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Fuzzy Controller Design for Dynamic Positioning of Unmanned Surface Vehicle

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Abstract:- This In this paper have a purposes to examine the performance of fuzzy logic controller used to control a dynamic position system of USV. The dynamic position system is controlled system which uses the thruster vessels such as propeller, bow thrusters and rudder. The thuster can be maintain the position and heading of the USV in automatically. By numerical simulation, the study to solve the problem motion and postion of dynamic positioning control. The environmental loads is wave disturbance with gaussian random noise as external forces to effect a changes position and angle heading of vessel. The fuzzy logic controller used in this paper is mamdani logic type to control the scheme of dynamic position system. The results show the system can be maintain the position and haeding of ship. Even though the surge position of ship have a long time response to maintain the position.

Keywords:- *Fuzzy Controller, Dynamic Position, USV.*

I. INTRODUCTION

Today, many growing technology especially in the field of robotics technology. Autonomous is a mechanical device that can perform physical tasks, using either human supervision and control, or programmed using a computer. Autonomous vessel has several advantages, one of its advantages is that it can be used in places difficult to reach and dangerous to humans[1].

In the military, many activities at sea are risky and require high costs. The used of unmanned surface vehicles (USV) is becoming more attractive for many purposed vessel with low-cost, autonomy, and to reduce human risks. In the world many USV already used in military. USV has actually been tested since World War II, but unmanned reconnaissance early generations such as OWL Mk II is still classified as an Autonomous Underwater Vehicle (AUV). Followed in 1944, Canada developed the concept of Comox torpedo before the invasion of Normandy. After World War II the use of USV became more developed, including to take samples of water exposed to radioactivity after the Able and Baker bombing of Bikini Atoll in 1946 [2] I.n addition, USVs are useful in the field of area observation, reconnaissance, and patrols because they have better capabilities using radar with low cost.

From the several purpose, USV with weapons system and reconnasissance system need dynamic positioning system features. The dynamic positioning system can maintain the position and it will useful to attack mission.

With the development in floating offshore vessel to operated in deep ocean, the mooring system had been required to operation vessel in the fixed position. And the anchoring system can be allowed to support the underwater operations. So operation vessel becomes difficult in the fixed position system. With dynamic position system, limitation of depth water not problem to operation fixed position of vessel[3]. Technology of dynamic positioning system can used with the vessel have an independent propulsion device. The propulsion devices to against the environmental load such as wind, waves, and currents. Without the mooring system vessel can be maintain the fix-point of position. So, the independent propulsion must be operation by automatically to complex the offshore operations. [4].

But, nowdays dp already used on small vessel to maintain the position and heading. With the surface vessel such rescue boat, yacht and usv DP is used to carry out the mission[5]. The DP system for marine vessels has been divided into a subsystem with designed tasks of dedicated modules. The important components are shown in Fig. 1

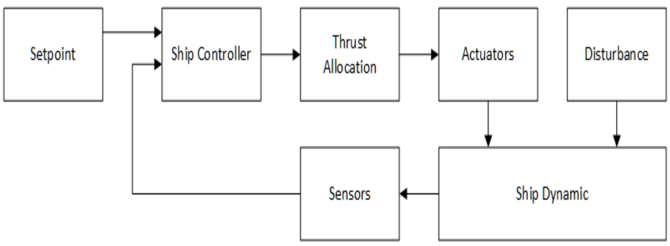

Fig. 1 Component of Ship Dynamic Positioning Control

The research on DP Systems has began from 1960s on vessel with spesial purposed using the conventional PID controller. The random disturbances with wind, wave, and current can't be predicted in the different condition. To control the object with large inertia and unprecision nonlinear mathematical model conventional PID is difficult to get the requirements of control. So, conventional PID controller is difficult to control the position in DP system[6].

The fuzzy logic control have characters[7]: (1) it's can control without accurated model for the object; (2) can effective to control nonlinear system; (3) it has a good adaptability. It has control effect to non-linear mathematical model with not precision measurement. But fuzzy logic controller does not have integral part, so the static error difficult to eliminated.

In this paper, we have examined simulation of dynamic position system of USV with environmentals load effect. The environmental load used wave disturbance with gaussian white noise random. With wave disturbance, a mathematical model of ship is explained. A fuzzy logic controller are used to control the DP system of scheme. The fuzzy logic are used in the system is three.

