status (field of view, viewing angle, autonomy status/mode)
configurePayload	Configure the payload parameters (sensor modes, sensor parameters)
recordRawSensorData	Control for recording of raw sensor data on a (removable) drive Display recording progress Display remaining space on drive for recording
Communication	
configureCommunicationLink	Controls to configure communication link
displayCommunicationLinkStatus	Display communication link status

Mission Planning	
planAreaCoverage	Enable continuous area coverage of designated areas Enable defined revisit times for area coverage Display estimated coverage
confirmISRInformation	Enable confirmation of ISR information
planMission	Controls for detailed path planning Controls for high level path planning with Path Management & Control component Display planned trajectories
planPayload	Controls for detailed payload planning Controls for high level payload planning with Payload Management & Control component
configureContingencyManagement	Controls to configure contingency management
exchangeMissionData	Control for transmission of mission data to UxVs UxVs may also exchange mission data
Mission Execution	
displayCommonOperationalPicture	Display COP with information age Update COP
displayMissionProgress	This function gives an update of the mission progress of a UxV or a team.
Control Station HMI	
provideMeaningfulHumanControl	Assure that humans stay in control and are responsible for critical decisions
provideMultiModalControl	Provide gesture-based control
provideMultiLanguage	Provide multi-language support

An interoperable control station architecture that provides the functions listed in the table above consists of several components. INTERACT identified the following components which are needed for an interoperable control station: components for platform, payload, and communication management, components for C4ISR interaction, for information services, mission execution, and for interaction between different control stations. In addition, components for configuring automatically a control station have been identified. Table 3 lists these components.

Table 3: Components of a control station

Component	**Description**	**Contents**
Platform Management		
Platform operation	Controls platform movement	Configuration, course, speed, waypoints, autonomy
Platform status	Describes platform status	Position, speed, remaining power, health status, autonomy status/mode, ownership
Payload Management		
Payload operation	Controls payload	Configuration, orientation
Payload status	Describes payload status	Field of view, viewing angle, autonomy status/mode, ownership, viewer, controller
Payload data	Publishes payload data	Video, images, tracks, detections
Payload data recorder	Records and replays payload data	Video, images

Communication Managemet		
Communication configuration	Configures communication link	Protocol
Communication status	Describes communication link status	Active configuration
C4ISR Interaction		
Mission description	Describes control station mission	Orders, pre-planned mission plans, changes requiring dynamic retasking
Mission status	Publishes mission status	Mission plan, progress, reporting
Common operational picture	Describes the common operational picture	Force positions, status, tracks, payload data, UxV teaming
UxV pool	Describes taskable UxVs within the operational area	Identifier, ownership, controller, status, availability, host communication link
UxV profiler	Obtains UxV capabilities	Identifier, domain, carrier class, sensors, protocol
Information Services		
Geographic information system	Stores geographic data	Map
Data fusion	Integrates multiple data sources	Tracks, behaviour
Mission planner	Automatic planning of platform and/or payload based on high-level input	Route, waypoints, payload coverage
Mission Execution		
Mission planning	Planning of platform, payload, and communication	Route, waypoints, payload coverage, communication settings
Mission progress	Describes accomplished tasks and reports operational situation	Tasks, tracks, detections
Tasking	Task assignment of UxVs	Surveillance, position, detection
Teaming	Teaming of UxVs	Team identification, role
Interaction between Control Stations		
Payload data sharing	Shares payload data	Request, authorisation, ownership, viewer
Handover	Interaction for platform and/or payload handover	Request, authorisation, ownership, controller
Mission status	Publishes mission status	Mission plan, progress
Mission coordination	Coordination of mission execution	Tasking
Control Station Configuration		
UxV profiles	Describes UxV capabilities	Identifier, domain, carrier class, payload, protocol
Control station profile	Discovers and describes control station capabilities	Display configuration, input/output devices
UxV combination	Describes the UxV combination and teaming	Domain, number of UxVs, team identification
Configuration library	Describes control station configurations	Display component layout, input mapping from inputs to commands
Configuration manager	Determines control station configuration	Display layout, input mapping from inputs to commands

Based on the components listed in the table above, a set of messages between the control station and UxVs that have been defined by INTERACT, a proposal for a standard UxV control station user interface has been developed. This proposal aggregates existing interface concepts and complements them with missing display components.

Humann 2019 [10] describes how scalability of multi-robot systems is limited by operators' cognitive abilities, decision making speed, and performance under stress. An overview of 24 empirical research studies shows that the limit for how many UxVs humans can control is 4-8 robots. The standard control station is limited to control of four UxVs, including shared payload data and handover of payload control. The rationale for limiting the control to four UxVs is to ensure that UxV operators are not experiencing work overload, even in more stressful situations.

