ESMERA
BOOSTING ROBOTICS INNOVATION

ESMERA ENERGY CHALLENGES

The energy sector covers a wide range of operations. However, many of these operations are undertaken in hazardous or extreme environments and they are frequently mission critical, meaning that failure can result in very heavy cost penalties. Many tasks are undertaken in the outdoors, often facing challenging weather conditions, and can involve land-based, surface-based, sub-sea or air access. Other operations are carried out in confined areas where human access would be dangerous. While robots have much potential in these environments, they also have to reach high levels of safety and robustness in order to be accepted as viable alternatives to current methods.

ESMERA has identified several industrial challenges and classified the needs for further technical advances in 2 main challenges. Under each Energy challenge ESMERA propose two options of industrial challenges that can be solved, option a) ESMERA proposed challenge and option b) Open challenge

Energy Challenge 1: Inspection and maintenance of structures in hazardous environments

Inspection is a key function in maintaining safe and effective facilities in the energy sector. Robots can play a key role in automating much of the inspection workload and also performing immediate maintenance or other interventions where the need is detected.

As defined in the Robotics 2020 Multi-Annual Roadmap, the key abilities that are paramount for this challenge are:

- **Motion ability:** A key attribute of the robots needed for this challenge is that they have to be able to move around difficult environments often with hazardous and difficult terrain. The robots also have to locate themselves accurately in environments with few features or with many similar features.
- **Perception ability:** Inspection is a key feature of the tasks and the ability to perceive features in the environment and interpret sensor data correctly will be a key determinant of success in this challenge.
- **Decisional autonomy:** The robots will have to operate autonomously for significant periods of time during a working day. Arguably the robot will have to exhibit Decisional Autonomy at, at least, Level 6 as defined by the Multi-Annual Roadmap, i.e. Task Autonomy.
- **Dependability:** The robots will have to operate reliably for significant periods of time to meet the requirements of the challenge providers, i.e. operators of energy plant. This will require exhibiting Dependability of at least level 4 and up to level 6 to meet the criteria for successful exploitation.

It is expecting from the system to fulfill the following metrics:

- **Navigation capability:** Successfully navigating around, or through, energy facilities consisting primarily of concrete and steel structures, notably pipes, vessels, walls and beams.
- **Accuracy:** Maintaining an accurate record of the vehicle position with reference to pre-existing maps and models or, where none are available, with reference to the starting point of the vehicle, and maintaining an accurate record of the geometry and state of specified structures within the facility and noting differences from previous inspections and, where they exist, maps and models.
- **Ability to fulfill the simple tasks*:*** Optionally, carry out light maintenance work of specified structures such as cleaning

- **Energy efficiency:** Maintaining, at all times, sufficient energy levels to return to the start point of the inspection

Under the above challenge ESMERA project proposes two options. The proposer must address at least one of these challenges although addressing more than one or highlighting where elements of the proposed system could be used for the benefit of more than one system would be beneficial.

A) ESMERA proposed challenges: this challenge is extracted from five industrial use cases which are:

ENERGY CHALLENGE 1.A1 (E1.A1)

Internal inspection of pipes in refineries. Oil refineries have pipes flowing between processes that need regular inspection for corrosion. Pipe sizes vary between 1 to 36 inches with the average being 12 inches. After being inserted into the inspection robot needs to:

- Carry out a high resolution, visual inspection of the pipe and note any areas of corrosion, defects, deformation or coke build-up and maintain a record of the entire inspection for later review
- Optionally carry out NDT (e.g. ultrasonic testing) on the pipe
- Be able to navigate past obstacles such as bumps, bends, branches and valves
- Be able to operate in horizontal and vertical pipes
- Be able to work at temperatures between 0^{0}C and 40^{0}C

Weight is a priority and the robot should not exceed 10kg. Also for final testing at the customer site and for the final product the robot needs to be designed to ATEX Zone 1.

This challenge is provided by the company TÜPRAŞ.

Figure 1: Pipe inspection

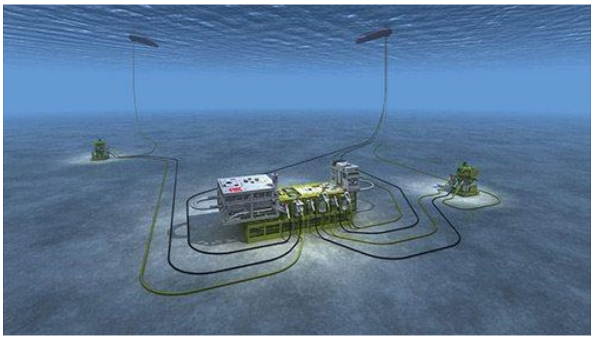
ENERGY CHALLENGE 1.A2 (E1.A2)

Surface and sub-sea facility Inspection: This challenge is to provide a multi-purpose survey / inspection surface / sub-sea robot that is capable of:

