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FUZZY LOGIC APPROACH OF DEPTH CONTROL OF SUBMARINE

Ajay Chhillar*[1] & Sandeep Khantwal[2]
*[1]Assistant Professor EE Department SET, Ganga Technical Campus Soldha, Haryana
[2]Assistant Professor ECE department Tula Institute of Engineering and Management, Dehradun

ABSTRACT

Ocean attracts the curiosity of the researchers due to its vital role on environmental problems, resources, different scientific works and military works that requires critical controlling operations of the submarine for achieving the required objectives. This paper describes the comparison of many controllers for controlling the depth of the submarine which employing the stern plane actuation method for actuating the stern plane motor to obtain the desired depth. The controllers like PI Controller, Controller based on Fuzzy logic (FLC) and Controllers based on type 2 Fuzzy logic (T2FLC) have been implemented for controlling the depth operation of the submarine and the experiment has been taken out which is based on quantitative performance analysis of the controllers by using different performance conditions in MATLAB Simulink© environment. The results indicates in parameters of Stern plane angle, change of rate of Depth and original depth, shows that the T2FLC gives improved performance compared to other controllers

Keywords: *Submarine; Depth control; Stern Plane; Fuzzy Logic Control; Type-2 Fuzzy Logic Control.*

I. INTRODUCTION

A Submarine is a watercraft ability of independent operation underwater derived from its origin from Bathyscaphe‖ which is produced from the Diving Bell and is commonly known to remote based Vehicles (ROVs) and Robots as well as smaller vessels like the Midget Submarine and Wet Sub. Modern submarines are normally based with submerged operation keep in mind and an inner pressure hull and an outer streamlined hull. It is a vital aspect in the operational affectivity of the submarine as the submarine in its operational life mainly performs underwater with its depth changing as per the requirement of the crew handling it. In order to make submarines whole tasks such as navigation at set depth rise quickly and quiet underwater the automatic control of such type vehicles presents several hurdles due to non-linearity present in dynamics the presence of unnecessary external interrupt and the high uncertain point in the model. The operation becomes more complex in the sequence of system fails like a stern plane jam. When the submarine is analyzed at periscopic depth in littoral water, depth control and pitch control is necessary because the water is like shallow and the effect of wave is very important. Systems which are acting under the sea can reach reference depth with oscillations in a short period. Oscillations the reference depth putsextra pressure on submarine.

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Figure 1.1 USS Sturgeon (Sturgeon Class Submarine)

In literature survey there are many observations about the depth control of the Submarine and design of controller. During II world war the U-boat force of Germany laided waste to the Allied Naval Force and previous depth-control autopilots were observed in German submarines at the end of the II World War. It is considered that French submarines presented improved aspects of the German designs methods after the war. These previous versions that include controllers typically considered as single-input single-output (SISO) Proportional Derivative designs bow and stern hydroplanes are geared together. The control surfaces for a submarine containing a rudder a set each of stem, sail and bow hydroplanes. A Lab VIEW depend submarine depth control simulator having PID and FLC was suggested by M. Ekici*et al.*in order to provide the submarine at a certain point below the sea surface, a FLC as a prime control unit was implemented and analyzed with Lab VIEW Control Design and Simulation Toolkit. Comparison between FLC and PID controlled system was given and results indicated that system gives better settling time and no overshoots with FLC. A Submarine multivariable Depth control System was produced by E. Liceaga-Castro and G.M. Van der Molen by using classical techniques providing the control system method with its robustness parameters expressed in terms of actual gain and phase margins. Lionel Lapierre gives the Robust diving control of the Submarine in which a diving control design depend on Lyapunov theory and back stepping method was verified. With a use of adaptive and switching techniques the control system was able to consider the necessary robustness in diving control.

