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Specification and First Prototype of Simulated Environment for Autonomous USV

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Preface

Some preface.

Trondheim, 2012-12-16

(Your signature)

Ola Nordmann

Acknowledgment

I would like to thank the following persons for their great help…

O.N.

(Your initials)

Summary and Conclusions

…

Contents

Chapter 1

Introduction

Introduction to the problem, some background about the Survey Explorer project..

1.1 Background

Where do we stand? What has been done before?

Problem Formulation

Literature Survey

What Remains to be Done?

...

1.2 Objectives

The main objectives of this project are

1. Investigate existing solutions for HIL testing of autonomous boat
2. Describe implementation of sensors and data processing on Odin and/or Jolner for situational awareness above the surface.

3. Discuss complexity and solutions related to simulation of raw sensor data from Radar, Lidar and camera versus simulation of pre-processed data.

4. Specify interface between simulator and autonomous navigation system.

5. Specify system for logging and visualization of simulation in real-time and for post simulation analysis.

6. Necessary protyping in C++ and MATLAB to verify assumptions.

7. Investigate which other agents (ships, small boats etc.) that can be interesting to implement as a part of the simulation environment.

8. Discuss methods for using the model as a part of an automated test environment related to ROS, MROS, scripting, repetition and regression testing.

1.3 Limitations

1.4 Approach

1.5 Structure of the Report

The rest of the report is organized as follows. Chapter 2 gives an introduction to ...

Chapter 2

Existing Solutions and Framework

This chapter goes through some of the existing tools used for HIL simulations of marine systems. The key properties of each tool are listed, and an evaluation is made about the possibilities of using the tools in the implementation of our own simulation environment.

2.1 Robot Operating System (ROS)

Short about ROS and how we can utilize it in the project. Will write this later as i gain more experience with ROS.

2.1.1 Marine Robotics Operating System (MROS)

Kongsberg Maritimes own version of ROS, with some extensions. Need to learn more about this (Rein will send a paper on it by the end of November).

2.1.2 Gazebo

Looks interesting. Even has done some research on this...

2.2 CyberSea Simulator

The CyberSea Simulator developed by Marine Cybernetics is an advanced simulator for HIL testing of Dynamic Positioning (DP) systems. It is *probably* super expensive (how can i investigate this?) and mainly focused on motion dynamics of big vessels at low speed (less than 3kts).

Key properties of the CyberSea Simulator (Johansen et al. (2005)):

- Capabilities for real-time presentation of results.
- Emphasis on vessel dynamics and accurate simulation of vessel motion during DP.
- Advanced simulation of wave, wind and current loads in six degrees of freedom.
- Several options for practical interfaces between simulator and computer control system, both analog and digital using for example NMEA protocol or normal network protocol.
- Generation of realistic signals from all the common sensors and position reference systems such as *"Gyro-compasses, VRUs, wind sensors, thruster feedback [...], power feedback from thrusters, switchboard and generator sets"* (Johansen et al. (2005)) used in modern DP technology. The signals can also be contaminated with noise levels typical for the sensors in use.
- Advanced generation of GNSS signals with possibility of simulating a broad specter of common failure modes.

The CyberSea Simulator, although powerful and highly customizable, is probably too expensive to use as a part of our simulation environment. It is also not certain to which extent the simulator can simulate other active agents such as ship traffic for testing of collision avoidance.

2.3 Marine Systems Simulator (MSS)

The Marine Systems Simulator (MSS) is a free toolbox for MATLAB/Simulink developed by several professors, MSc and PhD students at the Norwegian University of Science and Technology (NTNU). It is a merge of 3 previously existing toolboxes: Marine GNC Toolbox, Marine Cybernetics Simulator (MCSim) and DCMV. The toolbox contains possibilities for modeling of the dynamics of ships, underwater vehicles and floating structures under different wave, wind and current conditions.

Key properties of MSS (Perez et al. (2006)):

- Good modularity in Simulink.
- Emphasis on vehicle dynamics and thereby well suited for developing good motion control of such vehicles.
- Can be set up to do HIL simulations.
- Possibility of 3D animation using Marine Visualization Toolbox.

The Marine Systems Simulator is free software[1] under the terms of GNU General Public License[2]. Its also well suited for easy simulation of advanced marine vehicle dynamics. It is likely that this toolbox can be used as a part of our simulation environment to simulate Odins motions and possibly for 3D animations of such dynamics.

2.4 MCSim (Marine Cybernetics)

Trenger denne artikkelen: *Simulation-Based Design and Testing of Dynamically Positioned Marine Vessels.* Spør Roger Skjetne.

