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SMOKEBOT

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

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Duration: 3.5 years

Deliverable 5.3

Technical specifications for return procedures after communication loss

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Contents

Introduction and Purpose of this Document

A communication loss is a grave situation during a search and rescue scenario, because it cuts the connection between the human operator and the robot. In such environments, this can lead to damage of the robot hardware and unnecessary confusion on the operator's side.

Different approaches can be deployed to control a robot if teleoperation via network is not possible anymore. There are voice-operated solutions [1] in order to command the robot into certain directions. Another solution is the following of a human, who leads the robot out of his situation [2]. Another approach involves gestures via special gloves [3] or thermal imaging cameras [4]. A multi-robot-system can span a network [5], monitor the coverage and react accordingly.

In SmokeBot, the platform is able to return to areas where it can retrieve the communication autonomously. When returning, the mobile platform is avoiding obstacles and hazardous areas until the operator can take over control again. Since communication loss on a robot is always a risk, the robot provides assisting functionality to the operator in order to prevent the aforementioned situation.

This report is organized as follows: The reasons for a communication loss are explained in Section 1. In Section 2, we talk about strategies in order to actively prevent a loss of communication via autonomous behaviors. In Section 3, we introduce the placement of recovery points and in Section 4, we present four returning strategies involving recovery points. In Section 5, we explain how a hazard map is used when returning autonomously to a recovery point. In Section 6, we present the results of a survey, which we conducted in order to measure the advantage of autonomous behaviors.

1. Reasons for a Loss of Communication

There can be several reasons for a loss of communication between the operator, repeaters and the robot platform. The main reasons are:

- Low RF signal
- Mechanical damage of transmitting devices
- Thermal damage of transmitting devices
- The robot/repeater/controlling-device runs out of battery

A loss of communication due to low RF signal is forced when the robot is driven into an area with weak signal strength. This issue can be solved by dropping Wi-Fi repeaters or returning to areas with stronger signal via recovery points and the hazard map. The worst case of communication loss is mechanical or thermal damage, which forces the robot to return to the origin. In order not to endanger itself, the robot has to follow a path considering hazardous areas from the hazard map. If a single repeater runs out of battery, it can affect the RF signal strength and trigger a returning to an area with more cover. If the robot runs out of battery, it indicates a returning to the operator on time and plans a path considering hazards likewise.

The following chapters will introduce assisting functionalities in order to prevent a communication loss and returning strategies in order to re-establish a communication.

2. Assisting the Operator to Prevent a Loss of Communication

Ideally, a return procedure never has to be triggered, because it always carries the risk of damaging the robot considering a scenario with dangerous hazards. Therefore, the operator can select a mode where he gets assistance. In order not to lose the robot through a weak RF signal, the signal strength has to be checked permanently so that the operator gets a warning if it drops under a specific threshold. Then, the operator can drop Wi-Fi repeaters in order to extend the network. To avoid the damaging of the robot due to a crash, the robot provides an optional collision avoidance, based on the navigation sensor fusion. A thermal damaging of the robot is prevented due to GDIMs hazard map at the current location.