This paper is described as follows: describes the model of the submarine dynamics for Depth control by using Stern plane actuation. Different controllers which are usedfor Depth control are provided. Results and conclusions are given followed by References

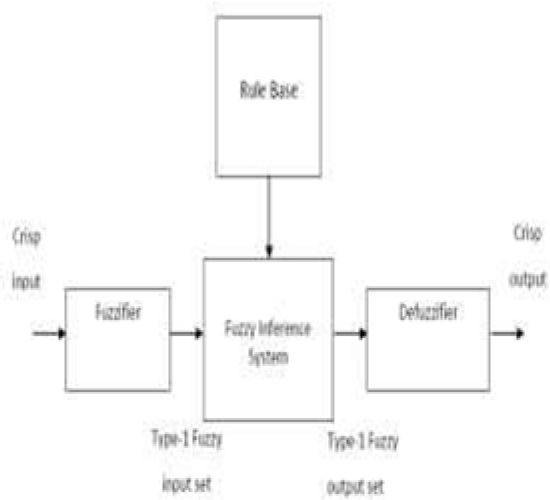
II. DESIGN OF CONTROLLERS

To control a techniques variable some control methods are essential. A control method contains of two aspects:
a) Control configuration
b) Controller.

Control process can be further segmented as: feedback control analysis, feed forward control analysis, cascade control analysis

III. FUZZY LOGIC CONTROLLER

Fuzzy control is a key method for a variety of challenge control applications since it gives a good method for developing nonlinear controllers with the the use of heuristic information. Such heuristic information may occur from an operator who has acted as a human-in-the-loop‖ controller for a process.In the fuzzy control design techniques we ask the operator to write down a set of instructions on how to control the process. In certain cases the heuristic information may arise from a control engineer who has performed good mathematical models, analysis, and production of control algorithms for an extreme process. A Basic functional scheme of a FLC is given in Figure 3.2.



Rule Base

The maximized rule base containing of 49 rules is shown in Table 3.1.

Table 3.1: Rule base table for FLC

e\de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PB
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

Type-2 FLS also used same set of maximize rule base consisting of 49 rules are given in Table 3.2.

Table 3.2: Rule base table for T2FLC

e\de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PB
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

IV. DISCUSSION OF RESULTS

In the current work, Submarine dynamics for Depth control movement simulated in MATLAB Simulink conditions. For this objective various used Controllers i.e. PI Controller, FLC and T2FLC is implemented. A comparison among all the controllers used was introduced and is given in Table 4.2. Stern plane angle (change to 0˚), Rate of change of Depth (change to 0) and Actual Depth (change to commanded depth or SP) and are given in figures 4.1, 4.2 and 4.3 respectively. Figure 4.1 gives the plot indicating Stern Plane Angles gained by different controllers described in this paper; the angle of the submarine at starting rises and reach to a peak value and then slowly changes to 0˚ in steps shows that the stern plane of the submarine is g settled horizontally and this comes when the submarine gain the commanded depth or the set point. Stern Plane Angle is considered as the output of the controller present in the loop for the Depth Control Process. The time at which the controller gained the change to 0˚, i.e., $t_{\theta,}$ is recorded.

