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Possible scenarios for radiation measurements and sampling using unmanned systems

ERNCIP thematic group
Radiological and nuclear threats to critical infrastructure
Task 3 deliverable 2

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ERNCIP thematic group for Radiological and nuclear threats to critical infrastructure

Possible scenarios for radiation measurements and sampling using unmanned systems

March 2015

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Related ERNCIP documents

1. List-mode data acquisition based on digital electronics, EUR 26715.
2. Critical parameters and performance tests for the evaluation of digital data acquisition hardware, EUR 26976.
3. Remote expert support of field teams — Reachback services for nuclear security, EUR 27099.
4. Current state-of-the-art of unmanned systems with potential to be used for radiation measurements and sampling, in preparation.

Executive Summary

There is significant potential for the use of unmanned remote control vehicles in sampling and measuring radiological events. No attempt to standardise sampling and measurement methods using these types of vehicles has been made so far. Common standards would simplify the use of remote control vehicles in an emergency scenario and would thus be very valuable in critical infrastructure protection. The main advantage of using unmanned systems in radiological events is the protection of the involved human personnel.

This document focuses on possible scenarios for remote control radiation measurements and sampling using unmanned systems. We identified scenarios that can be separated in two categories. First, there are prevention scenarios where unmanned systems can be used to prevent incidents involving radioactive material and deterrence. Second, there are response scenarios where unmanned systems can be used to gather information after incidents with radioactive material have occurred. We further condensed three main tasks (spatial mapping, search of sources and sampling) for unmanned systems in the identified scenarios.

In addition, this report summarises possible standards for unmanned systems. A very widely recognised standard collection of software frameworks for robot software development is the robot operating system. Further important standards concerning communication with robots and control of unmanned systems are battle management language, interoperability profile and joint architecture for unmanned systems.

Contents

Acronyms

BfS	Bundesamt für Strahlenschutz, Germany – Federal Office for radiation protection (Germany)
BRD	Backpack radiation detector
CBRNE	Chemical, biological, radiological, nuclear and explosive
CEA	Commissariat à l'énergie atomique et aux énergies alternatives — French atomic and alternative energies commission
CEN	Comité européen de normalisation; European Committee for Standardisation
CENELEC	Comité européen de normalisation électrotechnique; European Committee for Electrotechnical Standardisation
CSIC	Institutional Repository of the Spanish National Research Council
DEMA	Danish Emergency Management Agency
EDA	European Defence Agency
ERNCIP	European reference network for critical infrastructure protection (EC)
HC	Health Canada
IAEA	International Atomic Energy Agency
IND	Improvised nuclear device
IRSN	Institute for radiological protection and nuclear safety, French national public expert in nuclear and radiological risks
JRC	Joint Research Centre, the European Commission's in-house science service
LHC	Large hadron collider
LML	Linssi markup language (XML)
MORC	Material out of regulatory control
NaI	Sodium Iodide, scintillator crystal used in gamma spectrometer
NATO	North Atlantic Treaty Organization
NEN	Netherland Standardisation Institute
NIST	National Institute of Standards and Technology, US
NORM	Naturally occurring radioactive material
NPL	National physical laboratory, UK
NSDA	Nuclear security detection architecture
PRD	Personal radiation detector
RDD	Radiological dispersal device
RED	Radiation exposure device
RID	Radionuclide identification detector
RN	Radioactive and nuclear materials
RPM	Radiation portal monitor
SPRD	Spectroscopy-based personal radiation detector
SRPM	Spectroscopy-based radiation portal monitor
SQL	Structured query language
SSTC-NRC	State scientific and technical centre for nuclear and radiation safety, Ukraine
STUK	Säteilyturvakeskus, radiation and nuclear safety authority, Finland
WLCG	Worldwide LHC computing grid
XML	Extensible markup language

1 Introduction

There is significant potential for the use of unmanned remote control vehicles in sampling and measuring radiological events. For example, using unmanned aerial vehicles (UAV) to sample the radioactive plume from a nuclear reactor incident or dirty bomb could provide valuable information to emergency response personnel. This data could be used as an input in atmospheric transport modelling calculations that are an important part of the decision support systems in such events.
No attempt to standardise sampling and measurement methods using these types of vehicles has been done so far. Doing so would simplify the use of remote control vehicles in an emergency scenario and would thus be very valuable in critical infrastructure protection (CIP).
Analysis from a CIP point of view has not been done for these techniques. Such analysis would produce useful background information for the possible future standardisation of the techniques.
This report analyses scenarios, as well as radiation measurement and sampling methods, where US can be used. This allows for standardisation and tests for US to be used in radiological emergencies.
This report was written for end-users, procurement decision-makers and manufacturers, as well as for researchers and developers. We want end-users to see the possible potential of US for radiation measurements. Manufacturers should be inspired by the scenarios and encouraged to develop products to tackle the problems described or at least parts of them. Researchers and developers may find inspiration in the real-world scenarios and get an idea of features that are still missing and require more research.

The European reference network for critical infrastructure protection (ERNCIP) office[1] has established a thematic group on the protection of critical infrastructure from radiological and nuclear threats (RN thematic group) that looks at issues, such as the certification of radiation detectors, the standardisation of deployment protocols and the response procedures and communication to the public in the event of criminal or unauthorised acts involving nuclear or other radioactive material out of regulatory control, for example. In short, the focus of the RN thematic group is to advise the CEN/CENELEC on standardising formats and protocols used for sending the collected data to enable further analysis. The issue is closely related to the opportunity opened by the current developments in technology of utilising remote support of field teams (reachback) for radiation detection.
The RN thematic group works with the following three issues.

1. <u>List-mode data acquisition based on digital electronics</u>. The time-stamped list-mode data format produces significant added value compared to the more conventional spectrum data format. It improves source localisation, allows signal-to-noise optimisation and noise filtering, with some new gamma and neutron detectors requiring list-mode data to function. The list-mode approach also allows for the precise time synchronisation of multiple detectors

(1) The ERNCIP office operates within the organisational framework of the Institute for the protection and security of the citizen (IPSC) of the European Commission’s Joint Research Centre. The institute provides scientific and technological support to European Union policies in different areas, including global stability and security, crisis management, maritime and fisheries policies and the protection of critical infrastructures. The IPSC works in close collaboration with research centres, universities, private companies and international organisations in a concerted effort to develop research-based solutions for the security and protection of citizens. The ERNCIP's mission is to foster the emergence of innovative, qualified, efficient and competitive security solutions through the networking of European experimental capabilities. The ERNCIP office has been mandated by the Directorate-General for Migration and Home Affairs (DG HOME) of the European Commission.

enabling simultaneous singles and coincidence spectrometry, such as single gamma and UV-gated gamma spectrometry.

2. Expert support of field teams, i.e. data moves instead of people and samples. Fast and high quality response can be achieved with fewer personnel. Optimal formats and protocols are needed for efficient communication between frontline officers and reachback centres.

