Model Predictive Control for Underwater Robots in Ocean Waves

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***Abstract*—Autonomous marine vehicle decision making is an active avenue of research in the Field Robotics Community. Much of this work includes advancing underwater path planning, localization, and perception. Developments in this field can lead to cost-effective methods of deploying marine energy arrays. The purpose of this document is to summarize some of the more promising research applications as well as justify the use of autonomy in the offshore community.**

***Keywords*—TBD, marine robotics, wave energy, autonomous path planning, perception, oceanographic monitoring, SLAM, AUV, ROV**

I. Introduction

In the intermediate depths of the coastal ocean, the area of ocean bounded by the shoreline and the 200m isobath [**?**], wave forces are felt throughout the majority of the water column. Wave motion decays through the column exponentially such that it is neglible ($< 0.04\%$) at a depth equalling 1/2 of the surface wavelength [**?**]. Because of this, wave forces are often times neglected in robotic path planning. In field applications where there is a low operational depth and a persistent wave climate, this assumption can quickly break down. This paper will outline how Model Predictive Control (MPC) can reduce an underwater vehicle's position error when under the influence of ocean waves.

This paper is organized into the following sections. First, the remainder of section **??** contains a brief intro to wave energy extraction and marine vehicles. Section **??** is divided into four subsections detailing relevant research in vehicle path planning, localization, perception, and combined applications. Concluding Remarks are then provided.

According to Linear Wave Theory (LWT), the energy in one water wavelength is the sum of its potential and kinetic energies [**?**]. After some derivation it is reduced to:

$$E_L = 1/8\rho g H^2 L \tag{1}$$

Though simplified, this relationship illustrates a noteworthy point that neither the average potential nor kinetic energy per unit area depends on water depth, but instead is simply proportional to the squared waveheight term, H. The rate at which energy is transferred is the energy flux, and for LWT it is the rate at which work is being done by change in energy density of a fluid over a vertical face [**?**].

Underwater vehicles can be classified into one of two generic categories: manned and unmanned vehicles. Unmanned Underwater Vehicles (UUV) are often labeled as synonymous with Autonomous Underwater Vehicles (AUV). This can be misleading as it is not an accepted standard. For the scope of this paper, the term AUV will be used for an untethered unmanned vehicle. The term Remotely Operated Vehicle (ROV) will be used to describe a tethered manned vehicle whose operation may or may not be tele-operated [**?**]. No manned vehicles will be discussed.

The term "glider" may on occasion be used to describe a type of AUV. Gliders such as the Slocum shown in Figure **??** are designed to move efficiently through the water column by changing their weight [**?**]. Successive pitch adjustments up and down result in a sawtooth profile with no external propulsion.

II. Model Predictive Control

III. System Dynamics

A. Vehicle Model

Figure 1. A SeaBotix vLBV300 ROV similar to the one modeled in this work. The vehicle has six angled thrusters which control it along five degrees of freedom: heave, sway, surge, roll, and yaw.

B. Force Balance

C. State Space

IV. Simulator

A. Wave Field Model

B. Algorithm Layout

V. Results

A. Determination of Best Horizon

B. MPC comapred with PD, and drift

C. Optimal Horizon against noisy world

D. Future Work

VI. Conclusion

This paper presented some of the accomplishments in the marine robotic community. These included advancements in autonomous underwater path planning, localization, and perception. Efficient path planning helps reduce overall mission cost and time by optimizing methods of navigating. Localization issues in an environment absent GPS and long range wireless transmissivity prioritize the need for well-developed SLAM techniques with minimal input. Robotic perception in the underwater domain further complicates research efforts. In addition, multi-agent research such as the multi-glider work in [**?**] is an excellent demonstration of the value of autonomy in performing oceanographic monitoring.

These advancements in underwater autonomy will be pivotal in the development of offshore energy arrays, since low-cost robotic platforms inspecting, monitoring, and manipulating infrastructure can reduce deployment costs drastically. Over the course of the NNMREC ALFA project, robust algorithms for these marine platforms to support WEC's will lead to improved scaled economics and further global wave energy development. As more challenges are addressed, this will help secure wave energy extraction as the premier sustainable energy source for the 21st century.

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