Requirements Specification:
Search and Rescue - Coordination Between Quadcopter and Rover

Version 1.2

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Document History

Version	Date	Changes made	Reviewer
0.1	2019-09-17	First draft.	JA
0.2	2019-09-20	Second draft.	JA
0.3	2019-09-30	Third draft.	JA
0.4	2019-10-03	Fourth draft.	JA
1.0	2019-10-08	First version.	JA
1.1	2019-11-21	Requirements negotiation.	JA
1.2	2019-12-04	Requirements negotiation.	JA

Contents

1 Introduction

This document is a requirements specification for the project *Search and Rescue* in the course TSRT10, *Reglerteknisk projektkurs, CDIO*, at Linköping University. This document will give clear definitions of the goals associated with this project and list the corresponding requirements that need to be fulfilled to accomplish them. The requirements will be on the following form throughout the rest of this document:

Req. no.	**Version**	**Description**	**Priority**
1	Original	Description of requirement.	1
2	Revised YYYY-MM-DD	Description of requirement.	2

The number in the priority column determines the significance of each requirement and it ranges from 1 to 3. The different priority levels have the following definitions:

- **Level 1** - The most basic requirements that need to be accomplished in order to deliver the system to the customer.
- **Level 2** - Not essential for the basic functionality of the system but they are highly appreciated and should be implemented.
- **Level 3** - If there are time/resources left these requirements would propel the functionality of the final system.

The implementation of the requirements should be done in the priority order, hence all the priority 1 requirements should be implemented before the implementation of priority 2 requirements begins etc. The requirements are therefore written such that a lower priority level requirement is not dependent on the implementation of a higher priority level requirement.

A dialog will be kept between the project group and the customer throughout the entire project such that the implemented requirements meet the expectation of the customer. If some of the level 1 priority requirements cannot be implemented or if there are no resources/time left to implement them there must be a renegotiation with the customer. Thus the requirements cannot be removed unless the customer has confirmed it.

1.1 Parties

The parties in the project are the customer Torbjörn Crona at Saab Dynamics, the client Magnus Malmström at Linköping University, the three advisors Kristoffer Bergman at Linköping University, Joakim Mörhed and Axel Reizenstein which both are at Saab Dynamics. Finally there is a project group led by the project manager Jakob Jerrelind with Albin Andersson Jagesten in charge of ROS, Jens Grundmark in charge of software, Jesper Ahlander in charge of documentation, Jonathan Svensson in charge of testing, Linus Wiik in charge of hardware and Nils Hedner in charge of design.

1.2 Purpose and Goal

The purpose of the project is to design and implement an autonomous system that uses a tracked vehicle and a quadcopter simultaneously to search an unknown area for people in distress. The tracked vehicle should do the majority of the search because it has much more fuel and is therefore not as expensive as the quadcopter to operate. However, the mission takes place in an environment

where there are certain areas which the tracked vehicle cannot reach. In those places the quadcopter, which is situated on top of the tracked vehicle, should be used instead. When the tracked vehicle reaches an inaccessible area the quadcopter should take off and start exploring it while the tracked vehicle proceeds to some other unexplored area. When the quadcopter has searched through the inaccessible area it should return to the tracked vehicle and land on top of it. All this should be done autonomously. Hence, the main focus in this project is the cooperation between the tracked vehicle and the quadcopter.

1.3 Application

The intentional use of this system is to deploy it in an environment that is either dangerous to people due radiation or some hazardous substance or an area with harsh terrain. The system should after deployment start searching for people in distress while mapping the surrounding environment. When or if it finds someone in distress it should send the current position to the rescuing team.

1.4 Background Information

The platform for this project is delivered by Saab Dynamics and it consists of a tracked vehicle and a quadcopter. The platform has been used in a series of projects that has been conducted throughout the years. These projects have been a part of the course TSRT10 at Linköping University.

The goal of last year's project was to use the tracked vehicle together with a simulated quadcopter to find people in distress in an unfamiliar setting. The quadcopter started searching the unfamiliar area from above, sending positional data of people in distress to the tracked vehicle. The tracked vehicle then started to map the area and proceeded to find the person in distress while the quadcopter continued its search.

