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SciRoc

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ERL Emergency Service Robots Rulebook

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WP leader:	Antidio Viguria – FADA-CATEC Francisco J. Perez – FADA-CATEC

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Deliverable author(s):	Fausto Ferreira – NATO STO CMRE Gabriele Ferri – NATO STO CMRE Sarah Carter – UWE BRISTOL Francisco Cuesta – FADA-CATEC Francisco J. Perez – FADA-CATEC Antidio Viguria – FADA-CATEC
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Content

List of acronyms

AUV Autonomous Underwater Vehicle

CATEC Advanced Center for Aerospace Technologies

CMRE Centre for Maritime Research and Experimentation

CSV Comma Separated Values

EC Executive Committee

EU European Union

ERL European Robotics League

FBM Functionality Benchmark

GNC Guidance Navigation and Control

GPS Global Positioning System

OC Organizing Committee

OD Outside Diameter

OPI Objects of Potential Interest

ROS Robotic Operative System

ROV Remotely Operated Vehicle

RPAS Remotely Piloted Aircraft System

SCRAM Safety Control Rod Axe Manual Emergency shutdown of a nuclear reactor.

TBD To Be Defined

TBM Task Benchmark

TC Technical Committee

UAV Unmanned Aerial Vehicle

UGV Unmanned Ground Vehicle

USV Unmanned Surface Vehicle

UWE University of the West of England

VLOS Visual Line Of Sight

VTOL Vertical Take-Off and Landing

WP Waypoint

1. Introduction

ERL Emergency Service Robots is a civilian robotics competition; whose aim is to promote the development of multi-domain robotic systems for emergency response within the robotics community. In the case of emergencies, robotic systems play a key role by enabling rescue teams to sense and act at a distance from the emergency site. However, emergencies may take place in any scenario, and there is no guarantee of a communication infrastructure or even access to GPS. In order to perform the mission successfully, there is a need for additional competences in the robotic systems. In that sense, ERL Emergency Service Robots wishes to foster advanced developments on autonomous capabilities and seamless outdoor/indoor navigation for air and land robots, as these are important milestones to achieve for emergency-response robotic systems. This competition aims to provide real-world robotics challenges that will test the intelligence and autonomy of robots in demanding mock emergency-response scenarios.

The competition itself requires international teams of various disciplines and organisations to survey the scene, collect data, search for specific elements and identify critical hazards, all in a race against the clock. After three successful years under the name of 'euRathlon' (www.eurathlon.eu) and the ERL Emergency Robots 2017, the European Robotics League (www.robotics-league.eu) continues and will be extended to a Smart City context in the framework of the SciRoc Horizon 2020 project.

As in other leagues within ERL, it is composed of multiple Local Tournaments, held in different locations across Europe, and a few competitions as part of Major Tournaments. Teams participate in a minimum of two tournaments (Local and/or Major) per year and get scores based on their performances. ERL Emergency Service Robots competition included two Local Tournaments that took place during the first season 2018/19:

- ERL Emergency Service Robots 2018, focused on land and sea robotic systems, chaired by the Centre for Maritime Research and Experimentation (CMRE), Italy.
- ERL Emergency Service Robots 2019, focused on land and air robotic systems, chaired by the Advanced Center for Aerospace Technologies (CATEC), Spain.

For the third season 2020/2021, there will be again two Local Tournaments:

- ERL Emergency Service Robots 2020 La Spezia, focused on land and sea robotic systems, chaired by the Centre for Maritime Research and Experimentation (CMRE), Italy.
- ERL Emergency Service Robots 2020 Poznan, focused on land and air robotic systems, chaired by the Advanced Center for Aerospace Technologies (CATEC), Spain, with the collaboration of the European Space Foundation (ESF), Poland.

This document is a draft that describes the ERL Emergency Service Robots competitions.

This document is subject to change, refinement, and development.

2. ERL Emergency Service Robots Organization

The management structure of ERL Emergency Service Robots is composed of three committees: the Executive Committee, the Technical Committee, and the Organization Committee. The roles and responsibilities of each committee are described in this section.

2.1 Executive Committee

The Executive Committee (EC) is represented by the partners of ERL Emergency Service Robots. This committee is mainly responsible for the overall coordination of ERL Emergency Service Robots activities, and especially for dissemination in the scientific community.

The ERL Emergency Service Robots competition is chaired by the Advanced Center for Aerospace Technologies (CATEC), and includes three partners:

- Centre for Maritime Research and Experimentation (CMRE) (Italy)
- University of the West of England, Bristol (UWE Bristol) (UK)
- Advanced Center for Aerospace Technologies (CATEC) (Spain)

2.2 Technical Committee

The Technical Committee (TC) is responsible for the rules of the league. Each member of this committee is involved in maintaining and improving the current rule set, and also the adherence to such rules. Other responsibilities include the qualification of teams, handling general technical issues within the league, make sure teams comply with safety, as well as resolving any conflicts inside the league during an ongoing competition. The members of the committee are further responsible for maintaining the ERL Emergency Service Robots infrastructure.

The TC 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 the vehicle's behaviour that is the purpose of the event. The TC will announce any modifications of the rules with an e-mail to all entrants and a corresponding statement on the ERL Emergency Service Robots page (www.robotics-league.eu). The TC may provide an interpretation of the rules at any time and in any manner that is required.

Decisions of the TC are final.

The TC currently consists of the following members:

Chairs of ERL Emergency Service Robots 2020 La Spezia

- Dr. Gabriele Ferri (CMRE, Italy)
- Dr. Fausto Ferreira (CMRE, Italy)

Chairs of ERL Emergency Service Robots 2020 Poznan

- Dr. Francisco J. Perez Grau (CATEC, Spain)
- Dr. Antidio Viguria (CATEC, Spain)

The TC also includes members of the EC.

Referee Team

The referees are a group of officials designated by the TC. Referees are members of the TC during the tournament event. The TC is the final authority on all matters referred to in the rules and all matters affecting the operation of the ERL Emergency Service Robots competition. The Referee Team is divided according to the different domains that the competition involves (land, sea, and air). Each Referee Team is led by one Head Referee, which manages the activity of the Referee Team.

The Referee Teams will be announced closer to the competitions.

2.3 Organizing Committee

The Organizing Committee (OC) is responsible for the actual implementation of the competitions, i.e. providing everything that is required to perform the various tests. Specifically, this means setting up the test arena(s), providing any kind of objects (e.g. manipulation objects), scheduling the tests, assigning and instructing referees, recording and publishing (intermediate) competition results and any other kind of management and advertisement duties before, during and after the competition.

The OC of ERL Emergency Service Robots 2020 Local Tournament in La Spezia (Italy) is chaired by CMRE and includes members of the three project partners. The OC of ERL Emergency Service Robots 2020 Local Tournament in Poznan (Poland) is chaired by CATEC, with the collaboration of the European Space Foundation (ESF), and also includes members of the three project partners.

The OC currently consists of the following members:

- Dr. Gabriele Ferri (CMRE, Italy)
- Dr. Fausto Ferreira (CMRE, Italy)
- Dr. Francisco J. Perez Grau (CATEC, Spain)
- Dr. Antidio Viguria (CATEC, Spain)
- Łukasz Wilczyński (ESF, Poland)
- Sarah Carter (UWE Bristol, UK)
- Dr. Matthew Studley (UWE Bristol, UK)

3. ERL Emergency Award Categories

3.1 Individual Tournament Awards

Awards will be given to the best teams for each of the Task Benchmarks (TBMs) and Functionality Benchmarks (FBMs) per tournament by the local organizers.

In every Local/Major Tournament, each team is requested to perform several trials of the available TBMs and FBMs. The team score for a given TBM/FBM in a Local/Major Tournament is computed as follows:

1. Select the best five trials of the TBM/FBM performed by the team (or all the trials if less than five trial attempts are offered by the local organizers).

2. The team score is the median of the scores of the trials selected in 1.

The team with the highest score in each of the TBMs will be awarded the title ("Best ERL Emergency Service Robots Best-in-Class Task Benchmark <task benchmark title>"). The teams with the highest score ranking for each of the FBMs will be awarded the title ("Best ERL Emergency Service Robots Best-in-Class Functionality Benchmark <functionality benchmark title>") and ("ERL Emergency Service Robots Second Best-in-Class Functionality Benchmark <functionality benchmark title>").

Notes:

- The number of TBM/FBM trial attempts offered in a tournament is recommended to be a minimum of 1 and a maximum of 7 trials.

- When a single team participates in a given TBM or FBM, the corresponding benchmark award will only be given to that team if the EC and TC consider the team performance of an exceptional level.

- When only two teams participate in a given FBM, the ("ERL Emergency Service Robots Best-in-Class Functionality Benchmark <functionality benchmark title>") award will only be given to a team if the EC and TC consider that team's performance as excellent.

3.2 Best ERL Emergency Service Robots Team Award

Only one final “Best ERL Emergency Service Robots Team” will be awarded to the best performing team at the end of the Season. The Season ranking is computed as follows:

- To be eligible for an award, a team must have executed valid (i.e. scored) trials of at least one TBM in minimum two Local/Major Tournaments of the Season; in case the number of tournaments available for a TBM in a Season is only one, the team will be eligible for the award.

- Only TBMs are considered for computing the final score.

- A score is computed for every TBM as the median of the pooled trials used for scoring the best two performances of a team in the Local/Major Tournaments of the Season (see above). In case the number of tournaments available for a TBM in a Season is only one, the score is computed for every TBM as the median of the pooled trials used for scoring the best performance of a team in the tournament.

- The three teams with the highest scores receive points according to their ranking in each TBM (3 points for the highest score, 2 points for the second-best team and 1 point for the third-ranked team).

- The best team is the one that scores more ranking-based points after the Season.

- A minimum score value will be required for the award to be given.

4. ERL Emergency Service Robots Scenarios

The ERL Emergency Service Robots scenarios set out here have been designed to encourage maximum participation of teams while also focusing on multi-domain cooperation and task fulfilment. The scenarios aim to be

- technically demanding (pushing the boundaries of the state of the art),
- relevant to the research, industry user communities and
- achievable in the context of a competition both in terms of logistics and evaluation.

Although competing robots will face mock scenarios, the environmental conditions and difficulties are intended to be as realistic as reasonably possible, and the success criteria will reflect straightforward end-user priorities such as task completion and minimal intervention to manage the robots.

The proposed scenarios are subject to refinement and development before the competition. We welcome and encourage competition participants and the wider robotics community to participate in the continuing development of this draft with their comments.

All scenarios have been defined with safety in mind. Different measures will be adopted to guarantee the safety of participants and attendees as well as properties in the surroundings of the competition areas. Access to the competition arena will be restricted and under the direct control of the Organizing Committee, employing fences to delimit the areas that are closer to the competition arena. Special safety rules will be adopted for aerial vehicles and all conducted flights will comply with current regulation concerning the relevant national authority.

The scenarios for ERL Emergency Service Robots consist of the environment in which the competitions will happen, including all the objects and artefacts in the environment, and possibly the equipment brought into the environment for benchmarking and monitoring purposes. This section describes the locations chosen to celebrate the Local Tournaments.

4.1 ERL Emergency Service Robots 2020 La Spezia (Sea+Land)

This Local Tournament will be held in the tidal basin and surrounding area and one building at the CMRE, in La Spezia (Italy). The area can be viewed on Google Earth at 44.095842, 9.864575.

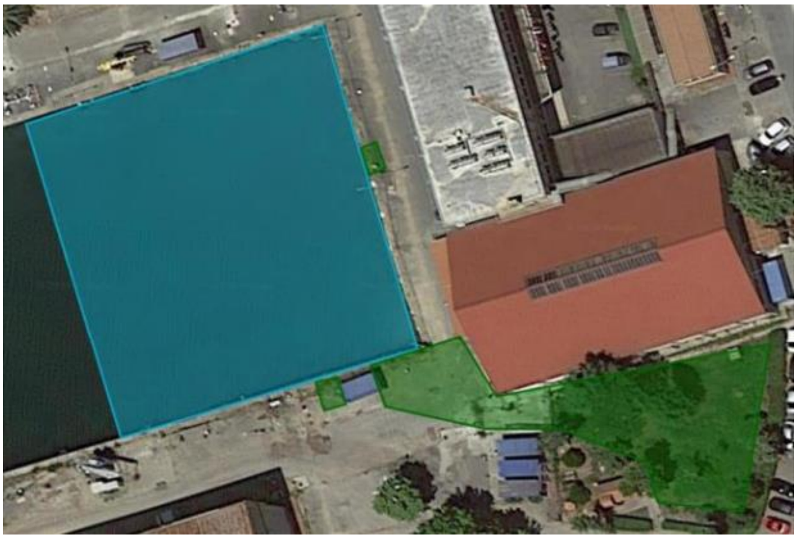

Figure 1. ERL Emergency Service Robots 2018 competition area (Source: Google Earth).

Static obstacles (i.e. debris, stones, holes, vegetation...) and dynamic obstacles (i.e. sea life, birds...) can be expected in the outdoor area. Loss of the Wi-Fi signal can be expected. As with any outdoor competition, there is the possibility of rain, wind, dust and muddy areas. If weather conditions are very poor the competition may be temporarily suspended for safety reasons.

Land robots competition area

Ground robots will operate in the proximity of the building in the area shown in Figure 2. In this area, teams should expect static obstacles such as debris, stones, holes, vegetation, etc. As in every outdoor scenario, there is the possibility of rain, wind, dust and muddy areas.

Figure 2. Area where the ground robots will operate. This area is indicative (Source: Google Earth).

It is important to note that the area shown in Figure 2 is just indicative and it is subject to minor changes.

Marine robots competition area

Marine robot competitions will be held primarily inside the docks area as shown in Figure 3.

The water basin is 120m long and 50m wide, the constant depth is 5.5 MSW. The currents are negligible and the water clarity can be seen from the available images of the competition web site. The salinity can be measured and made available to the competitors if required. For the information to the competitors close to the mid-water target, there is a source of fresh water coming out of the wall simulating the delta of a river. The AUV buoyancy compensation needs to be considered. The tidal range is approx. 10 cm on a spring tide. Ambient water temp in September is approx. 20° Celsius. The competition area will be 40m x 25m in the centre of the basin the centreline will be marked by a visible reference on the sea bed. Water visibility varies between 1 and 2 metres depending on weather conditions. Magnetic compass behaviour is indeterminate at this stage. However, we expect magnetic compasses to be useable 1 meter away from any structure.

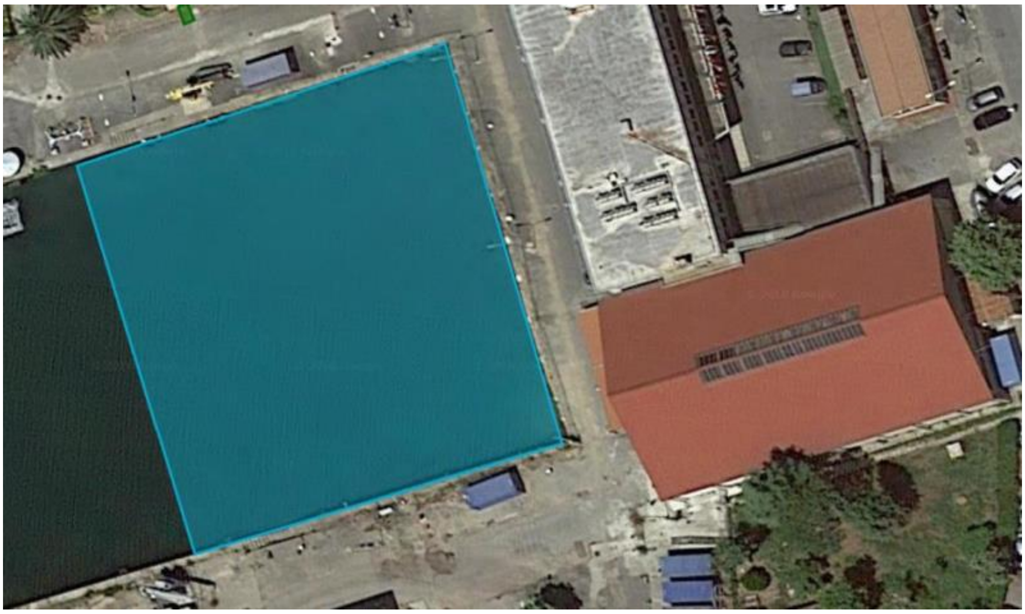

Figure 3. Area for marine robots in blue (Source: Google Earth).

Next to the competition arena, a smaller area will be prepared with OPIs for practicing.

The competition arena is divided into four sectors (see Figure 4). It will include one gate marked by the two buoys (detectable both by the sonar and video camera), spaced 2 metres apart. The arena will also contain several obstacles marked as red buoys in Sector 2 that the robots need to avoid. The fire marker will be located on one of the pipes of the two structures. The pinger is located in the same sector as that of the pipe containing the fire marker. The damages on the wall OPIs are represented in red rectangles. A mannequin will be moored in any sector except 2. All positions are indicative.

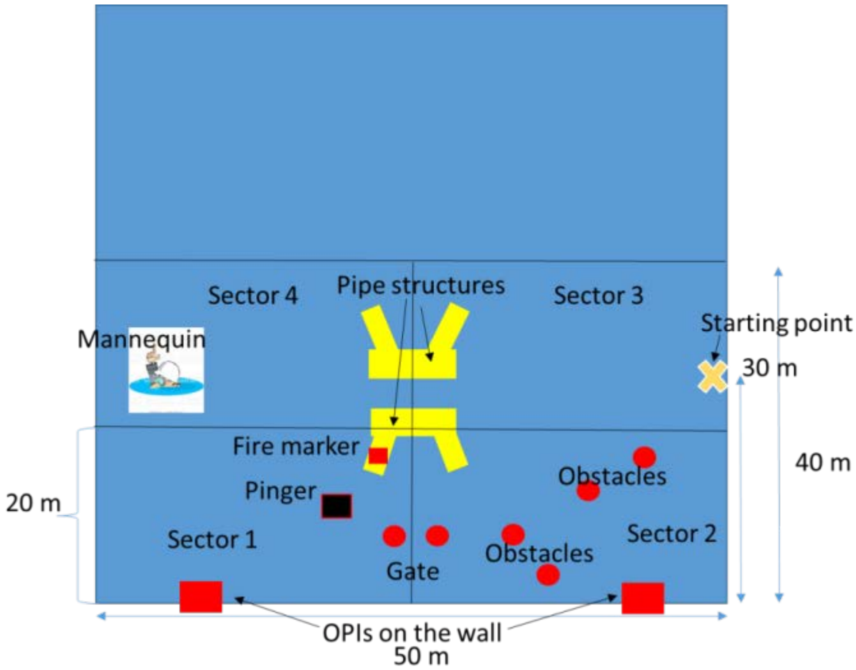

Figure 4. Schematic of the arena.

4.2 ERL Emergency Service Robots 2020 Poznan (Air+Land)

This Local Tournament needs to be held in an area with enough free space to safely operate aerial robots, as it will be detailed throughout this section. As an example, the first Air+Land Local Tournament in 2019 was celebrated in the fields surrounding the 'Hacienda de Oran', in Seville (Spain). The area can be viewed on Google Earth at 37.200814, -5.879996.

Figure 5. Aerial view of ERL Emergency Service Robots 2019 competition area.

Static obstacles (i.e. stones, holes, vegetation...) and dynamic obstacles (i.e. birds...) can be expected in the outdoor area. Loss of the Wi-Fi signal can be expected. As with any outdoor competition, there is the possibility of rain, wind, dust and muddy areas. If weather conditions are very poor, the competition may be temporarily suspended for safety reasons.

Competition arena

The proposed setup for the competition is an area of at least 150m by 60m free of obstacles, in an area where operating UAVs in Visual Line Of Sight (VLOS) is not forbidden according to current regulations in the host country.

There will be an area for the team's setup, where each team will count with a space of at least 4m x 4m. They will be equipped with tables and chairs. Next to the competition arena, there will be another two spaces of at least 4m x 4m which will be the Ground Control Stations, one for ground robots and another one for air robots. In front of these stations, there is the starting point for all robots during the competition. Besides, there will be a space reserved for judges and sponsors.

An example of the outdoor arena design is shown in the following picture. The flight height limit for aerial robots is 4m. There are controlled test/practice areas defined; one for ground robots (orange), and a bigger one (blue) in the same area for aerial robots. Additionally, there is a free test area only for ground robots (green). It is important to maintain a safe distance, at least 30 meters, between the test/practice areas and the area reserved for teams and sponsors.

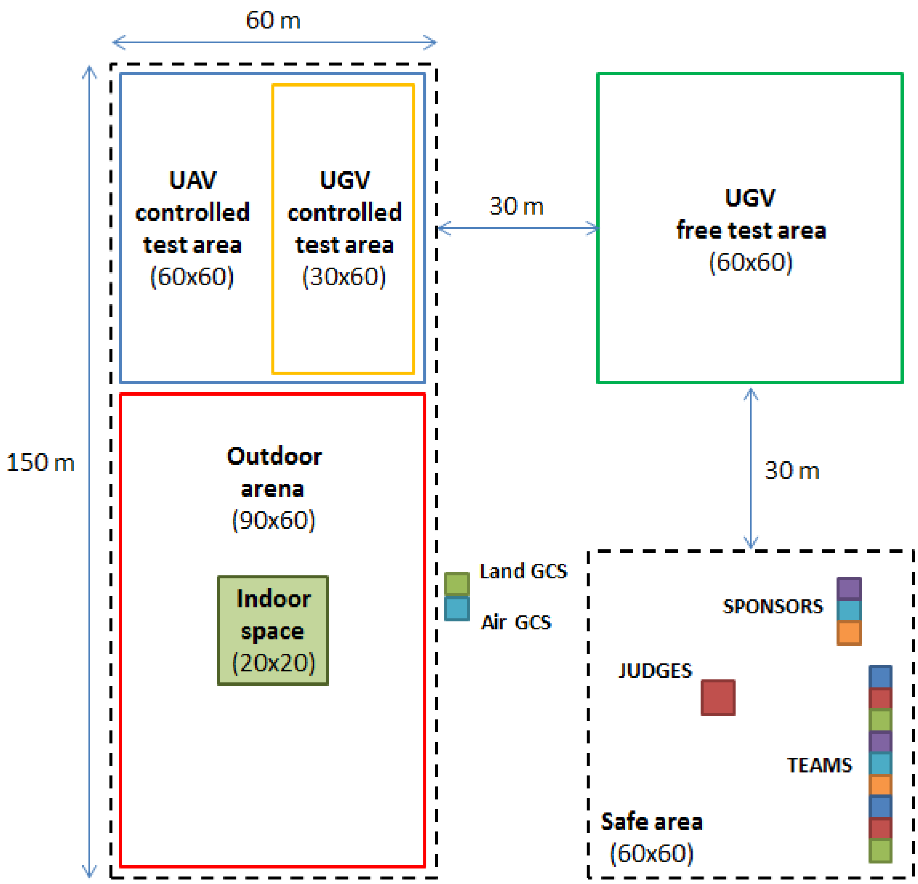

Figure 6. Area where land and air robots will operate. This design is indicative.

