INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

IUSAR Workshop

13th IAS Conference

Daniel Serrano (ASCAMM)
Interoperability among SAR platforms

ICARUS interoperability needs

Multiple heterogeneous vehicle operations

Way forward
Interoperability among SAR platforms
What do we call interoperability?

• Ability to operate in synergy in the execution of assigned tasks.

• Capability of diverse systems and organizations to share data, intelligence and resources.

• Easy compatibility with future and already existing platforms and C4I systems.

Source: BFAST
Why is it important?

Interoperability acts as the “glue” for unmanned systems: a common method for communicating different technologies.

- **Reduces development and integration time**: avoids custom implementations and speeds up the integration time by the use of proven technology.

- **Provides a framework for technology insertion**: new technology can be easily integrated, expanding the functionality currently available on the field.
What is the current situation?

- **Unmanned Systems in SAR operations**: initial demonstration of their benefits in the field.

- **Middleware and common tools**: some tools are supporting the developments and data exchange (ROS, MOOS, MAVlink, OGC standards, etc)

But there are no protocols or standards in place for the insertion and use of autonomous SAR platforms in the field.
Standardization for Unmanned Systems interfaces:
Several standards, addressing specific domains, place emphasis on different types of data:

- STANAG 4586: data from payloads onboard UAVs,
- JAUS: command and control (C2) of heterogeneous UxV,
- Unmanned Maritime Systems Standardisation Technologies (UMS-ST) at EDA,
ICARUS interoperability needs
ICARUS interoperability needs

• ICARUS involves a team of very diverse assistive unmanned air (4), ground (2) and sea vehicles (2 + n).

• They must collaborate as a coordinated, seamlessly-integrated team in the single C4I system of the human crisis managers.
How is ICARUS targeting interoperability?

1. **Single standardized Command and Control** for all platforms.

Source: Space Applications
2. Seamlessly integrated communication network.

Source: Integrasys
3. Platforms are to comply with the ICARUS standard interface, which shall be based on existing standards (see later).
ICARUS also considers interoperability in the operational scenario:

4. Definition of roles, tasks and responsibilities.

**Mission goal:** the overall objective that the team must accomplish.

**Mission planning:** responsible to coordinate the team and to allocate roles to each of the robots.

**Role:** the robot's behavior and its interactions with other members of the fleet or with humans.

**Tasks:** A set of actions to be executed by a robot.

**Responsibility:** Role allocated to a robot in an ICARUS mission.
**ICARUS roles**

<table>
<thead>
<tr>
<th>ICARUS Roles</th>
<th>Description</th>
<th>Modes/Platforms</th>
</tr>
</thead>
</table>
| Scout        | Provides a quick assessment of an unexplored area or route. | - Overview of an entire disaster zone (ENDUR UAS).  
- Traversability/best route exploration (ENDUR UAS). |
| Surveyor     | Provides a detailed scan of an area or building as support for a thoroughly assessment and inspection (structure integrity, victims, hazards, etc.). The platform intelligence shall support automation and ensure coverage and quality of data. | - 2D/3D geo-referenced “map” of the entire disaster zone as basis for sectorization (ENDUR UAS).  
- High resolution 2D/3D geo-referenced “map” of a sector (ENDUR UAS for higher altitude and AROT for lower altitude) or a structure (AROT).  
- Building indoors (autonomous) inspections (SROT and SUGV) for |
| Observer     | Steady target (both victims and structures) observation and assessment. | - Steady hover over a target (AROT), including harsh weather conditions (GYRO)  
- Victim medical state assessment outdoors (AROT), indoors (SROT) and both (SUGV). |
| Manipulator  | Heavy interventions on the environments | - Removing debris, clearing route with the robotic manipulator (LUGV)  
- Building shoring (LUGV) |
| Searcher     | Victims search | - Outdoors aerial long-range human detection on IR (ENDUR UAS)  
- Outdoors aerial short-range detection on IR (AROT)  
- Indoors short-range detection on IR (SUGV)  
- Indoors short-range detection on IR (SROT) |
| Rescuer      | Supports the rescue of victims | - Helps victims to escape from hazard areas (SUGV) or supports human rescuers in their activities.  
- Rescue capsule. |
| Deliverer    | Safety kit delivery | - Delivery of a survival kit to a victim, aerial (AROT), terrestrial (SUGV) or maritime (LUSV) |
| Cruiser      | Travel to a destination. | - All platforms when transiting to a final destination where another role is enabled.  
- The larger platforms (LUGV and LUSV) may also act as a Transporter carrying tools, debris or even the smaller platforms, such as the AROT and the rescue capsules. |

