Requirements Specification
Minesweeper

Version 1.1

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Project Identity

Linköping University, Department of Electrical Engineering (ISY)
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Document History

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1.1	28/11-17	Requirement renegotiation	-	EN

1 Introduction

This document is a requirements specification for the Minesweeper project in the course *TSRT10: Automatic Control - Project Course* at Linköping University. The purpose of the document is to clearly define the goals of the project and to state what functionality shall be implemented in the final system.

The different requirements on the system will be listed in tables according to the following format:

Req. no.	Version	Description	Level

The requirement level corresponds to the requirement's assessed importance. Level 1 means that the requirement must be fulfilled, level 2 means that it should be fulfilled and level 3 means that it will be attempted only if all other requirements already are fulfilled and time is still available.

1.1 Parties

The involved parties of the project are:

- Customer: Torbjörn Crona, Saab Dynamics.
- Technical advisor: Erik Ekelund, Saab Dynamics.
- Technical advisor: Axel Reizenstein, Saab Dynamics.
- Examiner: Daniel Axehill, the department of Electrical Engineering (ISY), Linköping University.
- Client: Martin Lindfors, ISY, Linköping University.
- Technical advisor: Per Boström-Rost, ISY, Linköping University.
- The project group: Eight students from Linköping University.

1.2 Purpose

The purpose of the project is to further develop a minesweeping system. The complete minesweeping system shall be improved by implementing SLAM on the ground vehicle (Balrog), for more accurate localization and mapping using a new scanning LIDAR sensor. The route planning and navigation shall also be improved for a better search of an unknown area. An UAV (Sauron) shall be integrated in the system to assist the Balrog with its minesweeping tasks. The long-term project goal is to develop a fully autonomous minesweeping system that is able to detect landmines safely, efficiently and accurately.

The focus of the course is to increase the students' knowledge and experience in project-based work. The purpose is to integrate the theoretical knowledge obtained in previous courses to successfully plan, execute and document a realistic project in close cooperation with a company.

1.3 Usage

The long term goal for the usage is to make an autonomous platform that is able to detect and locate mines under real life conditions. The system should work autonomously to efficiently map and locate landmines without triggering them. This information could help to assist in the clean-up process of known minefields or finding a safe route to traverse an area. This means that the product should be both inexpensive and have a high accuracy in mine localization.

1.4 Background

The platform is delivered by Saab Dynamics for a group of students at Linköping University. The project was first started in 2012 and continuous improvements have been made each year since. One of the additions to this year's project is a reconfiguration of the sensor rig used for navigation, a scanning LIDAR shall now be used as the primary sensor instead of a camera detecting known landmarks. The second big platform modification is the introduction of Sauron that will assist the tracked robot in the minesweeping task.

1.5 Definitions

Balrog/platform	The ground vehicle aimed for minesweeping used in the project.
Sauron/UAV	The drone used in the project for collaborating with the ground vehicle.
UAV	Unmanned Aerial Vehicle.
The project group	The group of students involved in the project.
Obstacle	An object in the test area that acts as an obstacle for the Balrog.
Mine	An object or image on the ground acting as a mine.
User	The human interacting with the system in any way.
Object	Any physical item in the testing area such as a mine, an obstacle or a wall.
Route/path	A set of way-points created by the user or the platform itself.
SLAM	Simultaneous localization and mapping.
Scanned area/searched area	The area that has been visited by Balrog.
Search area	The area that hasn't yet been searched for mines by Balrog.
AprilTags/QR-code	A matrix of bar codes used to identify predefined objects.
HAL	Hardware abstraction layer.
ROS	Robot Operating System. A set of open source software libraries and tools enabling communication between different modules in robotic systems.
GUI	Graphical user interface.
Raspberry Pi/Raspberry/RPI	A single circuit board computer.
Test area	An indoor area created in Visionen with fixed position on the boundaries and obstacles.
Test route	A route in the test area for manual drive with the hand controller to evaluate the functional requirements for the SLAM algorithm.
Test locations	Locations where Balrog is stopped in the test route and the functional requirements for positioning and mapping are evaluated.
Test point	In a test location, this is a point on an obstacle to evaluate the functional requirements on mapping accuracy.
Test map	A fully known map for which the project group is provided with an "optimal" exploration route.

