Test Protocol:
Search and Rescue - Coordination Between Quadcopter and Rover

Version 1.0

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Status

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Document History

Version	Date	Changes made	Reviewer
0.1	2019-12-03	First draft.	JA
0.2	2019-12-04	Second draft.	JA
0.3	2019-12-05	Third draft.	JA
1.0	2019-12-13	First version.	JA

Contents

1 Introduction

This document is a test protocol for the project *Search and Rescue* in the course TSRT10, *Reglerteknisk projektkurs, CDIO*, at Linköping University. The test protocol contains results from every test from the test plan and verifies how each test went.

1.1 Test structure

Each test will include a description of how the test will be executed. After reading the test description, it should be clear how the environment should be constructed and how the user starts the test. A column, *Expected result*, explains what result should be expected by executing the test. After executing the test, the results will be presented in the column *Test results* together with comments in the column *Comments* and the test will be marked as *Pass* or *Fail* depending on the results.

1.2 Pass or Fail

After a test is executed, it will be marked with *Pass* or *Fail* depending on how the test went. If the test was executed as in the description and all requirements were met, it will be marked with *Pass*.

A test will be marked with *Fail* if any requirement could not be met. If that is the case, an evaluation will be written including an explanation of what went wrong and how/if the problem can be solved if a new test is executed.

1.3 Definitions

This section lists and describes definitions and abbreviations that are used in this document.

- **Rover** - Tracked vehicle autonomously traversing the ground seeking out people in distress. Previously called Balrog.
- **Quadcopter** - Flying vehicle autonomously seeking out people in distress from the air. Previously called Sauron.
- **Qualisys** - Motion capturing system in one of ISY's research labs, Visionen. Used to track the Quadcopter and Rover.
- **Accessible area** - The area where it is possible for the Rover to move around and search.
- **Inaccessible area** - The area where only the Quadcopter can move around and search, due to the area being surrounded by walls. Inaccessible areas are obstacles as far as the Rover is concerned.
- **ROS** - Robot Operating System.
- **SLAM** - Simultaneous Localisation And Mapping.
- **Base Station** - Computer than handles information from the Quadcopter and Rover and also handles the GUI.
- **Obstacle** - Any object or feature that hinders the Rover.
- **Wall** - A vertical object that separates one part of an area from another, or makes up the boundary of an area. Walls are obstacles, not all obstacles are walls.

- **Distressed person** - A virtual marker that has to be found by the Rover or Quadcopter. Distressed persons are sensitive to percussive forces, therefore the Rover must not drive over them. Distressed persons can be considered obstacles and are defined as a circle with a radius of 0.1 m.
- **Test area** - The area of Visionen, where the tests will be executed.
- **Mission** - Defined task for the system to map and explore areas to find people in distress.

1.4 Test protocol

A test protocol is used to structure every test. It includes all requirements which will be tested when executing the test. There are requirements from previous years projects where the requirement number is marked with a preceding 'p' for clarification. The protocol also includes a test description which specifies how the test should be executed in order to achieve the expected result. There is also a column where the test result and comments on the result are written down.

Test nr:		**Test dependencies:**	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
Test description:		**Expected result:**	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

2 Rover

Test nr: 1, SLAM		**Test dependencies:** 30, 32, 33	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
p15	The position is estimated using both the odometry and LIDAR.		1
p16	Mapping and positioning is done simultaneously with a SLAM algorithm.		1
p17	The system will not reuse prior map knowledge, i.e. it will start with an empty map.		1
Test description:		**Expected result:**	
Drive the Rover manually in Visionen, subscribe to nodes of the LiDAR and the odometry and observe how the SLAM algorithm uses the data. Also open the GUI and observe how the map is updated continuously as the Rover is moving around.		The map should continuously be updated in the GUI as the Rover is moving around.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The map was continuously updated in the GUI when the Rover was moving, see Figure 1.	The requirements are fulfilled.		Pass
Test approved by: JS			

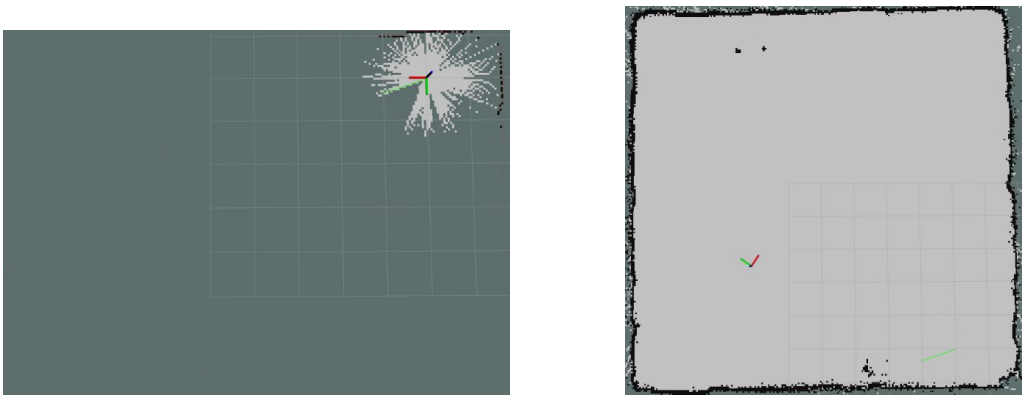

Figure 1: Map at the start (to the left) and at the end (to the right) of the test. Light grey indicates area covered by the LiDAR.

Test nr: 2, Route accuracy		**Test dependencies:** 30, 32, 33	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
p18	When driving the test route, the estimated position shall have an accuracy of: 0.2m.		1
p24	Route planning shall be done in real time.		1
p34	The Rover shall not deviate more than 0.1 m from the intended route provided by the navigation module.		1
p35	The Rover shall finish within 0.2 m of the intended goal node.		1
Test description:		**Expected result:**	
Have the Rover execute a mission which is to drive in a circle with a radius of 3 m in Visionen. Start the mission and observe how the route planning is done in real time through the GUI. When the mission is completed, the map with the path of the Rover is to be compared with a circle with a radius of 3 m. Verify that the Rover never deviates more than 0.1 m from the mission path and that it finishes within 0.2 m from the intended goal node.		The route planning is good and therefore the accuracy of the path fulfils the requirements.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	5/12
Test result:	**Comments:**		**Pass/Fail:**
The route planning was made in real time and the path accuracy fulfilled the requirements. This was confirmed by visual inspection of the GUI during a test run.	The requirements are fulfilled.		Pass
Test approved by: JS			

