SMOKEBOT

Mobile Robots with Novel Environmental Sensors for Inspection of Disaster Sites with Low Visibility

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Duration: 3.5 years

Deliverable 7.2

Second Iteration of the Requirement Analysis and Use Case Definition

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A Introduction and purpose of this document

The SmokeBot project will develop a new tele-operated robotic platform for supporting fire brigades for search and rescue missions with a special focus on operation environments with limited visibility. In order to showcase the developments made during the project a challenging and realistic demonstration scenario is required.

The document at hand represents the second iteration of work on requirements and use cases. It has been performed one year before the closing of the project to ensure the development has proceeded in the right direction and new insights from our end users are accounted for.

For that reason, a workshop with end-users has been organized and held as a two hour online conference (due to travel restriction of our end users). It took place on July 21, 2017 from 10:00 - 12:00 GMT+2.

Participants were from TAUR, ORU, FW Dortmund and FW Frankfurt.

B Key Take-Aways

B.1 Scenario "Laboratory Accident"

The scenario as described in Deliverable D7.1 and in section D of this document is still highly relevant. Over the last two years 4 related missions were instantly remembered by the persons in this workshop which come close to this scenario. The procedure of responding to such a threat has remained the same, i.e. if there is no time pressure, robot usage is still very viable. In situations with heavy smoke, humans do not have a significant speed advantage compared to a robot. The scenario can be extended by an imminent risk of explosion, e.g. through chemicals or home-made explosives. Such an extension would add another argument to use robots preferably over human responders.

B.2 Additions to Scenario Requirements and Use Cases

- As one hour operation time is relatively short, the battery should be easily changeable.
- A risk indicator should be added to the user interface.
- A temperature gauge should be added to the user interface.

B.3 General Desaster Information Model (GDIM)

- Re-Play functionality for mission de-briefing would be very welcomed.
- Annotated escape and rescue plans are seen as suitable means of communicating hazardous areas, waypoints and points of interest between the robot and first responders.

C Workshop Minutes

C.1 Welcome and what has happened so far

Erik presented pictures of the robot during the project review and explained the following components: Mechanical Pivoting Radar, Low Resolution Radar Camera, Thermal Cameras, 3D Laser Range Finder, Gas Sensing Unit, WiFi Repeater Deployment Mechanism. A video of Lidar and Radar Sensor Fusion was displayed (robot entering smoke filled room). Thermal robustness concept was briefly mentioned.

FW Dortmund wanted to know, if the robot is purely tele-operated. Erik explained that the robot should be able to drive autonomously in case the connection is lost, e.g. drive to a point where the signal is strong enough to re-establish communication.

FW Frankfurt asked what kind of control device is used, Lukas showed pictures of the current tablet PC controller (splash water protected, sun light readable, embedded joysticks, USB port for USB sticks, MS Windows based). SmokeBot generated maps are displayed on this control device.

FW Dortmund asked for differences between the camera images and the radar sensor. Lukas mentioned, that the cameras are de-facto unusable in a smoky environment. Erik explained, that thermal cameras are partly useable, depending on the smoke temperature. Radar is unaffected by the smoke. FW Dortmund referenced other project "Feuerware", two thermal cameras and a radar sensor are used in a hand-held configuration to detect persons.

Erik explained methodology for detecting hot smoke in thermal images - cold smoke makes background appear cooler than it actually is. If the smoke has the same temperature as the environment it becomes difficult to reconstruct the environment.

FW Dortmund mentioned differences of "Disco-Smoke" vs. real smoke. If real smoke contains hot particles, a thermal camera becomes de-facto blind.

Lukas stated that radar technology appears most promising in dense smoke scenarios. Prof. Pohl showed radar picture of bicycle during SmokeBot kick-off which contained great detail. This technology would make a real difference.

FW Frankfurt inquired whether the gas sensor is being newly developed or commercial-of-the-shelf. Erik and Lukas explained advantage (response speed) of newly developed sensors.

C.2 Presentation and discussion of existing scenarios

Lukas explained need to re-visit scenarios and requirements from initial project phase. We want to make sure, that we are not developing into the wrong direction.

Lukas recapped 1st scenario "laboratory accident" (see D7.1). He emphasized the assumption that no persons are remaining in the affected building, thus no time pressure exists. Otherwise fire fighters are assumed to be unwilling to deploy potentially slow moving robots, but would move in there themselves, accepting a remnant risk. FW Frankfurt agreed by stating that this assumption is still valid and the procedure for such incidents has not changed.