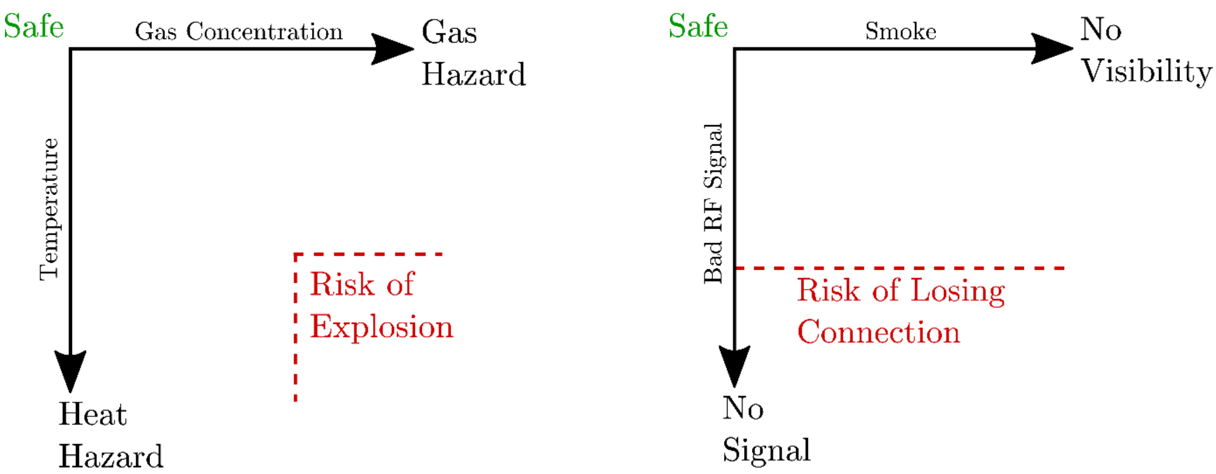


Figure 1: Potentially hazardous situations: Combination of heat and gas leads to a risk of explosion (left), while the combination of smoke and bad RF signal leads to bad tele-operation behavior (right).

Besides being an active assistance to the operator, GDIM provides an easy evaluation of the current situation through hazard plots, as indicated in Figure 1. For example, these plots help the operator to decide quickly if it is necessary to drop a Wi-Fi repeater or if there is a risk of explosion.

3. Placing Recovery Points

The robot platform provides the dropping of Wi-Fi repeaters (WP7) according to Figure 2. Every Wi-Fi repeater is a potential recovery point in case of a loss of communication. Therefore, repeaters should be dropped only in suitable areas, which are indicated to the operator through the hazard plots.

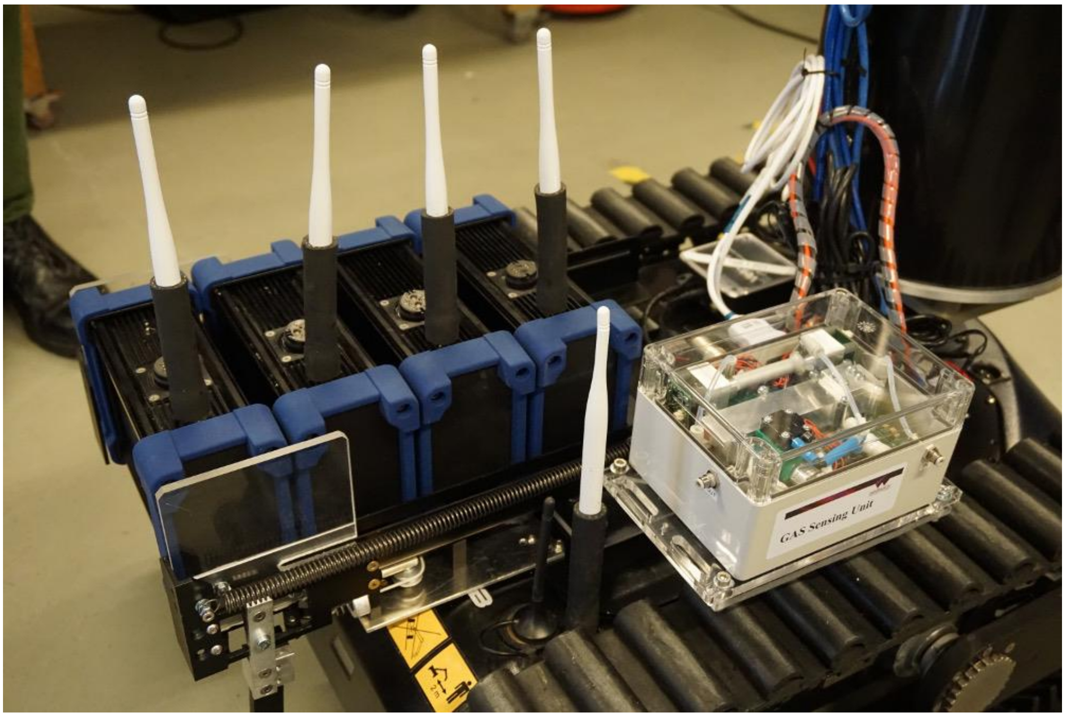


Figure 2: Dropping of Wi-Fi repeaters

In Figure 3, the blue areas are indicating areas suitable for dropping repeaters and setting recovery points. Repeaters should be dropped in areas without high temperature and risk of explosion. Additionally, it is not necessary to drop repeaters in areas with good RF signal. Likewise, if the RF signal is too low, it is not recommended to drop a repeater, since it leads to an unstable repeater connection chain.