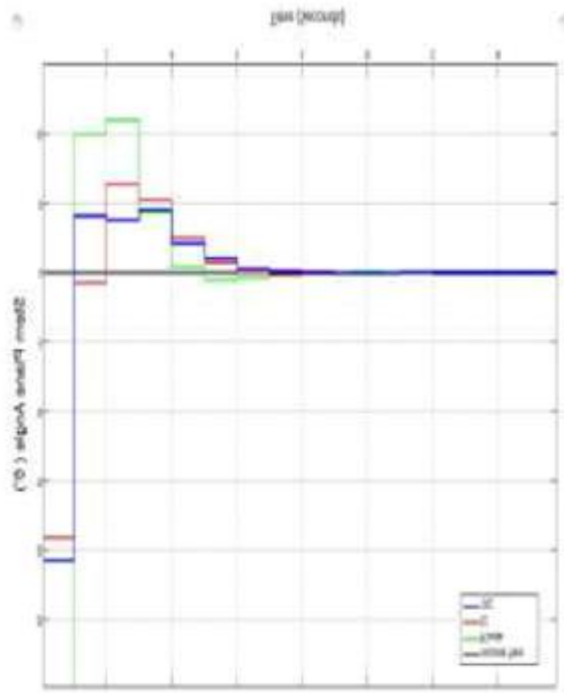


Figure 4.1 Stern Plane angle achieved by various controllers

Table 4.1 Peak Stern Plane Angle achieved by various controllers

Type of Controller	Peak Stern Angle (θ˚)
PI Controller	30˚
FLC	19˚
T2FLC	21˚

Figure 4.2 indicates the Rate of change of the Depth which rises at starting but after some time it decreases and change to 0 as the submarine gains the commanded depth. The time consumed by the controller for change of Rate of Change of Depth, t_v is produced and the time at which it changes with 0 for different controllers provided in this paper are shown in tabulated form in Table 4.3.

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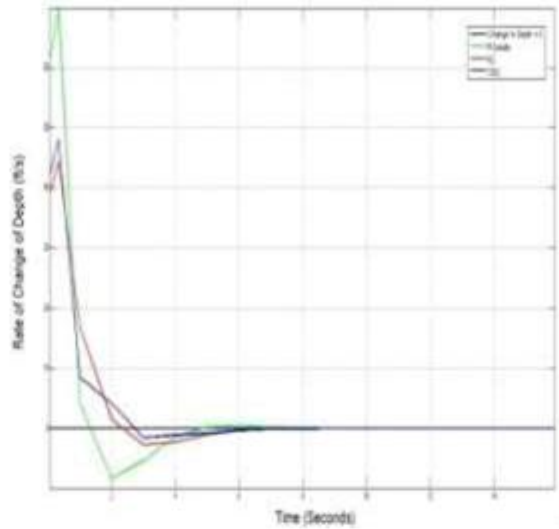

Figure 4.2 Rate of Change of Depth achieved by various controllers

Figure 4.3 gives the actual depth observation of the controller. The Set-point (Commanded depth) is considered as 50 feet (Periscopic Depth) and it is considered here that the response rises in the start which occurs due to the baseline constraints of the Submarine Dynamics named as$K_{\theta'}$ and K_{θ} and then slowly it changes using Commanded depth and the time it changes with the set point, t_s is reserved along with other constraints like Rise time, t_r; Peak, p; Overshoot, M_p and Steady state error, e_{ss} in Table 4.2.

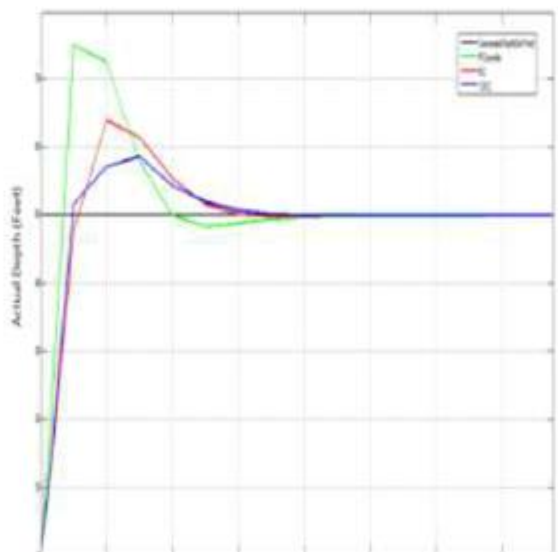

Figure 4.3 Actual Depth achieved by Various controllers

Table 4.2 Quantitative Analysis of Controllers in terms of Performance Criteria

Performance Criteria	Type of Controller		
	PI Controller	FLC	T2FLC
Settling Time, t_s (s)	6.3	5.5	5.6
Rise Time, t_r (s)	0.6	1.1	0.9
Peak, p	75	63.6	58.9
Overshoot, M_p	50%	27.2%	17.8%
Steady State Error, e_{ss}	0.02	-	-
ISE	3696	2905	2680
IAE	110	90	76
ITAE	189	158	115

