2022 RAMI (Robotics for Asset Maintenance and Inspection) Marine Robots competition

- Rule Book -

This document is subject to change, refinement and development.

Please visit the METRICS official website https://metricsproject.eu for the current version

Content

List of acronyms

AUV Autonomous Underwater Vehicle
CSV Comma Separated Values
EU European Union
GNC Guidance Navigation and Control
H Height
ID Inner Diameter
LG Length
OD Outer Diameter
OPI Objects of Potential Interest
RAMI Robotics for Asset Maintenance and Inspection
RIB Rigid Inflatable Boat
ROS Robotic Operative System
SAP Scenario Application Paper
S Sea
TBD To Be Defined
W Width
WP Waypoint

1. Introduction

The RAMI (Robotics for Asset Maintenance and Inspection) competition is organized in the framework of the METRICS (https://metricsproject.eu/) EU project and aims at addressing I&M tasks achieved by aerial and underwater robots in risky and/or hostile environments where human intervention is challenging or impossible, where direct link with an operator could not be guaranteed and where autonomous decisions are necessary to reduce operational time of the inspection tasks and ensure repeatability while maintaining an appropriate safety level for the mission. The evaluation process of RAMI competitions mainly involves tasks related to autonomous navigation, data acquisition, detection, classification and autonomous decision-making for inspection purposes. Since aerial and underwater domains are very different, both domains will be evaluated separately in two different tracks.

This document describes the rules for the RAMI (Robotics for Asset Maintenance and Inspection) competition dedicated to marine Autonomous Underwater Robots (AUVs).

The RAMI marine competition tasks are inspired by the following **user story**.

> *A gas&oil offshore site has to be investigated after that a malfunction has been reported by the plant safety systems.*
> *From what is known, a pipeline has started leaking and an explosion may occur soon.*
> *A robotics team composed of underwater robots (AUVs) is ready to intervene.*
> *It is time for the emergency team to act. The priorities are to reach the area of the accident, and to assess and quantify the entity of the leak. Then the robots have to reach the pipe assembly area for quantifying the damage to the plant and for identifying which pipe has been damaged and is responsible for the leak.*
> *Finally, the robots must intervene on the plant itself by closing a valve to stop the leak to prevent the explosion and further damages to the environment.*

2. RAMI Marine Robots Organisation

2.1 RAMI Marine Robots Management

The management structure of RAMI Marine Robots has been divided into three committees: *Executive Committee, Technical Committee* and the *Organisation Committee*.
The roles and responsibilities of those committees are described in the following paragraphs.

2.1.1 Executive Committee

The Executive Committee (EC) is represented by the RAMI Marine Robots partners. The committee is mainly responsible for the overall coordination of RAMI Marine Robots activities and especially for dissemination in the scientific community.

The RAMI Marine Robots competition is chaired by the Centre for Maritime Research and Experimentation (CMRE). The organization of RAMI competitions (aerial and marine robots) includes two partners:
• Advanced Centre for Aerospace Technologies (CATEC) (Spain)
• Centre for Maritime Research and Experimentation (CMRE) (Italy)
• Heriot Watt University (UK)

2.1.2 Technical Committee

The Technical Committee (TC) is responsible for the rules of the competition. Each member of the committee is involved in maintaining and improving the current rule set and also in the adherence of these rules. Other responsibilities include the qualification of teams, handling general technical issues within the competitions, 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 METRICS evaluation campaigns Infrastructure.

The Technical Committee 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 Technical Committee will announce any modifications of the rules with an e-mail to all entrants and a corresponding statement on the RAMI Marine Robots 2022 La Spezia page (sites.google.com/site/ramimarine/2021laspezia). The Technical Committee may provide interpretation of the rules at any time and in any manner that is required.

Decisions of the Technical Committee are final.
– **Referee Team**
The referees are a group of officials designated by the Technical Committee. Referees are members of the Technical committee during the tournament event. The Technical committee is the final authority on all matters referred to in the rules and all matters affecting the operation of the RAMI Marine Robots competition.
The Referee Team is led by one Head Referee which manages the activity of the Referee Team.
The Technical Committee currently consists of the following members:

Chair
- Dr Gabriele Ferri (Centre for Maritime Research and Experimentation, CMRE, Italy)

Co-Chairs
- Alessandro Faggiani (Centre for Maritime Research and Experimentation, CMRE, Italy)
- Dr Tommaso Fabbri (Centre for Maritime Research and Experimentation, CMRE, Italy)

The Referee Teams will be announced closer to the competition.
The assigned Head Referee is:
- Dr Fausto Ferreira (Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia)

This committee also includes members of the Executive Committee.

2.1.3 Organising Committee

The Organizing Committee (OC) is responsible for the actual implementation of the competition, i.e. providing everything what 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 organising committee of RAMI Marine Robots 2021 in La Spezia, Italy, is chaired by the Centre for Maritime Research and Experimentation (CMRE), and includes members of the three project partners.

Chair
- Dr Gabriele Ferri (Centre for Maritime Research and Experimentation, CMRE, Italy)

Co-Chairs
- Alessandro Faggiani (Centre for Maritime Research and Experimentation, CMRE, Italy)
- Dr Tommaso Fabbri (Centre for Maritime Research and Experimentation, CMRE, Italy)

Engineering Coordinator
- Milan Markovic (Centre for Maritime Research and Experimentation, CMRE, Italy)

Members
- Dr Fausto Ferreira (Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia)
- Francisco Javier Perez Grau (Advanced Centre for Aerospace Technologies, CATEC, Spain)
- Dr Antidio Viguria (Advanced Centre for Aerospace Technologies, CATEC, Spain)
- Dr Yvan Petillott (Heriot Watt University, UK)

3. RAMI Marine Robots Award Categories

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 RAMI evaluation campaign, each team may have the possibility to perform several trials of the available TBMs and FBMs. A **trial** is an attempt in a time-slot to accomplish a TBM or FBM.
The team score for a given TBM/FBM in a RAMI campaign 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 maximum 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 RAMI Marine 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 RAMI Marine Robots Best-in-Class Functionality Benchmark <functionality benchmark title>"), the second as ("RAMI Marine Robots Second Best-in-Class Functionality Benchmark <functionality benchmark title>") and so on.
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 exceptional level.

- When only two teams participate in a given FBM, the ("RAMI Marine 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.

See Section 6 for a detailed description of how the scoring of a single trial is computed.

3.1 Awards for Task Benchmarks

The team with the highest score in each task benchmark of RAMI Marine Robots will be awarded with prize money and a diploma ("RAMI Marine Robots. Best-in-class Task Benchmark <task benchmark title>"). The amount of the prize money will depend upon how much money the RAMI organisation can award.
If only one team participates in a given task benchmark, the corresponding task benchmark award will only be given to that team if the Executive and Technical Committees consider the team performance of exceptional level.

3.2 Awards for Functionality Benchmarks

The teams with the highest score ranking for each functionality benchmarks will be awarded a diploma ("RAMI Marine Robots. Best-in-Class Functionality Benchmark <functionality benchmark title>" and "RAMI Marine Robots. Second-Best-in-Class Functionality Benchmark <functionality benchmark title>"). If less than three teams participate in a given functionality benchmark, only the "RAMI Marine Robots. Best-in-class Functionality Benchmark <functionality benchmark title>" award will be given to a team, and only if the Executive and Technical Committees consider that team's performance as excellent.

4. The RAMI Marine Robots competition location

The RAMI Marine Robots competition will be held in the water basin at CMRE, La Spezia, Italy. The area can be viewed in Google earth at 44.095842, 9.864575. This protected harbour provides excellent conditions for real-life challenges. It has been used for marine robotics competitions in the past 10 years and has proven a challenging yet accessible testbed (see Figure 1). The seawater basin is 50 x 50 m with a depth of 4-5 meters. Both student-based competitions (Student Autonomous Underwater Vehicle Challenge- Europe/SAUC-E) and more advanced competitions such as euRathlon 2014, European Robotics League Emergency 2018 and 2019 took place in this testbed. The currents are negligible and the water clarity can be seen from the available images of the competition web site and of the cascade evaluation campaign. However, teams must expect a visibility between 1 and 2 metres depending on weather conditions. The salinity can be measured and made available to the competitors if required. For the information to the competitors close to the north-east wall there is a source of fresh water coming out of the wall that can be considered as simulating the delta of a river. The AUV buoyancy compensation needs to be considered. Tidal range is approx. 10 cm on a spring tide. Ambient water temp in July is approx. 29/20° Celsius (maximum-minimum). Magnetic compass behaviour is indeterminate at this stage. However we expect magnetic compasses to be useable 1 meter away from any structure.

