Implementation of Controllers for Operating an USV

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Project Plan - Master of science in engineering

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DTU Electrical Engineering
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Implementation of Controllers for Operating an USV

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List of Symbols and Units

[$^\circ$] Degrees

[Kg] Kilograms

[Knots] Unit for speed, 1 knots = 1 nautical mile = 0.514[m/sec]

[Kw] Kilowatt

[m/sec] meters per second

[m] Meter

[sec] seconds

List of Acronyms

DTU Technical University of Denmark

USV Unmanned Surface Vehicle (Vessel)

MBZIRC Mohamed Bin Zayed International Robotics Challenge

GPS Global Positioning System

IMU Inertial Measurement Unit

Gyro Gyroscope

P Center Point

PID Proportional Integral Derivative

CHAPTER 1

Project Plan

Project Description

Autonomous robots have become a huge topic both within the industry, and as help for ordinary everyday tasks. For many years, the autopilot in an airplane has been a reality. Furthermore, the development within cars has moved in the same direction. This means that autonomous robots more or less have become a normality in different types of products, if you are looking for a new car, it has now become so advanced that it can drive itself, rate risks, etc. This development is also reflected in small boats and of course vessels for commercial use. The development in automation has also impacted the new edition of the MBZIRC, which has become a much larger competition covering more automation subtask than in previous years. One of the tasks in this year's competition is to get an autonomous boat (USV) to maneuver around. The USV must be able to navigate to a vessel based on a position given by a drone network, as it is not allowed to use GPS in the competition. Based on the position of the vessel and the USV, the USV must be able to departure from the harbor and go to the vessel. When it has docked to the vessel it must load a package with a robotic arm. When the package has been loaded the USV must return to the harbor and dock to the quay again.

The purpose of this project is to design the necessary controllers for navigating and steering the USV by controlling the trusts of the two mounted motors and its angles. Due to the fact that the USV is not allowed to communicate with external systems such as GPS, the USV controller will use simple internal sensor systems such as an IMU for generating a reference point P, velocity- and heading information. With the design of the controllers, the USV will be able to hold its position and steer the boat in all directions, when it is going from one position to another.

Risk Assessment

Already in the early studies of the USV, it appears from the provided documentation that the dynamic model for the given simulator is a simplified version of what the real world looks like. Moreover, it has not been possible so far to identify the implementation of the dynamic model.

At the same time, the quality of the documentation variates a lot with different names of constants and values for the same types. This makes it complicated to describe the implemented model, and design a completely identical one. To overcome these issues it is necessary to describe the dynamic of the USV by following standard modeling method for vessels. To ensure that the dynamic model behaves like the one implemented in the simulator, it will be necessary to tune the model's parameters. In addition to low documentation level, it is observed that the reaction time for rotating the motors is longer than specified. If this only seems to be a problem in the simulation, it will be possible to tune the parameters in the simulator, so that the motors rotate a bit faster. Even if the response time meets the given specifications, a deviation of the position will exist during adjustment. In the real environment, the USV is also affected by other external forces, which can contribute to a larger offset.

Finally, the model will not take waves, wind and current into account, which also contributes to a larger deviation of the USV compared to the simulated tests. Due to the position of the motors and the rotational limitations, it will also be difficult to steer the boat when it is sailing sideways. Therefore, it will it be necessary to examine the controlling possibilities for harbor maneuvers in more details.

The issues specified above will all contribute to the fact that the designed controller must be adapted to the physical boat, which is why the controller parameters must be fine-tuned.

In addition, the overall system will be set up with a mixer matrix, which ensures that it is always possible to dynamically control the angle and trust of the motors. This way, it will be possible to navigate the USV in all directions independent of drift. This solution ends up giving infinitely many solutions to make the USV sail in a certain direction at a given velocity. It will be necessary to come up with a way to find the most efficient way to adjust the motors.

Project Objectives and Success Criteria

The overall goal for this project is to design the necessary controllers, that makes the USV able to be controlled autonomously. This includes a few different controllers for controlling the velocity and the heading of the USV in different situations.

