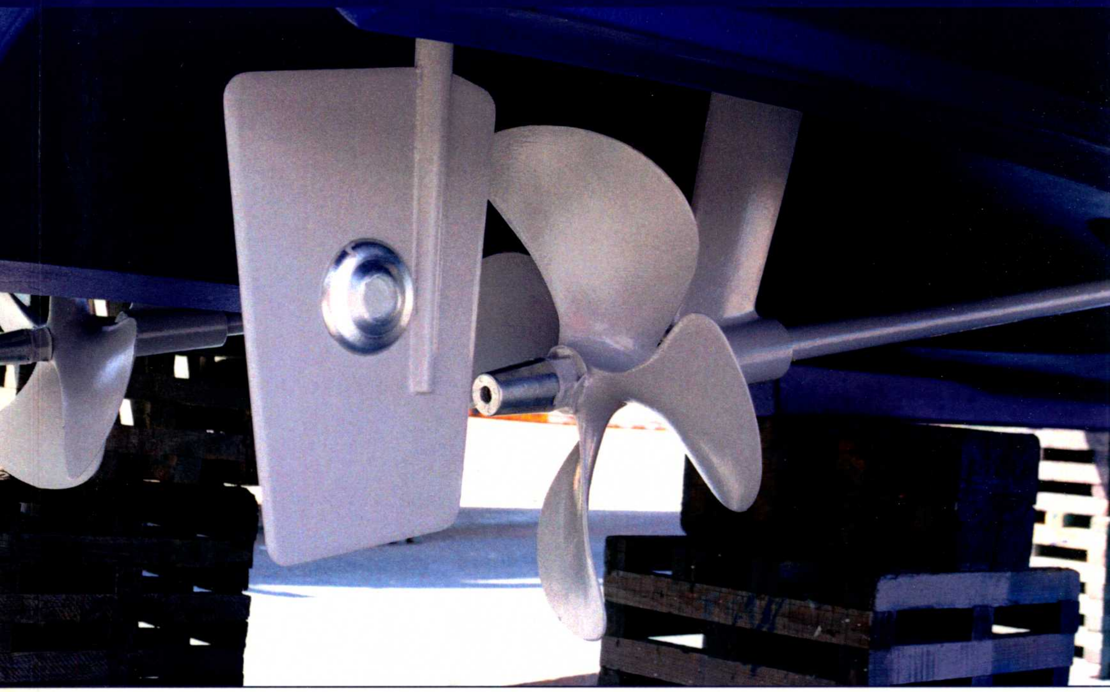

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Modeling, Optimization

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LIST OF ABBREVIATIONS

UUVs	-	Unmanned Underwater Vehicles
RBF - ANN	-	Radial Basis Function Artificial Neural Network
GA	-	Genetic Algorithm
ISE	-	Integral Square Error
AUVs	-	Autonomous Underwater Vehicles
IMU	-	Inertial Measurement Unit
CDM	-	Coefficient Diagram Method
CIS	-	Continuous Input Smoother
PID	-	Proportional Integral Derivative
DFS	-	Discrete Fuzzy Smoother
SIFLC	-	Single Input Fuzzy Logic Controller
CFLC	-	Conventional Fuzzy Logic Controller
LMI	-	Linear Matrix Inequality
ROV	-	Remotely Operated Vehicle
SNAME	-	Society of Naval Architects and Marine Engineers
DSRV	-	Deep Submergence Rescue Vehicle
DOF	-	Degrees Of Freedom
SF	-	Scaling Factor
FLSF	-	Fuzzy Logic Scaling Factor
DoE	-	Design of Experiment
MIMO	-	Multi Input Multi Output

LIST OF SYMBOLS

$\boldsymbol{x}-, \boldsymbol{y}-$ and $\boldsymbol{z}-$	-	Translational Motion
$\boldsymbol{u_0}$	-	Constant Speed of Vehicle
$\overline{\boldsymbol{BG_z}}$	-	Centre of Buoyancy
$\boldsymbol{q}$	-	Pitch Rate
$\boldsymbol{\theta}$	-	Pitch Angle
$\boldsymbol{z}$	-	Depth
$\boldsymbol{I_y}$	-	Moment inertia around the vehicle's y-axes
$\boldsymbol{w}$	-	Heave Speed
$\boldsymbol{W} \quad = \boldsymbol{mg}$	-	Vehicle's Weight
$\boldsymbol{m}$	-	Vehicle's Mass
$\boldsymbol{M}$	-	Mass and Inertia
$\boldsymbol{\delta_s}$	-	Stern Plane Deflection
$\lVert . \rVert$	-	Euclidean Norm
$\boldsymbol{\phi_k}$	-	Basis Function
$\mathrm{c_k} \in \Re^{Rx1}$	-	RBF centers in the input vector space

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1. Introduction

The oceans cover a large portion of the earth's surface. In order to explore this resource poses a serious challenge as they are over 6 km deep and the pressure at such depths is some 600 times that on the surface. The effects of currents, the hazardous environment and other complexities make the undersea operations become difficult. Underwater vehicles are important tools for undersea operations. The autonomous navigation of underwater vehicles is a growing research and application field. A contributing factor is the increasing need of underwater activities such as environmental and industrial monitoring or geological surveying. These applications that require data acquisition at precise locations usually resort to the use of unmanned underwater vehicles.