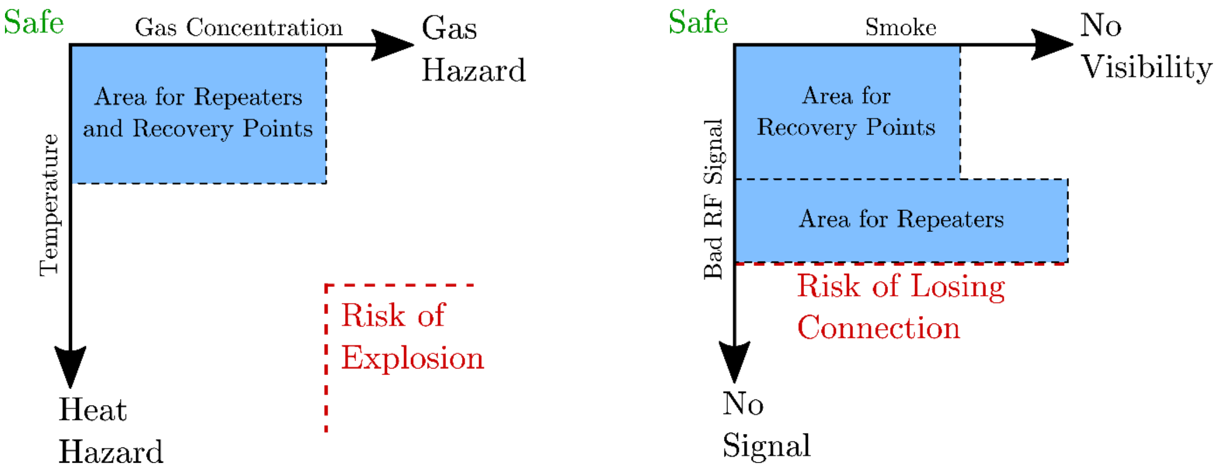


Figure 3: Blue areas indicate suitable situations for repeater drop off and recovery point assignment, in case of heat/gas combination (left) and no signal nor visibility combination (right).

Besides dropping repeaters, a recovery point can be placed in safe areas along the robot path. Instead of placing the recovery points along the path, a distribution can be achieved involving the hazard map under a given recovery point density.

4. Returning to Safe Areas via Recovery Points

In case of loss of communication, the robot has to return safely from its current position to areas with network service, considering that it starts its mission at the “Origin”, drops repeaters and places recovery points at the positions “R”. The following sections present four returning strategies involving the positions of recovery points.

4.1 Direct Returning

The simplest returning to a safe area is the returning to the origin (Figure 4), under the assumption that there is network service because the operator did not move away from the starting point very much. The advantage of this approach is its simplicity and robustness. The disadvantage is that these strategies do not consider repeaters nor closer safe areas.

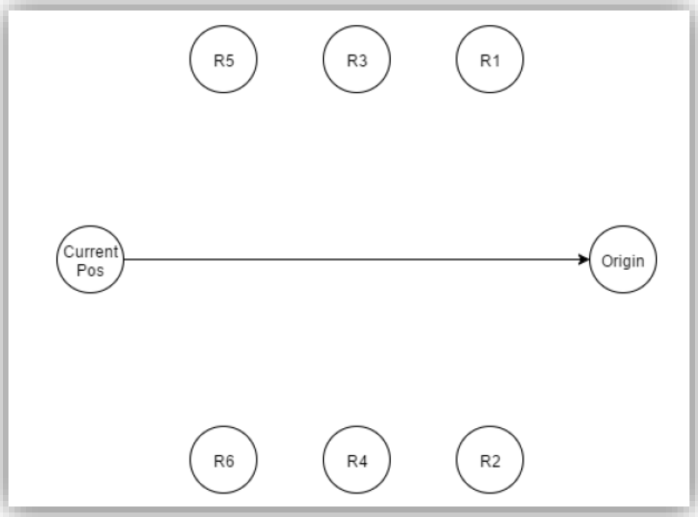


Figure 4: Direct returning to the origin

Even though this approach is trivial, it does not require many resources and it is an option when all repeaters, the robot or the controlling device run out of battery or are affected by mechanical or thermal damage.