2 System Overview

The system consists of two main platforms: Balrog and Sauron. Balrog is an autonomous tracked robot that uses several sensors and singleboard computers to navigate and map a certain area. Sauron is an UAV with sensors and a singleboard computer that assists Balrog in performing its task. Both platforms can be controlled remotely by a human user or be programmed to perform specific missions. The system also contains a base station computer to which relevant information is sent from the two platforms for visualization. The base station reads user input and relays this to the platforms. An overview of the entire system is seen in figure 1.

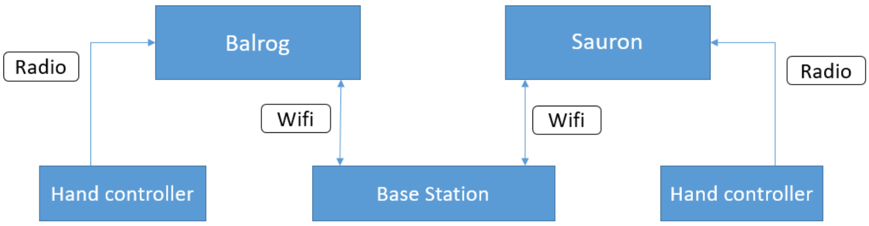

Figure 1: System overview.

2.1 Product Components

Balrog is equipped with the following components:

- Arduino x2
- Raspberry Pi
- Laptop
- Rotational encoder x2
- IMU
- Raspberry Pi camera
- 360 Rotational LIDAR
- Ultrasonic sensor x4
- Radio receiver
- RC hand controller

Sauron, a 3DR X8+ UAV, is equipped with the following:

- Radio transmitter/receiver
- RC hand controller
- PixHawk 2.4.5 with ArduCopter firmware, which includes:
  - Barometer for altitude measurements

  - IMU including accelerometer, magnetometer and gyroscope
  - GPS

- Raspberry Pi
- Raspberry Pi camera
- WiFi range extender

2.2 Subsystems

The software subsystems for Balrog are:

- SLAM - Estimation of the current Balrog position (localization) and map creation of the surrounding area including obstacles (mapping).
- Navigation - Decision making and computation of routes.
- Control - Route following.
- GUI - Visualization of the map and various sensor data, including a live stream from the onboard camera. Reading of user input.

The software subsystems for Sauron are:

- Detection - Detection of Balrog in video frames from the onboard camera.
- Tracking and Control - Controlling the UAV (Sauron) for tracking Balrog.
- Mapping - Assisting Balrog with map creation using the onboard camera.
- GUI - Visualization of various sensor data, including a live stream from the onboard camera. Reading of user input.

2.3 System Dependencies

Balrog:

The positioning module only depends on sensor data and provides an estimate of its position for the mapping module. The mapping module then combines this position estimate with further sensor data to create a map of the surrounding area. After which the navigation module uses positioning and mapping information to find a route for a given task set by the operator. The automatic control module uses this route as a reference and executes commands to ensure that the Balrog follows the route. The GUI will display the map and the Balrog as it explores the area. The operator also uses the GUI to choose what kind of mission the Balrog will perform and what navigation algorithms to use.

Sauron:

Sauron already has all the systems required for basic flight with the hand controller and software for automatic mission planning provided by the manufacturer. These systems will not be modified, however a system to automatically detect and follow an AprilTag will be implemented.

A Raspberry Pi with camera will be attached to Sauron that will enable communication with the existing software. The Raspberry Pi camera will transmit a live video feed via the Raspberry Pi to the base station, this is not dependent on any other system. AprilTags will be used to detect the Balrog and when detected the Raspberry Pi will send necessary commands to the PixHawk making tracking of the Balrog possible. The GUI will show the live camera feed and highlight the Balrog.

2.4 Delimitations

The test area shall be located indoors and on a flat surface. Existing hardware and HAL should be used as delivered and not tampered with. The airspace where Sauron is operating will be free of obstacles.

2.5 Design Philosophy

Functionality implemented in the project shall build upon previous work done on Balrog and follow the standards listed in this document. All newly designed software shall be module based to simplify future development.