3. Remote control radiation measurements and sampling using unmanned vehicles. There are several measurement and sampling scenarios that are too risky for humans to carry out. Envisaged scenarios are nuclear reactor accidents, the illicit release of radioactive material (radiological dispersion devices and dirty bombs, for example) and the search of radioactive material out of regulatory control.

This is the second report that deals with item 3, remote control radiation measurements and sampling using unmanned vehicles, focusing on scenarios for radiation detection using US.

The remainder of this document is organised as follows. Chapter 2 describes scenarios involving US for identified radiation measurements and sampling, while Chapter 3 discusses standards that are involved in the use of US in general.

2 Scenarios for radiation measurement with unmanned systems

There are several measurement and sampling scenarios that are too risky for humans to carry out. For these scenarios, remote control radiation measurements and sampling using US need to be developed. Note that the use of remote control devices, such as unmanned ground vehicles (UGVs) and small sized unmanned planes, may be more cost effective than the use of manned vehicles or piloted aircraft, as decontamination of measurement systems and related costs should be taken into account. Applications envisaged for remote control measurement and sampling devices are reactor and other accidents, such as Chernobyl and Fukushima, dirty bombs and the search of sources out of regulatory control, as well as long-term measurements.

Lessons learned from incidents like Fukushima and Chernobyl and the decommissioning of old nuclear power plants show that UGVs have some advantages. Equipped with radiation-resistant electronics, these vehicles can operate in areas with high radiation or danger of explosives (For example, boiling liquid expanding vapour explosion (BLEVE), collapsing structures, IED, booby trap, heat…). Additionally, they have the ability to manipulate the environment and to take potentially heavy samples, as they usually have a high payload. UGVs can also be used in the long-time surveying of contaminated areas and monitoring the movements of a threat with real-time data from multiple mobile sensor sources.

Unmanned aerial vehicles have their own advantages in a radioactive material dispersal case, as in the case of the search of sources or any RN threats. As these systems can be deployed in a short time frame to map large areas (on the order of square kilometres) with regards to dose rate, surface activity or radionuclide identification, they can collect vital data to be used by decision-makers. This was demonstrated by the United States when it used helicopter systems to map the fallout from Fukushima in the weeks following the accident. Furthermore, a smaller system mounted under a UAV would have been very useful for the daily-changing dose rate mapping on the site.

This chapter investigates possible radiation measurement scenarios where US could be useful. They are split into two types. The first covers scenarios where a release of radioactivity or irradiation of civilians or infrastructure has not yet occurred. The second type covers the release of radioactivity or significant irradiation of civilians, infrastructure or the environment. For clarification purposes, field personnel tasked with radiation measurement and protection are henceforth referred to as 'radiation task force'.

2.1 Possible applications for unmanned systems

We identified possible applications where US could be helpful. In Sections 2.4 and 2.5, we developed possible scenarios that mainly focus on radiation measurement. These scenarios include tasks from the following list of applications:

- repetitive/routine measurements;
- measurements in areas of high radiation and equipped with electronic radiation resistance;
- carrying of heavy equipment;
- search, localisation and identification of possible radiation sources;
- gamma mapping: dose rate, surface activities, point activities (including blank of critical infrastructures and sites);
- operation in dangerous and uncooperative environments (CBRNE scenarios, dirty bombs, inaccessible areas, etc.);
- collection of samples;
- manipulation of the environment;

- decontamination and containment actions.

2.2 Critical parameters

General parameters not specific to any task or scenario but critical for radiation measurement with remote control US were identified. These parameters are discussed in this subsection.

2.2.1 Time and space

It is usually very important for the radiation task force to quickly deliver the results or assessments of a given situation, which would render the rapid deployment of the US possible. Workspace for the radiation task force might also be limited, requiring the use of small robots.
The logistics time is the time it takes to get the equipment to the right place. The deployment time of a US is the time a specialist needs to get the system up and running, which includes unpacking and starting the robot, starting the remote control and driving or flying the robot to the target area.
The time constraint also includes the operation time, which is the time that the system is able to operate without leaving the operation to refuel or recharge batteries.
The space constraint consists of two parts. The first part is the transportation space that a US and all control components need during the transportation to the operation. The less space is needed, the more likely it will be brought to operation. The second part is the operation space that a US needs to be able to operate. For example, a ground robot needs some space to drive and turn, whereas a fixed wing unmanned aircraft needs space for take-off and landing.

2.2.2 Number of available robots

The number of robots is related to the available space for transportation and for the operation itself, but some operations include tasks that could involve more than one robot, such as setting up infrastructure for communication after a disaster. By having several robots acting as relay stations, this could potentially be accomplished faster than using only one robot or field personnel. Additionally, a group of robots sharing the task can save precious time in searching for a radiation source or in a scenario where the goal is to map the environment. Groups of robots can easily split up and divide the overall problem into smaller ones.
So a possible group of multiple robots can consist of vehicles from different domains (air, land and/or sea), as well as carry various kinds of sensors. The group behaviour might be coordinated by software and/or operators.

2.2.3 Sensors

Depending on the size and the loading capacity of the system, an appropriate sensor is necessary. A large sized UGV can carry heavy detectors, whereas small rotary wing unmanned air systems have to use small and lightweight sensors. Scenarios and objectives determine which system carrying which sensor is best suited for the application.

2.3 Types of incidents and scenarios

By taking a look at incidents that involve radioactivity or radiation measurement, we can easily see that there is quite a difference between dispersed radioactivity and non-dispersed radioactivity. When dealing with dispersed radioactivity, information has to be gathered on fallout, radiation plume and the level of dispersion. When dealing with non-dispersed radioactive material, the source has to be found and identified, and potential explosive materials have to be located and removed. As the action

or reaction differs significantly depending on the situation, three different types of incidents involving radioactivity have been identified:

1. radioactivity confirmed — dispersed;
2. radioactivity confirmed — no dispersal;
3. no radioactivity (possible threat).

These types of incidents are used to categorise scenarios covering radiological incidents. These kinds of scenarios can be found as response scenarios in Section 2.5. Prevention scenarios do not handle incidents and are therefore not categorised in this way.

Three different major tasks have been extracted from the possible applications in Section 2.1 for radiation measurements with US. The main tasks in the scenarios below can be related to one of these major tasks:

a. spatial mapping of RN sensor data (exploration, change detection, etc.);
b. searching for RN sources (active sensing, isocurves, hotspots, etc.);
c. sampling (air sampling, sweep sampling and material sampling).

2.4 Prevention scenarios

In the scenarios presented here, a radiation task force has been deployed to prevent a radiation incident or to deter people from bringing radioactive sources to a specific location. These scenarios focus on periodical inspection.

2.4.1 Exploration (harbour, re-locatable, illicit trafficking)

In this scenario, a specific area has been determined to possibly contain a radioactive source, for example a container harbour with the possibility of illicitly trafficking potentially dangerous radioactive material. This is a spatial mapping task (a).


[2]


[3]

Figure 1. Two images of container terminals: Hamburg (left) and Barcelona (right).

