Robotic Challenges in Energy for the First Open Call for ESMERA Experiments (ESMERA-FOCE)

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Expected duration:	9 months for experiments in Phase 1 (max 18 months for experiments advancing to Phase 2)
Total budget for the 1st Call:	€2,200,000 (maximum 16 experiments for the Phase 1 and maximum 8 experiments for the Phase 2). Maximum funding per proposal: €200,000 (€75,000 for the Phase 1, €125,000 for the Phase 2, including 25% indirect costs)
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Glossary/ Acronym Terms

ESMERA: European SMEs Robotics Application

SME: Small and Medium-sized Enterprises form a specific target group for the experiments and the CCs in ESMERA. The term is used in the same way as defined by the EC (http://ec.europa.eu/growth/smes/business-friendly-environment/sme-definition/).

Experiment: An experiment is a small to medium sized scientific research and/or technology development project carried out by a team of at least one SME and potentially additional research institutions, robot manufacturers and robot and automation users, which typically lasts no longer than 9 months.

CC: A Competence Centre is a physical infrastructure supporting different user groups by providing state-of-the-art hardware, software components, and support in form of experienced staff.

GNSS: Global Navigation Satellite Systems

ROS: Robot Operating System

RTD: Research and Technology Development.

ALARP: As low as reasonably practical

POCO: Post Operational Clean Out

QA/QC: Quality assurance/Quality control

TRL: Technology readiness level

Robotic Challenges in Energy for the First Open Call for ESMERA Experiments

The ESMERA project calls for contributions that propose solutions to two predefined real-life challenges in the energy area involving but not limited to nearly autonomous robots or human-robot collaboration and demonstrating these in real-world scenarios. In the first challenge, we ask SMEs to find a solution to "**Inspection and Intervention in Oil-Gas Environments**" problem in oil and gas area within "**ESMERA-E.1**" Challenge ID. The problem description, desired robotic technology and the support from the Challenge Provider, TechnipFMC, is explained in Section 1.

The second challenge in the energy area is in the nuclear area and we ask SMEs to find a solution to "**Nuclear Waste Sorting**" problem within "**ESMERA-E.2**" Challenge ID. The problem description, desired robotic technology and the support from the Challenge Provider, ANSALDO NUCLEAR, is explained in Section 2.

1. ESMERA-E.1 – Inspection in Oil-Gas Environment

1.1. ESMERA-E.1 challenge description

Introduction

The oil and gas industry is one of the biggest sectors in the world and the demand for oil and gas is high and expected to remain high in the future. Extracting the oil and gas out from the ground (onshore or offshore) is becoming more and more challenging due to the increasingly stringent regulations and the location of the facilities at the remote and hard-to-reach environments. To improve the working conditions and to increase the efficiency, it is necessary to robotize several inspection and maintenance tasks.

One of the biggest challenges in this area is the inspection and maintenance of the oil and gas platforms which is highly expensive and ecologically sensitive (especially in offshore). In case there is a problem during the maintenance, it might result in failures which have significant long-term and irreversible consequences to both nature and the human environment. Using robotics in inspection and maintenance could significantly improve the safety, inspection accuracy, and efficiency. In addition to its environmental benefit, the usage of robots will also help companies to reduce costs. One of the main difficulties in this area is robots are lack of navigation and localization autonomy.

The current process

Currently, inspection and maintenance tasks are performed by human operators, which is risky and expensive. Crawler robots are used in other areas without being fully autonomous in navigation and lacking ATEX certification. Some trials have been performed using vision-based navigation and positioning solutions using standard cameras, stereo vision solutions, LIDAR and other common positioning and mapping solutions. However, these solutions have not been proven to be fully compliant with the requirements.

Challenge scenario

In this call, we are looking for a localization/navigation/perception system which mainly focuses on positioning, environment mapping and autonomous navigation capabilities to perform various tasks in a platform/refinery. The system should be able to work in aggressive environments such as toxic gas, marine environment and extreme temperatures on both offshore platforms and onshore process factories/refineries (see Figure 1.1). It is also expected from the system to have an interface with the robot supervision, managing the maintenance/inspection scenario in ROS. Solution providers should consider the following constraints: i) the robot should be able to work in global navigation satellite system denied environment (i.e. no GNSS available), ii) the usage of retrofit external positioning sensors/beacons is limited since it should work in aggressive environments (passive markers should be acceptable) and iii) they should consider ATEX certification limitations in the design which are explained in performance metrics.

