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A Comparative Study on PID and Fuzzy Logic Controller for Depth Control of an Autonomous Underwater Vehicle

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Abstract: This paper deals with the dynamic model and analysis of Autonomous underwater vehicle for depth control. Out of many underwater vehicles, AUVs are chosen for most of the purposes. It offers better performance and are risk free since the tether cables are absent and is controlled using onboard computers.An AUV is a complex highly nonlinear system and are highly coupled, due to hydrodynamic forces. So impractical for controller implantation. A reduced order subsystem with dive plane dynamics is being considered and controller is implemented. Here a comparative study of two controllers PID and FLC are being studied.

Keywords: Autonomous underwater vehicles (AUV), depth control, PID, FLC, MATLAB

I. INTRODUCTION

The Ocean covers about two-third of the earth and has a great effect on survival and development. The abundant resources in the ocean are very important for the future of human. One of the safest way to explore the underwater is using small unmanned vehicles to carryout various missions and measurements, among others, can be done without risking people's life. An unmanned underwater vehicles may be divided into two categories, remotely operated underwater vehicles (ROVs), which are controlled by a remote human operator, and autonomous underwater vehicles (AUVs), which operate independently of direct human input. The latter category would constitute a kind of robot. An AUV is a submarine like robotic device powered by a propulsion system and controlled by an onboard computer. They are manoeuvrable in 3 dimension and can be programmed to flat passively or to actively near desired location or to swim at different depth. From the practical point of view it is important to design and investigate AUVs with six degree of freedom (6-DOF) [1].

The automatic control of underwater vehicle represents a difficult design problem due to the nature of the dynamics of the system to be controlled. Controllers based on simple models of vehicle mass and drag usually yield disappointing performance. Manoeuvring in the dive plane, depth changing and depth keeping are essential performance requirements for any AUVs. Vehicles response depends heavily on its particular design and configuration, operating conditions and environmental forces. Any automatic controller design must satisfy two conflicting requirements: First ,it should be sophisticated enough to perform its mission in the realm of complicated and ever-changing vehicle or environment interactions; Secondly, it has to be simple enough so that on-line implementation is possible by the onboard vehicle computer at a sufficiently high sample rate.

The AUV system is highly nonlinear complex and coupled so a reduced order subsystem with dive plane dynamics are being used for the depth control. PID controls are widely used as a basic control technology in the industrial control system today. However, tuning of PID control systems is not always easy, because of their simple control structures for wide classes of industrial control processes. The tuning method is Zeigler-Nicolas. The fundamental difficulty with PID control is that it is a feedback control system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise. The field of Fuzzy control has been making rapid progress in recent years. Fuzzy logic control has been widely exploited for nonlinear, high order & time delay system. A performance comparison between Ziegler Nichols tuned PID controller, fine-tuned PID controller and the proposed fuzzy logic controller is presented

II. AUV DYNAMICS

A.SYSTEM DESCRIPTION

The navigation system provides information related to the target and the vehicle itself using onboard sensor such as inertial navigation system, compass, pressure transducers

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etc. This information is fed to the guidance system which by utilizing some guidance law generates reference heading.

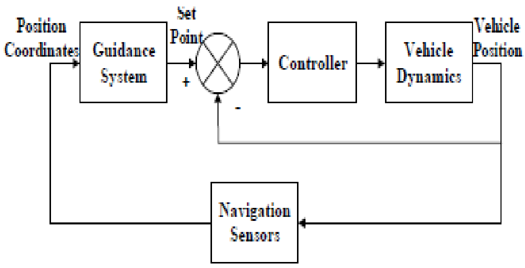

Fig.1.Navigation, Guidance and Control of vehicle

The control system is then responsible for keeping the vehicle on course as specified by the guidance system. A simple block diagram of an NGC system is shown in fig.1 [2].