2.6 General Requirements

Req. no. 1	Original	The project group will meet at least once a week.	1
Req. no. 2	Original	A simulation environment of the complete system should be implemented.	3

3 Balrog

This section contains all requirements for each of Balrog's software subsystems as well as the test area.

3.1 Test area

To separate the functional requirements for the SLAM and navigation subsystems, two different test systems will be used. Balrog will be run manually using the hand controller to test the SLAM algorithm for avoiding errors in the navigation module later when running autonomously. See section 1.5 for definitions of the test area. The platform will be tested continuously in Visionen, however a test area with static components as described below will be designed.

3.1.1 Design Requirements

Req. no. 3	Original	The test area shall have a size of 5 by 5 meters.	1
Req. no. 4	Original	The test area shall have at least 5 obstacles.	1
Req. no. 5	Original	The test route shall include at least 4 turns.	1
Req. no. 6	Original	The test route shall be at least 20 meters long.	1
Req. no. 7	Original	There shall be at least 3 test locations in the test route.	1
Req. no. 8	Original	Each test location shall have at least two test points on obstacles.	1

3.2 SLAM

Positioning and mapping of the Balrog is performed using the LIDAR and the wheel encoders. SLAM will be used to combine these sensors to give an accurate estimate of Balrog's position and produce a map of the test area, including all obstacles.

3.2.1 Interface

Req. no. 9	Original	The position of the platform shall be sent to the navigation module.	1
Req. no. 10	Original	The position and sensor data shall be sent to a GUI on a base station.	1
Req. no. 11	Original	The map shall be sent to the navigation module.	1
Req. no. 12	Original	The map shall be sent to a GUI on the base station.	1
Req. no. 13	Original	A laptop shall be placed on the platform to read sensor data from the LIDAR	1
Req. no. 14	Original	The laptop on the platform shall run ROS.	1

3.2.2 Design Requirements

Req. no. 15	Original	The position is estimated using both the odometry and LIDAR.	1
Req. no. 16	Original	Mapping and positioning is done simultaneously with a SLAM algorithm.	1
Req. no. 17	Original	The system will not reuse prior map knowledge, i.e. it will start with an empty map.	1

3.2.3 Functional Requirements

The test system described in section 3.1 shall be used to test the performance.

Req. no. 18	Original	When driving the test route, the estimated position shall have an accuracy of:	
Req. no. 18a	Original	0.2 m	1
Req. no. 18b	Original	0.1 m	2
Req. no. 18c	Original	0.05 m	3
Req. no. 19	Original	When driving the test route, the estimated angle shall have an accuracy of:	
Req. no. 19a	Original	10 degrees	1
Req. no. 19b	Original	5 degrees	2
Req. no. 19c	Original	2.5 degrees	3
Req. no. 20	Original	The system shall detect and map fixed objects with an accuracy of x % relative to the distance to the object, when driving the test route.	
Req. no. 20a	Original	$x = 15$	1
Req. no. 20b	Original	$x = 10$	2
Req. no. 20c	Original	$x = 5$	3

3.3 Navigation

The main purpose of the navigation module is to plan a route which the Balrog intends to follow. This route should plan a path to as many goal nodes as possible. When on a path the Balrog should navigate in such a fashion that the platform avoids any obstacles and finds the best route to each node with respect to cost. This further implies that the navigation module has the ability to perform an autonomous route-planning and decision-making. The area which the Balrog navigates through is unknown prior to start and therefore it has to be able to react to and learn where objects are located.

3.3.1 Interface

The navigation module receives an input which consist of a map and the state of the Balrog. The output of the navigation module is the path reference which is being provided to the controller.