<table>
<tr><td colspan="2">Test nr: 3, Obstacle avoidance</td><td colspan="2">Test dependencies: 1, 30, 32, 33</td></tr>
<tr><td colspan="4">Resources:</td></tr>
<tr><td>Req. nr:</td><td colspan="2">Requirement description:</td><td>Priority:</td></tr>
<tr><td>p21</td><td colspan="2">The navigation shall avoid obstacles between nodes.</td><td>1</td></tr>
<tr><td>p22</td><td colspan="2">The navigation module shall update the route if new obstacles appear.</td><td>1</td></tr>
<tr><td>p29a</td><td colspan="2">When navigating the test area, Rover shall explore at least 95 % of the map that are more than 0.5 meters from any obstacle.</td><td>1</td></tr>
<tr><td colspan="2">Test description:</td><td colspan="2">Expected result:</td></tr>
<tr><td colspan="2">Place three obstacles in Visionen. Have the Rover explore the area. When the exploration is completed, verify that no obstacles were hit by the Rover. The area coverage can be calculated by measuring Visionen and use the given explored area of the map from the GUI. The explored area can be calculated as:
$$ExploredArea = \frac{GUI_{area}}{Visionen_{area}}$$
If possible, the area coverage can also be approximated using visual inspection of the resulting map.</td><td colspan="2">The Rover is able to avoid obstacles between nodes and is able to explore and map at least 95% of the area more than 0.5 m from obstacles.</td></tr>
<tr><td>Executed by:</td><td>Participants:</td><td>Test week:</td><td>Test date:</td></tr>
<tr><td>JS</td><td>JS & JA</td><td>48</td><td>28/11</td></tr>
<tr><td>Test result:</td><td colspan="2">Comments:</td><td>Pass/Fail:</td></tr>
<tr><td>The Rover avoided the obstacles and calculated paths around them, see Figure 2. By visual inspection it was possible to confirm an area coverage of at least 95 %, see Figure 3.</td><td colspan="2">The requirements are fulfilled.</td><td>Pass</td></tr>
<tr><td colspan="4">Test approved by: JS</td></tr>
</table>

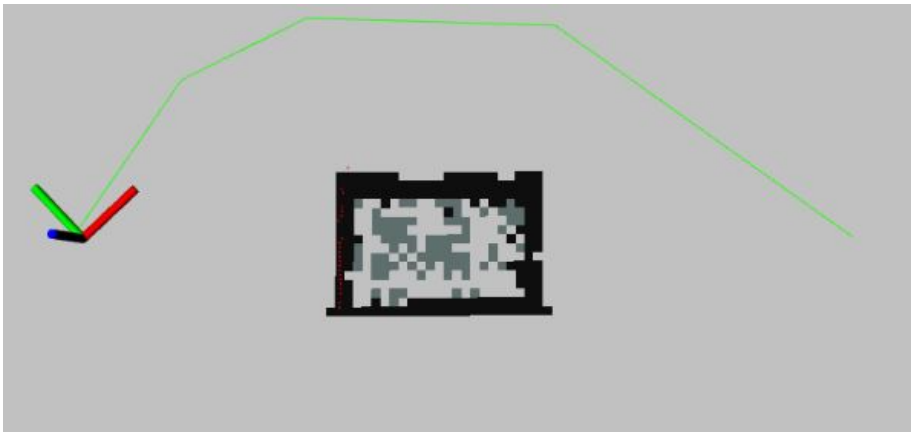

Figure 2: Calculated path around an obstacle.

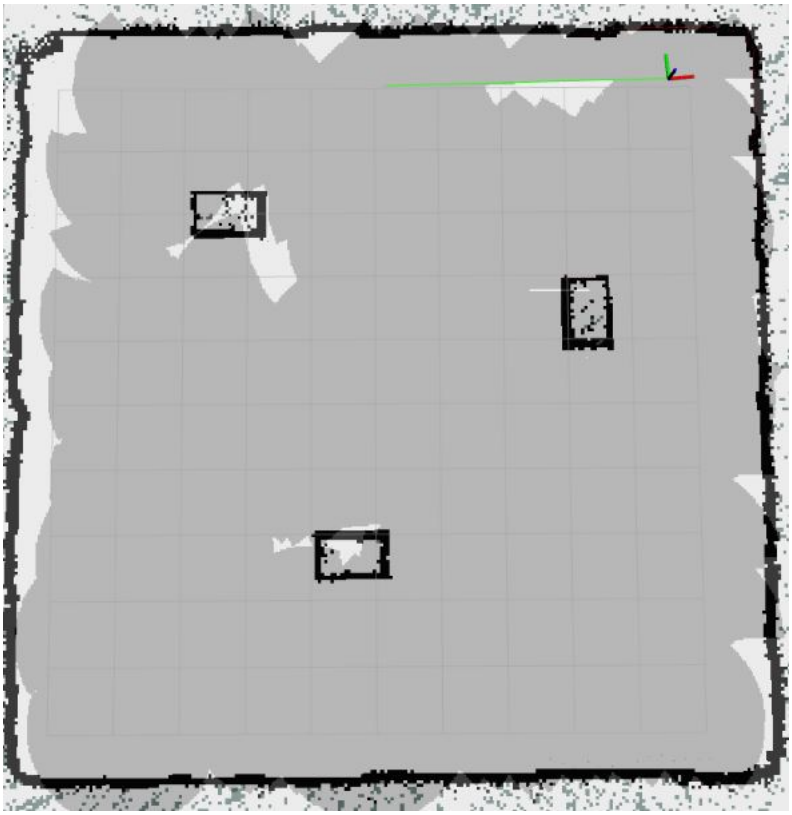

Figure 3: Finished exploration of the test area where dark grey represents the area seen by the virtual camera. The area the Rover should explore was the grid area.