The vehicle used in this study is called Hammerhead has a torpedo shaped body about three and a half meter long and approximately one-third of a meter in diameter. The control surfaces are the two rear rudders for steering and two front hydroplanes for diving. The rudder and hydroplanes are controlled by two separate on-board stepper motors and the signal to the stepper motors is sent through an umbilical attached to the rear end of the vehicle. The on-board sensors include inertial navigation system (INS), TCM2 compass, pressure sensor, global positioning system (GPS), and a shaft speed encoder. The data logged using the above mentioned sensors is summarised below:

INS — heading, pitch, roll, linear and angular velocities

TCM2 Compass — heading, pitch and roll

Pressure sensor — depth of the vehicle

GPS — co-ordinates of the vehicle on the Surface, forward speed

Shaft speed Encoder — vehicle speed

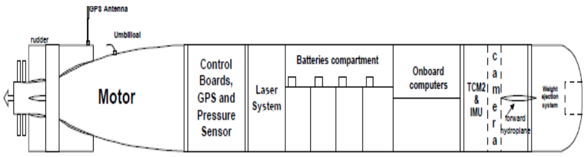

Fig.2 sectional view of the hammerhead AUV

Fig. 2 depicts the sectional view of the Hammerhead AUV[3] showing the hardware setup. The other end of the umbilical is attached to a control computer used to send and receive various signals. The rudder/ heading angle data pair is used to generate the yaw model while the hydroplane angle/depth is used to develop the depth channel model. Cross coupling effects between different channels such as yaw and roll of the vehicles.

B System modelling

Mathematical modelling of underwater vehicles is a widely researched area and unclassified information is available through the Internet and from other source of written publications. The generalized six-degree of freedom (6 – DOF) equations of motion (EOM) for an underwater vehicle will be developed. The underlying assumptions are that: The vehicle behaves as a rigid body; the earth's rotation is negligible as far as acceleration components of the centre of mass are concerned and the hydrodynamic coefficients or parameters are constant. The assumptions mentioned above eliminate the consideration of forces acting between individual elements of mass and eliminate the forces due to the Earth's motion. The primary forces that act on the vehicle are of inertial, gravitational, hydrostatic and hydrodynamic origins. These primary forces are combined to build the hydrodynamic behaviour of the body.

The standard AUV vehicle notation of 6-DOF are tabulated in table 1.

Independent positions and angles are required and it is very important to describe clearly the reference frames in order to understand the kinematics equations of motion. There are two orthogonal reference frames; the first one is the earth fixed frame XYZ which is defined with respect to surface of the earth as illustrated in Figure 3.

Table 1: standard notation

DOF	Motion	Forces and Moments	Linear and Angular velocities	Positions and Euler Angles
1	Surge	X	u	x
2	Sway	Y	v	y
3	Heave	Z	w	z
4	Roll	K	p	ϕ
5	Pitch	M	q	θ
6	Yaw	N	r	ψ

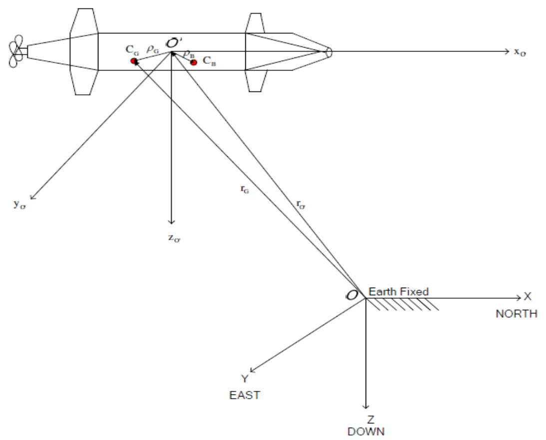

Fig. 3 body fixed and earth fixed reference frame[4]

A vehicle's position in this earth fixed frame will have the vector components:

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$$r_{o'} = [X\vec{I} + Y\vec{J} + Z\vec{K}] \quad (1)$$

When transforming from one Cartesian coordinate system to another, three successive rotations are performed. According to Euler's rotation theorem, an arbitrary rotation may be described by only three parameters. This means that to give an object a specific orientation it may be subjected to a sequence of three rotations described by the Euler angles. As a result, rotation matrix can be decomposed as a product of three elementary rotations. The earth fixed coordinate frame Euler angle orientation definitions of roll (φ), pitch (θ) and yaw (ψ) implicitly require that these rotations be performed in order. For the "roll, pitch, yaw" (XYZ) convention, a forward transformation is performed beginning with a vector quantity originally referenced in the body fixed reference frame. The rotation and angular velocity conventions of body fixed coordinate system are given in and Figure 4.

