

Application of Robust Design Techniques for Underwater Vehicle Control

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ABSTRACT

Application of robust design techniques in the design of controllers for Autonomous Underwater Vehicles (AUVs) is discussed in this paper. Proper tuning of controllers is essential in achieving the desired positional and tracking accuracy of AUVs in underwater missions. A new scheme of gain tuning using Taguchi method is introduced here for the proportional-integral-derivative (PID) control of an under-actuated AUV with less controllable degrees of freedom than the total number of degrees of freedom. With four controllable states, this vehicle has twelve controller gains to be tuned. Through the help of design of experiments (DOE) and robust design techniques, as applied in the Taguchi optimization method, an optimal and robust set of PID controller gains have been obtained. A simulation study of the pitch control of an AUV using the above method is presented in the paper. The simulation results are compared with the other tuning methods like Ziegler – Nichols, Auto tune, Tyreus – Luyben and Cohen-Coon method. The results show that the index of aggregate absolute error has reduced to 78.73% and 24.34% from the Ziegler – Nichols method 1 and Tyreus-Luyben method respectively.

KEY WORDS: Controller gain tuning; underwater vehicle control; robust design; Signal – to – Noise Ratio; Taguchi Method.

INTRODUCTION

Considering the importance of underwater technology in exploring the untapped resources beneath the sea, there seems to be a renewed interest in underwater robotics research, especially in developing advanced control strategies for autonomous vehicles. Recent developments in this area are well summarized in [Fossen, 1994 and Yuh, 2000]. Dynamics and control of AUV in a constrained environment poses great challenges to designers. This, coupled with the uncertainty of hydrodynamic parameters, make the controller design an extremely tough task. Many researchers have approached this problem and many solutions have been proposed in the literature, with varying degrees of success, which are summarized in [Antonelli, 2001, 2007 and Choi, 1996]. The control techniques proposed in literature can be broadly classified into two major categories: adaptive control and

robust control [Yuh, 2000]. In adaptive control the controller parameters are automatically varied to maintain a satisfactory level of performance when the system parameters are unknown and/or time varying. Robust control refers to the control of uncertain plants with unknown disturbance signals, uncertain dynamics and imprecisely known parameters making use of special fixed controllers. Among these, adaptive control is considered to be better for plant uncertainty. However, it is computationally intensive for higher order systems and requires exact knowledge of the dynamic parameters, apart from the computation of inverse Jacobian matrix. The robust control scheme provides a satisfactory performance with a simple control structure, but comes with undesired high control activity at steady state. On the other hand, the commonly used proportional – integral – derivative (PID) control [Perrier, 1996 and Fossen, 2003] does not require any information of the plant dynamics and has a simple standard structure. Moreover, owing to modeling uncertainties a more sophisticated control scheme is not necessarily more efficient than a well-tuned PID controller. Alongside the advantages, however, the problem of tuning PID controllers has remained an active research area.

Tuning is the adjusting of the feedback controller parameters to obtain a specified closed-loop response. Many techniques have been proposed for the manual or automatic tuning of PID controllers. Castrillon [Castrillon, 2005] has reviewed twenty-four different tuning methods and has concluded that most of the controllers are tuned using frequency responses due to the advantages in expressing the modeling errors directly in the frequency domain. However, like the auto-tuning technique, frequency response methods are difficult to implement in the MIMO systems. Ferrell et al., [Ferrell and Reddivari, 1995] believed that PID controllers are poorly tuned because of traditional methods of controller design and the tuning to achieve minimum variance requires the engineer to create a closed-form mathematical model of the system and controller dynamics. Tuning of controllers using Taguchi method [Byrne and Taguchi, 1986] was proposed by them to improve the controller performance. Though this was found to be very convenient, the controller gains were not optimal and noise factors were not considered.

Commonly, with changes in system dynamics and variations in operating points, PID controllers should be retuned regularly. It is very important that the controller gains obtained are robust even though