(2) 'Hamburg Hafen Containerterminal', photo by Raimond Spekking.
(3) 'Puertobarcelona2', photo by OneLoneClone — http://www.flickr.com.

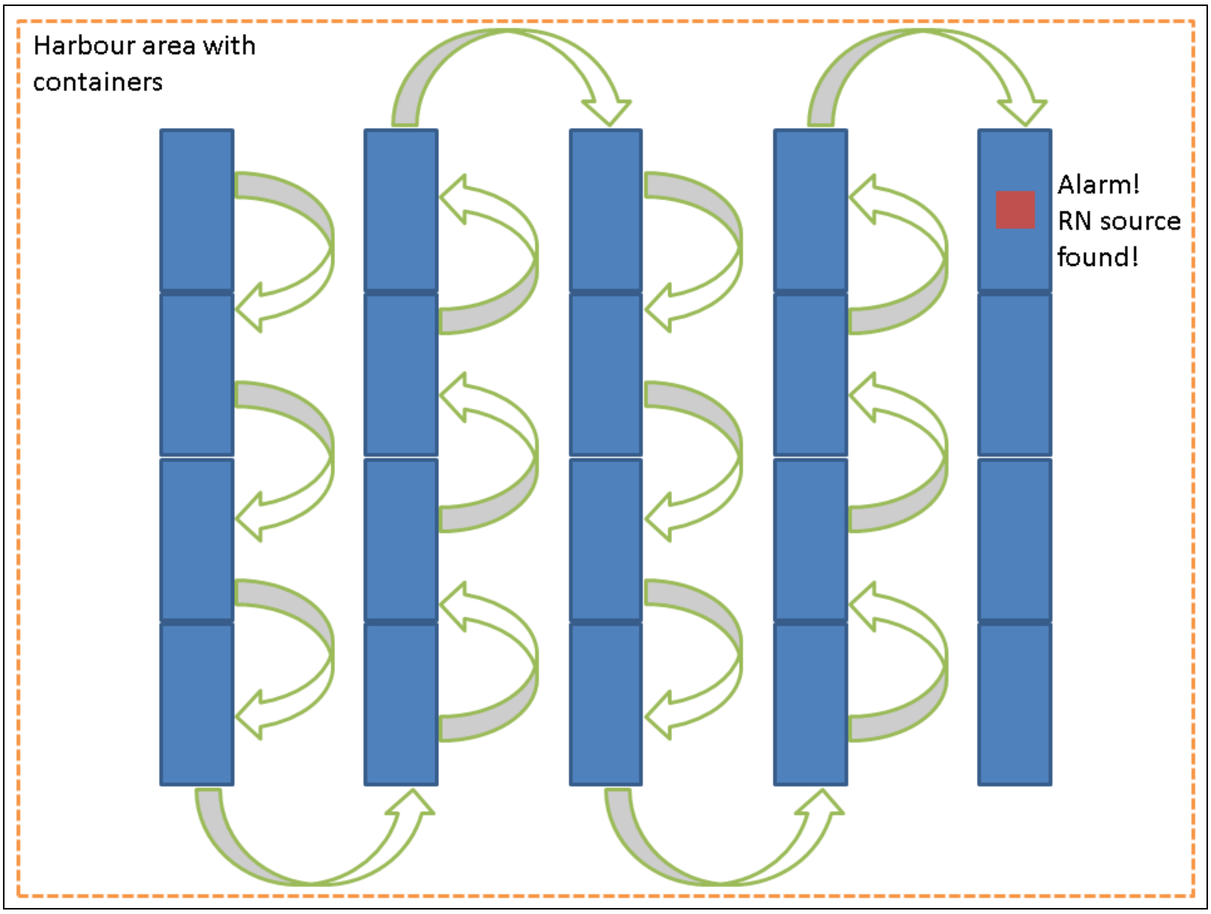

Figure 2. This figure shows an example of a container inspection for the scenario 'exploration'. There are several containers shown in blue that should be inspected one by one.

Unmanned systems should provide real-time sensor readings to the radiation task force at any time. The aerial or ground vehicle should inspect bigger objects one by one (containers or cars, for example). If suspicious radiation is found, the location of the measurement must be reported to the operator. After that, the real-time measurements of the US should enable the radiation experts in the safety zone or at any distant analysis centre to identify the nuclide or nuclides. After the localisation and confirmation of the source, the vehicle should map the surrounding area to determine the radiation field from the radioactive source.

2.4.2 Patrolling, search for source, change detection, major public event

In this scenario, a continuous search for radiation sources in a predefined area or on a specified route has to be performed. As this scenario requires mapping, the task that needs to be completed is of type (a).