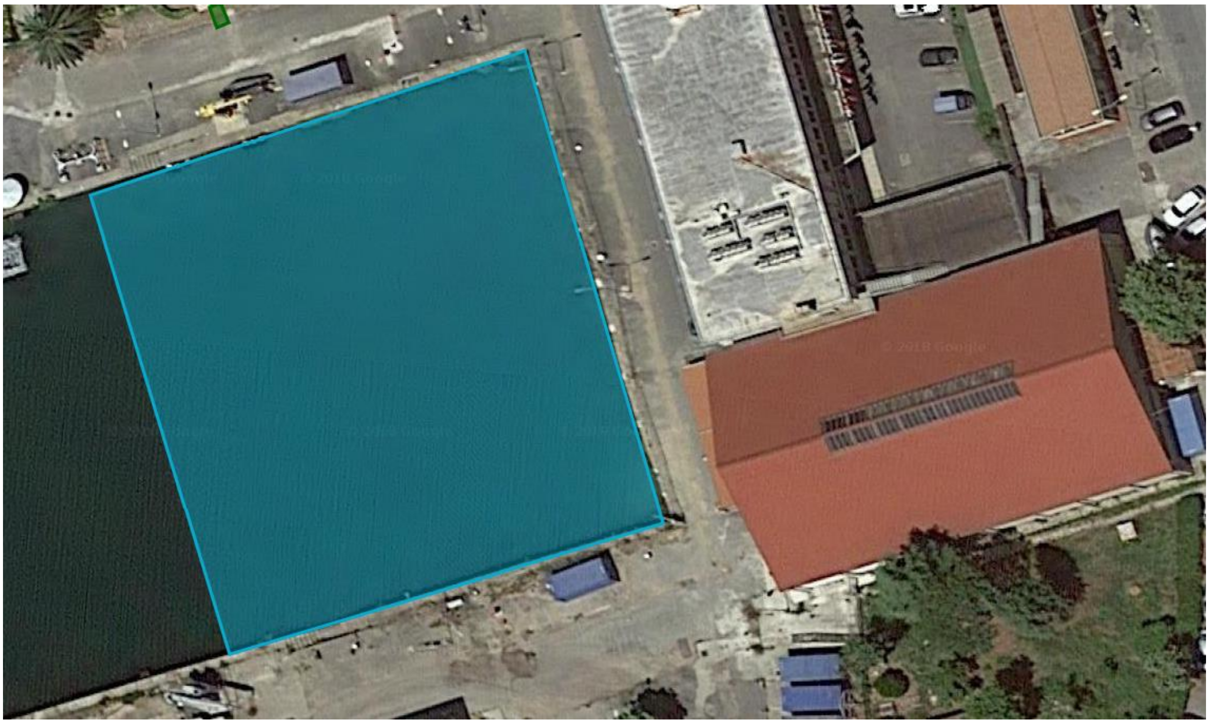

Figure 1. Area for marine robots in blue. (Source: Google Maps).

A more detailed schematic of the competition arena is reported in Figure 2. The competition area will be 40m x 25m. Next to the competition arena a smaller area (named practice arena) will be prepared with OPIs for enabling teams to practice.

All starting positions will be inside the delimited competition arena, except that for TBM1 (see later in the text). In that case, the robots may start their trial outside of the arena for evaluating their autonomous navigation features.

The competition arena will include one gate marked by two submersed yellow buoys (detectable both by the sonar and video camera), spaced 2 metres apart (see Fig. 4). Two pipeline structures will be present in the area. On the two areas, four pipes will be present, with two pipes connected to each pipeline structure. Each pipe is identified by a black number written on its surface. On one of these pipes the red marker that identifies the damage to the pipe will be positioned. On each pipeline structure a manipulation console will be positioned. The manipulation console is a white plane on which the valve and the ring-pole will be located. On each manipulation console a black number over a red background is also present. The buoy area is indicated by the shaded red area and will contain coloured submersed buoys to be mapped by the robots. All positions are indicative. Further description of the OPIs will be found later in the document.

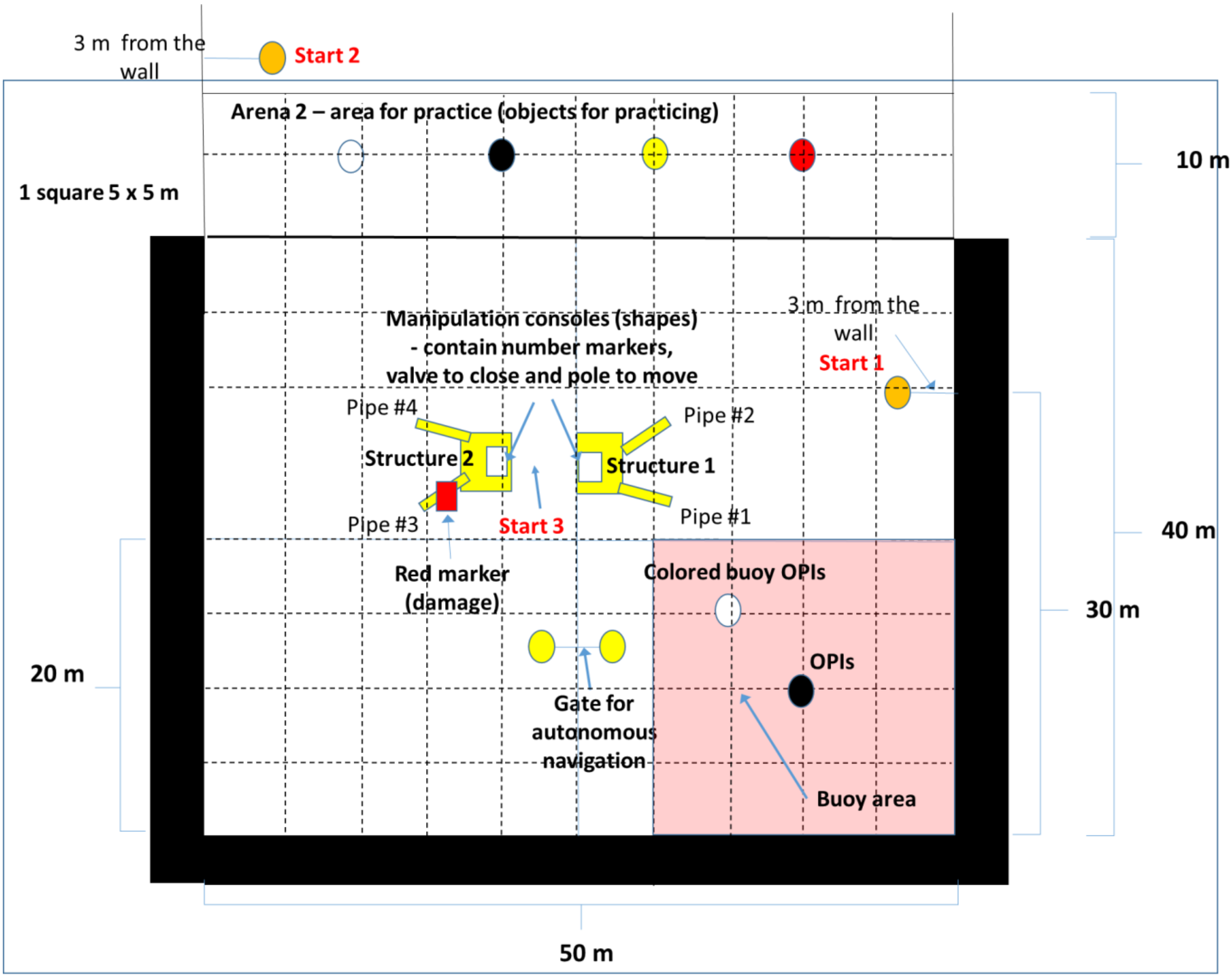

Figure 2. Schematic of the arena. Positions of the objects and OPIs are indicative and can change.

5. Robots and Teams

The purpose of this section is:

1. Specify 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.
2. The robot features specified here should be supplied in detail for any robot participating in the competition. This is necessary in order to allow better assessment of competition and benchmark results later on.

