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The unmanned systems trial for radiological and nuclear measuring and mapping

ERNCIP Thematic Group for Radiological and Nuclear Threats to Critical Infrastructure
2016 Task 3 deliverables 1 and 2

Frank E. Schneider, FKIE
Bastian Gaspers, FKIE
John Keightley, NPL
Juha Röning, UoO
Jan Paepen, JRC

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ERNCIP Thematic Group for Radiological and Nuclear Threats to Critical Infrastructure

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Harri Toivonen HT Finland Coordinator of the task group
Frank E. Schneider FKIE Germany Lead scientist for the development of this report

Other main contributors to the report:

Bastian Gaspers	Fraunhofer FKIE Institute	Germany
John Keightley	NPL	UK
Juha Röning	UoO	Finland
Jan Paepen	JRC	European Commission

Related ERNCIP documents:

1. List-mode data acquisition based on digital electronics (Report EUR 26715).
2. Current state of the art of unmanned systems with potential to be used for radiation measurements and sampling (Report EUR 27224 EN).
3. Possible scenarios for radiation measurements and sampling using unmanned systems (Report EUR 27225 EN).
4. Survey on the use of robots/unmanned systems in scenarios involving radiological or nuclear threats (Report EUR 27766 EN).

Executive summary

There is a significant potential in the use of unmanned remote-controlled vehicles in sampling and measuring radiological incidents. There are no standardised sampling and measurement methods using these types of vehicles. Common standards would simplify the use of remote-controlled vehicles in an emergency scenario and would thus be very valuable in critical infrastructure protection (CIP). The main advantage of using unmanned systems in radiological incidents is the protection of the human personnel involved.

This report is about the current state of the art of the unmanned systems that have potential to be used for radiation measurements and sampling. Search and rescue robotics is the domain that is closest to the robots applicable to the radiation measurement scenarios. In the report a definition of search and rescue robots and outlines of their major subsystems are given. This is followed by a review of deployment scenarios for search and rescue robots outlining case studies of major emergencies at which robots have been deployed. In addition, assessment of their value to the emergency services is given. Additionally, research and development in search and rescue robotics, including current projects, testing environments and search and rescue robotics competitions, are outlined.

This report shows unmanned robots and concepts for sensor systems capable of radiation detection based on state-of-the-art radiation sampling using unmanned ground vehicles, unmanned aerial vehicles with rotary wings or unmanned aerial vehicles with fixed wings.

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Tables and pictures

Acronyms

BfS	Bundesamt für Strahlenschutz — Federal Office for radiation protection (Germany)
BRD	backpack radiation detector
CBRNE (CBRN-E)	chemical, biological, radiological, nuclear and explosive
CEA	Commissariat à l'énergie atomique et aux énergies alternatives — French atomic and alternative energy 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 (European Commission)
HASS	high-activity sealed sources
HC	Health Canada
HT	HT Nuclear Ltd
IAEA	International Atomic Energy Agency
IND	improvised nuclear device
IRSN	Institut de Radioprotection et de Sûreté Nucléaire — 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 Organisation
NBC	nuclear, biological, chemical
NEN	Netherlands Standardisation Institute
NIST	National Institute of Standards and Technology (United States)
NORM	naturally occurring radioactive material
NPL	National Physical Laboratory (United Kingdom)
OPI	object of potential interest
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)
UAV	unmanned aerial vehicle
UoO	University of Oulu
WLCG	worldwide LHC computing grid
XML	extensible markup language

1 Introduction

The European Reference Network for Critical Infrastructure Protection (ERNCIP) ([1]) has established a Thematic Group on the Protection of Critical Infrastructure from Radiological and Nuclear Threats (the 'RN thematic group'). The group looks at issues such as certification of radiation detectors, standardisation of deployment protocols, response procedures and communication to the public, for example in the event of criminal or unauthorised acts involving nuclear or other radioactive material outside regulatory control. In short, the focus of the RN thematic group is to perform pre-normative research and advise European and international standardisation organisations CEN/Cenelec and ISO/IEC on standardising formats and protocols for sending collected data to enable further analysis. The issue is closely related to the opportunity, opened up by the current developments in technology, of utilising remote support of field teams (reachback) for radiation detection.

The work of this thematic group in 2016 has, inter alia, followed up the findings of the group's 2015 surveys, which gathered the views of the relevant actors on the findings of the Thematic Group on List-mode, Use of Robotics in Radiation Detection and Reachback (expert support to field operations in nuclear security).

- ***List-mode*** is data acquisition based on digital electronics. Time-stamped list-mode data format produces significant added value compared to the more conventional spectral 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 precise time synchronisation of multiple detectors enabling simultaneous singles and coincidence spectrometry such as singles gamma and ultraviolet (UV)-gated gamma spectrometry, among other applications.

  The work on list-mode data format standards instigated by this group is continued primarily in the Euramet EMPIR 14SIP07 — DigitalStandard project. This project builds upon the pre-normative work of this group, and is specifically dedicated to the development of a draft international standard, including tools to support its implementation, under the auspices of the IEC Technical Committee 45 'Nuclear Instrumentation'. A new work item proposal for the development of an international standard was submitted on 15 October 2015, and accepted by IEC/TC 45 in February 2016. The first committee draft of the standard was accepted by the IEC TC 45 national committees on 25 October 2016. The development of the new standard IEC 63047 is led by the JRC liaison officer to IEC/TC 45. JRC's work package 3883 Digital Standards for Nuclear

([1]) The ERNCIP Office operates within the organisational framework of the European Commission's Joint Research Centre. The JRC 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 JRC 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 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.

Security (DiSNU) supports the development of the standard, with the input of the EMPIR DigitalStandard project partners.

- ***Robotics*** for radiological applications refers to remote-controlled radiation measurements and sampling using unmanned air, underwater or ground vehicles. There are no standards for sampling or taking measurements when searching for nuclear and other radioactive material outside regulatory control (MORC), or responding to other incidents such as reactor accidents or explosions.

  Unmanned vehicles can operate in areas with high radiation or danger of explosives. They can also be used for monitoring the movements of a threat object in hostile environments by gathering real-time data from multiple mobile sensor sources. Remote-controlled radiation measurement and sampling techniques need to be developed for these kind of situations. For example, a standardised capability for UAV (unmanned aerial vehicle)-based sampling from a radioactive release plume would be a tremendous improvement for emergency management. Such empirical information would be used as input data in atmospheric transport modelling calculations that are an important part of the decision support systems.
- ***Reachback*** is the expert support of field teams. An efficient concept of operations is based on moving data instead of people or samples, achieving a faster and better response with fewer people.
  The conventional means to undertake in-field analysis is:
    - Front-line officers or first responders operating detection equipment;
    - If anomalous radioactivity is detected, secondary measurements being performed, and if required, experts with more sophisticated equipment being invited to the location (mobile expert support team).

However, analysis of collected data can more safely and thoroughly be done at a distance from an incident. As an alternative, front-line officers and first responders can be equipped with spectrometers that are gain-stabilised, easy to use and able to send the recorded high-quality data wirelessly to a database, which can be located far away from the field mission itself (cross-border support). In the analysis centre, experts follow and interpret the measurements in near real-time and provide advice to the command and control, or directly to the front-line officer. Defined formats and protocols are needed for efficient communication between front-line officers and a reachback centre, but there are no standards related to remote support of field teams.

1.1 2016 objectives of the thematic group

1. List-mode:

To continue to promote the EMPIR DigitalStandard project and to present the work at suitable scientific conferences or workshops. Communicate the benefits of digital data acquisition system to vendors, system-level manufacturers and end-users.

2. Robotics:

To support the development of European robotics/RN detection exercises, trials and/or competitions using the group’s work on RN scenarios, with the aim that existing and future standards shall be introduced into the field of robotics.

3. Reachback:

To raise awareness within EU Member States through international organisations (GICNT and IAEA), and through direct contacts, on the benefits of information sharing nationally, regionally and internationally through expert support (reachback) for prevention and detection of, or response to, nuclear security events.

This report deals with the second item, remote-controlled radiation measurements and sampling using unmanned systems, and will present the current state of the art in robotics for this domain.

2 Unmanned systems for radiological and nuclear measuring and mapping

There is significant potential for the use of unmanned vehicles in scenarios involving radiological and nuclear threats. These threats involve measurement and sampling scenarios that are too risky for humans to carry out. For these scenarios, unmanned radiation measurements and sampling, using robots, needs to be developed. Note that the use of unmanned ground vehicles (UGVs) may be more cost-effective than the use of manned vehicles. Situations envisaged for the use of remote-controlled measurement and sampling devices are:

- Reactor supervision and related accidents, such as Chernobyl and Fukushima;
- Illicit release of radioactive material (radiological dispersion devices and dirty bombs before or after an explosion;
- Search of sources out of regulatory control;
- Long-term measurements.

Lessons learned from incidents such as Fukushima and Chernobyl, as well as the decommissioning of old nuclear power plants, show that robots have some advantages. Robots can operate in areas with high radiation or danger of explosives, for example boiling liquid expanding vapour explosions (BLEVEs), collapsing structures, improvised explosive devices (IEDs), booby traps and heat.

Additionally, they have the ability to manipulate the environment and to take potentially heavy samples, as they usually have a high payload. Robots can also be used for long-time surveillance of contaminated areas and monitoring the movements of a threat with real-time data from multiple mobile sensors [1, 2].

Despite the huge potential presented by the use of robots, no standards, best-practices or norms for sampling or taking measurements have been developed for these systems. The development of such methods could prove to be very beneficial not only for critical infrastructure protection (CIP). For example, the use of unmanned aerial vehicles to perform standardised measurements of the radioactive plume from a nuclear reactor incident or dirty bomb explosion is of tremendous importance to emergency response personnel. This type of information could be used in atmospheric transport modelling calculations, which are important parts of the decision-support systems.

The ERNCIP RN thematic group has been active since 2014. A subgroup, which is focusing on the use of unmanned systems, has so far produced three major reports ([2]) on the topic.

The results of the robotic subgroup within the three published reports have shown that there is an inherent need for a practical element shaping the standardisation process in the robotics community. It was also obvious that there is currently no or only very little interest of the academic robotics community in the RN field. A robotics research field that comes close to those capabilities that are probably needed for RN scenarios is the community around robotics competitions. This research area deals with unknown environments,

([2]) https://erncip-project.jrc.ec.europa.eu/networks/tgs/nuclear sensing, search and rescue as well as manipulation. Therefore, it seems reasonable to review the current state of the art in robotics competitions to elaborate if there are similarities that could be beneficial.

2.1 References

[1] Schneider, F. E., Welle, J., Wildermuth, D. and Ducke, M., 'Unmanned multi-robot CBRNE reconnaissance with mobile manipulation system description and technical validation', IEEE Carpathian Control Conference (ICCC), 2012, 13th International.

[2] Schneider, F. E., Wildermuth, D., Ducke, M. and Brüggemann, B., 'Development of an Experimental Multi-robot CBRNE Reconnaissance Demonstrator', Future Security Proceedings, Springer Berlin.

3 Major European robotics competitions

EURATHLON ([3]) and ELROB are both well-established European outdoor robotics competitions. The aim is to test the capabilities and the autonomy of robotic systems in realistic emergency-response scenarios. Inspired by the Chernobyl, Fukushima and WTC incidents the competitions require land, air or even water-based robots to survey the scene, collect environmental data, and identify critical hazards. Sometimes, depending on the scenario, the goal can only be achieved in a cooperative system with multiple robots. The competitions are accompanied by annual workshops for the competitors. Linked public engagement activities connect EURATHLON and ELROB with robotics research, industry and emergency services, as well as the general public.
The competition scenarios are developed based on users' requirements and in close collaboration with experienced emergency services. Although the robots face mock scenarios, the environmental conditions are as realistic as possible and the success criteria fully reflect end-user priorities. These are foremost task completion and minimal intervention to 'manage' the robots. The set of benchmarks for each competition are developed in an open discussion involving potential participants as well as users, industry and academia. The goal of this process is to define unambiguous and fair marking to assess the performance, quality and effectiveness of all competitors. The user-designed scenarios, which are as close to today's deployment scenarios as possible, are the unique features of the two events. ELROB is worldwide the only competition with night scenarios.

Teams that are new to robotic contests or that have limited access to adequate hardware often face the problem that they cannot test their systems against typical settings appearing at the competition. To address this problem a major aim of the EURATHLON/ELROB projects is standardisation. One step towards this goal is offering standardised robot platforms and payload-carriers to participating teams, which brings important advantages: teams can easily exchange software, hardware and knowledge. Costs are significantly reduced and even non-hardware or non-robotic groups have the chance to participate. Another measure is to provide standardised common shared data sets (CSDS), enabling the opportunity to compare methods, algorithms and configurations that require an exactly reproducible data stream from all sensor inputs. For all scenarios, high-quality data sets for a wide range of sensor devices are provided to the participants, and, in turn, all teams are requested to add their own sensor logs to a common data pool. The final step is to enforce the use of already well established standards in software and hardware.