The main focus in this year's project is therefore to make the system fully autonomous and to use a real quadcopter instead of a simulated one. Another request for this year's project is that it should be able to serve as a demo system. Hence, it is of importance to include satisfying visualisation features.

1.5 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.

2 System Requirements

This section aims to outline general requirements for the project and the platforms involved. These requirements are meant to outline what different parts are needed for the project and how the search and rescue mission should work. The mission requirements include both what the system will be required to do and how the mission will be structured.

2.1 General Requirements

In this section the general requirements for the system are specified.

Req. no.	Version	Description	Priority
1	Original	The system must contain a Quadcopter that satisfies the requirements stated in section 4.	1
2	Original	The system must contain a Rover that satisfies the requirements stated in section 3.	1
3	Original	The system must be integrated with the Qualisys tracking equipment in Visionen.	1
4	Original	The system must be integrated with the projector system in Visionen.	2
5	Original	The system must be able to successfully complete a mission as described in section 2.2.	1
6	Original	A virtual representation of the test area must be made available to the ROS network.	1
7	Original	A mission is considered to be completed when all persons in distress have been found and the entire test area has been explored.	1
8	Revised 2019-11-20	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

2.2 Mission Requirements

In this section the requirements for the missions are presented.

Req. no.	Version	Description	Priority
9	Original	The mission shall take place in an environment satisfying the requirements in section 2.3.	1
10	Original	To be considered successful, the mission must be completed within 10 minutes.	1

Req. no.	Version	Description	Priority
11	Revised 2019-11-20	A distressed person is considered to be found when at least 60% of it appears in the field of view of one or more of the virtual cameras.	2
12	Revised 2019-12-03	The Rover must be placed in the middle of the test area at start the mission.	1

2.3 Environment

In this section the requirements for the environment are presented. An illustration of the test environment are described in Appendix A.

Req. no.	Version	Description	Priority
13	Original	Obstacles can be placed anywhere in Visionen as long as all other requirements in this section are met, see appendix for a sample environment.	1
14	Original	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	Original	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	Original	The inaccessible areas must be within the range of the Qualisys system.	1
17	Revised 2019-11-20	The distance between obstacles, inaccessible areas and walls of the room must be at least 2 m.	1
18	Revised 2019-11-20	The distressed persons are represented by points on the map.	1
19	Revised 2019-11-20	The distressed persons are represented by circles with a 20 cm diameter.	2
20	Original	The Rover must be able to access at least 60% of the test area.	1
21	Revised 2019-11-20	The obstacles and inaccessible areas must enclose an area of at least 1x1 m.	1

3 Rover

In this section the requirements for the Rover are listed. The requirements are split into three categories, the requirements from previous years, hardware requirements and functionality requirements.

3.1 Previous Requirements

The Rover has been a vital part of this project's predecessors and the functionality is intended to be reused to some extent. To ensure satisfactory basic performance some requirements are exactly the same as from previous years and are therefore cited.

Req. no.	Version	Description	Priority
22	Original	The Rover must fulfil the requirements specified in the 2017 project, since the the software developed that year will be reused and tested. The requirements that need to be satisfied are found in Table 2 in Appendix B.	1

3.2 Hardware Requirements

In this section the new hardware specific requirements for this project are determined.

Req. no.	Version	Description	Priority
23	Original	The Rover must have a landing pad where the Quadcopter can land.	1
24	Original	The Rover must be equipped with reflectors needed for Qualisys positioning.	1

3.3 Functionality Requirements

Here follows the requirements on the Rover's functionality.

