Master Thesis in Marine Technology - 2013

Study of Critical Imaging Parameters and Variables for Environmental Monitoring Using a ROV Compared to Other Platforms

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Problem

Taking images underwater is a challenge due to the lack of natural light, and the visual feedback given when investigating Objects Of Interest (OOI). The combination of understanding the underwater environment and effectively use the right platform to investigate can provide better methods at the right time. Developing a strategy to investigate the underwater environment combined with good control strategies for a ROV to be able to maneuver in unknown areas are therefore of great interest.

Introduction

This thesis is a part of the project MuDSCrIPE: Multi-Disciplinary Study of Critical Imaging Parameters and Variables for Environmental Monitoring. This project aims to investigate the potential improvement in underwater(UW) imaging. This is based on cooperation between the Department of Biology and the Department of Marine Technology at the Norwegian University of Science and Technology (NTNU). The concept of UW imaging is being developed to strengthen the environmental monitoring happening offshore.

Taking images underwater (UW) is a challenge due to the lack of natural light, and the visual feedback given when investigating Objects Of Interest (OOI). The combination of understanding the underwater environment and effectively use the right platform to investigate can provide better methods at the right time. In order to fully develop an Integrated Environmental Monitoring System (IEM), there is a need to investigate the use of technology in underwater imaging. With the use of technology it is possible to capture and describe the important aspects of the status of an underwater environment. There exist different UW platforms and optical camera solutions that can be used together with a processing system to capture and analyze the data of the UW environment. This technology needs to be investigated in terms of technical feasibilities, functional and operational requirements.

The starting history of Unmanned Underwater Vehicles(UUVs) may be tracked back to the self-propelled torpedo which was perfected in 1868 by Whitehead [Roberts and Sutton, 2006]. The US Navy contributed further through developing the design and construction of cable controlled underwater recovery vehicles. The commercial breakthrough for the use of UUVs came when oil was discovered in the North Sea. In these operations ROVs began and continued to be used extensively. A ROV is a marine vehicle that can receive instructions from an operator through an umbilical cable connecting the ROV with a ship on the surface. The ROV is not built with considerations for hydrodynamic performance and is often box shaped. ROV Minerva has been used in biological research and sampling, testing of equipment and development of new research technology, archaeological surveys, supplying ground truth in geological investigations, commissioned research and much else [Marine, 2012].

Previous work at the Applied Underwater and Robotics Laboratory (AUR-lab) has provided further advancement of ROV control. The work done on a Dynamic Positioning(DP) system for ROV Minerva can be further read about in Dukan et al. [2011] where good results were achieved for the observer and control system. This is based on some of the notable work done by Kirkeby [2010] and Candeloro [2011]. The work done by Krte [2011] focused on different guidance principles and guidance strategies.

An important aspect of working in the depths is the lack of natural light. The water has other properties then air, and therefore these needs to be studied as well. It does not help with a suitable platform if the platform equipment do not fulfill the task of the environment it will operate in. There are severe limitations of optical imaging in the underwater environment. There is a rapid attenuation of the electromagnetic radiation, and ambient lighting is practically non-existent after the first few tens of meters of depth [Pizarro and Singh, 2003]. This makes it very challenging to take good images, and usually means that there is a need for an extra light source. The lack of light also makes it important for the ROV pilot to be able to adapt easily to changes when exploring unknown areas. The ideal situation is presented when the pilot only needs to focus on the task at hand, and not compensate for environmental disturbances. This requires a quick reaction time when new commands are sent to the ROV.

Previous work on joystick control in a closed-loop control system is presented in Dukan and Sorensen [2012]. This paper presents how to relate the joystick commands to the ROV. The challenges related to having a pilot in the closed-loop control is presented, and how to limit the outputs of the desired velocity. The concept with a joystick in closed-loop control is to maximize the pilots focus on the task at hand, while the control system compensates for unknown disturbances.