*Table 2: ICARUS roles*
## ICARUS robot tasks

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Operations</th>
<th>Mobility</th>
<th>Advanced Mission Support</th>
<th>Perception</th>
<th>Action/Grasping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Launch</td>
<td>Set motion request</td>
<td>Scan 2D area</td>
<td>Enable Payload (i.e. cameras, deploy manipulator, etc)</td>
<td>Delivery</td>
</tr>
<tr>
<td></td>
<td>Recovery</td>
<td>Go to Waypoint</td>
<td>Scan 3D area</td>
<td>Disable Payload</td>
<td>Robotic arm teleoperation</td>
</tr>
<tr>
<td></td>
<td>Abort</td>
<td>Standby</td>
<td>Search in area</td>
<td>Capture payload sensor sample/frame</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Return home</td>
<td>Activate/Deactivate modules (collision avoidance, path planner, world modelling, etc)</td>
<td>Configure payload management (record, pause, stop)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Change Level of Automation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mission management (start, stop, pause)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. ICARUS tasks
5. Adjustable automation

The degree of intervention of the human operator

<table>
<thead>
<tr>
<th>Level of automation for decisional robot components</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
</tr>
</tbody>
</table>

Table 4. Level of autonomy for ICARUS robots

![Graph showing maximum automation level per platform](image-url)

Table 5. ICARUS robots autonomy
Levels of interoperability

To account for very diverse platforms technologies

**Level 1:** Indirect receipt/transmission of UxV metadata and payload data. 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. 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)
ICARUS data model
ICARUS data model

Definition of **standard concepts** (messages) describing capabilities and services commonly found in a ICARUS team.

**Groups of concepts:**
- System management
- Pose and velocity telemetry
- Modes, waypoints and motion commands
- Mission management
- Raw sensors
- Manipulator
- Sensing (perception)
- Mission command and control
System management

Basic interoperability mechanism between components and systems in an ICARUS system. Following sets and protocols builds upon these concepts

Examples:
- Heartbeat
- System status
- Clock
- Alarms
- Emergency

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestamp</td>
<td>uint32</td>
<td>Message time</td>
</tr>
<tr>
<td>Source ID</td>
<td>uint32</td>
<td>Sender address</td>
</tr>
<tr>
<td>Destination ID</td>
<td>uint32</td>
<td>Destination address</td>
</tr>
<tr>
<td>Status</td>
<td>uint8</td>
<td>0 – Standby</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 – Ready</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 – Failure</td>
</tr>
<tr>
<td>Error code</td>
<td>uint16</td>
<td></td>
</tr>
</tbody>
</table>

Example of system status
Pose and velocity telemetry

Robot states such as pose, velocity and attitude.

Examples:
- Global pose
- Local pose
- Attitude
- Velocity

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestamp</td>
<td>uint32</td>
<td>Message time</td>
</tr>
<tr>
<td>Source ID</td>
<td>uint32</td>
<td>Sender address</td>
</tr>
<tr>
<td>Destination ID</td>
<td>unit32</td>
<td>Destination address</td>
</tr>
<tr>
<td>Latitude</td>
<td>unit32</td>
<td>Degrees, WGS84</td>
</tr>
<tr>
<td>Longitude</td>
<td>unit32</td>
<td>Degrees, WGS84</td>
</tr>
<tr>
<td>Altitude</td>
<td>unit32</td>
<td>Meters ASL</td>
</tr>
<tr>
<td>Position Error</td>
<td>unit32</td>
<td>RMS</td>
</tr>
<tr>
<td>Roll</td>
<td>unit16</td>
<td>Radians</td>
</tr>
<tr>
<td>Pitch</td>
<td>unit16</td>
<td>Radians</td>
</tr>
<tr>
<td>Yaw</td>
<td>unit16</td>
<td>radians</td>
</tr>
</tbody>
</table>

Example of global pose
Modes, waypoints and motion commands

Robot commands such as change operation mode, position and velocity request.

**Examples:**
- Automation mode
- Global waypoint
- Local waypoint
- Velocity command
- Limits
- Local path
- Low level actuator

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestamp</td>
<td>uint32</td>
<td>Message time</td>
</tr>
<tr>
<td>Source ID</td>
<td>uint32</td>
<td>Sender address</td>
</tr>
<tr>
<td>Destination ID</td>
<td>uint32</td>
<td>Destination address</td>
</tr>
<tr>
<td>Velocity X</td>
<td>unit32</td>
<td>m/s</td>
</tr>
<tr>
<td>Velocity Y</td>
<td>unit32</td>
<td>m/s</td>
</tr>
<tr>
<td>Velocity Z</td>
<td>unit32</td>
<td>m/s</td>
</tr>
<tr>
<td>Roll rate</td>
<td>Unit16</td>
<td>Radians/s</td>
</tr>
<tr>
<td>Pitch rate</td>
<td>Unit16</td>
<td>Radians/s</td>
</tr>
<tr>
<td>Yaw rate</td>
<td>unit16</td>
<td>Radians/s</td>
</tr>
</tbody>
</table>

Example of velocity command
INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

Mission management

Definition of the mission adaptable to the automation mode.