Test nr: 4, Angle accuracy		**Test dependencies:** 1, 35	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
p19a	When driving the test route, the estimated angle shall have an accuracy of: 10 degrees.		1
Test description:		**Expected result:**	
Let the Rover drive along a 4 m straight line across Visionen autonomously. Measure the distance from the centre of the Rover perpendicular to the straight path and calculate the angular error.		The accuracy of the driven path is not more than 10° wrong.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The test was performed two times with resulting angular errors of 0.24° and 0.36°, well within the limit.	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 5, Distance accuracy		**Test dependencies:** 1, 30, 32, 33	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
p20a	The system shall detect and map fixed objects with an accuracy of 15 % relative to the distance to the object, when driving the test route.		1
Test description:		**Expected result:**	
Let the Rover move to a position 0.5 m in front of an obstacle, manually or autonomously. Compare the distance to the obstacle calculated by the SLAM algorithm with the real distance of 0.5 m. Calculate the accuracy as $Accuracy = \frac{SLAM_{distance} - Real_{distance}}{Real_{distance}}$		The Rover is able to map fixed objects within a 15% error relative to the real distance.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JA	JS & JA	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The SLAM distance was equal to 0.52 m and the real distance was equal to 0.50 m which resulted in an accuracy error of 4%, well within the limit of 15%. Figure 4 shows how the situation was seen in the GUI.	The requirement is fulfilled.		Pass
Test approved by: JS			

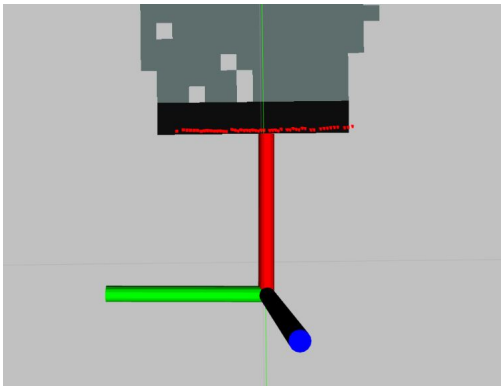

Figure 4: The Rover standing 0.5 m from an obstacle.

<table>
<tr><td colspan="2">Test nr: 6, Exploration accuracy</td><td colspan="2">Test dependencies: 1, 30, 32, 33</td></tr>
<tr><td colspan="4">Resources:</td></tr>
<tr><td>Req. nr:</td><td colspan="2">Requirement description:</td><td>Priority:</td></tr>
<tr><td>p28</td><td colspan="2">When navigating an area free from obstacles, the Rover shall explore at least 95 % of the area.</td><td>1</td></tr>
<tr><td colspan="2">Test description:</td><td colspan="2">Expected result:</td></tr>
<tr><td colspan="2">Have the Rover explore the mission area without any obstacles. Ensure that at least 95% of the map is explored when the Rover has finished its task. This can be calculated by measuring Visionen and use the given explored area of the map from the GUI. The explored area can be calculated as:
$$ExploredArea = \frac{GUI_{area}}{Visionen_{area}}$$
If possible, the area coverage can also be approximated using visual inspection of the resulting map.</td><td colspan="2">The Rover should be able to explore and map at least 95% of the test area.</td></tr>
<tr><td>Executed by:</td><td>Participants:</td><td>Test week:</td><td>Test date:</td></tr>
<tr><td>JS</td><td>JS & JA</td><td>48</td><td>28/11</td></tr>
<tr><td>Test result:</td><td colspan="2">Comments:</td><td>Pass/Fail:</td></tr>
<tr><td>By visual inspection it was possible to confirm an area coverage of at least 95 %, see Figure 5.</td><td colspan="2">The requirement is fulfilled</td><td>Pass</td></tr>
<tr><td colspan="4">Test approved by: JS</td></tr>
</table>

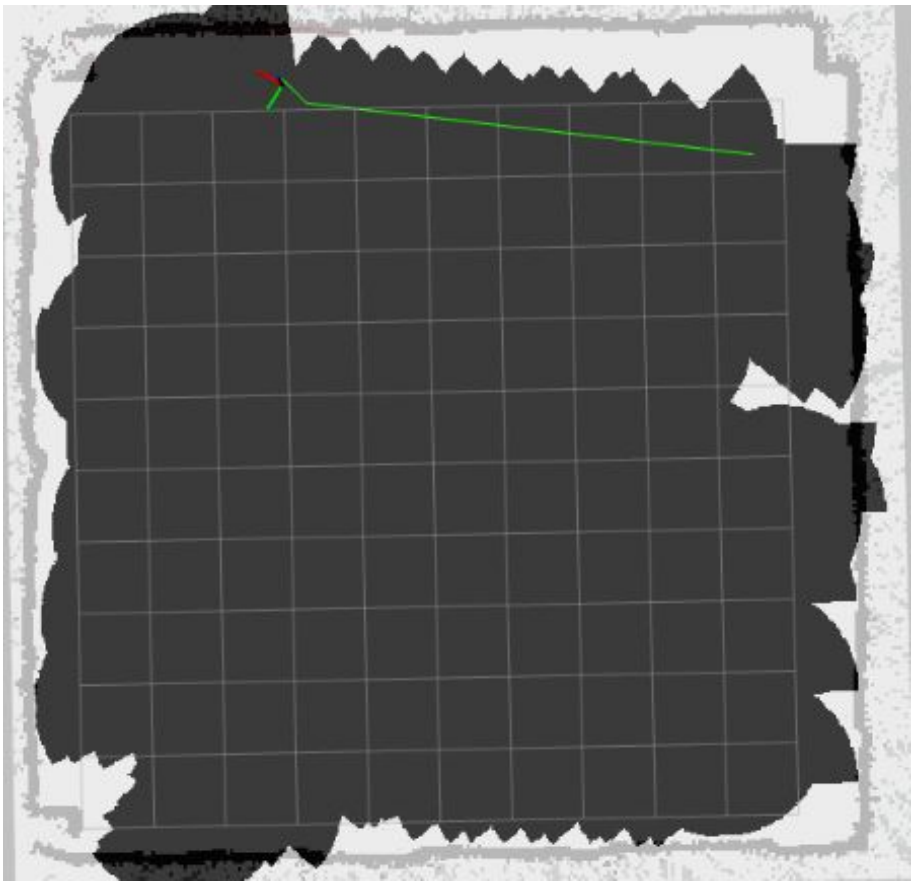

Figure 5: Finished exploration of the test area where dark grey represents the area seen by the virtual camera. The gridded area represents the area to explore.