In this thesis the use of joystick control with a ROV for efficient maneuvering in unknown areas have been further analyzed. The focus has been on relating the joystick commands to the body-frame of the ROV, as well as use a good velocity reference model to further enhance the ROV pilot's control of the vehicle. The system has been implemented in a simulation of the joystick and the ROV and tested to investigate the potential future use.

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Modeling

As the ROV has actuation in 4 DOF we therefore use a joystick with 4 axes to control the joystick. Figure 1 shows the reference frames for the joystick and the ROV body frame. The arrows indicate the positive directions. The origin of the x and y axes on the joystick are in the basis of the stick, while the z-axis is fixed to the stick. The w axis is a separate lever.

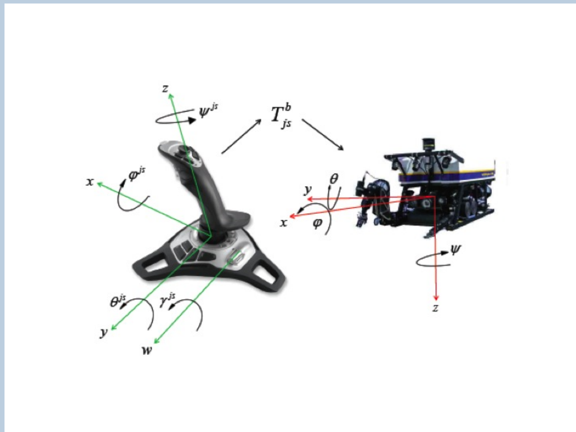

Figure 1: The Joystick and ROV reference frames [Dukan and Sorensen, 2012]

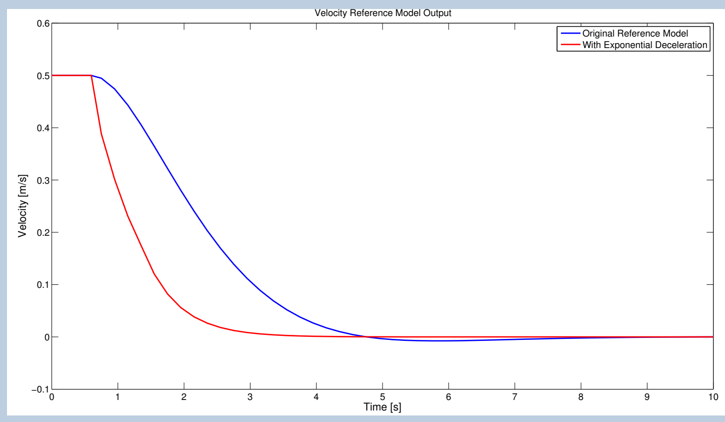

Figure 2: Response for the velocity reference model and the modified model.

From the joystick we get the output vector

$$\Theta^{js} = \begin{bmatrix}\phi^{js} & \theta^{js} & \psi^{js} & \gamma^{js}\end{bmatrix}^T$$

where ϕ^{js} is rotation around the x-axis, θ^{js} is rotation around the y-axis, ψ^{js} is rotation around the z-axis and γ^{js} is the rotation of the lever around the w-axis. The available actuation forces we have is given by

The joystick output command Θ^{js} is related to a reference frame and the ROV dynamics. Due to the limitations of possible space to move the joystick in, it's not practical to relate the joystick command directly to position. Therefore it is either related to thrust or velocity, given by τ^{js} and ν^{js}. The direct output from the joystick is given in bits in the order $[-2^{15}\ 2^{15}]$, and is transformed to $[-100\ 100]$ for simplicity. The different methods of relating the joystick command to thrust or velocity are now calculated and implemented with matrix operations.

The 2nd order reference model can be found in Fossen [2011] and is given by

$$\begin{aligned} \eta_d &= R(\psi)\nu_d && (1)\\ \ddot{\nu_d} + 2\Lambda\Omega\dot{\nu_d} + \Omega^2\nu_d &= \Omega^2\nu^{js}, && (2) \end{aligned}$$

where $\Lambda > 0$ and $\Omega > 0$ are design matrices for relative damping and frequencies.