It is important to note that the outdoor arena design shown in Figure 6 is just indicative and is subject to minor changes.

The competition arena will include a building or another indoor space where the aerial and ground robots need to go inside. Figure 7 shows an example of marquee used at the first Air+Land Local Tournament in 2019. The final design may be different and teams will be notified in due time. The dimensions of the indoor space should be at least 20m x 20m.

Figure 7. Example of marquee used as the indoor space

To go inside the indoor space, entrances will be marked as blocked or unblocked. Unblocked entrances to the indoor space for robots should be approximately 3m wide and 2m high at least. Markers for blocked and unblocked entrances will be located right above the entrances (see Appendix for more details about the markers). An example is shown in the following figure. The unblocked entrance is where the robots must enter the building, but to exit the indoor space the robots can use whatever opening they might find.

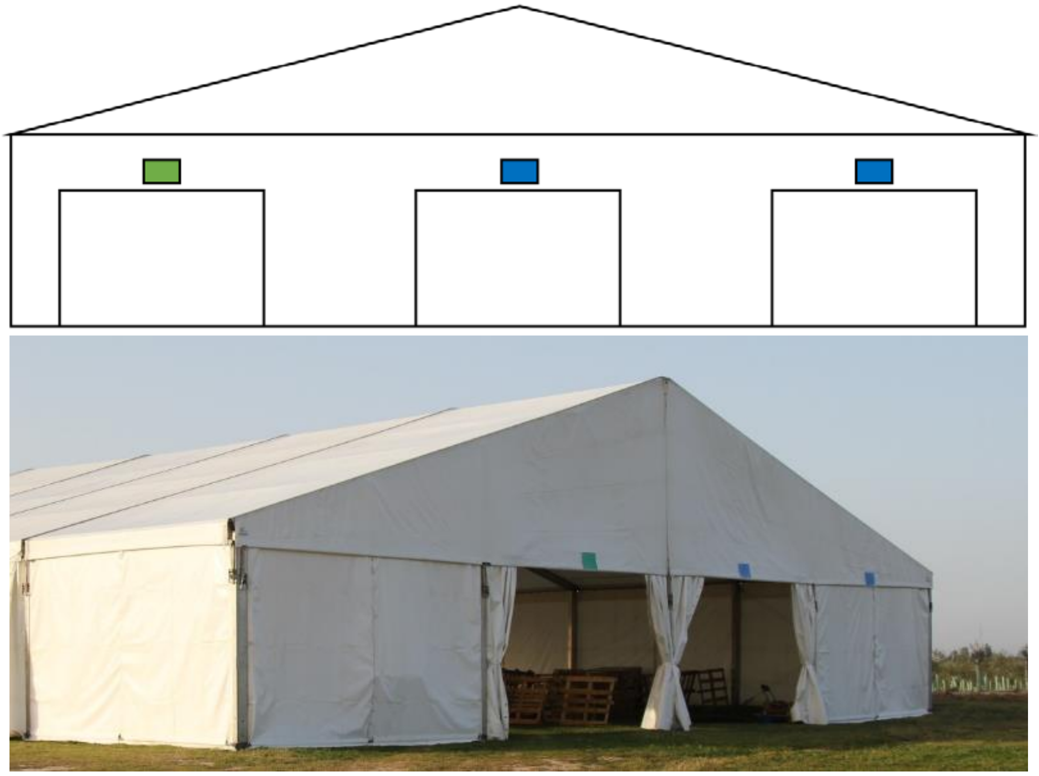

Figure 8. Example of entrances to the indoor space, and location of the markers

In the outdoor arena, there will be obstacles that robots need to detect and avoid. These obstacles can be made of any kind of soft material (e.g. Styrofoam) or hard material (e.g. plastic), as shown in Figure 9.

Figure 9. Obstacles to install in the competition arena.

Figure 10 shows an example of outdoor obstacles used at the first Air+Land Local Tournament in 2019.

Figure 10. Example of an obstacle used in the outdoor arena.

Indoor obstacles for ground robots will be based on pallets, in a way that robots need to find their way through the marquee to find the missing worker, and also to get out of the marquee. For aerial robots, there will be also a few obstacles similar to those shown in Figure 10, apart from the pallets at a low height. The following figure shows an example of indoor obstacles used at the first Air+Land Local Tournament in 2019.

Figure 11. Example of obstacles used in the indoor area.

The indoor obstacles based on pallets were placed in such a way that it was possible to modify the design of the labyrinth easily every day. Figure 12 shows an example of the maze used at the first Air+Land Local Tournament in 2019. In this design, the position of all the horizontal lines that formed the labyrinth could be modified.

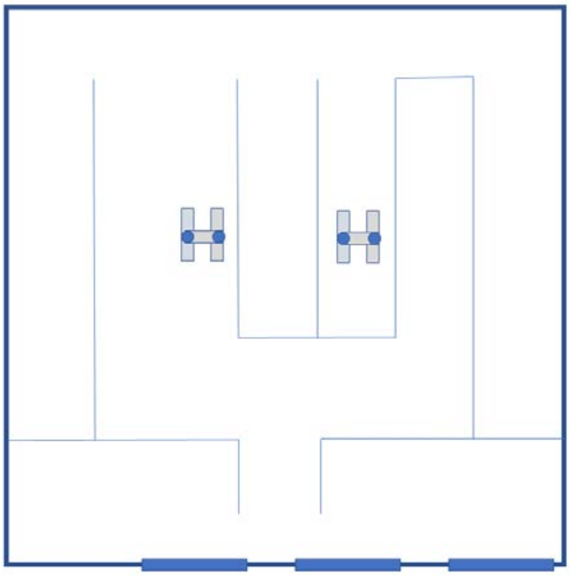

Figure 12. Example of labyrinth design used in the indoor area.

Ground robots should also expect static obstacles such as debris, stones, holes, vegetation, etc. As in every outdoor scenario, there is the possibility of rain, wind, dust and muddy areas.

As previously stated, all the aerial operations will be held in VLOS and daylight conditions, with a maximum distance between the aerial robot and the safety pilot of 160 meters, and a maximum altitude above ground level of 40 m.

All the flights will have to be conducted within the flight volumes that will be defined by the TC. In the case that an aerial robot gets out of the flight volumes, the safety pilot will have to take control of it, return it to the flight volumes and safely land in the defined landing areas.

The take-off and landing areas will be prepared for this purpose; they will be flat solid surfaces marked with visible markers, so it can be easily identified by the pilot. These zones will be about 3 x 3 meters with no obstacles in the surrounding area. Each of these take-off and landing areas has an associated control area close to them from where team members can control the operation of the aerial robot. Aerial robots will only be allowed to take-off and land in these areas (except in the case of an emergency). Aerial robots must land in these areas to be refueled or when a battery change is needed. Aerial robots with electrical engines will also be allowed to land and take-off inside the building when performing an indoor task for changing batteries. Aerial robots with combustion engines will not be allowed to refuel indoors for safety reasons.

Flights will be conducted over an unpopulated area. There is no overhead electrical wiring in the competition area.

5. Robots and Teams

The purpose of this section is twofold. On one hand, it specifies information about various robot features that can be derived from the environment and the targeted tasks. These features are to be considered at least as desirable, if not required for a proper solution of the task. Nevertheless, we will try to leave the design space for solutions as large as possible and to avoid premature and unjustified constraints. On the other hand, the robot features specified here should be supplied in detail for any robot participating in the competition. This is necessary to allow better assessment of competition and benchmark results later on.

5.1 General Specifications and Constraints

There is no limitation on the number of robots in a team. However, for safety reasons, we will limit the number of robots in simultaneous use during competition, as follows:

Land: Two ground robots may be concurrently used on the field during one Task Benchmark/ Functionality Benchmark.

Sea: One underwater robot may be used during one Task Benchmark/ Functionality Benchmark.

Air: One aerial robot may be used during one Task Benchmark/ Functionality Benchmark.

Teams with novel approaches that fall outside the guidelines above (i.e. multi-robot swarms) are strongly encouraged to enter and contact the organisers. Multimodal robots (e.g. amphibious robots that can operate both on the ground and at sea) may be used as long as they are registered for the domains in which it can operate. Only robots registered under a team's name and approved by the Technical Committee through the Scenario Application Papers (SAP) may participate in the competition. The organisers will provide teams with the opportunity to register new robots under their name if they submit information for approval prior to the competition.

The teams may use different robots during different time-slots. For instance, one team may use one aerial robot during the Monday time-slot and another one during the Tuesday time-slot. The referees must be informed of all robots that a team intends to use and each robot needs to pass a safety check before being used.

The maximum number of team members in the competition site is **8 plus a team leader**.

Note: special requests on the number of team members will be evaluated individually by the tournament organisers.

5.1.1 Mode of Operation

In the SAPs, each team must explain how they plan to target each task benchmark, including the mode of operation of their robot(s). During the competition, teams must inform the judges about changes in the modes of operation (in case they have changed from those specified in their SAPs). The three modes of operation are categorised as: autonomous, semi-autonomous and tele-operated. A robot may be operated in different modes depending on the scenario tasks. The categorisation will be verified and, if necessary, updated by the Technical Committee. The classification only applies to the mode of operation after the robot's launch/release and before the robot's retrieval/return. Robots in any mode of operation must be unmanned.

- **Autonomous Robot Operation**

For this competition, the autonomous operation is defined as operation in which a robot's low-level motor control including starting, stopping and steering, together with medium-level control such as navigation, are performed without human intervention.

In this mode, direct control via an operator device is prohibited. Interaction is only allowed to provide the robot with necessary input data before the robot is launched and to receive result data from the robot after its retrieval.

However, even in autonomous mode, a robot may be monitored* and supervised passively by a human operator, who can intervene and assume manual control if necessary. If the robot or operator console signals an incident it cannot cope with autonomously, the operator (or, on the operator's request, the "technical assistant"/safety pilot) may interact with the system. Note, however, that any interaction between the technical assistant/team safety pilot and the robot is likely to have a negative influence on the resulting evaluation.

Autonomous operation vehicles must be unmanned.

** In the case of marine robots, monitoring can only be done through acoustic modems, no LBL or USBL are allowed for localization. Neither WiFi is allowed to monitor the robot operations when the robot is submerged (for instance via a towed floating buoy).*

- **Semi-autonomous Robot Operation**

In semi-autonomous operation, a robot operates autonomously, but the operator is allowed to send high-level commands to the robot. High-level commands are instructions such as "move to waypoint 1", "search for the OPI" or "close the valve" which the robot must interpret into a series of medium- or low-level control actions. The use of such high-level commands still requires the robot to have a closed-loop control system with some autonomy. <u>In this mode, full manual control of the robot via a remote interface with a joystick or other human interface is prohibited.</u>

At any time, the operator (or, on the operator's request, the "technical assistant"/team safety pilot) may assume full manual control of the system. Note, however, that such interventions are likely to have a negative influence on the resulting evaluation.

In semi-autonomous operation, vehicles should be unmanned.

For land robots, a safety driver instead of a technical assistant is permitted by prior agreement with the organisers.

For marine robots, the high-level commands can be issued to the robot via an acoustic modem located on-shore.

- **Tele-operated Robot Operation**

Tele-operation is defined as full manual control of a robot via a remote interface with a joystick or other human interface.

For tele-operated robots, the operator is allowed to control the robot at any time during the Task Benchmark/Functionality Benchmark. On the operator's request, the "technical assistant" may interact with the robot. Note, however, that any interaction between the technical assistant and the robot may have a negative influence on the resulting evaluation. No tele-operation is allowed for marine robots.

Tele-operated vehicles must be completely unmanned.

5.1.2 Cooperation

Cooperation is defined as the act of working together toward a common purpose. Robots from different domains can cooperate in different ways to complete the scenarios. This may be through direct cooperation (i.e. robot1–robot2) or mediated by human operators (i.e. robot1–human–robot2, robot1–human1–human2–robot2, etc.).

5.1.3 Requirements for Ground Robots

Mass

There is an upper limit of 350 kg on the mass of ground robots. Teams with a ground robot > 350 kg must contact the organisers so that they can evaluate, in each case, the suitability of the robot for the terrain of the competition scenarios. Heavy robots will face difficulties in some scenarios; similarly, exceptionally small/light land robots may face difficulties with terrain. Ground robots weighing more than 75 kg must be equipped with a recovery facility. Ground robots must be able to travel on an asphalt pavement without damaging the pavement surface.

Traction

Ground robots must be propelled and steered by traction with the ground. The type of ground contact devices (e.g. tyres, treads or legs) is not restricted. The robot must not damage the environment or any infrastructure at the ERL Emergency competition site.

Size

There are no size limitations for the ground robots, but teams should be aware that large robots are likely to have difficulties with the 'indoor' part of the scenarios.

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 robot. The E-stop system must be fully functional for the participant to be eligible to participate in ERL Emergency. In case of emergency (i.e. imminent danger for individuals and/or the robot) the E-stop system must be activated immediately.

Triggering the E-stop mode must bring the motion of the robot to an immediate stop, with brakes applied to hold the robot 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 ruggedised to ensure functionality even after exposure to adverse (damp or dusty) environmental conditions and a high vibration environment.

The robot 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 run, and each E-stop event may last up to several minutes.

In the special case of a robot with a safety driver, entering the E-stop mode requires the driver to stop the robot immediately and completely. If applicable, additionally the handbrake must be put on and the gearbox/automatic transmission must be put into the neutral position.

Robot mounted Emergency Stop Unit

Each robot must be additionally equipped with an externally actuated emergency stop capability. Activating the emergency stop must promptly bring the robot 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 robot. The manual emergency stop must be easy to identify and to activate, even if the robot 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.

Warning Devices

Each robot shall display one or more flashing amber warning lights, the combination of which results in a visibility of 360 degrees azimuthally around the robot. The warning light(s) shall continuously operate whenever the robot is switched on. The robot may not commence movement until the warning light(s) has 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.

This warning light is mandatory for robots heavier than 20 kg and recommended for vehicles lighter than 20 kg.

General

Robots' operation must conform to any regulations or restrictions imposed by the applicable land-use authority.

5.1.4 Requirements for Marine Robots

Mass

There is a limit of 100 kg for Autonomous Underwater Vehicles (AUVs).

Size

There are no size limitations for any of the robots. A maximum of one AUV can be used at the same time during the runs even if the teams can bring spare robots. The robots to be used in a run must be communicated to the judges before the start of the run.

General

Power constraints: All entries must be battery powered. All batteries must be sealed. The open-circuit voltage of any battery in an entry may not exceed 60 Volts DC.

No materials (except for compressed air) may be released by the entry into the waters of the arena. Any robot leaking fluid will be deemed unsafe. All robots must carry a clearly legible 'label' showing the robot's weight in the air. All robots must have 2, 3 or 4 clearly identified lifting points onto which standard commercial lifting slings may be easily attached/detached – on land or in the water – in a safe manner.

All robots will be required to install strobe lights.

All entries must bear a clearly marked OFF switch that a diver can readily activate. The switch must disconnect the batteries from all propulsion components and devices in the AUV. Note that this does not have to kill the computer. Upon reactivation, the robot must return to a safe state (propellers do not start spinning). All entries must be positively buoyant by at least one half of one percent of their mass when they have been shut off through the OFF switch.

Robot operation must conform to any regulations or restrictions imposed by the applicable marine-use authority.

5.1.5 Requirements for Aerial Robots

Only Vertical Take-Off and Landing (VTOL) aircrafts will be allowed to participate in the competition. The area for taking-off and landing will be of 3x3m. The aircraft maximum take-off weight (MTOW) must be smaller than 25 kg.

The robotic system must include a flight termination system that must be capable of being remotely activated from the ground by pressing a "crash button". When remotely activated, the flight termination system must stop the aircraft motors. A member of the organization, an aerial expert, will be in charge of pressing the "crash button" only in the case that safety is seriously compromised. It is important to highlight that the flight termination system will only be activated in extreme circumstances in which is evident that the aircraft will put people in danger, crash against a critical building or element (e.g. a power plant) or is going so far that is evident that it won't be possible to recover its control. The member of the organization in charge of the "crash button" will be a highly experienced and qualified safety pilot. The device on the ground used to activate the flight termination system has to be completely independent from the rest of the system so if other parts of the system fail, the flight termination system can still work. This device must be physically independent from the standard radio used by the safety pilot, so the aerial expert from the organization can hold it during the aerial robot operation. Optionally, the flight termination system can also activate other complementary systems (e.g. activating a parachute) in addition to stopping the motors. Aircrafts with an MTOW lower than 2 kg will be exempt from this requirement.

The RC (Radio Control) radio used by safety pilots cannot operate at 2.4 GHz. Aircrafts with an MTOW lower than 2 kg will be exempt from this requirement. Alternative bands such as 433 MHz could be used for this purpose (this section includes more information about devices operating in this band). Teams using safety pilot radio links operating in the 5 GHz band must notify the organizing committee. It is compulsory that teams use RC radio links based on FHSS (Frequency Hopping Spread Spectrum) which makes the signal more robust against interferences. The Organising Committee does not impose any particular safety pilot radio system. Teams are free to choose the RC radio link as long as it fulfils these requirements.

Teams can bring multiple aerial robots to the competition (e.g. a back-up vehicle, different vehicles for different tasks, etc.) but only one aerial robot will be allowed to fly at a time. All the aerial robots to be used during the competition must pass the validation tests and provide the documentation described hereafter.

Requirements for pilots

- Each aerial team must have one or more safety pilots.
- The safety pilot must be exclusively devoted to manually control the aircraft using the RC radio if needed. If the aerial team chooses to perform a mission task flying manually the safety pilot will be in charge of controlling the aircraft. If the aerial team chooses to perform a mission task flying autonomously, the safety pilot will supervise the operation and will take manual control of the aerial robot if any misbehaviour is observed during the flight.
- Safety pilots must be over 18 years old.
- Safety pilots will have to provide a valid second class medical certificate. You can get more information on this e.g. on http://aviation.about.com/od/Career-Training/a/Qanda-Medical-Certificate-Requirements-For-Pilots.htm.
- Safety pilots must be properly identified with a photo ID during the competition.
- Only those pilots indicated in the documentation that is submitted to the organization will be allowed to fly.
- Not all the pilots that were included in the documentation must attend the competition (e.g. an aerial team can include in the documentation some pilots that might be attending the competition just in case the main pilot cannot attend).
- Safety pilots that intend to fly during the competition will have to perform the on-site validation flight tests.

Procedure for aerial team validation

In order to be accepted as a participating team in ERL Emergency Service Robots, aerial teams will have to provide evidence showing that their aerial system is safe and they have enough knowledge and skills to safely operate it. When applying for participation, aerial teams must submit a good-quality video showing their aerial system performing the following operations:

- Take-Off operation, in manual mode.
- Hovering operation, in manual mode at 40 meters from the ground.
- Fly following a rectangular trajectory as the one shown in Figure 13, both clockwise and counter-clockwise, in manual mode. These flights must be performed at an altitude of 20 meters.
- Perform vertical displacements of at least 20 meters, in manual mode.
- Landing, in manual mode.
- Execution of the flight termination functionality on the ground. The video must show how the motors are stopped when the crash button is pressed.

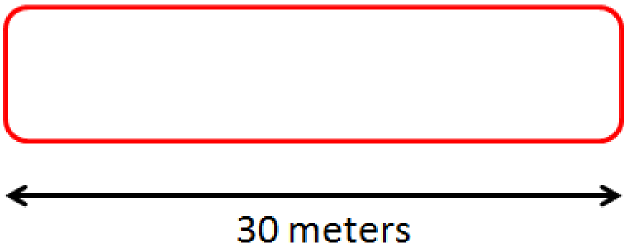

Figure 13. Flight trajectory for validation test.

Teams will also have to submit the following documentation:

1. Description of the aerial system.
2. Safety aeronautical analysis.
3. Operation and maintenance manuals.

Templates with guideline information on how to write those documents are available at the ERL Emergency Service Robots website. The submitted documentation and videos will be analyzed by the Organizing Committee. Based on this analysis the organization will decide which teams are accepted for participation.

During the competition, flights will be subject to approval from the aerial expert designated by the Technical Committee at any time. Aerial experts will be properly identified so teams can recognize him/her. No aircraft will be allowed to take-off and fly without the explicit authorization from the designated aerial expert. Obviously, teams cannot fly if an aerial expert is not physically present. Team pilots will always have to follow the indications of the aerial experts at any time before, during and after the flight.

Before the actual competition, validation test flights will be carried out on-site to test that the aircraft can be flown safely by the team pilot. The operations that will have to be performed will be basically the same as required for the video. However, the aerial experts will be able to request any additional operation. The aerial experts will decide if a team has proven they can operate the aerial vehicle safely and hence they are allowed to perform the aerial missions.