Test nr: 7, Precision requirements		**Test dependencies:** 1, 30, 32, 33, 38	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
24	The Rover must never return within a distance of 0.5 m to the starting position.		2
25	The Rover's path must not differ more than 0.09 m from the planned path.		1
26	The navigation precision should be 0.1 m		1
33	The Rover must keep a 0.2 m safety distance to found people in distress.		2
34	The Rover must keep 1 m safety distance to the walls in Visionen.		1
Test description:		**Expected result:**	
Have the Rover perform a mission containing a full mapping of the area and moving around in the entire area. Verify that the Rover does not return to the starting position, does not deviate from the planned path, that the navigation is precise enough, that the safety distance to people in distress is enough and that the safety distance to the walls is enough.		All precision requirements are fulfilled when the mission has been executed.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	5/12
Test result:	**Comments:**		**Pass/Fail:**
All the precision requirements were fulfilled.	All requirements were fulfilled		Pass
Test approved by: JS			

Test nr: 8, Control requirements		**Test dependencies:** -	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
35	The Rover must be manually controllable by remote.		1
Test description:		**Expected result:**	
Turn on the Rover and use the remote control for manual manoeuvring.		It is possible to manoeuvre the Rover using the remote control.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
It was possible to control the Rover manually.	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 9, Software requirements		**Test dependencies:** 30	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
23 36	The Rover must run ROS. The Rover must publish its position to the ROS network.		1 1
Test description:		**Expected result:**	
Start the SLAM node on the Rover. Verify that the Rover publishes its position on a ROS topic.		It is possible to access the positions of the Rover via a ROS topic.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The position of the Rover was published on the ROS topic *odom_pose*.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 10, Emergency landing requirement		**Test dependencies:** 9, 30	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
37	The Rover must stop where it is if the Quadcopter has to make an emergency landing.		1
Test description:		**Expected result:**	
Start a mission and disconnect the Quadcopter from the ROS network. Verify that the Rover stops at its current position and enters the fail state.		Once the Quadcopter is disconnected, the Rover stops and stays stationary.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
LW	JS & LW	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
The Rover stops if the Quadcopter has to make an emergency landing.	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 11, Sensor requirements		**Test dependencies:** 36	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
22 29	The Rover must be equipped with reflectors needed for Qualisys positioning. To find the target, the Rover must have a virtual camera with a simulated 50° field of view and a range of 1.5 m in the virtual environment.		1 1
Test description:		**Expected result:**	
Verify that the reflective markers are attached to the Rover. Verify that the map presented on the GUI displays the virtual camera data as expected.		Reflective markers are present on the Rover. The camera view is present with correct field of view and range.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JA	JS & JA	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
There are reflective markers attached to the Rover and the virtual camera view is presented as expected, see Figure 6.	The requirements are fulfilled.		Pass
Test approved by: JS			

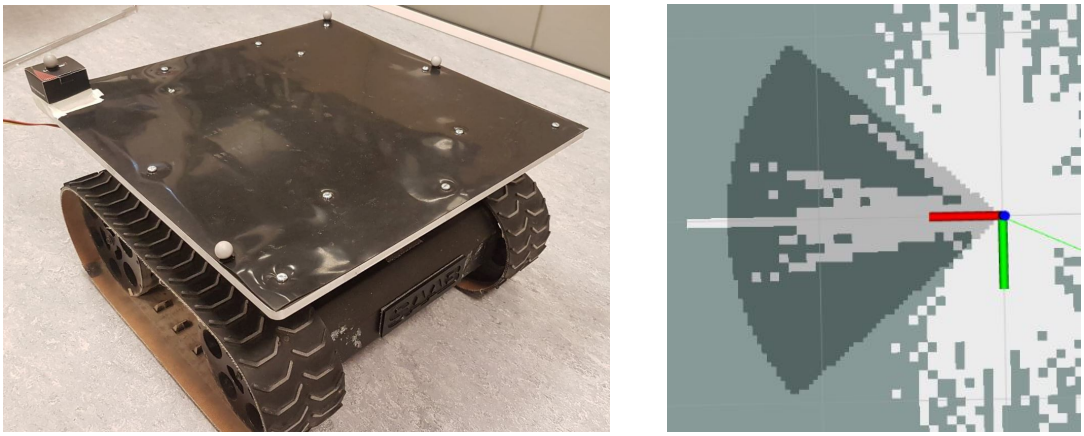

Figure 6: The Rover attached with reflective markers (to the left) and the camera view represented with dark grey colour (to the right).

Test nr: 12, Rover mission time		**Test dependencies:** 1-11, 38	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
30	The Rover must be able to search the accessible area within 600 s.		1
Test description:		**Expected result:**	
Set up a mission according to the environment requirements number 13-19. Start the mission and when the Rover finds an inaccessible area, send information that the Quadcopter has completed its mission. This is done so that the Rover's search does not depend on a working Quadcopter.		The accessible area is explored within 600 s.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & LW	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
The Rover searched the area in less than 600 s.	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 13, Rover system		**Test dependencies:** 1-12	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
1	The system must contain a Rover that satisfies the requirements stated in section 3.		1
Test description:		**Expected result:**	
Check so that requirement number 20-37 are met.		Every requirement for the Rover are met.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	4/12
Test result:	**Comments:**		**Pass/Fail:**
Requirement number 20-37 were met.	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 14, Person in distress		**Test dependencies:** 13, 28	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
18	The distressed persons are represented by points on the map.		1
Test description:		**Expected result:**	
Place one person in distress on map using the GUI and confirm that it is placed properly.		The point representing a person in distress is visible in the GUI.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
The person in distress is visible in the GUI.	The requirement is fulfilled.		Pass
Test approved by: JS			

3 Quadcopter

Test nr: 15, Manual flight		**Test dependencies:** -	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
38	The Quadcopter must be able to stabilise itself while in the air.		1
39	The Quadcopter must be manually controllable by remote.		1
Test description:		**Expected result:**	
Turn on the Quadcopter and the remote control and wait until there is a connection between them. Start flying the Quadcopter and try to hover in the air using only the remote control.		It is possible to manoeuvre the Quadcopter using the remote control and it stabilises itself while in the air.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
LW	LW & JJ	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
It was possible to manoeuvre the Quadcopter manually and it stabilised itself in the air.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 16, Qualisys integration		**Test dependencies:** 31	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
45	The Quadcopter must be equipped with reflectors required by the Qualisys positioning system.		1
65	The location of the Quadcopter as measured by Qualisys will be made available to the ROS network.		1
Test description:		**Expected result:**	
Implement the Quadcopter as a body in the Qualisys system. Start the Quadcopter and the ROS network and connect an external computer to the ROS network. Subscribe to the node which publishes the information about the position of the Quadcopter and move the Quadcopter in Visionen to receive different position data from Qualisys.		The reflectors are attached and the position of the Quadcopter can be accessed via the ROS network.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
LW	LW & JJ	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter was attached with reflective markers and the position is published on the ROS topic */posreg/qualisys_pos*.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 17, Mode switch stability		**Test dependencies:** 15, 18, 30, 31	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
40	The remote control must retain the ability to switch to manual control of the Quadcopter at any time. The stabilisation algorithms must remain active.		1
Test description:		**Expected result:**	
Start the Quadcopter in the autonomous mode, give instructions to take off and hover at 1 m in the middle of Visionen. Switch to manual mode and land safely on the ground.		The user is able to land the Quadcopter safely when switching to manual control.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
LW	LW & JJ	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The user was able to do a safe landing.	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 18, Positioning control		**Test dependencies:** 16, 30, 31	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
42	The Quadcopter must be able to fly at a user specified height between 2 m and 5 m.		1
43	The Quadcopter must be able to hold its position in the air with a maximum deviation of 0.09 m in each axis. This is measured using the Qualisys positioning system.		1
Test description:		**Expected result:**	
Start the Quadcopter in the autonomous mode, give instructions to take off and hover at 2 m. Hold the position for 5 s to make sure the Quadcopter is able to keep its position when hovering. Verify its ability to hover by looking at the plot and confirm that it never exceeds 0.09 m.		The Quadcopter is able to hover and hold its position a different heights.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JJ	JJ & LW	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter was able to hover and hold its position within the limits, see Figure 7. The test was executed at a height of 1 m since Qualisys was not reliable at a higher height at the moment of the test.	The requirements are fulfilled.		Pass
Test approved by: JS			