4.2 Returning in Inverse Repeater Dropping Order

Another simple approach is the returning in inverse repeater dropping order (Figure 5). However, this approach can lead to unnecessary time consuming detours.

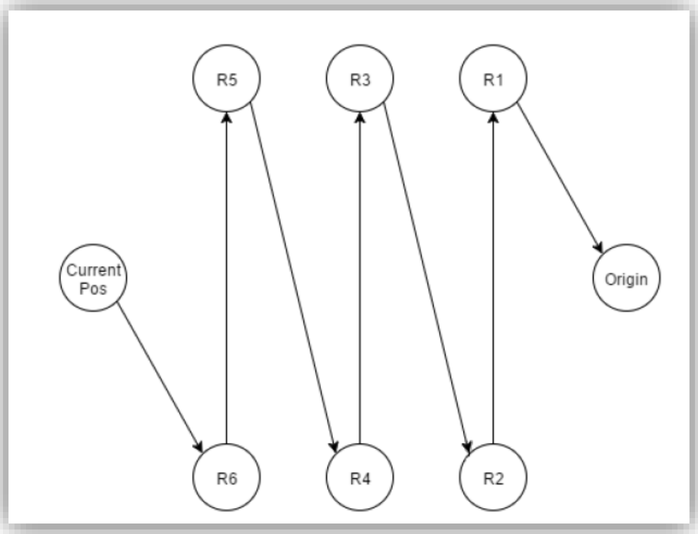


Figure 5: Inverse dropping order

4.3 Returning over all Recovery Points with Optimal Path Length

In order to avoid unnecessary detours, the global path can be minimized (Figure 6). Anyway, it can happen that the robot tries to reach a repeater which might be far away.

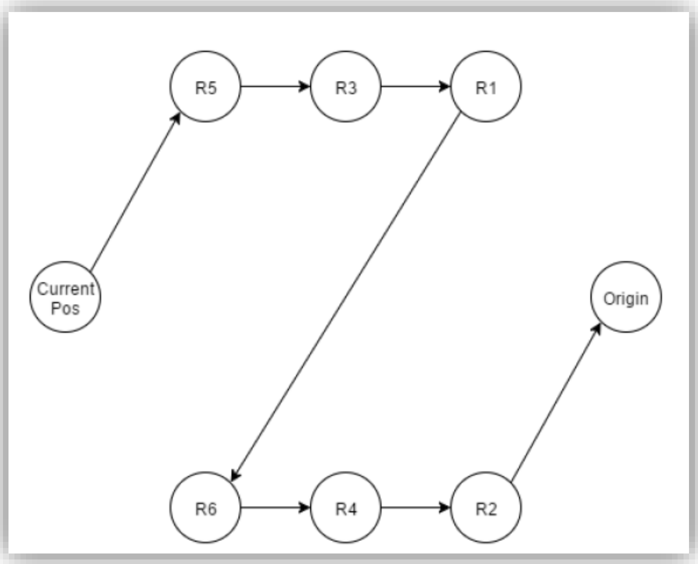


Figure 6: Minimizing path over all recovery points

4.4 Returning over a Selection of Recovery Points

Since it can happen that a repeater was dropped more far away from a preferred route, it is recommended to approach only a selection of recovery points.

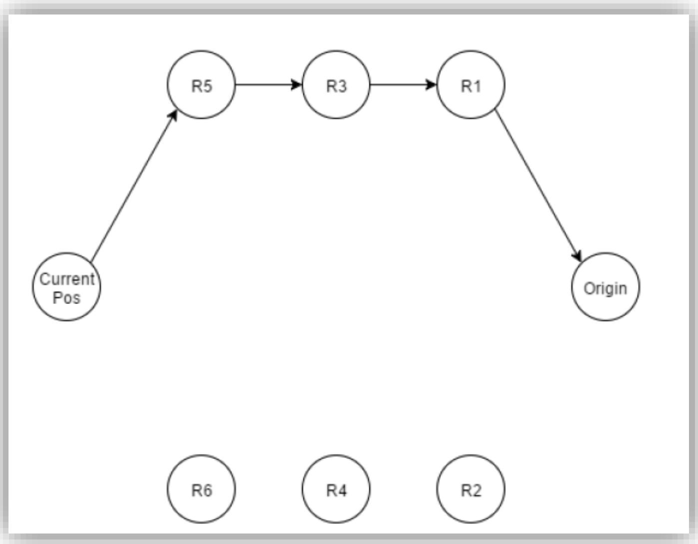


Figure 7: Selection of recovery points

In order to exclude certain recovery points, the minimum connection to the origin including a given number of points is calculated. In Figure 7, the minimum connection to the origin including three recovery points is calculated. In order to avoid detours, a criterion compares the direct length from the current position to the origin with the length including the recovery points.