[1] http://www.marinecontrol.org/license.html

[2] http://www.gnu.org/licenses/gpl.html

Chapter 3

Implementation and Simulation of Sensors

Using nautical charts, information about other simulated agents and 3D models of installations in sea it is possible to generate realistic sensor data for HIL simulations. This section contains an overview of the implementation of important sensors used on Odin and a brief discussion about how sensor data can be simulated. The Inertial Measurement Unit (IMU) is documented in (**Evens rapport, trenger referanse?**).

3.1 Sensors for Situational Analyzis Implemented on Odin

In section 3.1 a brief overview of the sensors on Odin used for situational awareness above the surface are presented. The overall layout of sensors and system architecture are visualized in Figure 3.1.

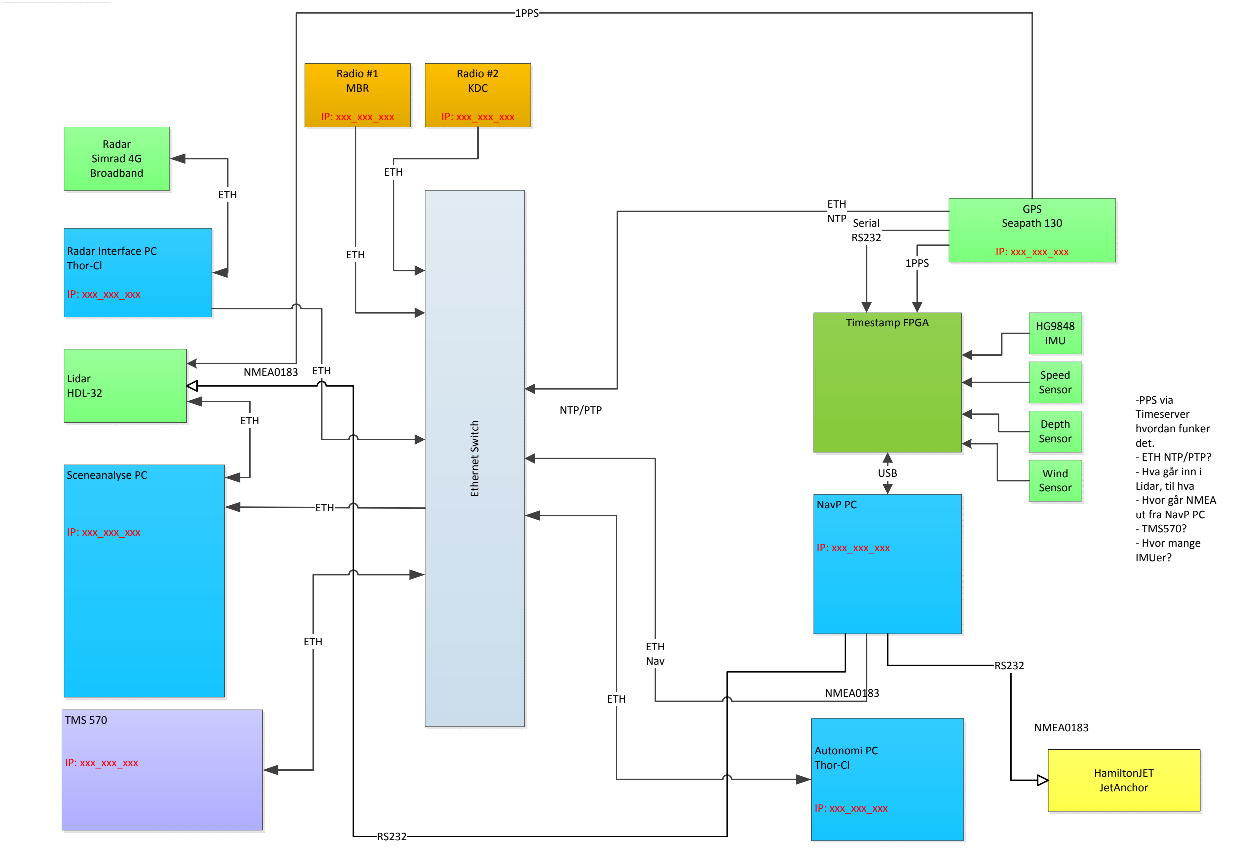

Figure 3.1: *Visualization of system architecture and network layout on Odin, including sensors and processing units.* **A better figure should be made when the final layout is determined!**

3.1.1 Seapath 134 GPS

The GPS used on Odin is the Seapath 134 developed by Kongsberg Seatex. Combining GNSS signals and IMU data the Seapath 134 gives highly accurate heading, position, heave, roll and pitch measurements (Kongsberg Seatex (2016)). Data is transmitted via standard NMEA protocoll over a serial RS232 cable for interpretation by the control system.