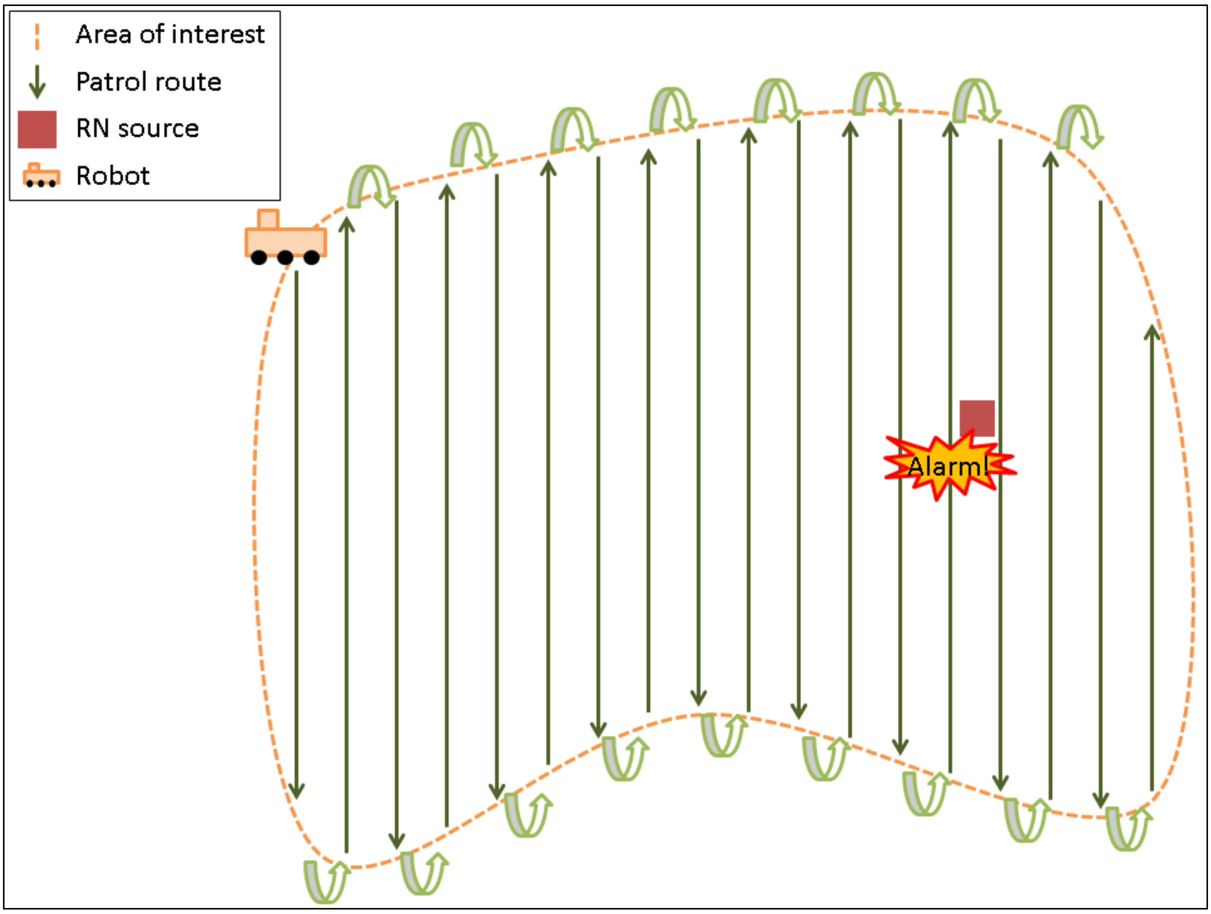

Figure 3. This is a sample of a patrolling scenario. The US sweeps a given area of interest and sends an alarm if anything suspicious is found.

Unmanned systems should provide real-time sensor readings to the radiation task force at any time. The vehicle has to perform a survey of a predefined area or a specified route. The system should be able to compare current measurement results to old ones from the same location/area/route in order to reduce false positives. If a suspected radioactive source is found, an alarm with measurement results and the location of those measurements must be sent to the operator. Unmanned ground systems can be used to carry very heavy devices and operate in dangerous terrain. Unmanned aerial vehicles can operate over the area by parallel and/or crossed trajectories in order to provide gamma mapping or simple detection localisation with an embedded gamma detector or spectrometer.

2.4.3 Background mapping, change detection

In this scenario, there is a predefined area that has to be continuously or periodically checked for radiation for a longer period of time. A map of the background radiation therefore has to be made first. After that, inspection runs have to be performed and the previously mapped background radiation measurements have to be compared with current measurements. This scenario requires the completion of a type (a) task.

Unmanned systems should provide real-time sensor readings to the radiation task force at any time. The vehicle has to perform an inspection of the previously mapped area. The system should be able to compare current measurement results to old ones from the same location/area/route. If a suspected radioactive source is found, an alarm with measurement results and the location of those measurements must be sent to the operator.

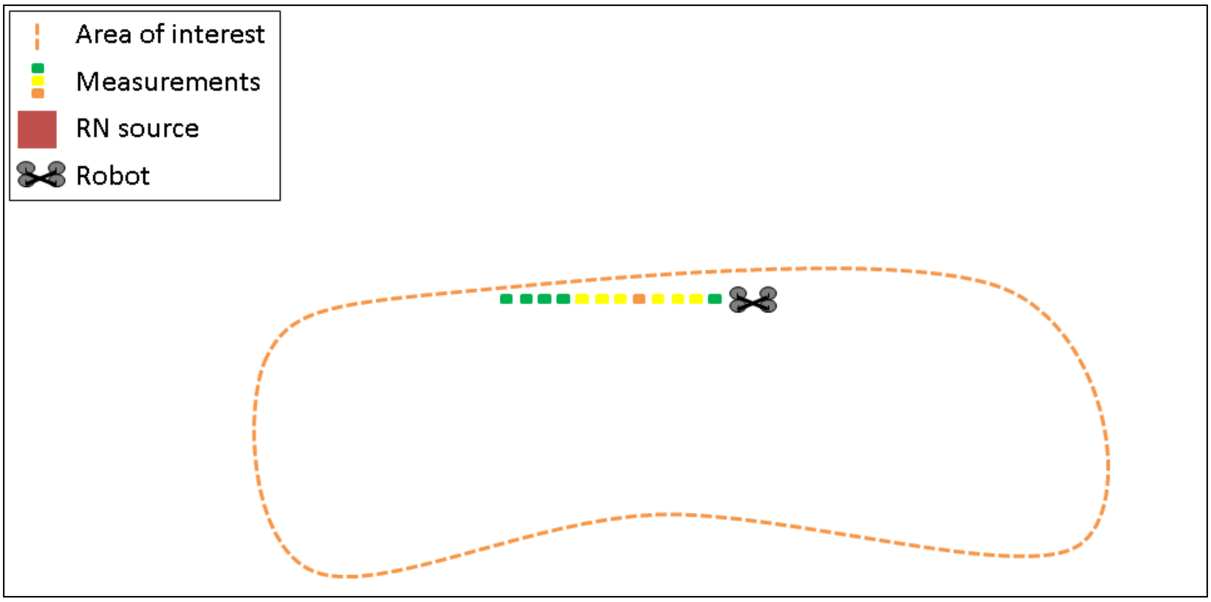

Figure 4. This is a sample of a background mapping scenario. Differently coloured dots show different measures in the background radiation map.

2.5 Response scenarios

This type of scenario involves the release of significant amounts of radioactive material in the surrounding area or high dose rate radiation fields from an unshielded or partially shielded point source.

2.5.1 Suspicious object

In this scenario, a possibly dangerous radioactive source is believed to be located in a specific area. We assume that a radiation task force is already onsite, has closed down the area and has established a safety zone from where it can operate. The main task for the radiation task force is to prevent any further disturbances of the environment, to get accurate situation awareness and to determine the location and characteristics of the radioactive object. This is therefore a category 2 scenario, as described above. The location of the object is roughly known, but it is unclear if explosives are involved. Furthermore, the activity of the source is unknown. The main task in this scenario is the mapping of the environment (a).