For the standard control station two monitors are recommended. The left monitor for mission management and the right monitor for display of payload data. Presentation of all information on only one monitor invariably seems to require switching of display pages when controlling multiple UxV, which should be avoided for real-time control of multiple UxVs.

Figure 4 shows an example of the display layout for the left monitor of the standard control station. On the left side there are three sections for (1) time and weather information, (2) summary of UxV mission phase, navigation information, alerts, and handover status, and (3) display components for each UxV that shows detailed telemetry information for carrier navigation, status, estimated time of arrival, fuel status, operating mode, alerts, payload status, and data link alerts. The type of carrier status and payload status information that is presented depends on the type of UxV and payload.

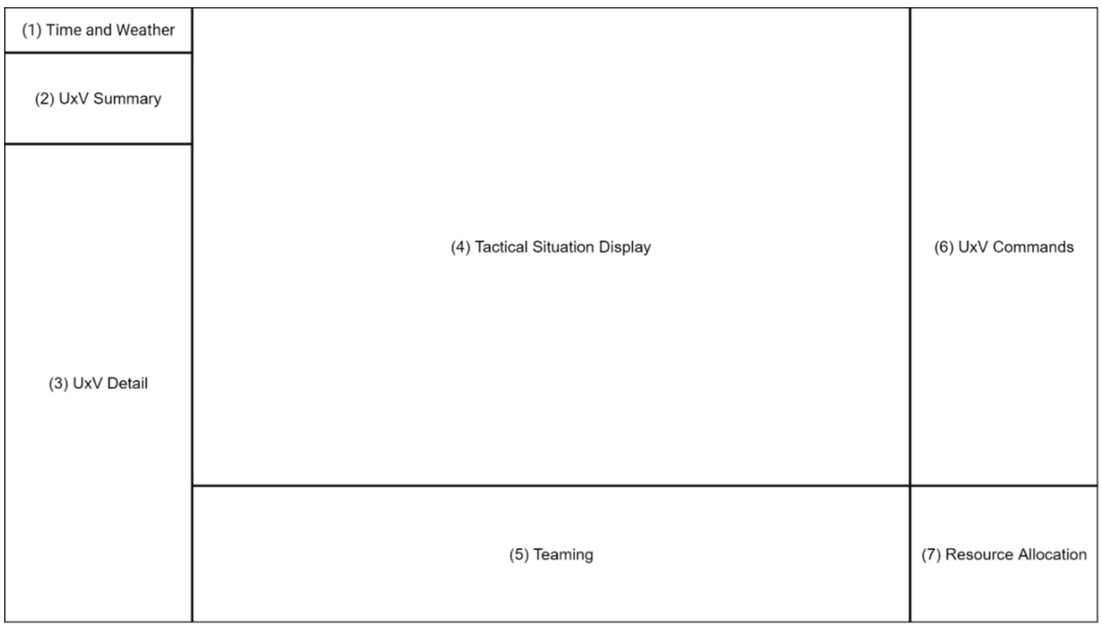


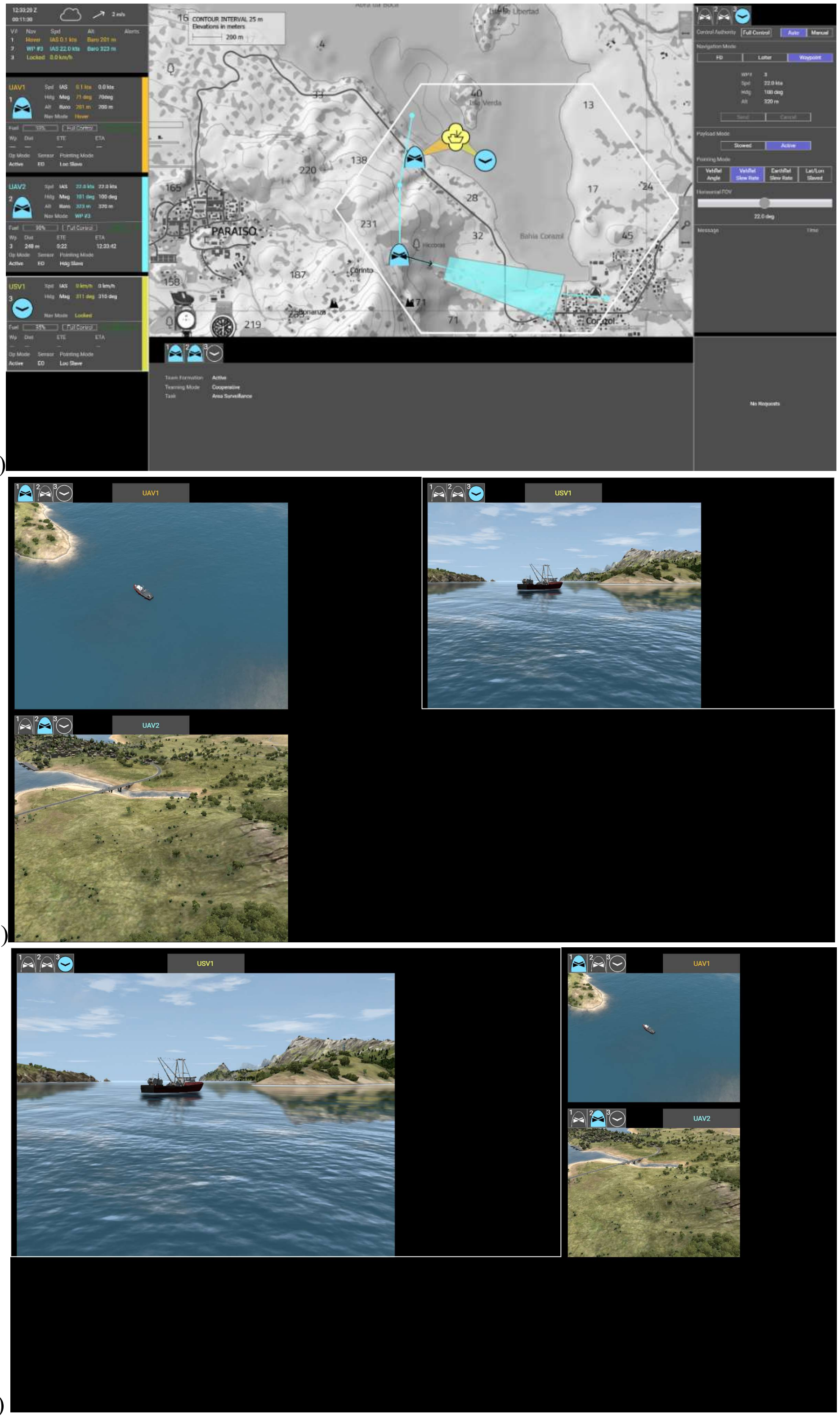
Figure 4: Display layout for the left monitor

In the middle there are two sections for (4) display for the Tactical Situation and (5) commands to teams of autonomous UxVs. The Tactical Situation display shows geo-referenced data, such as elevation, mission plan, UxV position, heading, and payload footprint. The team and autonomy command section is only shown for control of autonomous UxVs. On the right there are two sections for (6) commands and configuration of individual UxVs and (7) resource allocation. Some examples of UxV configurations are waypoint configuration, loitering configuration for UAVs, and payload configuration.

Each UxV has an icon, identifier, call sign, and colour that is used in display components to distinguish among UxVs and associate related information between sections. The identifiers are UAV1, UGV1, and USV1 etc. with sequentially increasing numbers. The UxV colours are orange, cyan, yellow, and pink.

The display layout of the right monitor of the standard control station consists of one section for payload data for each UxV. Operators can select the sections' size as needed. By default, all sections have the same size. Operators can enlarge one section while minimizing the other sections

Figure 5 shows a conceptual example of the left (a)) and right monitor (b) and c)) where a team of two UAVs performs area surveillance supported by one USV. One UAV detects a fishing boat that is inspected with the USV.



a) b) c)

Figure 5: Conceptual example of control station interface where a team of two UAVs performs area surveillance supported by one USV. One UAV detects a fishing boat that is inspected with the USV

5. CONCLUSION AND FUTURE WORK

The INTERACT project developed a set of interoperability concepts and standardization proposals, which will enable the coordinated deployment of multiple and potential heterogeneous platforms by a single, standardized control station as well as the controlled hand-over of platforms between INTERACT compliant control nodes.

Especially proposals for a standardized interface between payloads and carriers, based on the SOSA standard, command and control concepts for steering both unmanned assets as well as their payload have been developed.

In addition, a proposal for an interoperable control station, the functions to be provided by it, its components, and the graphical user interface has been developed.

Future work will combine these interoperability concepts into an open interoperability architecture, providing the interfaces for the design of unmanned systems and a description of all architectural components.

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