Figure 1.1. Some of the tasks that is expected from the robot to perform

The developed system should be able to locate the equipped robot in front of various items (such as valves) in the 3D environment with a centimetric accuracy, giving the possibility for the robot to climb stairs, routing the robot to the preferred direction in order to execute the given task at the desired position. The robot where the navigation/perception system will be installed will have to perform tasks such as:

- crawling on offshore platform decks,
- visual/audio inspection (routine inspection, gauges, safety equipment),
- leak inspection,
- opening/closing valves,
- liquid/gas sampling,
- Ultrasonic Testing /vibration inspection,
- 3D reconstruction of the environment for metrology applications,
- light payload maintenance tasks.

In the end of the project it is expected to have a finished and tested positioning, mapping and navigation system including hardware and software, ready for integration on a robot. Any additional functionality that will make the above listed task easier/more efficient will be positively evaluated.

General requirements

The robot should be capable of to verify the following features:

1. ***Collision avoidance performance:*** The developed solution must have collision avoidance protocol and use a communication protocol like Ethernet, Profinet, to exchange data and route towards the instructed/desired direction. The system should stop when it detects human and should replan its path when it detects an obstacle.
2. ***Software:*** The product should have an easy interface in order to use the output of localization and mapping system in a robot HMI/Supervision system.
3. ***Intelligence:*** The product should have the following abilities: reliability of computer vision, automation of tasks, detection of surrounding and sharp localization, navigation and collision avoidance, as much as possible embedded calculation vs low connectivity

4. ***Control:*** The system shall work continuously except for the power recharge phase of the equipped robot. Even if the robot is operated by a human operator, the system has to remain operational for mapping and localization.
5. ***Certifiability***: The developed solution is expected to be ready for certification for ATEX zone 1 (IIB T3). It should be noted that the pure certification with BV/ Apave/ Ineris is not part of the scope of work but a design as per ATEX standards is required. The main limitation is that the optical power should be lower than 35mW according to the selected technology and various criteria of protection mode can be considered. Except the criteria on optical power, solution providers need to confirm the possibility to embed the sensor in a safe box without disturbing the sensor functionalities and accuracy.

Performance metrics

The navigation system should verify the following features to allow the robot to perform its inspection and maintenance tasks:

1. ***Adaptability:*** It is expected from the developed solution to work in different conditions such as different weather conditions (snow, fog, sun, rain etc.) and different temperatures in the scale between -10 ºC to 40ºC.
2. ***Accuracy:*** The positioning, mapping and navigation accuracy should be centimetric. At the specific defined positions, another system like telemetry need to confirm the position of the robot (i.e. distance from the defined position to a wall). Various defined positions can be marked on a prepared routing, the robot will navigate on this routing withhold point on the defined position. Then the accuracy can be checked with telemetry. Moreover, the speed of the robot is limited to 4 km/h.
3. ***Repeatability:*** The positioning and mapping repeatability should be 1 cm for 10 m displacement.
4. ***Power Consumption:*** It is expected from the solution to be powered by the robot batteries: 48V DC consumption limited to 5A. Expectation from the system is to consume as low energy as possible.
5. ***Lightweight:*** The size/weight factor of the solution should be as small as possible. It should be noted that the weight constraint is priority and it is expected from the solution to be as light as possible. The weight is considered about maximum 10 kg and the footprint is not more than 400 mm x 200 mm.

1.2. Support to the experiment

Support from the lead Competence Center

The CEA CC is responsible for the challenge and the currently available equipment list can be seen in our website. The environment for the experiment is set in CEA CC and the selected proposals can do their experiments in CEA CC during Phase I. The Challenge Provider will provide a 3 m x 3 m x 2 m cell with valves, a stair and an obstacle to simulate the environment. Other ESMERA CCs are also available to support the development process if requested.

Support from the Challenge Provider

The Challenge Provider provides a system which involves a crawler robot equipped with a manipulator on it (see Figure 1.2) for the solution providers who mostly focus on navigation/localization/perception system design. The proposers are free to demonstrate the effectiveness either as standalone systems or integrated in robotic hardware platform provided by the Challenge Provider.

Figure 1.2. Example of robot platform that would be provided by the Challenge Provider

Moreover, the Challenge Provider provides an access to their laboratories if it positively affects the outcomes of the experiment, or if it is required to make cell hardware available for the experiment. Access would possibly be more convenient in the last phase of the experiment setup after a phase of integration at the SME company taking the challenge. The Challenge Provider will also provide a software engineer to test solutions and check some software interfaces.