- Autonomous survey inspections along a predetermined route
- Whole structure inspection following structure geometry, e.g. pipelines, buoys or ship hulls. The robot is to determine suitable scan patterns where appropriate and adjust to local sea currents.
- Deployment of equipment at sea undertaken through teleoperation once the robot has arrived autonomously at the site
- Optionally, performing light

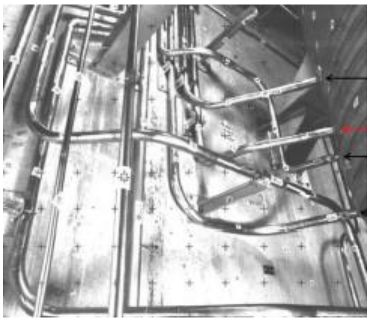
Figure 2: Sub-sea pipeline

maintenance such as ship hull cleaning	

ENERGY CHALLENGE 1.A3 (E1.A3) **Sub-sea facility Inspection:** This challenge is to provide a multi-purpose autonomous survey / inspection robot that is capable of: • Site (sea-bed) survey operations • Facility Inspection noting any significant defects or corrosion. It would also be necessary to compare results with previous inspections • Perform light duty cleaning of structures such as foundation piles in order to enable inspection • Autonomous location at pre-defined sub-sea location • Autonomous deployment and return to launch point	 **Figure 3:** Example of sub-sea oil production facility

ENERGY CHALLENGE 1.A4 (E1.A4) **Oil refinery / terminal inspection:** This challenge is to provide an inspection and monitoring robot for onshore oil refineries and terminals. The primary duties are inspection of facilities and detections of dangers, such as leaks. Particular requirements for this challenge are: • Energy autonomy, i.e. either providing long term operation recharging or re-fueling or providing automatic recharging / refueling with multiple robots capable of providing continuous operations. • Being able to locate itself accurately relative to a map or model of the facility and update such a map or model when discrepancies are found. • Facility Inspection noting any significant defects or corrosion. It would also be necessary to compare results with previous inspections • Detect hazards, such as leaks, and raise an alarm • Perform pre-determined operations (tasks) on receiving an operator command • Perform operations in a low connectivity environment that may have connectivity dead spots, low communications rates, etc. • Also for final testing at the customer	 **Figure 4:** Example of sub-sea oil production facility

site and for the final product the robot needs to be designed to ATEX Zone 1.	

ENERGY CHALLENGE 1.A5 (E1.A5) **Inspection of nuclear facility closed cells:** Many nuclear facilities feature cells (rooms) with limited access and poor viewing facilities. A robot is required that can enter these facilities through limited access points and perform visual inspections. Cells are of variable sizes but it is not uncommon to have cells of 6m x 6m x 20m. The cells are typically populated with steel structures, notably pipes, vessels and beams. Cells are often crowded with equipment. The robot required for this challenge should meet the following requirements: • Be capable of entering the cell through a 100mm porting hole. • Be capable of being retrieved in the event of failure. • Be capable of withstanding decontamination clean-down or being economic enough to be treated as a disposable consumable. • Capable of accessing all areas of the cell. In some cases this may not be possible for purely floor based robots. • Carry out full facility inspection and building a full 3D map of the cell equipment. A minimum requirement is to provide a full 3D photograph / geometric model of the cell • Have a means of communication with control equipment located outside the shielded cell. • Perform an automatic return to recovery point in the case of loss of communications • Monitor battery life and perform an automatic return to recovery point before battery expiry	 **Figure 5:** Nuclear plant inside closed cell

B) Open challenge (ENERGY CHALLENGE 1.B (E1.B))

Any other proposal for similar technologies is eligible for funding, provided that a thorough explanation of the industrial needs is presented. The proposals will also have to clearly identify the state of the art in commercially available solutions and highlight the differences/advances over it. More specific each proposal in order to be in line with the ESMERA requirements has to provide:

- Clear indication of the company, institution or other that are in need of the proposed solution (no funding is allocated to challenge providers)
- Description of the problem that the company or companies need to be solved.

- Proof that currently there is no comparable solution (concept or approach, performance, cost…) in the market.

Energy Challenge 2: Advanced high-level control methods / systems for robot operations

Energy Challenge 2 involves the development of planning and control systems for robots in hazardous environments. The current situation in several areas of the energy industries is that tele-operated robots are used for performing tasks that would otherwise be hazardous for humans to perform. However, teleoperation is not the most efficient form of control. Nevertheless, for various reasons, ranging from investment considerations to provable safety requirements, it is difficult to introduce autonomous robots into many of those applications. There is a requirement, nonetheless, for gaining some of the benefits of intelligent robots, either by retro-fitting more advanced control systems or using more advanced planners / controllers in incremental steps in order to make the case for autonomous operations.

