Requirement specification

Project Group

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Version 1.5

Status

Reviewed	Alexander	2019-10-17
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Project Identity

Group E-mail: --

Homepage: --

Orderer: Fredrik Ljungberg, Linköping University
Phone: +46 73 05 14 895
E-mail: fredrik.ljungberg@liu.se

Customer: Rikard Hagman, Combine Control Systems AB
Phone: +46 72 964 70 59
E-mail: rikard.hagman@combine.se

Supervisor: Anton Kullberg, Linköping University
Phone: –
E-mail: anton.kullberg@liu.se

Course Responsible: Daniel Axehill, Linköping University
Phone: +46 13 28 40 42
E-mail: daniel.axehill@liu.se

Participants of the group

Name	**Responsible**	**E-mail**
Emil Frid	Project Manager	emifr995@student.liu.se
Alexander Smith	Documentation	alesm512@student.liu.se
Alfred Fredriksson	Design	alffr694@student.liu.se
Fredrik Nilsson	Information	freni244@student.liu.se
Joel Wilander	Software	joewi374@student.liu.se
Joakim Wallin	Testing	joawa706@student.liu.se
Pontus Hållberg	Hardware	ponha807@student.liu.se

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DOCUMENT HISTORY

Version	Date	Changes made	Sign	Reviewer
0.1	2019-09-20	First draft.	All	Emil Frid
0.2	2019-09-26	Second draft. The performance requirements where placed under each module instead. The functionality of the Pathfinder module was down scaled.	All	Alexander Smith
0.3	2019-09-27	Third draft	All	Alexander Smith
0.4	2019-09-30	Fourth draft	All	Alexander Smith
0.5	2019-10-02	More specified requirements for the model.	All	Emil Frid
1.1	2019-10-17	Added requirement 12 in the sensor module section.	Joel Wilander	Alexander Smith
1.2	2019-11-25	Added requirements: 9,13,14,16,27,35,37,56,57,96 Priority of requirements downgraded: 11,12,19-23,38-49,59-61,78,80,82,83,97,98 Removed requirements: 15,17,34 Changed requirements: 95	Joel Wilander	Joel Wilander
1.3	2019-11-28	Fixed comments and changed requirements: 19-23	Alexander Smith	Alexander Smith
1.4	2019-11-29	Moved req. 2 and 15 to decision module Down-prioritized to prio. 2: 9, 17, 18, 19. Deleted: 13, 14, all requirements regarding model performance. Added: 13, 14, 15, 30, 31.	Fredrik Nilsson	Fredrik Nilsson
1.5	2019-12-4	req. 13 and 20 was changed to regard simulation environment. Updated logo.	Emil Frid	Emil Frid

NOTATIONS

- **API**: Application Programming Interface
- **DPi**: Decision Point nr. i
- **ESC**: Electronic Speed Controller
- **GUI**: Graphical User Interface
- **I/O**: Input/Output
- **IMU**: Inertial Measurement Unit
- **ISY**: Linköping University department of electrical engineering
- **LiU**: Linköping University
- **LQ**: Linear Quadratic
- **MPC**: Model Predictive Control
- **PWM**: Pulse Width Modulated
- **ROS**: Robot Operating System
- **ROV**: Remotely Operated Underwater Vehicle
- **RPi**: Raspberry Pi 3 B +

1 INTRODUCTION

Approximately two thirds of the earth surface is covered with water whereof only a small fraction of it has been explored. With such vast territory to be explored and an increasing demand for underwater construction and mapping there is an increased need for the vehicles adapted for these environments to execute tasks autonomously. The project described in this requirement specification could be an alternative to what exists on the market right now.

1.1 Partners

The project is a partnership between the division of automatic control at Linköping University and Combine Control Systems AB. The project group consists of seven students participating in the course TSRT10, Automatic Control Project Course at Linköping University. The client of the project is Fredrik Ljungberg at the department of Electrical Engineering (ISY), Linköping University and the supervisor is Anton Kullberg at the same department. The customer is Rikard Hagman at Combine Control Systems AB.