In general, the EURATHLON/ELROB organisers see standardisation as a great necessity towards the goal of smarter robots. Introducing and using open standards as well as licence-free solutions will boost cooperation between industry and academia. The acceptance of unmanned systems will also increase with the adoption of these standards, allowing easy interoperability between systems and structures. Hence, all participating teams are strongly encouraged to use the open Robot Operating System (ROS) for their systems, and all data

([3]) EURATHLON will emerge into the European Robotics League https://eu-robotics.net/robotics_league/

exchange during the competitions has to adhere to a set of common protocols and formats.
This report illustrates the EURATHLON and ELROB projects and their goals, and describes how the successfully conducted EURATHLON 2013 and ELROB 2014 competitions have been a major step towards reaching these goals.

3.1 Related work

It is generally a problematic task to compare different approaches and methods in the field of outdoor robotics [1]. In the majority of cases, results are reported only for a specific robotic system. All tasks are carried out in a static and often specially defined environment, making it hard to compare the outcome with results from other research groups, other approaches, and other robots. The commonly used means of 'proof by video' or 'proof by example' are insufficient for obvious reasons, even if widely used in the science community.
Standardised benchmarks or data sets are sometimes used as a means of comparison and, in fact, they are a good basis to accelerate the progress of state-of-the-art research. Many fields in science and engineering have employed these criteria to evaluate similar research, approaches or techniques and to provide a means for their comparison. However, these measures are questionable if they do not reflect the reality or complexity of the considered problem. Any severe simplification of reality within the benchmark or data set will lead to overconfidence in the evaluation of the system's accuracy and robustness. Even worse, research directions that are not promptly successful on such benchmarks might not be pursued any further because they cannot be published and therefore get no funding.
As one possible solution, robot competitions have been proposed for benchmarking real robot systems [2]. Of course, competitions do not automatically solve all problems in comparing scientific approaches. The difficulties of repeatability and controlled experimentation remain. In outdoor trials, for instance, weather and lighting conditions can dramatically change even for consecutive runs. Starting positions differ and obstacles are not always accurately placed, as exemplarily mentioned in [3]. The authors also notice that new kinds of problems arise. Participants often tend to exploit rules or create special-purpose solutions related only to a specific trial instead of developing adaptive and flexible approaches. On the other hand, competitions provide important advantages apart from the pure benchmarking purpose. In [4], for example, the opportunity to exchange ideas and possible code reuse are mentioned.

3.2 Outdoor search and rescue competitions

Surveying the World Wide Web shows a large number of robotic events or competitions, predominantly in the US. Most of these events are scheduled for pupils or students like the US VEX robot events; VEX as a manufacturer offers robotic kits which enable young people without experience to fit operative robotic systems. Another example is the FIRST competitions, which are also designed for pupils. Such competitions take place in gyms or similar halls with mostly artificial obstacles. Competitions like the aforementioned have the aim of inspiring young people, but not in developing robots and software for real world

applications. Therefore, the following chapters will contain details of other competitions with a greater focus on practicability.
A bit more sophisticated regarding urban search and rescue (USAR) aspects is the RoboCup Rescue competition, which is a part of the global annually organised RoboCup competition. Nevertheless, even this competition is far from working in realistic environments. More real-world related are the SAUC-E and the ongoing DARPA robotic challenge which is in progress. One of the very few events that uses pure and unspoiled real-world scenarios with user-centred tasks is ELROB.

The RoboCup Rescue is a special part of the worldwide RoboCup competition. The idea for such a competition is based on the Great Hanshi-Awaji earthquake, which hit Kobe City in 1995. Damage to houses and infrastructure caused more than 1 million casualties. The intention of RoboCup Rescue is to promote research and development in interdisciplinary research themes around robot-aided search and rescue. Similar to all other competitions in the RoboCup the majority of the teams are made up of students. Normally the teamwork is done in the form of practical exercises, which correlate with the academic studies. Therefore, most of the teams are re-formed annually. The environment used in the competition is constructed based on standard test methods for emergency response robots developed by the US National Institute of Standards and Technology (NIST). The greatest advantage of these so-called arenas is that they allow repeatable tests in an environment anybody can build [5]. There are color-coded arenas with different levels of difficulty available. In all arenas, the robots have to find simulated victims and generate a map, which help other rescuing personnel to locate and rescue the victims.
The DARPA challenges started with the Grand Challenge in 2004 [6]. The goal was to travel more than 240 km in a desert-like area. No participant reached the destination. The team with the maximum covered distance had driven 12 km. The Grand Challenge 2005 [7] took place in a comparable surrounding, but navigation had to be done based on a path network with more than 3 000 waypoints. Terrain and routing were easier, mainly due to kerbstones and less curves. Additionally, the distance was reduced and many rules were simplified. This was followed up by the DARPA Urban Challenge demanding autonomous capabilities with a primary urban environment. However, the environment and rules were significantly adapted to the desired result.
Especially in the context of USAR, the new DARPA Robotics Challenge (DRC) is relevant. The DRC is designed as a competition of robot systems and software teams competing to develop robots capable of assisting humans in responding to natural and man-made disasters. The competition is in its second phase. After some preliminary decisions, 16 teams were elected to participate in the semi-finals in December 2013. In the semi-finals, the participants had to deal with eight tasks. Details and results can be found at [8]. The finals took place in June 2015. The event aimed to transform the current level of USAR robotics to a 'new sphere'.

3.2.1 The European Land Robot Trials (ELROB)

The ELROB trials have been started in 2006 as an annual competition, which alternates its key aspect between military and civilian [9]. In contrast to the DARPA challenges, the teams can choose different scenarios. Among these scenarios are different kinds of reconnaissance and surveillance missions combined with the detection of special objects, or transportation, which can be carried out with a single vehicle or in form of a convoy with at least two vehicles. Additionally, monitoring of a defined property was sometimes offered. In recent years several scenarios from the search and rescue domain have been added, e.g. the search for injured persons or the inspection of partially wrecked urban and semi-urban structures.

There are two principal reasons for this wide choice of tasks. First, as already mentioned, all scenarios are developed in close collaboration with experienced users from possible application domains. Obviously, different users express different requirements and specifications for robot systems depending on their field of application. Instead of combining these demands into one large scenario, as in the DARPA challenges, it might be more meaningful to have different tasks, which correspond to the various application scenarios. The second motivation for ELROB's multi-scenario approach is participant driven. A wider range of robot platforms is applicable at least for a subset of the tasks. Smaller robots, for example, can be used for monitoring or surveillance missions, whereas large vehicles are more suitable for transportation tasks. Since participants can freely choose among the scenarios, the competition is attractive for nearly any company and research institution related to outdoor robotics.

ELROB was designed to create overview concerning the state of the art in outdoor and/or off-road robotics, mainly for Europe. However all countries are welcome to participate but only European led are eligible for funding. The scenarios take place in urban and non-urban surroundings at varying venues in Europe. Usually, ELROB has between 10 and 15 participating teams, 10-50 exhibitors and hundreds up to 1 000 spectators.

In 2014, ELROB was hosted by the Warsaw Military University of Technology (WAT). The trials took place from 23 to 27 June. Twelve teams from all over Europe showed their performance in five different scenarios. Among these scenarios, those with the strongest search and rescue (SAR) relation have been 'Search and retrieval of human casualties in outdoor environments' and the USAR task 'Reconnoitring of urban building structures'.

The rescue of wounded persons is an important yet often difficult task in civil catastrophes as well as in military scenarios. The use of robotic vehicles, first, to find injured persons and, second, to autonomously pick them up and transport them back to safe areas is obviously a great improvement. The situation in the so-called MedEvac task of ELROB 2014 was the following: two wounded (artificial) persons are lying at two roughly known positions in distances of 50-75 m. A vehicle had to search and locate the bodies, and then transport them (one after another) back to the starting point. Fences, barriers or any kind of blockades and 'negative' obstacles, like trenches, had to be expected. See Figure 3-1 to get an impression.

Figure 3-1: ELROB 2014 MedEvac scenario: the Defender D2.1 of team MED-ENG trying to rescue one of the artificial victims

Reconnaissance of wrecked structures, buildings and the surrounding environment is an important prerequisite for any kind of USAR mission. The availability of robots for autonomously searching buildings is a great relief for rescue personnel and delivers valuable information for the mission planning. In the USAR scenario, the participants faced the following situation: An area of interest at a distance of about 50 m, about 100 m × 50 m in size, with a number of small buildings, had to be approached. After reaching a building, the complete scene had to be examined. The buildings were first searched from the outside, e.g. through windows or doors, and afterwards by entering the building and performing mapping.

3.2.2 The EURATHLON competition

Funded by the European Commission, EURATHLON is an international competition that welcomes university, industry or independent teams from any EU country [10]. EURATHLON provides real-world robotics challenges for outdoor robots in demanding scenarios. The trials and scenarios are chosen in the frame of an important research topic of the European Union: 'Restoring security and safety in case of crises'. This field of research addresses all major robotics goals such as cognition, autonomy, adaptivity and robustness. Ideally, autonomous air, land and underwater robots should act together to survey the situation, collect environmental data, and identify potential hazards.
The focus of the first EURATHLON competition in 2013 was land robots, and had five scenarios, each consisting of a series of tasks, which these terrestrial robots had to complete. The scenarios covered a number of the key competencies needed in outdoor disaster response, including mapping the disaster site, searching for objects of potential interest (e.g. survivors), turning off valves (i.e.

a gas leak), finding hazardous materials and making them safe, and navigating autonomously from one place to another. The longer-term vision of EURATHLON is a multi-robot multi-domain competition scenario in which robots of all three domains, land, air and water, act together.

Inspired by the Fukushima accident of 2011, the EURATHLON 'grand challenge' will require cooperating groups of land, sea and flying robots to investigate the scene, collect environmental data, then identify and stabilise critical hazards. The focus of EURATHLON 2014 was underwater robots, and EURATHLON 2015 will finally add flying robots, to cover all three domains. To promote the participation of the maximum number of teams, in this final event three different categories of scenarios have been defined: single-domain trials, two-domain sub-challenges, which are essentially a combination of single-domain trials, and a three-domain challenge (the 'Grand Challenge'), which is basically a combination of all sub-challenges. In the Grand Challenge robots from the land, air and sea domain will have to cooperate to achieve the specified missions, which are based on the two-domain sub-challenges.

As already mentioned the setting of the Grand Challenge is comparable to the Fukushima accident of 2011. An earthquake and tsunami have been experienced in the area of a nuclear reactor building causing serious damage to the building and other parts of the nuclear plant as well as resulting in injured and/or dead workers who are missing. The damage has affected the cooling system and some pipes are leaking contaminated water. In the area surrounding the building and inside the building there are many obstacles, e.g. debris, rocks, holes on the ground, stairs, etc. In addition, some of the entrances to the reactor building might be blocked by debris.

Due to the risks of nuclear leaks, the first response team will use multi-domain robots. There are two main missions that have to be performed: find the missing workers in the shortest time, and find and stem the leaks in the pipes. The most urgent mission is to find the missing workers. They may be in the area surrounding the reactor building on the ground or by the sea on the coast and they can also be inside the building. To look for the missing workers aerial and ground robots can be used. To search for the missing workers at the sea autonomous underwater vehicles (AUV) and optionally unmanned surface vehicles (USV) can be used. The other mission is also of vital importance from an environmental point of view. The leaking pipes must be located and the leaks must be stemmed. The stopcocks can be indoor, outdoor, on the ground, or underwater. Figure 2 provides an overview of this rather complex scenario.