2. ESMERA-E.2 - Nuclear Waste Sorting

2.1. ESMERA E.2 challenge description

Introduction

One of the challenges in nuclear area is the sorting of debris, resulting from the decommissioning of fuel elements of Magnox type reactors. This process seeks to retrieve highly radioactive parts from the debris that are contaminated by the fuel during their operational life. These are usually pieces of the outer shell originally containing the nuclear fuel, as well as springs or other small items.

The debris material, called *Magnox swarf,* was originally stored in concrete wet silos; however, due to the high risk of accidents, this method of storage is no longer considered as the best solution. Storage in dry form in discrete containers offers the advantage of being more passive and more practical to manage. Processing plants have been constructed to receive dry Magnox swarf, encapsulate it in cement and seal it in steel drums. The main problem in this case is that the swarf contains material with different activity levels that must be sorted and stored with different standards. In particular, the contaminated Magnox springs exhibit high levels of radioactivity and are thus classified as *medium-level waste*. They must be picked from the rest of the swarf and put in special led pots which are subsequently packaged into larger containers.

The robotic system should be able to operate inside a confined environment and proofed for medium levels of radioactivity. Batches of swarf will be transferred on trays by means of conveyor belts. Magnox springs should be separated and put in lead containers. Robots, sensors and other devices should be resistant to medium radiation levels (i.e. full resistance or low maintenance).

The current process

Currently, this sorting procedure is mainly performed by manually-driven, remotely-operated manipulators. A human-robot interface is used (monitor, with a joystick-like device) for manually driving the manipulator and spring grasping. The process is laborious and requires constant attention by the operator that leads to strain, fatigue and consequent errors. However, since this is a rather complicated task (the springs are only a few centimetres long), it results in very long processing times.

In fact, it is estimated that only 100 kilograms of waste are processed per day which means that with this rate the processing of all of Magnox swarf will require 6-7 years. In the current process, 20-30 springs per day are manually taken from approximately 100 kg of waste. A major progress is expected from the introduction of automated (or human-assisted) robotic systems capable of performing the task with higher reliability and efficiency. A self-contained sorting cell allowing autonomous, reliable and fast handling of Magnox swarf, for safe downstream waste management, and extending the principles of ALARP[1] for operator safety is expected to greatly reduce the risk of accidents.

So far, there have been attempts to achieve the general sorting and pick and place operation, however these have only been validated in laboratory conditions and have not accounted the constraints of the radioactive environment and other industrial quality metrics.

[1] As Low As Reasonably Practicable (ALARP) is a principle that should be applied to the task being carried out. The ALARP principle is that the residual risk shall be reduced as far as reasonably practicable. By automating this process, the ALARP principle is used for several issues such as removing the operator from the risk of dose uptake and repetitive strain.

Challenge scenario

The challenge may be broken down into the following tasks:

STEP 1: Visual detection of Magnox springs on a tray of standard dimensions 1.2 m × 0.8 m. Trays contain a mixture of Magnox debris of unknown and irregular shape (around 30 kg). The shape and dimensions of the springs are known (around 3 cm length, 0.8 cm diameter). The debris may partially or fully cover the springs.

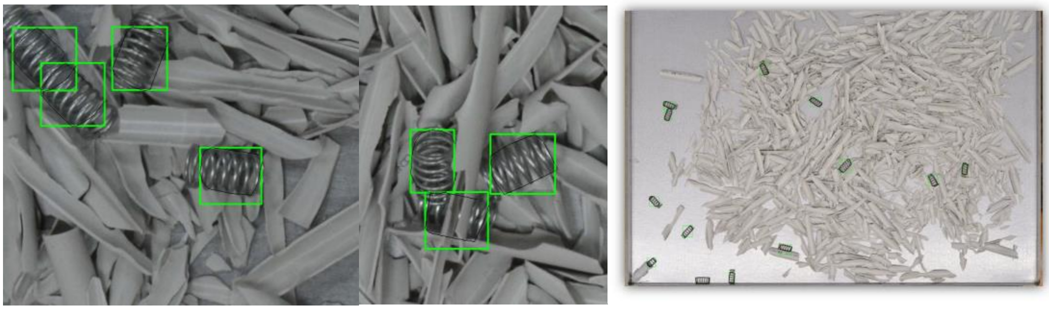

Figure 2.1. Visual detection of Magnox springs

STEP 2: Grasping of detected springs and placement into a lead container. The system should be able to assess grasp success or failure. Grasp success is defined when a single spring (no other material) is transferred into the lead container.