Req. no.	Version	Description	Priority
25	Original	The Rover must run ROS.	1
26	Revised 2019-12-03	The Rover must never return within a distance of 0.5 m to the starting position.	2
27	Original	The Rover's path must not differ more than 0.09 m from the planned path.	1
28	Original	The navigation precision should be 0.1 m.	1
29	Original	The navigation precision should be 0.05 m.	2
30	Original	The navigation precision should be 0.01 m.	3

Req. no.	Version	Description	Priority
31	Original	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
32	Original	The Rover must be able to search the accessible area within 600 s.	1
33	Original	The Rover must be able to search the accessible area within 300 s.	2
34	Original	The Rover must be able to move from a point in the SLAM reference to a point in the general coordinate system with 0.1 m precision.	1
35	Revised 2019-12-03	The Rover must keep a 0.2 m safety distance to found people in distress.	2
36	Original	The Rover must keep 1 m safety distance to the walls in Visionen.	1
37	Original	The Rover must be manually controllable by remote.	1
38	Original	The Rover must publish its position to the ROS network.	1
39	Original	The Rover must stop where it is if the Quadcopter has to make an emergency landing.	1

4 Quadcopter

In this section the requirements concerning the Quadcopter are presented. The requirements are divided into four different categories. The *General Functionality* section presents the basic functionality and the unsorted requirements on the Quadcopter. In the *Autonomy Functionality* section the requirements regarding the autonomy of the system are stated. The section *Detection Functionality* contains the requirements regarding the ability of detection and identification of the person in distress. In the last section, *Interaction with the Rover*, the requirements regarding the interaction between the Rover and Quadcopter are stated.

4.1 General Functionality

In this section requirements of the general functionality are presented.

Req. no.	Version	Description	Priority
40	Original	The Quadcopter must be able to stabilise itself while in the air.	1
41	Original	The Quadcopter must be manually controllable by remote.	1
42	Original	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
43	Original	The Quadcopter must have a maximum speed of 5 m/s.	1
44	Original	The Quadcopter must be able to fly at a user specified height between 2 m and 5 m.	1
45	Original	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
46	Original	The Quadcopter must have a low battery voltage warning indicator.	1
47	Original	The Quadcopter must be equipped with reflectors required by the Qualisys positioning system.	1
48	Original	The Quadcopter must be implemented using ROS.	1
49	Original	The Quadcopter must abort the search if the battery voltage drops under 11 V.	1

4.2 Autonomy Functionality

In this section requirements of the autonomy functionality are presented.

Req. no.	Version	Description	Priority
50	Original	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
51	Original	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
52	Original	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
53	Original	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
54	Original	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
55	Original	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
56	Original	The Quadcopter must, on command, autonomously land on flat ground from a maximum height of 5 m.	1
57	Original	The Quadcopter must, on command, autonomously land within 20 s.	2
58	Original	The Quadcopter must be able to follow the generated path.	1

4.3 Detection Functionality

In this section requirements of the detection functionality are presented.

Req. no.	Version	Description	Priority
59	Original	The Quadcopter must have a virtual camera with a simulated circular maximum view area of 20° in any direction at a maximum height of 3 m.	1
60	Original	The Quadcopter must be able to detect a person in distress if it can be found within the view specified by requirement 55.	1
61	Original	The Quadcopter must not return to the Rover until the entire designated area has been searched.	1

4.4 Interaction with the Rover

In this section requirements for the interaction with the Rover are presented.

Req. no.	Version	Description	Priority
62	Original	The Quadcopter must be able to take off from the Rover when the Rover is stationary.	1
63	Original	The Quadcopter must be able to take off from the Rover when the Rover is moving.	2
64	Original	The Quadcopter must be able to land on the Rover when the Rover is stationary.	1
65	Original	The Quadcopter must be able to land on the Rover when the Rover is moving.	2
66	Original	The Quadcopter must be able to obtain the location of the Rover in the global coordinate system.	1
67	Original	The location of the Quadcopter as measured by Qualisys will be made available to the ROS network.	1
68	Original	The Quadcopter and the Rover will optimize their search trajectories in order to minimize the return trip of the Quadcopter.	3

5 Communication between Rover, Quadcopter, Base Station and Qualisys

This section presents the requirements regarding the communication between the different units.

5.1 Design Requirements

Requirements linked to hardware and physical attributes are presented here.

Req. no.	Version	Description	Priority
69	Original	The Rover, Quadcopter and Base Station must all be equipped with WiFi for communication.	1

5.2 Functionality Requirements

Here the requirements regarding functionality are presented.