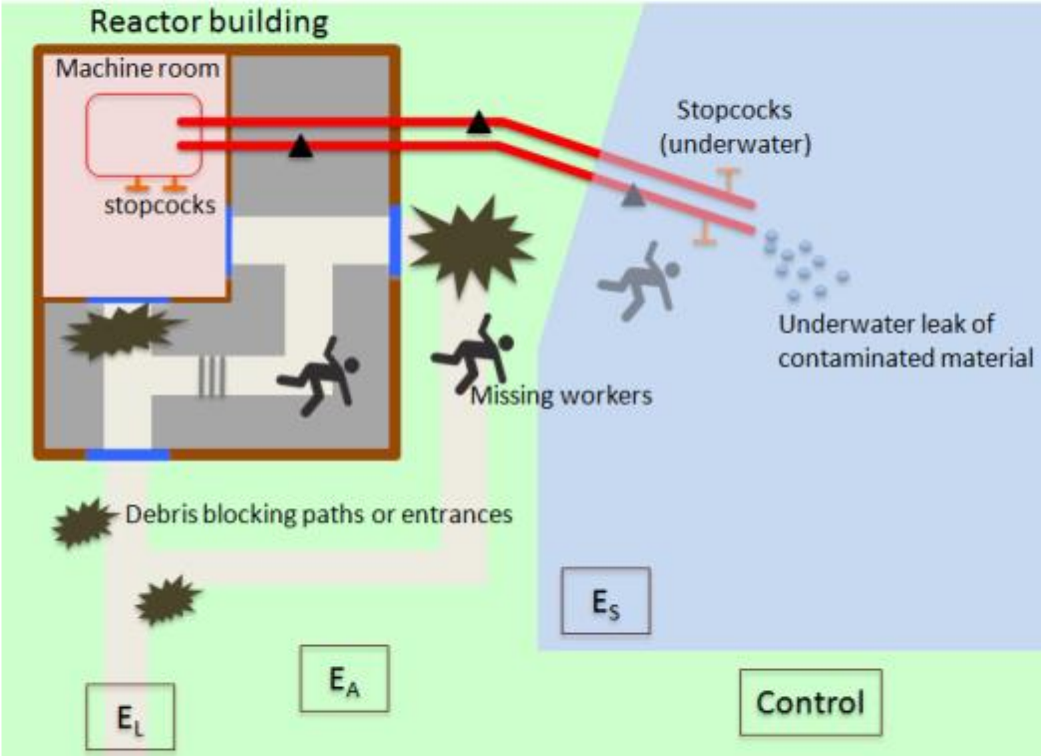

Figure 3-2: The 'Grand Challenge' scenario of EURATHLON 2015

3.3 Steps towards standardisation

3.3.1 Platforms and payload-carrier

For EURATHLON 2014 and 2015, a standardised AUV robotics kit has been offered for lending to the participating teams. The selected kits are reliable and at the same time provide the teams with the capability of an easy customisation and the possibility of integration of additional sensors/actuators. The selected vehicles are the SPARUS II AUV (see Figure 3-3) provided by the University of Girona and two Doppler Velocity Logs (DVL), specifically 300 m DVL from Teledyne Company. The teams that receive the platforms are selected by the EURATHLON project consortium after the evaluation of the quality of the team applications. Priority is given to the quality and novelty of the proposed algorithms.

Figure 3-3: One of the standardised autonomous underwater vehicles of type SPARUS II offered to the teams in the EURATHLON competition

3.3.2 Common shared data sets (CSDS)

Teams that are new to the competition or teams with limited access to proper hardware and training areas face the problem that they cannot test their system against typical settings appearing at the competition. In addition, the comparison of methods or configurations requires an exactly reproducible data stream from all (sensor) inputs.

A classic way to cope with this situation is to provide standardised common shared data sets (CSDS). One example is the project Rawseeds [12]. Standardised CSDS can be used as a means of comparison and, in fact, they are a good basis to accelerate the progress of state-of-the-art research. Many fields in science and engineering have employed those criteria to evaluate similar research, approaches, or techniques and to provide a means for their comparison.

To provide the participants of the EURATHLON/ELROB with an impression of the different scenarios, several example data sets were produced. The data sets are collected in realistic environments and in different conditions. Every year, the data sets will be incrementally expanded using new data collected during the competition or made available by any third party. A structured data repository will be set up to maintain the database. The data sets are recorded as so-called ROS-bags and are easy to use with the robot framework ROS. The data sets include all relevant sensor and navigation information, namely laser sensors looking at different angles, a Microsoft Kinect providing video and RGBD data, and additional inertial measurement (IMU) data, as well as timestamps for all data.

It was decided as a requirement that the data sets would only be made available to participants who agreed to provide data sets collected from their runs during the EURATHLON/ELROB competition, thus aiming to encourage participants to share their data with the community. Sadly, only very few participants were able to make use of this possibility. Hence, the EURATHLON/ELROB CSDS database still is of limited extent.

3.4 Metrics and benchmarks

Obviously, benchmarks have to be used to rank competitors, but they can be also a good means to measure progress and inform the end-users of the level of maturity of the various technologies involved. Defining benchmarks however is only useful if they are going to be used. Robotics is too broad a field to define general benchmarks and, thus benchmarks should focus on particular domains and tasks (control, visual servoing, navigation, etc.).

Regarding ELROB and EURATHLON the benchmarking aspect is addressed using a variety of different approaches. First, a common operating environment and task description provide a reference point for different platforms. The lack of mandatory guidelines, other than a high-level task description, allows complete freedom with regard to exploring hardware and software solutions, non-standard components, etc. This enables creativity and benchmarking of tasks where the 'systems' aspects are important. This is the approach currently taken in ELROB and EURATHLON as well as in a number other successful competitions (SAUC-E, DARPA, Mobile Manipulation Challenge). The output of the benchmarking process in this mode is a grade from 1 to 5 akin to the widely used technology readiness

levels (TRL). This has the benefit of providing a non-metric, yet very useful evaluation of technologies, especially from the end-user point of view.
A second aspect is the systematic benchmarking of algorithms on monotype platforms. A standardised hardware platform may be used by multiple research groups, allowing for direct comparisons and interoperability of the software components. With ROS the organisers also provide a middleware to support and ease integration on platforms, test algorithms on third party hardware and integrate third party software. The third important aspect is the systematic benchmarking of algorithms on common data sets (as described in section IV.B). Each data set is associated to the benchmarks used to validate the technology demonstrated and the current performance of the best algorithms to date. This allows not only the competition participants but also any interested research group to realistically evaluate their developed methods and algorithms.

3.4.1 Land robotics benchmarks

In contrast to the benchmarking of competition participants, which is called 'marking' in the context of the EURATHLON, an additional project goal is to measure progress and the level of maturity of the relevant outdoor robotic technologies. This general benchmarking information is gathered during all EURATHLON events.
So far, only for ground robots, a methodology for benchmarking performance has been developed based on robot capabilities, i.e. guidance-control-navigation, scene understanding, manipulation, deliberation, and interaction. The methodology entails metrics applied to various capabilities when robots perform tasks associated to specific mission scenarios. The assessment method (marking) considers different grades of autonomy for unmanned ground vehicles including tele-operation, supervised autonomy and unsupervised autonomy. It evaluates the performance of robots carrying out the tasks for the scenarios, and takes into account manual interventions (penalty).
General benchmarks for the air and sea domain are currently under development or have been applied for the first time in the sea-based EURATHLON 2014 event, but still lack a complete evaluation.

3.4.2 Marking of competitors

As said before, 'marking' in the context of EURATHLON (and 'scoring' for ELROB) means to create a ranking among the participants of a competition scenario — in contrast to the general benchmarking approach addressed in the last section. The marking schemes used for ELROB and EURATHLON assume that robots can be either tele-operated, autonomous but with live feedback to an operator (supervised autonomy) and fully autonomous with no feedback. For each mode of operation, points are allocated for each subtask of the scenarios. There is a desire to encourage more autonomy and therefore autonomy is rewarded more than tele-operation.

Performance measures	***Tele-operated***	***Supervised autonomy***	***Unsupervised autonomy***
Enter building	100	200	300

Map of urban structure produced	See table Max 500	(See table)*2 Max 1 000	(See table)*3 Max 1 500
Detection of OPI (i.e. position entry in the map)	100 per OPI	200 per OPI	300 per OPI
Image of OPI produced	50 per OPI	100 per OPI	150 per OPI
Image of OPI transmitted online to control station	100 per OPI	200 per OPI	300 per OPI
% of correct OPIs compared to total reported OPIs	– 5*(100-x)	1*x	2*x
Vehicle trajectory drawn in map	100	100	100
Mission completed in time	See table Max 500	(See table)*2 Max 1 000	(See table)*3 Max 1 500
Penalty for n manual interventions	– 300*n	– 100*n	– 50*n
Penalty for manual intervention duration t	$-3000 * \frac{\text{T-IAT}}{\text{runtime}}$	– 1 500*t/runtime	– 1 000*t/runtime
Penalty for using elevator (instead of stairs)	– 1000	– 750	– 500
Bonus: open door/ map dark room/map smoke room	*500 for each*	*1 000 for each*	*1 500 for each*

Percentage of building mapped	***Score***	***Mission completion before***	***Score***
< 10 %	0	… half of trial time	500
Between 10 % and 25 %	125	… ¾ of trial time	250
Between 25 % and 50 %	250	… end of trial time	100
Between 50 % and 75 %	375		
> 75 %	500		

Figure 3-4: An example of the marking scheme used for ranking the participants in the EURATHLON 2013 Urban Search and Rescue scenario. The teams could choose among the different levels of autonomy.

Teams have the choice of performing each subtask either autonomously or in tele-operation mode. However, there is a large bonus for teams succeeding in performing a full mission (which might involve only a number of subtasks and not the full scenario) autonomously. In all operational modes, there is a penalty for any manual intervention with the robot itself such as moving the robot or restarting it, but the penalty is higher for tele-operated robots as they should have more control on the vehicle trajectory.

An example of the marking scheme from EURATHLON 2013 can be found in Figure 3-4. It was used to assess the urban search and rescue scenario 'Reconnaissance and surveillance in urban structures', in which the robots had to build a map representation of a building and search for special objects of interest. The necessary numbers were collected by the members of the judging team, and the results as well as the final ranking were computed and published directly after each trial.

3.5 References

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[4] Helmer, S., Meger, D., Viswanathan, P., McCann, S., Dockrey, M., Fazli, P., Southey, T., Muja, M., Joya, M., Little, J., Lowe, D. and Mackworth, A. (2009), 'Semantic Robot Vision Challenge: Current State and Future Directions', Proceedings of the IJCAI-09 Workshop on Competitions in Artificial Intelligence and Robotics, Pasadena.

[5] Jacoff, A., Messina, E. and Evans, J. (2000), 'A Standard Test Course for Urban Search and Rescue Robots', Proceedings of the NIST Workshop on Performance Metrics for Intelligent Systems (PerMIS), Gaithersburg.

[6] DARPA Grand Challenge 2004, website archive for scientific purposes, http://archive.darpa.mil/grandchallenge04

[7] DARPA Grand Challenge 2005, website archive for scientific purposes, http://archive.darpa.mil/grandchallenge05

[8] The DARPA Robotics Challenge, https://en.wikipedia.org/wiki/DARPA_Robotics_Challenge

[9] The European Land Robot Trials (ELROB), official website, http://www.elrob.org

[10] Official EURATHLON project website, http://www.eurathlon.eu

[11] The Robot Operating System (ROS), official documentation, http://wiki.ros.org

[12] Official RAWSEEDS project web page, http://www.rawseeds.org

4 The ERNCIP supported scenario at ELROB 2016

Since 2006, the European Land Robot Trials (ELROB [4]) have successfully provided real world scenarios to test the state of the art in outdoor and/or off-road robotics, mainly for Europe. ELROB offers realistic scenarios, which have been developed in close cooperation with users and practitioners to reflect the up-to-date requirements. The event is not organised as a competition but as a trial, allowing academia, industry and users to work together in an open atmosphere. The community has the chance to assess current technology as well as to pilot and govern further development. The major difference with other competitions [1] is that not only the tasks and scenarios are designed by the users but also the performance of the systems is assessed by field experts. Furthermore, the event offers the fantastic opportunity to mingle with international experts from the field, the industry and the R & D sector.

In 2016, ELROB was hosted by the Austrian Army in the Tritolwerk in Eggendorf. The Tritolwerk is an old ordnance factory, which is used for CBRNE training as well as training for emergency services [2].

Figure 4-1: Partial view of the Tritolwerk in Eggendorf, Austria

These premises gave the perfect setting for the ERNCIP special scenario: Reconnoitring of urban structures with focus on radiological and nuclear measuring and mapping. This was the first real world live scenario with strong radiation sources on a robotics competition ever! The task was to search and detect an unknown number of radiation sources. The system should measure the radiation, display the measurement to the operator, acquire imagery and mark the position of the source in the online-build map representation. Figure 4-2 shows the teams that participated in the scenario.

([4]) http://www.elrob.org

No	Team (5)
1	AVRORA
2	bebot
3	Cobham
4	ELP
5	FKIE
6	IMM
7	TAUT
8	TNO
9	activeROBOTICX

Figure 4-2: List of participants in ERNCIP scenario at ELROB 2016

More details can be found on the official ELROB web page:
http://www.elrob.org

Media footage can be found on FLICKR® and YOUTUBE®:
http://www.flickr.com/photos/europeanrobotics/collections
http://www.youtube.com/user/EuropeanRobotics

4.1 Scenario: Reconnoitring of structures with focus on radiological and nuclear measuring and mapping

The outlines of the possible scenario had to be adapted to the boundaries set by the already planned ELROB event. The host nation Austria was able to provide strong radiation sources, an appropriate building and enough qualified personnel to conduct the scenario. The story behind the reconnaissance task was as follows:

> Search and detect a number of unknown radiation sources in a primarily unknown building. Measure the radiation, display the measurement to the operator, mark position inside a digital map representation, and acquire live imagery.

Radiation source	Co-60
Type	15HH
Serial number	70
Activity (strength of source)	2.89 GBq ± 2.5 %

(5) By clicking on the team name, you will be directed to a PDF document with the team description. The document is hosted on the ELROB web page. You will need internet access.