An Autonomous Underwater Vehicle (AUV) is a robotic device that is governed through a propulsion system, controlled and piloted by an onboard computer, and maneuverable in three dimensions. This level of control, under most environmental conditions, permits the vehicle to follow precise preprogrammed trajectories wherever and whenever required. Sensors on board the AUV sample the ocean as the AUV moves through it, providing the ability to make both spatial and time series measurements. Sensor data collected by an AUV is automatically geospatially and temporally referenced and normally of superior quality. Multiple vehicle surveys increase productivity, can insure adequate temporal and spatial sampling, and provide a means of investigating the coherence of the ocean in time and space. These submarines normally being deployed for various dangerous underwater tasks that include search and rescue operation. The fact that an AUV is normally moving does not prevent it from also serving as a

Lagrangian, or *quasi Eulerian*, platform. This mode of operation may be achieved by programming the vehicle to stop thrusting and float passively at a specific depth or density layer in the sea, or to actively loiter near a desired location. AUV's may also be programmed to swim at a constant pressure or altitude or to vary their depth and or heading as they move through the water, so that undulating sea saw survey patterns covering both vertical and/or horizontal swaths may be formed. AUV's are also well suited to perform long linear transects, sea sawing through the water as they go, or traveling at a constant pressure. They also provide a highly productive means of performing seafloor surveys using acoustic or optical imaging systems.

Control design for underwater vehicles is a difficult task stemming for their inherent nonlinear behavior coupled with the fact they are typically under actuated. The success of a mission depends on the ability of a robust control law. The design and tuning of the controllers required, on most methodologies, a mathematical model of the system to be controlled. It is rapidly increasing as they can operate in deeper and riskier areas where divers cannot reach. Underwater vehicles of varying types have been designed and developed as an alternative for various tasks like inspection, repairs and retrieval that would be impractical with a manned mission *(J. Yuh, 1993)*.

Unmanned underwater vehicles (UUVs) have provided an important tool in pilot free under water operations due to the increased operating range and depth. Additionally operation survival and less risk to human life are also important factors. Typical applications of UUVs today incorporate; survey, search and reconnaissance, surveillance, inspection, recovery, repair and maintenance, construction etc. Particularly in the offshore industry UUVs have become indispensable *(Robert D. Christ and Robert L. Wernli Sr.-2007).*

The first use of such devices was purely military, but typical applications today include: survey and research, surveillance, mine neutralization, inspection of man-made systems, recovery, repair and maintenance, construction, cleaning, and cable burial and repair *(Lea, R.K, 1998)*. Since underwater vehicles development require a high degree of operator skill for effective operation, the development of vehicles having greater hydrodynamic model becomes highly desirable. One of the critical parts of the vehicle is the control system that would affect the vehicles motion while descending into water.

With the technology advancement in power, material, computer communication, and artificial intelligence, AUVs has become more attractive in exploring oceanic resources. Comparing with other means of exploration, underwater vehicle have wider exploring scope and more mobility. In order to design, simulate and develop suitable control systems for underwater vehicles, a dynamic model and relevant parameters first must be identified and obtained, respectively through performing system identification. System identification approaches for modeling AUVs have been undertaken extensively for various types of underwater vehicles *(Ridao, P. 2004).*

1.1 Review of Unmanned Underwater Vehicle (UUV)

Autonomous Underwater Vehicles (AUVs) are unmanned, tether-free, powered by onboard energy sources such as batteries or fuel cells, equipped with various navigation sensors such as Inertial Measurement Unit (IMU), sonar sensors, laser ranger and pressure sensor, and controlled by onboard devices, generally computers with preprogrammed mission.

