Requirement Specification

Editor: Martin Drangel

Version 1.3

Status

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Project Identity

2018/HT, ROV

Linköping University, Department of Electrical Engineering (ISY)

Project Email: tsrt10rov2018@gmail.com

Web site: www.isy.liu.se/edu/projekt/reglerteknik/2018/rov/

Client: 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

Course Responsible: Daniel Axehill, Linköping University

Phone: +46 13 28 40 42,

E-mail: daniel.axehill@liu.se

Group members:

Name	**Responsibility**	**Phone**	**E-mail** (@student.liu.se)
Kristian Ericsson	Project Leader (PL)	070 64 38 923	krier714
Martin Drangel	Documentation (DOC)	076 765 83 65	mardr222
Casper Johansson	Hardware (HW)	073 07 30 858	casjo385
Tommy Karlsson	Design	073 07 32 095	tomka260
Philip Öhrn	Software	073 07 59 759	phioh654
Victor Petersson	Testing	073 03 30 126	vicpe520
Mikael Nådin	Information	073 43 49 157	mikna029

Document history

Version	Date	Changes	Sign	Reviewed
0.1	2018-09-20	First draft.	All	MD
0.2	2018-09-24	Minor changes upon request from client	All	MD
0.3	2018-09-26	Minor changes upon request from client	All	MD
1.0	2018-09-27	First version.	All	MD
1.1	2018-10-11	Req. 6 changed from priority 2 to priority 1 and reworked to only detect collisions in the ROV's x-direction. A sub-requirement 31A was added. Req. 32 was removed. Req. 52 was reworked in regards on how the reference signals are sent in manual mode. Req. 53 was reworked to estimate distance with reference to sensor fusion estimates instead of real world distance. Req. 89 was changed from priority 2 to priority 1 and reworked to only detect collisions in the ROV's x-direction. Req. 90 was changed from priority 2 to priority 1 and reworked to only detect collisions in the ROV's x-direction. Req. 33 changed to leds instead of flashlight. Removed velocities from req. 42. Req. 59 was divided into two requirements. Lowered priority on requirements 62 and 63.	KE, PÖ	MD
1.2	2018-11-22	Req. 9 was changed to hold no demands on the EKF-filter. Req. 15 was changed to only regard LCS x-axis. Req. 19 was removed. Requirements 37-40 were updated to already fulfilled by previous projects, since no changes to the model were done in this project. Lowered priority on req. 41. Req. 44 and 50 were changed to distance in LCS x-axis rather than velocity. Heightened priority on req. 81.	All	MD
1.3	2018-11-30	Req. 5 changed to not maintain position. Changed allowed error in req. 18 to 0.2 m/s. Lowered priority on req. 56.	All	MD

Contents

Notations

ESC Electronic Speed Controller
IMU Inertial Measurement Unit
ROV Remotely Operated Underwater Vehicle

1 Introduction

There is an increasing interest and demand for autonomous vehicles in both civilian and military applications to carry out missions at sea, in air or on land. The utilities of such vehicles range from surveillance, mapping, tactical operations, repairs and more.

This project aims to further develop a remotely operated underwater vehicle (ROV), with this document specifying requirements regarding both project and product.

1.1 Parties

The project is a partnership between the division for control systems 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 Daniel Arnström. The customer is Rikard Hagman at Combine Control Systems AB.

1.2 Purpose

The purpose of the project is to enhance the performance of the ROV's control system and navigation system. This is to be achieved using the results of the previous projects as basis. The project also intends to further develop the ROV's vision system and sensor fusion estimates.

1.3 Goals

The project's goal is to develop a robust system for controlling the vehicle and creating autonomous behaviours in a pool-like environment.

The long-term goal is to develop the ROV into a fully autonomous underwater vehicle that can perform different tasks on its own. Thus, after this project ends it is important that the ROV easily can be further developed.

1.4 Usage

The ROV is meant to be used as a test-platform for development of control systems for underwater vehicles. Another usage is to showcase the ROV's capabilities in demonstrations for a broad audience.

1.5 Background information

During previous projects the ROV was assembled, tested and some basic modeling was done together with the implementation of control systems [1, 2]. Functionality for positioning in a global environment has been done, partly with the help of a camera and artificial tags, and partly using sonars.