1.2 Aims and goals

The long term goal of the ROV is to become completely autonomous and to be able to perform a set of different missions independently. Examples of such missions could be to explore an environment by creating a 3D-map over it or to search it for interesting objects. Another goal could be to use the ROV as a test platform for development of control system for underwater vehicles, from which it should be possible to migrate the software to other types of underwater vehicles.

The purpose of this project is to use the result from the earlier projects and improve the control and navigation of the ROV, with camera and ultrasound as starting point. In order to facilitate the development, the current simulation environment and its associated mathematical model needs to be improved.

The current iteration of the ROV has its vision module and some of its Sensor fusion module implemented on an external computer. Because of this, the ROV is currently tethered to the external computer using an Ethernet-cable. The ROV should be able to operate independently so part of the functionality that is located at the land based computer will be moved to the RPi that is mounted on board so that the ROV will be able to operate without an Ethernet-cable attached.

1.3 Use

The ROV developed in this project could be used wherever there is a need for autonomous operating and execution of specific tasks underwater. The ROV could be essential in both the military and private sector. For example tasks such as:

- Mapping environments and detecting objects or organisms of interest
- Rescuing people by giving coordinates to another vessel
- Maintenance of underwater constructions

Some of these tasks could be done without the control or influence of an operator.

1.4 Background information

This project is a collaboration between the division of automatic control at ISY and Combine Control Systems AB. The ROV in the project is a BlueROV from Blue Robotics, it is supplied by Combine Control Systems AB.

In previous projects the underwater vehicle has been assembled and tested. Basic modeling and control has also been developed. The functionality has been developed for positioning in swimming pools, which is based on data from camera and ultrasound sensors.

1.5 Mission Definition

Here follows the definition of the mission the ROV should be able to perform.

1.5.1 *Move to predefined destinations*

1. The ROV will start on the surface of the pool.
2. The ROV will receive target positions via WiFi from the GUI.
3. The ROV will then move to the target positions. If this is not possible, the ROV will resurface.
4. When the last position has been reached the ROV will resurface, transmit data and await a new mission.

2 SYSTEM OVERVIEW

The system is a BlueROV provided by Combine Control Systems AB. The BlueROV is a submersible ROV kit controlled by a external workstation through an ethernet cable. To this the components listed in section 2.1 are added to give the ROV autonomous behavior. The sensors are collecting environmental data and sensor fusion is performed in the ROV in order to estimate position and orientation and also to detect objects. The on board controller uses the estimates to calculate controlled PWM-signals to the ESC.

2.1 Product components

The ROV is equipped with:

- A Raspberry Pi 3 B+
- A HKPilot Mega 3.7 including IMU, Barometer, Magnetometer
- Three ultrasonic sensors
- A pressure transducer
- A Raspberry Pi Camera V2

All of the components above are used by the ROV to sense the environment, estimate its state and to control its orientation. Other components such as a land based computer with a GUI and a Xbox-controller can be used in order to manually operate and collect information from the ROV.

2.2 Dependency of other systems

Right now the ROV is dependent on an external workstation, which it communicates with through an Ethernet cable. During the project the necessary functionality is supposed to be moved from the external workstation to the ROV so that it can operate independently.

2.3 System Modules

In order to make it easier to replace parts of the ROV the system is designed in a modular fashion. The different modules are presented below together with a brief description.

2.3.1 *Hardware module*

The hardware module consists of the ROV itself, with all attached components and the workstation.

2.3.2 *GUI module*

The GUI module presents the user with information about the current state of the ROV and its planned trajectory.

2.3.3 *Control module*

Given the reference from the Pathfinder module and the estimated state of the ROV given by the Sensor fusion module, the Control module's task is to send control signals to the thrusers.

2.3.4 *Sensor fusion module*

The Sensor module's purpose is to filter and combine raw sensor data in order to estimate states such as position and orientation.

2.3.5 *Simulation module*

The purpose of the Simulation module is to be able to test control strategies without having hardware in the loop. The Simulation module will run on an external workstation using Matlab and Simulink.

2.3.6 *Pathfinder module*

The path finder will be provided with desired state in position and attitude and will provide a suitable reference to the controller.