To accommodate for the slow deceleration, a modification was proposed based on previous sea trials. This was then implemented to test the potential to enhance the pilots experience of control. The new reference system is suggested as:

$$\eta_d = R(\psi)\nu_d \tag{3}$$

$$\nu_d = \begin{cases} \ddot{\nu_{d_i}} + 2\zeta_i\omega_i\dot{\nu_{d_i}} + \omega_i^2\nu_{d_i} = \omega_i^2\nu_i^{js} & \text{if } \nu_i^{js} \neq 0,\\ \nu_{d_i} = \nu_{0_i}e^{-a_i(t-t_0)} & \text{if } \nu_i^{js} = 0 \text{ and } \mid \nu_i \mid > \nu_i^{tol},\\ \nu_{d_i} = 0 & \text{if } \nu_i^{js} = 0 \text{ and } \mid \nu_i \mid \leq \nu_i^{tol}. \end{cases} \tag{4}$$

Where ν_i^{tol} is the tolerance limit for each DOF i, and tells when the velocity is low enough to switch to DP control. For the deceleration part, ν_{0_i} is the velocity at the time the joystick command becomes zero, a_i sets the speed of deceleration, and t_0 is the initial time when the joystick command is set to zero and the deceleration starts.

The velocity reference model and the modification are shown in Figure 2. The difference is quite big on the deceleration and it is possible to achieve a significant reduction for this phase, and give the pilot a faster visual response that the ROV is slowing down when the joystick is released.

Simulations

Based on the velocity reference a simulation has been conducted with the use of a joystick-ROV simulation system. The ROV data is based on the model developed of ROV Minerva. The simulations consists of generating an output to thrust or velocity based on the joystick command, and a non linear PID controller is used for velocity control. The goal is to investigate the response when giving a command for velocity in surge and then reaching a full stop.

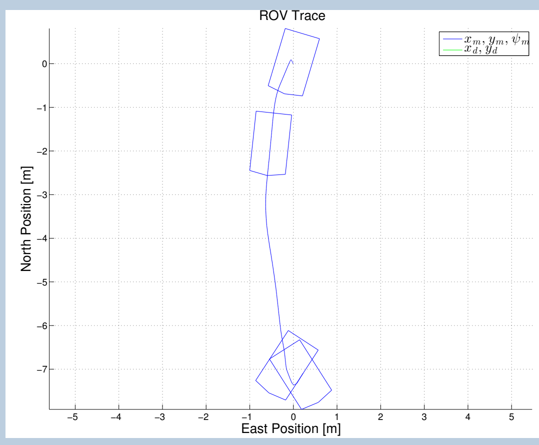

Figure 3: The movement of the ROV when trying to do a complete stop with thrust commands.

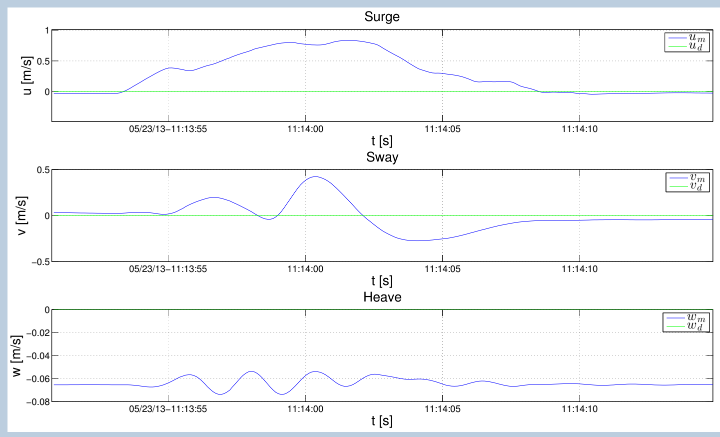

Figure 4: The velocity and of the ROV when trying to do a complete stop with thrust commands.