5.1 General Specifications and Constraints on Robots and Teams

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

a single underwater robot is to be used during one trial (time-slot) for a Task Benchmark.

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 marine 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 is **8 plus a team leader (9 in total)**. This number may be changed considering the restrictions and the logistics imposed by the COVID19.

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 referees 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 the purposes of this competition, 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 is able to 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.
** In 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 submersed (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.
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.
This kind of operation is allowed only during manipulation: specifically, for closing the valve and for moving the ring-pole**. It is warmly recommended to the teams to develop a floating buoy system connected via cable to the underwater robot**. The buoy can be reached via radio from the Control Station and can be used as a relay for tele-operation. This facilitates the robot tele-operation avoiding the need of a cable from the shore. It is also faster for switching robot control mode during a TBM attempt. Finally, this floating device can also be used **during test and practice** for controlling and monitoring the robot operations.
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 physically with the robot. Note, however, that any interaction between the technical assistant and the robot may have a negative influence on the resulting evaluation.

5.1.2 Requirements for 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 single AUV can be used during a time-slot. The team can bring spare robots and use another robot in a different time-slot. The robot to be used in a time-slot must be communicated to the referees before the start of the time-slot.

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 a fluid will be deemed unsafe. All robots must carry a clearly legible 'label' showing the robot weight in 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.

5.1.3 Classified Data and Devices

No classified data or devices can be used by a team in preparation for or during the RAMI competition. All data produced and used during the event will be Public Release.

5.2 Safety Check and Robot Inspection

During the set-up days, all robots will be checked by the RAMI Marine Robots 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 RAMI Marine Robots Technical Committee. The inspection can be repeated at any time during the competition days, upon request of the RAMI Marine Robots 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 for 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 RAMI Marine 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 RAMI Marine Robots competition.

5.3 *Health & Safety Standards*

All teams and robots must comply with all applicable safety regulations (see https://osha.europa.eu/en for details).
All teams must obey the health & safety rules and laws of the host country.

5.4 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 will lead to disqualification of the team.

5.5 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 RAMI Marine 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.

5.6 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.

5.7 Set-up and Pre-Competition Testing

Testing of robots or components is the sole responsibility of each team.
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 – the practice arena, or the competition arena when not in use for competition) for sea robots

Note that:

- Teams must provide their own consumables, hand tools, drill bits and 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.

Inspection of the competition area by any participants is not allowed outside of the schedule set by the organisers.

Robots will be given time slots and will be able to practise in the competition arena and pools. Practising in the competition arena without permission from the organisation will lead to disqualification of the team.

6. Task Benchmarks

Details concerning rules, procedures, as well as scoring and benchmarking methods, are common to all task benchmarks.

Rules and Procedures

There are mandatory pre-competition safety-checks described in Section 5 of this Rule book. 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 Committee or 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.

Trial and run terms in RAMI

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 task benchmarks 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 which received less penalization is considered as better.
- If the two robots received the same amount of penalization, the performance of the one which finished the task more quickly is considered as better (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. In the computation of the achievements some of them may have a multiplier different from 1.to increase their importance. For instance if achievement X has a multiplier of 3, in the final counting its fulfilment counts as 3. This is clearly stated in the list of achievement available for each TBM. If no multiplier is indicated, it is assumed to have a value of 1.
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 task).

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 Task Benchmark (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 competitions arena. They will not have line of sight with the robots all the time.
One or two team members, the **Technical assistants** can accompany their robot (when applicable) along the run on the organisation support boat. Technical assistants can intervene (when allowed) to get the robot and to re-position it for starting a new run.
During a task benchmark run, members of other teams (than the one participating) will not be allowed in the control stations.

Maximum number of people allowed (excluding referees and organisers) inside the control station is 5 people.

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 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

A Control Station (physical location) will be prepared in the competition area. It is located in the dock area near the marine competition arena. The robot operator with all the control equipment will be located in the Control Station tent. The operators must not leave their respective control stations during the Task Benchmark execution.

Figure 3. Example of the area of the Control Stations. (Source: Google Maps)

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 AUVs, tele-operation is forbidden (except for manipulation tasks) and only acoustic monitoring can be used in the case of semi-autonomous.

The technical assistants can accompany the robot in the rubber boat and interact with it as defined in Section 5.1 for navigation tasks. At any time in the preparation phase and during a scenario run an RAMI 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 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.

Only due to an explicit request of the operator or 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 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 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.

The underwater robot can receive messages directly from the Control Station on-shore through an acoustic link. The type of messages allowed are 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 rule document.
No physical link is admitted (wires or cables) to communicate/tele-operate the robots in all the tasks, except that in the manipulation ones (close the valve and move the ring-pole).

6.1.3 Start Procedure

Each team has to name one or two "technical assistants" and an "operator". Each team will be allocated a time slot for their participation in the competition. Map and waypoints (whenever applicable) will be given on site, prior the start of the Task Benchmark.
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 the departure signal is given by an RAMI official (referee), the robot can depart from the start point.
During the departure procedure, the robot 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 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, nearby the deployment point of the 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 should be in the start point prepared and waiting for the referees' signal. At 9:55 the robot should be enable for operation. At 10:00 referees will give the start signal and the task benchmark will start. 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 on the starting time of the task benchmark, the referees may decide, depending on the factors that have cause the delay, to reallocate time-slots or to disqualify the team for that task benchmark run.
The technical assistants are responsible for operating the emergency stop systems. The whole run will be supervised by the RAMI officials.
Only the referees can signal the start of operations. Competition officials may deploy and recover the robots (marine robots) or supervise the robot deployment/recovery by teams (technical assistants). 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 robot must avoid collisions with any obstacles on the route. Incidental or non-damaging contact with obstacles may not result in the abortion of the run.
During the Task Benchmark there will be no communication between the operator and other individuals with the exception of communication with:

- RAMI officials.
- Technical assistants on the rubber boat
- Team members allowed to be inside the Control Station

Apart from the technical assistants, 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 is returned to the team. A robot is returned to the team after the Task Benchmark is aborted or after the robot returns to the respective starting point.
During the Task Benchmark charging batteries is not permitted.

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

The underwater robot can surface up to a maximum number of times defined per each Task Benchmark. During the surface, it is allowed to get a GPS fix and to communicate with the Control Station. In this case, it can receive high-level command (e.g. start action X, see 5.1.1). No tele-operation or navigation while on surface are allowed.

6.1.5 Restart Procedure

A team can request for a restart 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 in 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. No penalties will be given for a restart. But any score achieved so far before the restart will be cancelled (and counted as achieved in the stopped run) and the time will not be stopped during the restart procedure.

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 arena 15 minutes after the end of the time-slot.

6.1.7 Abortion Procedure

A robot must not continue on the route if the Task Benchmark was aborted. The organisers will coordinate the recovery of the robot 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.
If a team aborts a trial (after aborting several runs) because of technical difficulties, the Technical Committee may allow repeating it, depending on available start slots.

6.2 TBM-1: *Pipeline area inspection*

In TBM1, the robot has to reach through autonomous navigation the area where the damage has been reported. Once in the area, the robot has first to assess the entity of the oil leak identifying the oil plume in the area (to map the buoy position in the buoy area – buoys simulate the presence of the chemical). Then, it has to inspect the pipeline structure to localize and quantify the damage on the structure that is producing the leak.
This is the TBM in which the robots survey the accident area and provide an assessment of the situation for further intervention. This is crucial for further intervention of the robotic team.

6.2.1 Task Description TBM-1

Robots will start their mission at the position Start 2 as indicated in Figure 2 and have to:

- Reach some waypoints provided by the organisers in underwater autonomous navigation (see 6.2.4, achievement set A1).
- Pass through the gate (see Figure 2 and see 6.2.4, achievement set A1).
- Mapping the coloured buoy area providing a geo-localized map with the buoy positions (see 6.2.4, achievement set A2).
- Detect the colours of each buoy and react in a specific mode (e.g. turning around the buoy – see later for details) (see 6.2.4, achievement set A2).
- Survey the pipeline structure (see 6.2.4, achievement set A3).
- Detect, localize and determining the dimensions of the damage (a red marker) positioned on one of the two pipes connected to one pipeline structure (see 6.2.4, achievement set A3).

6.2.2 Feature Variation TBM-1

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

- Coloured buoys.

- The position of the damage on one of the four pipes of connected to the underwater structures.

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.