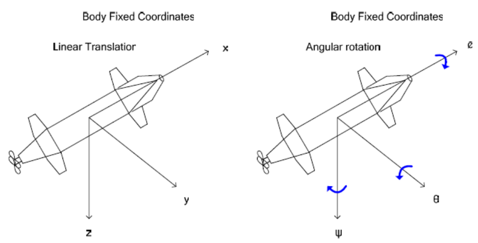

Fig 4. Body fixed coordinate system linear and angular velocity convention[4]

As a result the transformation will be

$$r_{ijk} = [R]^{-1} r_{ijk} \quad (2)$$

It can be said that any position vector in a rotated reference frame may be expressed in terms of the coordinates of original reference frame given by the operation in (2). Kinematic and dynamic equation of motion makes the mathematical model of 6 DOF of AUV.

Kinematic equations are:
Matrix notation from body to earth transformation:

$$[V]_{earth} = \begin{bmatrix} [R] & 0 \\ 0 & [T] \end{bmatrix} [V]_{body} \quad (3)$$

Matrix notation from earth to body transformation:

$$[V]_{body} = \begin{bmatrix} [R]^{T} & 0 \\ 0 & [T]^{-1} \end{bmatrix} [V]_{earth} \quad (4)$$

2. Dynamic equation of motion

The general translational equation of motion

$$\Sigma F_{translational} = m(\dot{v}_0 + \omega\rho_G + \dot{\omega}\,\omega\rho_G + \omega\rho_G) \quad (5)$$

The rotational equation of motions

$$\Sigma M_{rotational} = I_0\dot{\omega} + \omega(I_0\omega) + m(\rho_G \dot{v}_0 + \rho_G) \quad (6)$$

Equation (3) to (6) formulate the 6 DOF euation of an AUV.

$$X = m\begin{bmatrix} \dot{u} - vr + w\dot{q} - x_G(q^2 + r^2) + y_G(pq - \dot{r}) \\ + z_G(pr + \dot{q}) \end{bmatrix} \quad (7)$$

$$Y = m[\dot{v} + ur - wp + x_G(pq + \dot{r}) - y_G(p^2 + r^2) + z_G(pr - \dot{q})] \quad (8)$$

$$Z = m[\dot{w} - uq + vp + x_G(pr - \dot{q}) + y_G(qr + \dot{p}) - z_G(p^2 + q^2)] \quad (9)$$

$$K = I_x\dot{p} + (I_z + I_y)qr + I_{xy}(pr - \dot{q}) - I_{yz}(q^2 - r^2) - I_{xz}(pq + \dot{r}) + m[y_G(\dot{w} - uq + vp) - z_G(\dot{v} + ur - wp)] \quad (10)$$

$$M = I_y\dot{q} + (I_x - I_z)pr - I_{xy}(qr + \dot{p}) + I_{yz}(pq - \dot{r}) + I_{xz}(p^2 - r^2) - m[x_G(\dot{w} - uq + vp) - z_G(\dot{u} - vr + wq)] \quad (11)$$

$$N = I_z\dot{r} + (I_y - I_x)pq - I_{xy}(p^2 - q^2) - I_{yz}(pr + \dot{q}) + I_{xy}(qr - \dot{p}) + m[x_G(\dot{v} + ur - wp) - y_G(\dot{u} - vr + wq)] \quad (12)$$

For depth control of AUV, The vehicle is assumed to be in vertical plane. For a vertical motion of vehicle the following assumptions are forward speed is constant, Sway and yaw can be neglected, in steady state θ_0 is a constant and (q_0=ϕ_0=0).
From all the equations and standard notation and considering the specification of the vehicle considered the equation of the vehicle, drooping out unwanted terms and considering the heave velocity is being very small and is neglected the state space equation of the system will be

$$\begin{bmatrix} I_y - M_{\dot{q}} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{q} \\ \dot{z} \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} -M_q & 0 & M_\theta\theta \\ 0 & 0 & u1 \\ -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} q \\ z \\ \theta \end{bmatrix} = \begin{bmatrix} M_{fs} \\ 0 \\ 0 \end{bmatrix} \quad (13)$$

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By substituting the standard values and the state space matrix will be

$$A = \begin{bmatrix} -1.09 & -0.52 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 0 & 3.18 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \end{bmatrix}$$

And the transfer function will be

$$G_{\theta}(s) = \frac{-3.18}{s^2 + 1.09 s + 0.52} \quad (14)$$

III. CONTROLLER DESIGN

The relatively complex AUV can be broken into separate layer to simplify the controller design. The controlling scheme of an AUV is divided into three

1 heading control
2. dive plane control
3. speed control

Here, only dive plane dynamics are considered and is used for depth control using PID and FLC and a comparative study has been carried out.