Date	**11.12.2008**
Radiation source	**Co-60**
Type	**15 HH**
Serial number	**68**
Activity (strength of source)	**2.78 GBq ± 2.5 %**
Date	**11.12.2008**

Figure 4-3: Specifications of the two sources used in the scenario

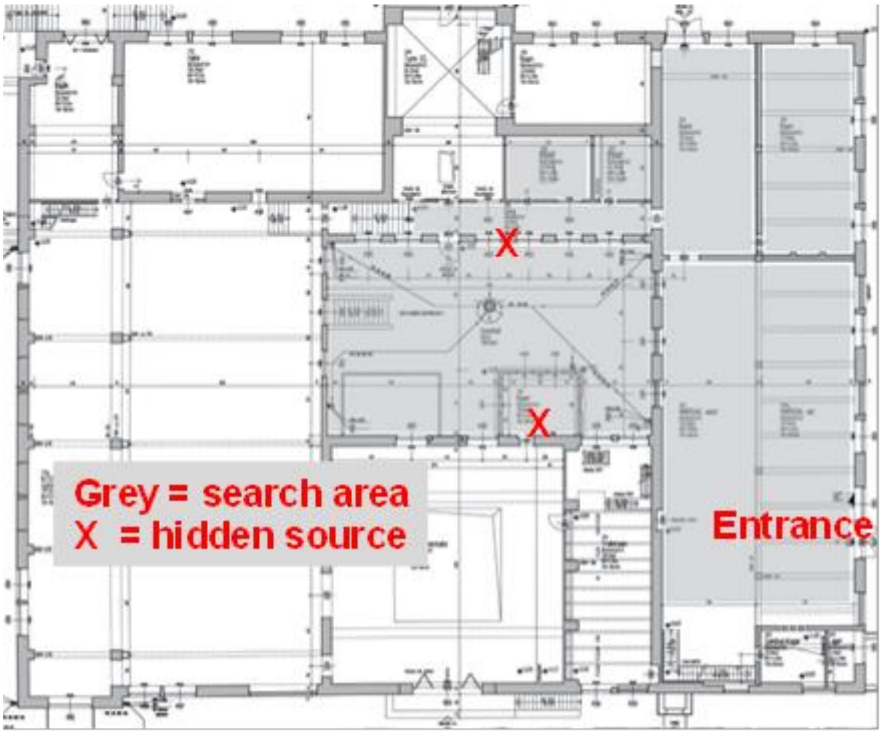


Figure 4-4: Floor plan of the building to be searched.
The locations of the entrance as well as the two sources are marked in red.

4.1.1 Scenario description

The following information was given to the participants of the scenario beforehand. At the start, they also received the floor plan shown in Figure 4-4, without the location of the sources of course:

Scenario:
Reconnaissance of structures and buildings and the surrounding environment is an important prerequisite for urban and semi-urban emergency operations. At the same time, this is one of the most dangerous tasks responders face during a mission. Therefore, having robots for autonomous reconnoitring of buildings definitely means a great relief for the troops.

Environment:

An urban structure, stairs, low or no light, closed doors, sand, water, stones, rubble and debris.
The urban structure that has to be entered is approximately 50 m long and 25 m wide; it can be dilapidated or even partially wrecked.

Situation:
Reconnoitre the interior of the building.
There will be static and dynamic obstacles present. Dead ends, sharp turns, blocks, stairs and narrow passages can occur.

Objective:
Search for objects of potential interest (OPI) inside the building, i.e. particular markers with special characteristics as defined in the rules.
Use highest autonomy possible. Build a 2D/3D map of the building.
Whenever an OPI is found, acquire imagery and mark its position inside the map representation. Report all gathered data to the control station, online or offline after having returned to the starting point. Plot the robot's path and detected OPI positions into the generated map.
If possible, transmit live position and imagery to the control station.
If possible, search and detect a number of hidden radiation sources. Measure the radiation, display the measurement to the operator, acquire imagery and mark its position inside the map representation.

Remarks:
Be prepared to deliver additional data in ROS bag format; exact specification and data types will follow.

Timing:
Duration approximately 30 minutes. The scenario ends with reaching the time limit and must include the transmission of the acquired data.

Pictures:

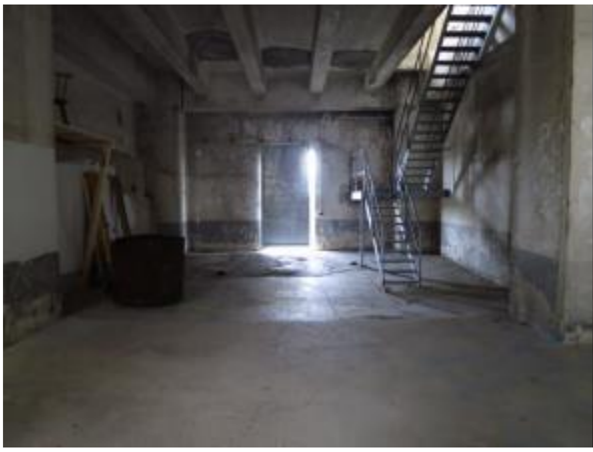





Figure 4-5: Sample pictures of the environment to be expected in the ERNCIP scenario

4.2 Required standards for ELROB

Standardisation should not only be seen as the process of developing and implementing technical standards but as a necessity towards the goal of smarter robots. The acceptance of unmanned systems will increase with the adoption of standards that enable interoperability with existing systems and structures.
The step of standardisation within the trials will generate a state in which all parties can realise mutual gains, by making guided mutually consistent decisions. The sum of these effects will lead to more comparable results for the trials and a significant speed-up in research. Introducing open standards will also boost the cooperation between industry and academia substantially as well as interaction between teams.

Standards may be introduced in nearly all fields of robotics-related hardware and software, e.g. technical interfaces; cables and connectors; protocols, encodings and data formats; or even complex systems like payload specifications, software architectures or a complete robot middleware.

In all recent ELROB events, for example, electronic data transfer/exchange had to be done via the WebDAV protocol. Access to the mission data on a dedicated ELROB server was effected using WebDAV (HTTP V1.1 based). The access required a login, which was received from the organisers beforehand. When a mission was finished, the results had to be loaded onto the same ELROB server, again using WebDAV with the same login data. The data formats that had to be used were specified beforehand. The used formats are open standards and licences free to ensure the open sciences spirit. All data coming from the participant (robots) that were not in accordance with the required standards were discarded. So the participants were forced to comply with the standardisation process.

Additionally, for all ELROB and EURATHLON events the use of the popular middleware Robot Operating System (ROS) is strongly encouraged. ROS is well developed and accepted in the land, air and maritime domains and presents a number of real advantages, like open and free usage, good logging and debugging abilities, good existing support for hardware and software, large user and support group, etc. To help the potential participants with their decision the available CSDS are ROS based. Furthermore, software elements and examples provided by the organisers are also ROS based, just as are drivers for special hardware that can be used in the trials. The results could already be seen in ELROB 2014 where various teams exchanged software shreds as well as replacements for broken hardware. Some newbies to the competition were able to keep at least up with more mature teams due to the fact that they could use the existing free software. This enabled them to concentrate on their main focus, e.g. mechatronics or vision modules.

Reusable code is therefore an important output of a successful trial. Since one goal of trials is to move the state of the art in research in a desired direction, successive solutions to the trials problem could be supported by having previous work available as a starting point. Reusable code would also make the entry easier for teams new to the competition, enhancing accessibility of the competition and, in turn, its visibility.

For the ERNCIP driven scenario, all data requirements mentioned in the following sections had to be met. Submitted data, which do not comply with the formats specified in the following section, was not accepted.

4.2.1 Standards used in ELROB

All electronic data transfer/exchange in ELROB activities had to be done via WebDAV. For any electronic data exchange a computer has to be connected to a standard IPv4-based Ethernet using a CAT6 twisted pair 8P8c/RJ45 cable. The cable will connect the computer via a switch to a special ELROB server. There will be no other devices on this dedicated network. Either an arbitrary static IP address in the range of 10.10.10.[11-111] may be selected, or an IP address can be obtained via DHCP from the ELROB server with the range 10.10.10.[112-254].

Access to the mission data on the dedicated ELROB server is realised using WebDAV (HTTP V1.1 based). The access requires a login and a password, which will be received from the organisers beforehand. The general format of mission input data is described in section 4.2.6. When a mission is finished, the results have to be put on the same ELROB server, again using WebDAV with the same login and password. The general format of mission output data is described in section 4.2.7.

The following schematic drawing illustrates the principle of electronic data exchange for the actual ELROB trials:

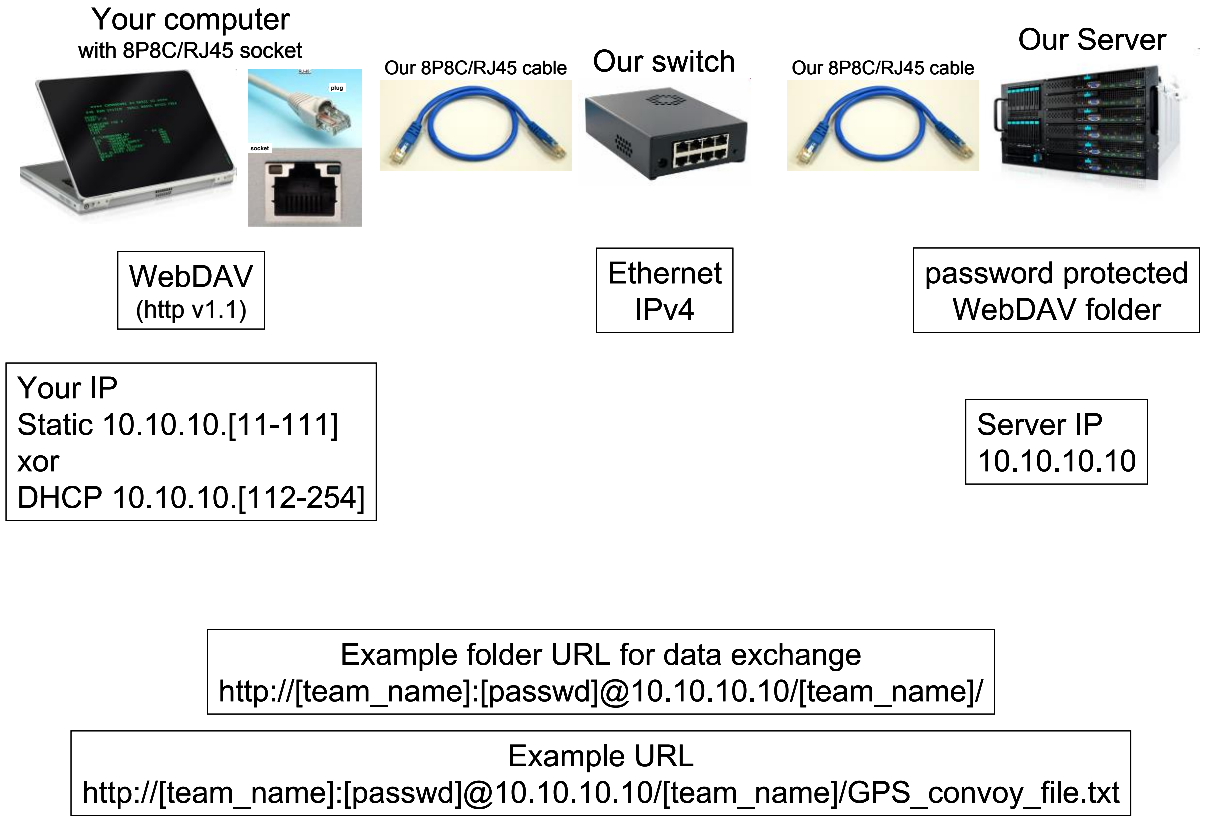


Figure 4-6: Network set-up for ELROB

For a list of standards and references related to this electronic data exchange mechanism, refer to paragraph 4.2.8.

4.2.2 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

4.2.3 Position encoding

The geographic coordinate system that is used in all ELROB activities is:
Universal Transverse Mercator (UTM) coordinate system
http://en.wikipedia.org/wiki/Universal_Transverse_Mercator_coordinate_system

The geodetic reference system that is used in all ELROB activities is:
World Geodetic System (WGS) 84
http://en.wikipedia.org/wiki/World_Geodetic_System

The following example shows how a waypoint list (e.g. as part of the mission data) will look like:

#UTM (WGS84) 3 waypoints
#alpha
32U 559431.82 5545416.83

```
#bravo
32U 559427.28 5545324.43
#exit point
32U 559422.03 5545299.19
```

4.2.4 Time encoding

The time zone and time formats that are used in all ELROB activities 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, for example, result in an output like: 915148798.750000.