In Figure 3 we see the movement of the ROV when the joystick is related directly to thrust commands, meaning no closed-loop controller is active. Having only manual control it is hard to avoid any velocity also in sway as can be seen in Figure 4. When the pilot tries to stop the ROV the surge and sway velocity can be controlled to zero, but we can also see there is an extra component in yaw that is difficult to compensate for. The result is therefore some unwanted change in heading when trying to stop the ROV.

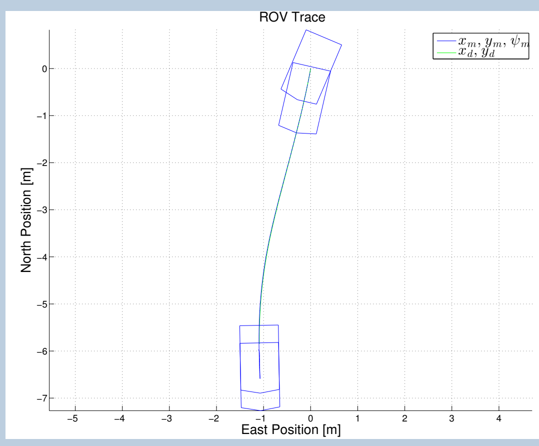

Figure 5: The movement of the ROV when trying to do a complete stop with the ref. model.

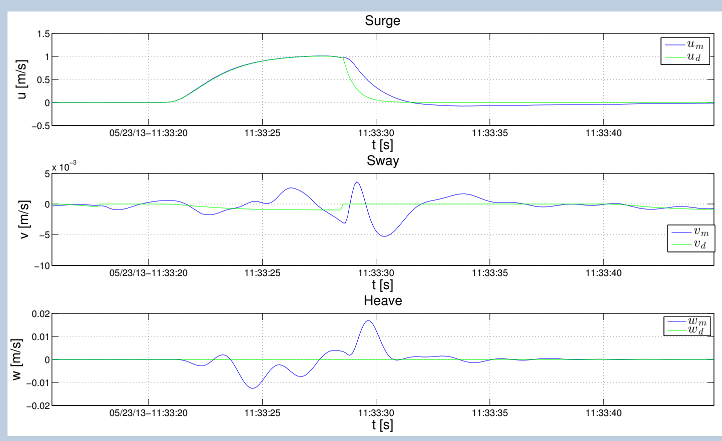

Figure 6: The velocity and desired velocity of the ROV when trying to do a complete stop with the ref. model.

In the next simulation the joystick command in surge is transformed to a desired velocity that is handled by the velocity reference model. From Figure 6 we can see that the ROV accelerates to the desired velocity with much less sway velocity. The exponential function is activated when the joystick is released, and the desired velocity goes quickly to zero as expected. There is no unwanted movement in heading when the closed-loop controller is activated. As seen in Figure 5 there is a small overshoot of the ROV, and the surge velocity will for a short period be negative to compensate to slow down the ROV. Further tuning of the PID controller might support a better result and less overshoot.

The simulations show that there is an improvement in the control of the ROV and lesser time to stop when using the velocity reference model. The time the ROV uses to reach zero velocity is half when the modified reference model is implemented. Further the closed-loop control provides a better support for steering then in the case of direct thrust commands. In unknown areas with low visibility this system can help to enhance the maneuvering capacities of the ROV pilot.

Conclusion

A simulation system for using a joystick to control a ROV has been developed, with the focus on the velocity reference model. The connection between the joystick and the ROV reference frames are implemented, as well as a simulation based on the work done on ROV Minerva. The modified reference system shows potential for a better deceleration phase in the simulations, but there is still a overshoot created by the rapid stop. Further field tests are to be analyzed to see how the behavior adapts from the simulation to the real environment, and how the ROV can be used more effectively in the Integrated Environmental Monitoring scenario.