Figure 2.2. Grasping of the detected springs

STEP 3: Detection of additional springs on the tray possibly fully covered by debris (visually occluded) by means of radioactivity sensing devices.

Figure 2.3. Detection of additional springs with radioactivity sensing devices

STEP 4: Actions to achieve the revealing of covered springs (once detected) to allow grasping and sorting of springs.

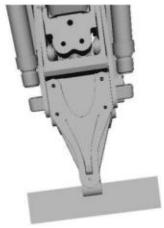

Figure 2.4. Grasping and sorting of springs

STEP 5: Repetition from STEP 1 until all springs have been recovered, then proceed with the next batch (tray).

STEP 6: The ability for semi-autonomous operation when autonomous recovery has failed (e.g. after a certain number of attempts). An interface where a user can advise high-level robotic actions (such as “Start”, “Stop”, “Reset”). Low-level actions such as picking or motion planning should still be performed autonomously.

The details of proprietary steel spring which is similar to the Magnox springs in size and shape can be seen in Figure 2.5. The outer plastic pipe is to simulate the Magnox fuel debris will be made up contaminated magnesium swarf.

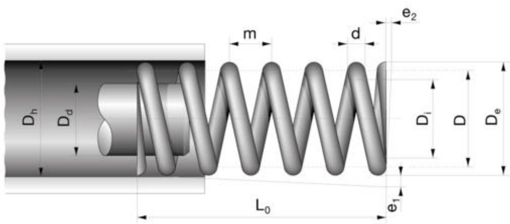

Figure 2.5. Technical drawing of a spring where L_0=30 mm, D_o=10 mm, D_i=8 mm d= 1 mm, m=2 mm, Θ_2=1mm

General requirements

The fundamental requirement of this equipment is that it can operate in an environmentally challenging and within a radiation / contaminated cell. The main factor is the cost of the procedure which may be broken down into the speed of operation with high accuracy and short maintenance downtime. Otherwise, there are no specific preferences other than those dictated by the radioactivity related constraints. Due to the harsh environment, equipment should be radiation-proof, e.g. by protecting sensitive components such as electronics. Since maintenance (e.g. replacement of components) is costly due to safety reasons (workers can enter the hot chamber for a short time only) it should be infrequent. Equipment should comply with current Post Operational Clean Out (POCO[2]) and decommissioning requirements such as: i) putting no additional burden on the existing waste streams, ii) optimising the protection and safety for the operators, iii) reducing the hazard for the operator by processing the hazardous material, and iv) creating no new waste routes during the project. At the end of the project it is expected to achieve TRL7 / TRL8 following the determination that the basis of this project achieved TRL5 in most areas. There will be some assumptions to be made regarding radiation tolerance of equipment that may be on independent testing of the equipment to radiation to claim its operational use.

[2] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/625697/sellafield-magazine-issue-2.pdf

Performance metrics:

It is expected from the developed solution to verify the following features:

1. ***Operational time***: the solution should be able to work for 24/7 operation with downtime only for a maintenance period less than 1h every 2 days of operation.
2. ***Speed of operation:*** the solution should be able to operate faster than an equivalent human operator (ideally at least 4 times faster than human). The target is to remove 80-100 springs per day from the automated process.
3. ***Accuracy:*** the solution should give a false positive rate of less than 0.5% after the first robot removal round, afterwards it should be reduced to zero with the QA-QC independent check done by dedicated sensing and a second round of removal.
4. ***Low cost:*** installation and maintenance costs of the solution should be comparable to or cheaper than current solutions.
5. ***Reliability:*** the solution should not require non-routine human intervention more than once every 2 hours.

2.2. Support to the experiment

Support from the lead Competence Center

The TUM CC is responsible for the challenge and the currently available equipment list can be seen in our website. The environment for the experiment is set in TUM CC and the selected proposals can do their experiments in TUM CC during Phase I. Other ESMERA CCs are also available to support the development process if requested.

Support from the Challenge Provider

The Challenge Provider provides information on simulated, non-radioactive batches of all relevant materials to be processed. Outline requirements for a cell infrastructure will be provided, in order to replicate a real case installation at the highest possible level of reality to create a significant environment for the experiment. Moreover, the Challenge Provider may provide an access to their laboratories if it positively affects the outcome of the experiment, or if it is required to make available the cell hardware for the experiment. Access would possibly be more convenient in the last phase of the experiment setup after a phase of integration at the SME company taking the challenge.