The following input will be provided to teams before the starting of the trial:

- The pipeline structure id (one of the two present in the competition area).
- A high-level schematic map of the pipeline structure with the position of the two yellow pipes connected to it. One of the two pipes (the teams do not know which one before their time-slots) has the damage marker.
- A set of waypoints to be reached during the underwater navigation.
- The number of the buoys positioned in the buoy area.
- The association between the buoy colors and the action the robot has to take upon a successful buoy detection. Possible behaviours are:
    - Clock-wise rotation around the buoy.
    - Counter-clockwise rotation around buoy.
    - Stopping next the obstacle for 30 sec and rising 0.5m.
    - Stopping for 30 sec and going down 0.5m.

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

TBM-1 OPIs
1 damage (red marker) on one of the pipes
1 pipe structure with two yellow pipes connected to each of them
1 gate (made of 2 yellow submersed buoys)
coloured buoys (number may vary, but teams will know in advance how many buoys there are in the water). Four possible colours are possible: white, yellow, red and black

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

6.2.4 Scoring and Ranking TBM-1

The set A of achievements for this task are:

Set A1: Autonomous navigation

- *A robot reaches a given waypoint with an error < 8 m.
- *A robot reaches a given waypoint with an error < 5 m.
- Different waypoints may have a different multiplier. Teams will be informed about this before their time-slot.
- The underwater robot provides geo-localised acoustic and/or optical images of the gate (1 per each gate buoy and per each sensor).
- The underwater robot passes through the gate without touching it (multiplier=2).
- The underwater robot passes through the gate within the first 30 minutes from the start of time-slot.

** To get awarded with these points, the robot has to start from Start 2 location and these achievements have to be accomplished at the beginning of the run and according the given sequence. That is, if waypoint 1 and waypoint 2 are provided, the robot has to reach (or demonstrating clearly the actions to reach it) first waypoint 1 and then waypoint 2.*

Set A2: Monitoring the leak

- The underwater robot provides geo-localised acoustic or optical images of the coloured buoys.
- The underwater robot identifies the colour of the buoy in real-time (1 per each buoy) (multiplier=2), or in post-processing (1 per each buoy) (multiplier=1). If the same buoy is recognised in real-time, recognising it in post-processing does not bring additional points.
- The underwater robot performs the correct action depending on the colour of the obstacle (rotating counter-clockwise and clock-wise around the buoy – at a distance of > 0.5 m and < 2 m, stopping at a distance > 0.5 m and < 2 m for 30 sec and going up for 0.5m, stopping for 30 sec and going down for 0.5m). If more actions are executed for a given buoy, the first one is considered for the scoring
  (multiplier=4).

Set A3: Inspecting the pipeline structure for localising the damage

- The underwater robot measures the length (max error 20% of real dimensions) of the damage marker on the pipe in real-time (multiplier=3) or in post-processing (multiplier=2).
- The underwater robot gives the length (max error 20% of real dimensions) of the damage marker on the pipe in real-time (multiplier=3) or in post-processing (multiplier=2).
- The underwater robot provides images of the black number stamped on the damaged pipe with its position.
- The underwater robot identifies the number of the damaged pipe (either by its geometric position or detecting the stamped number on the pipe) (multiplier=2).
- The underwater robot provides images of the pipeline structure (1 achievement each half of each structure – 2 maximum).
- The underwater robot provides a 3D reconstruction of the pipeline structure (front and rear) (1 achievement per part) (multiplier=2).

Set A4: General

- The underwater robot surfaces in a controlled way at the end of the run.
- The robot transmits live position 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). Note: when the maximum number of interventions reaches the allowed maximum, the run is considered terminated and a new run is restarted.
- The 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 continuing its mission. Only one surfacing is admitted. If the robot surfaces for the second time, 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 competition arena (including OPIs).
- A robot does not conform to safety regulations for the competition.
- A robot is tele-operated (except for safety reasons agreed by the technical committee).
- 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.

6.2.5 Procedures and Rules TBM-1

- The team can decide to start a run either from Start 2 or Start 1 location informing a referee before the run begins.
- To accomplish the achievements (and get the relative points) relative to the waypoints (highlighted in green in 6.2.4) the robot has to start from Start 2 position.
- Each accomplished achievement in set A1 (with the relative scoring) is maintained along all the trial and the achieved score is added to all the possible subsequent runs in the time-slot.
  For example, the robot starts Run 1 from Start 2 location and reaches a waypoint scoring 2 points. Then, Run 1 is terminated and Run 2 starts with the robot beginning at position Start 1. The 2 scored points achieved from the set A1 of achievements will be added to the scoring obtained in the Run 2. However, to score
- One surfacing is allowed for the robot. While on the surface, the robot can get a GPS fix and receive high-level commands from the Control Station. Then, it can re-submerge and continue the ongoing run.
- The Task Benchmark ends when the robots accomplished all the requested achievements or when reaching the time limit (**Time limit: 60 min**), whatever occurs first.
- 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 the actions carried out in real-time.
  Teams must provide the automatically processed data (i.e. 2D/3D maps, etc.) to the referees **within 60 min from the start of post-processing operations** that **begin at the end of the team's time-slot**.

6.2.6 Expected Robot Output for TBM-1

The following information type will be collected for TBM-1 (information about the data format can be found in Section 8):

- **Vehicle Navigation Data.**
- **Mission Status Data.**
- **Map Information:**
  - ***A metric map of the buoy area will be collected but not be evaluated specifically in this Task Benchmark. It will be evaluated for the FBM-1: Mapping the area (see 7.1)***. 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 (a map of the area – e.g. acoustic and the location of the OPIs – the buoys) and be legible by an end-

user/external person.

- **Object Recognition Information:**
    - **Data about the identification of the coloured buoys will be used for the *FBM-2 : Object detection (see 7.2).***

6.3 TBM-2: *Intervention on the pipeline structure*

In this TBM, the robot has to intervene to stop the leak caused by the accident. The robot first has to assess the entity of the damage with direct measurements on the pipes (i.e. staying in touch with one of the pipes for some time). Then, it has to reach the manipulation console, recognising it through the detection of a black number over a red background. Finally, it has to close the valve present on the console and grab a pole-ring and bring that on the surface.

6.3.1 Task Description TBM-2

Robots will start their mission at the position Start 3 (in front of the pipeline structure to investigate) as indicated in Figure 2 and have to:

- Identifying the manipulation console recognizing and determining the shape of a black number over a red marker positioned on the manipulation console (see 6.3.4 achievement set A1).
- Intervene on the pipeline structure: staying in touch with the damaged pipe, closing a valve and finally grab the ring-pole and bringing that to the surface (see 6.3.4 achievement set A2).

6.3.2 Feature Variation TBM-2

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

- Black number over the red background positioned on the manipulation console.

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>

The following input will be provided to teams before the starting of the trial:

- The pipeline structure id (one of the two present in the competition area).
- A high-level schematic map of the pipeline structure with the position and number of the damaged yellow pipe (the robot has to stay in contact for 30 s).

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

TBM-2 OPIs
1 manipulation console 1 valve 1 ring-pole 1 pipe structure with two yellow pipes 1 black number over red background positioned on the manipulation console

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

6.3.4 Scoring and Ranking TBM-2

The set A of achievements for this task are:

Set A1: Identify the manipulation console

- The robot provides images of the black number on the manipulation console (control mode: tele-operated multiplier=1, semi-autonomous/autonomous multiplier=2).
- The robot provides the position of the black number on the manipulation console in real-time (tele-operated multiplier=2, semi-autonomous/autonomous multiplier=3) or in post-processing (tele-operated multiplier=1, semi-autonomous/autonomous multiplier=2).
- The underwater robot gives the geometrical shape of the red marker containing the black number (the contour can be provided) in real-time (control mode: tele-operation multiplier=3, semi-autonomous=4, autonomous=5) or in post-processing time (control mode: tele-operation multiplier=2, semi-autonomous=3, autonomous=4).
- The underwater robot correctly identifies the black number on the manipulation console in real-time (control mode: tele-operation multiplier=3, semi-autonomous=4, autonomous multiplier=5), or in post-processing (control mode: tele-operation multiplier=2, semi-autonomous=3, autonomous multiplier=4),

Set A2: Manipulation

- The robot touches the pipe containing the damage (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot stays in touch with the pipe containing the damage for > 15 s (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot stays in touch with the pipe containing the damage for 30 s (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot provides images of the valve (control mode: tele-operated multiplier=1, semi-autonomous multiplier/autonomous multiplier=2).
- The robot touches the valve (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot closes the valve of 45 degrees (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot closes completely the valve (at least 90 degrees) (control mode: tele-operated multiplier=2, semi-autonomous multiplier=4, autonomous multiplier=5).
- The robot provides images of the ring-pole (control mode: tele-operated multiplier=1, semi-autonomous/autonomous multiplier=2).
- The robot touches the ring-pole (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot moves the ring-pole from the manipulation console (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot surfaces grabbing the ring-pole (control mode: tele-operated multiplier=1, semi-autonomous multiplier/autonomous multiplier=3).