The objectives and success criteria are to

- Learn to communicate with the existing systems and controllers
- Determine data from internal positioning sensor(s), such as velocity, heading and the position coordinate
- Come up with a good solution for the physical starting points to be able to steer the USV in all directions (forward, backward, sideways and rotating).

- Get an insight or design the mathematical model, which describes the dynamic for the USV
- Design the controllers for going long distances
- Design the controllers for berthing and hold the position for the USV
- Perform specific tests both in simulation and in implementation.
- Follow the project plan as far as possible
- Create a final report with the documentation and specifications of the entire project

Hardware Devices

- USV

The USV is a 6.969[m] times 3.465[m] catamaran with a draft of 0.6[m]. The USV has a weight of 775[Kg] and a payload of around 600[Kg] with a possibility to have a overload up to 1000[Kg]. [SL23] Each hull consists of three watertight sections made of fiberglass which are joined together. Each hull has a rotateable center motor which can rotate +/- 90° with a maximum rotation speed of $15^{\circ/sec}$ and a encoder resolution of 0.1°. The two motors have a max motor power of 4[Kw] each which results in a crusing speed of 4[Knots] and a max speed around 10[Knots]. The angle and trust controllers for the two motors are implemented so it is possible to use the trust and the angle as input.[MBZ23]

The Specific dimensions of the USV are shown in figure 1.1 and 1.2.

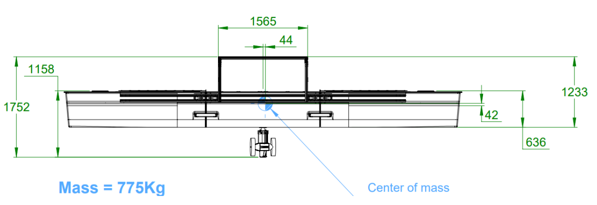

Figure 1.1: The USV seen from the side [SL23].

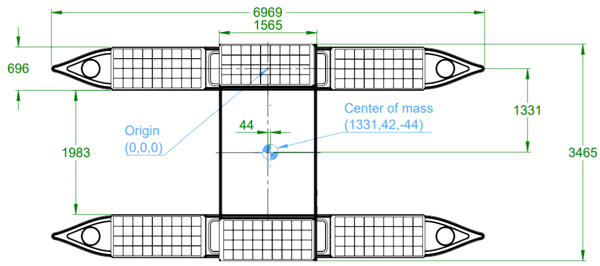

Figure 1.2: The USV seen from the top [SL23].

- Sensor(s)

A team, in the form of a special course, will implement the needed sensors for the controllers. As a starting point, a gyro/IMU will be used to generate heading data for the controller. Because the drone network is not available for this thesis, a GPS will be used to determine the positioning of the USV. Since GPS is not permitted for the competition, the GPS is just a solution for test of the controller before the USV positioning network is designed. Additionally, the team will investigate the possibilities for using other types of sensors for the controller.

Schedule

Below the project schedule is shown in a gant-chart. The expected activities and critical deadlines are inserted in table 1.1 and 1.2.