Req. no.	Version	Description	Priority
70	Original	The Rover, Quadcopter and Base Station will send and receive data from each other via WiFi.	1
71	Original	The communication will be implemented in ROS.	1
72	Original	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

6 GUI and Visualisation

In this section the requirements concerning the Graphical User Interface (GUI) and visualisation are presented. The requirements are divided into two parts concerning the two topics.

6.1 GUI

In this section the requirements for the GUI are presented.

Req. no.	Version	Description	Priority
73	Original	The delivered system must contain a GUI.	1
74	Original	The GUI must contain a map of the area of operation.	1
75	Original	The map must display a representation of the Rover, its orientation and position.	1
76	Original	The map must display a representation of the Quadcopter, its orientation and position.	1
77	Original	The map must display identified obstacles.	1
78	Original	The map must display the explored area.	1
79	Original	The map must display identified people in distress.	1
80	Revised 2019-11-20	The GUI must enable the user to start and stop the mission.	1
81	Original	The GUI allows the user to control the Rover.	2
82	Original	The GUI allows the user to control the Quadcopter.	2
83	Original	The GUI allows the user to place virtual persons in distress on the map.	2
84	Original	The GUI displays the mission state.	1

6.2 Visualisation

In this section the requirements for the visualisation are presented.

Req. no.	Version	Description	Priority
85	Original	The delivered system must be able to visualise the map using the projectors available in Visionen.	2
86	Original	The visualisation should contain a representation of the Rover, its orientation and position.	1

Req. no.	Version	Description	Priority
87	Original	The visualisation should contain a representation of the Quadcopter, its orientation and position.	1
88	Original	The visualisation must contain identified obstacles.	1
89	Original	The visualisation must contain identified people in distress.	1
90	Original	The visualisation must contain the view from the virtual camera on the Quadcopter.	1
91	Original	The visualisation must contain the view from the virtual camera on the Rover.	1
92	Original	The visualisation may convey which parts of the area of operation have been explored.	1
93	Original	The test area can be designed by publishing obstacle coordinates to the ROS network.	2
94	Original	There is a map editor where the test area can be designed. The map editor contains tools to define positions of persons in distress.	2
95	Original	The visualisation contains the planned path of the Rover.	1
96	Original	The visualisation contains the planned path of the Quadcopter.	1

7 Safety Requirements

The following section describes the safety requirements on the system.

Req. no.	Version	Description	Priority
97	Original	A safety protocol for the Quadcopter and the Rover must be created and followed.	1

8 Economy

This section describes the economic requirements on the project.

Req. no.	Version	Description	Priority
98	Original	Each member of the project group will spend 240 hours on the project.	1
99	Original	ISY will provide up to 40 hours of guidance.	1
100	Original	ISY will provide a project room on campus Valla.	1
101	Original	Saab Dynamics will provide up to 40 hours of guidance.	1
102	Original	Expenses on extra equipment related to the project will be paid by the customer upon their approval.	1
103	Original	A limited amount of time is available in Visionen.	1

9 Delivery Requirements and Partial Deliveries

This section describes every requirement on the deliveries in the project and are divided according to the tollgates (BP).

9.1 BP2

The following requirements must be met for BP2.

Req. no.	Version	Description	Priority
104	Original	A verbal presentation of the current system shall be given at BP2.	1
105	Original	A requirements specification shall be delivered at BP2.	1
106	Original	A project plan (including a time plan) shall be delivered at BP2.	1
107	Original	A draft of a design specification shall be delivered at BP2.	1

9.2 BP3

The following requirements must be met for BP3.

Req. no.	Version	Description	Priority
108	Original	A design specification shall be delivered at BP3.	1
109	Original	A test plan shall be delivered at BP3.	1

9.3 BP4

The following requirements must be met for BP4.

Req. no.	Version	Description	Priority
110	Revised 2019-11-20	A planning system for scanning an area shall be delivered at BP4.	2
111	Revised 2019-11-20	A detection system used for finding people in distress shall be delivered at BP4.	2
112	Revised 2019-11-20	A Quadcopter able to fly autonomously shall be delivered at BP4.	2
113	Revised 2019-11-20	A test protocol covering the two requirements above shall be delivered at BP4.	2
114	Revised 2019-11-20	Connection between the system and Qualisys positioning is to be delivered at BP4.	2

9.4 BP5

The following requirements must be met for BP5.