Set A3: General
- The underwater robot surfaces in a controlled way at the end of the run.
- The robot transmits live position 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). Note: when the maximum number of interventions reaches the allowed maximum, the run is considered terminated and a new run is restarted.
- The 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 continuing its mission. Only one surfacing is admitted for getting GPS fix. If the robot surfaces for the second time, the run is terminated and the team must restart a new run.
  It is admitted to surface to change the control type of the robot before the manipulation tasks.

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 competition arena (including OPIs).
- 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 and when admitted – robot in tele-operation control mode).
- 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.

6.3.5 Procedures and Rules TBM-2

- The team starts a run from Start 3 in front of the selected pipeline structure.
- Each achievement (with related scoring) of set A1 accomplished in a run is maintained along all the trial and the achieved score is added to all the possible subsequent runs of the time-slot.
  For example, the robot starts Run 1 and scores 3 points from sets A1. Then in a Run 2 it scores another 5 points from set A1 (different achievements from Run 1, scoring for the same achievements is not counted more than once). In all the successive runs, the number of points from sets A1 will be 8.
- One surfacing is allowed for the robot to get a GPS fix and receive high-level commands from the Control Station. Then, it can re-submerge and continue the ongoing run.
- The team can change the control type once during the run. In that case, the robot can surface and a cable can be connected to the robot (e.g. a floating buoy with a cable connected to the robot). In that case, the robot will be moved to Start 3 position and will be able to re-submerge to continue its run.
- The robot can start from the beginning of a run in tele-operation control mode (connected to a cable).
- The Task Benchmark ends when the robots accomplished all the requested achievements or when reaching the time limit (**Time limit: 50 min**), whatever occurs first.

- 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 the actions carried out in real-time.
  Teams must provide the automatically processed data (i.e. 2D/3D maps, etc.) to the referees **within 60 min from the start of post-processing operations** that **begin at the end of the team's time-slot**.

6.3.6 Expected Robot Output for TBM-2

The following information will be collected for TBM1 (information about the data format can be found in Section 8):

- **Vehicle Navigation Data.**
- **Mission Status Data.**
- **Map Information.**
- **Object Recognition Information.**
    - Some of the requested data relative to the black number on the manipulation console will not be evaluated specifically in TBM-2, but will be evaluated for the FBM-3: Shape recognition (see 7.3).

6.4 TBM-3: *Complete I&M mission at the plant*

TBM-3 combines TBM-1 and TBM-2 and proposes a complete I&M mission at the plant. The robot first has to map the leak caused by the accident, then it moves to the pipeline structure to assess the damage and finally intervenes to stop the leak by closing the correct valve.

6.4.1 Task Description TBM-3

Robots start their mission at the position Start 1 as indicated in Figure 2 and have to:

- Mapping the coloured buoys area providing a geo-localized map with the buoy positions (see 6.4.4, achievement set A1).
- Detecting the colours of each buoy and react in a specific mode (e.g. turning around the buoy) (see 6.4.4, achievement set A1)
- Pass through the gate (see Figure 2 and 6.4.4, achievement set A1).
- Survey the pipeline structure providing images of the pipeline structure of interest and to localize the position of the red marker on one of the two pipes connected to the pipeline structure (see 6.4.4, achievement set A2).
- Identifying the manipulation console recognizing and determining the shape of a black number over a red marker positioned on the manipulation console (see 6.4.4, achievement set A2).
- Intervene on the pipeline structure: closing a valve (see 6.4.4 achievement set A3).

6.4.2 Feature Variation TBM-3

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

- Coloured buoys.
- The position of the damage on one of the four pipes connected to the underwater structures.
- Black number over the red background positioned on the manipulation console.

6.4.3 Input Provided TBM-3

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.

The following input will be provided to teams before the starting of the trial:

- Number of the present buoys in the buoy area.
- The association between the buoy colors and the action the robot has to take upon a successful buoy detection. Possible behaviours are:
  - Clock-wise rotation around the buoy.
  - Counter-clockwise rotation around buoy.
  - Stopping next the obstacle for 30 sec and rising 0.5m.
  - Stopping for 30 sec and going down 0.5m.
- The pipeline structure id (one of the two present in the competition area).
- A high-level schematic map of the pipeline structure with the position of the two yellow pipes connected to it. The damage marker is located on one of the two pipes (the teams do not know which one before their time-slots).

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

TBM-3 OPIs
1 damage (red marker) on one of the pipes
1 pipe structure with two yellow pipes
1 manipulation console
1 valve
1 black number over red background
1 gate (made of 2 yellow submersed buoys)
coloured buoys (number may vary, but teams will know in advance how many buoys there are in the water). Four possible colours are possible: white, yellow, red and black

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

6.4.4 Scoring and Ranking TBM-3

The set A of achievements for this task are:

Set A1: Monitoring the leak

- The underwater robot provides geo-localised acoustic or optical images of the buoys.
- The underwater robot identifies the colour of the buoy in real-time (1 per each buoy) (multiplier=2), or in post-processing (1 per each buoy) (multiplier=1). If the same buoy is recognised in real-time, recognising it in post-processing does not bring additional points.
- The underwater robot performs the correct action depending on the colour of the obstacle (rotating counter-clockwise and clock-wise around the buoy – at a distance of > 0.5 m and < 2 m, stopping at a distance > 0.5 m and < 2 m for 30 sec and going up for 0.5m, stopping for 30 sec and going down for 0.5m). If more actions are executed, the first one is considered for the scoring (multiplier=4).
- The underwater robot provides geo-localised acoustic and/or optical images of the gate (1 per each gate buoy and per each sensor).
- The underwater robot passes through the gate without touching it (multiplier=2).
- The underwater robot passes through the gate within the first 30 minutes from the start of time-

slot.

Set A2: Survey the pipeline structure

- The underwater robot provides images and the position of the centre of the damage (red marker) on the pipe in real time (multiplier=2), or in post-processing (multiplier=1).
- The robot measures the length (max error 20% of real dimensions) of the damage marker on the pipe in real-time (multiplier=3) or in post-processing (multiplier=2).
- The underwater robot provides images of the black number stamped on the damaged pipe with its position.
- The underwater robot correctly recognizes the number of the damaged pipe (multiplier=2).
- The underwater robot provides images of the pipeline structure (1 achievement each half of each structure – 2 maximum).
- The underwater robot provides a 3D reconstruction of the pipeline structure (front and rear) (1 achievement per part) (multiplier=2).

Set A3: Intervention on the manipulation console

- The robot provides images of the black number on the manipulation console (control mode: tele-operated multiplier=1, semi-autonomous/autonomous multiplier=2).
- The robot provides the position of the black number on the manipulation console in real-time (tele-operated multiplier=2, semi-autonomous/autonomous multiplier=3) or in post-processing (tele-operated multiplier=1, semi-autonomous/autonomous multiplier=2).
- The underwater robot gives the geometrical shape of the red marker containing the black number (the contour can be provided) in real-time (control mode: tele-operation multiplier=3, semi-autonomous=4, autonomous=5) or in post-processing time (control mode: tele-operation multiplier=2, semi-autonomous=3, autonomous=4).
- The underwater robot correctly identifies the black number on the manipulation console in real-time (control mode: tele-operation multiplier=4, semi-autonomous=5, autonomous multiplier=6), or in post-processing (control mode: tele-operation multiplier=2, semi-autonomous=3, autonomous multiplier=4),
- The robot provides images of the valve (control mode: tele-operated multiplier=1, semi-autonomous multiplier/autonomous multiplier=2).
- The robot touches the valve (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot closes the valve of 45 degrees (control mode: tele-operated multiplier=1, semi-autonomous multiplier=2, autonomous multiplier=3).
- The robot closes completely the valve (at least 90 degrees) (control mode: tele-operated multiplier=2, semi-autonomous multiplier=4, autonomous multiplier=5).