4.2.5 Graphics encoding

The graphics file formats that are used in all ELROB activities are:

Portable Network Graphics (PNG)
http://en.wikipedia.org/wiki/Portable_Network_Graphics

and/or

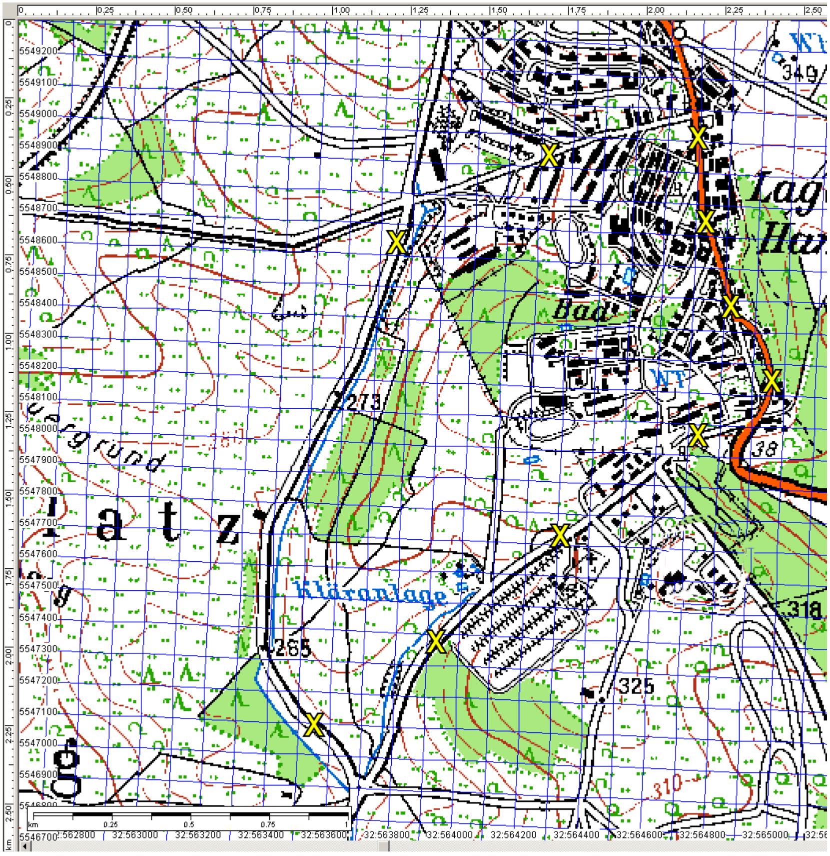
JPEG (ITU-T T.81, ISO/IEC IS 10918-1 and, if needed, ITU-T T.84)
http://en.wikipedia.org/wiki/Jpg

4.2.6 Input data

Input data refers to the data that will be received from the ELROB officials in electronic format via the data link described in section 4.2.1.

The input data consists of:

1. A section of a digital map with UTM grid and UTM coordinates in JPG or PNG format (see example below).



2. A list of UTM coordinates that might specify a list of target areas, a list of waypoints or a list of boundary points (see example for waypoints below).

   # UTM (WGS84) 8 waypoints
   35W 427433.55 7216222.93
   35W 427241.47 7216235.05
   35W 427117.71 7216185.88
   35W 427088.03 7216191.55
   35W 427108.11 7216218.62
   35W 427520.44 7216880.68
   35W 427503.51 7216931.69
   35W 427481.76 7216963.17

4.2.7 Output data

Output data refers to the data that the ELROB officials receive from a participant in electronic format via the data link described in section 4.2.1.

The output data should include:

1. A text file containing a list of UTM coordinates, including a full UNIX time stamp, that reflects the route driven by your vehicle, all in consecutive order (see example below).

   # UTM (WGS84)
   [full UNIX time stamp] 35W 427433.55 7216222.93
   [full UNIX time stamp] 35W 427241.47 7216235.05
   [full UNIX time stamp] 35W 427117.71 7216185.88
   [full UNIX time stamp] 35W 427088.03 7216191.55

[full UNIX time stamp] 35W 427108.11 7216218.62
[full UNIX time stamp] 35W 427520.44 7216880.68
[full UNIX time stamp] 35W 427503.51 7216931.69
[full UNIX time stamp] 35W 427481.76 7216963.17
[full UNIX time stamp] 35W 427476.80 7217015.29

2. Additionally, a section of a digital map in JPG or PNG format that contains the driven route as a plotted path and the position of the detected objects of potential interest (OPI), labelled with an X. (See example below: driven paths are plotted as yellow lines, OPI as red X).

3. The file name of the digital pictures for the detected OPI must contain the UTM coordinate of the OPI (see example below).

   [full UNIX time stamp]_35W427433.55_7216222.93.png
   resp.

   [full UNIX time stamp]_35W427433.55_7216222.93.jpg

4. Additionally, a text file containing the list of UTM coordinates, including a full UNIX time stamp, that reflect the positions of the detected OPI, all in consecutive order (see example below).

   # UTM (WGS84)
   [full UNIX time stamp] 35W 427433.55 7216222.93
   [full UNIX time stamp] 35W 427117.71 7216185.88
   [full UNIX time stamp] 35W 427503.51 7216931.69
   [full UNIX time stamp] 35W 427481.76 7216963.17

[full UNIX time stamp] 35W 427476.80 7217015.29

4.2.8 Standards for electronic data exchange

The following links refer to standards related to the electronic data exchange mechanism used for ELROB:

- Ethernet
  http://en.wikipedia.org/wiki/Ethernet
- IP v4
  http://en.wikipedia.org/wiki/IPv4
- DHCP
  http://en.wikipedia.org/wiki/Dhcp
- WebDAV
  http://en.wikipedia.org/wiki/WebDAV
- HTTP v1.1
  http://en.wikipedia.org/wiki/Hypertext_Transfer_Protocol
- 8P8C/RJ45
  http://en.wikipedia.org/wiki/8P8C
  http://en.wikipedia.org/wiki/Registered_jack_naming_confusion
- Twisted pair Cat6 cable
  http://en.wikipedia.org/wiki/Twisted_pair
  http://en.wikipedia.org/wiki/Category_6_cable
- IP address
  http://en.wikipedia.org/wiki/IP_adress
- URL
  http://en.wikipedia.org/wiki/URL
- Switch
  http://en.wikipedia.org/wiki/Network_switch
- Server
  http://en.wikipedia.org/wiki/Web_server
  http://en.wikipedia.org/wiki/File_server

4.3 Results

Since this was the first of this RN scenario attempted in the ELROB trials, the expectations were modest. However, the teams performed reasonably well under the given circumstances. An overall of nine teams did 15 runs of 30 minutes each. The best three teams found both sources, two only one source, and only three submitted a map. Most of the teams had some RN-sensor readings. A lot of them struggled with radio communication problems. In the end, it was obvious that there was not enough background knowledge within the teams on radiation detection to produce better results. The search patterns (the

robots were driven by humans) were more or less erratic. The only team that had a semi-autonomous approach failed because of a broken radio link. Most of the teams did not consider the measuring cycle of their detector. So when receiving the actual RN-sensor reading the robot had already moved on, making it very hard to determine the direction from where the radiation was coming. Some of the teams also overestimated the magnitude of the measurements to be expected leaving them with rather low/small changes in the radiation level when moving through the building.
The following tables depict the metrics and benchmarking scheme used in the ERNCIP scenario.

Performance measures	***Tele-operated***	***Supervised autonomy***	***Unsupervised autonomy***
Vehicle entered building	100	200	300
Map of area produced	See table below max. 500	(See table below)*2 max. 1 000	(See table below)*3 max. 1 500
Detection of OPI (i.e. position entry in the map)	100 per OPI	200 per OPI	300 per OPI
Image of OPI produced	50 per OPI	100 per OPI	150 per OPI
Image of OPI transmitted online to control station	100 per OPI	100 per OPI	100 per OPI
% x of correct OPIs with respect to overall number of OPIs reported	0.5*x	1*x	2*x
Vehicle trajectory drawn in map	100	100	100
Live position and video transmitted to start point	100	100	100
Mission completed in time	See table below max. 1 000	(See table below)*2 max. 2 000	(See table below)*3 max. 3 000
Penalty for n manual interventions	– 100*n	– 50*n	– 25*n
Penalty for manual intervention duration t (i.e. *t = IAT + TIAT*)	$-2\,000 * \frac{\text{TIAT}}{\text{runtime}}$	– 1 000*t/runtime	– 500*t/runtime
Bonus: Detection of radiological source (i.e. position marked in the map)	*750 each*	*1 500 each*	*2 000 each*

Percentage of area mapped	**Score**
< 10 %	0
Between 10 % and 25 %	125
Between 25 % and 50 %	250
Between 50 % and 75 %	375
> 75 %	500

Mission completion before	**Score**
… half of trial time	1 000
… ¾ of trial time	750
… end of trial time	500

Figure 4-7: Metrics and benchmarking scheme for ERNCIP scenario

For each of the teams all available data was recorded online together with several video streams produced by cameras distributed within the building. Additionally two judges took notes and gave subjective impressions on the performance. Together with the standardised data that had to be delivered by the teams, the chief judge compiled the 'ranking' chart (Figure 4-9) for the teams. It should be kept in mind that this is not intended to be a scientific correct experiment but a trial that incorporated a more Olympic spirit.

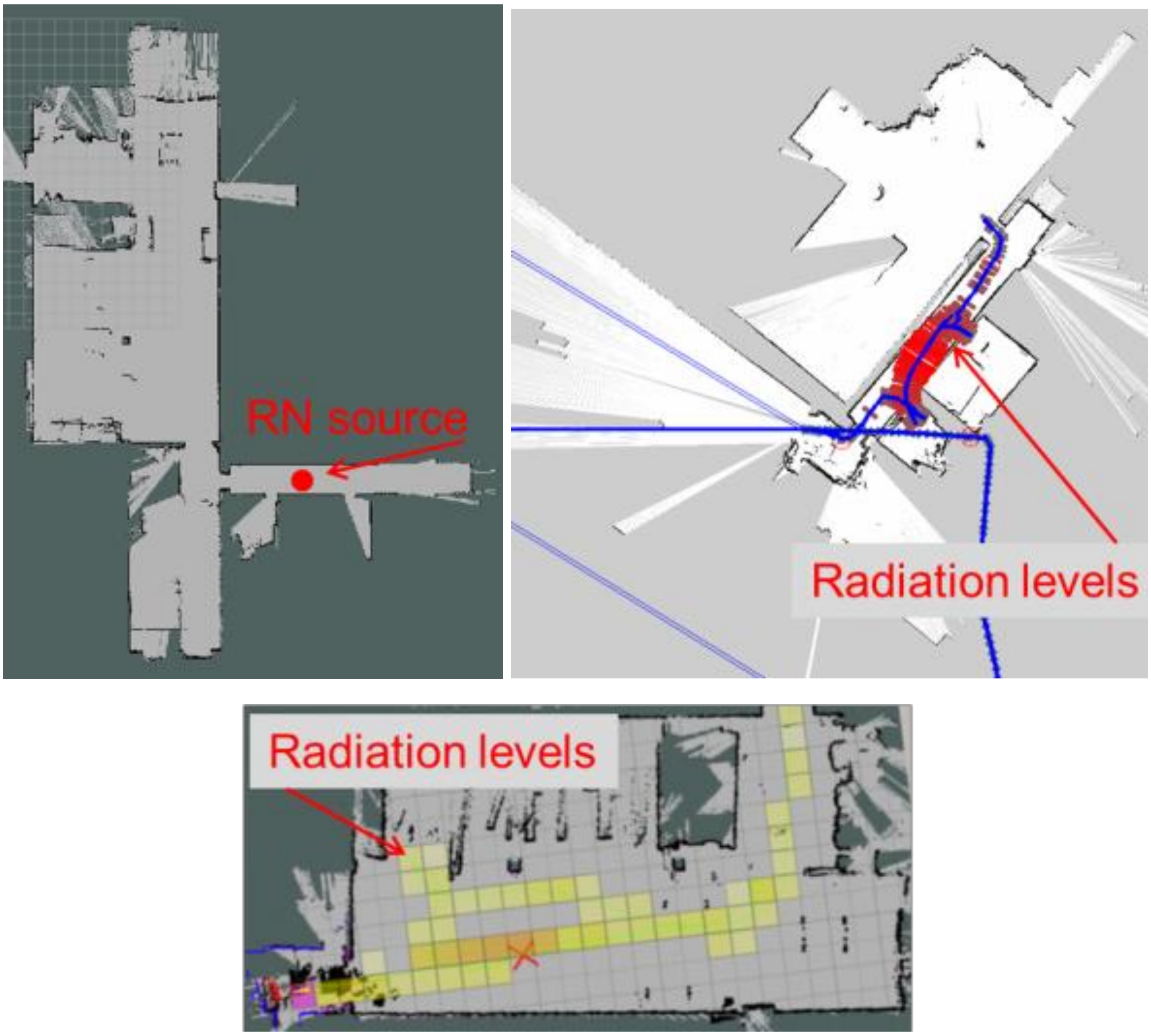


Figure 4-8: Examples of radiation maps that where submitted by the participants

	ELP	**AVRORA**	**IMM**	**Cobham**	**bebot**	**Fraunhofer FKIE**	**Austrian technology**	**TNO–NLD EODD**	**active ROBOTICX**
Mode of operation	*Teleoperated*	*Withdrawn*	*Autonomus*	*Teleoperated*	*Teleoperated*	*Supervised*	*Teleoperated*	*Teleoperated*	*Teleoperated*
Best run	*2*		*1*	*2*	*2*	*2*	*2*	*2*	*2*
Vehicle entered building	100		300	100	100	200	100	100	100
Map of area produced	0		750	0	375	500	375	0	250
Detection of OPI (i.e. position entry in the map)	0		0	300	0	0	200	300	0
Image of OPI (in the digital result data)	100		0	150	0	0	0	100	50
Image of OPI transmitted online to control station	300		0	300	0	0	200	300	100
% x of correct OPIs	0		0	50	0	0	50	50	50
Vehicle trajectory drawn in map	0		0	100	0	100	100	0	100
Live position and video transmitted to control station	100		0	100	100	100	100	100	100
Mission completed in time	500		0	500	0	0	0	500	0
Penalty for n manual interventions	0		0	0	0	– 50	0	0	– 100
Penalty for manual intervention duration t	0		0	0	0	– 16	0	0	– 133
Bonus: Detection of radiological source marked in map	750		0	1 500	750	0	1 500	1 500	0
Overall result	**1 850**		**1 050**	**3 100**	**1 325**	**834**	**2 625**	**2 950**	**517**

Figure 4-9: Result chart for the ERNCIP scenario

4.4 References

[1] Schneider, F. E., Wildermuth, D. and Wolf, H.-L., 'Professional Ground Robotic Competitions From an Educational Perspective', 2012 IEEE 6th International Conference Intelligent Systems.