Safety pilot radio link

Aerial robots must be remotely controlled by a pilot on the ground. When operating in manual mode, the pilot is in charge of directly controlling the aircraft. When operating in autonomous mode, the aircraft is controlled by the autopilot and the pilot on the ground is in charge of taking manual control of the aircraft when any issue is experienced during the flight of the aircraft. Hence, this pilot is normally referred to as the safety pilot. A specific radio link must be used exclusively as the safety pilot radio link.

It is critical that the security pilot can take control of the aircraft when needed. Therefore, this radio link must assure connectivity between the security pilot and the aircraft. Most of the commercial radio links used by security pilots operate in the 2.4 GHz ISM band. It is widely known that the 2.4 GHz ISM band is very populated as it’s used by a lot of radio systems including WiFi devices, Bluetooth, etc. For this reason, security radio links use Frequency Hopping Spread Spectrum (FHSS) techniques in order to increase the robustness against interferences. However, some interference issues affecting 2.4 GHz security radio links have been reported and experienced in the past. Although these issues are not common, their effects can be catastrophic and hence it is preferred to avoid any risks. In a multi-domain robotic competition as ERL Emergency Service Robots, it is expected that many 2.4 GHz radio devices are used by the different robots for different communication tasks (and control, telemetry or payload sensor management). For these reasons, it is mandatory that safety pilot radio links operate in a different frequency band of the spectrum.

Note: The use of 2.4 GHz RC radio links is only allowed in aircrafts with an MTOW lower than 2kg. For more information, please read the section about the requirements for aerial robots.

The Organizing Committee does not impose any particular safety pilot radio system. Teams are free to choose the system that better fits their requirements as long as it doesn´t operate in the 2.4 GHz band. Nevertheless, after analyzing the different commercial solutions available in the market, the Organizing Committee proposes using LRS (Long Range System) devices as they can be easily integrated with existing systems with a minimum effort.

LRS radio links

Long Range Systems (LRS) operate in the 433 MHz band. In addition to an extended range, using lower frequencies also increases the penetration of the radiofrequency signals into buildings which is important for indoor scenarios as those found in ERL Emergency Service Robots competition.

Figure 14. LRS module installed on a transmitter.

RC radio transmitters are the most expensive component of the safety pilot's radio link. Additionally, safety pilots are often reluctant to change the radio transmitter that they normally use. Fortunately, LRS transmitters are sold as modules that can be connected to RC transmitters via what is called the trainer port as shown in Figure 14. The output of the trainer port is a PPM (Pulse Position Modulation) signal that contains the values of the different channels as commanded by the transmitter controls. When operating with an LRS module it is important to disable the 2.4 GHz radio of the RC transmitter to avoid extra radiation in that band.

Figure 15. Elements of an LRS system.

In order to use LRS, adequate LRS receivers and antennas must be installed on-board the RPA. Figure 15 shows the elements that form the LRS system including the transmitter, receiver, transmitting and receiving antennas, and cables.

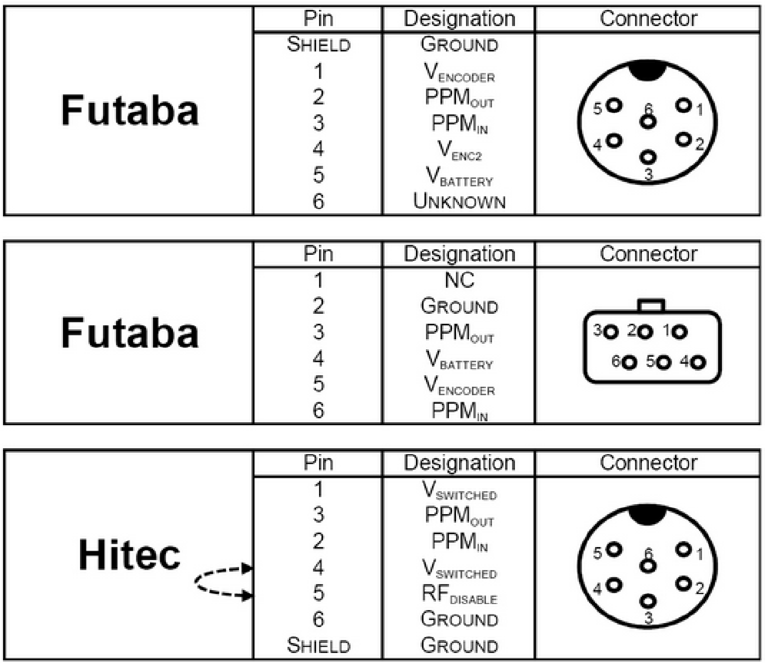

Figure 16. Futaba and Hitec trainer-port connectors.

When choosing an LRS device it is important to check the compatibility with commercial RC transmitters (basically this is a matter of electrical and physical characteristics of the connector). Figure 16 shows some examples of trainer ports. The cables that are used for connecting the RC transmitter to another device via the trainer port are commonly called buddy box cables.

LRS products

There is a wide variety of commercial of the shelf LRS products that are available in the market. Some of these commercial systems are presented below.

1. **ImmersionRC** (http://www.immersionrc.com/) EzUHF transmitter costs 209 $. It uses a 4-pin round connector (as an S-Video connector). This device can be connected to the trainer port of the following RC radios:
   - Futaba radios with square connector (see Figure 17).
   - Futaba radios with a round connector (see Figure 18).
   - Radios with jack connectors (Spektrum, JR, Turnigy, Hitec, Graupner radios).
   - Radios with Multiplex DIN connectors.

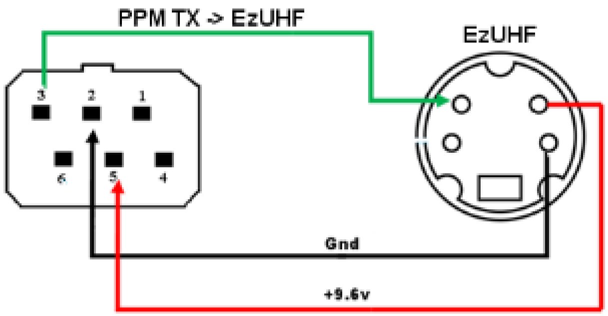

Figure 17. Connection between Futaba with square connector and EzUHF.

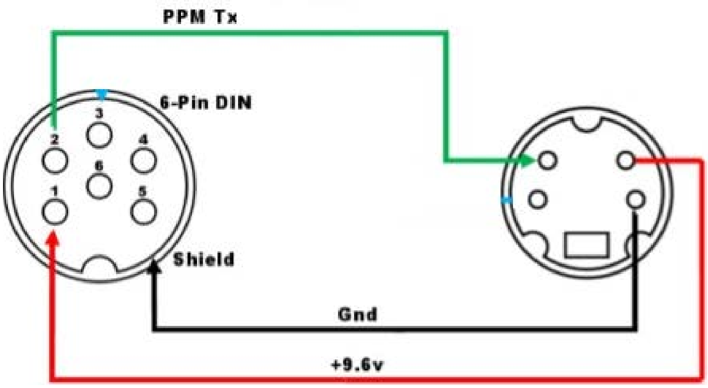

Figure 18. Connection between multiplex DIN connector and EzUHF.

Figure 19. Buddy cable for EzUHF and Spektrum, JR, Turnigy, Graupner, Fly Sky and Hitec radios.

With regards to the receiver devices, there are two suitable options:

- 8 channels with antenna diversity: 124 $.
- 8 channels without antenna diversity: 109 $.

EzUHF receivers can be connected to PixHawk, APM2 and Paparazzi autopilots which are the most common open-source autopilots. A complete kit including the transmitter, receiver, cables (for a specific RC radio) and antennas can be bought for 269 €.

2. **Dragon Link**: Dragon Link transmitters cost 234 $ (http://www.dragonlinkrc.com/instructions/v3equipment/). It uses a flat cable with 3

pins. This device can be purchased with cables for connection with the following radios (via the trainer port):

- Futaba radios with square connector.
- Radios with jack connectors (Spektrum, JR, Turnigy, Hitec, Graupner radios).

Very little evidence of people using this system with open source autopilots has been found. However, at first glance, they appeared to be able to connect to these autopilots. A complete kit including the transmitter, receiver, cables (for a specific RC radio) and antennas can be bought for 336 $.

3. **TBS Crossfire:** TBS Crossfire systems are also popular long-range links. Transmitters can cost around 150 $ (https://www.team-blacksheep.com/shop/cat:cat_crossfire#product_listing), while receivers may be up to 125 $.

5.1.6 Classified Data and Devices

No classified data or devices may be used by a team in preparation for or during the ERL Emergency Service Robots.

5.2 Safety Check and Robots Inspection

During the set-up days, all robots will be checked by the Technical Committee for compliance with the specifications and constraints described in Section 5.1. Teams will be asked to show the safety mechanisms of their robots and to demonstrate their use. A live demonstration is necessary: for example, pushing an emergency stop button while the robot is moving and verifying that the robot immediately stops. If the robot has other mechanical devices (e.g. a manipulator), their safety must be demonstrated as well.

This inspection can be done at any time during the set-up days. When teams are ready for an inspection, they can request one to the Technical Committee. The inspection can be repeated at any time during the competition days, upon request of the Executive or Technical Committees. Referees, organisation and technical members, team members and any other user who is interacting with the robot are always allowed to operate the safety mechanisms when there is a clear risk for the safety of any person or the damage of any part of the environment.

Robots that are not considered safe by the Technical Committee or the Organisation Committee are not allowed to participate in the competition!

Note: The organisers do not guarantee the safety of any robot entered in the ERL Emergency Service Robots competition, notwithstanding any rule or the organisers' acceptance of any application document, robot specification sheet, video demonstration or any inspection or demonstration required for participating in the ERL Emergency Service Robots.

5.2.1 Specific Aerial Vehicles Safety

Before the competition starts, all the aerial teams will have to attend a workshop and safety briefing given by the Organization Committee.

During the first day of the competition, the organisation committee will inspect all the aerial robots to be sure that they fulfil with the description provided during the application and registration phases. Flight termination mechanism will be tested on the ground to check that, when actuated, the motors are stopped. The teams whose aerial vehicles have passed the inspection test will have to perform a controlled flight in the competition area (with no public) according to a flight plan provided by the Organizing Committee, so they can show that they can operate their system in safe conditions and that they follow all the safety rules for its operation.

Safety briefings will be held at the beginning of each competition day.

Aerial teams will have to provide the organization committee with the flight plan that will be performed during the competition in advance, at least an hour before their participation. The organization committee can require the teams for introducing modifications in the flight plan to ensure safe flight operations. The flight plan will have to be approved by the organizing committee before the flights can be authorized. Before authorizing the flights each team will have to conduct pre-flight checks under the supervision of the organization safety pilots. Pre-flight checks will include at least:

- Visual structural inspection of the aircraft and wiring.
- Testing the security radio link between the aerial robot and the safety pilot checking that movements of control surfaces are coherent with the commands issued by the safety pilot.
- Checking that GPS signal is good enough and GPS data are available for the autopilot and ground control station.

The team safety pilot of the aerial robot will be out of the Control Station tent and can get into the competition arena in order to have line of sight with the aircraft when flying outdoors and indoors.
Two safety pilots will be responsible for the safety of flights. One of the safety pilots will be side by side with the team safety pilot for the whole flight time, monitoring the aircraft in line-of-sight. The other safety pilot will stay with the aircraft operator of the team (who is in charge of the Ground Control Station).
One of the safety pilots will be in charge of pressing the “crash button” only in the case that safety is <u>seriously</u> compromised. It is important to highlight that the flight termination system will only be activated in extreme circumstances in which is evident that the aircraft will put people in danger, crash against a critical building or element (e.g. a power plant) or going so far that is evident that it won’t be possible to recover its control.

Team pilots will always have to follow the indications of the organization aerial experts at any time before, during and after the flight. Not doing so will cause the disqualification of the team from all ERL Emergency competitions.

During the competition, teams cannot fly anywhere if the safety pilots are not present. Not doing so will cause the disqualification of the team from all competitions.

The organization safety pilots will be considered as the maximum authorities for the aerial operations as they are in charge of ensuring their safety. Hence, they will always have the last word concerning the operation of the aircrafts.

5.2.2 Health & Safety Standards

All teams and robots must comply with all applicable safety regulations (see http://europe.osha.eu.int/ for details).

All teams must obey the health & safety rules and laws of the host country.

5.3 Environmental Impact

Any aspect of robot activity or operation that has an unacceptable impact on the environment is prohibited. These activities include destructive robot 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 (robot) specification sheet and at the site visit. Going out of the competition area or/and affecting the area will lead to disqualification of the team.

5.4 RF and other communication equipment

Please note that the participants must take care of the frequency regulations themselves, but the organisation committee has the right to verify and enforce the regulations.

Teams must bring their own communication devices between team members. Note that the ERL Emergency Service Robots organisation will not provide them.

No antenna of any RF or other communication equipment used by the team shall exceed the overall height of 2.5 m.

5.5 Position Determination

Robots 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. Any costs associated with any subscription service are borne by the team.

GPS signals might not be available throughout the route at all times (e.g. inside the building/marquee). Be aware that GPS alone might not provide adequate navigation information to the robot.

5.6 Set-up and Pre-Competition Testing

Testing robots or components are the sole responsibility of each team. The use of public lands or private spaces for this purpose is at the team's own risk and must be following the applicable country’s laws.

Teams will be based in gazebos and will be provided with the following resources:

- About 16 square metres including tables and benches.
- 220 V mains electricity supply.
- Internet access.

Teams will have access to the following shared facilities:

- Pools (and possibly areas in the dock, when not in use for competition) for sea robots
- Areas for land/air robots test and set-up.

Note that:

- Teams must provide their own consumables, hand tools, drill bits, test equipment, etc.
- All team members must be skilled in the operation of all tools and equipment utilised.
- Only low voltage battery-powered tools and equipment will be permitted within 2 metres of the pool in the case of sea robots.

Inspection of the competition area (e.g. entering the building, marquee, etc.) by any participants is not allowed without the organiser's agreement and <u>will cause the disqualification of the team</u>.

Land/air robots will be given time slots to practice in a specific practice area designated by the organisers. <u>Practising outside that specific area (e.g. practising in the competition area) without permission from the organisation will lead to disqualification of the team.</u>

Marine robots will be given time slots to practise in the competition arena and pools. <u>Practising in the competition arena without permission from the organisation will lead to disqualification of the team.</u>

6. Task Benchmarks

Details concerning rules, procedures, as well as scoring and benchmarking methods, are common to all task benchmarks (TBMs). The two Local Tournaments organised during the ERL season 2020-2021 are based in two-domain benchmarks; the first tournament involves land and sea robots while the second one includes land and air robots.

Rules and Procedures

There are mandatory pre-competition safety-checks described in Section 5 of this Rulebook. Only teams that successfully pass the safety checks will be able to participate in the competition. Random safety-checks may be performed before some runs if required by the Organising Committee, the Technical Committee or another team.

The team members must inform at least one of the Organising / Technical Committee members present during the execution of the task of any change done to the robots since the safety-check was performed.

Members of the Organising Committee / Technical Committee present during the execution of the task will make sure if the robot complies with the other safety-related rules and robot specifications presented in Section 5.

All teams are required to perform each task according to the steps mentioned in the rules and procedures sections for the tasks.

A **trial** is an attempt to complete the Task Benchmark during a time-slot. A **run** is an attempt of completing a trial. Multiple runs are allowed within the trial time-slot, and the final score of the trial will be the best-run score.

Scoring and Ranking

Evaluation of the performance of a robot according to TBMs is based on performance equivalence classes.

The criterion defining the performance equivalence class of robots is based on the concept of *tasks required achievements*. The ranking of the robot within each equivalence class is obtained by looking at the performance criteria. In particular:

- The performance of any robot belonging to performance class N is considered as better than the performance of any robot belonging to performance class M whenever $M < N$.

- Considering two robots belonging to the same class, then a penalization criterion (penalties are defined according to task performance criteria) is used and the performance of the one that received less penalization is considered as better.

- If the two robots received the same amount of penalization, the performance of the one that finished the task more quickly is considered as the best (unless not being able to reach a given achievement within a given time is explicitly considered as a penalty).

Performance equivalence classes and in-class ranking of the robots are determined according to three sets:

- A set *A* of **achievements**, i.e. things that should happen (what the robot is expected to do).

- A set *PB* of **penalised behaviours**, i.e. robot behaviours that are penalised if they happen (e.g., manual intervention).

- A set *DB* of **disqualifying behaviours**, i.e. robot behaviours that absolutely must not happen.

Scoring is implemented with the following 3-step sorting algorithm:

1. If one or more of the elements of set *DB* occur during task execution, the robot gets disqualified (i.e. assigned to the lowest possible performance class, called class 0), and no further scoring procedures are performed.

2. Performance equivalence class X is assigned to the robot, where X corresponds to the number of achievements in set A that have been accomplished.

3. Whenever an element of set *PB* occurs, a penalisation is assigned to the robot (without changing its performance class).

One key property of this scoring system is that a robot that executes the required task completely will always be placed into a higher performance class than a robot that executes the task partially. Moreover, the penalties do not make a robot change class (also in the case of incomplete tasks).

6.1 General Procedures

This section specifies the roles of the team members, the robot control and the procedures that will be followed for the start, restart or exit of each TBM.

6.1.1 Roles of Team Members

Each team must designate a single individual to serve as the **Team leader**. The team leader will serve as the primary point of contact with the organisers. The Team Leader, and only the Team Leader, will speak for the team during the competition.

For each robot one **Operator** is allowed to control/monitor (when applicable) the robot from a dedicated Control Station. Robot operators will be located in an operations tent located close to the competition arena. They will not have line of sight with the robots all the time. In the case of aerial vehicles, one of the ERL Emergency safety pilots will stay with the operator to supervise the operation and ensure its safety.

One “**Command and Control Operator**” is allowed to manage the overall control of the team and supervise the coordination between robots. The Command and Control Operator has to stay in the Control Station.

For aerial robots, the **“Team Safety Pilot”** will be present in the competition arena within visual line of sight of the aerial robot. The safety pilot will need to stay in the indicated area close to the arena and will be allowed to approach or enter the building for indoor flights. One of the ERL Emergency safety pilots will stay with the team safety pilot to supervise the operation and ensure its safety.

For marine robots, one or two team members, the “**Technical assistants”** can accompany their robot (when applicable) along the trial on the organisation support boat.

For ground robots, one or two team members, the “**Technical assistants”** can accompany their robot (when applicable) along the trial.

For example, in a multi-domain team with 2 ground robots and 1 aerial robot, the people involved in the management of the team competition would be:

- 1 team leader
- 3 operators @Control Station (maximum)
- 1 command and control operator @Control Station
- 2 technical assistants for land robots
- 1 safety pilot for the air robot

During a Task Benchmark trial, members of other teams (than the one participating) will not be allowed in the control stations. Red/white tape will delimit the perimeter of the tent and prevent other teams/people to come inside or stay around.

The maximum number of people allowed (excluding referees and organisers) inside the control station is 5 people (i.e. 1 team leader, 3 operators, 1 command and control operator).

Teams must behave respectfully keeping a distance and quiet environment near the control stations while another team is competing. Entering in the control stations while another team is competing is completely prohibited and is a cause of disqualification. Showing disrespectful behaviour may also be grounds for disqualification.

Team members are kindly asked to respect referees’ decisions.

Teams are welcome to watch the competition from the spectators’ areas.

6.1.2 Robot Control

There will be two Control Stations (physical location) in the competition area at any of the two Local Tournaments, i.e. one control station per domain.

In the case of the first Local Tournament, the control station for marine robots will be located in the dock area near the marine competition arena. The control station for ground robots will be located near the building area, and the control station for aerial robots will be close to the designated take-off and landing place. All operators with their control equipment will be located in their respective control stations. The control stations are part of the starting area (see Figure 20). It is not possible to see the entire competition area from the control stations. The operators must not leave their respective control stations during the Task Benchmark.

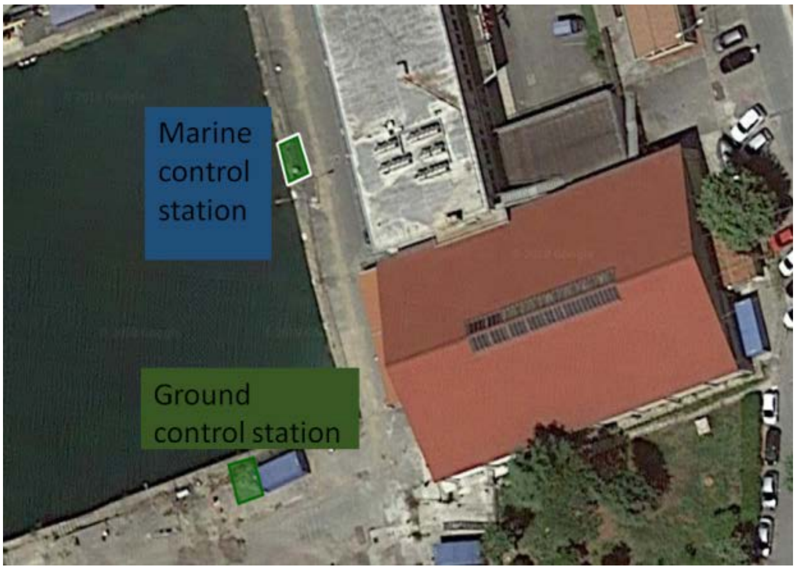

Figure 20. Example of the Control Stations area for ERL Emergency Robots 2018. (Source: Google Earth)

In the case of the second Local Tournament, the location of the two control stations (one for ground robots and another one for aerial robots) will be close to the competition area and the designated take-off and landing place for aerial robots, as well as the starting area for ground robots. Besides, if the control stations are far from the indoor space, there will be an additional control station close to the building/marquee, from where aerial and ground robots can start their trials. Teams must communicate the Organizing Committee from which control station they wish to start, prior to their time slot. Nevertheless, only one aerial robot will be allowed to fly at a time. In the case of ground robots, the Organizing Committee will decide if there can be more than one robot operating at a time (teams are encouraged to contact the Organizing Committee to evaluate this possibility).

