Abstract

Both the scientific and commercial communities are increasingly utilising autonomous underwater vehicles (AUVs) for progressively challenging tasks. In order to improve the level of autonomy in these vehicles, a controller capable of accurately controlling such a complex system within a highly dynamic environment is required.

The mathematical model of an underwater vehicle is highly complex and nonlinear. This is due to hydrodynamic forces such as lift, drag, buoyancy and added mass effects. The addition of sensory equipment to the vehicle, especially those that protrude outside of the hull of the vehicle, can have a significant influence on one, or all, of these hydrodynamics. Furthermore, the complexity of the vehicle model increases significantly when highly dynamic and unknown water currents are acknowledged.

As the methods used to obtain this vehicle model are prone to error, a control strategy that is robust to modelling uncertainty and unknown water current disturbances is required. Furthermore, both computational and manoeuvring efficiency is desirable as both these factors contribute to the overall endurance of the vehicle. Current state of the art control strategies place various assumptions on the vehicle model such that a stable and realisable control law can be obtained. However, due to the nature of these assumptions, highly manoeuvrable underwater vehicles may not be utilised to their full potential, as they cannot safely operate outside the regions where some of these assumptions are violated. Minimising the use of these assumptions when designing a control system will ultimately lead to a more stable control algorithm that is capable of controlling a vehicle over a much wider range of operation.

The goal of this thesis is to propose and analyse the performance of various control algorithms that are robust to both modelling uncertainty and unknown disturbances, while also improving the computational and manoeuvring efficiency of highly manoeuvrable AUVs. The results presented here are produced using a high fidelity simulation environment such that accurate and reliable behaviour of an AUV is realised without the need for a physical vehicle.

These goals are achieved by presenting a thorough analysis of the mathematical model that determines the dynamic nature of an underwater vehicle. Using a rigorous and systematic mathematical approach, this thesis then derives several simplified models for control design purposes, based on assumptions commonly employed for underwater vehicles. The behaviour of each simplified model is then validated against the behaviour of the model representing the real vehicle under control to verify the integrity of each simplified model.

Based on one of these simplified models, this thesis proposes a novel nonlinear controller utilising the body frame of the vehicle, as opposed to the navigation frame, which is widely adopted in the literature. This control strategy, namely the body frame coupled sliding mode controller (BFCSMC), offers several advantages compared to its existing navigation frame counterpart, namely the navigation frame coupled sliding mode controller (NFCSMC). In particular, the BFCSMC reduces the computational demand, and hence shortens the control execution time, of the vehicle along the desired trajectory. This is achieved while preserving, or improving in some cases, the manoeuvring ability of the vehicle. As part of the control algorithm development, a new uncoupled control strategy based on the literature, namely the body frame uncoupled sliding mode controller (BFUSMC), is also proposed to demonstrate the importance of incorporating the inherent coupling of the vehicle into the design of the control law.

The aim of this thesis is to present control strategies that can be applied to any underwater vehicle. The three control strategies, the BFUSMC, the NFCSMC, and the BFCSMC, are then implemented, and simulation studies are conducted covering a wide range of manoeuvring complexity. The REMUS 100 AUV is chosen specifically for case study purposes. In particular, the hydrodynamic coefficients that are used by previously presented research for this vehicle are adopted by this thesis to avoid the need for estimating the coefficients.

These simulation studies demonstrate the superior performance of the BFCSMC over the NFCSMC, while the comparison of performance against the BFUSMC demonstrates the importance of including the inherent coupling of the vehicle within the control law.

Following is an analysis of common actuators utilised for AUV manoeuvring, and a novel control allocation scheme is proposed such that the manoeuvring ability of these vehicles is maintained while the manoeuvring efficiency is improved. Simulation studies conducted with this allocation scheme demonstrate that the manoeuvring ability of the vehicle is maintained while utilising this allocation scheme.

Overall, this thesis demonstrates the superior performance of the proposed controller utilising minimal assumptions for the vehicle model, while also demonstrating an allocation scheme that improves the manoeuvring efficiency of an AUV without sacrificing the manoeuvring ability.