Lukas argued, that the assumption "no time pressure" obviously limits the number of incidents where our robots can be used. This would be one important aspect for a follow-up-project, i.e. make the robots as fast or even faster than human responders. He made the point that moving through the small smoke room in Örebro during the project review took about 5 minutes, which he thought was quite slow. FW Dortmund responded by saying that if human firefighters are advancing in their protection suits with zero visibility, they are also extremely slow. This becomes even worse if there is a danger of rupturing the protection suit in environments with sharp objects - then fire fighters need to be even more cautious. Here a radar sensor would make a huge difference.

Lukas asked whether there were any real-life missions which come close to this scenario within the last two years.

FW Dortmund mentioned two missions of the "Analytical Task Force" in Germany. One was at the end of 2016 where a person manufactured some home-made explosives in an underground apartment. Some substances were extremely volatile and contained in regular bottles. There was no smoke present. The explosive substances were brought out of the building and were de-fused by a planned explosion outside. Lukas asked if robots were used. In the end, a human with protective suit and extension gripper went in and carried the explosives outside.

Lukas mentioned a similar incident, were a recycling company refused to transport highly volatile chemicals (similar to nitroglycerine). In the end the suspicions bottles were defused by humans with robot assistance - they were placed into hydraulic sheers and cut over a pool of water. The robot provided live-images to the persons operating the hydraulic sheers from a safe distance.

FW Dortmund remembered the second mission, approximately one and half or two years ago. A person wanted to produce biological warfare agents. This was also a situation where they would have preferred to send a robot in.

Lukas summarized that in all three scenarios there was no time pressure.

FW Frankfurt was personally involved in an incident where a suspicious white powder was found in front of an industrial compound. In the end it was just fructose, detected by the First Defender RMX sensor. Obviously, in this scenario a robot would have been preferable. It could not be determined if the powder was an explosive as no dogs were available to the police at the scene.

Lukas and FW Frankfurt agreed that the scenario can be extended by an imminent risk of explosion, e.g. through chemicals or home-made explosives. Such an extension would add another argument to use robots preferably over human responders.

Lukas recapped tasks of the robot in scenario definition. They are all deemed still valid. Regarding stair climbing Lukas mentioned that it remains questionable whether the robot will be able to climb stairs because of the high center of gravity due to the current configuration of sensors. Erik explained concept of sketch maps and that escape and rescue maps are deemed more suitable.

Erik presented the GDIM and explained internal data structures and different layers. He further elaborated on the question which data should be available during a mission and after a mission. Regarding the later, FW Frankfurt thought that an overview where the robot has been at which point in time would be very valuable (similar to re-play functionality). Erik explained click-and-drive control mode (user clicks to a point where the robot should drive to). Erik presented hazard-signs, which are automatically added to the map as the robot detects hazards. Lukas showed a short ARGOS Challenge video to explain how obstacles could be handled by ROS. Erik mentioned advantage of using annotated escape and recue maps, i.e. that they are mutually understood by roboticists and first responders. FW Frankfurt welcomed this idea. Lukas asked if those plans are available in digital format. FW Frankfurt confirms that fire fighting maps are available in digital format in the Frankfurt area, but only for public buildings, not for private residences. Escape and rescue maps are available on site (not digitally) at each level of the building. The difference is, that hazard symbols are only available in fire fighting maps, not in escape and rescue maps.

With regards to flashovers, Lukas asked whether there are certain indicators available for predicting them. FW Frankfurt thought that this will be very difficult for the robot, as this is already hard for the human fire fighter. However, he himself believed that this topic has been a bit "hyped" as he has only had one flashover in over 30 years of fire fighting service. Lukas then explained the strategy of deploying the heat shield and shows videos.

C.3 Presentation and discussion of existing requirements

Regarding the operating time, 1 hour was seen relatively short by FW Dortmund - thus the battery should be easily changeable.

Regarding ambient temperature: A breathing apparatus for fire fighters is also specified to +60°C, thus the ambient temperature seems specified appropriately.

Erik explained the aim of maps, providing a kind of risk assessment of the environment, e.g. this region looks unsafe due to high temperature. A risk indicator should be added to the user interface.

FW Frankfurt asked if the current temperature is displayed in the user interface. Lukas answered that we will add a corresponding requirement. Erik added that it would be also possible to colorize the walls of the environment with temperature information. He further elaborated on the method developed by LUH to measure temperatures of unknown objects (objects with unknown emissivity).