All operators with their control equipment will be located in their respective control stations. It is not possible to see the entire competition area from the control stations. The operators must not leave their respective control stations during the Task Benchmark.

Only the operator/safety pilot is allowed to control the robot. The exact kind of permitted interaction depends on the chosen mode of operation, as defined in Section 5.1.1. For marine robots, tele-operation is forbidden and only acoustic monitoring can be used in the case of semi-autonomous.

The technical assistants accompany the robot during the run and operate the E-stop (ground robots). For marine robots, the technical assistants can accompany the robot in the rubber boat and interact with it.

At any time in the preparation phase and during a trial, an ERL Emergency official may prompt the technical assistant to put the robot in emergency stop mode due to safety or operational reasons. As soon as the official agrees, the robot may be resumed from the emergency mode. In case of emergency (i.e. imminent danger for individuals and/or the robot) the technical assistant must self-reliantly activate the emergency stop. In the case of aerial vehicles, the organization safety pilots will be in charge of the emergency stop system.

Only due to an explicit request of the operator or for safety reasons, the technical assistant/team safety pilot may interact with the robot. Without the operator's request, the technical assistant/team safety pilot may interact with the robot only in case of emergency (i.e. imminent danger for individuals and/or the robot) and only after activation of the emergency stop. In the case of aerial vehicles, the safety pilots will activate the emergency stop system in case of emergency

In the special case of a ground robot with a safety driver, the driver may interact with the robot only in case of emergency (i.e. imminent danger for individuals and/or the robot). If so, he/she must put the robot immediately into the E-stop mode.

Any other unauthorised interaction between the technical assistant/safety driver and the robot will lead to the abortion of the run.

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

Specific for marine robots:
The underwater robot can receive messages directly from the Control Station on-shore through an acoustic link. The type of messages allowed is navigational helps and commands to surface to get a GPS fix (when applicable) from the control station or orders to switch/abort tasks (or general high-level commands – see the description of Semi-autonomous Mode of operation in section 5.1.1) from the Control Station. For instance, if a team cannot perform a subtask, it can decide to interrupt it and start the next subtask from a closer point.
The underwater robot MUST remain fully submerged at a depth ≥ 1 m in all tasks. Surfacing at any time will result in termination of the Task Benchmark run except when explicitly stated. In those cases, the underwater robot can emerge for GPS fixes.
The underwater robot cannot communicate via radio link with an operator neither emerge to use GPS, unless explicitly stated in this rules document.
No physical link is admitted (wires or cables) to communicate/tele-operate the robots.

6.1.3 Start Procedure

Each team has to name one or two technical assistants and an operator. For aerial robots, each team has to identify also the team safety pilot.

Each team will be allocated a time slot for their participation in the competition. A schematic map of the building and waypoints will be provided on-site, prior to the start of the TBM.

Each robot must be enabled for operation within 5 minutes after entering the start area. Robots must be prepared and waiting in the start area up to 10 minutes before the task benchmark starts. At the designated starting time the robot must be waiting in the start area, readily prepared for operation. As soon as an ERL Emergency official (referee) gives the departure signal, the robot can depart from the start point.

During the departure procedure, the robot(s) will be put into operation and prepared for the start. All required material has to start being moved by the team from the unload location to the start area or deployment area (marine robots) 30 minutes before their allocated time slot. A team must place its robot in the start area prior to enabling it for operation. Note that there will be no support at this location (no table, no chair, no electricity, etc.). The support will be located at the control station, near the starting points of the land and aerial robots and the deployment point of the marine robots.

As an example, if your time slot is at 10:00, you should start moving your robots and materials at 9:30. At 9:50, your robot(s) should be in the start point prepared and waiting for the referees' signal. At 9:55, the robots should be enabled for operation. At 10:00, referees will give the start signal and the TBM will start. Not all the robots need to start after the referees' signal, as it will be the decision of the team when they enter into action. However, all the robots participating in that task benchmark must be prepared and waiting in the starting points. The team will have first to communicate to the referee that they want to start and when given the approval, they will have 5 minutes to enable the robots before the referee gives the start.

Teams must respect their official time slot and be ready to start on time. If there is a delay in the starting time of the TBM, the referees may decide, depending on the factors that have caused the delay, to reallocate time-slots or to disqualify the team for that task benchmark trial.

The technical assistants are responsible for operating the emergency stop systems (i.e. E-stop for land robots). Thus, he/she will leave the starting area (and the control station) and will accompany the robot as soon as the start signal has been given. In the case of aerial robots, ERL Emergency safety pilots will be in charge of operating the emergency stop system. The whole trial will be supervised by the ERL Emergency officials.

Only the referees can signal the start of operations. Only competition officials may deploy and recover the robots (marine robots) or supervise the robot deployment/recovery by teams (ground robots). This is to prevent unsafe actions in an attempt to speed the deployment and recovery processes.

6.1.4 On Route Procedure

While a robot is on the route, the Technical Committee might follow it.

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 robot must avoid collisions with any obstacles, moving or static, on the route. The organisers will place obstacles along the route (before the TBM run) to test obstacle avoidance capabilities. Incidental or non-damaging contact with obstacles may not result in the abortion of the run.

During the TBM there will be no communication between the operator and other individuals, especially other team members, with the exception of communication with:

- ERL Emergency officials.
- Technical assistants on the rubber boat
- The team safety pilot.
- Other team's operators (one per domain), i.e. to indicate what his/her robot(s) has detected, mapped, etc.

Apart from the technical assistant, no team member will physically intervene in any aspect of robot operation or physically participate in robot tracking from the time the robot clears the start area until it returns to the team. A robot returns to the team after the Task Benchmark is aborted or after the robot returns to the respective starting point or designated landing area.

The aerial robots must take off and land at the specified areas (the landing area might be different from the take-off area).

During the TBM, refuelling or charging batteries of the ground and marine vehicles is not permitted. Teams are allowed to change batteries or refuel the combustion engines of aerial robots. The time-clock will not be stopped for this, so any penalty will be on the time lost, not on the points. Aerial teams will only be able to change batteries and/or refuel combustion engines at the take-off and landing areas which will also be used as a pit stop area.

Apart from designated viewing areas, teams may not operate any robot or position any team members on or near a route at any time during the ERL Emergency Service Robots event.

If the ERL Emergency officials determine that letting a robot proceed on the route would hinder subsequent ERL Emergency operations, the TBM can be aborted. The team may apply for a second attempt.

A team may perform multiple runs during the time-slot operations period. A trial is an attempt at completing one TBM. A trial is a set of runs during a time-slot.

Specific regulations for marine vehicles on route

The underwater robot can surface up to a maximum number of times defined per each Task Benchmark to communicate with the Control Station in the competition arena, but without the possibility of navigating while on the surface. In this case, it can communicate via radio with other robots/Control Station receiving direct commands from the operator.

6.1.5 Re-start Procedure

A team can request a restart per domain at any time during a run. There is not a maximum of restarts. In this case, the team is allowed to bring the robot outside the competition arena and perform any operation on the robot. It is not allowed to work on the robot within the competition area (unless the robot is stuck in a position that requires intervention on-site; this will be decided by the Technical Committee).

Whenever the robot is ready, it can re-enter the competition area and start a new run from the beginning. In case of having more than one robot per domain, all the robots of the domain that asks for a restart will start a new run from the beginning. No penalties will be given for a restart, <u>but any score achieved in the domain (by any of the robots of that domain) before the restart will be cancelled, and the time will not be stopped during the restart procedure</u>.

6.1.6 Exit Procedure

One trial ends when any of the following occur:

- The time-slot ends.
- Referees order the end of a trial.
- The Team Leader requests the end of the trial.

The same applies to each run that is part of a trial.

After the end of the time-slot, and thus the trial, as communicated by the referee(s), the robots must quickly exit the competition areas from the designated exits. The team members are allowed to manually drive, push or lift the robot. A penalty (in terms of an absolute negative score) will be given to the team if the robots are not outside the arenas 15 minutes after the end of the time-slot.

6.1.7 Abortion Procedure

A robot must not continue on the route if the TBM is aborted. The organisers will coordinate the recovery of the robot or robots together with the team. Teams may enter the competition area only if directed by the Technical Committee.

An abortion procedure can be done at any point during a run.

A team may decide to abort one domain and continue the run with the rest of the domains. The referees will inform the operators of the domain that has aborted the run.

If a team aborts a trial (after aborting several runs) in one or more domains because of technical difficulties, the Technical Committee may allow repeating it, depending on available start slots.

6.2 TBM-1 Yacht accident in the harbour (Land+Sea)

This two-domain task benchmark is focused on acquiring knowledge about the environment and its explicit representation, and to cooperate between domains to search for the missing workers and assist them. The ground and underwater robots are required to understand the changes in the environment and interact with it either through cooperation between them (autonomous robot-robot) or their operators (human-robot interaction) or with a mixed approach.

Note: A minimum of one land robot and one underwater robot is required to participate in this task.

6.2.1 Task Description TBM-1

An accident occurs in the harbour. A yacht is arriving into the harbour but something goes wrong and it damages a gas pipeline. The pipeline starts leaking and in a few moments, an explosion takes place. The massive explosion affects also the building containing the pipeline section on land and people that were in the docks area are dispersed. There is a need for quick and effective intervention. The emergency response team arrives soon but members of the response team must maintain a safe distance from the fire. For this reason, the use of robotic vehicles is essential. A robotics team composed of land (UGV) and underwater robots (AUV) is ready to intervene.

It is time for the emergency teams to act. The priorities are to discover missing people, if the dock area has suffered any serious damage, check which pipe is on fire and put off the fire. It is known that a certain number of people were in the dock area at that time. During a head-count, it is discovered that two workers are missing: one in the land area and one at sea. The robots have to search for these workers, find them as soon as possible and deploy an emergency kit to the one on land. At the same time, the robots must check any damage that the explosion may have caused to the dock wall or the building and which pipes are on fire. In case any pipe on land is on fire, it has to be sealed by closing the corresponding valves inside the building and the fire has to be put off. Nevertheless, special care has to be taken as closing the wrong valves will not help the end of the fire.

This task benchmark comprises three missions' goals:

- **Mission-A**: Search for missing workers.
- **Mission-B**: Reconnaissance and environmental survey.
- **Mission-C:** Pipe inspection and stopping the fire.

A map showing the outdoor and sea areas of this Task Benchmark is shown in Figure 21. This figure shows the two indicative locations of the missing workers (on land outdoors, and underwater).

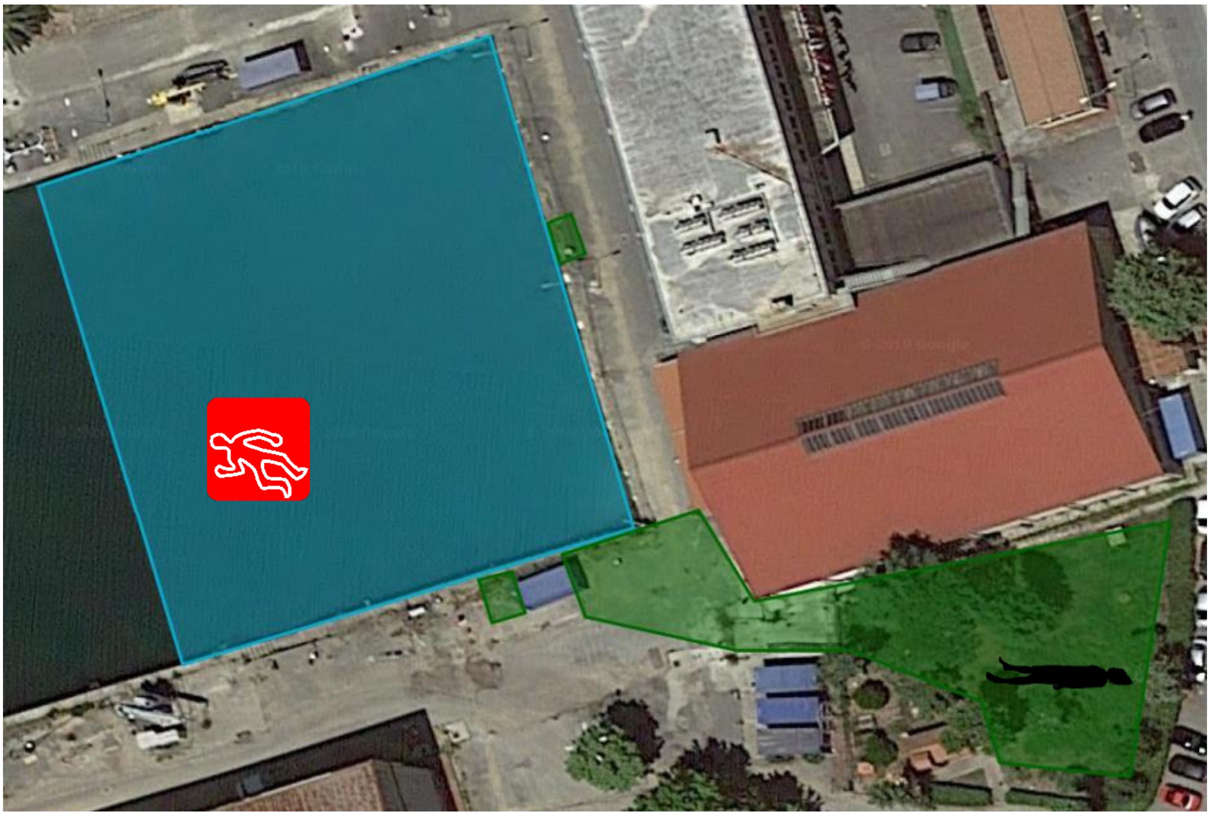

Figure 21. Missing people approximate locations (Source: ERL Emergency and https://openclipart.org/image/2400px/svg_to_png/128233/body.png)

6.2.2 Feature Variation TBM-1

The following elements may feature a variation and be rearranged before the run:

- Missing workers.
- Blocked/unblocked entrances.
- Outdoor/Indoor Obstacles
- Damages on the dock wall.
- Damages on the building
- Pipe fire on land
- Pipe fire underwater

6.2.3 Input Provided TBM-1

The teams will be able to test in the competition areas during the set-up days in dedicated time slots given by the organisation committee. Teams cannot test in the competition arenas without authorisation of the Technical Committee.

A schematic map of the building will be given to the teams at the beginning of the task. However, it will not have all detailed dimensions and may not be up to date. Entrances, corridors, and rooms are shown on the map. Teams need to be aware that the explosion has probably damaged part of the external and internal structure of the building, blocking some paths and entrances. The map will indicate the Area 1 and Area 2 that must be inspected.

A set of waypoints the ground robots must reach will be given to teams during the competition days. An example is shown in Figure 22

Figure 22. Example of the path consisted of the waypoints that robots must reach. (Source: Google Maps)

The points that define the walled search areas described in the achievements will be given to teams during the competition days.

The Objects of Potential Interest (OPIs) are summed up in the following chart:

Underwater	Outdoor	Indoor
1 fire marker 1 gate (made of 2 orange buoys) 2 pipe structures 1 acoustic pinger 1 missing worker 2 sets of obstacles (made of 2 orange buoys)	X Blocked entrances. 1 unblocked entrance. Y Damages on the building. 1 missing worker. 1 first-aid kit.	1 Pipe on fire on land. 3 Pipes not on fire. 1 correct valve (of four valves) 1 canister 1 fire marker Z Damages on the building

The exact location of the objects is unknown. These obstacles are fixed and will not be changed between trials. Teams can expect an unknown number of obstacles outdoors and indoors. These obstacles are fixed and will not be changed between trials. The number of damages and blocked entrances will be defined later.

Information and images on the OPIs can be found in Appendix I of this Rulebook.

6.2.4 Expected Robot Behaviour or Output TBM-1

Mission-A: Search for missing workers.

Search for 2 workers that are missing in the area around the dock. The two missing workers must be found as quickly as possible.

One worker is missing in the area around the building and another is known to have fallen in the water as a result of the accident and it is expected to be trapped underwater. The worker on land found during the first 30 minutes of the Task Benchmark has a good chance to be rescued alive. The worker underwater is considered a casualty, but his/her position needs to be known for emergency brigades to recover the body.

Once found, the missing worker on land will require immediate first-aid assistance. For this reason, the rubble trapping him/her must be removed and he/she must be provided with a first-aid kit as soon as possible.

Mission-B: Reconnaissance and environmental survey

The robots must reconnoitre the area in order to provide situational awareness to the emergency response team. For this purpose, they must create a map of the building and its surrounding area and a map of the area of the submerged pipes. Robots need to find a safe path to the building, in which the valves and pipes are located. The marine robot has to inspect the underwater pipe area to find a fire and to localise an acoustic pinger which is signalling a leak from one pipe. The robots must create a 2D and/or 3D map of the submerged pipe structures.

For the ground robot to enter the building, an unobstructed entrance must be found first as well as a safe and unblocked path from the starting position of the ground robot. Robots will have to create a floor (2D) or 3D map of the indoor part of the building as well as a 2D or 3D map of the outdoor area surrounding the building. Underwater robots will have to create accurate representations of the damage on the vertical wall of the dock, in order to obtain valuable information for the emergency response team, such as the position and the size or height of the damage and the number drawn on it.

Mission-C: Pipe inspection and stopping the fire

In the port, pipelines are transporting natural gas. After the accident, these pipes might have been damaged and on fire. The valves that close and open the pipes are located inside the building.

If any fire is detected underwater, the robots must stop it by closing the correct valves inside the building. Special care has to be taken as closing a wrong valve may cause unexpected events. The damage to the pipe has caused a fire also inside the building and the land robot has to stop it by pouring water.

Note: there is no real fire, it will be simulated with a marker.

Expected output

The output provided by the teams is a set of files that must be saved in a USB stick given to the teams before the test. The USB stick will be formatted with the NTFS file system and all the files should be saved in a folder with the name of the team.

The following information will be evaluated:

- Built map of the vertical dock wall with marker width and heights required.
- Built maps with OPI marks and positions as well as the path to the building room (and inside)
- OPI images, class and associated positions.
- The robot communication data
- Timing data

Vehicle Navigation Data: this must be in KML (Keyhole Markup Language) format and has the following requirements

- The data sampling frequency: 1 Hz, i.e. a data sample every one second.
- Time: UTC
- Position: Latitude, Longitude (in decimal degrees)
- Heading: (in degrees)
- Depth: Sea domains (in meters)

Mission Status Data: This gives the information related to the status of the mission undertaken must be in KML format with the following requirements:

- Subtask undertaken: Text
- Key decision message and event message (e.g. the detection of an OPI has to be recorded here): Text
- Time: UTC. Should be a series of Time corresponding to a series of events, e.g. the subtask starts, the subtask ends, start to close a valve, finish closing the valve, etc. Time can be used as one of the measurements for Functionality Benchmarking.

Each team will produce a log file with the mission data. **The data must be provided to the referees 90 min for this Task Benchmarks from the end of the team's time- slo**t. The log file(s) has/have to clearly show the actions of the robot(s) during the tasks.

Map Information: this must include the following information and formats:

- The map file: KML format (Keyhole Markup Language) or KMZ files
- Abstract Level information: OPIs, Features. This should be integrated into the KML/KMZ file
- 2D/3D map in raster or vector format with geo-reference information for high bandwidth data.

Note: Maps will be accepted in different formats. Files must be provided in accessible formats, either image files or 3D maps accessible through open software such as MeshLab, which support a large number of formats and are usually not unfamiliar to ROS users (if using PCD format, it can be converted to PLY format using PCL's "pcd2ply" utility). However, for benchmark purposes we would appreciate that the teams try to submit the map in KML format. A KML tutorial can be found in the following link: https://developers.google.com/kml/documentation/kml_tut

Vertical Map Information: this must include the following information and formats:

- File with the name 'vertical_map' containing the built map of the designated vertical wall. If the map is 2D, an image in a standard format must be provided (e.g. JPEG, PNG…), and a scale factor must be specified within the same image or inside a text file with the same filename as the map image ('vertical_map.txt'). If the map is 3D, the file type must be readily accessible using open tools such as MeshLab or CloudCompare.
- Text file with the name 'vertical_wall.txt' containing the five requested measurements in millimetres (except for GPS coordinates), each one in a different text line (Latitude, Longitude, width of the marker, height of the marker, depth of the bottom side of the marker).

Object Recognition Information: this information must be stored in KML format and include the following:

- Target ID: Text/Number

- Target position (Latitude, Longitude, Depth)
- Target image: image files (JPEG, PNG, BMP, PPM).

Robot-Robot communication data: the log of the message exchanged (with timing information) has to be provided. The teams must provide the Technical Committee a brief description of the communication protocol used between domains until the day before the run. The teams need to let the referees know before the run if there is going to be robot-robot communication or not. If there is, the team will have to specify when (during which tasks) and between which robots, and provide logs of the messages exchanged.

All data requirements have to be met (see data exception regarding maps format). Submitted data that do not comply with the formats specified will not be accepted.

All data submitted will be used for the Functionality Benchmarking when required and as shared data, as planned for the ERL Emergency Service Robots competition.

6.2.5 Procedures and Rules TBM-1

Task Benchmark 1 is successfully met if all the subtasks are accomplished within the Task Benchmark time. How teams decide to tackle the Task Benchmark is their decision. The starting locations will be given to the teams. Robots do not need to start at the same time. Teams are free to decide if they want to tackle the mission goals in parallel or sequence and which order. Not all of these decisions need to be communicated to the judges in advance and may be taken and changed during the run[1]. The success of the team might thus not only depend on their robots' performance but also their team strategy.