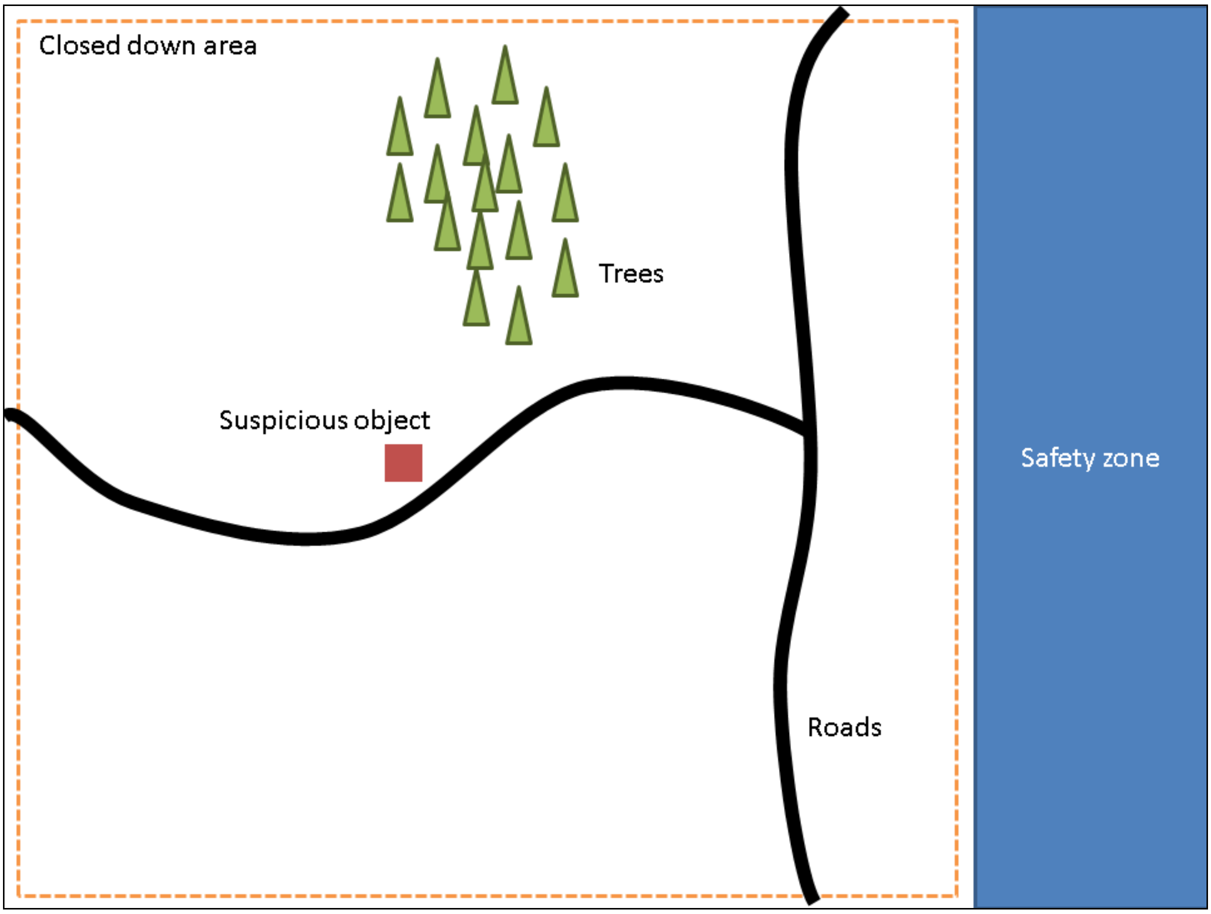

Figure 5. This is a drawing of an example for the scenario 'suspicious object'. The suspicious object is in the middle of the closed area and the radiation task force is operating from a safety zone nearby.

The US should provide real-time sensor readings to the radiation task force at all times. The US should approach the suspicious object from the deployment safety zone, where the US operator is located. The objective of the US would be to find the approximate or exact location of the source. Using the instruments in the vehicle, real-time measurements should enable the radiation experts in the safety zone or at any distant analysis centre to identify the nuclide or nuclides. This would be followed by mapping the radiation field of the source in the area near to the source in order to determine collimation and shielding of the source.

2.5.2 Isocurves (contour mapping)

If the location of a point source or contaminated area is roughly known, the radiation task forces will be tasked with creating iso dose rate curves, which are curves around the source where the dose rate is constant. This type of scenario could be of category 1 or 2. The location, activity and dispersion of the source, as well as if explosives are involved, are unknown. The main task in this scenario is the active search of the RN source (type (b) task).

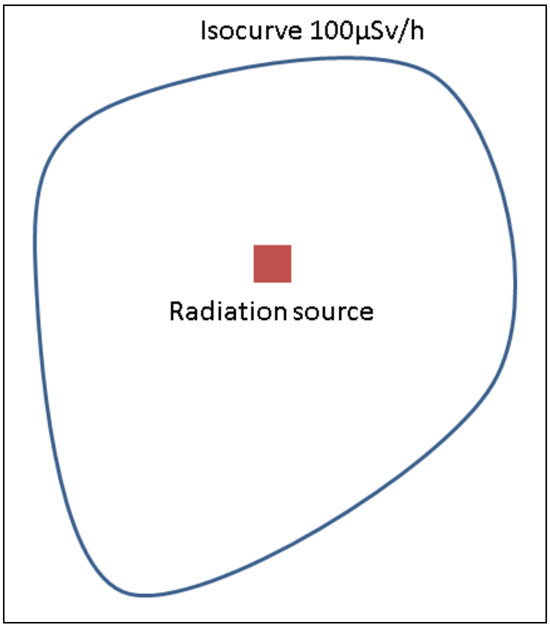

Figure 6. This is a sketch of an isocurve for a radiation source (red square). On every point of the blue curve, the radiation level is 100µSv/h, for example.

The US should provide real-time sensor readings to the radiation task force at all times. The vehicle should identify the boundaries (create isocurves) of the contaminated area with a given criteria (100µSv/h, for example). This should be followed by a survey to more precisely determine the location of the source.

2.5.3 Terror lab, mapping

In this scenario, a workspace or laboratory that contains radioactive sources, which are intended for illicit use, has been located. The radiation task force is called in to investigate the scene. This is a category 1 or 2 scenario. The location, activity and dispersion of the source, as well as if explosives are involved, are unknown. The main task is the mapping of the environment (type (a) task).

The US should provide real-time sensor readings to the radiation task force at all times. The task of the vehicle would be to map the radiation field in the area, starting outside and proceeding inside of the lab. If a suspected radioactive source is found, an alarm containing measurements and location of those measurements must be transmitted to the operator. This should be followed by identifying the nuclides present, as well as by a survey of the nearby area.

2.5.4 Scrap metal (sort out piece by piece)

In this scenario, an elevated radiation field has been found to originate from a large collection of scrap metal (a container or a large pile at a scrap metal yard, for example). Due to the high density of metal that collimates the source and the difficulty of separating radioactive scrap metal from non-radioactive scrap metal by visual means, every piece of metal has to be separated and checked. This is typically a category 2 scenario. The location and the activity of the source might be roughly known, though the dispersion is unlikely. It is unknown if any explosives are involved. The main task of this scenario is the mapping of the source.

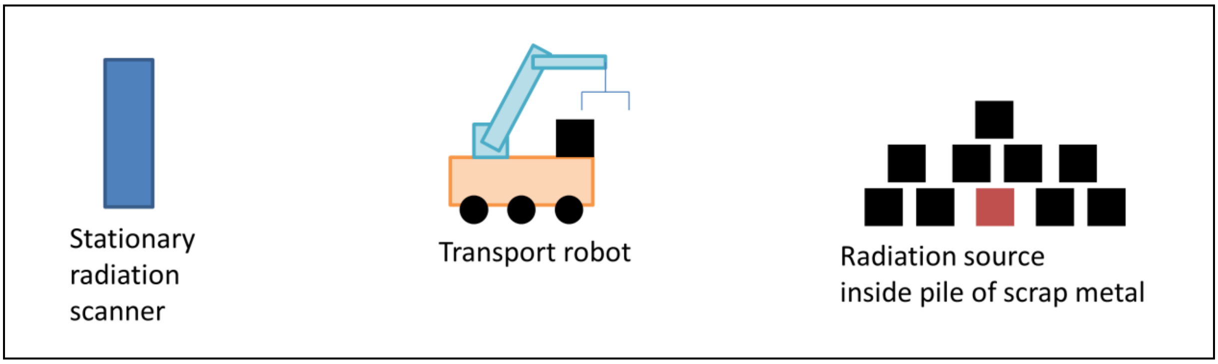

Figure 7. Sketch of a possible 'scrap metal' scenario. On the right is a pile of scrap metal with a radioactive source. The robot has to bring the pieces one by one to the stationary scanner for inspection and radiation measurement.