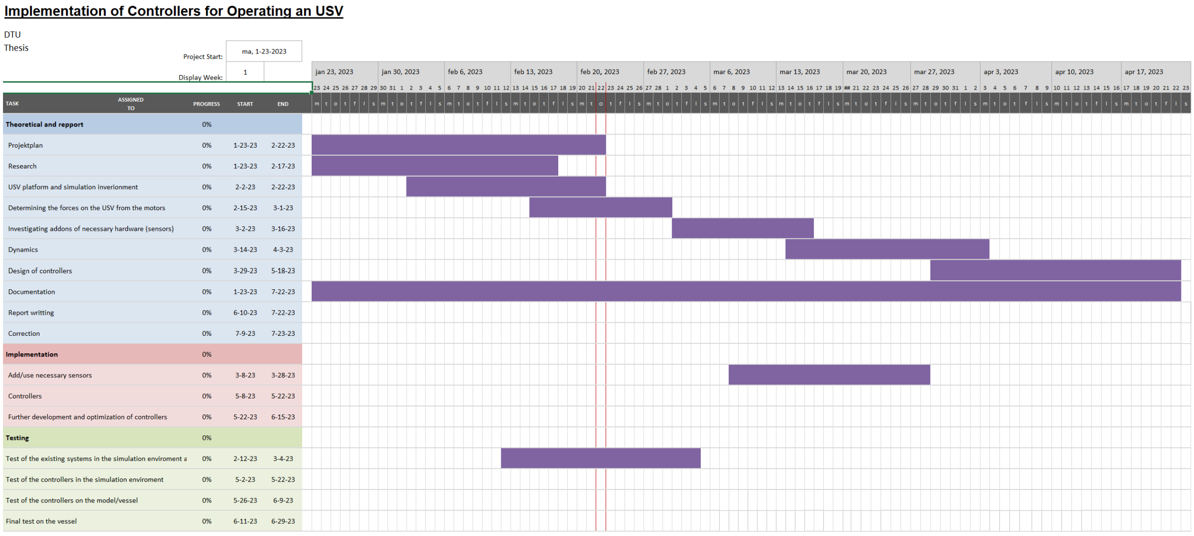

Table 1.1: Week 1 to 13 [Ver].

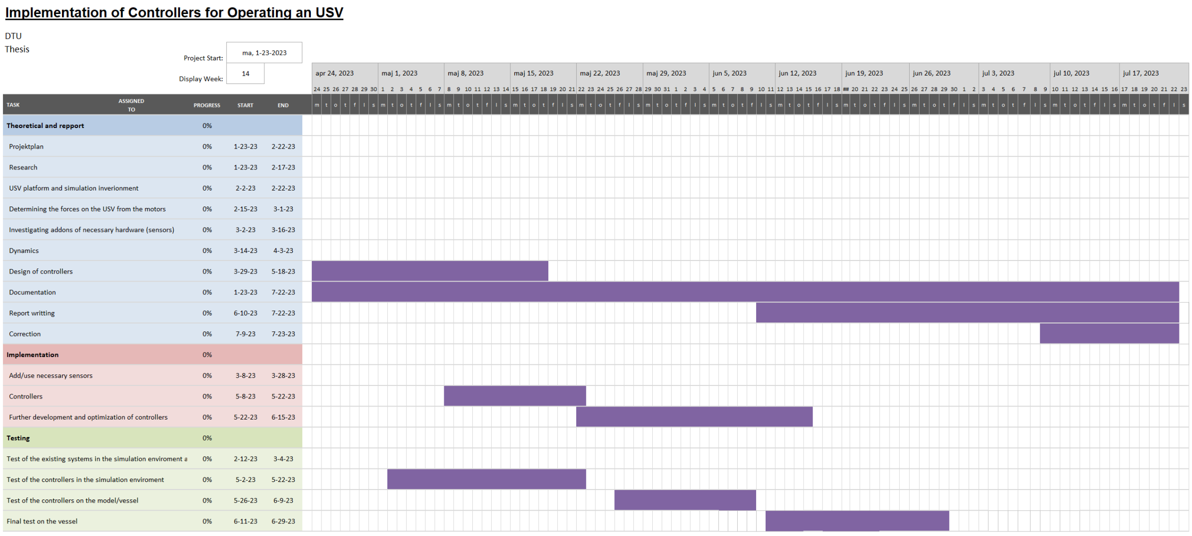

Table 1.2: Week 14 to the end of project [Ver].

Sub-Components of the Project Plan

Theoretical and report

Project-plan

A detailed and descriptive plan must be created for the entire project and its tasks. In addition to a break down of the different task and sub-task, the schedule must list all important milestones as start- and end dates of the main activities.

Research

The research phase will mainly take place in the first sub-period, where the USV and the external elements that impact the control of the USV are being investigated. The research will be based on articles and other reliable sources that describes the given issues.

USV platform and simulation environment

First of all, it is important to examine the USV platform and the given simulator environment. This part covers everything from examining the USV's specifications and setup to examining how it responds to specific commands. Additionally, the phase includes an examination of the implementation of the existing commands and the interface between different parts of the system.

Determining the forces on the USV from the motors

When it has been clarified how the USV is controlled and how it probably will react in different scenarios, it will be possible to determine the resulting force in the center point P of the USV. Based on the forces of the two motors it will then be possible to determine expected maneuver of the USV.