A. PID controller

A proportional–integral–derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a desired set point and a measured process variable. Conventional Proportional-Integral-Derivative (PID) controllers exhibit moderately good performance once the PID gains are properly tuned. However, when the dynamic characteristics of the system are time dependent or the operating conditions of the system vary, it is necessary to retune the gains to obtain desired performance. The PID is tuned for its gain value using zeigler-nicolas technique.

Frequency response method suggested by Ziegler-Nichols is applied for design of PID controller [4], [6], [8]. By setting Ti = ∞& Td = 0 and using the proportional control action (kp) only, the value of gain is increased from 0 to a critical value ku at which the output first exhibits oscillations. Tu is the corresponding period of oscillation.

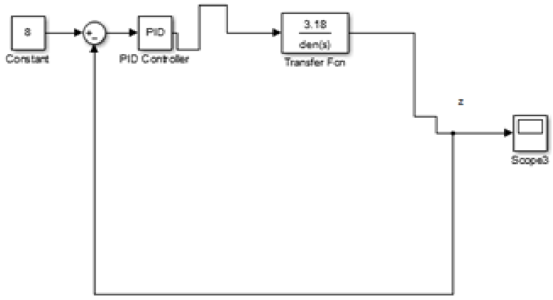

Fig 5: PID controller on the system

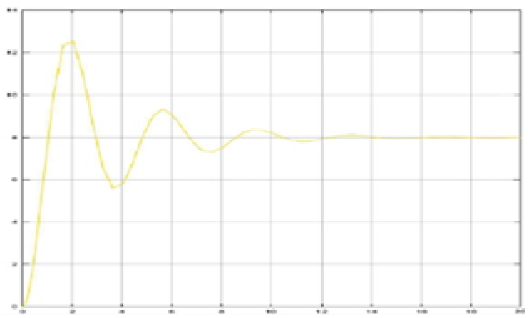

Fig 6: step response of PID

From the fig.6, the unit step response of the closed loop system with kp = 0.906, Ti =2.5 and Td = 0.11, Mp = 37.5 %, ts = 11.33 sec. Both Mp and ts are too large.

B. Fuzzy Logic Controller

To reduce the overshoot of the depth control of the system another controller fuzzy logic controller can be used instead of PID. It is also a feedback controller which generate the gain Values depending on some rule base. A fuzzy logic control algorithm provides the autonomous decision making strategy. Attributes of fuzzy logic that made it appealing for this application are the ability to model nonlinear functions, robustness in the face of imprecise input and ease of code generation. A FLC based on some rule base which has been formulated using the parameter of the system.the input considered here are the error and derivative of error which is processed using certain rule base based on mamdani rules and are used for getting the output of fuzzy which is then connected feedback to the system

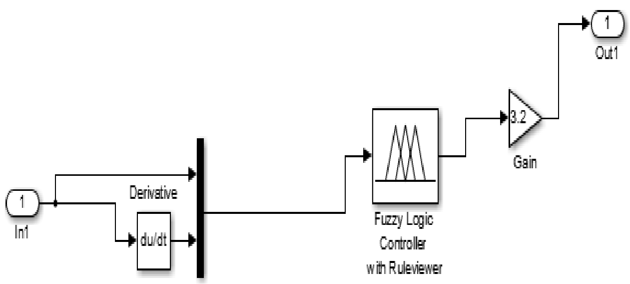

Fig 7: fuzzy logic controller

The fig 7 is made as a subsystem and is fed to the system dynamic to generate the desired output

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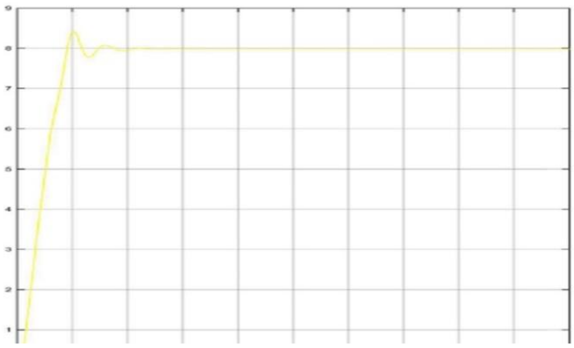

Fig.8 FLC depth control plot

From the figure 8 it can be observed that the overshoot, rise time, delay time comparatively increased bt giving a better performance of the system.