5. Returning to Safe Areas via Hazard Map

The hazard map contains the probabilities for the risk. If the robot is driving autonomously, it has to calculate and follow a path to the next recovery point or origin. Normally, a robotic system considers a global and local cost map in order to avoid obstacles in the scene. Usually, the global cost map is derived from the environmental map by inflating the occupied cells via a given radius. The local cost map considers objects, which are not necessarily in the environmental map. The local cost map is derived from the fused obstacle scan (WP1). Besides obstacles, there can be hazards like hot areas or areas with risk of explosion, which have to be avoided. Therefore, the hazard map, which includes the mentioned facts, is considered for path planning as well. In Figure 8, a robot is returning via recovery points (blue points) to the origin. The robot path is avoiding a hazard (green object).

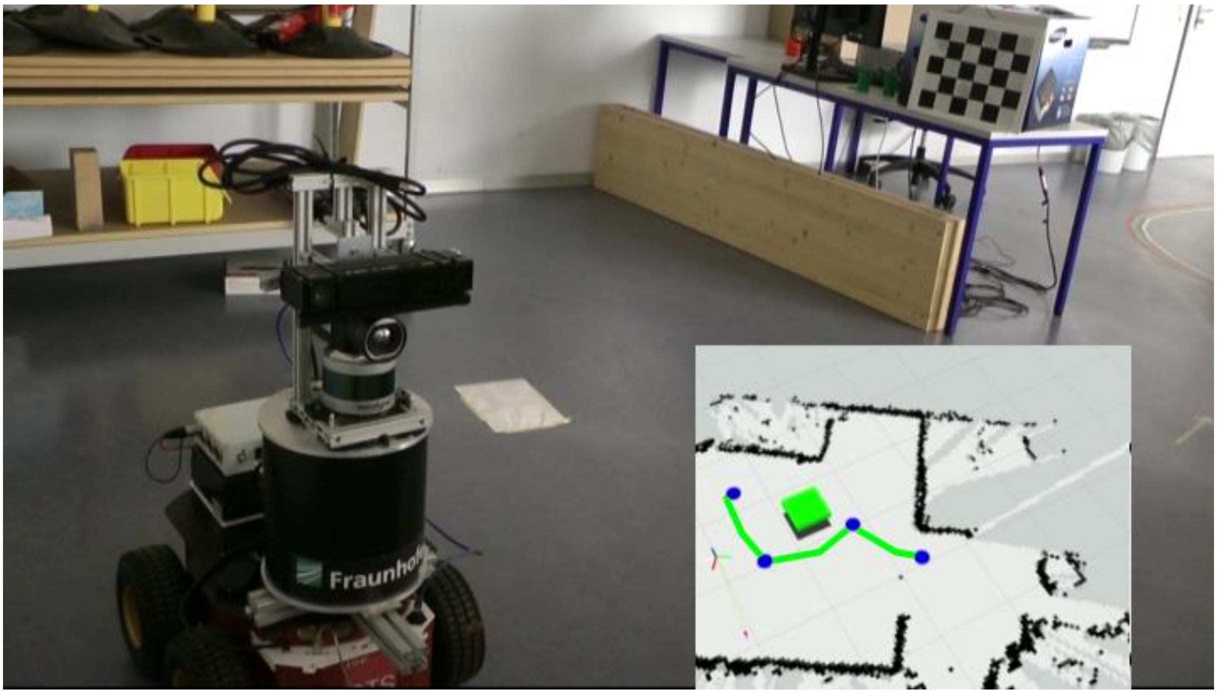


Figure 8: Autonomous returning of a mobile platform via a hazard map and recovery points.