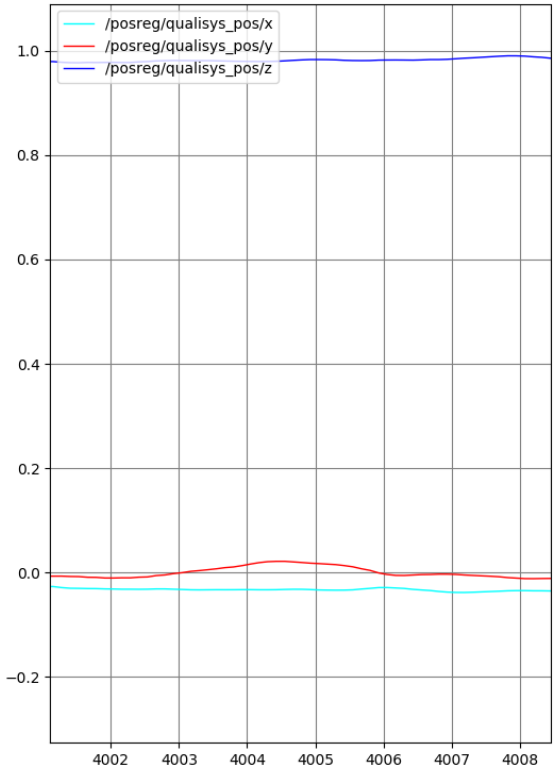

Figure 7: Plot of the hover position for the Quadcopter.

Test nr: 19, Maximum speed		**Test dependencies:** 16, 18, 20	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
41	The Quadcopter must have a maximum speed of 5 m/s.		1
Test description:		**Expected result:**	
Place the Quadcopter in the center of Visionen. Connect a computer to the ROS network and create a path that the Quadcopter should follow. Send the instructions to the Quadcopter. Try different paths and save the data from the Quadcopter, check so it does not violate the maximum speed of 5 m/s at any time. Paths should be long straight lines where the Quadcopter can accelerate.		The Quadcopter never violates the maximum speed of 5 m/s.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JJ	JJ & LW	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter never violated the maximum speed.	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 20, Autonomous path following		**Test dependencies:** 16, 18, 30, 31, 32	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
48	A search route must be calculated for the Quadcopter to follow when engaging the search for people in distress. The route will be based on the gathered map information.		1
49	The Quadcopter must, on command, autonomously take off to a pre-specified height anywhere above 2 m and below 5 m over the ground and stay there with a deviation not more than 0.2 m in height. This is measured using the Qualisys positioning system.		1
56	The Quadcopter must be able to follow the generated path.		1
Test description:		**Expected result:**	
Place the Quadcopter in the center of Visionen. Connect a computer to the ROS network and create a path that the Quadcopter should follow and send the instructions to the Quadcopter. Try different paths and save the data from the Quadcopter. Check so the margin of error is less than 0.2 m when hovering at any position.		The path following and the height control in the air works.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JJ	JJ & LW	48	28/11
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter was able to follow the generated path with an accuracy at hovering within the specified limit.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 21, Autonomous Rover interaction part 1		**Test dependencies:** 16, 18, 20, 30, 31, 32	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
21	The Rover must have a landing pad where the Quadcopter can land.		1
60	The Quadcopter must be able to take-off from the Rover when the Rover is stationary.		1
62	The Quadcopter must be able to land on the Rover when the Rover is stationary.		1
Test description:		**Expected result:**	
Place the Quadcopter on top of the Rover and send a path for the Quadcopter to follow. It shall then land on the same place as it took off from. Observe if the Quadcopter is able to accomplish this. Try different starting positions for the Quadcopter on the Rover, not only just in center of the platform.		The Quadcopter is able to take off and land at the stationary Rover.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	LW, JS & NH	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter took off from and landed on the Rover autonomously.	The requirements are fulfilled.		Pass
Test approved by: JS			

<table>
<tr><td colspan="2">Test nr: 22, Autonomous Rover interaction part 2</td><td colspan="2">Test dependencies: 16, 18, 20</td></tr>
<tr><td colspan="4">Resources:</td></tr>
<tr><td>Req. nr:</td><td colspan="2">Requirement description:</td><td>Priority:</td></tr>
<tr><td>64</td><td colspan="2">The Quadcopter must be able to obtain the location of the Rover in the global coordinate system.</td><td>1</td></tr>
<tr><td colspan="2">Test description:</td><td colspan="2">Expected result:</td></tr>
<tr><td colspan="2">Let the Rover send its position to the Quadcopter to use as reference. The Quadcopter shall then be able to hover above the Rover at a fixed height specified by the user. Verify the position of the Quadcopter by logging the position data of the Quadcopter.</td><td colspan="2">The Quadcopter is able to hover above the Rover.</td></tr>
<tr><td>Executed by:</td><td>Participants:</td><td>Test week:</td><td>Test date:</td></tr>
<tr><td>LW</td><td>LW & JJ</td><td>48</td><td>28/11</td></tr>
<tr><td>Test result:</td><td colspan="2">Comments:</td><td>Pass/Fail:</td></tr>
<tr><td>The Quadcopter was able to hover above the Rover.</td><td colspan="2">The requirement is fulfilled.</td><td>Pass</td></tr>
<tr><td colspan="4">Test approved by: JS</td></tr>
</table>