3.3.2 Design Requirements

Req. no. 21	Original	The navigation shall avoid obstacles between nodes.	1
Req. no. 22	Original	The navigation module shall update the route if new obstacles appear.	1
Req. no. 23	Original	Balrog shall find the next node autonomously.	1
Req. no. 24	Original	Route planning shall be done in real time.	1
Req. no. 25	Original	The user should be able to change between different optimization strategies depending on different objectives.	2
Req. no. 26	Original	The user should be able to manually select an arbitrary point to which Balrog, if possible, finds a safe route.	2

3.3.3 Functional Requirements

Req. no. 27	Original	Balrog shall avoid getting stuck by re-optimizing the route.	1
Req. no. 28	Original	When navigating an area free from obstacles, Balrog shall explore at least 95 % of the area.	1
Req. no. 29	Original	When navigating the test area, Balrog shall explore at least 95 % of the map that are more than x meters from any obstacle.	
Req. no. 29a	Original	$x = 0.5$	1
Req. no. 29b	Original	$x = 0.3$	2
Req. no. 29c	Original	$x = 0.1$	3
Req. no. 30	Revised	When mapping and covering the test map in simulation, Balrog shall cover at least 95 % of the area that is no more than 0.5 meters from any obstacle, by following a route that is no more than x % longer than the shortest known route.	
Req. no. 30a	Original	$x = 40$	1
Req. no. 30b	Original	$x = 20$	2
Req. no. 30c	Original	$x = 10$	3
Req. no. 31	Original	Given two points in a known map, Balrog should plan a route between the points that is no more than x % longer than the shortest path between the points.	
Req. no. 31a	Original	$x = 15$	2
Req. no. 31b	Original	$x = 5$	3

3.4 Control

The control module acts on the input given by the navigation module in order to make the Balrog fully autonomous. This also requires the current position in order to accurately provide a control signal to the actuators.

3.4.1 Interface

Given the current position and path reference as an input the output of the control module is the rotation speed of the wheels.

3.4.2 Design Requirements

Req. no. 32	Original	The control module acts on a reference signal which is given externally from the navigation module.	1
Req. no. 33	Original	The user shall be able to adjust the speed of the Balrog.	1

3.4.3 Functional Requirements

Req. no. 34	Original	The Balrog shall not deviate more than 0.1 m from the intended route provided by the navigation module.	1
Req. no. 35	Original	The Balrog shall finish within 0.2 m of the intended goal node.	1

3.5 GUI

The Base station has a GUI that will display various data and give the user options to control Balrog depending on the requirements being fulfilled. The features from the previous edition will be kept, such as displaying the map and adding new waypoints.

3.5.1 Interface

Req. no. 36	Original	The GUI shall receive and display data from the sensors on the platform.	1
Req. no. 37	Original	The GUI shall receive and display data from the SLAM subsystem such as the position of the platform.	1

3.5.2 Design Requirements

Req. no. 38	Original	The map created by the SLAM algorithm shall be presented in the GUI.	1
Req. no. 39	Original	The GUI should display live stream from the on board camera on Balrog.	2

3.5.3 Functional Requirements

Req. no. 40	Original	The GUI shall function on the Base station.	1
Req. no. 41	Original	The data presented in the GUI shall be displayed in less than 1 second from real time.	1
Req. no. 42	Original	From the GUI the user shall be able to send commands to control the platform.	1

4 Sauron

This section contains all requirements for each of Sauron's software subsystems. All of the following requirements are made under the assumption that the airspace is free and that there is no obstacles present in the airspace where Sauron is operating.

4.1 Detection

The onboard camera on Sauron will be used to locate and interpret one or more known objects. The known objects will be represented by, for example, sharp colors or an April-Tag.

4.1.1 Interface

The Raspberry on board the UAV will use the camera to estimate the distance and bearing to the known object. This information along with the camera feed will be sent using WiFi to the base station.

Req. no. 43	Original	The position of Sauron relative the known object shall, given free line of sight, be transmitted to the base station.	1

4.1.2 Design Requirements

Req. no. 44	Original	The UAV shall be able to detect any known object using the on board camera.	1

4.1.3 Functional Requirements

Req. no. 45	Original	The system shall stream the video feed to the base station in real time.	1
Req. no. 46	Original	Sauron shall when operating at a constant height of 3 m, estimate its relative position in 2D to a known object with an accuracy of:	
Req. no. 46a	Original	0.5 m	1
Req. no. 46b	Original	0.3 m	2
Req. no. 46c	Original	0.1 m	3

4.2 Tracking and Control

Using the implemented functionality for detecting known objects, the UAV should be able to autonomously track the known object. If the known object is the Balrog, the UAV should be able to track the Balrog.