Set A4: General

- The underwater robot surfaces in a controlled way at the end of the run.
- The robot transmits live position 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. Note: when the maximum number of

interventions reaches the allowed maximum, the run is considered terminated and a new run is restarted.
- The 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 continuing its mission. Only one surfacing is admitted for getting GPS fix. If the robot surfaces for the second time, the run is terminated and the team must restart a new run.
  It is admitted to surface to change the control type of the robot before the manipulation tasks.

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 competition arena (including OPIs).
- 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 and when admitted – robot in tele-operation control mode).
- 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.

6.4.5 Procedures and Rules TBM-3

- The team starts a run from Start 1.
- The <u>*best values of scores obtained in achievement sets A1 and A2 during a run are maintained along all the trial*</u> and the achieved score is added to all the possible subsequent runs of the time-slot.
- One surfacing is allowed for the robot to get a GPS fix and receive high-level commands from the Control Station. Then, it can re-submerge and continue the ongoing run.
- The team can decide to start a run at a location in front of the manipulation console (from Start 3 see Figure 2). In that run the robot can achieve points only from achievements of the set A3. Before the start of the run, the team can change the robot control mode, for instance connecting a buoy with a wire to the robot for tele-operating the robot.
- 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.
- 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 the actions carried out in real-time.
  Teams must provide the automatically processed data (i.e. 2D/3D maps, etc.) to the referees **within 60 min from the start of post-processing operations** that **begin at the end of the team's time-slot**.

6.4.6 Expected Robot Output for TBM-3

The following information will be collected for TBM1 (information about the data format can be found in Section 8):

- **Vehicle Navigation Data.**
- **Mission Status Data.**

- **Map Information.**
  - ***A metric map of the buoy area will be collected but not be evaluated specifically in this Task Benchmark. It will be evaluated for the FBM-1: mapping the area (see 7.1)***. 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 (a map of the area – e.g. acoustic and the location of the OPIs – the buoys) and be legible by an end-user/external person.
- **Object Recognition Information.**
  - **Data about the identification of the coloured buoys will be used for the *FBM-2 : Object detection (see 7.2).***
  - Some of the requested data relative to the black number on the manipulation console will not be evaluated specifically in TBM-3, but will be evaluated for the FBM-3: Shape recognition

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 runs mentioned in each case. Thus, all data must be obtained autonomously by the robots (in real-time) or automatically (in post-processing) and no manual/human data processing is allowed. The data provided for the Functionality Benchmarks will be evaluated by the organiser after the end of the competition.
In the following sections we will define the three Functionality Benchmarks for RAMI Marine Robots:

- FBM-1: mapping the area
- FBM-2: object recognition
- FBM-3: shape recognition.

7.1 *FBM-1: Mapping the area*

7.1.1 Functionality Description FBM-1

This functionality benchmark measures a robot’s ability to explore (cover) a 2D area containing some OPIs that can be detected via optical and/or acoustic imaging. The area to be mapped is the 20 m x 20 m **“buoy area”** (see Figure 2) that contains some coloured buoys.
FBM-1 results will be calculated from data collected in TBM-1 and TBM-3. The highest scoring for the FBM achieved in the performed runs of TBM-1 and TBM-3 is considered for the final FBM ranking.

7.1.2 Feature Variation FBM-1

The variation space for this Functionality Benchmark is as described in TBM-1 and TBM-3.

7.1.3 Input Provided FBM-1

Teams will be provided with:
- GPS coordinates of the boundaries of the area to map.
- Number of the buoys present in the area.

7.1.4 Expected Robot Behaviour or Output FBM-1

The robots will navigate through the buoy area, searching for the coloured buoys located in the area. The following information will be collected (information about the data format can be found in Section 8):

- **Vehicle Navigation Data.**
- **Mission Status Data.**
- **Map Information**
  - A metric map of the buoy area with the position the buoys
  - A map showing the coverage of the area (e.g. optical or acoustic map)
- **Object Recognition Information.**
  - Specifically information related to the position and images of the buoys.

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 which do not comply with the formats specified will not be accepted. Data must be provided to the referees **within 60 min from the start of post-processing operations** that **begin at 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-3.

7.1.6 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 actually covered by the robot. Map coverage cannot exceed 100%. It is computed evaluating the map data and the robot navigation data.
- **Accuracy:** we make use of the Root-Mean-Square Error (RMSE) between real (ground truth) x, y positions of the buoys and the robot's estimated x, y positions of the same features. 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 (Euclidean 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 buoys 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. 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'		Euclidean 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* (or if a certain buoy is not reported on the map) are capped to *MaxError* and error values e_i < *MinError* are set to zero. A possible value of *MaxError* is 15m and *MinError* at 2m, thus any *e* values < 2m are 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.

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: Object detection*

7.2.1 Functionality Description FBM-2

This functionality benchmark (FBM) has the objective of assessing the capabilities of an underwater robot in processing sensor data in order to extract information about observed objects. Specifically, the objects to be recognised in this FBM are the coloured buoys (see Appendix I) located in the ~ 20 m x 20 m **“buoy area”.** Each buoy is identified by a different colour and is a particular instance of the buoy class. The benchmark requires that the robot detects the buoys and identifies them, based on their colour. FBM-1 results will be calculated from data collected in TBM-1 and TBM-3. The highest scoring for the FBM achieved in the performed runs of TBM-1 and TBM-3 is considered for the final FBM ranking.

7.2.2 Feature Variation FBM-2

The variation space for this Functionality Benchmark is as described in TBM-1 and TBM-3.

7.2.3 Input Provided FBM-2

Teams will be provided with:

- GPS coordinates of the boundaries of the area to map.
- Number of the buoys present in the area.
- Each obstacle buoy is identified by a different colour. Colour can be black, white, yellow or red. The colour identifies the object unique ID. Teams need to recognise the colour and localise the object correctly to label them.
- Object ID= [object class, object instance]

Object class	**Object instance**
Buoy	1 – colour White
Buoy	2 – colour Yellow
Buoy	3 – colour Black
Buoy	4 – colour Red

7.2.4 Expected Robot Behaviour or Output FBM-2

The robots will navigate through the buoy area, searching for the coloured buoys located in the area. The following information will be collected (information about the data format can be found in Section 8):

- **Vehicle Navigation Data.**
- **Mission Status Data.**
- **Map Information.**
- **Object Recognition Information.**
    - Position and object instance of each detected buoys.

The optical imaging sensors of the underwater robot must gather the data. Acoustic sensors can be used for the localisation of the obstacle.

The robot must clearly 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 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).

All data requirements have to be met (see data exception regarding maps format). Submitted data which do not comply with the formats specified will not be accepted. Data must be provided to the referees **within 60 min from the start of post-processing operations** that **begin at 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 Benchmarks TBM-1 and TBM-3, the applied procedures and rules for FBM-1 are the same as TBM-1 and TBM-3.

7.2.6 Scoring and Ranking FBM-2

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 colour (instances of buoy class with relative colour – recognised ID).

2. The number of correctly classified (CC) objects (instances of buoy class without the detection of the colour – 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. In case of not detected buoy, a max position error will be defined (e.g. a value of 10 m). The value will be communicated to teams before their time-slots.

7.3 *FBM-3: Shape recognition*

7.3.1 Functionality Description FBM-3

This functionality benchmark (FBM) has the objective of assessing the capabilities of an underwater robot in processing sensor data in order to extract information about the shape of observed objects. Specifically, the objects to be recognised in this FBM are the black number over the red background positioned on the manipulation console (see Appendix I) in the pipeline structure area**.** The benchmark requires that the robot identifies the number and indicate on an image the centroid of the number.

FBM-1 results will be calculated from data collected in TBM-2 and TBM-3. The highest scoring for the FBM achieved in the performed runs of TBM-2 and TBM-3 is considered for the final FBM ranking.

7.3.2 Feature Variation FBM-3

The variation space for this Functionality Benchmark is as described in TBM-2 and TBM-3.

7.3.3 Input Provided FBM-3

- The black number instances will be one of the following five: number “4”, “5”,”6”,”7”,”8”.
- Object ID= [object class, object instance]

Object class	**Object instance**
Black number	“4”
Black number	“5”
Black number	“6”
Black number	“7”
Black number	“8”

7.3.4 Expected Robot Behaviour or Output FBM-3

The robots will have to get images of the black number over the manipulation console.