2.3.7 *Decision module*

The Decision module is responsible for all the decision making, for example when the ROV needs to resurface or cancel a task given. Since the ROV is becoming increasingly more autonomous, it is sensible that all decisions when performing a task are made by one singular module.

2.4 Limitations

The ROV in this project will only be operating in swimming pools.

2.5 Design philosophy

The system should be designed in such a way that its components should be easy to change in case of malfunction or upgrading. Simulations of the system will be performed before implementing the solutions on hardware. Some software solutions from previous years projects will be reused, modified or ported to work on other systems.

3 SENSOR FUSION

The purpose of sensor fusion is to obtain estimates of relevant states of the ROV using models and raw data from the different sensors listed in Section 2.1. The requirements of the sensor fusion are presented here.

3.1 Interfaces

The requirements of the interfaces are listed below.

Requirement	Description	Priority
1	The Sensor fusion module must be able to communicate position and attitude via ROS topics.	1
2	The Sensor fusion module must be able to communicate the current position and attitude of the ROV (to be able to update the desired trajectory from the new sensor inputs) via ROS topics.	1

3.2 Design requirements

The design requirements are listed below.

Requirement	Description	Priority
3	The Sensor fusion module has to be implemented on the RPi on board the ROV.	1

3.3 Functional requirements

The requirements of the functionality are listed below.

Requirement	Description	Priority
4	The Sensor fusion module must be able to read sensor data from the IMU on board of the ROV.	1
5	The Sensor fusion module must be able to read sensor data from the magnetometer on board of the ROV.	1
6	The Sensor fusion module must be able to read sensor data from the pressure sensor on board of the ROV.	1
7	The Sensor fusion module must be able to read sensor data from the sonar sensors on board of the ROV.	1
8	The Sensor fusion module must be able to provide an estimate of the ROV's position in the pool's frame of reference and the uncertainty of this estimate.	2
9	The Sensor fusion module must use the magnetometer in its attitude estimation.	2

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Requirement	Description	Priority
10	The Sensor fusion module must be able to remove the magnetometer from its attitude estimation if the absolute value of the magnetic field detected is above a threshold.	1
11	The Sensor fusion module must be able to remove at least 80% of static magnetic field disturbance. (Static magnetic disturbances meaning when the ROV's thrusters are enabled but not spinning)	2
12	The Sensor fusion module must be able to handle the bias and variance from magnetic field disturbances caused by the thrusters so that the magnetometer measurements are usable	2
13	The Sensor fusion module must be able to estimate attitude through an EKF in simulation environment.	1
14	The Sensor fusion module must be able to estimate position through an EKF.	2
15	The Sensor fusion module must be able to estimate linear velocity through an EKF.	2

3.4 Performance requirements

The requirements for performance are listed below.

Requirement	Description	Priority
16	Depth estimation should be within ± 15 cm from an independently measured value.	1
17	Estimated x and y-position should be within ± 25 cm of an independently measured value.	2
18	Estimated x-and-y speed should be within ± 0.2 m/s from the independently measured value.	2
19	Estimated z speed should be within ± 0.15 m/s from the independently measured value.	2
20	Estimated attitude in simulation should be within $\pm \pi/8$ rad from the independently measured value.	1

4 HARDWARE

The ROV consists of a chassi with six T200 thrusters and the components listed in Section 2.1 above. Together these make up a system which can then be used to navigate and execute tasks in a swimming pool.

4.1 Design requirements

The design requirements are listed below.

Requirement	Description	Priority
21	The system must remain modular.	1
22	Remove the nuts and floating bags while maintaining neutral angle and floating equilibrium while submerged in water.	2

4.2 Functional Requirements

The requirements of the functionality are listed below.

Requirement	Description	Priority
23	A new physical step-down controller needs to be added to the ROV.	1
24	A leakage sensor needs to be installed on board the ROV	1
25	The ROV must be waterproof to a depth of 3.8 meters.	1
26	It must be possible to replace the battery of the ROV in less than 20 minutes.	1
27	It must be possible to access the RPi in the ROV.	1
28	The new floating mechanism should not change capacity after being in water.	2

4.3 Performance Requirements

The requirements for performance are listed below.