Examples:
- Platform mission
- Platform mission status

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestamp</td>
<td>uint32</td>
<td>Message time</td>
</tr>
<tr>
<td>Source ID</td>
<td>uint32</td>
<td>Sender address</td>
</tr>
<tr>
<td>Destination ID</td>
<td>unit32</td>
<td>Destination address</td>
</tr>
<tr>
<td>Mission ID</td>
<td>unit32</td>
<td>Destination address</td>
</tr>
<tr>
<td>Mission mode</td>
<td>uint16</td>
<td>Modes identifier</td>
</tr>
<tr>
<td>Goals definition</td>
<td>array</td>
<td>Mission goals</td>
</tr>
<tr>
<td>Segments</td>
<td>array</td>
<td>Legs</td>
</tr>
<tr>
<td>Waypoints</td>
<td>array</td>
<td>Locations</td>
</tr>
</tbody>
</table>

Example of a mission file
Raw sensors

Sensor data as provided by the platforms sensors

Examples:

• Global pose sensor
• Inertial sensor
• Altimeter sensor
• Other sensors

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestamp</td>
<td>uint32</td>
<td>Message time</td>
</tr>
<tr>
<td>Source ID</td>
<td>uint32</td>
<td>Sender address</td>
</tr>
<tr>
<td>Destination ID</td>
<td>unit32</td>
<td>Destination address</td>
</tr>
<tr>
<td>Latitude</td>
<td>unit32</td>
<td>Degrees, WGS84</td>
</tr>
<tr>
<td>Longitude</td>
<td>unit32</td>
<td>Degrees, WGS84</td>
</tr>
<tr>
<td>Altitude</td>
<td>unit32</td>
<td>Meters ASL</td>
</tr>
<tr>
<td>Error estimation</td>
<td>unit32</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>Number of Sats</td>
<td>unit16</td>
<td></td>
</tr>
<tr>
<td>Type of solution</td>
<td>Label</td>
<td>GPS, D-GPS, RTK, etc</td>
</tr>
</tbody>
</table>

Raw GPS sensor data
INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

Manipulator
Manipulator states, commands and tools

Examples:
- State estimation
- Limits and parameters
- Tooling state
- Tolling limits and parameters

ICARUS SUGV with manipulator
Sensing
Perception of the environment.

Examples:
- Digital imagery data
- Planar laser range finder
- Audio
- Video
- Other sensors (chemicals, etc)
- Sensor configuration

Aerial images
Command and control

Information related to SAR missions and external parties.

**Examples:**
- Sectors
- Maps
- Team mission file
- Disaster alerts and coordination info
- Satellite images
- Humanitarian related info

Example of a third-party: Global Disaster Alert and Coordination System (GDACS)
INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

ICARUS standard interface
ICARUS standard interface

Lack of a single standard of reference for interoperability of unmanned systems. Harmonizing the existing standards, by combining them into one, would obviously solve most of the problems.

ICARUS standard interface is highly based on JAUS. It is compatible with popular transport protocols (TCP, UDP, serial) independently of the communication link beneath it. And it is already multi environment (air, sea and land).
INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

ICARUS Topology

System

Subsystem

Node

Component

ICARUS

UAV

C2I

UAV

C2I

Global Pose

Waypoint

...

C2I
INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

ICARUS Services

ICARUS Services

SERVICES

CORE
1. Transport
2. Events
3. AccessControl
4. Management
5. Time
6. Liveness
7. Discovery

MOBILITY
Sensors:
1. GlobalPoseSensor
2. LocalPoseSensor
3. VelocityStateSensor
4. AccelerationStateSensor

Drivers
1. GlobalWaypointDriver
2. GlobalWaypointListDriver
3. LocalWaypointDriver
4. LocalWaypointListDriver
5. GlobalVectorDriver
6. LocalVectorDriver
7. VelocityStateDriver
8. PrimitiveDriver

ENVIRONMENT SENSING
1. VisualSensor
2. RangeSensor
3. DigitalVideoSensor
Adaptation strategy for heterogeneous platforms to the ICARUS standard interface

Robot A
- ROS node 1
- ROS node 2
  - ROSRobot
  - JAUSRobot

Robot B
- Oceansys node 1
- Oceansys node 2
  - Oceansys robot
  - JAUSRobot

Robot C
- JAUSRobot

C2I
- fleet
  - JAUSFleetHandler
  - robotHandler #A
  - robotHandler #B
  - robotHandler #C