The following information will be collected (information about the data format can be found in Section 8):

- **Vehicle Navigation Data.**
- **Mission Status Data.**
- **Map Information.**
- **Object Recognition Information.**
    - o Object instance (the specific number identified).
    - o The Length and Width of the smallest rectangle containing the number (see https://www.mathopenref.com/coordbounds.html).

The robot must clearly provide the object ID (Object class, Object instance) of the black numbers. The imagery of the black number 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 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)

- Up to three images with clearly indicated the computed Length and Width of the smallest rectangle containing the number.
- Object image: image files (JPEG, PNG, BMP, PPM).

All data requirements have to be met (see data exception regarding maps format). Submitted data which do not comply with the formats specified will not be accepted. Data must be provided to the referees **within 60 min from the start of post-processing operations** that **begin at the end of the team's time-slot**.

7.3.5 Procedures and Rules FBM-3

As Functionality Benchmarks are calculated from data collected during the Task Benchmarks TBM-2 and TBM-3, the applied procedures and rules for FBM-3 are the same as TBM-2 and TBM-3.

7.3.6 Scoring and Ranking FBM-3

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

1. The correct identification (CI) of the black number (recognized number) (0 or 1).

2. Length Error (LE) for the length of the smallest rectangle circumscribing the number. The LE will be calculated based on the Euclidean distance error between the provided value and the ground truth.
   Note that in case that *LE* > *MaxErrorLength, LE* is capped to *MaxErrorLength.*
   The lowest LE over the provided three images is considered.

3. Length Error (WE) for the width of the smallest rectangle circumscribing the number. The WE will be calculated based on the Euclidean distance error between the provided value and the ground truth.
   Note that in case that *WE* > *MaxErrorWidth, WE* is capped to *MaxErrorWidth.*
   The lowest WE over the provided three images is considered.

LE and WE are then normalised as follows to produce the Geometric Length Error (GLE) and Geometric Width Error (GWE):

$$GLE = (MaxLE - LE) / MaxLE \quad (5)$$

This function normalises GLE between [0…1]. The value of *MaxLE* is based on the maximum value of *LE* of all teams competing.

And for GWE:

$$GWE = (MaxWE - LE) / MaxWE \quad (6)$$

This function normalises GWE between [0…1]. The value of *MaxWE* is based on the maximum value of *WE* of all teams competing.

The formula used for scoring the FBM is then: SCORE=2.5*CI+GLE+GWE.

8. Expected output

This section describes how the data produced by the robots are collected and produced and the different requested data types is present.

8.1 Data collection and post-processing analysis

All data must be produced in **real-time** by the robot or **automatically** by the robot/software **in post-processing**.
The team must provide a set of files saved in an USB memory given to the teams before the task. The USB memory will be formatted with NTFS file system.
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 the actions carried out in real-time.
Teams must provide the automatically processed data (i.e. 2D/3D maps, etc.) to the referees **within 60 min from the start of post-processing operations** that **begin at the end of the team's time-slot**.
In case of post-processed data (e.g. object recognition), this must be done by using software and no human/manual processing is allowed. *The operator with a referee supervising will launch the software and the referees will collect the output. These produced data will be evaluated for scoring.* Referees will control the respect of this procedure during the 60 min given to the team to process data.

All data requirements have to be met (see data exception regarding maps format). Submitted data which 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 RAMI METRICS competition.

8.2 Output data format description

The output provided by the teams is a set of files that must be saved in a USB. The USB stick will be formatted with NTFS file system and all the files should be saved in a folder with the name of the team and the date and time of the time-slot (e.g. YYYYMMDD_HHMM, TEAM_X_20210715_1530).
The different types of data produced by the robots are:

1) **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 time.
- Position: Latitude, Longitude (in decimal degrees).
- Heading: (in degrees).
- Depth: Sea domains (in meters).

2) **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 time. 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. The Time can be used as one of the measurements for Functionality Benchmarking.

3) **Map Information:** this must include the following information and formats:
- The map file: (KML format – Keyhole Markup Language). KMZ files with a kmz extension.
- Abstract Level information: OPIs, Features. This should be integrated in the kmz file.
- 2D/3D map in raster or vector format with geo-reference information for high bandwidth data.

4) **Structure Map Information:** this must include the following information and formats:
- File with the name 'structure_map' containing the built map of the underwater structures. 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 ('structure_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 'structure_map.txt' containing the two requested measurements in millimeters, each one in a different text line (width of the marker, height of marker).

5) **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 features (dimensions, shape, etc.).
- Target image: image files (JPEG, PNG, BMP, PPM).

6) **Robot-Control Station 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 until to the day before the run.

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 or CloudCompare, which support a large number of formats and are usually not unfamiliar to ROS users. 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

9. Contact information

Official information concerning rules, interpretations, and information about the competition can be found on RAMI Marine Robots website https://sites.google.com/view/ramimarine2021laspezia or you can contact us at im@metricsproject.eu.

Appendix I: Objects of Potential Interest (OPI)

This appendix describes the Objects of Potential Interest (OPI) that are found in the RAMI Marine Robots 2021 Task and Functionality Benchmarks.

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

More images of the OPIs will be available on the website.

It also includes a summary of the OPIs as help.

The list of OPIs regarding to the Task Benchmarks are:

1. <u>Gate and coloured buoys</u>

The marine buoys OPIs will be soft reflective (both acoustically and optically) approximately spherical objects (see Figure 4) 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 0.20-0.40 m. The gate will be constituted by two orange buoys OPIs positioned at 2 m of distance with OD of about 0.2 m. Other buoys (OD=~30 cm) will be used in the "buoy area". They can have be of one of the following colours: black, white, yellow, red. The colour defines the type of movement the underwater robot should do.

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).

It is suggested to use adaptive area survey approaches to get good quality images of the buoys from a short distance.

Figure 4. Image of the buoy outside of the water (top-left) used for the gate and of a red buoy underwater (coloured buoys in the "buoy area")(top-right). The OD of the sphere is about 30 cm. (Bottom) the buoys with four possible colours.

2. <u>Pipes and pipeline assembly structures</u>

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 5). 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. 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 6). Each of these pipes will be identified by an ID number (from 1 to 4) painted in black colour on the pipe surface. A red marker marks the damaged pipe as seen in Figure 7.

Figure 5. 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).

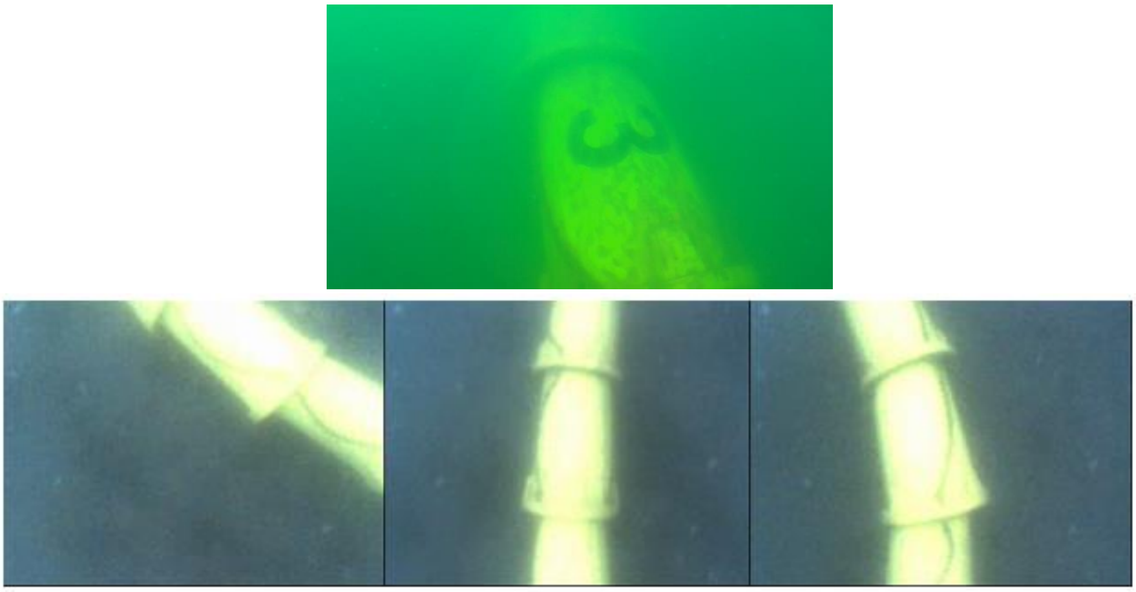

Figure 6. Pipe composed of yellow cylinders (OD=0.5 m). Two pipes will be positioned starting from the piping assembly. The pipes will be at least 3 m long. On each pipe a black number (from 1 to 4) will be stamped. (Top) Black 3 number is visible on the pipe. (Bottom) Images of one pipe.