The key abilities involved with this challenge are:

- **Cognitive Ability:** The robots will have to understand and reason about its environment and task in order to meet this challenge. Arguably the robots will have to operate somewhere between levels 6 to 9 to achieve all the aspects of the challenge, albeit in a limited environment. Nevertheless, it is likely that the robots will have to operate at the state of art, if not beyond, to achieve the necessary performance.
- **Decisional Autonomy:** The robots will have to operate autonomously for significant periods of time during a working day. Arguably the robot will have to exhibit Decisional Autonomy at, at least, Level 6 as defined by the Multi-Annual Roadmap, i.e. Task Autonomy.
- **Perception Ability:** The robot for this challenge needs to have a good understanding of its environment based on sensor inputs. The environments often encountered in the energy industries present challenges for current perception systems that require a step change in performance.
- **Interaction Ability:** The robots in this challenge have to interact, albeit remotely and intermittently, with operators who need to understand the current situation and authorise autonomous operation based on a good situational awareness. This requires a two way interaction
- **Dependability:** The robots will have to operate reliably for significant periods of time to meet the requirements of the challenge providers, i.e. operators of energy plant. This will require exhibiting Dependability of at least level 4 and up to level 6 to meet the criteria for successful exploitation.

It is expecting from the system to fulfill the following metrics:

- **Task planning capability:** Planning the task sequence of a robot based on a pre-determined mission and, the perhaps incomplete, known geometry of the task cell, and planning the detailed sequence of moves to complete a task.
- **Decisional autonomy:** At key stages to determine the state of the task cell or key elements within the cell and to re-plan the mission based on these readings, and to spontaneously react to external and internal (to the robot) signals and alarms and adjust the plan appropriately.
- **Data storage ability:** To maintain a record of all actions and readings during a mission

Under the above challenge ESMERA project proposes two options. The proposer must address at least one of these challenges although addressing more than one or highlighting where elements of the proposed system could be used for the benefit of more than one system would be beneficial.

A) ESMERA proposed challenges: this challenge is extracted from two industrial use cases which are:

ENERGY CHALLENGE 2.A1 (E2.A1)

Control and Inspection system for offshore platform crawler. A planning and control system is required to be retrofitted onto an existing crawler robot with manipulator (built by TechnipFMC) to perform operations on an offshore oil platform. The control system needs to plan the daily mission of the robot in performing inspection and maintenance tasks. Specifically the control system should provide the robot with the capability to:

- Autonomously plan a route around the platform to take in designated inspection points and way-points.
- Plans to include navigation around the platform, including climbing stairs, taking readings at designated points and undertaking Ultrasonic testing of specified components.
- Accurately assess the position of the robot within the platform.
- Make inspections of various gauges, dials and valves and, if necessary, re-plan mission based on readings.
- Open or close valves based on mission parameters and sensor data.
- Undertake metrology readings and produce 3D map of platform.
- Detect leaks and perform pre-specified tasks on detection
- React, i.e. re-plan, to any external or internal alarms or signals as according to pre-determined rules including returning to charging station before battery is exhausted.

The control system and any sensors should be capable of being certified to ATEX Zone 1.

Figure 6: Offshore oil platform environment

ENERGY CHALLENGE 2.A2 (E2.A2) **Perception and planning system for nuclear decommissioning.** Sellafield facilities are mostly made up of process plant and equipment. To decommission these facilities the internal plant needs to be cut up and removed. The main plant to be cut are pipes and vessels of various sizes. Currently this is undertaken through manual teleoperation. The intention is to move to more autonomous operation through a series of incremental steps, starting with a system that can advise operators of the optimum cutting strategy with the next step being the control of the robots after authorisation from the robots. The Challenge covers these first two steps. To enable in-facility cutting and moving of plant there is a need to dynamically model local plant (eg pipes and vessel) and provide real time cut paths options that an operator can select and use with advice to the operator of optimal cut lines that are both accessible and that will maximise stability of the rest of the plant. Following the choice of the desired cut path the system will monitor the cut and modify the cut path in real-time to maximise the stability of the plant and the effectiveness of the operation. To achieve the monitoring and modelling system should, ideally, be capable of operating at 30 frames a second to account for the plant movement during cutting. The key characteristics of the systems are: • Dynamic modelling of plant • Real time cut path planning • Real time updating to allow for plant movement during the dismantling process tasks on detection The system would need to: 1. Produce an initial geometric and physics model of the plant sub-set to be decommissioned based on sensor data and existing design data (although the latter is not always available in an accurate geometric state) 2. Determine the optimum cutting pattern for safe decommissioning of the plant sub-set which include the plant support and holds points during	 **Figure 7:** Example of complex pipework in a UK nuclear facility

cutting 3. Monitor the plant behaviour as the cutting proceeds 4. Modify, in real-time, the optimum cut path to maintain safe and stable cutting The initial system would display the system to a human operator in charge of tele-operating the remote cutting equipment, but the output should be capable of also being input to a semi-autonomous robot system. The control system will be located outside the cell but sensors are likely to be located inside the cell.	

B) Open challenge (ENERGY CHALLENGE 2.B (E2.B))

Any other proposal for similar technologies is eligible for funding, provided that a thorough explanation of the industrial needs is presented. The proposals will also have to clearly identify the state of the art in commercially available solutions and highlight the differences/advances over it. More specific each proposal in order to be in line with the ESMERA requirements has to provide:

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