Requirement	Description	Priority
29	The sonar performance dependency on power should be investigated.	1
30	The sonar performance dependency on thruster activity should be investigated.	1

5 MODELING

In order to predict how the system will act in reality, a good model will be needed. The requirements listed below will have an effect of the simulation environment used in this project.

5.1 Design Requirements

The design requirements are listed below.

Requirement	Description	Priority
31	The new model of the ROV must be implemented in Matlab Simulink.	1

5.2 Functional Requirements

The requirements of the functionality are listed below.

Requirement	Description	Priority
32	The new model must be possible to use in the controller.	1
33	The model must include Coriolis effects and effects from centripetal forces.	1

6 CONTROL SYSTEM

The control system will take reference values from the Planning module and calculate controlled PWM-signals to the ESC's.

6.1 Interfaces

The requirements of the interfaces are listed below.

Requirement	Description	Priority
34	Must be able to read the trajectory from the Planning module.	1
35	Must be able to read the current state from the Sensor fusion module.	1
36	Must be able to send "steer commands" to the ESC:s.	1

6.2 Design requirements

The design requirements are listed below.

Requirement	Description	Priority
37	The Control module has to be implemented on the RPi on board the ROV.	1
38	The controller implemented in the simulation environment must be ported to the ROV using code generation.	1

6.3 Functional requirements

The requirements of the functionality are listed below.

Requirement	Description	Priority
39	Implement an LQ controller in the simulation environment to control position and attitude.	1
40	The Control module must be able to control the ROV in depth, and attitude simultaneously.	1

7 GUI

The GUI is not the prioritized during this project. Therefore, most GUI requirements have lower priority.

Requirement	Description	Priority
41	The GUI should be able to take a mission as input. The mission is specified as a series of destination points which the ROV should visit in order.	2
42	The GUI should be more user friendly.	2
43	The GUI should be able to visualize logged mission data, such as position and attitude over time.	3

8 SOFTWARE

The software module connects all modules within the RPi as well as the GUI.

8.1 Design Requirements

Requirement	Description	Priority
44	Newly written ROS-code must be written according to the ROS code standard: http://wiki.ros.org/CppStyleGuide	1
45	Newly written code, except for ROS-code, must be written according to Google's code standard: https://google.github.io/styleguide/cppguide	1
46	Error messages must be in English.	1
47	Newly written code must be commented in English.	1
48	All code must be version controlled on the LiU gitlab repository.	1
49	The development of the model and the controller must be done using model based design in Simulink from which code is auto generated.	1
50	All code must be written in a modular fashion with API:s specifying the interface used for communication between modules. This is a consequence of Requirement 11.	1

9 VISION

The main focus is not to develop a more advanced vision module but to transfer the existing one to the RPi.

9.1 Interface Requirements

Requirement	Description	Priority
51	The vision module must be able to send information about objects (like balls or hula hoops) to the Decision module via ROS topics.	1
52	The vision module must be able to send data to the Sensor fusion module via ROS topics about the position of objects of interest (balls , hula hoops).	1

9.2 Design requirements

Requirement	Description	Priority
53	The vision module has to be implemented on the RPi on board the ROV.	1

9.3 Functional Requirements

Requirement	Description	Priority
54	The ROV should be able to detect a frame or hula hoop.	3
55	The ROV must be able to detect colored balls under water.	1

9.4 Performance requirements

Requirement	Description	Priority
56	The vision module must be able to detect a colored ball under water from a distance of at least 2 meters.	2
57	The vision module must maintain the same performance after it is moved to the RPi on board the ROV.	1

10 PLANNING

The Planning module should be able to take a desired state and provide a suitable reference for the controller. The requirements for this task are listed below.

10.1 Interfaces

The requirements on the interface are listed below.

Requirement	Description	Priority
58	The Planning module be able to receive a series of destination points specified by the user from the GUI module.	2
59	The Planning module be able to send a destination point to the controller.	1
60	The Planning module must be able to send a reference to the controller.	1

10.2 Design requirements

The design requirements are listed below.

Requirement	Description	Priority
61	The path planner has to be implemented on the RPi on board the ROV.	2

11 POSSIBILITIES TO UPGRADE

Since the ROV in this project is upgraded every year, every new group of student must be able to understand how the system works with the information given in the deliveries.