Figure 7. Marker to represent the damage on the pipe.

3. Manipulation console

Manipulation consoles are white panels positioned over the pipeline assembly structures (see Figure 8) (one console on each pipeline assembly structure). On each manipulation console a cross-shaped valve is placed is like the one shown in Figure 8 and Figure 9. The cross-shaped handle (OD of the handle=10/20 mm, length of each cross arm = 400 mm, orange in colour is linked at its middle to a vertical axis shaft and is thus operated on a horizontal plane. The vehicle should then turn the handle counterclockwise (or clocksiwe), by at least 90 degrees. A negligible friction has to be expected to perform the handle rotation.

A pole (OD=10/20 mm, L= 0.8 m, orange in colour) with a ring on its top (ID 100/150 mm) (see Figure 8 and Figure 9) will be inserted in a 400 mm deep, vertical axis hole, located in the horizontal panel of the console. The vehicle should catch, extract and recover the stick up to the surface, by grabbing it either along the vertical stick or at/in the upper ring.

Finally, the black number over the red background is visible on it position on the manipulation console. One number will be present on each console.

One red card roughly of A4 of size with black border will be placed horizontally over the manipulation console (as shown in in Figure 8).

For the A4 cards, the exact shape and dimensions may differ from this model and will not be known in advance but the colour and size will be similar to this. The red card has a black number printed on it (numbers vary from 4 to 8 as below). The number will be long from 75% to 90% of the longest dimension of the marker (different numbers may have different measures).

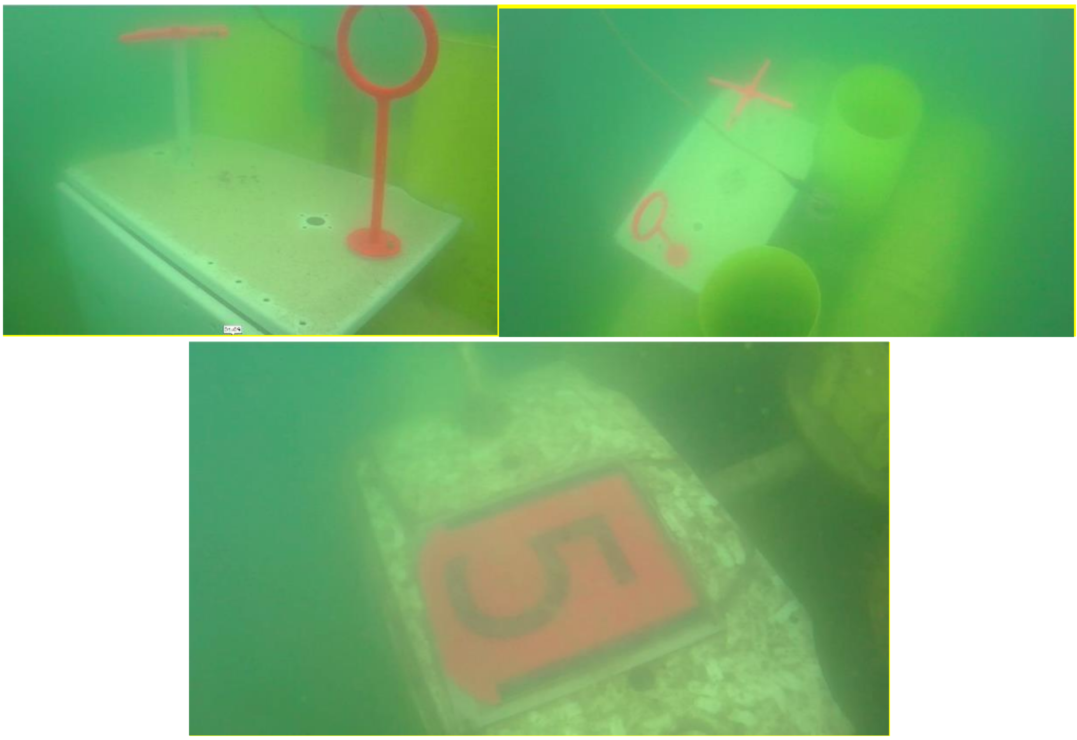

Figure 8: Manipulation console with the cross-shaped lever amd the ring-pole (top). (Bottom) the black number “5” on the red background is visible.

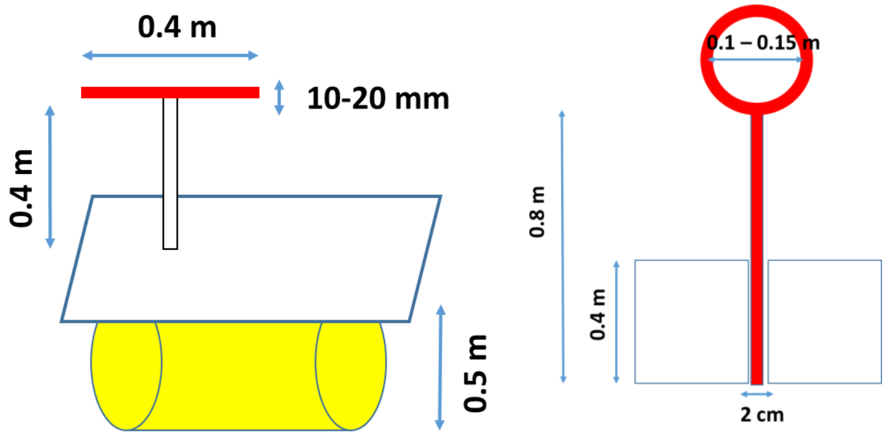

Figure 9. (Left) Front view of the cross-shaped lever. The lever is linked to a vertical shaft supported by the horizontal plane of the console. The horizontal plane is fixed to one pipe of the underwater piping assembly structure. (Right) View of the pole with the ring (the ring-pole).

SUMMARY OF OPIs

OPI	Task Benchmark	Description	Picture
Gate and coloured buoys	TBM-1 TBM-3	The sea gate will be marked using two (both acoustically and optically) approximately spherical orange buoys. Their diameter will be between ~0.2 m. 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. Similar buoys in shape and size (OD ~0.3 m) will be used in the “buoy area”. Colours can be black, white, yellow and red.	 
Pipe assembly structures	TBM-1 TBM-2 TBM-3	The two pipeline assembly structures that will be located underwater will consist of yellow cylindrical pipe sections arranged to form a 3D structure. They will have a diameter about 0.5 m and a length of about 1.5 m. The assemblies will be placed on the bottom and will not be moved during the competition. The dimensions of the whole structure are: 2 m (front area) x 3 m x 1.8 m (height).	
Underwater pipes	TBM-1 TBM-2 TBM-3	From each structure, two pipes will depart. The underwater pipes will have a diameter about 0.5 m and a length of at least 3 m. They will be connected to the piping assembly structure. On each pipe, a black number will be stamped reporting the pipe ID. Possible numbers are:1,2,3,4.	
Red marker for damage on a pipe.	TBM-1 TBM-3	Red marker to indicate damage to the pipe. It is positioned on one of the yellow pipes.	

Manipulation console (valve and ring-pole)	TBM-2 TBM-3	A manipulation console is present on each pipeline assembly structure.On the manipulation console a cross-shaped valve is placed/ The cross-shaped handle (OD of the handle=10/20 mm, length of each cross arm = 400 mm, orange in colour is linked at its middle to a vertical axis shaft and is thus operated on a horizontal plane. A pole (OD=10/20 mm, L= 0.8 m, orange in colour) with a ring on its top (ID 100/150 mm) is also inserted in a 400 mm deep, vertical axis hole, located in the horizontal panel of the console. The pole is named ring-pole in this document.	
Black number on red card positioned on the manipulation console	TBM-2 TBM-3	One red card roughly of A3 of size with black border will be placed horizontally over the manipulation console. For the A3 cards, the exact shape and dimensions may differ from this model and will not be known in advance but the colour and size will be similar to this. The red card has a black number printed on it (numbers vary from 4 to 8 as below). The number will be long from 75% to 90% of the longest dimension of the marker (different numbers may have different measures). An indicative number is shown in the figure.