How many and which type of robots to deploy and how and when the tasks are going to be done is a decision of the team (as long as they do not exceed the limits established in this section).

Robots may communicate directly or via their operators at the control station (e.g. to know if an area has already been explored and if all workers have been found).

<u>Mission-A: Search for missing workers.</u>

The workers will be represented by mannequins. There will be a worker outside the building and one underwater. The workers will be located in a supine or prone position. The mannequins will not move during the mission.

The ground robot will have to find the mannequin in the outdoor area and remove the rubble that covers it. The robot must leave the first-aid kit within a radius of 1 metre within the mannequin.

[1] Although teams will be asked to advise referees of changes of strategy, as the competition unfolds.

The first-aid kit will be a commercial one with dimensions smaller than 30x30x30 cm and weighs less than 1Kg. It will be made from a material that will not break if dropped to the floor. The kit will also have a handle or handling system (made of soft or hard material). It is possible for teams to design their own handling system to be applied or adjusted to the object.

The underwater robot must look for the worker underwater. For emergency brigades to be able to recover the body is necessary to know his/her location and position. The ground area where the mannequin will be located is shown in Figure 23. Underwater, the mannequin can be located in any sector except 2.

<u>Mission-B: Reconnaissance and environmental survey</u>

From the starting points, inspect and map the area (Structures area). Teams must find an unblocked entrance that can be used by a ground robot to enter the building. Different markers will be used for indicating blocked and unblocked entrances.

A ground robot must then enter the building and reach the pipes area. The building must also be mapped from the inside. There will be unobstructed paths (at least 70 cm wide) to the pipes area from the entrance of the building.

Figure 23. Outdoor area to be mapped during the TBM-1 mission-B.

The underwater robot must inspect the underwater pipes area and find the acoustic pinger using acoustics and/or underwater imagery. It will have to create a 2D or 3D optical/sonar map of the underwater structures, and localise the underwater obstacles.

Mission-C: Pipe inspection and stopping the leak

There will be 4 pipe sections on land inside the building and 4 pipe sections underwater. Each of the 4 pipe sections on land will be logically connected to one of the underwater pipe sections. There will be also two piping assemblies underwater. Two of the underwater pipe sections will be connected to one of these assemblies while the other two will be connected to the other assembly. In the building, there will be 4 sets of valves, each of them logically associated with one of the pipes. Each set is identified by one ERICard positioned on the wall behind the valves.

The piping sections will consist of cylindrical yellow shapes. The pipe sections and valves will not be moved during the competition (i.e. they will be fixed). Their positions will also determine the correspondence between valves and pipes. A schematic map will be provided to the teams indicating this correspondence. As an example, consider the correspondence shown in Figure 24. If a team finds that the pipe on fire underwater is Pipe 2 they know that the valve to be closed is number 2. To identify pipe 2, teams have to localise the OPI (red marker) that marks the Pipe 2. With this information, the land robot can look for valve 2 in the building and close it. Closing more than one wrong valve on land will incur in a disqualifying behaviour.

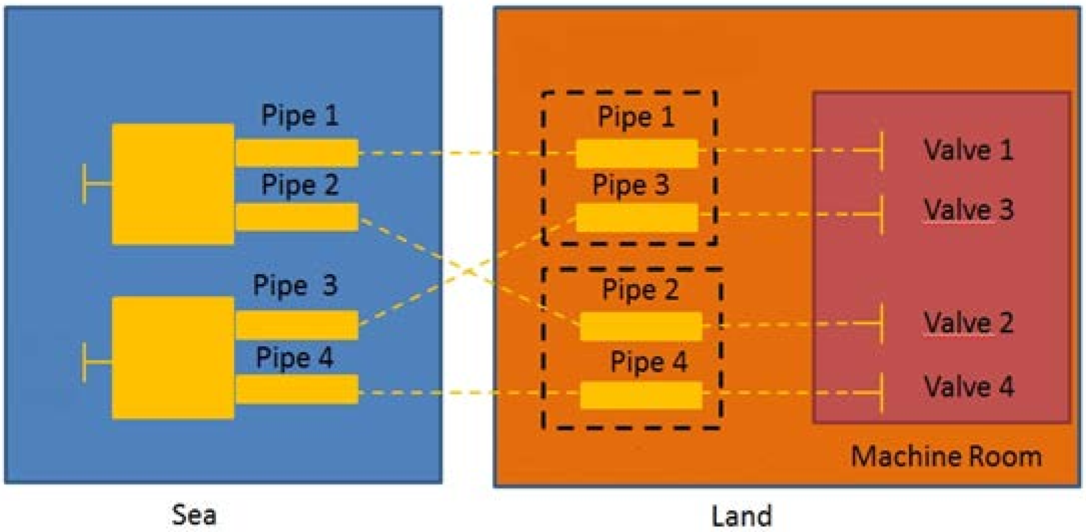

Figure 24. Schematic representation of the distribution of piping sections and valves and their correspondence. (Source: ERL Emergency).

Land robots have also to localise a fire inside the building in the pipe area finding the fire marker inside the building (which might be next to a different pipe as the fire has spread). The ground robot must also carry a canister of water to fire place to stop it.

Different markers will be used for representing fire on land and underwater. There will be different OPIs and markers, each team will be assigned randomly a set of them. *Note: there will be no real fire during the competition.*

Robots may communicate directly or via their operators at the control station to determine which valves must be closed. Only robot-robot communication will be considered as an achievement.

The robots must find the OPIs that mark blocked/unblocked entrances, damage to the wall (both on the building and on the dock wall), the missing worker, etc. When an OPI is found, images must be acquired and the positions of the OPIs with respect to the map(s) built must also be provided. No recovery of OPIs is required.

The metric map will not be evaluated specifically in this Task Benchmark; it will be evaluated in the Functionality Benchmarks. However, a poor quality metric map or an out-of-date map can affect the evaluation of the position of the objects selected for the task or the path the robot has to follow. The metric map must contain the information requested and be legible by an end-user/external person.

The Task Benchmark ends when the robots accomplished all the requested achievements or when reaching the time limit (**Time limit: 90 min**), whatever occurs first. No manual intervention is allowed to save files on the USB stick during the run.

The first collection of data must be provided to the Technical Committee when the team's time-slot just finishes, this data will allow referees to check if a task has been performed autonomously or not. Teams must provide the processed data (i.e. 2D/3D maps, etc.) to the referees **within 90 min** of the end of the team's time-slot.

6.2.6 Acquisition of Benchmarking Data TBM-1

During this Task Benchmarks, the Internal Data defined in Section 6.2.4 will be collected for the Functionality Benchmarks.

6.2.7 Scoring and Ranking TBM-1

The set A of achievements (in no specific order) for this task are:

Set A1: Outdoors

- A ground robot reaches WP1 with a precision of 3 m avoiding obstacles along the route.
- A ground robot reaches autonomously WP2 with a precision of 3 m avoiding obstacles along the route.
- Within the first 30 minutes of the start of the run, a robot reports correct location (within a radius of 5 m) of the missing worker outside the building
- The missing worker is detected in real-time in an automatic way.
- A ground robot removes the rubble from the missing worker (1 per each rubble piece).
- A ground robot deploys the first-aid kit within a radius of 1 m from the worker found outside the building.
- Robots recognise the damages in the area outside the building (1 achievement for damage – each damage can only be scored once).

- A robot localises the unobstructed entrance in real-time in an automatic way.

- Robots localise the obstructed entrances (1 achievement per entrance – each entrance can only be scored once).
- Robots build an outdoor map of the outdoor area with OPIs (North-West side)
- Robots build an outdoor map of the outdoor area with OPIs (North-East side).
- Robots build an outdoor map of the outdoor area with OPIs (South-West side).
- Robots build an outdoor map of the outdoor area with OPIs (South-East side).

Set A2: Indoors

- A ground robot enters the building.
- The ground robot(s) build a geometric indoor map of the building (Area1). (Use the best map or a combination of ground robots maps).
- The ground robot(s) build a geometric indoor map of the building. (Area2) (Use the best map or a combination of ground robots maps).
- Robots recognise the damages in the area inside the building (1 achievement for damage – each damage can only be scored once).
- The ground robot recognises the ID of the correct set of valves in the machine room.
- The ground robot closes the correct valve. The robot must close one valve of the set autonomously and the other one manually (1 achievement each to be scored only once). The process must be recorded by the on board camera of the robot.
- The ground robot identifies the fire marker.
- The ground robot picks the canister and brings it to the fire area.
- The ground robot drops the canister on the fire marker.

Set A2: Underwater

- The underwater robot provides geo-localised acoustic or optical images of the obstacles (1 per each obstacle).
- The underwater robot passes in between the obstacles without touching them (1 per each pair of obstacles).
- The underwater robot provides geo-localised acoustic or optical images of the gate (1 per each gate buoy).
- The underwater robot passes through the gate without touching it.
- The underwater robot passes through the gate within the first 30 minutes from the start of the run.
- The underwater robot detects (providing images and the position of the centre) the fire marker on the pipe in real-time.
- The underwater robot gives the length of the fire marker on the pipe.
- The underwater robot provides images of the black number stamped on the pipe on fire.
- The underwater robot identifies the number of the pipe on fire (either by its geometric position or detecting the stamped number).
- The underwater robot provides images of the structure sides (North, South, East and West) (1 achievement each).
- The underwater robot provides a 3D reconstruction of the structure (front and rear) (1

achievement per part).
- The underwater robot localises the missing worker underwater within a radius of 5 meters. Provide images and latitude/longitude.
- The underwater robot provides a 3D reconstruction of the worker.
- The underwater robot provides images and the position of the marker in the damaged wall.
- The underwater robot gives the dimensions and geometrical shape of the marker in the damaged wall.
- The underwater robot identifies the number printed in black on the damaged area marker.
- The underwater robot finds the pinger acoustically (e.g. hydrophone).
- The underwater robot finds the pinger with an optical camera or a sonar.

Set A4: Cooperation

- The underwater robot communicates the correct damaged pipe to the ground robot. Directly or through the control station (without human intervention).
- The ground robot receives and decodes the message with the damaged pipe on fire sent directly by the underwater or through the control station.
- The ground robot communicates the correct area with the wall damage to the underwater robot (directly or through the control station without human intervention).
- The underwater robot receives and decodes the message with the area where the wall damage has occurred sent by the ground robot directly or through the control station.

Set A5: General

- The ground robots return to the landing area all the tasks have been done.
- The underwater robot surfaces in a controlled way once all the tasks have been done.
- Benchmarking data is delivered appropriately (time and format)
- The ground robot(s) transmits live positions and images/video to the control station during the run.
- The marine robot(s) transmits live positions and images/video to the control station during the run.

The set **PB of penalised behaviour** for this task are:

- The robot needs manual intervention (e.g. a robot gets stuck). Zero intervention is permitted for marine robots and up to a maximum of two interventions are permitted for land robots. Note: when the maximum number of interventions reaches the allowed maximum, the run is considered terminated and a new run is restarted.
- A ground robot leaves the operating area.
- A ground robot hits the obstacles.
- The ground robot changes batteries or is refuelled during the run. Maximum one change/refuel during the run.
- The marine robot needs to change batteries. Only one change permitted.
- The underwater robot surfaces at any point (where GPS fix can be obtained) and re-submerges for the second time for communication (One surfacing is allowed for

communication with the ground robot and a second to finish the mission). When it reaches a maximum of three times, the run is terminated and the team must restart a new run.

Additional penalised behaviours may be identified and added to this list if deemed necessary.

The set **DB of disqualifying behaviours** for this task are:

- A robot damages the competition arena (including obstacles).
- A robot does not conform to safety regulations for the competition.
- A marine robot is tele-operated (except for safety reasons agreed by the technical committee).
- A robot closes more than one wrong valve on land.
- The team does not provide the data after the required time.

Additional disqualifying behaviours may be identified and added to this list if deemed necessary. These sets will be completed in later rule revisions.

6.3 TBM-2 Emergency in a building (Land+Air)

This two-domain task benchmark is focused on acquiring knowledge about the environment and its explicit representation; and to cooperate between domains to search for the missing workers and give them assistance. The ground and aerial robots are required to understand the changes in the environment and interact with it either through cooperation between them (autonomous robot-robot) or their operators (human-robot interaction) or with a mixed approach.

Note: A minimum of one land robot and one aerial robot is required to participate in this task.

6.3.1 Task Description TBM-2

An earthquake has occurred in an industrial area near a factory building. The emergency response team arrives soon but members of the response team must maintain a safe distance from the building. For this reason, the use of robotic vehicles is essential. A robotic team composed of land (UGV) and air robots (UAV) is ready to intervene.

It is time for the emergency teams to act. The priorities are to discover missing people and if the building has suffered any serious damage. It is known that a certain number of people were in the factory at the time of the earthquake. During a head-count, it is discovered that two workers are missing: one inside the building and another one was last seen outside the building. The robots have to search for these workers, find them as soon as possible and deploy an emergency kit to both of them. Besides, the robots must check the state of the building after the earthquake, for which a detailed map of the area is required by the emergency team to assess the safety of the area.

This task benchmark comprises two missions' goals:

- **Mission-A**: Delivery of emergency kits to missing workers.
- **Mission-B**: Mapping for safety assessment of the building.

6.3.2 Feature Variation TBM-2

The following elements may feature a variation and be rearranged before the run:

- Missing workers.
- Outdoor/Indoor Obstacles
- Damages to the building.

6.3.3 Input Provided TBM-2

The teams will be able to test in the competition areas during the set-up days in dedicated time slots given by the organisation committee. <u>Teams cannot test in the competition arenas without authorisation of the Technical Committee.</u>

A schematic map of the building will be given to the teams at the beginning of the task. However, it will not have all detailed dimensions and may not be up to date. Entrances, corridors and rooms are shown on the map. Teams need to be aware that the earthquake has probably damaged part of the external and internal structure of the building, blocking some paths and entrances. The blocked entrances and unblocked entrance are represented by markers, as shown in Section 4.2 and the Appendix. The unblocked entrance is where the robots must enter the building, but in order to exit the indoor space, the robots can use whatever opening they might find.

A set of waypoints (latitude, longitude) that the ground robots must reach will be given to teams during the competition days. Similarly, another set of waypoints (latitude, longitude, altitude) will be specified for aerial robots. An example is shown in Figure 25. Near the waypoints, teams can expect the presence of static obstacles that the robots need to detect and avoid.

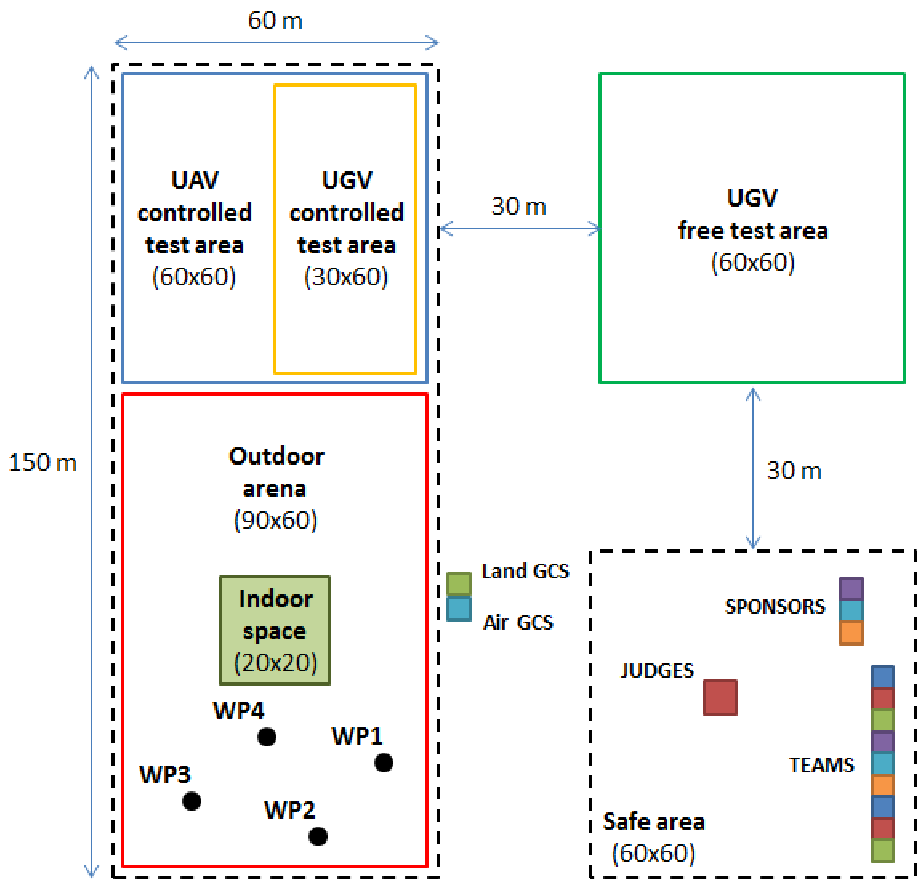

Figure 25. Example of the waypoints that robots must reach.

Teams can expect an unknown number of obstacles outdoors and indoors. These obstacles are fixed and will not be changed between trials.

As long as distance requires, teams will be offered two starting points for both aerial and ground robots, one at the beginning of the track and another one close to the building entrance, so they can focus on the outdoor and/or the indoor achievements, according to their mission preferences.

6.3.4 Expected Robot Behaviour or Output TBM-2

Mission-A: Delivery of emergency kits to missing workers.

Search for 2 workers that are missing in the area around the building. The two missing workers must be found as quickly as possible.

One worker is missing in the area around the building and another is stuck inside the building. Both workers have a good chance to be rescued alive if they are found during the first 30 minutes of the Task Benchmark.

Once found, the missing workers will require immediate first-aid assistance. For this reason, they must be provided with a first-aid kit as soon as possible.

Mission-B: Mapping for safety assessment of the building

The robots must reconnoitre the area in order to provide situational awareness to the emergency response team. For this purpose, the robots must find damage caused to the building, as well as create an indoor 2D and/or 3D map of the building.

Both ground and air robots need to enter the building after finding a safe and unobstructed path from the starting position, and an unblocked entrance to the building itself. Robots will have to create a floor (2D) or 3D map of the indoor part of the building.

Expected output

The output provided by the teams is a set of files that must be saved in a USB stick given to the teams before the test. The USB stick will be formatted with the NTFS file system and all the files should be saved in a folder with the name of the team.

Data must be provided to the referees 60 min from the end of the team's time-slot.

Vehicle Navigation Data: this must be in KML (Keyhole Markup Language) format and has the following requirements

- The data sampling frequency: 1 Hz, i.e. a data sample every one second.
- Time: UTC
- Position: Latitude, Longitude (in decimal degrees)
- Heading: (in degrees)

Mission Status Data: This gives the information related to the status of the mission undertaken must be in KML format with the following requirements:

- Subtask undertaken: Text
- Key decision message and event message (e.g. the detection of an OPI has to be recorded here): Text
- Time: UTC. Should be a series of Time corresponding to a series of events, e.g. the subtask starts, the subtask ends, start to close a valve, finish closing the valve, etc. Time can be used as one of the measurements for Functionality Benchmarking.

Each team will produce a log file with the mission data. The log file(s) has/have to clearly show the actions of the robot(s) during the tasks.

Map Information: this must include the following information and formats:

- The map file: KML format (Keyhole Markup Language) or KMZ files
- Abstract Level information: OPIs, Features. This should be integrated into the KML/KMZ file
- 2D/3D map in raster or vector format with geo-reference information for high bandwidth data.

Note: Maps will be accepted in different formats. Files must be provided in accessible formats, either image files or 3D maps accessible through open software such as MeshLab, which support a large number of formats and are usually not unfamiliar to ROS users (if using PCD format, it can be converted to PLY format using PCL's "pcd2ply" utility). However, for benchmark purposes we would appreciate that the teams try to submit the map in KML format. A KML tutorial can be found in the following link: https://developers.google.com/kml/documentation/kml_tut

Object Recognition Information: blocked/unblocked entrances, damages on the building and missing workers. This information must be stored in KML format and include the following:

- Target ID: Text/Number
- Target position (Latitude, Longitude)
- Target image: image files (JPEG, PNG, BMP, PPM).

Robot-Robot communication data: the log of the message exchanged (with timing information) has to be provided. The teams must provide the Technical Committee a brief description of the communication protocol used between domains until the day before the run. The teams need to let the referees know before the run if there is going to be robot-robot communication or not. If there is, the team will have to specify when (during which tasks) and between which robots, and provide logs of the messages exchanged.

All data requirements have to be met (see data exception regarding maps format). Submitted data that do not comply with the formats specified will not be accepted.

All data submitted will be used for the Functionality Benchmarking when required and as shared data, as planned for the ERL Emergency Service Robots competition.

6.3.5 Procedures and Rules TBM-2

Task Benchmark 2 is successfully met if all the subtasks are accomplished within the Task Benchmark time. How teams decide to tackle the Task Benchmark is their decision. The starting locations will be given to the teams. Robots do not need to start at the same time. Teams are free to decide if they want to tackle the mission goals in parallel or sequence and which order. Not all of these decisions need to be communicated to the judges in advance and may be taken and changed during the run (although teams will be asked to advise referees of changes of strategy, as the competition unfolds). The success of the team might thus not only depend on their robots' performance but also their team strategy.

How many and which type of robots to deploy and how and when the tasks are going to be done is a decision of the team (as long as they do not exceed the limits established in this section).

Robots may communicate directly or via their operators at the control station (e.g. to know if an area has already been explored and if all workers have been found).

Mission-A: Delivery of emergency kits to missing workers.

The workers will be represented by mannequins. There will be a worker outside the building within the competition arena and another one inside the building. The workers will be located in a supine or prone position. The mannequins will not move during the mission.

The ground robot will have to find the two mannequins, outdoors and indoors, and must deliver the first-aid kit to each mannequin within a radius of 1 metre.

The aerial robot will have to find the two mannequins, outdoors and indoors, and must deliver the first-aid kit to each mannequin within a radius of 2 metres.