II. MATHEMATICAL MODELLING

The kinematic characteristics of the ship are described by 6 degrees of freedom (DOF). In the DP system, ship motion can described by 3DOF which surge, sway, and yaw motion that can be effected to force and moment of ship[8]. The environmetal disturbances consist to mathematical model of ship kinematic equation. Mathematical model of ship have two frequency. The low frequency produces force and moment that can changes the temporary position of ship. The high-frequency will not change the position but makes the ship swing. The motions vessel in surge, sway and yaw can described the horizontal axis of marine vessel with low speed in 3DOF[9][10]. The vector of ship velocity is given by,

$$v = [u, v, r]^T \tag{1}$$

The vector of position and orientation vessel given by,

$$\eta = [\dot{x}, y, \psi]^T \tag{2}$$

One principal rotation z-axis in matrix of 3DOF euler show the relation between v and η. The vertical motion of dynamics is ignored[11]. So, the equation given by,

$$\dot{\eta} = R(\psi)v \tag{3}$$

where, R is euler matrix about z axis can be defined by,

$$R(\psi) = \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

The equation of motions for a vessel in 3DOF can ignored the Corolis-centripetal forces with quadratic velocity. It can used by hydrodynamic term of linear forces and moment rigid body. That's can be stated as,

$$M\dot{v} + Dv = \tau_{thr} + \tau_{env} \tag{5}$$

with assumption symmetrical in xy vessel and distribution of mass is same the inertia matrix is notation as M [11]. The matrix can defined by,

$$M = \begin{bmatrix} m - X_{\dot{u}} & 0 & 0 \\ 0 & m - Y_{\dot{v}} & mx_G - Y_{\dot{r}} \\ 0 & mx_G - Y_r & Iz - N\dot{r} \end{bmatrix} \tag{6}$$

The nonlinear terms is ignored for the DP system. Used damping term is the linear matrix with notation is D. The matrix can be defined,

$$D = \begin{bmatrix} -X_u & 0 & 0 \\ 0 & -Y_v & -Y_r \\ 0 & -N_v & -N_r \end{bmatrix} \tag{7}$$

tthr is the matrix of forces and moment that generated by propeller, bow thruster and rudder. *t env* is the environmental forces and moment that effect to vessel from disturbance load.

$$\tau_{thr} = [\tau_X, \tau_Y, \tau_N]^T \tag{8}$$

$$\tau_{env} = [\tau_{Xenv}, \tau_{Yenv}, \tau_{Nenv}]^T \tag{9}$$

For the applied in DP system can be assume *Nv* = *Yv* [3]. So the model can be implemented in MATLAB/SIMULINK used the parameter of coefficients hydrodynamic value for USV. The coefficients hydrodynamiscs value can be seen in Table I

Table 1. Hydrodynamics Coefficient USV

No	Parameter	Value
1	$-X'_u$	0.000421
2	$-X'_{\dot{u}}$	0.00386
3	$-Y\dot{v}'$	0.00910137
4	$-Y\dot{r}'$	0.001116851
5	$-Yv'$	0.018045388
6	$-Yr'$	-0.00278297
7	$-N\dot{v}'$	0.001120513
8	$-N\dot{r}'$	0.000218878
9	$-Nv'$	0.006532665
10	$-Nr'$	0.002922122
11	Ir'	0.00002042
12	Iz'	0.00002707

III. ENVIRONMENTAL DISTURBANCE

The environmental disturbance used the wave distrubance second order. The spectrum of wave disturbance defined base on linear wave theory with the transfer function is given as [12]

$$h(s) = \frac{K\omega s}{s^2 + 2\xi\omega_0 s + \omega_0^2} \tag{10}$$

where, Ki is gain for each motion that representing surge, sway, and yaw motion with the notation is X,Y, and N. Saelid (1983) is defined the model in first time[13]. But Pierson-Moskowitz spectrum improvement to better the shape of damping term. In the equation 10 defined about the transfer function forces and moments of wave are simulated used limited band of random gasussian white noise. To different the transfer functions can used the different gains (*KXw;KYw;KNw*) to generate forces (*tXenv;tYenv*) and moment (*tNenv*).

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IV. CONTROL DESIGN

In the equation 5 is equation motion of the ship. And the equation 6 is matrix of inertia system with the damping matrix in equation 7. From the equation that can be dedined the motion of ship is separated from the surge, sway and yaw[14]. This means that in the surge motion, sway motion and yaw motion each has fuzzy logic for control purposes.

In this study mamdani fuzzy logic use to solved the problems. With the advance strategy control can be consider the problem and result the real time sulutions.