<table>
<tr><td colspan="2">Test nr: 23, Mission interaction</td><td colspan="2">Test dependencies: 16, 18, 20, 21, 30-34, 36</td></tr>
<tr><td colspan="4">Resources:</td></tr>
<tr><td>Req. nr:</td><td colspan="2">Requirement description:</td><td>Priority:</td></tr>
<tr><td>57</td><td colspan="2">The Quadcopter must have a simulated circular maximum view area of 20° in any direction at a maximum height of 3 m.</td><td>1</td></tr>
<tr><td>59</td><td colspan="2">The Quadcopter must not return to the Rover until the entire designated area has been searched.</td><td>1</td></tr>
<tr><td colspan="2">Test description:</td><td colspan="2">Expected result:</td></tr>
<tr><td colspan="2">Create a mission with the same outputs as if the mission was created by the Rover. Publish the information on the node which the Quadcopter is subscribing to and let the Quadcopter execute the mission. The searched area will be logged and plotted in the GUI continuously, and also the fraction of explored area will be calculated. To verify that the mission interaction test is successful for the Quadcopter, the logged data will be verified towards the plot to see that the Quadcopter has not returned to the Rover during the mission and that the Quadcopter only have updated its search area with the pre-defined field of view when executing the mission.</td><td colspan="2">The planning system on the Quadcopter is able to search the given area before the Quadcopter returns to the Rover.</td></tr>
<tr><td>Executed by:</td><td>Participants:</td><td>Test week:</td><td>Test date:</td></tr>
<tr><td>JS</td><td>JS, JA, NH & LW</td><td>49</td><td>3/12</td></tr>
<tr><td>Test result:</td><td colspan="2">Comments:</td><td>Pass/Fail:</td></tr>
<tr><td>The camera view was present according to the specifications and the Quadcopter successfully searched its area before returning to the Rover.</td><td colspan="2">The requirements are fulfilled.</td><td>Pass</td></tr>
<tr><td colspan="4">Test approved by: JS</td></tr>
</table>

Test nr: 24, Detection		**Test dependencies:** 16, 18, 20, 21, 30-34	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
50	The Quadcopter must be able to search a whole inaccessible area and, if present, find the person(s) in distress within 180 s from takeoff to landing.		1
58	The Quadcopter must be able to detect a person in distress if it can be found within the view specified by requirement 55.		1
Test description:		**Expected result:**	
Create a mission with the same outputs as if the mission was created by the Rover. Include person(s) in distress in the inaccessible area. Publish the information on the node which the Quadcopter is subscribing to and let the Quadcopter execute the mission. Visualise the map and the searched area, by logging and plotting the data continuously as the Quadcopter is searching the area. Check that the person(s) in distress is found and the coordinates are saved in the map. The maximum time for this mission is 180 s.		All person(s) in distress are detected within 180 s.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	5/12
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter were able to search the inaccessible area and find the people in distress within 180 s.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 25, Battery warning		**Test dependencies:** 16, 18	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
44	The Quadcopter must have a low battery voltage warning indicator.		1
47	The Quadcopter must abort the search if the battery voltage drops under 11V.		1
52	The Quadcopter must return and land at its starting position if the Rover cannot be reached by the Quadcopter or if the battery voltage drops below 11 V.		1
Test description:		**Expected result:**	
Place the Quadcopter 2 m in any direction from the centre of Visionen. Give instructions to the Quadcopter to take off and hover at a height of 3 m in the middle of Visionen until the low battery voltage indicator indicates the voltage has dropped below 11 V. Ensure that the system is able to handle a safe landing with low battery. Verified if the Quadcopter is able to land at its starting position.		The Quadcopter returns to its starting position.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	5/12
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter returned to its starting position when the battery voltage dropped below 11 V.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 26, Connection error		**Test dependencies:** 16, 18, 20, 30, 31, 32	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
53	The Quadcopter must immediately land straight down and the Rover stop, if problems with connection to the localisation system is detected or when the connection with the Base Station/hand controller is lost.		1
Test description:		**Expected result:**	
Start the Rover and the Quadcopter. Formulate a mission which includes an inaccessible area in the middle of Visionen. Start the mission. Lost connection for the Quadcopter means that it does not receive any control input within 20 μs. For the Rover, lost connection means that it does not update its position or receive any data from the Base Station within 0.1 s. The Quadcopter should immediately land straight down and the Rover should stop if the connection is lost for either the Rover or the Quadcopter. Verify by disconnecting the Base Station when the mission is executed.		The Rover shall stop and the Quadcopter land straight down.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	5/12
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter landed straight down and the Rover stopped when the connection error occurred	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 27, Fail safe command		**Test dependencies:** 16, 18, 30-32, 34	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
54	The Quadcopter must, on command, autonomously land on flat ground from a maximum height of 5 m.		1
Test description:		**Expected result:**	
Start the Quadcopter in autonomous mode and give instructions to hover in the centre of Visionen at a height of 5 m. Use the implemented command in the GUI to land the Quadcopter. Verify by using the command and observe the Quadcopter land safely.		The Quadcopter lands straight down on command.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	5/12
Test result:	**Comments:**		**Pass/Fail:**
The Quadcopter was able to land straight down on command.	The requirement is fulfilled.		Pass
Test approved by: JS			

Test nr: 28, Quadcopter system		**Test dependencies:** 15-27	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
1	The system must contain a Quadcopter that satisfies the requirements stated in section 4.		1
Test description:		**Expected result:**	
Check that requirement number 38-66 are met.		Every requirement for the Quadcopter is met.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	5/12
Test result:	**Comments:**		**Pass/Fail:**
Requirement number 38-66 were met.	The requirement is fulfilled.		Pass
Test approved by: JS			

4 System

Test nr: 29, System test		**Test dependencies:** 14, 38, 39	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
5	The system must be able to successfully complete a mission as described in section 2.2.		1
Test description:		**Expected result:**	
Check that requirement number 9-12 are met through earlier tests.		Every requirement for the system is met.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	4/12
Test result:	**Comments:**		**Pass/Fail:**
Requirement number 9-12 were met.	The requirement is fulfilled.		Pass
Test approved by: JS			