The task for the US is to scan the pile piece by piece and gather non-radioactive material at a safe place, as well as to raise an alarm for active material and separate this from the non-active pieces. The US has to repeat this task until every piece has been scanned and all radioactive sources have been found and removed.

2.5.5 Sampling

In this scenario, the dispersion of a radioactive source has not been confirmed. Sampling has to be performed in order to determine the possible dispersion of the source and the extent of this dispersion. The radiation task force has already established a safety zone at a safe distance from the source. This is a category 1 or 2 scenario. The location and activity of the source are unknown and dispersion is possible but not confirmed. The main task of this scenario is the sampling of a source (type (c) task).
The task for a US is to gather samples and bring them out of the area containing the suspected radioactivity. There could be different kinds of samples to gather, including air samples and dust that could be gathered by sweeping with a tissue. The US must provide real-time sensor readings to the radiation task force at all times. Additional constraints may apply, as gathering evidence is highly regulated.

2.5.6 Map and search radioactivity, map and search hotspots and identification of nuclides

In this scenario, the radiation task force needs a map of a given area. In this map, hotspots and radioactivity sources have to be tagged and nuclides have to be identified. The main task of this scenario is a spatial mapping (type (a) task) of the environment. This is a category 1 or 2 scenario. The location and activity of the source are unknown and dispersion is possible but not confirmed.
The task for a US is gather geo-referenced RN-sensor readings and put the information together in a map. The US must provide real-time sensor readings to the radiation task force at all times.

3 Possible standards for unmanned systems

A rough survey of existing standards for all kinds of US has been done. However, one very important precondition is that all considered standards should be freely available and without any licence restrictions. In addition, open source and open science solutions should be favoured.

The following are some of the 'standards' affecting US.

- NATO STANAG 4586 for UAVs https://en.wikipedia.org/wiki/STANAG_4586
- SAE JAUS https://en.wikipedia.org/wiki/JAUS
- ASTM F41 on USV-UUV http://www.astm.org/COMMITTEE/F41.htm
- MIL-STD-1760 (SAE AS-1) https://en.wikipedia.org/wiki/MIL-STD-1760
- Universal Armament Interface http://papers.sae.org/2012-01-2136/
- IOP http://www.peogcs.army.mil/ugv.html
- DDS https://en.wikipedia.org/wiki/Data_Distribution_Service
- MAJIIC http://www.nato.int/docu/update/2007/pdf/majic.pdf
- BML https://en.wikipedia.org/wiki/Battle_management_language
- EMWARE https://www.eda.europa.eu/our-work/projects-search/embarked-middleware---emware
- ROS http://www.ros.org/

Due to the limited work capacities within the group, only a brief discussion of the listed standards has been done. The main reason for including the robot operating system is that it is available for free and most of the academic robotics R&D groups are running it on their US anyway. In addition, the robot operating system has the appeal of coming with at least rudimentary interfaces for joint architecture for unmanned systems and the interoperability profile. Battle management language is also available for free (https://netlab.gmu.edu/trac/OpenBML) and, beside its capabilities to connect people, USs and simulators, it provides a high-level graphical user interface.

3.1 Robot operating system

The ROS is a collection of software frameworks for robot software development (see also 'robotics middleware') that provides operating system-like functionality on a heterogeneous computer cluster. The ROS provides standard operating system services, such as hardware abstraction, low-level device control, implementation of commonly used functionality, message passing between processes and package management. Running sets of ROS-based processes are represented in a graph architecture where processing takes place in nodes that may receive, post and multiplex sensor, control, state, planning, actuator and other messages. Despite the importance of reactivity and low latency in robot control, the ROS itself is not a real-time operating system, though it is possible to integrate the ROS with a real-time code.

Software in the ROS ecosystem can be separated into three groups:

- language- and platform-independent tools used for building and distributing ROS-based software;

- ROS client library implementations, such as roscpp, rospy, and roslisp;
- packages containing an application-related code that uses one or more ROS client libraries.

Both the language-independent tools and the main client libraries (C++, Python and LISP) are released under the terms of the BSD license, and as such are open source software and free for both commercial and research use. The majority of other packages are licensed under a variety of open-source licenses. These other packages implement commonly used functionality and applications, such as hardware drivers, robot models, data types, planning, perception, simultaneous localisation and mapping, simulation tools and other algorithms.

The main ROS client libraries (C++, Python and LISP) are geared toward Unix-like systems, primarily due to their dependency on large collections of open-source software. For these client libraries, Ubuntu Linux is listed as 'supported', while other variants, such as Fedora Linux, Mac OS X and Microsoft Windows, are designated 'experimental' and are supported by the community only. However, the native Java ROS client library, rosjava, does not share these limitations and has enabled ROS-based software to be written for the Android OS. Rosjava has also enabled ROS to be integrated into an officially-supported MATLAB toolbox that can be used on Linux, Mac OS X and Microsoft Windows. A JavaScript client library, roslibjs, has also been developed, enabling the integration of software into a ROS system via any standards-compliant web browser.

3.2 Battle management language

Battle management language (BML) is an artificial, unambiguous, human-readable language and open standard used to express and to exchange orders, reports and requests among command and control systems (C2 systems), simulation systems and real units. In addition, BML can also be used to interact with robotic forces. In short, BML allows C2 systems and their users to interact with robot systems in the same way as with real units or units simulated in simulation systems. NATO developed BML in its research groups, MSG-48 and MSG-85.

BML must be unambiguous to allow for automatic processing, which is not self-evident for a language. For example, in English, the lexical term 'bark' can refer to the sound a dog produces or to the skin of a tree. The interpretation of such ambiguous terms depends on the situational context and on the world knowledge of the listener. As such, ambiguity can (mostly) be handled by human information processing systems, but not by artificial ones.