Req. no.	Version	Description	Priority
115	Original	All functionality shall be delivered at BP5.	1
116	Original	A complete test protocol shall be delivered at BP5.	1
117	Original	A user manual including an installation guide shall be delivered and presented at BP5.	1
118	Original	A presentation showing all the achieved requirements in the requirements specification shall be delivered at BP5.	1

9.5 BP6

The following requirements must be met for BP6.

Req. no.	Version	Description	Priority
119	Original	A technical report shall be delivered at BP6.	1
120	Original	An after study evaluating the project shall be delivered at BP6.	1
121	Original	A poster presentation shall be delivered at BP6.	1
122	Original	A web page describing the project shall be delivered at BP6.	1
123	Original	A demo film shall be delivered at BP6.	1

10 Documentation

This section describes the requirements on the documentation in the project. All the documentation serves as a basis of communication between the different parties associated to the project in present time and in the future. Table 1 contains explanations of all the documents that will be produced.

Req. no.	Version	Description	Priority
124	Original	All documentation must follow the LIPS method.	1
125	Original	All code must be written according to the Google coding standard.	1
126	Original	A status report of the project must be delivered to the customer and to the client every week.	1

Table 1: Description of the project documentation.

Document	Language	Purpose	Target group	Format/media
Requirements Specification	English	Describes all the requirements that must be fulfilled in the project.	Client, customer	PDF/electronic
Project Plan	English	Describes how the project is to be executed and also contains activities and milestones.	Client, customer	PDF/electronic
Time Plan	English	Describes how much time each activity is planned to take.	Client, customer	PDF/electronic
Design Specification	English	Describes in detail how the different parts of the system are supposed to be constructed and implemented.	Client	PDF/electronic
Test Plan	English	Describes how the system is supposed to be tested in order to verify functionality.	Client	PDF/electronic
Test Protocol	English	Describes the results of all the performed tests.	Client	PDF/electronic
User Manual	English	Describes how the system is correctly used. An installation guide is also included which describes how the system is correctly installed.	User	PDF/electronic

Document	Language	Purpose	Target group	Format/media
Technical Report	English	Describes in detail all the technical aspects of the system.	Client, customer	PDF/electronic
After Study	English	Contains a discussion about the work flow, time consumption, experiences and problems encountered during the project.	Client, customer	PDF/electronic
Status Report	English	Describes the current status of the project.	Client, customer	PDF/electronic
Time Report	English	Describes the actual time consumption of the different activities in the project.	Client, customer	PDF/electronic

Appendices

A Test Environment

In Figure 1 an illustration of the test environment is visible. The starting point of the mission is indicated by the blue area. The green area is accessible by the Rover but the red area is inaccessible and must therefore be explored by the Quadcopter. The two persons in the figure are people in distress that the Rover and Quadcopter must locate.