Figure 3.2: *The Seapath 134 developed by Kongsberg Seatex is used on Odin for position, heading and attitude measurements.*

3.1.2 Radar

No long text about how radars work is necessary.

Introduction to ARPA

Thoughts to consider:

- Blind zone (minimum detection range).
- Range dependent on weather and the shape and orientation of target.
- During precipitation clutter a target may or may not be detected. Use randomize function to determine detection? In that case, reproducitivity of simulation might be difficult.
- Accuracy and how to model errors resulting from inaccuracy.

  Bole et al. (2005) gives great details about possible errors.
- Assume (with good reason) that information from ARPA is available as incoming strings following some NMEA like protocol. The information includes at least the detected targets bearing, distance, heading and time. Other possible available data might be time and point of collision, radar cross section (or other target size info), conditions and noise conditions.

3.1.3 Velodyne LiDAR HDL-32E

Figure 3.3: *Velodyne LiDAR HDL-32E used on Odin for above-the-surface 3D analysis.*

For analysis of the nearby environment above the surface a LiDAR is used to create a 3D point cloud. The model used on Odin is a Velodyne HDL-32E as seen in Figure 3.3. A LiDAR can measure the distance to points around the sensor by firing a laser and measure the time it takes for the light to return. The distance is then saved along with the horizontal and vertical angle of the laser, so that the positions of the measured points can be used to generate a 3D model of the nearby environment. Velodyne HDL-32E generates 700,000 points per second with ±2cm accuracy at 80m-100m range. The LiDAR spins around the vertical axis to achieve a 360° horizontal field of view (FOV), and a combination of 32 lasers stacked vertically yields a 40° vertical FOV (+10° to −30°). An external GPS should be connected to the LiDAR for time pulse synchronization.

Uncalibrated point cloud data packets are transmitted from the LiDAR over a standard ethernet cable using UDP. The packet format is well documented in the user manual so that they should be easy to decompose by a custom made point cloud processing unit. A calibration table must be used for vertical correction for each laser. This table is included on a CD delivered with the HDL-32E.

3.2 Simulation of Sensor Data from Virtual Environment

The feasibility of simulating realistic sensor data from a virtual environment will be discussed in this section, as well as complexity and benefits regarding simulation of raw versus preprocessed sensor data. Information, hardware and software needed to generate data from each sensor will also be discussed.

3.2.1 Simulating Data from Radar

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3.2.2 Simulating Data from LiDAR

The protocol of the data transfer from Velodyne HDL-32E is well documented. Given a 3D model of the surrounding environment with easy access to angle and distance calculations it should be feasible to generate a realistic point cloud. The point cloud can be represented as data packets using the HDL-32E protocol and sent over ethernet to the interface between HIL simulator and the control system. This way it would be possible to simulate raw sensor readings from the HDL-32E. This is assumed to be beneficial to the developers of the simulated vehicle as a larger chain of HW/SW can be tested in the simulated environment.

Something about preprocessed data here.

- *Should the GPS used for clock synchronization also be simulated or could we use the one on the vehicle being tested?*. It is assumed that the system including simulator and hardware is synchronized in time using either NTP or PTP network timing. A real or simulated GPS is therefore not necessary for time synchronization.

3.2.3 Raw vs Preprocessed Sensor Data

Complexity and benefits regarding generating raw data versus preprocessed information.

Chapter 4

Simulator - HIL interface

4.1 Physical Interface

4.2 Software Interface

4.2.1 Necessary Exchange of Information

4.2.2 Message Protocol

Chapter 5

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5.1 Logging

5.2 Visualization

5.3 C++ example?

Chapter 6

Use of Model in Autonomous Testing Environment (ROS)

Chapter 7

Other Agents and their Behavior as Part of Simulated Environment

7.1 Possible Agents

7.1.1 Ships

7.1.2 Boats

7.2 Pros and Cons of Agents Behavior

7.2.1 Reactivity?

7.2.2 Predictability

7.2.3 Possibility of Repeating Scenario

Chapter 8

Summary and Recommendations for Further Work

8.1 Summary and Conclusions

8.2 Discussion

8.3 Recommendations for Further Work

Appendix A

Acronyms

FTA Fault tree analysis

MTTF Mean time to failure

RAMS Reliability, availability, maintainability, and safety

Appendix B

Additional Information

This is an example of an Appendix. You can write an Appendix in the same way as a chapter, with sections, subsections, and so on.

B.1 Introduction

B.1.1 More Details

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