Lukas confirmed with FW Frankfurt and FW Dortmund that the robot can be indeed carried by two persons. Lukas explained why the robot currently weights about 75 kg.

Lukas mentioned, that it will be difficult to achieve the robustness requirement because the sensors are not in a state yet, where they can be sufficiently protected without compromising their performance. Same applies to changing the gas sensor within one minute.

C.4 Presentation GDIM (General Disaster Information Model)

Discussed under C.2 (Presentation and discussion of existing scenarios)

C.5 SmokeBot Final Demo in Hannover / Dortmund

Erik and Lukas explained that a final demo will take place in Hannover and/or Dortmund. FW Dortmund and FW Frankfurt will be invited. Erik may touch base with FW Dortmund regarding "handling" end of the year / beginning of next year.

C.6 Closing remarks

Erik will distribute the slides shown to FW Dortmund and FW Frankfurt.

D Adapted Scenario, Requirements and Use Cases

Additions and changes compared to the first iteration of the requirement analysis described in Deliverable D7.1 are marked in bold and italic.

D.1 Scenario Specification - Laboratory Accident

Chemical laboratories are very common in modern industry and accidents there are not uncommon.

As people working in laboratories are trained professionals it is realistic that they escape the building in the case of an accident in time. Furthermore all people working in a laboratory at a time are known and thus it is possible to check that all people have left the building. This would grant the scenario being not time critical. Also hazardous materials are used and stored in laboratories which set up unpredictable conditions for fire brigades in case of an accident.

Following Assumptions are made for the scenario:

- Caused by a chemical accident a fire was breaking loose – different hazardous materials are stored in various places – harmful and/or poisonous vapor are most likely to occur – a list of all stored materials is available.
- The fire has been put out by the sprinkler system in the lab or from the outside widely – Currently the laboratory is full of smoke and fog, possible some small hot spots have remained.
- All workers were able to exit the building safely. However there is a considerable health risk for the fire fighters due to the unknown conditions inside.
- The building is completely evacuated – the operation is not time critical
- ***Explosive substances are present, which support the use of a robot***

The low visibility explorer robot shall perform the following mission:

- The robot shall enter the disaster site semi-autonomously (control of the robot by waypoints) → Radar camera and thermal imaging necessary
- Identification and localization of gasses and remaining hot spots→ Thermal imaging and gas sensor needed

Additional conditions that have to be considered:

- The laboratory is not on the ground floor – the robot has to overcome the staircase.
- The journey to the laboratory is 500m long – repeaters have to be deployed
- The Wi-Fi connection is not stable – the available bandwidth of the standard Wi-Fi has to be improved, repeaters have to be dropped by the robot, the robot shall be able to recover to the last position of a good radio signal
- A sketch of the locations of possible hazardous materials is available → integration in the robots path planning
- The robot shall be controlled by high level commands (e.g. entering waypoints) and shall proceedsemi - autonomously through the disaster site.

- Acute hazards (flash over) might occur→ GDIM
- A user might give a command which is dangerous for the robot→ Self-preservation of the robot. (e.g. avoiding areas of high temperatures)

D.2 Scenario requirements

Stairs: The robot shall be able to climb standard stairs up to an inclination of 45°.

Robot Speed: The speed of the robot should be 5km/h at least. For long journeys (up to 500m) to disaster sites a faster speed of at least 10km/h or an additional faster transportation method has to be fulfilled.

Operation Time: The operation time shall be at least 1 hour with all sensors active permanently.

Battery Change: ***The robot's battery shall be quickly changeable.***

Ambient Temperature: The robot shall be able to permanently operate at a temperature of -20°C to +60°C. Additionally it shall withstand 120°C for 30 minutes.

Self-Preservation – Limit values:

Following conditions shall trigger the self-preservation behavior:

- The robot is exposed to a temperature between 60°C and 120°C for at least 30 minutes
- The robot is exposed to a temperature between 120°C and 600°C for at least 5 minutes
- The robot is exposed to a temperature of more than 600°C
- The robot loses its remote connection to the operator

Self-Preservation – User commands: The robot shall alert the operator if a command would lead the robot to areas with conditions that could damage the robot.

Self Preservation – change of conditions: If the conditions change to be critical for the robot the user should be alerted and the robot shall suggest moving to a safe area by user choice.

User Interface - Information: The User Interface shall display the following information by user choice.