[2] Schneider, F. E., Wildermuth, D. and Wolf, H.-L., 'ELROB and EURATHLON: Improving Search and Rescue Robotics through Real-World Robot Competitions', Proceedings of the 10th International Workshop on Robot Motion and Control, Poznan University of Technology, Poznan, Poland, 6-8 July 2015.

5 Conclusions and lessons learned

The problems of robots in the field of hazardous operations and emergency response and especially in threats involving radiological and nuclear components are diverse. Trials like ELROB have shown that there are still several technical challenges, such as communication, sensors, situational awareness, mobility/locomotion and robustness. Some of these just accrue from the fact that these systems have not been used enough to gather a solid treasure trove of experience. There are still a lot of lessons to be learned.

The ERNCIPThematic Group on Radiological and Nuclear Threats to Critical Infrastructure has also identified a huge gap between what the research and development community is able to deliver, the existing industry state of the art and the user requirements (if properly determined). This includes the complete absence, non-observance or non-compliance of standards, best practices and norms.

Naturally, the research and development community does not have a focus on standardisation, manageability, sustainability, robustness or reliability. A more constructive way ahead for the future is the use of trials and challenges for the unmanned systems community. These events can be used to bring together users, academia and industry. The users can visualise their needs as real world scenarios that have to be tackled by the R & D community and industry. At the same time, the industry will be able to mingle with the R & D community to improve their innovation gap.

The ERNCIP scenario on ELROB was worldwide the first time ever that so many different heterogeneous robotic teams participated in a completely RN-related trial with live radiation sources of this strength. Making this happen in the short time frame given can be considered a reasonable result. In addition, the fact that the group was able to enforce already so many standards at this early stage is a good step forward for further improvements such as the implementation of data format standards IEC 63047 and IEC 62755.

Top five lessons learned from ELROB 2016:

1. (academic) Robotics community is unaware of the RN field needs;
2. Lack of knowledge in RN sensor handling and measuring;
3. Lack of possibilities for testing (e.g. strong sources);
4. Lack of inexpensive and simple robust RN sensors;
5. Lack of standards and harmonisation.

From these findings, it is clear that there is an urgent and immediate need for a dedicated RN robotics activity.

- Goal:
    1. Start community building and raise awareness;
    2. Implement standards (e.g. IEC 63047, IEC 62755, etc.);
    3. Supply community with professional and regular real world tests.
- Approach:
    1. Implement ERNCIP-driven RN robotics trial;
    2. Use the rules of the trial to enforce the usage of standards;
    3. No competitive format to ease the involvement of industry;
    4. Feed results/outcomes back into community (therefore Hackathon!).

5.1 Recommendation for future activities

As a major action item for the future, the ERNCIP task group on Radiological and Nuclear Threats should plan to conduct a workshop on the use of unmanned systems in the RN domain in mid-2017. The workshop should focus on the use of standards (e.g. ANSI N42.N42/IEC 62755, IEC 63047 list-mode, ROS, NATO ATP-45, etc.) for unmanned systems in this field of application. It should be run in conjunction with a robotic trial similar to the one at ELROB but more focused on RN topics. The plan should be to have both events in the inoperative nuclear power plant Zwentendorf ([6]), Austria. The teams will be provided with free detectors as well as with the necessary interface software. The task will be similar to the one at ELROB: search and locate the unknown number of sources and map the radiation as well as the environment. All information has to be passed on to a reachback team for further evaluation. If possible, another task for the unmanned systems will be mobile manipulation in this hazardous materials incident response operations (Hazoper) mission.

- Scenario:
  A technical problem or accident leads to unpredictable radioactivity inside the plant.
  The robotic system should do an autonomous exploration of the scene
- Task:
  The exploration task consists of three sub-tasks: first, a digital 3D map of the area of interest has to be built; second, radiation and its sources should be detected, measured and marked inside a digital map; and, third, if your system is equipped with a manipulator device some radioactive material has to be handled. Teams may work on any combination of these sub-tasks. One or more robots may be used.

([6]) https://en.wikipedia.org/wiki/Zwentendorf_Nuclear_Power_Plant

Figure 5-1: Nuclear Power Plant Zwentendorf, Austria (pictures: Wikipedia)

As a general way ahead:

- All countries should contribute and enforce harmonisation and standardisation to the area of robotics;
- There is a strong need to coordinate the civil–military cooperation (There are a lot of standards already in place in the military world);
- A modular payload concept should be established to enhance the speed of separate development of robot chassis and sensor/effector payloads;
- A regular testing and information exchange event should be installed at an official European level.

6 Annex A: Generic template for the design and configuration of future events

6.1 Scenario description document

Reconnoitring of urban structures {descriptive title}

Search and detect a number of unknown radiation sources in a primarily unknown urban structure. Measure the radiation, display the measurement to the operator, mark position inside a digital map representation, and acquire live imagery. {Short summary of the deployment scenario}

Scenario: {A more general description of the broad situation}
Reconnaissance of structures and buildings and the surrounding environment is an important prerequisite for urban and semi-urban emergency operations. At the same time, this is one of the most dangerous tasks responders face during a mission. Therefore, having robots for autonomous reconnoitring of buildings definitely provides great relief to the troops.

Environment: {Description of the general environment to be expected}
An urban structure, stairs, low or no light, closed doors, sand, water, stones, rubble and debris.
The urban structure that has to be entered is approximately 50 m long and 25 m wide; it can be dilapidated or even partially wrecked.

Situation: {What is the specific situation for the relief units?}
Reconnoitre the interior of the building.
There will be static and dynamic obstacles present. Dead ends, sharp turns, blocks, stairs and narrow passages can occur.

Objective: {What is the prime objective for the relief units; main tasks?}
Search for objects of potential interest (OPI) inside the building, i.e. particular markers with special characteristics as defined in the rules.
Use highest autonomy possible. Build a 2D/3D map of the building.
Whenever an OPI is found, acquire imagery and mark its position inside the map representation. Report all gathered data to the control station, online or offline after having returned to the starting point. Plot the robot's path and detected OPI positions into the generated map.
If possible, transmit live position and imagery to the control station.
If possible, search and detect a number of hidden radiation sources. Measure the radiation, display the measurement to the operator, acquire imagery and mark its position inside the map representation.

Remarks: {Special considerations, additional rules or guidelines}

Be prepared to deliver additional data in ROS bag format; exact specification and data types will follow.

Timing: {Exact timing + timeframe for the task}
Duration approximately 30 minutes. The scenario ends with reaching the time limit and must include the transmission of the acquired data.

Pictures: {Example pictures of the environment}

6.2 Event rules document

Concept and rules

{EventName}

{Date/Timeframe}

{Location}

{Internet URL}

Contact details:

{Place organisers address here.}

1 Introduction

The {EventName} is a robotics competition. Its purpose is to demonstrate and compare the capabilities of unmanned systems in realistic scenarios and terrains. All tasks and scenarios are developed in close collaboration with experienced users from possible application domains. The {EventName} explicitly addresses the field of robotics in Europe.
This document contains the rules for participating at the {EventName} and further notes on the organisation of the event.

1.1 Potential participants

The {EventName} is open to:

- Users
  These are (future) professional users of robots.
- Industry
  These are designers and manufacturers of integrated ground robots or accessories for these robotic systems.
- Research facilities
  These are universities and other research institutes focusing on (partial) solutions relevant to the considered domains.

See section 3 on how to apply for participation.

1.2 Scenarios and tasks

The {EventName} defines a variety of scenarios instead of only one single mission. These scenarios include, for example, security missions, convoying and reconnaissance by day and night. All scenarios are developed in collaboration with users from possible application domains. For a description of current scenarios visit the {EventName} website.
The different scenarios are chosen to test specific aspects of robot deployment. Some challenges are common to all tasks; others are specific to certain tasks. Most of the scenarios have a focus on driving distances of up to several kilometres. A continuous broadband radio communication between a control station and the unmanned vehicle cannot be expected. Furthermore, it may be difficult to have continuous GPS reception.
The organisers strongly encourage autonomous solutions.
Each participant can subscribe to one or more scenarios. In advance of the event the organisers will define and publish the scenarios (for details see section 5.2.1) and provide sensor data sets recorded on the actual trial area (see section 5.4). This allows the participants to adequately prepare for the environmental and technical conditions.

1.3 Course of action during a trial

All teams that successfully completed the application procedure (see section 3) and whose vehicle meets the necessary requirements (see section 4) will receive time slot(s) in each registered scenario. A general schedule for the event can be found on the {EventName} website; a detailed schedule for each scenario will be published on site at least 1 day in advance.

In the set-up phase, the vehicle will be put into operation and prepared for the start on the actual track. One team member, the ‘operator’, is allowed to control the vehicle from a dedicated control station. A second team member, the ‘technical assistant’, accompanies the vehicle on the track. This technical assistant, however, is not allowed to control the vehicle. The run will be supervised by the organisers. Participants might be allowed to repeat the run on request.
Detailed regulations regarding the actual trials can be found in section 5.2.

1.4 Rules

Please read all information available on the {EventName} website carefully — especially this document!
The exact organisation and conditions of the trial will be governed by a set of rules and descriptions published on the {EventName} website. Rules (including this document) and scenarios are subject to change. **Please check the {EventName} website for updates regularly!**
In case of any questions, remarks and problems regarding the rules, participants are advised to contact the organisers immediately. Violations of the organisers’ rules or instructions will result in exclusion from the event.

2 Eligibility

2.1 Team membership

Each organisation (from the research, industry or user domain) which is going to take part in the {EventName} must establish a team. This team represents its organisation and effectively participates in the trial.
A team is comprised of the individuals identified to the organisers on the team roster. Only these individuals are team members. Each team must designate a single individual to serve as the team leader. The team leader must be at least 21 years of age and must hold European citizenship. Proof of European citizenship for the team leader must be provided with the application as described in the application instructions (see section 3.1). The organisers' representatives will verify these documents.
The team leader will serve as the primary point of contact with the organisers. The team leader must sign the application, must provide a letter of intent (LOI) including the liability statement, and must be present at the team leader meeting. An individual may be the leader of only one team, but team members may serve on multiple teams.
Team leadership may be transferred from the team leader to another eligible individual. However, there may be only one team leader at any time. Transfer of team leadership occurs when the organisers receive a new LOI. The form must be signed by the former team leader and the new team leader. The new team leader must also submit proof of citizenship.
Although the number of individuals listed on the team roster is not expressly limited, the organisers will impose a limit on the number of team members allowed into the designated areas at the {EventName} event. The organisers will communicate the limit to the team leaders upon notification of selection.
For details on the application procedure and the necessary documents (letter of intent, liability statement, team roster, etc.) look at section 3 below.

2.2 Non-European participation and sponsorship

Non-European team members are eligible; however, the team leader must hold European citizenship. Non-European corporations and non-governmental organisations may participate as team sponsors. Teams receiving funding or any form of support from non-European governments or non-European governmental organisations are not eligible to participate.

2.3 Team funding and support

The cost of developing, fielding and insuring entered vehicles is the sole responsibility of the individual teams. The organisers will not provide funding for the purpose of {EventName} entry or participation. However, depending on the available budget there might be the possibility of getting compensation for students' travel costs, see section 7.1.

3 Application procedure

3.1 Basic requirements

World Wide Web access, email access and basic word processing are necessary to complete and submit the application and to communicate with the organisers of the {EventName}.
The application consists of four parts:

Part 1: Team application including letter of intent (LOI) and liability statement.

Part 2: Team information, selection of scenario, and vehicle, radio and exhibition specification sheet.

Part 3: Team roster, scenario application paper (SAP).