4.2.1 Interface

The camera on board the UAV transmits to the Raspberry Pi. The Raspberry Pi interprets the information and uses the functionality to detect the known object to get the distance and bearing to the AprilTag. This information is then used to send steering commands to the UAV so that the UAV is following the known object.

Req. no. 47	Original	The system should send relevant flight data to the base station.	2

4.2.2 Design Requirements

Req. no. 48	Original	The user shall be able to perform a safe landing of Sauron in any operational mode using the RC-controller.	1
Req. no. 49	Revised	If the connection between Sauron and the BaseStation is lost, manual control of Sauron shall be available. If Sauron was in automatic mode when the connection was lost, Sauron shall land.	1
Req. no. 50	Original	The user shall be able to control the movement of Sauron using a RC-controller.	1
Req. no. 51	Original	The user shall be able to perform a safe landing using the GUI in any mode of operation.	2

4.2.3 Functional Requirements

Req. no. 52	Original	The system shall be able to locate the stationary Balrog with an accuracy of:	
Req. no. 52a	Original	0.5 m	1
Req. no. 52b	Original	0.1 m	2
Req. no. 53	Original	Sauron should be able to maintain a position hovering at constant height. The position should not deviate more than 1 m in any direction.	1
Req. no. 54	Original	The UAV should be able to track a known object in a 2D space while the height of the UAV is kept constant. The accuracy of the tracking shall be within:	
Req. no. 54a	Original	0.5 m	2
Req. no. 54b	Original	0.1 m	3
Req. no. 55	Original	The system should be able to track a moving Balrog with an accuracy of:	
Req. no. 55a	Original	0.5 m	2
Req. no. 55b	Original	0.1 m	3
Req. no. 56	Original	The system should be able to land and start operations from top of the Balrog platform.	3
Req. no. 57	Original	The system should have different operational modes eg maintaining a fix position, following Balrog or active reconnaissance.	3

4.3 Mapping

Using the UAV:s camera for mapping is not prioritized in the project. If there is sufficient time, mapping using the UAV may be examined.

4.3.1 Interface

The Raspberry Pi onboard the UAV will use the camera feed and map the surrounding area and send the map to the base station.

Req. no. 58	Original	The system should be able to send map data to the base station	3
Req. no. 59	Original	The system should be able to receive map data from the base station	3

4.3.2 Design Requirements

Req. no. 60	Original	Mapping will be made using the camera on the UAV to assist the mapping of the Balrog.	3
Req. no. 61	Original	It shall be able to detect mines from above using the on-board camera.	3

4.3.3 Functional Requirements

Req. no. 62	Original	The system should, from the image data, be able to generate a map understandable by Balrog.	3
Req. no. 63	Original	The system should be able to provide a map estimate of uncharted areas to the base station.	3
Req. no. 64	Original	Mines shall be detected and located within a 0.5 m radius of the true position.	3

4.4 GUI

A GUI will be developed to display the information available from the UAV in an easily interpretative way. The GUI enables the operator to easily interpret the information from it. The GUI will show a map of the area of interest and display a live feed from what the camera on the UAV is seeing.

4.4.1 Interface

Req. no. 65	Original	The communication between the GUI and the Raspberry Pi on the UAV will be done using WiFi.	1
Req. no. 66	Original	The Raspberry Pi shall communicate with the controller of the UAV (PixHawk).	1

4.4.2 Design Requirements

Req. no. 67	Original	The GUI will be written in ROS.	1
Req. no. 68	Original	The Sauron part of the GUI shall function independent on a connection with Balrog.	1

4.4.3 Functional Requirements

Req. no. 69	Original	The GUI shall include a live stream of the video from Sauron.	1
Req. no. 70	Original	The GUI shall highlight the position of Balrog (if applicable) in the video.	1
Req. no. 71	Original	The GUI should allow the user to send movement directions to Sauron.	2
Req. no. 72	Original	The GUI should allow the user to switch between operational modes of Sauron.	3

5 Development Requirements

It is important to use the former documentation and code during the process. The project has been performed and developed over many years which means a lot of information is available. Since the project is likely to continue to be developed in the coming years, all new important information must be clearly documented.