5 Communication

Test nr: 30, Communication		**Test dependencies:** -	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
46	The Quadcopter must be implemented using ROS.		1
67	The Rover, Quadcopter and Base Station must all be equipped with WiFi for communication.		1
68	The Rover, Quadcopter and Base Station will send and receive data from each other via WiFi.		1
69	The communication will be implemented in ROS.		1
70	The Rover, Quadcopter and Base Station must be able to receive information from the Qualisys positioning system, defined as the global coordinate system, directly or via another node.		1
Test description:		**Expected result:**	
Connect an external computer to the ROS network and run the command rostopic list in the terminal to view all active topics. Information of the Rover and the Quadcopter should be available. Also check so that the Qualisys node publish data of the position of the Rover and the Quadcopter.		The communication between the systems is working.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	2/12
Test result:	**Comments:**		**Pass/Fail:**
All required topics were published.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 31, Qualisys		**Test dependencies:** 30	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
3	The system must be integrated with the Qualisys tracking equipment in Visionen.		1
Test description:		**Expected result:**	
Check that test number 30, *Communication* passed.		Qualisys tracking equipment is working in Visionen.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	2/12
Test result:	**Comments:**		**Pass/Fail:**
Test number 30 passed.	The requirement is fulfilled.		Pass
Test approved by: JS			

6 GUI and Visualisation

Test nr: 32, Positioning on map		**Test dependencies:** -	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
71	The delivered system must contain a GUI.		1
72	The GUI must contain a map of the area of operation.		1
73	The map must display a representation of the Rover, its orientation and position.		1
74	The map must display a representation of the Quadcopter, its orientation and position.		1
Test description:		**Expected result:**	
Open the GUI on a computer and create a map of Visionen. Start up the Rover and the Quadcopter in Visionen and observe how the Rover and Quadcopter moves on the map and how the orientations and positions changes with time.		Verify that the GUI shows the map, the Rover and the Quadcopter.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
The GUI contains a map in which both the position and the orientation of the Rover and the Quadcopter can be observed.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 33, Positioning on map 2		**Test dependencies:** 32	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
75	The map must display identified obstacles.		1
76	The map must display the explored area.		1
77	The map must display identified people in distress.		1
Test description:		**Expected result:**	
Open the GUI on the computer and set up a mission in Visionen. Include obstacles and people in distress. Run the mission and watch the Rover/Quadcopter complete the mission and how the identified obstacles and people in distress are shown in the GUI. The explored area should also be continuously updated as the Rover and Quadcopter explore new areas.		Verify that the GUI shows the explored area, identified obstacles and identified people in distress.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
Identified obstacles, explored area and identified people in distress are displayed in the map.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 34, User interaction		**Test dependencies:** 32, 33	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
78	The GUI must enable the user to start and stop the mission.		1
82	The GUI displays the mission state.		1
Test description:		**Expected result:**	
Open the GUI on the computer and set up a mission. Start the mission in the GUI. Try both to pause and to stop the mission in the GUI and observe the mission state. By logging the data one can see that a pause should temporarily stop the mission and that a stop should completely stop the mission.		Start, pause and stop a mission is working on the GUI and it also displays the mission state.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	4/12
Test result:	**Comments:**		**Pass/Fail:**
The user is able to start and stop the mission using the corresponding buttons and at the same time observe the current mission state, see Figure 8.	The requirements are fulfilled.		Pass
Test approved by: JS			

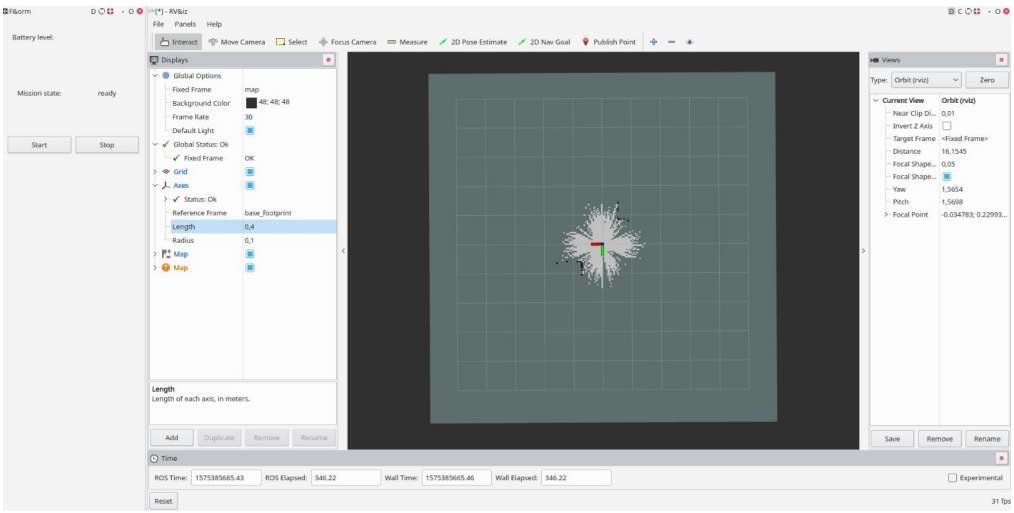

Figure 8: The user is able to start and stop the mission using the buttons to left, and the mission state is displayed above these buttons.

Test nr: 35, Visualisation		**Test dependencies:** 32, 33	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
83	The delivered system must be able to visualise the map using the projectors available in Visionen.		2
84	The visualisation should contain a representation of the Rover, its orientation and position		1
85	The visualisation should contain a representation of the Quadcopter, its orientation and position.		1
86	The visualisation must contain identified obstacles.		1
87	The visualisation must contain identified people in distress.		1
90	The visualisation may convey which parts of the area of operation have been explored.		1
93	The visualisation contains the planned path of the Rover.		1
94	The visualisation contains the planned path of the Quadcopter.		1
Test description:		**Expected result:**	
Ensure that what should have been included in the visualisation is visible in the GUI.		What should have been included in the visualisation is visible in the GUI.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
Everything requested is visible in the GUI.	The priority 1 requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 36, Visualisation 2		**Test dependencies:** 11, 23, 32, 33, 35	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
88	The visualisation must contain the view from the virtual camera on the Quadcopter.		1
89	The visualisation must contain the view from the virtual camera on the Rover.		1
Test description:		**Expected result:**	
Open the GUI and start the Rover and the Quadcopter in Visionen. Manually drive the Rover and the Quadcopter and observe the camera view of the Rover and the Quadcopter in the GUI. Take photos for the test protocol.		Verify that the virtual cameras are shown in the GUI.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
The camera view from both the Rover and the Quadcopter can be observed in the GUI.	The requirements are fulfilled.		Pass
Test approved by: JS			