In order to be unambiguous, BML has been designed as a formal language. A formal language is the set of all sentences generated by formal grammar. Formal grammar consists of a lexicon (the words of a language) and a set of rules (how to combine the words). In the case of BML, this grammar is the command and control lexical grammar (C2LG). To be more precise, BML's lexicon contains the attributes and values provided by the joint consultation command and control information exchange data model (JC3IEDM) (see https://mipsite.lsec.dnd.ca/). This set of rules has been developed based on the doctrines of ordering and reporting (STANAG 2014, for example) and incorporates the idea of the 5Ws (who, what, when, where and why) for individual BML expressions. With respect to orders, the central grammatical rules are those that assign a task to a unit. These rules are therefore centred on the task expression (the what). Rule form (1) illustrates how these 'tasking' rules are constructed. They consist of a task verb (taskverb) such as 'advance', a reference to the one assigning the task (tasker), a reference to the one who has to execute the task (taskee) — in our case, robots — and, in some cases and depending on the type of task, a reference to something that is affected by the task. This is either an object (affected) or another task (action). In addition, a task assignment includes spatial and temporal constraints (where, start-when and end-when), modifiers (mod) and a reason why the task has to be

executed (why). The task assignment ends with a label that can be used in other expressions to refer to that task assignment.

3.3 Interoperability profile

In 2010, the Robotic Systems Joint Project Office launched an initiative to identify and define interoperability standards to be organised and maintained within a UGV interoperability profile (IOP). This IOP will be employed by Product Manager, Unmanned Ground Vehicle in future programs of record, in the upgrade of fielded systems and in the evaluation/acquisition of commercial-off-the-shelf (COTS) products.

A primary goal of this initiative is to leverage existing and emerging standards within the unmanned vehicle community, such as:

- the society of automotive engineers (SAE) AS-4 joint architecture for unmanned systems (JAUS) standard;
- the advanced explosive ordnance disposal robotic system (AEODRS) architecture description documents version 1.0;
- the army unmanned aircraft systems (UAS) project office IOPs.

With an end goal of:

- facilitating interoperability among new UGV initiatives and legacy systems;
- facilitating interoperability between controllers and unmanned robotic system(s);
- facilitating collaboration between UGV and UAS systems;
- providing a path forward to standardised interoperable technology solutions;
- promoting payload and on-board subsystem modularity and commonality across the portfolio of UGV systems.

The IOP has been developed using a government/industry working integrated product team structure and defines the interoperable interfaces and protocols necessary to enable interoperability and modularity to be introduced to the capabilities that have already been widely fielded. The RS JPO intends to publish annual revisions to the IOP in order to expand and evolve its scope as necessary, based on the evolution of warfighter capability requirements and technological advances.

The IOPs will contain a set of interface definitions and requirements for physical, electrical, software, control, data, communications and human elements, as well as implementation guidance for SAE AS-4/JAUS message sets.

The following overall process is being utilised for the development and application of the IOPs.

- Develop and refine mission profiles and use cases — a summary of operational requirements and how unattended ground sensor (UGS) are currently being used.
- Decompose to understand functional requirements — a listing of which functions the UGS fleet must perform in relation to interoperability.
- Develop IOPs to define software and hardware interfaces — this will lead to the publishing of the IOPs themselves.

- Refine IOPs over time to outpace army training and doctrine command (TRADOC) requirements and technology advancements.
- Utilise robotic system integration lab (RSIL) to validate IOPs and assess conformance to them — this will be used in confirming that the IOPs ensure interoperability as planned and in determining commercial vendors' level of compliance with the IOPs.
- Implement IOPs in performance specifications for UGV acquisitions — this will ensure that the actual fielded system acquisitions are interoperable.

The IOPs consist of the following series of documents.

- Overarching IOP — defines platform level mobility, network, messaging and environmental requirements, as well as their conformance/validation criteria.
- Mission analysis attachment — includes a summary of operational requirements and use cases.
- SAE JAUS profiling rules attachment — includes specification, clarification and implementation guidance on the SAE JAUS standards.
- Private transports attachment — includes guidance on the formulation of messages not currently within the SAE JAUS message sets.
- Payload IOP — defines payload classifications, standards, requirements and conformance approach.
- Communications IOP — defines communication standards, requirements and conformance approach.
- Control IOP — defines operator control unit logical architecture, standards, requirements, conformance approach and command and control messages.

3.4 Joint architecture for unmanned systems

The joint architecture for unmanned systems (JAUS) is mandated for use by all of the programs in the joint ground robotics enterprise (JGRE). This initiative is to develop architecture for the domain of US. JAUS is an upper-level design for the interfaces within the domain of UGVs. It is a component-based, message-passing architecture that specifies data formats and methods of communication among computing nodes. It defines messages and component behaviours that are independent of technology, computer hardware, operator use and vehicle platforms and isolated from mission.

JAUS uses the society of automotive engineers generic open architecture (SAE GOA) framework to classify the interfaces. It complies with the joint technical architecture and the joint technical architecture-army. JAUS is prescriptive as opposed to descriptive, and it is sufficiently flexible to accommodate technology advances. Any US — air, ground, surface or underwater — can use JAUS, be it commercial or military.

The JAUS working group is responsible for defining and implementing the architecture across a variety of unmanned vehicles, sensors and munitions. The architecture supports the following objectives:

1. support all classes of unmanned systems;
2. rapid technology insertion;
3. interoperable operator control unit;
4. interchangeable/interoperable payloads;

5. interoperable unmanned systems.

It also has the following constrains:

1. defence acquisition system;
2. operational procedures;
3. intellectual property and data rights;
4. systems engineering;
5. research and development;
6. product acquisition.

The architecture furthermore respects the following standards:

1. joint technical architecture (JTA);
2. 4D/real-time control system (4D/RCS);
3. rotorcraft open systems avionics (ROSA);
4. air vehicle standard interface (AVSI).

JAUS defines 11 functional (command, manoeuvre, navigation, payload, communication…) and five informational capabilities (status, world model, library…).

The architecture dictates a hierarchical system built up of subsystems, nodes and components, and contains a strictly defined message set to support an unprecedented level of interoperability. Significant portions of the architecture, including the definitions for subsystem, node and component, have been loosely defined in order to accommodate for the five principles that it is based on. The net effect is more efficient development, reduced ownership cost and an expanded range of vendors.