- Live feeds of color cameras
- Live Feed of thermal camera
- Gas sensor response
- Radar camera visualization
- LIDAR visualization
- Generated map
- 3D model of robot in current pose

The User Interface shall display the following information permanently

- Battery status
- Radio Signal strength
- Overturn prevention
- ***General risk indicator***
- ***Temperature gauge***

User Interface – Control Commands: The robot shall have two operation modes – a tele-operated mode and a Semi–autonomous mode.

Tele – Operated mode: The robot shall be controllable with joysticks by the user.

Semi-autonomous mode: The robot shall be controlled by the input of waypoints on a map.

Obstacle avoidance: The robot shall avoid obstacles during navigation. The obstacle avoidance shall also be active in the tele-operated mode and prevent to robot of colliding into obstacles caused by user commands.

Integration of existing maps: The robot shall be able to extract pertinent information from a map image and fuse that with map data generated during operation. The initially extracted map should be of sufficient quality for specifying a navigation task.

Generation of maps: The robot shall be able to generate a consistent structural map of the environment and provide an estimate of its pose in the map, also in a smoky environment.

Protection class: The complete robot including sensors shall be rated IP67.

Transport: It shall be easily possible for two persons to handle the robot.

LED light: LED lights shall be included in the robot.

Color Cameras: Color Cameras shall be integrated in the front and back of the robot.

Gas Sensor Placement: At least two sensors shall be placed on the robot – one as far to the ground as possible, the other approximately 1 meter above (+/- 10cm).

Gas sensor Protection: The gas sensor needs to be protected from dust.

Gas sensor change: The Gas sensor module shall be changeable within 1 minute for different gases.

Decontamination: It shall be easily possible to decontaminate the robot.

Temperature Sensors: Temperature sensors shall be placed inside and outside of the robot.

D.1 General Setup and mobility requirements

Drivetrain: The robot shall have two tracks, each track providing at least 40Nm.

Arm: The mounting Arm for the sensors shall provide 3 DOF.

Weight: The overall weight of the system must not exceed 60kg.

Measurements: The robot must not exceed horizontal measurements of 1000x600mm. The mounting Arm for the sensors shall be at least 800mm long.

Batteries: The robot shall have a rechargeable battery which grants the minimum operation time of one hour.

Change of Tracks: The tracks shall be changeable in less than 5 minutes by a trained person.

Safe state: When losing the connection to either a sensor or the remote control the robot must stop all movements.

Loss of power: The robot must not perform any movement in case of loss of the supply voltage.

Visibility: Camera and sensor windows shall be protected against fogging and rain.

D.2 Sensor Suite requirements

Sensor integration: All sensors shall be protected against shocks, vibration and be rated IP67 – either the sensor itself or an additional housing.

Sensor Range: The sensors shall enable to capture an area of 20 meters around the robot for safe navigation.

Smoky conditions: The sensors shall enable the robot to identify its surrounding in smoky conditions.

Weight: The overall weight of the sensor suite shall not exceed 6kg.

Further requirements for the sensors will be outlined in the Deliverable "D7.2 - Second iteration of the requirement analysis and use case definition". Based on the results from the first tests and demonstrations the requirements will be set to meet all necessary functionalities.

D.3 Computing power and communication requirements

Data Link: Gigabit Ethernet shall be used as backbone between all components.

Interfaces: Following interfaces shall be provided on the robot: 12V/1A and RS232 for the gas sensor

- 5V/600mA (USB Power) and Gigabit Ethernet for the Radar camera
- 2-24V, 24W max, and Gigabit Ethernet connection for the thermal camera)
- 12V/1A and Gigabit Ethernet LIDAR

Cable Connection: All Ethernet connections shall provide Gigabit – speed.

Middleware: ROS, Version Indigo, shall be used.

ROS Messages and Nodes: A comprehensive list of ROS messages and nodes shall be defined as the software communication interface between all the different sensors and the main computers. This list will be created and maintained over the whole development cycle of the different sensors that developed and integrated throughout the SmokeBot project.

Droppable Repeaters: To enhance the wireless range 3 repeaters shall be stored on the robot and deployed autonomously. The robot therefor shall define the ideal spots for placing the repeaters during its mission.

Self-preservation of radio signal: On loss of signal the robot shall return to the last known position of good connection.

Bandwidth enhancement: For a better bandwidth the protocol of the radio connection shall be adapted to use several paths of transmission simultaneously.

Embedded PC: An embedded PC with following basic features shall be used: Core i7, RAM 16GB, Harddisk 256GB SSD

E Summary

The document summarizes the second iteration of requirement engineering for the low visibility explorer robot. Based on an end-user workshop, the project is still on track with its current set of scenarios and requirements. Only minor additions were made.