1.6 Definition of requirements

All requirements are defined in tables using four columns. The first column specifies the number of the requirement. The second column shows in which version of the document the requirement was last updated. Column three describes the requirement in detail and column four determines the requirement's priority. Priority one means the requirement must be fulfilled, while priority two means the requirement is desired.

2 System Overview

The system is a BlueROV provided by Combine Control Systems AB. The BlueROV is a submersible ROV kit with a watertight acrylic enclosure for electronics, six thrusters and multiple sensors. In addition to the ROV itself there is also a computer connected through an ethernet cable. The external workstation is used to communicate with the ROV aswell as running simulations and pathfinder algorithms. A custom GUI is used on the workstation to make communicating with the ROV user friendly. A user also has the possibility to control the ROV with an XBOX-controller which is connected to the ROV through the external workstation.

2.1 Product components

As mentioned above, the product consists of the ROV and an external workstation. The ROV consists of six thrusters connected to a body frame which has a watertight acrylic tube to hold the electronics. The sensors on the ROV include an inertial measurement unit (IMU), two pressure sensors, a magnetometer, a camera and three sonar sensors. All sensors are connected to an Arduino which in turn is connected to a Raspberry Pi and mounted on the ROV.

Besides the BlueROV itself, several documents and other informational material will be produced during the project. These include a technical documentation, user manual, poster, website and a movie.

2.2 Product dependencies

The BlueROV is dependent on a connection with the external workstation through the ethernet cable to be able to operate.

2.3 System modules

Below the different modules of the system are briefly described. The modules are designed to be easily exchanged with other implementations that inputs and outputs the same variables.

2.3.1 Hardware module

The hardware module includes the ROV with all the components attached to it and the external workstation.

2.3.2 GUI module

The GUI is run on the external workstation and is constructed to provide a user friendly way of controlling and operating the ROV.

2.3.3 Control module

The control module includes multiple controllers. Input from the sensor fusion module will be supplied to the control module and it in turn produces outputs to the electronic speed controllers (ESC) which control the thrusters. The control module controls the ROV's attitude and position or its linear and angular velocity depending on which mode the system is set to.

2.3.4 Sensor fusion module

The sensor fusion module is used to generate state estimates of the position and attitude of the ROV.

2.3.5 Simulation module

The simulation module is implemented on the external workstation in MATLAB and Simulink. It is used to simulate the ROV based on developed models.

2.3.6 Pathfinder module

The pathfinder module is integrated with the GUI module and is used to generate 2D-paths between two points, avoiding virtual obstacles.

2.4 Limitations

Requirements stated in this document only apply when the system is used in a controlled environment, i.e. a well lit swimming pool with calm and clear water.

2.5 Design philosophy

All parts of the system are designed to be modular, i.e. they should be easy to replace, easy to further develop and the interface between them should be well defined. This will make it possible to develop different modules in parallel. It will also allow for easier integration into the larger system.

2.6 General requirements

Below the general requirements for the project are listed.

Req. 1	**1.0**	ROS will be used as the main framework for software and communication with the ROV.	**1**
Req. 2	**1.0**	Raw sensor data, reference signals, control signals and state estimates can be logged for offline analysis.	**1**
Req. 3	**1.0**	The ROV's thrusters should be able to be controlled by an XBOX controller.	**Removed**
Req. 4	**1.0**	The ROV's attitude should be able to be controlled by an XBOX controller by outputting reference signals.	**1**
Req. 5	**1.3**	There shall exist a hover mode where the ROV will maintain its attitude.	**1**
Req. 6	**1.0**	When controlling the ROV in a special manual mode, the ROV should automatically brake if a potential collision is detected in the ROV's positive x-direction.	**DEPRECATED**
Req. 6A	**1.1**	When controlling the ROV in a special manual mode, the ROV should automatically brake if a potential collision is detected.	**2**

3 Sensor Fusion

A lot of different sensors record data that have to be processed. The different sensors are: a 3 degrees of freedom (DOF) accelerometer, a 3 DOF gyroscope, a 3 DOF magnetometer, a pressure sensor and three ultrasonic distance sensors. The sensor fusion module is tasked with processing this data.
The existing sensor fusion algorithm will be replaced with a new attitude estimator as well as a new position estimator.

3.1 Interface

The requirements of the interface to the sensor fusion module are listed below.