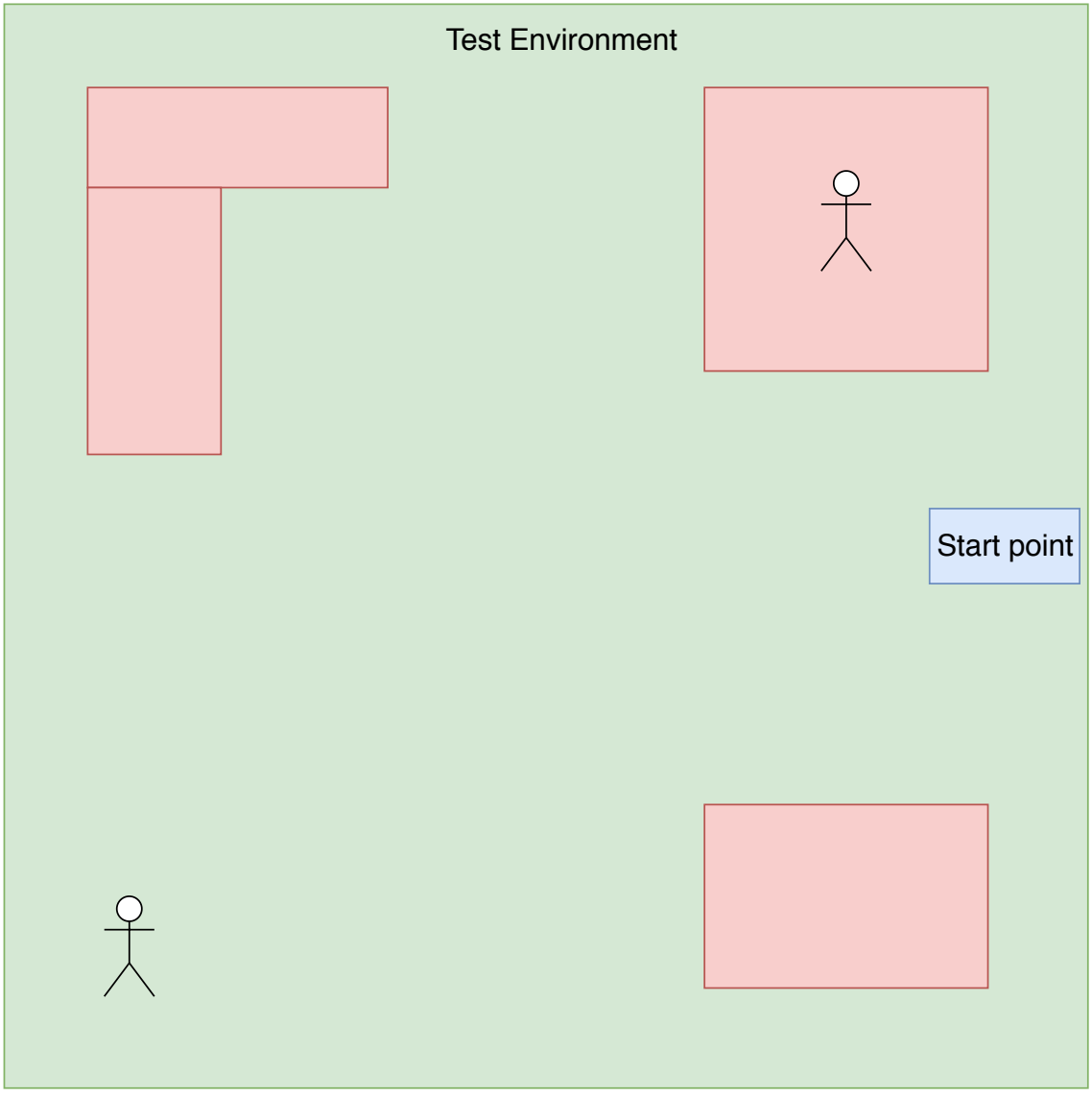

Figure 1: Test environment for the mission. Blue colour indicates starting position, green indicates accessible area and red indicates inaccessible area.

B Previous Requirements

Below are requirements from the project made in 2017 that need to be satisfied for this year's project.

Table 2: Requirements from the project made in 2017 that need to be fulfilled this year.

Req. no.	Version	Description	Priority
15	Original	The position is estimated using both the odometry and LIDAR.	1
16	Original	Mapping and positioning is done simultaneously with a SLAM algorithm.	1
17	Original	The system will not reuse prior map knowledge, i.e. it will start with an empty map	1
18a	Original	When driving the test route, the estimated position shall have an accuracy of: 0.2m.	1
19a	Original	When driving the test route, the estimated angle shall have an accuracy of: 10 degrees	1
20a	Original	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
21	Original	The navigation shall avoid obstacles between nodes.	1
22	Original	The navigation module shall update the route if new obstacles appear.	1
24	Original	Route planning shall be done in real time.	1
28	Original	When navigating an area free from obstacles, Rover shall explore at least 95 % of the area.	1
29a	Original	When navigating the test area, Rover shall explore at least 95 % of the map that are more than 0.5 meters from any obstacle.	1
33	Original	The user shall be able to adjust the speed of the Rover.	1
34	Original	The Rover shall not deviate more than 0.1 m from the intended route provided by the navigation module.	1
35	Original	The Rover shall finish within 0.2 m of the intended goal node.	1