The first-aid kit will be a commercial one with dimensions smaller than 30x30x30 cm and weighs less than 0.5Kg. It will be made from a material that will not break if dropped to the floor. The kit will also have a handle or handling system (made of soft or hard material). It is possible for teams to design their own handling system to be applied or adjusted to the object.

Mission-B: Mapping for safety assessment of the building

From the starting points, robots must inspect and map the building indoors. Robots must find damage caused to the building and surroundings, as well as find a suitable entrance that can be used to enter the building.

Safe paths from the starting points of both ground and air robots must be found, as well as obstacle detection and avoidance of the obstacles inside the building.

The building will only have one level, i.e. only the ground floor must be inspected.

6.3.6 Acquisition of Benchmarking Data TBM-2

During this Task Benchmarks, the Internal Data defined in Section 6.3.4 will be collected for the Functionality Benchmarks.

6.3.7 Scoring and Ranking TBM-2

The set A of achievements (in no specific order) for this task are:

Set A1: Outdoors

- An aerial robot reaches WP1 within 3 m avoiding obstacles along the route.
- An aerial robot autonomously avoids obstacle 1.
- An aerial robot reaches WP2 within 3 m avoiding obstacles along the route.
- An aerial robot autonomously avoids obstacle 2.
- An aerial robot reaches WP3 within 3 m avoiding obstacles along the route.
- An aerial robot autonomously avoids obstacle 3.
- A ground robot reaches WP1 within 3 m avoiding obstacles along the route.
- A ground robot reaches autonomously WP2 within 3 m avoiding obstacles along the route.
- A ground robot reaches autonomously WP3 within 3 m avoiding obstacles along the route.

- Within the first 30 minutes of the start of the run, a robot reports the correct location (within a radius of 5 m) of the missing worker outside the building.
- The missing worker is detected by the robot in real-time in an automatic way.
- An aerial robot deploys the first-aid kit within a radius of 2 m from the worker found outside the building.
- A ground robot deploys the first-aid kit within a radius of 1 m from the worker found outside the building.
- Robots recognise the damages in the area outside the building (1 achievement per damage – each damage can only be scored once).
- A robot localises the unobstructed entrance in real-time in an automatic way.
- Robots localise the obstructed entrances (1 achievement per entrance – each entrance can only be scored once).

Set A2: Indoors

- A ground robot enters the building through the unobstructed entrance.
- An aerial robot enters the building through the unobstructed entrance.
- The ground robot enters the building autonomously through the unobstructed entrance after completing the outdoor achievements.
- The aerial robot enters the building autonomously through the unobstructed entrance after completing the outdoor achievements.
- The ground robot(s) build a geometric indoor map of the building (use the best map or a combination of ground robot maps).
- The ground robot builds the map on-board during the flight (the map must be shown to the referees just after the run finishes).
- The aerial robot builds a geometric indoor map of the building.
- The aerial robot builds the map on-board during the flight (the map must be shown to the referees just after the flight finishes).
- Robots recognise the damages in the area inside the building (1 achievement per damage – each damage can only be scored once).
- Within the first 30 minutes of the start of the run, a robot reports the correct location (within a radius of 5 m) of the missing worker inside the building.
- The missing worker is detected by the robot in real-time in an automatic way.
- An aerial robot deploys the first-aid kit within a radius of 2 m from the worker found inside the building.
- A ground robot deploys the first-aid kit within a radius of 1 m from the worker found inside the building.

Set A3: General

- The ground robots return to the starting area once all the tasks have been done.
- The aerial robot returns to the take-off/landing area once all the tasks have been done.
- The ground robot transmits live positions and images/video to the control station during the run.
- The aerial robot transmits live positions and images/video to the control station during the run.

The set **PB of penalised behaviour** for this task are:

- The robot needs manual intervention (e.g. a robot gets stuck and needs to be physically picked up; this does not apply to manual teleoperation mode). A maximum of one intervention is permitted for aerial robots. A maximum of two interventions is permitted for land robots. Note: when the maximum number of interventions reaches the allowed maximum, the run is considered terminated and a new run is restarted.
- A ground robot leaves the operating area.
- A ground robot hits the obstacles.
- The ground robot changes batteries or is refuelled during the run. Maximum one change/refuel during the run.

Additional penalised behaviours may be identified and added to this list if deemed necessary.

The set **DB of disqualifying behaviours** for this task are:

- A robot damages the competition arena (including obstacles).
- A robot does not conform to safety regulations for the competition.
- The aerial robot leaves the flight volumes defined by the organisation.
- The team does not provide the data after the required time.

Additional disqualifying behaviours may be identified and added to this list if deemed necessary. These sets will be completed in later rule revisions.

7. Functionality Benchmarks

In the current competition plan, the Functionality Benchmarks scenarios are not designed separately to evaluate individual functionalities. Instead, they are implemented in the Task Benchmarks, so the data required for the Functionality Benchmarks will be collected during the task benchmark trials mentioned in each case. The Functionality Benchmarks will be post-processed right after the competition.

This section defines the Functionality Benchmarks for ERL Emergency Service Robots based on these six aspects:

- FBM-1: 2D Mapping (Land)
- FBM-2: Mapping (Air)
- FBM-3: Object Recognition (Land)
- FBM-4: Object Recognition (Sea)
- FBM-5: Object Recognition (Air)
- FBM-6: Vertical Wall Mapping (Sea)

7.1 FBM-1: 2D Mapping Functionality (Land)

7.1.1 Functionality Description FBM-1

This functionality benchmark measures a robot's ability to explore (cover) the 2D area and, while doing so, visit a number of waypoints. This FBM applies to ground robots only. It will be calculated from data collected in TBM-1 and TBM-2.

7.1.2 Feature Variation FBM-1

The variation space for this Functionality Benchmark is as described in TBM-1 and TBM-2.

7.1.3 Input Provided FBM-1

Teams will be provided with GPS coordinates of the waypoints, together with the boundaries of the search areas (indoor and outdoor) during the competition. See the figure below for an example with 2 waypoints (WP1… WP4) and 4 points (C1 … C4) marking the corners of a search area.

Figure 26. Example of waypoints

7.1.4 Expected Robot Behaviour or Output FBM-1

The robots will navigate through the 2D search and rescue area, via the waypoints provided, searching for Objects of Potential Interest (OPIs) (see for example FBM-3).

Each team must provide a set of files saved on the USB stick given to teams before the execution of TBM-1 or TBM-2. The USB stick will be formatted with the NTFS file system and all the files must be saved in a folder with the name of the team.

The following information must be provided:

Vehicle Navigation (Coverage) Data: this must be in KML (Keyhole Markup Language) format and has the following requirements:

- Data sampling frequency: 1 Hz, i.e. a data sample every one second.
- Time: UTC
- Position: Latitude, Longitude (in decimal degrees)

- Heading: in degrees
- Altitude: in meters

Waypoint Data: this must be in KML format – as a KML <placemark> - and include the following:

- Waypoint ID: text (i.e. WP1, WP2, etc.)
- Waypoint position: Latitude, Longitude (in decimal degrees)

Map Information: map of the area to be surveyed produced by a robot. Maps will be accepted in different formats. Files must be provided in accessible formats, either image files or 3D maps accessible through open software such as MeshLab, which support a large number of formats and are usually not unfamiliar to ROS users.

Each team will produce a log file with the mission data. The log file(s) must clearly show the actions of robots during the task.

All data requirements have to be met (see data exception regarding maps format). Submitted data that do not comply with the formats specified will not be accepted.

Data must be provided to the referees 60 minutes after the end of the team's time-slot.

7.1.5 Procedures and Rules FBM-1

As Functionality Benchmarks are calculated from data collected during the Task Benchmarks TBM-1 and TBM-2, the applied procedures and rules for FBM-1 are the same as TBM-1 and TBM-2.

7.1.6 Acquisition of Benchmarking Data FBM-1

During the execution of the Functionality Benchmark, the following internal data will be collected:

- The GPS coordinates of the waypoints visited by the robot(s), and
- The path(s) followed by the robot(s) showing the actual coverage of the search area.

After the Task Benchmark is completed, and within the time limit specified in the corresponding TBM, the teams must deliver the waypoint and coverage data outlined to the organisers, as a KML file that can be loaded into Google Earth.

7.1.7 Scoring and Ranking FBM-1

The 2D mapping functionality benchmark is defined as follows. The FBM combines two values, map coverage and accuracy:

- **Map Coverage (MC):** This is simply the % of the expected map coverage covered by the robot. Map coverage cannot exceed 100%.
- **Accuracy:** we make use of the Root-Mean-Square Error (RMSE) between real (ground truth) x, y positions and the robot's estimated x, y positions of the same features (i.e. waypoints). This is measured in m, and it is a real value metric – the lower the better.

The Error is the (Euclidean) distance between two waypoints *e*.

$p_i = (x_i, y_i)$

$p_i' = (x'_i, y'_i)$

The error (Euclidian distance) between p_i and p'_i, is

$$e_i^2 = (x_i - x'_i)^2 + (y_i - y'_i)^2 \qquad (1)$$

Thus if we have 3 points, p_1, p_2 and p_3:

$$RMSE = SQRT((e_1^2 + e_2^2 + e_3^2) / 3) \qquad (2)$$

Example (Team A):

Suppose we have 3 features (i.e. waypoints) in the map, and the known (x, y) positions, with reference to a fixed origin or datum point, for these features are, p_1 = (1, 1); p_2 = (2, 4) and p_3 = (4, 4), all in metres. Then the robot, using the same fixed origin, maps the terrain and locates the same three features – perhaps using SLAM or a related approach. The robot's position estimates for these features will be *p'*. Suppose that p'_1 = (0.9, 1.1), p'_2 = (2.05, 3.8) and p'_3 = (4.1, 3.95).

The Root Mean Square Error is calculated using (1) and (2) above, giving an *RMSE* = 0.158m (see table below).

Root Mean Square Error					
	Ground truth p_i		Estimates p_i'		Euclidian distance
i	*x*	*y*	*x*	*y*	e_i
1	1	1	0.9	1.1	0.14
2	2	4	2.05	3.8	0.2

3	4	4	4.1	3.95	0.11
				RMSE	**0.15m**

Note that prior to calculation of the RMSE error values e_i > *MaxError* are capped to *MaxError* and error values e_i < *MinError* are set to zero. In the 2015 euRathlon competition, on which this FBM is based, *MaxError* was set at 15m and *MinError* at 2m, thus any *e* values < 2m were rounded down to zero.

The RMSE is then normalised as follows:

$$MI = (MaxRMSE - RMSE) / MaxRMSE \quad (3)$$

This function normalises *MI* between [0…1]. The value of *MaxRMSE* is based on the maximum value of *RMSE* of all teams competing. In the 2015 euRathlon competition, on which this FBM is based, *MaxRMSE* was set at 6.124 (rounded up to 3 places of decimals).

The 2D coverage FBM-1 in the range [0…1] will be computed using the mean of the metric index *MI* (equation 3) and the Map Coverage *MC*.

$$FBM1 = (MI + MC) / 2 \quad (4)$$

For example, assume that *MaxRMSE* is 4 meters and the map coverage is 75% for team A, the team would score a map coverage FBM-1 of (0.96+0.75)/2 = 0.85.

Teams will be ranked within FBM-1 based on the numerical values calculated by equation 4. In the event that two teams score the same FBM-1, the team with the highest normalised RMSE score *MI* will be ranked highest.

7.2 FBM-2: Mapping Functionality (Air)

7.2.1 Functionality Description FBM-2

This functionality benchmark measures a robot's ability to explore (cover) the competition area and, while doing so, visit a number of waypoints. This FBM applies to air robots only. It will be calculated from data collected in TBM-2.

7.2.2 Feature Variation FBM-2

The variation space for this Functionality Benchmark is as described in TBM-2.

7.2.3 Input Provided FBM-2

Teams will be provided with GPS coordinates of the waypoints, together with the boundaries of the search areas (indoor and outdoor) during the competition.

7.2.4 Expected Robot Behaviour or Output FBM-2

The robots will navigate through the search and rescue area, via the waypoints provided, searching for Objects of Potential Interest (OPIs) (see for example FBM-4).
Each team must provide a set of files saved on the USB stick given to teams before the execution of TBM-2. The USB stick will be formatted with the NTFS file system and all the files must be saved in a folder with the name of the team.

The following information must be provided:

Vehicle Navigation (Coverage) Data: this must be in KML (Keyhole Markup Language) format and has the following requirements:

- Data sampling frequency: 1 Hz, i.e. a data sample every one second.
- Time: UTC
- Position: Latitude, Longitude (in decimal degrees)
- Heading: in degrees
- Altitude: in meters

Waypoint Data: this must be in KML format – as a KML <placemark> - and include the following:

- Waypoint ID: text (i.e. WP1, WP2, etc.)
- Waypoint position: Latitude, Longitude (in decimal degrees)

Map Information: map of the area to be surveyed produced by a robot. Maps will be accepted in different formats. Files must be provided in accessible formats, either image files or 3D maps accessible through open software such as MeshLab, which support a large number of formats and are usually not unfamiliar to ROS users.

Each team will produce a log file with the mission data. The log file(s) must clearly show the actions of robots during the task.

All data requirements have to be met (see data exception regarding maps format). Submitted data that do not comply with the formats specified will not be accepted.

Data must be provided to the referees 60 minutes after the end of the team's time-slot.

7.2.5 Procedures and Rules FBM-2

As Functionality Benchmarks are calculated from data collected during the Task Benchmark TBM-2, the applied procedures and rules for FBM-1 are the same as TBM-2.

7.2.6 Acquisition of Benchmarking Data FBM-2

During the execution of the Functionality Benchmark, the following internal data will be collected:

- The GPS coordinates of the waypoints visited by the robot(s), and
- The path(s) followed by the robot(s) showing the actual coverage of the search area.

After the Task Benchmark is completed, and within the time limit specified in the corresponding TBM, the teams must deliver the waypoint and coverage data outlined to the organisers, as a KML file that can be loaded into Google Earth.

7.2.7 Scoring and Ranking FBM-2

The 2D mapping functionality benchmark is defined as follows. The FBM combines two values, map coverage and accuracy:

- **Map Coverage (MC):** This is simply the % of the expected map coverage covered by the robot. Map coverage cannot exceed 100%.
- **Accuracy:** we make use of the Root-Mean-Square Error (RMSE) between real (ground truth) x, y positions and the robot's estimated x, y positions of the same features (i.e. waypoints). This is measured in m, and it is a real value metric – the lower the better.

The Error is the (Euclidean) distance between two waypoints *e*.

$p_i = (x_i, y_i)$

$p_i' = (x'_i, y'_i)$

The error (Euclidian distance) between p_i and p'_i, is

$$e_i^2 = (x_i - x'_i)^2 + (y_i - y'_i)^2 \qquad (1)$$

Thus if we have 3 points, p_1, p_2 and p_3:

$$RMSE = SQRT((e_1^2 + e_2^2 + e_3^2) / 3) \qquad (2)$$

Example (Team A):

Suppose we have 3 features (i.e. waypoints) in the map, and the known (x, y) positions, with reference to a fixed origin or datum point, for these features are, p_1 = (1, 1); p_2 = (2, 4) and p_3

= (4, 4), all in metres. Then the robot, using the same fixed origin, maps the terrain and locates the same three features – perhaps using SLAM or a related approach. The robot's position estimates for these features will be *p'*. Suppose that p'_1 = (0.9, 1.1), p'_2 = (2.05, 3.8) and p'_3 = (4.1, 3.95).

The Root Mean Square Error is calculated using (1) and (2) above, giving an *RMSE* = 0.158m (see table below).

Root Mean Square Error					
	Ground truth p_i		Estimates p_i'		Euclidian distance
i	*x*	*y*	*x*	*y*	e_i
1	1	1	0.9	1.1	0.14
2	2	4	2.05	3.8	0.2
3	4	4	4.1	3.95	0.11
				RMSE	**0.15m**

Note that prior to calculation of the RMSE error values e_i > *MaxError* are capped to *MaxError* and error values e_i < *MinError* are set to zero. In the 2015 euRathlon competition, on which this FBM is based, *MaxError* was set at 15m and *MinError* at 2m, thus any *e* values < 2m were rounded down to zero.

The RMSE is then normalised as follows:

MI = (MaxRMSE – RMSE) / MaxRMSE (3)

This function normalises *MI* between [0…1]. The value of *MaxRMSE* is based on the maximum value of *RMSE* of all teams competing. In the 2015 euRathlon competition, on which this FBM is based, *MaxRMSE* was set at 6.124 (rounded up to 3 places of decimals).

The 2D coverage FBM-1 in the range [0…1] will be computed using the mean of the metric index *MI* (equation 3) and the Map Coverage *MC*.

FBM1 = (MI + MC) / 2 (4)

For example, assume that *MaxRMSE* is 4 meters and the map coverage is 75% for team A, the team would score a map coverage FBM-1 of (0.96+0.75)/2 = 0.85.

Teams will be ranked within FBM-1 based on the numerical values calculated by equation 4. In the event that two teams score the same FBM-1, the team with the highest normalised RMSE score *MI* will be ranked highest.

7.3 FBM-3: Object Recognition Functionality (Land)

7.3.1 Functionality Description FBM-3

This functionality benchmark has the objective of assessing the capabilities of ground robots in processing sensor data in order to recognise objects. All objects presented to the robots in this functionality benchmark are items that might be found in an outdoor and indoor disaster response environment. The benchmark requires that robots detect Objects of Potential Interest (OPIs) and identify the type of each object found. This FBM applies to ground robots only. It will be calculated from data collected in TBM-1 and TBM-2.

7.3.2 Feature Variation FBM-3

The variation space for this Functionality Benchmark is as described in TBM-1 and TBM-2.

7.3.3 Input Provided FBM-3

The input provided to teams is the set of all OPIs used within the competition: blocked entrances and unblocked entrance, damages on building and missing workers. These are described in Appendix 1. Note that for FBM-3 the underwater OPIs are not applicable.

7.3.4 Expected Robot Behaviours or Output FBM-3

The robots perceive the presence of the specific objects of interest in the environment by making use of its sensors. The Object Recognition here includes object detection (the presence of an object) and recognition that identifies the type of object (e.g. a missing worker, pipe, valve, ERIcard, etc.). The Object Recognition functionality also needs to provide location information of the object, and an image, although this additional information is not needed for the quantitative benchmark but only as confirmation that the correct objects have been found. The location of each object found must be marked on the same KML file provided for FBM-1, together with evidence that the OPI has been recognised (i.e. an image).

Each team must provide a set of files saved on the USB stick given to teams before task TBM-2. The USB stick will be formatted with the NTFS file system and all the files must be saved in a folder with the name of the team.

The following information must be provided:

Vehicle Navigation (Coverage) Data: this must be in KML (Keyhole Markup Language) format and has the following requirements

- The data sampling frequency: 1 Hz, i.e. a data sample every one second.
- Time: UTC
- Position: Latitude, Longitude (in decimal degrees)

- Heading: (in degrees)
- Altitude: Air Domain only (in meters)

Waypoint Data: this must be in KML format - as a KML <placemark> - and include the following:

- Waypoint ID: text (i.e. WP1, WP2 etc.)
- Waypoint position (Latitude, Longitude)

Object Recognition Information: this information must be in KML format - as a KML <placemark> - and include the following:

- Object type: text (types as specified in Appendix 1)
- Object position (Latitude, Longitude)
- Object image: image files (JPEG, PNG, BMP, PPM).

All data requirements have to be met. Submitted data that do not comply with the formats specified will not be accepted.

Each team will produce a log file with the mission data. The log file(s) must clearly show the actions of robots during the task.

The data must be provided to the referees 60 minutes from the end of the team's time- slot.

7.3.5 Procedures and Rules FBM-3

As Functionality Benchmarks are calculated from data collected in the Task Benchmarks, the applied procedures and rules are the ones of the TBM-1 and TBM-2:

7.3.6 Acquisition of Benchmarking Data FBM-3

After the task benchmark is completed, and within the time limit specified in the TBM, the internal data will be collected:

- The location (GPS coordinates) of each OPIs found
- The type of each OPI found (types as defined in Appendix 1), and
- An image (or equivalent scan) of the OPI as confirmation that the OPI was found.

7.3.7 Scoring and Ranking FBM-3

The output of the FBM is (1) object detected and (2) the type of the object.

Inspired by domains of Pattern Recognition and Information Retrieval, several metrics will be used:

- Precision and Recall: Precision is measured as the percentage of correctly recognized objects against all recognized objects which include correct ones and incorrect ones. The

Recall (also known as sensitivity) is measured as the percentage of correctly recognized objects against all objects that could be detected in the scene.

For example, suppose there are 2 missing workers, 4 pipes and 4 ERIcards (8 OPIs in total). If 3 objects are recognized but of these only 2 are correctly recognized, the precision will be 2 / 3 = 66.66%, and the recall will be 2 / 8 = 25%.

Precision can be seen as a measure of exactness or quality, whereas recall is a measure of completeness or quantity.

- F-measure: Both precision and recall are real-valued, the higher the better, but to properly benchmark object recognition we need to consider them together. We use a combined measure, the traditional F-measure or balanced F-score.

  The general form of F measure is

$$F_\beta = \left(1+\beta^2\right)\cdot\frac{precision\cdot recall}{\beta^2\cdot precision + recall} \quad (5)$$

  where β is a non-negative real value.

  The traditional F-measure or balanced F-score (F_1 score) is the harmonic mean of precision and recall. The F_1 measure will be used here, i.e. β = 1.

  For the example given above, the F_1 measure would be (from equation 5) 2*(0.66 * 0.25)/(0.66 + 0.25) = 0.36. This is the value of the Object Recognition FBM-3.

Teams will be ranked within FBM-3 based on the numerical values calculated by equation 5. In the event that there is a tie between two teams that score the same FBM-3, the position data for OPIs will be taken into account – the team with the lowest RMSE position error will be ranked highest.