Requirement	Description	Priority
62	It should be possible to migrate software to other ROV's.	2
63	All documentation must be written in a way so that a future group can further develop the ROV.	1

12 ECONOMY

Here requirements regarding the projects economy is described.

Requirement	Description	Priority
64	Each group member should spend at least 240 hours on the project.	1
65	Combine Control Systems AB will provide access to a swimming pool one day a week.	1
66	Combine Control Systems AB will provide a maximum of 40 hours of supervision.	1
67	ISY will provide a maximum of 40 hours of supervision.	1
68	ISY will provide one project room.	1
69	ISY will provide a small pool.	1

13 SAFETY REQUIREMENTS

Safety requirements are listed below and will be implemented to ensure that the ROV will be as intact as possible.

Requirement	Description	Priority
70	The ROV should be able to detect leakage.	1
71	The ROV should be able to warn the operator via the on board LEDs if a leakage is detected.	1
72	The ROV should be able to resurface if a leakage is detected	1
73	The ROV should be able to detect upcoming collision.	2
74	The ROV should be able to warn if a collision is detected.	2
75	The ROV should be able to avoid collisions if detected.	2

14 DELIVERY

In this section all delivery requirements are described. There are some deliveries that occur weekly, while some are divided into decision points (DP).

Requirement	Description	Priority
76	A time report (per activity and person) and status report should be delivered to the client weekly. The status report should also be sent to the customer.	1
77	Before DP2 a present ation of the existing system should be held for the client.	1
78	DP2: Requirement specification, project plan, time plan and draft of design specification should be delivered at latest three weeks after first lecture.	1
79	DP3: Deliver design specification and test plan.	1
80	DP4: Deliver complete simulation environment and all new hardware should be implemented.	1

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Requirement	Description	Priority
81	DP5: Deliver all functionality, test protocol, user manual and an presentation showing that all requirements in the requirement specification are fulfilled.	1
82	DP6: Before the project conference deliver: technical report, post study, poster presentation, website describing the project and a project video.	1

15 DOCUMENTATION

Table 25 lists all documents that shall be produced in the project. All documentation will be written or presented in English.

Table 25: Documents to be produced.

Document	Aim	Target	Format
Meeting minutes	Written meeting record.	Project group	Google doc
Status report	Bringing the client up to date with how the project is going.	Client, project group	PDF
Time report	Documentation of how much time each group member has spent on each task.	Client, project group	Excel
Requirement specification	Describe what the product is required to do.	Client, customer, project group	PDF
Project plan	Execution, collaboration and division of labor.	Client, customer, project group	PDF
Time plan	Schedule when tasks should be executed and for how long.	Client, customer, project group	Excel
Test plan	Plan describing what, how and when tests should be performed.	Client, customer, project group	PDF
Test protocol	Protocol documenting the result from carried out tests.	Client, project group	Excel
Design specification	Detailed description of how the product should be constructed.	Client, project group	PDF
Technical report	Documentation of the project results and technical description of the system.	Client, customer	PDF
User manual	Instruction on how to use the product.	Customer	PDF
Post study	Follow-up of result and time spent.	Client, customer	PDF
Poster	For presenting the project.	Customer, other course attendances	Printed poster
Website	Website describing the project and linking to other documentation.	Client, costumer	Website
Project video	Youtube video showing functionalities of the finished product.	Client, costumer	Youtube video

16 TRAINING

Lectures will be given on how to write a technical report and how to make a poster. Other than that the project group is responsible for obtaining all training needed to complete the project, with the help of supervisors. At the end of the project, the customer will be briefed on the product through presentation, technical documentation and a user manual.

17 QUALITY

In this section quality requirements are presented.

Requirement	Description	Priority
83	Tests will be documented in a test protocol.	1
84	Changes in the product must first be negotiated with the client and customer.	1

18 MAINTAINABILITY

Maintainability of the product is discussed in this section.

Requirement	Description	Priority
85	All code developed for the product shall be saved in a git repository that will be available for future development.	1
86	Code will be commented in such a way that makes it easy for future developers to maintain and further develop the system.	1