Fault Tolerant Control of an AUV using Periodic Output Feedback with Multi Model Approach

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ABSTRACT

Active thruster control is an important problem in AUV. One of the way to tackle this problem is to make the dynamic system like AUV as adaptive and self-controlling. This article discusses the fault tolerant controller design with periodic output feedback for Autonomous Underwater Vehicle using multi model approach. The entire system is modelled in state space. Assuring high degree of reliability and persisting autonomy under thruster failure the controller has to be designed such that the thrust distribution is effectively controlled if any one of the signals and corresponding thrusters fails. The AUV is modelled in six degrees of freedom having six inputs and six outputs. Four thrusters are used for vertical and horizontal movements in AUV. Fault tolerant controller is designed for depth control of AUV, with periodic output feedback gains with multi model approach. To each thruster failure the multi model is presented with the gain matrix having all off diagonal terms zero. The designed robust fault tolerant controller with periodic output feedback with multi model approach provides satisfactory stabilization to AUV depth system.

KEYWORDS

Autonomous Underwater Vehicle (AUV), Fault Tolerant, Multi Model, POF

1. INTRODUCTION

The oceans are of immense importance so far as human life is concerned. Since ancient times till today, man has been depending on oceans for various needs. Oceans occupy about 71% of the earth and thus they are the main resource of energy.

Many marine activities are mainly hampered due to climatic changes in ocean. Therefore various systems are used for exploring extreme depths of ocean and monitoring the inside changes. These systems work under severe conditions such as high hydrostatic pressure, hydrodynamic forces and electromagnetic waves. Autonomous underwater vehicles (AUV) are one of the popular ways of doing above tasks. Autonomous Underwater Vehicles (AUVs) (Yuh, 2000) are programmable robotic vehicles (Azar and Serrano 2015a), depending on their design they glide or dive in ocean.

Majority AUVs are categorized under one group which is used for survey missions. They include AUVs like HUGIN, REMUS and ISE EXPLORER. These AUVs are required to operate at a specific depth and maintain low and constant speed. Therefore speed control of thruster is of importance.

AUVs are controlled by on board control system. It uses the information received from sensors to determine the command to be sent to an actuator to complete the defined mission. The main constraint in using AUV is limited energy supply available with it in the form of battery. Therefore the key
design factors of control system of AUVs must include robustness, fault tolerance and reliability. The control system of AUV is very challenging task due to unpredictable environmental forces generated by the sea currents. If control system of AUV fails in operation it is not possible to correct the control parameters manually. Hence proper design of controller of AUV, taking care of all these parameters is a need of today. Various control systems for underwater vehicles are developed, some of them are summarized below:

1. **Adaptive Control**: Adaptive Control in AUV modifies control gains according to the changes in hydrodynamics and underwater disturbances. This type of controller may give failure when dynamics of vehicle crosses its defined specified parameters. Yuh and Nie designed adaptive control system using parametric estimations to tune the control gains;

2. **Neural Network (NN) Control** (Vaidyanathan and Azar 2015a): Neural Network can achieve nonlinear mapping. This type of controller does not require the knowledge of dynamics of the system. Hence it was found more suitable for AUV in earlier days. However this controller does not require mathematical modeling of the system, hence validation of the system has to be done only through experiments. Since this is not feasible all the times this type of controller is not suitable for AUV;

3. **Fuzzy Logic Control**: Fuzzy Logic controller design means approximation of nonlinear mapping between system input and output space. This is suitable for nonlinear systems. However determining the membership functions following linguistic rules requires experimental data, hence it is time consuming and not suitable for AUV (Zhu and Azar 2015);

4. **Robust / Optimal Control**: Robust / Optimal Control is model based control system: To design accurate optimal controller the model of the system must be completely known. However due to difficulty in deriving the accurate model of AUV, it is not possible to apply Robust Control strategy. Riedel and Healey proposed the optimal controller that uses auto tuned regression model to predict the wave induced hydrodynamic disturbance (Azar and Serrano 2014);

5. **Sliding mode control (SMC)** (Azar and Zhu 2015) (Vaidyanathan and Azar 2015b): Sliding mode controlled design requires estimation of system uncertainties for switching surface approximation and variable structure control law design. SMC is robust in nature but it has limitations of chattering phenomena. Hence it is not suitable for AUV;

6. **Proportional Integral and Derivative (PID) control** (Azar and Serrano 2015b): It is a base line controller. AUV is divided into different subsystems and are separately controlled using PID (Mousa et.al.2015) type controller. Different tuning techniques are implemented. It is easier to tune PID manually (Bahgaat et.al. 2014). Hence it is used in most of the AUV. But the tuning requires more time and process becomes lengthy.

Nowadays AUVs are used for longer and deeper missions and it can face uncertainties and environmental disturbances, due to which thruster or sensor failure may occur. This may lead to loss of vehicle or even termination of mission. In case of failure, redundant sensors are usually much easier and less expensive, however redundant thrusters (Podder and Sarkar, 2001) are impossible due to their size and cost. In case of failure of thrusters, to maintain performance design of proper fault tolerant controller is essential (Antonelli, 2003).

A fault tolerant control in dynamic system is traditionally Achieved using parallel hardware redundancy. Parallel redundancy protects against sensor or actuator failure in a passive way, as the system remains insensitive to failures. This type of controller is straight forward and is preferred in aircraft systems, nuclear plants, where safety is critical issue. The major problem with hardware redundancy is cost of redundant hardware, weight and additional space required for hardware. For autonomous systems weight and additional space, both the factors are not affordable.

Analytical redundancy (Azar and Vaidyanathan 2015b) is a signal conditioning technique in which state estimation, adaptive filtering and decision making is significant. Analytical redundancy can
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