Req. 7	**1.0**	The sensor fusion module shall be able to receive measurements from sensors by subscribing to ROS topics.	**1**
Req. 8	**1.0**	The sensor fusion module shall be able to transmit the estimated states by publishing it to a ROS topic.	**1**

3.2 Design requirements

The requirements on the design of the module is described below.

Req. 9	**1.2**	The Complementary filter will run on the Raspberry pi.	**1**
Req. 10	**1.0**	The sensor fusion for position estimate is to be remade.	**1**
Req. 11	**1.0**	The sensor fusion for attitude estimation is to be remade.	**1**
Req. 12	**1.0**	The sensor fusion filter states shall use quaternion to avoid singularities.	**1**

3.3 Functional requirements

The required functionality of the module is described below.

Req. 13	**1.0**	The module shall be able to estimate the ROV's position in a known environment.	**1**
Req. 14	**1.1**	The module shall be able to estimate the ROV's attitude in pitch and roll.	**1**
Req. 15	**1.2**	The module shall be able to estimate the ROV's linear velocity in x-direction.	**1**
Req. 16	**1.0**	The module shall be able to estimate the ROV's angular velocities.	**1**

3.4 Performance requirements

Req. 17	**1.1**	The ROV shall be able to estimate its attitude in real world values when the attitude is initially unknown, except for yaw which will be known from start.	**1**
Req. 18	**1.3**	The estimate of linear velocity in x shall not have an error greater than 0.2 m/s, measured as an average velocity over 3m when traveling with a velocity between 0.3 m/s and 0.4 m/s.	**1**
Req. 19	**1.2**	The estimate of linear velocity in y shall not have an error greater than 0.1 m/s, measured as an average velocity over 3m when traveling with a velocity between 0.15 m/s and 0.25 m/s.	**Removed**
Req. 20	**1.1**	The estimate in z-axis depth shall not error more than 0.1 m from the real value.	**1**
Req. 21	**1.0**	The estimation of a 90°rotation will not deviate more than 10°from real value	**1**

4 Hardware

The hardware for the ROV contains a BlueROV chassi with six T200 thrusters and six 30A ESCs, a raspberry pi, three ultrasonic sensors of type HRXL-MaxSonar- WR-MB7360 which have a measurement range from 1.3 to 20 meters underwater. The ROV is also equipped with an IMU, magnetometer, barometer and a pressure sensor, which are used to control, stabilize and estimate the depth of the ROV.

4.1 Interface

The interface and the requirements between sensors and the other components are described in a table below.

Req. 22	**1.0**	The ultrasonic sensors shall be able to communicate with the I/O-module.	**1**
Req. 23	**1.0**	The magnetometer shall be able to communicate with the I/O-module.	**1**
Req. 24	**1.0**	The barometer shall be able to communicate with the I/O-module.	**1**
Req. 25	**1.0**	The IMU shall be able to communicate with the I/O-module.	**1**
Req. 26	**1.0**	The pressure sensor shall be able to communicate with the I/O-module.	**1**
Req. 27	**1.0**	The I/O-module shall be able to publish sensor data on ROS topics.	**1**
Req. 28	**1.0**	The I/O module shall be able to communicate with the ESC.	**1**
Req. 29	**1.0**	The I/O-module shall be able to receive control signals by subscribing to ROS topics.	**1**

4.2 Functional requirement

The table below describes the requirements on the hardware functionality.

Req. 30	**1.0**	The functionality on the Raspberry PI 2 shall be transferred to a Raspberry PI 3.	**1**
Req. 31	**1.0**	The Raspberry PI CPU shall have a heat sink mounted to it.	**1**
Req. 31A	**1.1**	A step down regulator with a capacity to power the Raspberry Pi properly shall be mounted on the ROV	**1**
Req. 32	**1.1**	Additional distance measuring sensors shall be mounted.	**DEPREC-ATED**
Req. 33	**1.1**	A strip of led-lights will be mounted onto the ROV.	**1**
Req. 34	**1.0**	The ROV shall be waterproof to a depth of 3.8 meters.	**1**
Req. 35	**1.0**	It shall be possible to replace the battery of the ROV in less than 20 minutes.	**1**
Req. 36	**1.0**	It shall be possible to access the RPI and I/O-module of the ROV.	**1**

5 Modeling

A model of the system is an important tool to be able to answer questions about the system without actually conducting any experiment. With a good model in place the behavior of the system can be predicted. A good model can also lay as ground for a simulation environment as well as model based control strategies.