The results indicated that the T2FLC gives good performance compared to other controllers when analyzed in forms of various performance parameters and Submarine constraints and following results has been considered from Tables 4.2 and 4.3:

In terms of Performance parameters, it is analyzed that the Settling time t_s is greater for PI controller, smaller for FLC. Rise time is greater in FLC whereas it is smaller in PI controller; T2FLC‘s rise time is greater compared to PI controller. Peak and Peak overshoot is greater in PI controller, smaller in T2FLC and FLC is giving performance in between PI Controller and T2FLC‘s. There is a too small Steady state error observed in PI controller whereas it is zero for FLC and T2FLC. In parameters of ISE, PI controller has greaterISE; T2FLC gives smaller ISE and it is in between PI controller and T2FLC for FLC. IAE is greater for PI Controller, smaller for T2FLC and it is in between PI controller and T2FLC for FLC.

Table 4.3 Comparison of Results in terms of Submarine Parameters

Type of Controller	Submarine Parameter		
	Convergence of Stern Plane Angle (θ) , t_θ (s)	Convergence of Rate of Change of Depth (v), t_v (s)	Actual Depth (c), t_s (s)
PI Controller	12	14.6	6.32
FLC	13	12.8	5.54
T2FLC	9	9	5.69

In terms of Submarine constraints, Stern plane Angle present in in all the controllers rises and then slowly changes to 0˚ (longitudinal axis of submarine) in steps showing that the stern plane of the submarine is settled horizontally and this produced when the submarine gains the commanded depth. This convergence time, t_θ is larger for PI controller and least for T2FLC. Rate of change of the Depth is decreases and changes to 0 as the submarine gains the commanded depth and this convergence time, t_v is large in PI controller and small in T2FLC. In the real depth indication of all the controllers it is to be pointed that the observation shoots in the start which is due to of the constant constraints of the Submarine Dynamics named as$K_{\theta'}$ and K_θ and the convergence to set point or commanded depth is measured in terms of Settling time, t_s which is larger for PI Controller and smaller for FLC, the comparison between settling time of other controllers is too small hence we can observed that T2FLC gives the best performance compared to other the controllers. FLC's performance is good when compared to other PI controller.

V. CONCLUSION

This paper describes a depth control of a submarine.. A deep study depend on manyControllers i.e PI Controller, Type 1 Fuzzy logic depend controller and Type 2 Fuzzy logic depend controllers done in MATLAB Simulink atmosphere.. The causes of environmental disturbances is leaving in this paperand all simulations performed are without any analysis of these disturbances on the Submarine. MATLABSimulink is considered asa flexible and powerful program. With the help of recorded results two differences have been implemented.. In the first comparison presented in Table 4.2 performance of these controllers is analyzed interms of common performance criteria and in Table 4.3 performances of these controllers has been observed interms of Submarine Parameters and an implication can be drawn from both these comparisons that T2FLC isgiving better control then the other controllers.

Following conclusions can be drawn from the Results:

a) T2FLC gives good performance compared to the other controllers in terms of various performance parameters and Submarine constraints predicted with time response parameters..
b) Stern plane Angle present in all the controllers rises and then slowly changes to 0˚ in steps showing that the stern plane of the submarine is settled horizontally and this comes as the submarine gains the commanded depth.
c) Decrease in rate of change of the Depth and changes to 0 as the submarine gains the commanded depth.
d) In the reall depth obsevevation of all the controllers it is to be indicated that the response shoots in the start due to the inherent constraints of the Submarine Dynamics namely $K_{\theta'}$ and K_θ.