6. Experiments Regarding the Advantage of Autonomous Behavior

In order to evaluate the autonomous behavior when tele-operating a mobile platform, we conducted an experiments involving testers in order to demonstrate the advantage of the autonomous behavior over a pure manual operation. Therefore, we implemented a collision avoidance, which is based on the fused obstacle scan. Furthermore, the collision avoidance does not permit the operator to drive over hazardous areas, which are stored in the hazard map. During the experiment, nine people had the task to tele-operate the robot from the origin “S” to point “1” and then to point “2”. When arriving at point “2”, a Wi-Fi disconnection was simulated and the robot returned to “S”. The people were only able to see a thermal camera image while maneuvering the platform. Additionally, they had an “emergency map” of the scene including the location of points “1” and “2” (see Figure 9).

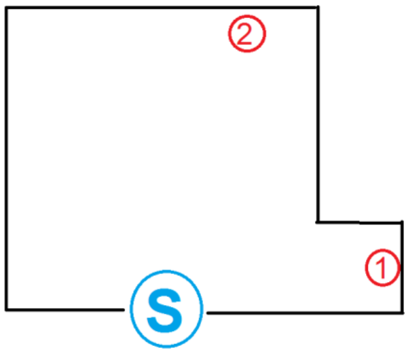


Figure 9: Map, which was provided during the experiment to the testers.

The testers did not know that there were two hazards in the scene as indicated in Figure 10.

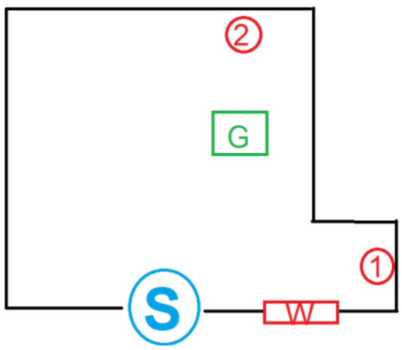
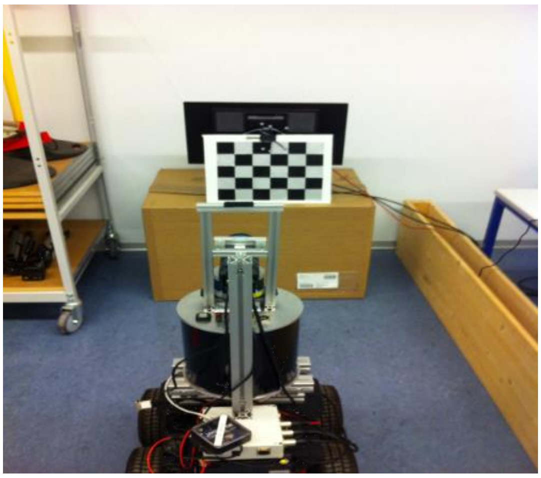


Figure 10: A gas hazard "G" and a thermal hazard "W".

Every tester had to run the experiment two times: Once with and once without autonomous behavior.



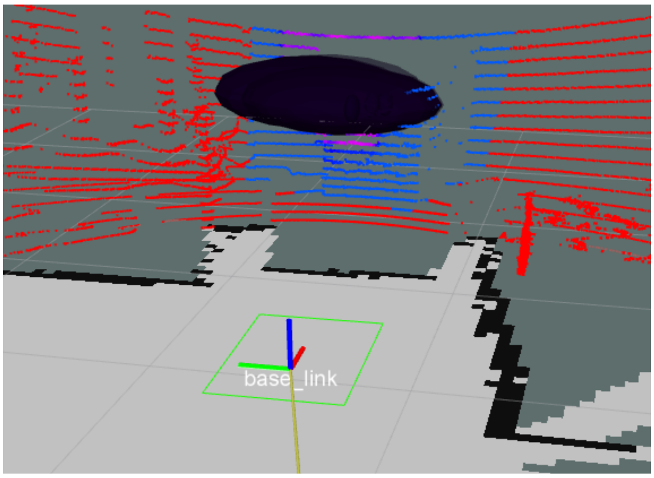
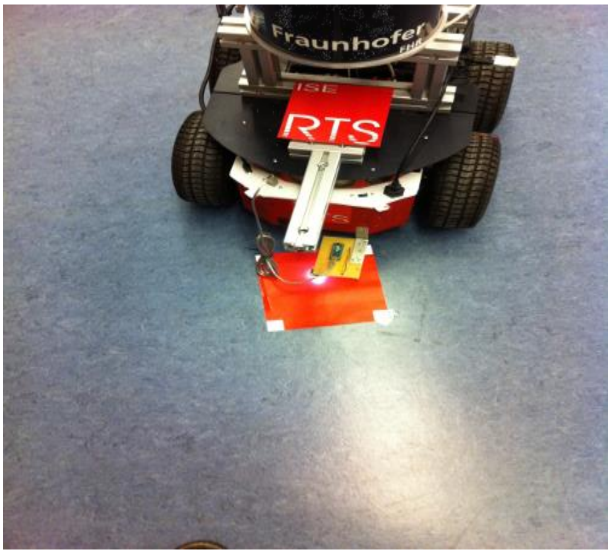