The requirements established are regarding the actual model which will be used and evaluated through the simulation environment. In previous projects the coordinate systems have been used for modeling and this project will use the same. These are LCS - Local coordinate system which is a coordinate system in the frame of the ROV and PCS - Pool coordinate system which is a coordinate system in the frame of the pool.

5.1 Functional requirements

Req. 37	**1.2**	The model shall describe the ROV's velocity along the x-,y,z-axes in the LCS.	**Removed (Already fulfilled)**
Req. 38	**1.2**	The model shall describe the ROV's angular velocity around the x-,y-,z-axes in the LCS.	**Removed (Already fulfilled)**
Req. 39	**1.2**	The model shall describe the ROV's position around the x-,y-,z-axes in the PCS.	**Removed (Already fulfilled)**
Req. 40	**1.2**	The model shall describe the ROV's angular velocity around the x-,y-,z-axes in the PCS.	**Removed (Already fulfilled)**

6 Control System

The requirements regarding the control system for the ROV are presented in this section. The requirements are separated into four different categories; interface, design, function and performance. Previously developed controllers for the ROV are not to be used. Instead new controllers are to be developed during the course of this project. The customer requested using Simulink to generate controller code for position control. A controller for attitude will be implemented from scratch since no previous attitude controller exists.

6.1 Interface requirements

The interface requirements for the control system.

Req. 41	**1.2**	The control system shall be able to receive reference signals to a trajectory by subscribing to a ROS topic.	**2**
Req. 42	**1.1**	The control system shall be able to receive reference signals for the attitude and position by subscribing to a ROS topic(s).	**1**
Req. 43	**1.0**	The control system shall transmit control signals to the thuster by publishing to a ROS topic.	**1**

6.2 Design requirements

The design requirements for the control system.

Req. 44	**1.2**	A controller shall be designed for control of the distance in LCS, x-direction.	**1**
Req. 45	**1.0**	A controller shall be designed for control of the angular velocity.	**Removed**
Req. 46	**1.0**	A controller shall be designed for control of the attitude.	**1**
Req. 47	**1.0**	A controller shall be designed for control of the position.	**1**

6.3 Functional requirements

The functional requirements for the control system.

Req. 48	**1.0**	The attitude of the ROV can be controlled.	**1**
Req. 49	**1.0**	The angular velocity of the ROV shall be controllable in x direction.	**Removed**
Req. 50	**1.2**	The distance of the ROV in LCS x-axis can be controlled.	**1**
Req. 51	**1.0**	The 3D position of the ROV can be controlled.	**1**
Req. 52	**1.0**	When the ROV is operated in a certain manual mode the inputs from the operator shall be reference values for pitch, yaw and the velocities along the x,y and z-axes.	**DEPRECATED**
Req. 52A	**1.1**	When the ROV is operated in a certain manual mode the inputs from the operator shall be reference values for angular velocity in pitch and roll, absolute angle in yaw and linear velocities along the x- and z-axes.	**2**

6.4 Performance requirements

The performance requirements for the control system.

Req. 53	**1.0**	The ROV shall be able to follow the edge of a pool without deviating more than 10 cm from the reference real world distance to the wall.	**DEPREC-ATED**
Req. 53A	**1.1**	The ROV shall be able to move straight forward three meters without deviating more than +/- 5°in yaw,pitch and roll supplied by the sensor fusion.	**1**
Req. 54	**1.0**	The angle of the ROV shall not deviate more then 10°from the reference attitude when the signal is constant.	**DEPREC-ATED**
Req. 54A	**1.1**	The pitch angle of the ROV shall not deviate more then 5 degrees from the reference attitude when the signal is constant between -45 $\rightarrow$ 45°and the ROV is stationary.	**1**
Req. 54B	**1.1**	The roll angle of the ROV shall not deviate more then 5 degrees from the reference attitude when the signal is constant between -45 $\rightarrow$ 45°and the ROV is stationary.	**1**
Req. 55	**1.1**	The position of the ROV along the z-axis shall not deviate more than 5 cm from the reference altitude when the reference altitude is constant.	**1**
Req. 56	**1.3**	The position of the ROV along the x and y-axes shall not deviate more than 50 cm from the reference position when the reference coordinates are constant.	**2**

7 GUI

The workstation is run via the Graphical Interface (GUI) which can both send commands to and receive information from the ROV.