Part 4: Payment of [AMOUNT EUR] non-refundable registration fee {set fee to reasonable amount}

Instructions for obtaining the abovementioned {EventName} application materials and for proper submission can be found on the {EventName} website.
Note that modified LOIs will NOT be accepted!
A team that has submitted application parts 1 and 2 before the deadline and has received acknowledgement from the organisers becomes an {EventName} entrant. However, to remain an entrant and to successfully finish the application procedure, part 3 and part 4 have to be completed before the deadlines as well. All deadlines will be published on the {EventName} website.
Materials received after the respective deadlines cannot be considered and will be discarded by the organisers.

3.2 Submission procedures

Application documents must be submitted using the transmittal instructions on the forms. The receipt of application documents will be acknowledged by the organisers.
Application materials remitted using any kind of delivery service should be addressed to the organisers:

{put address here}

The time of receipt for each package will be logged in the organisers' mailroom. The time of receipt for each electronic document will be logged by the organisers' email system.

3.3 Qualification process

A scientific qualification process is obligatory for all {EventName} entrants. For each scenario in which a team is going to participate a scenario application paper (SAP) has to be prepared. Therein the participants have to describe how their team will tackle the challenges of the selected trial scenario. The participants should explain how their system will cope with problems typically arising in the selected task.

A scientific advisory board will then perform an evaluation of the SAP. Currently, this board is identical to the Chief Judge Team (see section 5.1). To gain as much scientific progress as possible, all scenario application papers and their evaluation will be published on the {EventName} website.
This qualification process must be completed by all teams that wish to take part in the {EventName}.

3.4 Publication of materials

For each team the following documents will be published on the {EventName} website:

- The team information, to enable contact from potential sponsors, other teams and media;
- The scenario application papers (SAP) and the corresponding evaluation results for each selected scenario (see section 3.3); and
- All measures collected for evaluation purposes; see section 6.

Additionally, any information related to the participants' awards (see section 7) will be published on the {EventName} website.
See the {EventName} website on what information is exactly contained in these published materials.

3.5 Registration fee

Each team which successfully completed the application procedure will have to pay a non-refundable registration fee of [[AMOUNT EUR]. This fee, together with additional donations for the {EventName} from sponsors and companies, builds the budget for selective travel support. The resulting budget will be completely redistributed among the participants according to the rules described in section 7.

4 Vehicle requirements

4.1 Mode of operation

During the application procedure, each team has to specify the mode of operation for their vehicle. The mode of operation can be chosen from three categories: full autonomy, supervised autonomy and tele-operation. The categorisation will be verified and, if necessary, corrected by the {EventName} authorities (e.g. the 'Chief Judge Team', see section 5.1).

4.1.1 Fully autonomous vehicle operation

In fully autonomous operation, the operator is not allowed to interact in any way with the vehicle after it has left the starting area and entered the trial route. Direct control as well as passive monitoring via an operator device is prohibited. Interaction is only allowed to provide the vehicle with necessary input data (see section 4.2.6) before the vehicle leaves the starting area and to receive result data from the vehicle (see section 4.2.7) after the trial has finished.
If the vehicle or operator console signals an incident it cannot cope with autonomously, the operator (or, on the operator's request, the 'technical assistant'; see section 5.2) may interact with the system. Note, however, that any interaction between the technical assistant and the vehicle will have a negative influence on the resulting evaluation (see section 6).
In autonomous operation, vehicles and control station must be completely unmanned.

4.1.2 Supervised autonomous vehicle operation

In supervised autonomous operation, a vehicle operates autonomously, but at the same time retains continuous human oversight ('man-in-the-loop'). Direct control is only allowed to provide the vehicle with necessary input data (see section 4.2.6) before the vehicle leaves the start chute and to receive result data from the vehicle (see section 4.2.7) after the trial has finished.
During the trial the operator is allowed to execute perception tasks and to monitor the system. At any time the operator (or, on the operator's request, the 'technical assistant'; see section 5.2) may actively control the system. Note, however, that any interaction between the technical assistant and the vehicle will have a negative influence on the resulting evaluation (see section 6).
In supervised autonomous operation, vehicles should be unmanned. After prior agreement with the organisers, each vehicle can be manned with a safety driver (accompanied by a member of the chief judge team). Operator and safety driver may be the same person. In any case, only one operator is allowed.

4.1.3 Tele-operated vehicle operation

For tele-operated vehicles the operator is allowed to control the vehicle at any time during the trial. On the operator's request, the 'technical assistant' (see section 5.2) may interact with the vehicle. Note, however, that any interaction between the technical assistant and the vehicle will have a negative influence on the resulting evaluation (see section 6).
In tele-operation, vehicles must be completely unmanned.

4.2 Vehicle limitations for UGVs

A team's entry to the trial must be at least one ground vehicle that is propelled and steered principally by traction with the ground. The type of ground contact devices (e.g. tyres, treads and legs) is not restricted. The vehicle must not damage the environment or any infrastructure at the {EventName} location. Vehicle operation must conform to any regulations or restrictions imposed by the applicable land-use authority.
Vehicles weighing more than 75 kg must be equipped with a recovery facility.
The vehicle must be able to travel on asphalt pavement without damaging the pavement surface.
The participants should be aware of the fact that huge and/or heavy vehicles will face difficulties in some scenarios. The same holds for small/light vehicles in long-distance scenarios.

4.3 Vehicle limitations for UAVs

The UAV must weigh less than 5 kg or have special and valid flight permission according to the law of the host country. Obtaining the permission is the sole responsibility of the team.
The team must have appropriate and valid aircraft liability insurance for the UAV and the operator. Obtaining the aircraft liability insurance is the sole responsibility of the team.
The maximum cruising altitude is 30 m over ground.
Tethered systems that are designed to extend more than 10 m above the surface must be painted to enhance their visibility. Entrants are advised that the European Aviation Safety Agency (http://www.easa.eu) regulates the operation of moored (tethered) balloons. Entrants are advised that the route may be adjacent to utility and power structures and high-voltage power lines.
All teams must obey the aviation rules and laws of the host country. After the final location for the trials is announced, there might be additional local regulations that must be adhered to.

4.4 Classified data and devices

No classified data or devices may be used by a team in preparation for or during the {EventName}.

4.5 Vehicle safety

The organisers do not guarantee the safety of any vehicle entered in the {EventName}, notwithstanding any rule or the organisers' acceptance of any application document, vehicle specification sheet, video demonstration or any inspection or demonstration required for participating in the {EventName}.

4.5.1 Health and safety standards

All trial teams and vehicles must comply with all applicable safety regulations (see http://europe.osha.eu for details).
After the final location of the trials is announced, there may be additional local regulations that must be followed. All teams must obey the health and safety rules and laws of the host country.

4.5.2 Environmental impact

Any aspect of vehicle activity or operation that has an unacceptable impact on the environment is prohibited. These activities include destructive vehicle behaviour, the use of abnormally hazardous substances or materials, and generally reckless operation. Potentially hazardous equipment or activities must be identified to the organisers for review in the vehicle specification sheet and at the site visit.

4.5.3 Wireless emergency stop and E-stop mode

It is the sole responsibility of the team to properly install a wireless emergency stop (E-stop) system in its vehicle. The E-stop system must be fully functional for the participant to be eligible to participate in the {EventName}.
In case of emergency (i.e. imminent danger for individuals and/or the vehicle) the E-stop system must be activated instantaneously.
Triggering the E-stop mode brings the motion of the vehicle to an immediate stop, with brakes applied to hold the vehicle even if it is on a slope. The E-stop mode should be latched so that its state cannot be changed unintentionally after initiation. Electrical connections to the E-stop must be ruggedized to ensure functionality even after exposure to adverse (damp or dusty) environmental conditions and a high vibration environment.
The vehicle should be ready to promptly resume motion as soon as the E-stop mode has ended. The E-stop mode may be entered numerous times during a trial, and each E-stop event may last up to several minutes.
In the special case of a **vehicle with a safety driver**, entering the E-stop mode requires the driver to stop the vehicle immediately and completely. If applicable, additionally the handbrake must be put on and the gearbox/automatic transmission must be put into the neutral position.

4.5.4 Vehicle-mounted emergency stop unit

Each vehicle must be additionally equipped with an externally actuated emergency stop capability. Activating the emergency stop must promptly bring the vehicle into the E-stop mode, leading to an immediate and complete stop. At least one actuator and its labelling must be easily visible and accessible from anywhere around the vehicle. The manual emergency stop must be easy to identify and to activate, even if the vehicle is moving at a walking pace. The operation instructions for emergency stop actuators must be clearly labelled in English. The instructions must not be interfered with by any other labelling or advertising.

4.5.5 Warning devices

Each vehicle shall display one or more flashing amber warning lights, the combination of which results in a visibility of 360 degrees azimuthally around the vehicle. The warning light(s) shall continuously operate whenever the vehicle is switched on. The vehicle may not commence movement until the warning light(s) have been in operation for 5 seconds.
The warning light(s) shall comply with standards for warning lights and shall not produce light that can be confused with those of public safety vehicles such as law enforcement, fire or ambulance.

4.6 Towing requirements

Each vehicle over 75 kg must be designed to facilitate removal from the route should the vehicle be disabled. These vehicles should have towing points front and rear, or if the vehicles design precludes towing, the vehicles should have hoist points. Wheeled or tracked vehicles must have a freewheel mechanism that enables the wheels or tracks to spin freely in order to allow towing.

4.7 RF and other communication equipment

After the final location for the trials is announced, there will be additional national and local regulations for RF and other communication that must be adhered to.
Please note that the participants must take care of the frequency regulations themselves. The frequencies reported by the teams will be published on the {EventName} website. **There will be no frequency management by the organisers!**
The overall height of the control station antenna must not exceed 2.5 m. The overall height of the vehicle antenna must not exceed 2.5 m.
To be precise: No antenna of any RF or other communication equipment used by the team shall exceed the overall height of 2.5 m.

4.8 Position determination

Vehicles may be equipped to receive and process electronic position determination signals (such as GPS, GLONASS, Galileo, WAAS, EGNOS, etc.) that are openly available to all teams. Position determination signals that are not available for free (e.g. OmniStar, SAPOS, etc.) are prohibited. Any costs associated with any subscription service are borne by the team.
GPS signals might not be available throughout the route at all times. Be aware that GPS alone will not provide adequate navigation information to the vehicle. Additionally, visual navigation may be disturbed. There may be dust, smoke and other visual obscurants on the route, and visual-spectrum-only sensing may not be adequate under these conditions.

4.9 Pre-trial testing

Testing of trial vehicles or components is the sole responsibility of each team. The use of public lands for this purpose is at the team’s own risk and must be in accordance with the applicable laws.

5 Regulations

Pushing the development of revolutionary technologies is a key objective of the {EventName}. Entrants are invited to communicate directly with the organisers regarding any rule that restricts their ability to demonstrate technical achievement and innovative solutions concerning intelligent ground vehicle behaviour.

5.1 The Chief Judge Team

The Chief Judge Team is a group of officials designated by the organisers as such. The Chief Judge Team is the final authority on all matters referred to in the rules and on all matters affecting the operation of the {EventName}.
The Chief Judge Team has the authority to modify the rules at any time. Reasons for modifications include, but are not limited to, the accommodation of promising but unexpected technical approaches that would have been prohibited by the rules and the exclusion of approaches that seek to participate without demonstrating the desired technical achievement in vehicle behaviour that is the purpose of the event. The organisers will announce any modifications to the rules with an email to all entrants and a corresponding statement on the {EventName} website.
The Chief Judge Team may revise the schedule of the trials and provide interpretation of the rules at any time and in any manner that is required. The Chief Judge Team's decisions regarding the rules are based on a number of factors, such as safety, legal compliance, fairness, trial goals, environmental protection and efficient operations.
Decisions of the Chief Judge Team are final.

5.2 Procedures at {EventName}

5.2.1 Route definition

Per scenario, three route definitions will become available over time. See the {EventName} website for further details and examples from former events. These definitions are:

1. A preliminary general description of the scenario and the route;	(via {EventName} website, together with the general announcement of the {EventName})
2. A detailed description of the scenario and the route;	(via {EventName} website, about 3 months before the event)
3. Map and waypoints of the route.	(on site, with the start of a trial)

Inspection of the trial area by any entrants is not allowed or possible.

Note that, instead of physically inspecting the trial area in advance, there is the possibility of receiving recorded sensor data in form of standardised common shared data sets (CSDS) for each scenario. These data can be used to train and improve various parts of a robot’s software architecture. See section 5.4 for further details.

5.2.2 Starting area/departure procedure

Each team must name a ‘technical assistant’ and an ‘operator’; these two people build the team.
Trial vehicles start in sequential order at specified time intervals. The start order is announced on the {EventName} website. The whole run will be supervised by the {EventName} officials.
During the departure procedure, the vehicle will be put into operation and prepared for the start on the actual track. All required material must be moved promptly by the troop from the unload location to the start chute. The start chute is a part of the starting area directly before the departure line. A team must place its vehicle in the start chute prior to enabling it for operation. Note that there will be no support at this location (no table, no chair, no electricity, etc.).
Each vehicle must be enabled for operation within 5 minutes after entering the start chute. Vehicles must be prepared to wait in the start chute for up to 30 minutes. At the designated starting time the vehicle must be waiting in the start chute, readily prepared for operation. As soon as the departure signal is given by an {EventName} official, the vehicle must depart from the start chute.
The technical assistant is responsible for operating the wireless emergency stop system (E-stop); see section 4.5.3. Thus, he will leave the starting area (and the control station) and will accompany the vehicle as soon as the start signal has been given.