Figure 11: While approaching point “1”, the robot detects a thermal hazard (left) and includes it into GDIMs hazard map (right).



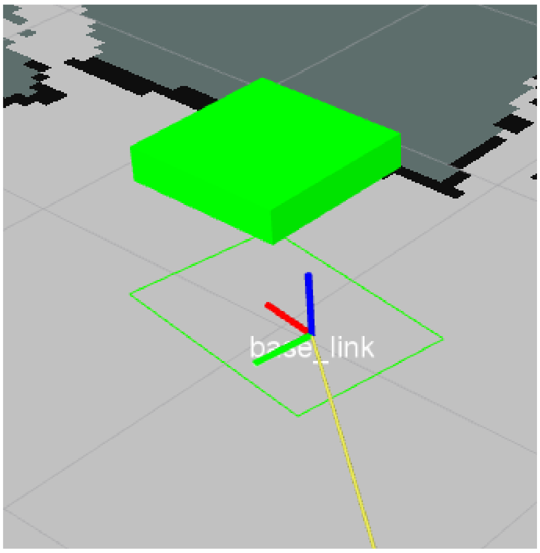


Figure 12: While approaching point “2”, a gas hazard is detected.

During the experiments (Figure 11 and Figure 12), we measured with a tracking system the average distance between the robot and the hazards. The results are presented in Table 1 and Table 2.

Table 1: Average distance to the thermal hazard

Tester	Average distance without active hazard avoidance [m]	Average distance with active hazard avoidance [m]	Difference [m]
1	1,25	1,04	0,21
2	1,44	1,18	0,26
3	1,31	1,24	0,07
4	1,51	1,61	-0,1
5	1,57	1,32	0,25
6	1,48	1,45	0,05
7	1,6	1,65	-0,05

8	1,03	1,18	-0,15
9	1,39	1,33	0.07
Average	**1,4**	**1,33**	**0.067**

Table 2: Average distance to gas hazard

Tester	Average Distance without active Hazard avoidance [m]	Average Distance with active Hazard avoidance [m]	Difference [m]
1	1,44	1,04	0,4
2	1,28	1,04	0,24
3	1,20	1,20	0
4	1,38	1,12	0,26
5	1,40	0,96	0,44
6	1,30	0,95	0,35
7	1,24	1,07	0,17
8	1,39	1,00	0,39
9	1,29	1,05	0.24
Average	**1,32**	**1,05**	**0.27**

These tables show that an active collision avoidance via the hazard map reduces the average distance to hazards. During the test runs, we counted the collisions between platform and obstacles, which is presented in Table 3.

Table 3: Number of collisions

Tester	Number of collisions without active Hazard avoidance	Number of collisions with active Hazard avoidance	Difference
1	2	0	2
2	0	0	0
3	0	0	0
4	0	1	-1
5	0	0	0
6	0	1	-1
7	2	0	2
8	3	2	1
9	0	0	0
Average	**0,77**	**0,44**	**0.33**

This table shows that an active collision avoidance reduces the amount of collisions. Collisions happened even with collision avoidance during rotations to very close and flat objects, which were out of the detection field of the scanners.

Summary

This report presents solutions for a loss of communication. On one side, autonomous behavior can reduce the risk of losing the connection to the robot. This is achieved by actively steering and stopping the robot in order not to crash or drive into hazardous areas. Practically, this is implemented through GDIM’s hazard map. On the other side, the robot is able to return to recovery points autonomously in order to re-establish a connection. When driving autonomously, it avoids hazards and obstacles. In order to estimate an advantage of our methods, we conducted a survey including testers. The result of our survey is that the autonomous behavior results in less collisions and smaller distances between the robot and hazards.

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