7.1 Interface

Table below lists the requirements of the GUI interface.

Req. 57	**1.0**	The GUI shall receive information from the other modules by subscribing to ROS topics.	**1**
Req. 58	**1.0**	The GUI shall send information to the other modules by publishing to ROS topics.	**1**

7.2 Functional requirements

Table below lists the requirements on the functionality of the GUI.

Req. 59	**1.0**	There shall exist functionality in the GUI to manually input references in angles (roll, pitch, yaw), angular velocities (roll, pitch, yaw), position and linear velocity by using a script.	**DEPRECATED**
Req. 59A	**1.1**	There shall exist functionality in the GUI to manually input references in angles (roll, pitch, yaw).	**1**
Req. 59B	**1.1**	There shall exist functionality in the GUI to manually input reference position in x,y,z-axes and thrust forward.	**1**
Req. 60	**1.0**	There shall exist functionality in the GUI to present state estimates, references,control signals and active operating mode.	**1**
Req. 61	**1.0**	There shall exist functionality in the GUI to present a graphical representation of the reference trajectory.	**Removed**
Req. 62	**1.1**	There shall exist functionality in the GUI to present a graphical representation of the map and the ROV's position estimate.	**2**
Req. 63	**1.1**	There shall exist functionality in the GUI to present a graphical representation of the map and the ROV's attitude estimate.	**2**
Req. 64	**1.0**	There shall exist functionality in the GUI to switch between operating modes.	**1**
Req. 65	**1.0**	Parameters and settings for the modules on the ROV shall be adjustable from the GUI.	**1**

8 Software

Since the ROV is a complex construction of different systems, involving sensors, cameras and thrusters, there must be a software interface which can connect these to each other and still supply the workstation with information. The code of the software will be written in such a way that improvements and changes can be implemented without unnecessary restructuring.

8.1 Design requirements

The requirements in the table below describes how the code will be written and formatted.

Req. 66	**1.0**	The C++ source code written for ROS shall fulfill the ROS coding standard	**1**
Req. 67	**1.0**	Other written C++ code shall fulfill Google's coding standard	**1**
Req. 68	**1.0**	All written code shall be commented in English	**1**
Req. 69	**1.0**	The code shall be version-controlled	**1**

9 Vision

The following table specifies the requirements for the vision system.

Req. 70	**1.0**	The ROV shall be able to detect a ball, from a distance less than 0.5 meters in front of the ROV with its camera.	**1**
Req. 71	**1.0**	The ROV shall be able to detect a stationary ball in the pool with its camera.	**1**
Req. 72	**1.0**	The ROV shall be able to detect a moving ball in the pool with its camera.	**1**
Req. 73	**1.0**	The ROV shall be able to detect a stationary hula hoop with its camera.	**2**

10 Autonomy

In this section requirements regarding the autonomous behaviour of the ROV are presented.

Req. 74	**1.0**	If communication with the external workstation is lost, the ROV shall slowly rise to the surface.	**1**
Req. 75	**1.0**	A return to home function shall be implemented so that the ROV returns to the starting point of the mission if communication with the external workstation is lost.	**2**
Req. 76	**1.0**	The ROV shall be able to detect and follow a moving object using its camera. The object could be a ball or a tag.	**1**
Req. 77	**1.0**	The ROV shall be able to detect and move through a stationary hula hoop using its camera to detect the hula hoop.	**2**
Req. 78	**1.0**	The ROV shall be able to perform an autonomous mission moving through several stationary hula hoops on a predefined track.	**2**
Req. 79	**1.0**	When supplied with a mission from the external workstation, the ROV shall be able to perform the mission without the ethernet cable attached.	**2**
Req. 80	**1.0**	The ROV shall be able to communicate with the external workstation wireless when surfacing.	**2**
Req. 81	**1.2**	The ROV shall be able to spin and search for the ball around it (0.5 meters) and signal to the workstation when the object is found.	**1**
Req. 82	**1.0**	The ROV shall be able to perform an autonomous mission moving to several predefined locations in the pool when the layout of the pool is known.	**DEPRECATED**
Req. 82A	**1.2**	The ROV shall be able to perform an autonomous mission moving to a predefined location in the pool when the layout of the pool is known. The ROV shall be able to reach the predefined location within 50 cm in X,Y,Z supplied by the sensor fusion.	**1**

11 Possibility of Further Development

The project will be continued in the future by another project group since the goal is to make the ROV fully autonomous. To achieve this proper documentation is required.