5.2.3 Vehicle control

There is only one control station allowed; this control station is part of the starting area (see section 5.2.2). It is not possible to see the entire trial area from this control station. The operator must not leave the control station during the trial.
Only the operator is allowed to control the vehicle. The exact kind of permitted interaction depends on the chosen mode of operation, as defined in section 4.1.
The technical assistant accompanies the vehicle during the trial and operates the E-stop. At any time in the preparation phase and during the trial, an {EventName} official may prompt the technical assistant to put the vehicle in E-stop mode due to safety or operational reasons. As soon as the official agrees, the vehicle may resume from E-stop mode.
In case of emergency (i.e. imminent danger for individuals and/or the vehicle), the technical assistant must self-reliantly activate the E-stop.
Only due to an explicit request of the operator, may the technical assistant interact with the vehicle. **Without the operator’s request, the technical assistant may interact with the vehicle only in case of emergency** (i.e. imminent danger for individuals and/or the vehicle) and **only after activation of the E-stop**.
In the special case of a **vehicle with a safety driver**, the driver may interact with the vehicle only in case of emergency (i.e. imminent danger for individuals and/or the vehicle). If so he must put the vehicle immediately into E-stop mode (see 4.5.3).
Any other unauthorised interaction between the technical assistant/safety driver and the vehicle will lead to the abortion of the trial.

Note, moreover, that any interaction between the technical assistant and the vehicle, including any activation of the E-stop, will have a negative influence on the resulting evaluation (section 6).
In the following situations the actual trial can be aborted by the {EventName} officials. However, depending on free timeslots, the team may apply for another attempt:

- If a maximum number of E-stop activations per trial is reached;
- If a vehicle that is not in E-stop mode does not progress for longer than 5 minutes;
- If dangerous or destructive behaviour of a vehicle is imminent (and an {EventName} official places the vehicle in E-stop mode).

The organisers will take measures to stop a vehicle that does not respond promptly to an E-stop command, even if these measures may result in damage to the vehicle.

5.2.4 Regulations for the trial route

While a vehicle is on the route, {EventName} officials might follow it.
During the trial there will be no communication between the operator and other individuals, especially other team members, with the only exception of communication with {EventName} officials.
The technical assistant may be contacted by the operator, but only indirectly via the {EventName} officials. There will be no direct communication between operator and technical assistant during the trial.
Apart from the technical assistant, no team member will physically intervene in any aspect of vehicle operation or physically participate in vehicle tracking from the time the vehicle clears the start chute until it is returned to the team. A vehicle is returned to the team after the trial is aborted or after it crosses the arrival line. During the trial refuelling of vehicles is not permitted.
Apart from designated viewing areas, teams may not operate any vehicles or position any team members on or near the route at any time during the {EventName} event.
If the {EventName} officials determine that letting a vehicle proceed on the trial route would hinder subsequent {EventName} operations, the trial can be aborted. The team may apply for another attempt.

5.2.5 Obstacles on the trial route

The route will include mobile obstacles and on-the-fly modifications. For example, a dead-end can appear where the previous participant had a free road. The vehicle must avoid collisions with any obstacles, moving or static, on the route. The organisers will place obstacles along the route to test obstacle avoidance capabilities. Incidental or non-damaging contact with obstacles may not result in trial abortion.

5.2.6 Abortion of trials

A vehicle must not continue on the route if the trial was aborted. The organisers will coordinate the recovery the vehicle together with the team. Teams may enter the trial area only if directed by the {EventName} officials.
If a participant has to abort the trial because of technical difficulties, the Chief Judge Team may allow repeating the trial, depending on available start slots.

5.3 Required standards to be used

{This part of the document should contain a detailed description of all the standards that shall be used within the event. Whenever possible refer to a reference page in the internet for detailed and official literature.}

5.4 Common shared data sets (CSDS)

The organisers publish recorded real data sets for every scenario in the competition. These common shared data sets (CSDS) will be created with commonly used sensor devices and will be logged directly on the actual trial area. CSDS shall allow teams that are new to the competition or that have limited access to proper hardware and training areas to test their systems against typical settings of the competition.
The CSDS will be available as early as possible but maximum 1 year before the actual competition. In addition, CSDS from a pool of former competition data sets are available for software improvement, benchmarking, testing, and comparison.

5.4.1 Format of CSDS

All CSDS will be distributed in the ROS bag format. This is the standard log format of the openly available Robot Operating System (ROS). A variety of tools are freely available to get raw sensor information out of recorded ROS bags. See http://www.ros.org for further details.
The exact composition of sensor devices in a CSDS is scenario-dependent and cannot be generally specified.

5.4.2 Access and usage of CSDS

The open science driven rules of {EventName} require that any participant who uses CSDS provided via the {EventName} web page must publish his own data, collected on the competition. This data will become part of the CSDS pool.
This exchange mechanism has to be supervised and verified. Thus, there is no open access to the CSDS. Instead, if a participant is interested in using one or more data sets, he is kindly requested to contact the organiser.

6 Evaluation measures

For each {EventName} trial which has not been aborted, a variety of measures will be collected. The collected parameters are:

- **Total runtime (RT)**

  The total runtime (RT) is the time from receipt of the mission data until the submission of the result data, limited by the maximum trial time for the scenario. Note that any data handling is part of the RT.

- **Operator's interaction time (IAT)**

  The operator's interaction time (IAT) measures the time span in which the vehicle does not act autonomously but is controlled by the operator. For an exact definition see section 6.1 below.

- **Technician's interaction time (T-IAT)**

  Same definition as for IAT, but regarding interactions by the 'technical assistant'; see section 6.1 below.

  Note that technician's interactions have a significantly larger influence on the resulting evaluation than simple E-stop activations.

- **Total distance driven on the track (DoT)**

  The DoT does not measure the absolute driving distance of the vehicle. Instead, the covered distance regarding the optimal track of the scenario is measured.

- **Number of E-stop activations**

  Every activation of the E-stop has a negative influence on the resulting benchmark.

- **Number of correct detections of objects of potential interest (OPI)**

  OPI positions must be reported in a specially formatted text file; see section 4.2.7. For a general specification of OPI in the context of the {EventName} see appendix A.

- **Number of false detections of OPI**

  Of course, there should be the fewest possible false positives reported in the abovementioned text file.

- **Delivery of a digital map including the vehicle's track**

  See section 4.2.7 for required data formats.

- **Delivery of a GPS log file of the vehicle's track**

  See section 4.2.7 for required data formats.

- **Delivery of a digital map with correctly marked OPI**

  See section 4.2.7 for required data formats.

- **Delivery of OPI pictures**

  Section 4.2.7 defines required data formats; refer to appendix A for required contents.

Depending on the scenario and the vehicle's mode of operation (see section 4.1), only a subset of these measures may be determined. All parameters are either derived from the delivered trial result data or they are externally measured by the organisers. Special access or interfaces to the vehicle's (software) system are not necessary.
Note that all collected data will be published on the {EventName} website.

6.1 Definition of operator's/technician's interaction time (IAT/T-IAT)

Interaction time starts with the moment when someone interacts with the vehicle and/or the operator console (or any other device that interoperates with the vehicle) and ends when this interaction has finished. The operator's interaction time (IAT) measures only interactions by the operator; technician's interaction time (T-IAT) regards interactions by the technical assistant. Refer to section 5.2 for a detailed description of these two roles.
If a vehicle is completely remote controlled, this results in an IAT identical to the runtime (RT); T-IAT is determined additionally.
Examples of IAT-relevant activities:

- Manual handling of the input data in order to put it into the system;
- The operator steers the vehicle manually;
- A new GPS waypoint is entered via the operator console;
- Only for **fully autonomous operation**: the operator passively watches a video stream, e.g. to detect potential dangers for the vehicle.

The mode of operation (see section 4.1) has an influence on what is rated as IAT-relevant interaction:

- In **fully autonomous operation** direct control as well as passive monitoring via an operator device is measured as IAT;
- In **supervised autonomous operation** the operator is allowed to execute perception tasks and to monitor the system; only active control is measured as IAT;
- For **tele-operation** the IAT is not measured since, per definition, it is identical to the runtime (RT).

Note that, in all cases, the time for manual handling of the system's input/output data is measured as IAT.
While on the track, the technical assistant just accompanies the vehicle and operates the E-stop system (see sections 4.5.3 and 5.2). Any further interaction between technical assistant and vehicle is counted as T-IAT.

7 Awards for participants

Highly committed/dedicated participants as well as best performance in the scenarios and also novel scientific or creative solutions will be awarded. Therefore, the organisers established two complementary award systems: selective compensation for travel costs and non-monetary awards.
The non-refundable registration fee paid by the participants and further donations from sponsors and companies build the budget for the selective travel cost compensation. This budget will completely redistributed among the beneficiary.

7.1 Travel cost compensation

A selective compensation of travel costs for students will be granted through the 'evaluation measures'. Only receipt-proven costs resulting from travelling and accommodation will be covered. Note, however, that even for receipt-proven costs there exists an upper limit for travel compensation per student. This limit depends on the particular location of the event and will be published on the website. Refer to Appendix B for an example calculation.
The basis for the selection of the teams that might receive travel support are the actual 'Evaluation Measures', see section 6. The first team of each scenario will receive a compensation for travel costs for a maximum of three students. Each team can only claim this travel support once. If there is money left, then the second team of each scenario receives travel support, and so on.
NOTE: The application for travel cost compensation must be sent to the organisers BEFORE the event takes place!
The remaining budget after considering all legitimate applications will be used to cover receipt-proven travel expenses of the judge team (except those judges belonging to the organisers).

7.2 Non-monetary awards

Nominations for these awards can be made in the categories:

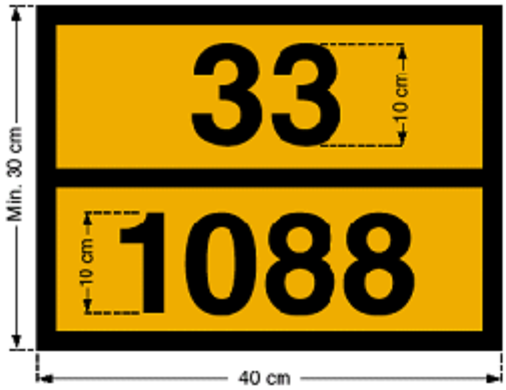
- Best Scenario Performance (for **each** of the provided scenarios)
- Novel Scientific Solution
- Creative Solution
- Best Team Effort (commitment, dedication)

While the best performance in each scenario is clearly governed through the 'evaluation measures' (see section 6), the beneficiaries of the other categories will be elected by the Chief Judge Team (see section 5.1) together with the votes from all official participants (each team has one vote per category). All results ('evaluation measures', votes, etc.) and awards will be immediately published on the web pages.

Please be sportsmanlike and play fair!
If there are weaknesses in this ranking system, feel free to tell us.
If the jury gets the impression that someone is trying to cheat, trick or outsmart anybody, it will take appropriate action.

Appendix A: Objects of potential interest (OPI)

Objects of potential interest (OPI) denote specific objects, threats or intruders. Currently, in all {EventName} trials ERICard number plates are used as OPI, special hazard signs which are easily detectable and are used to mark dangerous fluids and gases in the transportation domain (see pictures below for examples). To correctly detect an OPI respectively ERICard number plate, its position (in UTM coordinates) must be reported with a minimum accuracy of 5 m. Additionally, a photograph of the ERICard number plate shall be taken. This photo is considered as sufficient if all digits are clearly readable.



Appendix B: Example calculation for travel support limit

The amount of the travel cost compensation per student, which is distributed among the participants after the event, is limited, depending on the particular location of the event. As a general guideline, the travel support shall be high enough to cover accommodation in a basic (2*) double room for the duration of the competition event and the cost of a hypothetical economy class return flight. Note that the travel support limit is independent of a participant's place of residence. Hence, flight costs always refer to flights from Frankfurt Airport (FRA), Germany, because this is a hub airport with a large number of connections and it is located pretty near the centre of Europe.
The exact height of the maximal travel cost compensation per student will be announced on the website prior to the event.
To get an idea of the amount of money that can be expected, look at the following calculation. The example refers to ELROB 2016, taking place in Eggendorf, Austria, from 20 June until 24 June 2016. Accommodation prices refer to the neighbouring city of Wiener Neustadt. The nearest international airport is Vienna/Wien (VIE), about 50 km from the {EventName} site.

Basic accommodation (2** double room incl. breakfast) in Wiener Neustadt is about EUR 30 per person and night; six overnight stays for attendance at the event (including one additional day for arrival and one for departure)	EUR 180
Economy class return flight Frankfurt (FRA) — Vienna (VIE), timely booking supposed	EUR 140
Total limit for travel cost compensation per student	EUR 320

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