7.4 FBM-4: Object Recognition Functionality (Sea)

7.4.1 Functionality Description FBM-4

This functionality benchmark (FBM) has the objective of assessing the capabilities of an underwater robot (only data from marine robots will be considered in this FBM) in processing sensor data in order to extract information about observed objects. Specifically, the objects to be recognised in this FBM are the orange buoys (see Appendix I) that act as obstacles. Each obstacle buoy is identified by a black number, from 1 to 4.

Each buoy is a particular instance of the buoy class. The benchmark requires that the robot detects the buoys and identifies them, based on the black number and their location for the obstacles.

The data required for this functionality benchmark will be collected from TBM-1.

7.4.2 Feature Variation FBM-4

4 orange buoys (described in Appendix I) will be present in each run. The position of the 4 obstacles buoys may be varied from one trial to another, but will not be changed during the task benchmark.

7.4.3 Input Provided FBM-4

The present objects in this FBM will be instances of the buoy class. 4 instances will be present in an area to be surveyed (~20 m x 20 m). The area will be given to the teams in the previous days of the competition.

Each obstacle buoy is identified by a black distinctive number (H between 100 mm and 150 mm, reproduced twice or thrice along the equatorial plane). Numbers will go from 1 to 4. The number identifies the object instance unique ID. Teams need to recognise the number and localise the object correctly to label them.

Object ID= [object class, object instance]

Object class	Object instance
Buoy	1
Buoy	2
Buoy	3
Buoy	4

7.4.4 Expected Robot Behaviours or Output FBM-4

The acoustic and/or optical imaging sensors of the underwater robot must gather the data.

The robot must provide the object ID (Object class, Object instance) of the detected buoys. The robot must also provide the position of the objects. The imagery of the object must be acquired by the robot. The provided log of the robot must show together with the robot navigation data, the timing at which the detection has been carried out with the object ID and position.

The team must provide a set of files saved in the USB stick given to the teams before the task. The USB stick will be formatted with the NTFS file system and all the files must be saved in a folder with the name of the team.

The following information must be provided:

Object Recognition Information: this information must be stored in KML format and include the following:

- Object ID: Class/Instance
- Object position (Latitude, Longitude, Depth)
- Object image: image files (JPEG, PNG, BMP, PPM).

Vehicle Navigation Data: this must be in KML (Keyhole Markup Language) format and has the following requirements

- The data sampling frequency: 1 Hz, i.e. a data sample every one second.
- Time: UTC
- Position: Latitude, Longitude (in decimal degrees)
- Heading: (in degrees)
- Depth: Sea Domain only (in meters)

Mission Status Data: This gives the information related to the status of the mission undertaken must be in KML format with the following requirements:

- Subtask undertaken: Text
- Key decision message and event message (e.g. the detection of the OPI has to be recorded here): Text
- Time: UTC. Should be a series of Time corresponding to a series of events, e.g. the subtask starts, the subtask ends, start to close a valve, finish closing the valve, etc.

Each team will produce a log file with the mission data. The log file(s) must clearly show the actions of the underwater robot during the task.

The data must be provided to the referees 60 minutes from the end of the team's time- slot.

Map Information: map only produced by an underwater robot of the area to be surveyed containing the buoys; this must include the following information and formats:

- The map file: KML format (Keyhole Markup Language) or KMZ files
- Abstract Level information: OPIs. This should be integrated into the KMZ file.

All data requirements have to be met. Submitted data that do not comply with the formats specified will not be accepted.

7.4.5 Procedures and Rules FBM-4

As Functionality Benchmarks are implemented in the Task Benchmarks, the applied procedures and rules are the ones of the TBM-1.

7.4.6 Acquisition of Benchmarking Data FBM-4

During the execution of the benchmark, the Internal Data will be collected:

- Number and ID of detected buoys
- Imaging of the detected buoys (acoustic and/or optical)
- Position of the detected buoys
- Robot navigation log
- Robot log showing the executed detection

7.4.7 Scoring and Ranking FBM-4

Evaluation of the performance of a robot according to this functionality benchmark is based on:

1. The number of correctly identified (CI) objects via the black distinctive number (instances of buoy class with the relative number – recognised ID).

2. The number of correctly classified (CC) objects (instances of buoy class without the detection of the black number – the team must provide evidence from imaging, navigation log and object position related to the classified object).

3. Position error (PE) for all correctly identified/classified objects. The position error will be calculated based on the Euclidean distance error between the detection and the ground truth.

The previous criteria are in order of importance since this functionality benchmark is primarily focused on object recognition.

The formula used for scoring the FBM is SCORE=2.5*CI+CC.

The ties are broken by using the position error for all the identified/classified objects. The average of the best two position errors for the detected objects (i.e. the minimum and second minimum) will be considered.

7.5 FBM-5: Object Recognition Functionality (Air)

7.5.1 Functionality Description FBM-5

This functionality benchmark has the objective of assessing the capabilities of aerial robots in processing sensor data in order to recognise objects. The benchmark requires that robots detect Objects of Potential Interest (OPIs) and identify the type of each object found. This FBM applies to aerial robots only. It will be calculated from data collected in TBM-2.

7.5.2 Feature Variation FBM-5

The variation space for this Functionality Benchmark is as described in TBM-2.

7.5.3 Input Provided FBM-5

The input provided to teams is the set of all OPIs used within the competition: blocked entrances and unblocked entrance, damages on building and missing workers. These are described in Appendix 1. Note that for FBM-5 the underwater OPIs are not applicable.

7.5.4 Expected Robot Behaviours or Output FBM-5

The robots perceive the presence of the specific objects of interest in the environment by making use of its sensors. The Object Recognition here includes object detection (the presence of an object) and recognition that identifies the type of object (e.g. a missing worker, pipe, valve, ERIcard, etc.). The Object Recognition functionality also needs to provide location information of the object, and an image, although this additional information is not needed for the quantitative benchmark but only as confirmation that the correct objects have been found. The location of each object found must be marked on the same KML file provided for FBM-2, together with evidence that the OPI has been recognised (i.e. an image).

Each team must provide a set of files saved on the USB stick given to teams before task TBM-2. The USB stick will be formatted with the NTFS file system and all the files must be saved in a folder with the name of the team.

The following information must be provided:

Vehicle Navigation (Coverage) Data: this must be in KML (Keyhole Markup Language) format and has the following requirements

- The data sampling frequency: 1 Hz, i.e. a data sample every one second.
- Time: UTC
- Position: Latitude, Longitude (in decimal degrees)
- Heading (in degrees)
- Altitude: Air Domain only (in meters)

Waypoint Data: this must be in KML format - as a KML <placemark> - and include the following:

− Waypoint ID: text (i.e. WP1, WP2 etc.)
− Waypoint position (Latitude, Longitude)

Object Recognition Information: this information must be in KML format - as a KML <placemark> - and include the following:

− Object type: text (types as specified in Appendix 1)
− Object position (Latitude, Longitude)
− Object image: image files (JPEG, PNG, BMP, PPM).

All data requirements have to be met. Submitted data that do not comply with the formats specified will not be accepted.

Each team will produce a log file with the mission data. The log file(s) must clearly show the actions of robots during the task.

The data must be provided to the referees 60 minutes from the end of the team's time- slot.

7.5.5 Procedures and Rules FBM-5

As Functionality Benchmarks are calculated from data collected in the Task Benchmarks, the applied procedures and rules are the ones of the TBM-2:

7.5.6 Acquisition of Benchmarking Data FBM-5

After the task benchmark is completed, and within the time limit specified in the TBM, the internal data will be collected:

- The location (GPS coordinates) of each OPIs found
- The type of each OPI found (types as defined in Appendix 1), and
- An image (or equivalent scan) of the OPI as confirmation that the OPI was found.

7.5.7 Scoring and Ranking FBM-5

The output of the FBM is (1) object detected and (2) the type of the object.

Inspired by domains of Pattern Recognition and Information Retrieval, several metrics will be used:

- Precision and Recall: Precision is measured as the percentage of correctly recognized objects against all recognized objects which include correct ones and incorrect ones. The Recall (also known as sensitivity) is measured as the percentage of correctly recognized objects against all objects that could be detected in the scene.

For example, suppose there are 2 missing workers, 4 pipes and 4 ERIcards (8 OPIs in total). If 3 objects are recognized but of these only 2 are correctly recognized, the precision will be 2 / 3 = 66.66%, and the recall will be 2 / 8 = 25%.
Precision can be seen as a measure of exactness or quality, whereas recall is a measure of completeness or quantity.

- F-measure: Both precision and recall are real-valued, the higher the better, but to properly benchmark object recognition we need to consider them together. We use a combined measure, the traditional F-measure or balanced F-score.
  The general form of F measure is

  $$F_\beta = \left(1+\beta^2\right) \cdot \frac{precision \cdot recall}{\beta^2 \cdot precision + recall} \quad (5)$$

  where β is a non-negative real value.
  The traditional F-measure or balanced F-score (F_1 score) is the harmonic mean of precision and recall. The F_1 measure will be used here, i.e. β = 1.
  For the example given above, the F_1 measure would be (from equation 5) 2*(0.66 * 0.25)/(0.66 + 0.25) = 0.36. This is the value of the Object Recognition FBM-5.

Teams will be ranked within FBM-5 based on the numerical values calculated by equation 5. In the event that there is a tie between two teams that score the same FBM-5, the position data for OPIs will be taken into account – the team with the lowest RMSE position error will be ranked highest.

7.6 FBM-6: Vertical Wall Mapping Functionality (Sea)

7.6.1 Functionality Description FBM-6

This functionality benchmark has the objective of assessing the capabilities of marine robots in extracting specific information about the damaged pier. The data will be collected during the TBM-1.
Marine robots must inspect and map a vertical wall of the pier in which damage is present, in order to obtain valuable information for the emergency response team. In this context, a map is defined as “any digital representation of the environment suitable for performing other functionalities” such as localisation, path planning or object recognition. Depending on the

specific robot platform under test, mapping requires a more or less extended exploration of the environment.

The emergency response team is interested in obtaining high valuable information of the damaged pier from the outside, to assess further inspections to be performed by other response teams. The teams will be required to explore a specific wall of the damaged pier. The wall to be explored will be communicated to the underwater robot by the ground robot. After the exploration, teams must provide a 2D or 3D map of the designated wall along with several metric measurements, which must be calculated from such a map. The requested metric measurements are the size of the marker, the position of the marker and the depth of the marker.

7.6.2 Feature Variation FBM-6

The wall varies from team to team (between two options). The marker itself will be the same in both walls but can vary from trial to trial.

7.6.3 Input Provided FBM-6

The teams will be provided during the competition days with the two possible wall areas to be vertically inspected.

7.6.4 Expected Robot Behaviours or Output FBM-6

The teams must command the underwater robot to go to the designated wall and gather data in order to obtain the requested information. The underwater robot should carry out a mission to acquire the necessary sensor information to build the map. The underwater robot must keep a minimum safety distance of 1 meter from the wall. Impacts against the wall will be penalised. The map must be built using sensor information, and it is mandatory that the requested metric measurements that the teams calculate are derived or extracted from such a map (not from human inspection of the pier). If the provided map is 2D, an appropriate scale factor must be also specified to derive the metric measurements. If the map is 3D, there is no need for specifying a scale factor.

The output provided by the teams is a set of files that must be saved in a USB stick given to the teams before the task. The USB stick will be formatted with the NTFS file system and all the files must be saved in a folder with the name of the team.

The following information will be evaluated for this Functionality Benchmark:

- File with the name 'vertical_map' containing the built map of the designated vertical wall. If the map is 2D, an image in a standard format must be provided (e.g. JPEG, PNG…), and a scale factor must be specified within the same image or inside a text file with the same filename as the map image ('vertical_map.txt'). If the map is 3D, the file type must be readily accessible using open tools such as MeshLab or CloudCompare.

- Text file with the name 'vertical_wall.txt' containing the five requested measurements in millimetres (except for GPS coordinates), each one in a different text line (Latitude, Longitude, width of the marker, height of the marker, depth of the bottom side of the marker).

7.6.5 Procedures and Rules FBM-6

As Functionality Benchmarks are implemented in the Task Benchmarks, the applied procedures and rules are the ones of TBM-1.

The underwater robot must keep a minimum safety distance of 1 m from the wall. Impacts against the wall will be penalised.

7.6.6 Acquisition of Benchmarking Data FBM-6

After the task benchmark is completed, and within the time limit specified in the TBM, the teams must deliver the organisers the following data to be used for this FBM:

- a 2D or 3D map of the designated vertical wall,
- position of the marker,
- the width and height of the marker and,
- the depth of the bottom side of the marker.

7.6.7 Scoring and Ranking FBM-6

For each team, an accuracy metric will be used to score the performance of this functionality. We propose the Root-Mean-Square Error (RMSE) between real (ground truth) distances and the robot's estimated measurements. This is measured in mm, and it is a real value metric – the lower the better.

We require the teams to obtain the following information:

position of the marker,

width and height of the marker and

depth of the bottom side of the marker.

If we have these five ground truth distances d_i and the five estimated distances $\hat{d}_i$ for evaluation, the RMSE is calculated as follows, and rounded so it does not have decimals:

$$RMSE = \sqrt{\frac{1}{5}\sum_{i=1}^{5}\left(d_i - \hat{d}_i\right)^2}$$

For this error, a metric $Index$ is calculated so the score is between 0 and 1. This is performed by using a maximum admissible error $MaxError$, so that

$$Index = \begin{cases} \frac{MaxError - RMSE}{MaxError} & if\ RMSE\ < MaxError \\ 0 & if\ RMSE \geq MaxError \end{cases}$$

The value of MaxError will be determined based on the competitor's performance.

Teams will be ranked based on this $Index$, from highest to lowest. Ties are broken by observing which team obtained less error in the estimated size of the marker (width error + height error), then in the estimated depth error, and finally in the estimated position error.

Example:

Suppose the ground truth values and the estimated measurements from one team are the ones indicated in the following table:

Measurements	Ground truth values (mm)	Team's estimated values (mm)
Width of the marker	d_1=2034	$\hat{d}_1$=2156
Height of the marker	d_2=2506	$\hat{d}_2$=2387
Latitude of the marker (after conversion)	d_3=1243	$\hat{d}_3$=1492
Longitude of the marker (after conversion)	d_4=1688	$\hat{d}_4$=1517
Depth of the marker	d_5=6342	$\hat{d}_5$=6791

Thus, for the example above, the RMSE will be 254 mm.

Errors between values (mm)	Squared errors	Averaged sum of squared errors
-122	14884	64377,6
119	14161	
-249	62001	RMSE
171	29241	253,7274128
-449	201601	

From this error, the final metric $Index$ is calculated by establishing a maximum admissible error $MaxError$. If for example this maximum error is set to 500 mm,

$$Index = \frac{MaxError - RMSE}{MaxError} = 0.49$$

8. Contact Information

Official information concerning rules, interpretations, and information about the competition can be found on the ERL Emergency website http://www.robotics-league.eu or you can contact us at erl.emergency@robotics-league.eu.

Appendix 1: Objects of Potential Interest (OPI)

This appendix describes the Objects of Potential Interest (OPI) that have to be found in the ERL Emergency Service Robots Task Benchmarks.

All OPIs are indicative and may change in dimensions and colours in updated rules. Teams will be promptly informed in case of changes.

It also includes a summary of the OPIs as help.

The list of OPIs regarding the Task Benchmarks are:

1. Blocked and unblocked entrances

Cards of different colours (similar to those shown in Figure 27) will be used as markers for the blocked entrances and unblocked entrance to the building. They will be A3 in size and will be located close to (Sea+Land tournament) or right above (Air+Land tournament) the entrance they refer to. In order to find the blocked entrances and unblocked entrance to the building, robots will have to find these markers and provide evidence to the referees. The green marker may include an Augmented Reality code. The code represented in the figure is only representative. The exact code will be given prior to the competition.

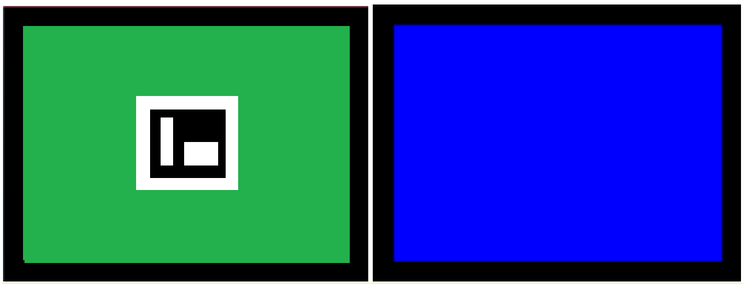

Figure 27. Markers for unblocked (left) and blocked (right) entrances.

2. Damages on land pipes and building

Red markers cards similar to those shown in Figure 28 will be used to represent structural damages in the building. And they also will be used to represent the fire on the land pipes. They will be A3 in size and can be located both outside and inside the building. A similar card will be used for the damages in the dock wall (with an added printed number).

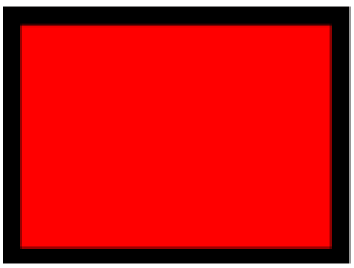

Figure 28. Marker for damages on the pipes and also structural damages in the building and the dock wall.

3. Missing worker

Mannequins wearing bright-colour work clothes will be used to represent the missing workers. An example is shown in Figure 29.

Figure 29. Mannequin representing a missing worker. Photo: euRathlon

4. First-Aid Kit

The first-aid kit will be a commercial one with dimensions smaller than 30x30x30 cm and weighs less than 1Kg. It will be made from a material that will not break if dropped to the floor. The kit will also have a handle or handling system (made of soft or hard material). It is possible for teams to design their own handling system to be applied or adjusted to the object.

The first-aid kit that the organisation will use is a "Reliance Medical Green Scandi Copenhagen First Aid Bag". http://www.reliancemedical.co.uk/product/helsinki-bag/

Figure 30. First-Aid kit. Photo: Reliance Medical

5. Gate and obstacles

The marine OPIs will be soft reflective (both acoustically and optically) approximately spherical objects (see Figure 31) and they will be located at mid-water (between 0.5 m and 1.5 m altitude from the bottom). They will be tethered to the ground by a light rope. For what concerns the dimensions, they will fit in spheres with OD between 0.25 m to 0.5 m. OPIs will be orange in colour. The gate will be constituted by two of these OPIs without any number. The other four of these buoys will be used as obstacles.

We suggest that teams assume that the buoys will be visible only from a close (1-2 m) distance but these conditions constantly change according to the weather (lighting conditions, sea state, water turbidity…).

Figure 31. Image of the buoy without a number (gate). The OD of the sphere is 30 cm.

6. Pipes and Leaks

During the Sea+Land competitions, there are several tasks related to pipe inspection. The following pipes are located inside the building and at sea.

On land:

On land, 4 pipes are positioned inside the building. For details about how these pipe sections look like see Figure 32 and Figure 33. The pipes will have red markers such as in Figure 28 in their vicinity.

Underwater:

There will be two piping assembly structures underwater. These piping assemblies consist of cylindrical shapes, yellow in colour, OD=0.5 m by LG=1.5 m (shown in Figure 32). The structure, composed of yellow pipes, has the following dimensions: 2 m (front area) x 3 m x 1.8 m (height), arranged to form a 3D structure. The assembly will be placed on the bottom and will not be moved during the competition (but its position will be unknown until the time-slot of the first participant team). A map with the positions and IDs of the pipes located underwater will be given to the teams.

Departing from each of the piping assemblies, two pipes at least 3 m long will be present (see Figure 33). Each of these pipes will be identified by an ID number (from 1 to 4) painted in black colour on the pipe surface. This ID number indicates to which of the land valves the underwater pipe is logically connected. A red marker marks the pipe on fire as seen in Figure 34.

Figure 32. Piping assembly structure. The structure, composed of yellow pipes, has the following dimensions: 2 m (front area) x 3 m x 1.8 m (height).

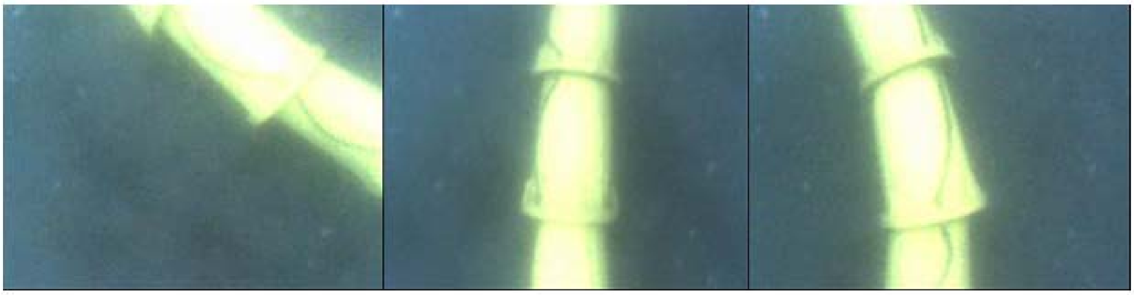

Figure 33. Pipe composed of yellow cylinders (OD=0.5 m). Two pipes will be positioned starting from the piping assembly. The pipes will be at least 3 m long.

Figure 34. Marker to represent the pipe on fire underwater.

7. <u>Valves</u>

As specified, inside the building there are 4 valves. Each valve will be represented by a set of two different types of valves (one gate valve and one lever valve, as shown in Figure 35. So physically, there will be 4 sets of two valves (8 valves in total). There will be achievements associated with closing the gate valve and closing the lever valve.