Req. no. 73	Original	The system shall be based on the current one.	1
Req. no. 74	Original	New components should be easy to implement.	1
Req. no. 75	Original	The Balrog shall be able to run with and without Sauron.	1

6 Economy

Req. no. 76	Original	All expenses will be paid by Saab Dynamics (primarily) or ISY.	1
Req. no. 77	Original	All of the group members will be working at least 240 hours with the project.	1
Req. no. 78	Original	40 hours guidance by Per Boström Rost.	1
Req. no. 79	Original	40 hours guidance by Erik Ekelund or Axel Reizenstein.	1
Req. no. 80	Original	A project room will be offered by ISY for storage and working space.	1

7 Safety Requirements

The most important is that no people is hurt during the project. Safety should therefore, at all times, be considered when working with the project.

Req. no. 81	Original	No person shall be hurt by Balrog.	1
Req. no. 82	Original	No person shall be hurt by Sauron.	1
Req. no. 83	Original	The system should be easily shut down when an error occurs.	1
Req. no. 84	Original	A dead man's switch should exist to stop Balrog and Sauron.	1
Req. no. 85	Original	Changing from automatic to manual control of Sauron should always be possible with a switch on the transmitter unit.	1

8 Delivery Requirements

Req. no. 86	Original	A requirements specification shall be delivered at latest 2017-09-18 (BP2).	1
Req. no. 87	Original	A project plan including a time plan shall be delivered at latest 2017-09-18 (BP2).	1
Req. no. 88	Original	A draft of the design specification shall be delivered at latest 2017-09-18 (BP2).	1
Req. no. 89	Original	A time plan shall be delivered at latest 2017-09-18 (BP2).	1
Req. no. 90	Original	A test plan shall be delivered at latest 2017-10-04 (BP3).	1
Req. no. 91	Original	The final design specification shall be delivered at latest 2017-10-04 (BP3).	1
Req. no. 92	Original	Mapping with the LIDAR and odometry shall presented at latest 2017-11-07 (BP4). Implies that all requirements in section 3.2.2, as well as prio 1 requirements in section 3.2.3, shall be fulfilled.	1
Req. no. 93	Original	A test protocol ensuring the functionality for BP4 shall be delivered at latest 2017-11-07 (BP4).	1
Req. no. 94	Original	Test protocols shall be delivered at latest 2017-12-01 (BP5).	1
Req. no. 95	Original	A demonstration focused on the requirements shall be done at latest 2017-12-01 (BP5)	1
Req. no. 96	Original	A user manual shall be delivered at latest 2017-12-01 (BP5).	1
Req. no. 97	Original	The system will be delivered to the customer after BP5	1
Req. no. 98	Original	A technical report shall be delivered at latest 2017-12-15 (BP6).	1
Req. no. 99	Original	An after study shall be delivered at latest 2017-12-15 (BP6).	1
Req. no. 100	Original	A poster presentation shall be preformed at latest 2017-12-15 (BP6).	1
Req. no. 101	Original	A web page shall be delivered at latest 2017-12-15 (BP6).	1
Req. no. 102	Original	A movie shall be delivered at latest 2017-12-15 (BP6).	1
Req. no. 103	Original	An installation manual shall be delivered at latest 2017-12-15 (BP6).	1
Req. no. 104	Original	Time status for each person and activity shall be reported to client every week.	1
Req. no. 105	Original	Status for the whole project shall be reported to client and customer every week.	1

9 Documentation

9.1 Documents & Code

Req. no. 106	Original	All documentation shall follow the LIPS method.	1
Req. no. 107	Original	All official documents shall be written in English.	1
Req. no. 108	Original	A poster shall be designed for presenting the project and system.	1
Req. no. 109	Original	All code shall follow Google and MATLAB coding standard.	1
Req. no. 110	Original	All code should be commented in English.	1

9.2 Web page & Movie

Req. no. 111	Original	A web page shall be made and put on the ISY server.	1
Req. no. 112	Original	A movie shall be made for demonstration.	1