Req. 83	**1.0**	There shall exist a technical report.	**1**
Req. 84	**1.0**	There shall exist a user manual.	**1**
Req. 85	**1.0**	The system shall be modular.	**1**

12 Economy

The economical demands are listed below.

Req. 86	**1.0**	Each member of the group shall spend 240 hours on the project. Accepted deviation is $\pm$ 10 %.	**1**

13 Security Requirements

In the table below the requirements to ensure safety for involved participants are listed.

Req. 87	**1.0**	The ROV shall detect if the connection with the workstation has been lost.	**1**
Req. 88	**1.0**	All group members shall sign the document *Föreskrifter för användning av pool på innergård B25 till B27* before using the pool at LiU. This document regulates the terms and conditions for the pool. All activities in the project must comply with these terms and conditions.	**1**
Req. 89	**1.0**	The ROV shall be able to detect a collision.	**DEPRECATED**
Req. 89A	**1.1**	The ROV shall be able to detect a collision in the ROV's positive x-direction.	**2**
Req. 90	**1.0**	The ROV should warn if a collision is imminent.	**DEPRECATED**
Req. 90A	**1.1**	The ROV should warn if a collision is imminent with the ball in the ROV's positive x-direction.	**1**
Req. 91	**1.0**	The ROV should stop if a probable collision is detected.	**2**
Req. 92	**1.0**	The ROV shall be able to detect leakage.	**2**

14 Delivery

The following decision points and deliveries are required during the project.

Req. 93	**1.0**	BP2. 2018-09-27. Requirement specification, project plan, time plan and an oral presentation of the first draft of design specification shall be approved by the client.	**1**
Req. 94	**1.0**	BP3. 2018-10-16. Design specification and test plan shall be approved by the client.	**1**
Req. 95	**1.0**	BP4. 2018-11-16. The requirements for the simulation environment and replacement of the RPI2 to RPI3 shall be fulfilled.	**1**
Req. 96	**1.0**	BP5. 2018-12-04. All requirements with priority 1 shall be fulfilled. Test protocol, user manual and a presentation that shows that all requirements are fulfilled shall be approved by the client.	**1**
Req. 97	**1.0**	Final delivery. 2018-12-06. A presentation shall be held for the customer to demonstrate that at least all priority 1 requirements are fulfilled.	**1**
Req. 98	**1.0**	BP6. 2018-12-17. A technical report, poster, website, presentation film and a post study that reflects the result and used time shall be approved by the client.	**1**

15 Documentation

The following table lists all documents produced during the project, gives a brief description about their content and specifies their target audience.

Document	Description	Target audience
Group contract	Rules and expectations for the project agreed by within the group.	Project group.
Meeting protocol	A protocol produced in order for the group and client to stay up to date on what is happening in the project.	Project group and client.
Requirement specification	A list of requirements to achieve set goals for the project.	Project group, client and customer.
Project plan with time plan	A plan describing how the project is to be conducted and a time plan for when and by who certain activities should be carried out.	Project group, supervisor and client.
Design specification	A more detailed technical description of the system and its modules that is designed to fulfill the requirement specification.	Project group and client.
Test plan	Describe how and when tests should be carried out to ensure that the requirement specification is fulfilled.	Project group and client.
Test protocol	Protocol showing the results from carried out tests described in the test plan.	Project group, supervisor and client.
Technical report	Description of the entire system with technical details.	Project group, supervisor and client.
User manual	A manual on how to use the system.	Project group, supervisor and customer.
Poster	Visual presentation of the project that should appeal to a broad audience.	Customer and general audience.
Video presentation	A video illustrating the completed product and showcasing reached goals.	Client, customer and general audience.
Web page	A web page that presents the product, project members and documents produced during the project.	Client, customer and general audience.
Presentation to client	Sales pitch and demonstration of the final project result	Customer, client and examiner.
Post study	Reflection on results and project as a whole.	Examiner

References

[1] Adam Aili and Erik Ekelund. *Model-Based Design, Development and Control of an Underwater Vehicle.* Msc Thesis - LiTH-ISY-EX-16/4979-SE, Sweden: Linköping University, 2016.

[2] Marcus Homelius *Techincal documentation, Remotely Operated Underwater Vehicle.* 2017.