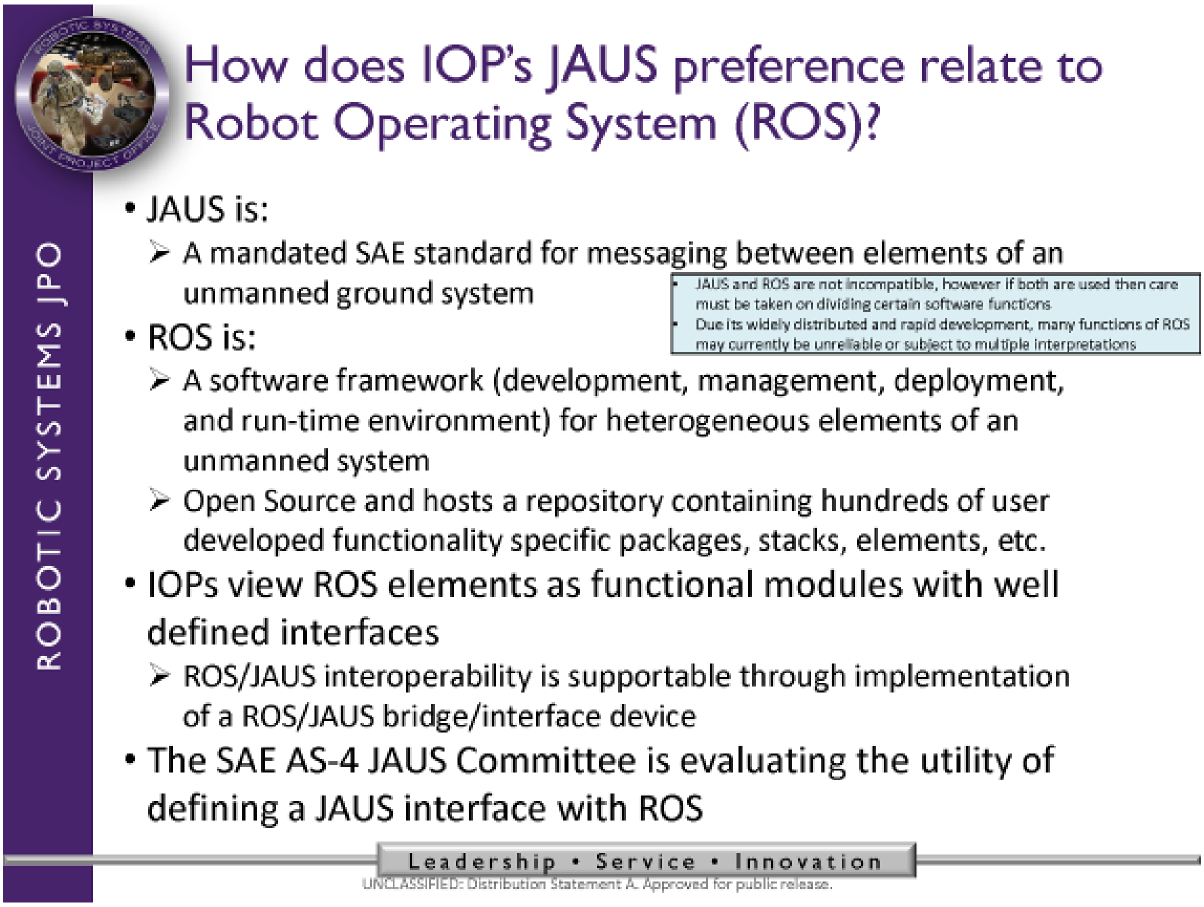

Figure 8. Relations between JAUS, IOP and ROS (ref. Robotics Systems JPO).

3.5 Fundamental standards for unmanned ground vehicles

The group also surveyed applicable NATO activities regarding the use of standards and discovered the MAJIIC I/II projects. Due to the issues regarding licencing, it not possible to use anything directly related to MAJIIC, but the according NATO standards can still be used, which are the following.

- STANAG 3277 — air reconnaissance request/task form
  http://www.nato.int/structur/AC/224/standard/4545/4545_documents/4545_ed1_amd1.pdf
- STANAG 3377 — RecceExrep message.
- STANAG 3596 — air reconnaissance requesting and target reporting guide.
- STANAG 4545 — SAR, EO and IR Data (NSIF)
  http://www.nato.int/structur/AC/224/standard/4545/4545_documents/4545_ed1_amd1.pdf
- STANAG 4559 — NATO standard image library interface
  http://www.nato.int/structur/AC/224/standard/4559/4559Eed03.pdf
- STANAG 4607 — ground moving target indicator format, GMTIF
  http://www.nato.int/structur/ac/224/standard/4607/4607_documents/AEDP-7.pdf
- STANAG 4609 — motion imagery
  http://www.nato.int/structur/AC/224/standard/4609/4609_documents/AEDP-8%283%29.pdf
- STANAG 4676 — NATO ISR tracking standard, DRAFT
  http://www.nato.int/structur/AC/224/jisrcg/jisrcg.htm
- STANAG 5516 — link 16 data exchange, track management.

3.5.1 Data standardisation commonly used with unmanned systems (not exhaustive)

3.5.1.1 Character encoding

The character encoding that is used in all ELROB activities is:

UTF-8 (8-bit UCS/unicode transformation format)
http://en.wikipedia.org/wiki/UTF-8

3.5.1.2 Position encoding

The geographic coordinate system that should be used is:

UTM coordinate system
http://en.wikipedia.org/wiki/Universal_Transverse_Mercator_coordinate_system

The geodetic reference system that should be used is:

world geodetic system (WGS) 84
http://en.wikipedia.org/wiki/World_Geodetic_System

3.5.1.3 Time encoding

The time zone and time formats that should be used are:

Central European Time (CET) respectively Central European Summer Time (CEST)
http://en.wikipedia.org/wiki/Central_European_Time

For example: 1971-05-16T23:46:01 CET

And for program use: UNIX time/POSIX time

http://en.wikipedia.org/wiki/POSIX_time

The following code sample produces a valid ‘full UNIX time stamp’:

```
#include <stdio.h>
#include <sys/time.h>
int main(void)
{
  struct timeval tv;
  gettimeofday (&tv, 0);
  printf ("%d.%06d", tv.tv_sec, tv.tv_usec);
  return 0;
}
```

It should result in an output such as 915148798.750000.

3.5.1.4 Graphics encoding

The graphics file formats that should be used are:

portable network graphics (PNG)
http://en.wikipedia.org/wiki/Portable_Network_Graphics

and/or:

JPEG (ITU-T T.81, ISO/IEC IS 10918-1 and, if needed, ITU-T T.84)
http://en.wikipedia.org/wiki/Jpg

3.5.1.5 Video encoding

The graphics file formats that should be used are:

H.264/MPEG-4 AVC
https://en.wikipedia.org/wiki/H.264/MPEG-4_AVC

and/or:

high efficiency video coding (HEVC, H.265)
https://en.wikipedia.org/wiki/High_Efficiency_Video_Coding

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ERNCIP thematic group Radiological and nuclear threats to critical infrastructure - Task 3 deliverable 2

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Abstract

There is significant potential for the use of unmanned remote control vehicles in sampling and measuring radiological events. No attempt to standardise sampling and measurement methods using these types of vehicles has been made so far. Common standards would simplify the use of remote control vehicles in an emergency scenario and would thus be very valuable in critical infrastructure protection. The main advantage of using unmanned systems in radiological events is the protection of the involved human personnel. This document focuses on possible scenarios for remote control radiation measurements and sampling using unmanned systems. We identified scenarios that can be separated in two categories. First, there are prevention scenarios where unmanned systems can be used to prevent incidents involving radioactive material and deterrence. Second, there are response scenarios where unmanned systems can be used to gather information after incidents with radioactive material have occurred. We further condensed three main tasks (spatial mapping, search of sources and sampling) for unmanned systems in the identified scenarios. In addition, this report summarises possible standards for unmanned systems. A very widely recognised standard collection of software frameworks for robot software development is the robot operating system. Further important standards concerning communication with robots and control of unmanned systems are battle management language, interoperability profile and joint architecture for unmanned systems.

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