ROS-C2I
- Oceansys node 1
- Oceansys node 2

ROS
- JAUSRobotHandler #A
- JAUSRobotHandler #B
- JAUSRobotHandler #C

JAUS

Oceansys

Interoperability among different SAR platforms
## Traceability between JAUS and ROS

<table>
<thead>
<tr>
<th>Core Service Set</th>
<th>Concept</th>
<th>JAUS++</th>
<th>ROS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robot profile</td>
<td>JAUS::Identification</td>
<td>icarus_msgs/RobotInfo</td>
<td></td>
</tr>
<tr>
<td>Heartbeat</td>
<td>JAUS::HeartBeatPulse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System status</td>
<td>JAUS::Management::Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clock</td>
<td>JAUS::Time</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mobility Service Set</th>
<th>Concept</th>
<th>JAUS++</th>
<th>ROS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors (Robot C2I)</td>
<td>Global pose</td>
<td>JAUS::GlobalPose</td>
<td>icarus_msgs/GlobalPoseWithCovarianceStamped</td>
</tr>
<tr>
<td></td>
<td>Local pose</td>
<td>JAUS::LocalPose</td>
<td>geometry_msgs/PoseWithCovarianceStamped</td>
</tr>
<tr>
<td></td>
<td>Velocity state</td>
<td>JAUS::VelocityState</td>
<td>geometry_msgs/TwistWithCovarianceStamped</td>
</tr>
<tr>
<td></td>
<td>Acceleration state</td>
<td>JAUS::AccelerationState</td>
<td></td>
</tr>
<tr>
<td>Drivers (C2I Robot)</td>
<td>Global Waypoint</td>
<td>JAUS::GlobalWaypoint</td>
<td>icarus_msgs/GlobalWaypointStamped</td>
</tr>
<tr>
<td></td>
<td>Local Waypoint</td>
<td>JAUS::LocalWaypoint</td>
<td>icarus_msgs/LocalWaypointStamped</td>
</tr>
<tr>
<td></td>
<td>Driving global vector</td>
<td>JAUS::GlobalVector</td>
<td>Nav_msgs/Path</td>
</tr>
<tr>
<td></td>
<td>Driving local vector</td>
<td>JAUS::LocalVector</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Velocity Command</td>
<td>JAUS::VelocityCommand</td>
<td>geometry_msgs/TwistStamped</td>
</tr>
<tr>
<td></td>
<td>Low Level Actuators</td>
<td>JAUS::WrenchEffort</td>
<td>geometry_msgs/WrenchStamped</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment Sensing Set</th>
<th>Concept</th>
<th>JAUS++</th>
<th>ROS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Imagery</td>
<td>JAUS::Image</td>
<td>sensor_msgs/Image</td>
<td></td>
</tr>
<tr>
<td>Planar Laser Range</td>
<td>JAUS::RangeScan</td>
<td>sensor_msgs/LaserScan</td>
<td></td>
</tr>
<tr>
<td>Video Stream</td>
<td>JAUS::DigitalVideo</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Using existing standard messages
New ROS msg approved by ICARUS partners
New ROS message proposed but no approved
To be discussed later
Optional/not required for ICARUS
ICARUS heterogeneous platforms
Aerial Platforms

Source: ASL ETHZ

Source: ASCAMM

Source: Skybotix
INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

Ground Platforms

Source: UKL/AV

Source: META
Maritime Platforms

Source: CALZONI

Source: INESC
ICARUS multiple heterogeneous platforms operations
INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

Sea trials (REX14 Portuguese Naval School - July 2014)
Air trials (Barcelona UAV Test Centre - July 2014)

The CTC also includes Temporarily Segregated Airspace:
Name: TSA-31 CTC-MOIA,
Extension: 2.500 ha. and a maximum ceiling of 4.000 ft.
Coordinates of the four corners of this airspace:
414845N 0020840E; 414940N 0021200E;
414610N 0021230E; 414600N 0021000E;
Air-Land trials (Marche-en-Fammene – September 2014)
INTEROPERABILITY AMONG DIFFERENT SAR PLATFORMS

Air-Sea trials (La Spezia – October 2014)
Dissemination
• ICARUS is leading a NATO STO Exploratory Team (SCI-ET-009) to promote standardization for unmanned systems. The topic is "Command and Reporting Standards and Development Tools for UxS“ and will run during 2014. Several partners are contributing.

• A set of NATO STO Lecture Series (SCI-LS-271) will follow this study to disseminate the outcomes. The candidates locations are Portugal (Lisbon), Spain (Barcelona), Belgium (RMA-Brussels) and Italy (La Spezia).

• For any further information or contributions, contact me at: dserrano@ascamm.com
Thank you any questions?

Interoperability among different SAR platforms

IUSAR Workshop
13th IAS Conference
Daniel Serrano (ASCAAMM)