A comparison of both the controllers has been tabulated and is shown in the table 2.

Table 2: comparison of PID and FLC

Controller	%overshoot	Rise time in sec	Settling time in sec
PID	37.5	2	12
FUZZY	12.5	4	9.5

IV. CONCLUSION AND FUTURE SCOPE

The paper presented an overview of PID controller, design of PID controller using Z-N technique and design of fuzzy logic controller for higher order system. Simulation results using MATLAB / SIMULINK are discussed for Ziegler Nichols tuned PID control and fuzzy logic control. Ziegler Nichols technique gives high overshoot and settling time with zero steady state error. Initial controller parameters obtained using Z-N formula need to be adjusted repeatedly through computer simulation to get satisfactory performance. The Fuzzy Logic controller gives low overshoot, zero steady state error and smaller settling timethan obtained usingZiegler Nichols tuned PID controller. The simulation results confirms that the proposedFuzzy logic controller with simple design approach and rule base can provide better performance comparing with theZiegler Nichols tuned PID controller. Both the controllers FLC and PID has their own disadvantages and this can be overcome by using fuzzy tuned PID controller instead of PID and FLC.

REFERENCES

[1] Mohammed Amjad,Kashif Ishaque,Saman Abdullah "An alternative approach to design a Fuzzy logic controller for an autonomous underwater vehicle"in proceedings of IEEE conference on cybernetics and intelligent system, January 2010
[2] Prezemyslaw Herman "Decoupled PD set-point controller for underwater vehicles" ocean engineering ELSEVIER FEBRUARY 2009
[3] Amrul Faruq, Shahrum Shah Bin Abdullah, M. Fauzi Nor Shah "Optimization of an Intelligent Controller for an Unmanned Underwater Vehicle" TELKOMNIKA, Vol.9, No.2, August 2011, pp. 245-256 ISSN: 1693-6930
[4] S. D. Joshi, D. B. Talange "PERFORMANCE ANALYSIS: PID AND LQR CONTROLLER FOR REMUS AUTONOMOUS UNDERWATER VEHICLE (AUV) MODEL" IEEE Volume 3, Issue 2, July – September (2012), pp. 320-327
[5] Nanang Syahroni, Young Bong Seo, Jae Weon Choi "Depth Control of Autonomous Underwater Vehicle Based on Open Control Platform" Proceedings of the 17th World Congress The International Federation of Automatic Control Seoul, Korea, July 6-11, 2008
[6] Yang Shi , Weiqi Qian "Adaptive Depth Control for Autonomous Underwater Vehicles Based on Feedforward Neural Networks", International Journal of Computer Science & Applications 2007 Technomathematics Research Foundation Vol. 4 Issue 3, pp 107-118
[7] [Roberto Cristi,Fotis A.Papoulias,Anthony J.Healey, "Adaptive Sliding Mode Control of Autonomous Underwater Vehicles in the Dive Plane ",IEEE journel of OCEANIC ENGINEERING, vol. 15, no. 3, july 1990
[8] Sujay D. Kadam, Kunal N. Tiwari," A simplified approach to tune PD controller for the depth control of an autonomous underwater vehicle", Communication, Computation and Networking Technologies ISBN:978-93-82880-09-7
[9] Neal M patel, Shawn E Gano, John E Renaud, Jay D. Martin, Michael A. Yukish,"Simulatiom model of an Autonomous under water vehicle for design optimization",45th AIAA/ASME/ASCE/ASC structures, structural dynamics &materials conference 19-22 April 2004,palm springs ,California
[10] W.nazeam, R Suttan, J Chudley, "System identification, modelling and control of an autonomous underwater vehicle", In: Proceedings of the IFAC conference on control applications in marine systems, 2003
[11] H.Ying, Fuzzy Control & Modeling:Analytical foundations and applications. New York, IEEE Press, 2000.