P. Ridao et al. have explored an identification method of non-linear models for UUVs *(Ridao, P. 2004).* For the off-line identification, the integral method which is based on the minimization of the velocity one step prediction error gave better results compared to the direct method which is based on minimizing the acceleration prediction error. Agus et al. described the Coefficient Diagram Method (CDM) controller that can achieve a satisfactory performance with relatively simple design process *(Budiono, A. 2009).*

There have been various efforts of the conventional and more than modern control schemes to develop the controller for the AUV which include Unmanned Underwater Vehicle. Simple control techniques such as PID control have been more commonly used because of the relative ease of implementation *(Santhakumar, M. 2010).* Two different control schemes which included Continuous Input Smoother (CIS) block, which smoothes the Proportional Integral Derivative (PID) reference input and Discrete Fuzzy Smoother (DFS) have been proposed by Silvia M. Zanoli et al. to reduce potentially dangerous overshoots for depth control of the UUVs (Zanoli, S.M. 2003). In Kashif a Single Input Fuzzy Logic Controller (SIFLC) was designed and shown to give identical response with Conventional Fuzzy

Logic Controller (CFLC) *(Kashif, S. 2010).* The SIFLC requires very minimum tuning effort and its execution time is in the orders of two magnitudes less than CFLC. Another application was described by S.M Smith et al. to control heading, pitch, and depth by three separates Fuzzy Logic Controllers. The fuzzy controllers were tested using a nonlinear simulation model of the Ocean Voyager and show good performances over a range of velocities *(Smith, S.M. 1993).*

A model based on fuzzy modeling and control for AUV was used to describe the nonlinear AUV system in *(Chang, W.J. 2003),* by applying a Linear Matrix Inequality (LMI) method to design a stability condition for non linear FLC Takagi–Sugeno (T-S) type fuzzy model. A multivariable sliding mode autopilot have been designed by Haeley et al. based on state feedback, decoupled modeling of a slow speed for combining, steering and diving response of the AUV *(Healey, J. 1993).* Intelligent techniques included Genetic Algorithm and neural network approaches have been proposed and implemented with success on AUVs in several cases *(Euan, W.M. 2000, Kodogiannis, V.S. 1996)* using neural networks for constructing controllers has the advantage that the dynamics of the controlled system need not be completely known.

In the traditional and modern control schemes, controller design requires an accurate model of the system to be controlled. In this book, the design is based on fuzzy logic which requires only an understanding on the relation between the input and output of the system and thereby can be derived to control the system. The rules for fuzzy logic control of a UUV in this work are based on that derived by Kashif et al. *(Kashif, S. 2010).* The focuses here are on optimizing the controller's scaling factors such that it minimizes the Integral Square Error (ISE) between the set point and the measured depth of an Unmanned Underwater Vehicle (UUV).

Effective control schemes require relevant signals in order to accomplish the desired positions and velocities for the vehicle. A suitable controlling method of underwater vehicles is very challenging due to the nature of underwater dynamics *(Louis Andrew Gonzalez-2004)*. The outgoing book will focus in controlling the vehicles in a vertical motion in order to maintain the desired depth position.

1.2 Underwater Vehicle Model

Underwater vehicles can be classified into two basic categories; Manned Underwater Vehicles and Unmanned Underwater Vehicles (UUVs) *(Chuhran, C.D. 2003).* Unmanned Underwater Vehicles (UUVs) is the term referring to Remotely Operated Underwater Vehicles (ROV) and Autonomous Underwater Vehicles (AUVs). These two types of UUVs contribute to the same control problems. These vehicles have been used for over 100 years and have been known to be an interesting research area for universities and industries *(Chin, C.S. 2006).*

Using the *Society of Naval Architects and Marine Engineers* (SNAME) 1950 *(SNAME. 1950)* notation, the Deep Submergence Rescue Vehicle (DSRV) modeling will be more discussed on that suggested by Fossen, 1994 *(Fossen, T.I. 1994).* For marine vehicles moving in six Degrees Of Freedom (DOF), six independent coordinates are necessary to determine the position and orientation of a rigid body in three dimensions. The first three coordinates and their time derivatives correspond to the position and translational motion along the $x-, y-$ and $z-$ axes respectively, while the last three coordinates and their time derivatives are used to describe orientation and rotational motions. The six motion components are conveniently defined as surge, sway, heave, roll, pitch and yaw *(Fossen, T.I. 1994)*.

The general motion of an underwater vehicle in six DOF is modeled by using the notation of Fossen *(Fossen, T.I. 1994)*. The velocity of the vehicle is described as a vector v:

$$v = [u \ v \ w \ p \ q \ r]^T \tag{1.1}$$

Where u, v, w are translational along, and p, q, r are rotations around the three axes [X –axis, Y –axis, Z –axis] respectively. Using Euler angles the position and orientation of the vehicle may be described as a vector η relative to the global reference frame:

$$\eta = [x \ y \ z \ \phi \ \theta \ \psi]^T \tag{1.2}$$

And the nonlinear vehicle dynamics can be expressed in a compact form as:

$$M\dot{v} + C(v)v + D(v)v + g(\eta) = B(v)u \tag{1.3}$$