Figure 35. Set of valves. (Left) Gate valve, (Right) Lever valve

The association between the pipe leaking underwater and the correct valve in the machine room will be indicated by ID numbers. The valves on the machine room will be identified by ERICards (similar to that shown in Figure 36) positioned on the wall behind the valves. Each one of the four ERICards will be associated with one underwater pipe (i.e. underwater pipe number 4 will be associated with an ERICard like the one shown in Figure 36). The association between underwater pipe numbers and ERICards images will be given to teams. This way the ID number on the pipe on fire underwater will indicate the valve in the machine room. For example, if the pipe on fire underwater is number 4, the land robot will have to look for the ERICard associated with number 4 and close the valve (the gate valve and the lever valve).

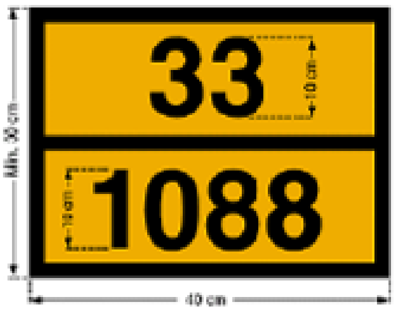

Figure 36. Example of an ERICard that will be positioned on the wall behind each valve.

Pinger

An acoustic pinger will ping 1 pulse per second, at the frequency of 15 kHz, will have a pulse length of 10 ms, and will have a power output of 153.5db at 1m. The pinger will be inside an orange box of 50x40x20 cm.

Figure 37. Orange box containing the acoustic pinger (Source: AUV Team TomKyle).

Canister

An empty 15L canister will be used.

Figure 38. Canister.

Obstacles

Obstacles representing debris in the land area of the competition will be created by grouping objects already present in the area (e.g. rocks, trunks) and/or wooden /cardboard boxes or will be natural obstacles (e.g. vegetation).

Obstacles for aerial and ground robots will be installed in the competition area, made of any kind of soft material (e.g. Styrofoam) or hard material (e.g. plastic). Pallets and plastic pipes were used as obstacles at the first Air+Land Local Tournament in 2019, as shown in Figure 36.

Figure 39. Obstacles for aerial and ground robots.

Appendix 2: Evaluation sheets

This appendix presents the evaluation sheets of TBM-1, TBM-2, FBM-1, FBM-2, FBM-3, FBM-4, FBM-5, and FBM-6.

TBM 1: Yacht accident in the harbour (Land +Sea)

Team name: ___________________________________

Referee I (Land): ____________________, Referee II (Land):_____________________

Referee I (Sea): _____________________, Referee II (Sea):______________________

Date (DD/MM/YYYY): ____________________________ , Time (24:00): ____________

Duration: ______________________ (Max. 90 min) ☐ Timeout

Achievements

Set A1: Outdoors

A **ground robot** reaches the waypoints within a precision of 3m.	A1.1 WP1 L ☐	
A **ground robot** reaches the WPs within a precision of 3 m in **autonomous navigation.**	A1.2 WP2 L ☐	
Within 30 minutes of the start of the run, a robot reports the correct location (within radius 5 m) of the missing worker outside the building.	A1.3 ☐	
The missing worker is detected in real-time in an automatic way.	A1.4 ☐	
A ground robot removes the rubble from the missing worker (1 per each rubble piece).	A1.5 ☐ A1.6 ☐	
A ground robot deploys the first-aid kit within a radius of 1 m from the worker found outside the building.	A1.7 ☐	
Robots report the damages the area outside the building *(Each damage can only be scored once).*	A1.8 D1 ☐ A1.9 D2 ☐ A1.10 D3 ☐	
A robot localises the unobstructed entrance in real-time in an automatic way.	A1.11 ☐	
Robots localise the **obstructed entrances.**	A1.12 E1 ☐	A1.13 E2 ☐

Robots build an outdoor map of the land pipes area with OPIs (North-West side).	A1.14 ☐
Robots build an outdoor map of the land pipes area with OPIs (North-East side).	A1.15 ☐
Robots build an outdoor map of the land pipes area with OPIs (South-West side).	A1.16 ☐
Robots build an outdoor map of the land pipes area with OPIs (South-East side).	A1.17 ☐

Set A2: Indoors

A **ground robot** enters the building through the unobstructed door.		A2.1 ☐
The ground robot(s) builds a geometric indoor map of the building. *(Use the best map or a combination of ground robots maps).*	Area 1 ☐ A2.2	Area 2 ☐ A2.3
The ground robot(s) recognise the damages in the area inside the building. *(Each damage can only be scored once).*	A2.4 D1 ☐	A2.5 D2 ☐
A **ground robot** recognises the ID of the correct set of valves in the machine room.		A2.6 ☐
A **ground robot** closes the correct valve. The robot must close one valve of the set autonomously and the other one manually. The process must be recorded by the on board camera of the robot. (Note: Each set of valves has two types: gate and lever)	Valve manual ☐ A2.7 Specify type valve: _____	Valve autonomous ☐ A2.8 Specify type valve: ______
The **ground robot** identifies the fire marker.		A2.9 ☐
The **ground robot** picks the canister and brings it to the fire area.		A2.10 ☐
The **ground robot** drops the canister on the fire marker.		A2.11 ☐

Set A3: Underwater

	Type of images	
The **underwater robot** provides geo-localised images of the obstacles.	Acoustic buoy-1 ☐ A3.1 Acoustic buoy-2 ☐ A3.2 Acoustic buoy-3 ☐ A3.3 Acoustic buoy-4 ☐ A3.4	Optical buoy-1 ☐ A3.5 Optical buoy-2 ☐ A3.6 Optical buoy-3 ☐ A3.7 Optical buoy-4 ☐ A3.8
The **underwater robot** provides images of the gate.	Acoustic buoy L ☐ A3.9 Acoustic buoy R ☐ A3.10	Optical buoy-L ☐ A3.11 Optical buoy-R ☐ A3.12

The **underwater robot** passes through the gate without touching it.	A3.13 ☐			
The **underwater robot** passes through the gate within the first 30 minutes from the start of the run.	A3.14 ☐			
The underwater robot detects (providing images and the position of the centre) the fire marker on the pipe in real-time.	A3.15 ☐			
The underwater robot gives the length of the fire marker on the pipe.	A3.16 ☐			
The underwater robot provides images of the black number stamped on the pipe on fire.	A3.17 ☐			
The underwater robot identifies the number of the pipe on fire (either by its geometric position or detecting the stamped number).	A3.18 ☐			
The **underwater robot** provides images of the structure sides.	North☐ A3.19	South☐ A3.20	East☐ A3.21	West☐ A3.22
The **underwater robot** provides a 3D reconstruction of the structure.	Front ☐ A3.23	Rear ☐ A3.24		
The **underwater robot** localises the missing worker underwater within a radius of 5 meters.	A3.25 ☐			
The **underwater robot** provides a 3D reconstruction of the worker.	A3.26 ☐			
The **underwater robot** provides images and the position of the marker in the damaged wall.	A3.27 ☐			
The **underwater robot** gives the dimensions and geometrical shape of the marker in the damaged wall.	A3.28 ☐			
The **underwater robot** identifies the number printed in black on the damaged area marker.	A3.29 ☐			
The **underwater robot** finds the pinger acoustically (e.g. hydrophone).	A3.30 ☐			
The **underwater robot** finds the pinger with an optical camera or a sonar.	A3.31 ☐			

Set A4: Cooperation

The **underwater robot** communicates the correct underwater damaged pipe to the **ground** robot. Directly or through the surface robot.	A4.1 ☐
The **ground robot** receives and decodes the message with the damaged pipe on fire sent by directly by the underwater or through the control station.	A4.2 ☐
The **ground robot** communicates the correct area with the wall damage to the underwater robot (directly or through the control station without human intervention).	A4.3 ☐
The **underwater robot** receives and decodes the message with the area where the wall	A4.4 ☐

damage has occurred sent by the ground robot (directly or through the control station).	

Set A5: General

The **ground robots** return to the landing area once all the tasks have been done.	A5.1 ☐
The **underwater robot** surfaces in a controlled way once all the tasks have been done.	A5.2 ☐
Benchmarking data is delivered appropriately (time and format)	A5.3 ☐
The **ground robot(s)** transmits live positions and images/video to the control station during the run.	A5.4 ☐
The **marine robot(s)** transmits live positions and images/video to the control station during the run.	A5.5 ☐

Penalised Behaviours

The robot needs manual intervention during a run (e.g. the robot is stuck):	
Marine robot	Not permitted
Ground robot 1	PB2 ☐ ☐ (max. 2)
Ground robot 2	PB3 ☐ ☐ (max. 2)
The ground robot leaves the operating area.	PB4 ☐ (max. 1)
The ground robot-1 hits the obstacles.	PB5 ☐ ☐ ☐ ☐
The ground robot-2 hits the obstacles.	PB6 ☐ ☐ ☐ ☐
The ground robot changes batteries or is refuelled.	PB7 ☐ (max. 1)
The underwater robot changes batteries.	PB8 ☐ (max. 1)
The underwater robot surfaces at any point (GPS fix can be obtained) and re-submerges. *(One surfacing is allowed for communication with the ground robot and a second to finish the mission)*	PB9 ☐ ☐ (max. 2)

Disqualifying Behaviours

A robot damages the competition arena (including the obstacles).	DB1 ☐
A robot does not conform to safety requirements for the competition.	DB2 ☐
A marine robot is tele-operated (except for safety reasons agreed by the Technical Committee and the manipulation task).	DB3 ☐
A robot closes more than one wrong valve on land.	DB4 ☐
The team does not provide the data after the required time.	DB5 ☐

Comment: ____

WARNING: A disqualifying behaviour discards all other achievements in the current task. Use it only when it is really necessary (e.g. cheating).

Benchmarking data delivered appropriately: ☐ yes / ☐ no

(Time is 60 min after the end of the team's time-slot, formats as described in the TBM)

Team leader signature: ____

Referee signature: ____

TBM 2: Emergency in a building (Land + Air)

Team name: ______________________________

Referee I (Land): _________________, Referee II (Land):__________________

Referee I (Air): __________________, Referee II (Air):___________________

Date (DD/MM/YYYY): ________________________ , Time (24:00): ___________

Duration: ___________________ (Max. 90 min) ☐ Timeout

Achievements

Set A1: Outdoors

An **aerial robot** reaches WP1, WP2, and WP3 within 3m, avoiding obstacles along the route.	A1.1 WP1 A ☐ A1.2 WP2 A ☐ A1.3 WP3 A ☐
An **aerial robot** autonomously avoids obstacles 1, 2 and 3.	A1.4 ☐ A1.5 ☐ A1.6 ☐
A **land robot** reaches WP1 within 3m, avoiding obstacles along the route.	A1.7 WP1 L ☐
A **land robot** reaches autonomously WP2 and WP3 within 3m, avoiding obstacles along the route.	A1.8 WP2 L ☐ A1.9 WP3 L ☐
Within **30 minutes** of the start of the run, a robot reports the correct location (within radius 5 m) of the **missing worker** outside the building.	A1.10 ☐
The missing worker is detected by the robot in real-time in an **automatic** way.	A1.11 ☐
An **aerial robot** deploys the first-aid kit within a radius of 2 m from the worker found outside the building.	A1.12 ☐
A **land robot** deploys the first-aid kit within a radius of 1 m from the worker found outside the building.	A1.13 ☐
Robots recognise the **damages** in the area outside the building *(each damage can only be scored once).*	A1.14 D1 ☐ A1.15 D2 ☐ A1.16 D3 ☐
Robots localise the **unobstructed entrance** in real-time in an automatic way.	A1.17 ☐
Robots localise the **obstructed entrances** *(each unobstructed entrance can only be scored once),*	A1.18 E1 ☐ A1.19 E2 ☐

Set A2: Indoors

A **land robot** enters the building through the unobstructed entrance.	A2.1 ☐
An **aerial robot** enters the building through the unobstructed entrance.	A2.2 ☐
A **land robot** enters the building autonomously through the unobstructed entrance after trying to complete the outdoor achievements.	A2.3 ☐
An **aerial robot** enters the building autonomously through the unobstructed entrance after trying to complete the outdoor achievements.	A2.4 ☐
The land robot(s) builds a geometric indoor map of the building *(use the best map or a combination of land robots maps).*	A2.5 ☐
The land robot(s) builds the map on-board during the operation. *(the map must be shown to the referees just after the run finishes).*	A2.6 ☐
The aerial robot builds a geometric indoor map of the building.	A2.7 ☐
The aerial robot builds the map on-board during the flight. *(the map must be shown to the referees just after the run finishes).*	A2.8 ☐
Robots recognise the **damages** in the area inside the building. *(each damage can only be scored once).*	A2.9 D1 ☐ A2.10 D2 ☐
Within **30 minutes** of the start of the run, a robot reports the correct location (within radius 5 m) of the **missing worker** inside the building.	A2.11 ☐
The missing worker is detected by the robot in real-time in an **automatic** way.	A2.12 ☐
An **aerial robot** deploys the first-aid kit within a radius of 2 m from the worker found inside the building.	A2.13 ☐
A **land robot** deploys the first-aid kit within a radius of 1 m from the worker found inside the building.	A2.14 ☐

Set A3: General

The **land robot(s)** returns to the starting area once all the tasks have been done.	A3.1 ☐
The **aerial robot(s)** returns to the take-off/landing area once all the tasks have been done.	A3.2 ☐
The **land robot(s)** transmits live positions and images/video to the control station during the run.	A3.3 ☐
The **aerial robot(s)** transmits live positions and images/video to the control station during the run.	A3.4 ☐

Penalised Behaviours

The robot needs manual intervention during a run (e.g. the robot is stuck):		
Aerial robot	PB1 ☐ (max. 1)	
Land robot 1	PB2 ☐ ☐ (max. 2)	
Land robot 2	PB3 ☐ ☐ (max. 2)	
The land robot leaves the operating area.		PB4 ☐ (max. 1)
The land robot-1 hits the obstacles.		PB5 ☐ ☐ ☐ ☐
The land robot-2 hits the obstacles.		PB6 ☐ ☐ ☐ ☐
The land robot changes batteries or is refuelled during the run.		PB7 ☐ (max. 1)

Disqualifying Behaviours

A robot damages the competition arena (including the obstacles).	DB1 ☐
A robot does not conform to safety requirements for the competition.	DB2 ☐
The aerial robot leaves the flight volumes defined by the organisation.	DB3 ☐
The team does not provide the data after the required time.	DB5 ☐

Comment: ____

WARNING: A disqualifying behaviour discards all other achievements in the current task. Use it only when it is really necessary (e.g. cheating).

Benchmarking data delivered appropriately: ☐ yes / ☐ no

(Time is 60 min after the end of the team's time-slot, formats as described in the TBM)

Team leader signature: ____

Referee signature: ____

FBM 1: 2D Mapping Functionality (Land)

Team name: ____

Referee I (Land): ______________________, Referee II (Land):_________________________

FBM-1 is calculated from data collected in **TBM-1 Yacht accident in the harbour (Land+Sea)** and/or **TBM-2 Emergency in a building (Land+Air)**.

TBM Date (DD/MM/YYYY): _________________, TBM Time (24:00): _________________

Duration TBM: ____________________ (Max. 45 min) ☐ Timeout

Provided data

Vehicle navigation data	☐
Waypoint data	☐
Map information	☐

Scoring calculation

	Waypoint Error (m)	**Path error**
W1		
W2		
W3		
W4		
Root Mean Square Error		
Normalised RMSE		

Notes:

1. Errors >15m are rounded down to 15m. 15m is also used as the value for waypoints not visited or when data is not provided or unclear.

2. Any waypoint error < 2m is rounded down to zero.

Outdoor ground coverage: ___________________

Note: Ground coverage is based on TBM 1 achievements A1.14 - A1.17, which are estimated by referees inspecting KML maps submitted

Overall score FBM-1: ____________________ (Calculated post-competition)

Note: For details on FBM-1 calculations refer to the ERL Emergency Robots Rulebook.

Referees that have calculated and reviewed the overall score:

Referee I: ______________________________________

Referee II: ______________________________________

Referee signature: ____

FBM 2: Mapping Functionality (Air)

Team name: ____

Referee I (Air): _________________________

Referee II (Air):____________________________

FBM-2 is calculated from the best run in **TBM-2 Emergency in a building (Land+Air).**

TBM-2 Date (DD/MM/YYYY): ___________________, TBM-2 Time (24:00): ___________

Provided data

Vehicle navigation data	☐
Waypoint data	☐
Map information	☐

Scoring calculation

	Waypoint Error (m)
W1	
W2	
W3	
W4	
Root Mean Square Error	
Normalised RMSE	

Notes:

1. Errors >15m are rounded down to 15m. 15m is also used as the value for waypoints not visited or when data is not provided or unclear.

2. Any waypoint error < 2m is rounded down to zero.

Overall score FBM-2: _____________ (Calculated post-competition)

Note: For details on FBM-2 calculations refer to the ERL Emergency Robots Rulebook.

Referees that have calculated and reviewed the overall score:

Referee: _______________________________________

Referee signature: ____

FBM 3: Object Recognition Functionality (Land)

Team name: ____

Referee I (Land): _____________________, Referee II (Land):________________________

FBM-3 is calculated from data collected in **TBM-1 Yacht accident in the harbour (Land+Sea)** and/or **TBM-2 Emergency in a building (Land+Air).**

TBM Date (DD/MM/YYYY): ______________, TBM Time (24:00): ________________

Duration TBM: ___________________ (Max. 45 min) ☐ Timeout

Data provided

The location (GPS coordinates) of each OPI found	☐
The type of each OPI found	☐
An image (or equivalent scan) of the OPI as confirmation that the OPI was found	☐

Scoring calculation

The maximum number of Objects of Potential Interest (OPIs) in TBM-1 is 9.

The maximum number of Objects of Potential Interest (OPIs) in TBM-2 is 10.

Number of OPIs correctly identified		
OPI	Data from TBM-1	Data from TBM-2
Missing worker outside the building		
Missing worker inside the building	N/A	
Obstructed entrances (max. 2)		
Unblocked entrance (max. 1)		
Damage to the outdoor walls (max. 3)		
Damage to the indoor walls (max. 2)		
Total correctly identified objects		

Note: incorrectly identified OPIs are ignored since some are manually and some autonomously detected.

Total OPIs found	
Precision	
Recall	
Index	

Note: For details on FBM-3 calculations (i.e. precision, recall, etc.) refer to the ERL Emergency Robots Rulebook.

Overall score FBM-3: ____________________ (Calculated post-competition)

Referees that have calculated and reviewed the overall score:

Referee I: ______________________________ Referee II: ______________________________

Referee signature: ____

FBM 4: Object Detection (Sea)

Team name:

FBM-4 is calculated from the marine data collected from TBM-1 Yacht accident in the harbour (Land+Sea).

Referee I (FBM-4 overall score calculation):

Referee II (FBM-4 overall score calculation):

Provided data

Map file in an appropriate format (sonar, schematic, visual)	☐
Sonar detection images:	☐
Optical detection images:	☐
Navigation log	☐

Note: Not all data is necessarily needed to evaluate the FBM. E.g. either optical or sonar detections can be considered, no need for both.

Object to be detected	Buoy 1	Buoy 2	Buoy 3	Buoy 4	Buoy 5	CI	CC	Score
TBM-1								

Overall score: 0 (Calculated post-competition)

The overall score is calculated as the median of the trials of TBM-1 as mentioned in the Rulebook.

The score is SCORE=2.5*CI+CC. where CI is correctly identified buoys (via black number) and CC is correctly classified buoys (without the detection of the black number).

Referee signature (overall score calculation): ________________________

Date:

FBM 5: Object Recognition Functionality (Air)

Team name: ____

Referee I (Air): _______________________

Referee II (Air):__________________________

FBM-5 is calculated from data collected in **TBM-2 Emergency in a building (Land+Air).**

TBM-2 Date (DD/MM/YYYY): _________________, TBM-2 Time (24:00): ___________

Data provided

The location (GPS coordinates) of each OPI found	☐
The type of each OPI found	☐
An image (or equivalent scan) of the OPI as confirmation that the OPI was found	☐

Scoring calculation

The maximum number of Objects of Potential Interest (OPIs) in TBM-2 is 10.

Number of OPIs correctly identified	
OPI	Data from TBM-2
Missing worker outside the building	
Missing worker inside the building	
Obstructed entrances (max. 2)	
Unobstructed entrance (max. 1)	
Damages outdoor (max. 3)	
Damages indoors (max. 2)	
Total correctly identified objects	

Note: incorrectly identified OPIs are ignored since some are manually detected.

Total OPIs found	
Precision	
Recall	
Index	

Overall score FBM-5: _____________ (Calculated post-competition)

Note: For details on FBM-5 calculations refer to the ERL Emergency Robots Rulebook.

Referees that have calculated and reviewed the overall score:

Referee: ___________________________________

Referee signature: ____

FBM 6: Vertical Wall Mapping Functionality (Sea)

Team name: ____

Referee I: ______________________, Referee II: ______________________

Date (DD/MM/YYYY): ______________________, Time (24:00): ____________

Provided data

Map file named 'vertical_map': 2D map with scale factor or 3D map, in an appropriate format.	☐
Text file named 'vertical_wall.txt': including the five metrics (except GPS) measurements: – Width of the marker. – Height of the marker. – Latitude of the marker. – Longitude of the marker. – Depth of the bottom side of the marker.	☐

Team leader signature: ____

Referee signature (on site): ____

Measurements	**Ground truth values (mm)**	**Team's estimated values (mm)**	**Errors between values (mm)**	**Errors^2**	**Avg. sum of squared errors**
Width of the marker.	d_1=	$\hat{d}_1$=			
Height of the marker	d_2=	$\hat{d}_2$=			**RMSE**
Latitude of the marker (converted)	d_3=	$\hat{d}_3$=			
Longitude of the marker (converted)	d_4=	$\hat{d}_4$=			**MaxErr**
Depth of the bottom side of the marker	d_5=	$\hat{d}_5$=			
					Index

Overall score: ____________________ (To be calculated post-competition)

Referee signature (overall score calculation): ____