VI. FUTURE SCOPE

Controllers that are used in this paper can be realized using many Optimization methods like Ant-colony optimization, Genetic Algorithm, Particle Swarm Optimization, Biogeography depend optimization etc. In this paper all the calculations are done without taking into consideration the effect of Hydrodynamic and Hydrostatic Forces observed in the sea environment acting on a body that is submerged and/or operating in the sea, such as Hydrodynamic Force, Radiation Force, Excitation Force And Drag Force. Also, in this paper all the observation are used without taking the effect of different disturbances observed in the sea environment on a body submerged and/or operating in the sea. Some techniques to produce the disturbances suffered by the waves which are listed below:

a) The Bretschneider Spectrum
b) The Pierson and Moskowitz Spectrum
c) The JONSWAP Spectrum

REFERENCES

1. *D.K. Brown, ―The technology of Submarine design – a historical survey 1905-1945‖, Interdisciplinary Science Reviews, Taylor and Francis, 1990, 15(3), 235-251.*

2. R.F. Burges, —Ships beneath the Sea: A History of Submarines and Submersibles‖, McGraw-Hill, New York, 1975.
3. A.G. Bovis, —Optimal control, safety and silence- Trends in design of maneuvering systems for French submarines‖, Proceedings of
4. Warship 88 International Symposium on Conventional Naval Submarines, London, UK, 1988.
5. W. Braugnier, —Automatic depth control of submarine split plane model‖, Naval Ship Systems Command Technical News 15, part
6. 7, July, 1966.
7. H. Klee and R. Allen, —Simulation of Dynamic Systems with MATLAB and Simulink‖, 2nd Edition, Boca Raton, Florida, USA, CRC press, Taylor and Francis Group, 2011, 85-89.
8. M. J. Grimble, G.M. Van Der Molen and E. Liceaga-Castro, —Submarine Depth and Pitch Control‖, 2nd IEEE Conference on Control Applications, September 1993, Vancouver, Canada, 953-958.
9. M. Ekici, H. Kahveci and A.S. Akpinar, —A LabVIEW based submarine depth control simulator with PID and Fuzzy controller",
10. Innovations in Intelligent systems and applications (INISTA), 2013, Albena, 1– 6.
11. R. Xu and C. Kwan, —Submarine Pitch and Depth control using FCMAC neural Networks‖, Proceedings of the American Control Conference, July 1998, Philadelphia, Pennsylvania, USA, 379-383.
12. E. Liceaga-Castro and G.M. Van der Molen, —Submarine H∞ depth control under wave disturbances", IEEE Transactions on Control Systems Technology, Vol. 3 , No. 3, 1995, 338 – 346.
13. E. Liceaga-Castro and G.M. Van Der Molen, —A submarine Depth Control system design‖, International Journal of Control, Taylor and Francis, 1995, 61:2, 279-308.
14. Y. Hao, D. Shen and Z. Xiong, —Design of Submarine near Surface Depth Controller‖, Proceedings of the 5th world congress on intelligent control and automation, June 2004, Hangzhou, China, 4530-4533.
15. L. Lapierre, —Robust Diving control of an AUV‖, Ocean Engineering 36, Elsevier Ltd., 2009, 92-104.
16. G.M. Van der Molen and M.J. Grimble, —H∞ submarine depth and pitch control‖, IEEE Conference on Decision and Control, 1993,Dec 1993, vol .3, 2511 – 2516.
17. S.K. Lee, K.H. Sohn, S.W. Byun and J.Y. Kim, —Modeling and controller design of Manta-type unmanned underwater test vehicle‖, Journal of Mechanical science and technology 23, Springer-verlag, 2009, 987-990.
18. E. Liceaga-Castro, J. Liceaga-Castro, C.E. Ugalde-Loo and E.M. Navarro-Lopez, —Efficient multivariable Submarine depth control system design‖, Ocean Engineering, 35, 2008, 1747-1758.
19. K.H. Low, —Locomotion and Depth Control of Robotic fish with modular undulating Fins‖,