The resulting force from the motors is found as a combination of the trust and the angel. For different scenarios it would then be possible to form an overview of which solutions/combinations of trust and angel that will be the most effective when going in different directions.

Investigating addons of necessary hardware (sensors)

To navigate an USV, it is necessary to have sensors that detect the changes in the boat's position. As a starting point an gyro/IMU will be used, from which it will be possible to obtain the sufficient heading information.

Even that it is not allowed to use external signals to control the USV, a GPS will be used for test, until the drone network is available.

As previously mentioned, this part of the project will be assisted by a special course group of two people, who will be primarily responsible for the hardware parts. However, it still requires knowledge sharing between this project and the special course team.

Dynamics

In order to be able to design the controllers for the USV, it is important to know how to model the USV. The implemented model/construction in the simulator will be examined to establish the dynamics for the specific USV. Based on the dynamic model, it will be possible to design the controller in Matlab. To ensure that the established model describes the same model as implemented in the simulator, these will be compared for different step responses, from which a fine-tuning of the parameters occurs. If it is not possible to achieve the desired result with the above process, a state space form will be set up, from which it will be possible to examine the system and the transfer functions.

In addition to the model, it is important to design the mixer-matrix, which aims to control the motors dynamically and individually. This part will be a non-linear model as it contains sine and cosine terms. It is therefore necessary to linearize this part. This matrix will convert the input forces to the USV into a direction and trust on the motors.

Design of controllers

Overall, two controllers will be used - one for velocity and one for heading. This way, it will be possible to give the USV a heading and a velocity when it sails from one position to another.

As previously described, the kinematics for the USV will contribute to an infinite number of solutions, from which the most optimal one will be tried to be achieved. This means that the controllers must be able to steer the USV both when it performs distance sailing and when it sails sideways during example docking.

The simple solution for sailing distances is in principle based on the differential drive principle, where a heading controller handles the direction and a velocity controller handles the given speed. Whereas other maneuvers for example sailing sideways become a much more dynamic collaboration between the angle of the motors and the thrust.

Documentation

During the project, it is important to document the progress and the obtained result, so it is possible for later use in the project and for the thesis report.

Report writing

Finally, the project is concluded with a report that describes the project in detail as well as issues and considerations that have arisen along the way.

Correction

To ensure that the assignment contains the necessary topics, the various parts will be read through in the end of the project. In addition, the final assignment will be read through to ensure that the wording and formulations are understandable and to correct any errors.

Implementation

Add/use necessary sensors

In order to get inputs to the designed controllers, it will be necessary to use the right data from the sensor(s). The output must be converted to the correct units for the controllers.

This part will be prepared in collaboration with the special course team, who will ensure that the hardware is ready, but there is still some work to be done to understand the correct use of the sensor output.

Controllers

After the controllers are designed, they must be implemented as a software program that can be executed both on the simulator and on the USV. The program must be able to run in its own thread, and receive input from the sensor network and send trust and angle commands to the steering interface of the USV.

Further development and optimization of controllers

During the testing of the controller, it will probably be necessary to adjust the parameters setting to reduce the differences between the ideal Matlab model and the code implementation for the simulator and the real USV.

Testing

Test of the existing systems in the simulation environment and the physical USV

To understand the behavior of the USV, and to specify the requirements for the controller a lot of different tests will be done in the virtual simulator environment.

Test of the controllers in the simulation environment

To verify the controller design a numbers of tests will be executed on the virtual simulator during the design phase. The design will be tested towards the specified requirements.

Test of the controllers on the model/USV

Some of the test during the project will also be done on the physical USV for tuning the parameters to fit in the real world too. In the end of the project the test will primarily be done on the physical model.

Final test on the USV

In the end when the controllers are tuned for the real physical USV, A number of test cases are executed to verified that the controller fulfill the specifications.

Bibliography

[MBZ23] MBZIRC. *USV DETAILS*. 2023. URL: https://www.mbzirc.com/usv-details?keyword=USV.

[SL23] S SPANO and F LAGALA. "INERTIA USV ASPIRE MBZIRC." 2023.

[Ver] Vertex42.com. *SIMPLE GANTT CHART by Vertex42.com*. URL: https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html.

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