7 Full scale test

Test nr: 38, Environment setup		**Test dependencies:** 31	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
12	The Rover must be placed in the middle of the test area at start the mission.		1
13	Obstacles can be placed anywhere in Visionen as long as all other requirements in this section are met, see appendix A for a sample environment.		1
14	There must be at least two inaccessible areas in the test area where the minimum size of such area is 1x1 m and the maximum size is 3x3 m.		1
15	There must be at least two people in distress in the test area. At least one of them should be in the accessible area and at least one of them should be in the inaccessible area.		1
16	The inaccessible areas must be within the range of the Qualisys system.		1
17	The distance between obstacles, inaccessible areas and walls of the room must be at least 1 m.		1
18	The distressed persons are represented by points on the map.		1
Test description:		**Expected result:**	
Set up an environment according to requirement number 13-19. Verify that all requirements are met. Place the Rover at any edge of the test area in Visionen. The environment is then ready for test number 39, *Full scale test*.		The test area is ready for test number 39, *Full scale test*.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
It was possible to construct the environment.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 39, Full scale test		**Test dependencies:** 13, 28, 30-38	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
7	A mission is considered to be completed when all persons in distress have been found and the entire test area has been explored.		1
10	To be considered successful, the mission must be completed within 10 minutes.		1
Test description:		**Expected result:**	
Start the projectors to visualise all mission data. Start the mission and observe how the Rover together with the Quadcopter strategically solves the mission within the time limit of 10 minutes. Repeat the test three times and vary the positions of the people in distress.		All the people in distress are found and positioned correctly within 10 minutes.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS, JA, LW, JJ, JG, AAJ & NH	49	5/12
Test result:	**Comments:**		**Pass/Fail:**
All the people in distress were found within the time limit.	The requirements are fulfilled.		Pass
Test approved by: JS			

Test nr: 40, Virtual test area		**Test dependencies:** 30	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
6	A virtual representation of the test area must be made available to the ROS network.		1
Test description:		**Expected result:**	
Construct a virtual environment of the test area used for the full scale test including the same distressed people and obstacles. Publish to a ROS node.		The virtual test area is a copy of the physical test area.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
JS	JS & JA	49	3/12
Test result:	**Comments:**		**Pass/Fail:**
A virtual representation of the test area is visible in the GUI and therefore available to the ROS network	The requirement is fulfilled.		Pass
Test approved by: JS			

8 Test priority 2 and 3

Test nr: 37, Projector Visionen integration.		**Test dependencies:** 35, 36	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
4	The system must be integrated with the projector system in Visionen.		2
Test description:		**Expected result:**	
Check that test number 35-36 passed.		The system is integrated with the projector system in Visionen.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

Test nr: 41, Simulation of Full scale test		**Test dependencies:** 30-38, 40	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
8	It must be possible to simulate a mission without using the hardware Rover and the hardware Quadcopter, or using the hardware Rover without the hardware Quadcopter.		2
Test description:		**Expected result:**	
Simulate *Full scale test* and verify that all requirements regarding the simulation are met similarly to the real full scale test.		All the persons in distress are found and positioned correctly within 10 minutes.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

Test nr: 42, Improved precision requirements		**Test dependencies:** 7	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
27	The navigation precision should be 0.05 m.		2
28	The navigation precision should be 0.01 m.		3
Test description:		**Expected result:**	
Redo test number 7, *Precision requirements*, but with a more strict precision requirement.		The Rover is able to perform a mission and the navigation error never exceeds 0.01 m for best result but 0.05 m is also an improvement.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

Test nr: 43, Faster mission		**Test dependencies:** 39	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
31	The Rover must be able to search the accessible area within 300 s.		2
51	The Quadcopter must be able to search a whole inaccessible area and, if present, find the person(s) in distress within 120 s from takeoff to landing.		2
Test description:		**Expected result:**	
Redo test number 39, *Full scale test*, but let the Rover and the Quadcopter execute the mission faster.		The Rover is able to search the accessible area within 300 s and the Quadcopter is able to search the inaccessible area within 180 s.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

Test nr: 44, Quadcopter command		**Test dependencies:** 16, 18, 20, 30-34	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
55	The Quadcopter must, on command, autonomously land within 20 s.		2
Test description:		**Expected result:**	
Give instructions to the Quadcopter to hover at a height of 4.5 m. Use the implemented landing command on the GUI. Verify that the requirement is fulfilled.		The Quadcopter is able to land within 20 s.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

Test nr: 45, Moving Rover		**Test dependencies:** 13, 28	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
61	The Quadcopter must be able to take-off from the Rover when the Rover is moving.		2
63	The Quadcopter must be able to land on the Rover when the Rover is moving.		2
Test description:		**Expected result:**	
Set up an environment including an inaccessible area which the Quadcopter has to explore. Change the settings for the takeoff and landing on the Rover for the Quadcopter. The Rover should instead of standing still move slowly when the Quadcopter takes off and lands on the Rover. Repeat the test and increase the speed of the Rover as long as a safe landing is possible.		The Quadcopter is able to takeoff and land on the Rover when the Rover is moving.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

Test nr: 46, GUI improvements		**Test dependencies:** 32-34	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
79	The GUI allows the user to control the Rover.		2
80	The GUI allows the user to control the Quadcopter.		2
81	The GUI allows the user to place virtual persons in distress on the map.		2
Test description:		**Expected result:**	
Place the Quadcopter in Visionen and use the controls on the GUI to control it. Repeat with the Rover. Place a person in distress through the GUI and obtain the data.		It is possible to control the Quadcopter and the Rover using the GUI. It is also possible to place virtual presons in distress on the map.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

Test nr: 47, Environment improvements		**Test dependencies:** 30-34	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
91	The test area can be designed by publishing obstacle coordinates to the ROS network.		2
92	There is a map editor where the test area can be designed. This is implemented on the Base Station and the map will be communicated to the Rover and the Quadcopter when necessary.		2
Test description:		**Expected result:**	
Create the map for the mission including obstacles using the ROS network. Execute the mission and observe how the Rover and the Quadcopter treats the map.		The mission should be executed as if the obstacles were placed in Visionen.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			

Test nr: 48, Reduce cost of Quadcopter		**Test dependencies:** 39	
Resources:			
Req. nr:	**Requirement description:**		**Priority:**
66	The Quadcopter and the Rover will optimize their search trajectories in order to minimize the return trip of the Quadcopter.		3
Test description:		**Expected result:**	
Execute a mission with the implemented optimization where the return trip for the Quadcopter to the Rover is minimized. Verify that the requirement is fulfilled.		The Rover should move towards the Quadcopter when the Quadcopter has finished its search of the inaccessible area.	
Executed by:	**Participants:**	**Test week:**	**Test date:**
Test result:	**Comments:**		**Pass/Fail:**
Test approved by:			