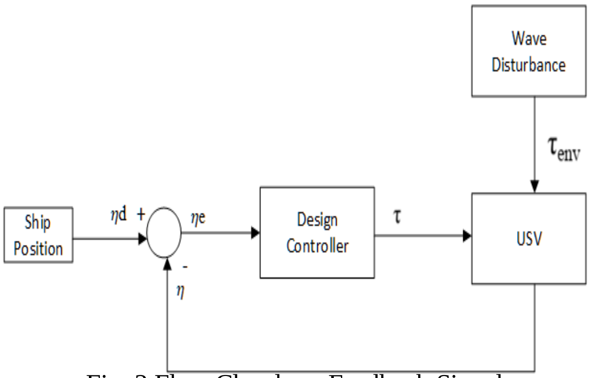

Fig. 2 Flow Closeloop Feedback Signal

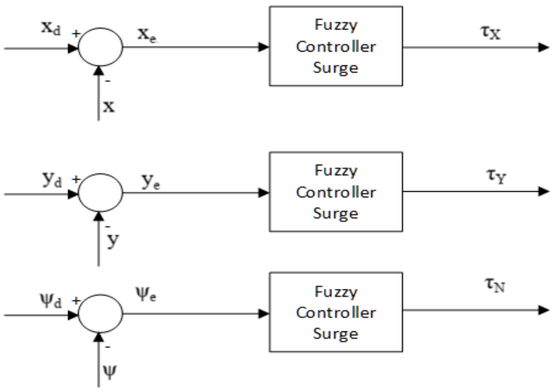

Fig. 3 Block Diagram of Control Scheme

The figure 2 represented of closeloop feedback used for dynamic position system. Signal ηd used in the sistem as the input and signal η is output of system. The different of position calculated from position references to make a error value. The error of position used to controller signal input. The position signal input is vektor (X,Y) coordinate and heading angle of vessel. The control scheme to produce thrust and moment command of vessel. The subject of resultant command thrust and moment is a USV mathematical model. The wave disturbance model generated with thrust and moment to processing in the mathematical model. To see the control cheme of system, block diagram is presented in figure 3. The fuzzy logic controller have an individual function to control error position in the surge, sway and yaw motion.

V. FUZZY LOGIC CONTROLLER

Fuzzy Logic is processing variable from multiple input with value of posible truth to processed with that variable. The posible decision that given can be designed from all available information which input in fuzzy logic. The controller is divided into three steps : fuzzification, fuzzy inference with rules based and defuzzification [15]. The fuzzification have two inputs. One of input is error with the membership function show in figure 4. Each one of input is rate error or speed of change the error that can be seen in figure 5. The membership function of fuzzy logic using five member, each is labeled fuzzy associations, and the variables of signal value is -1 to 1. The triangular membership function is used to fuzzy association variables such as NS (negative small), Z (zero) and PS (positive small). The trapezoidal membership functions is used to fuzzy association variables such as NM (negative medium) and PM (positive medium) that present at the profuse condition.

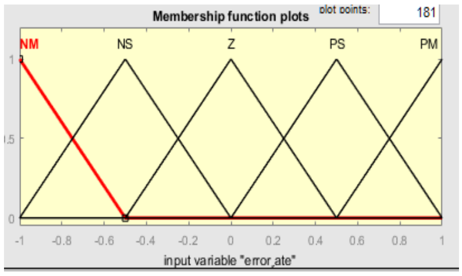

Fig. 4 Membership Function input error

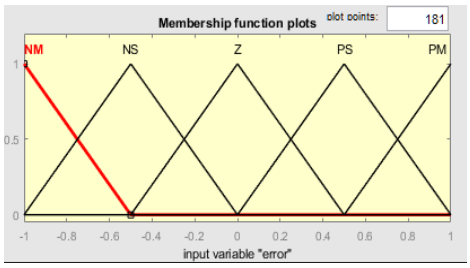

Fig. 5 Membership Function Input ErrorRate

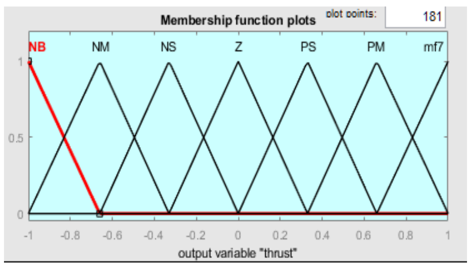

Fig. 6 Membership Function Output Thrust

The output thrust can see in the figure 6. The thrust is divided into seven fuzzy association variables, the five fuzzy association used the triangular membership function. Profuse condition, NB (Negative Big) and a positive big (PB) use the trapezoidal membership function. And than to make a decision from the fuzzy logic can use rules like this with IF-THEN principles

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IF error is Negative Medium, and
IF rate of error is Negative Medium,
THEN Positive Big is thrust output

The rules is show in Table 2. Rules can be checked to easy the design. Defuzzification of output using centroid method [15].

Table 2. Rules Based Fuzzy

	NM	**NS**	**Z**	**PS**	**PM**
NM	PB	PB	PM	PS	Z
NS	PB	PM	PS	Z	NS
Z	PM	PS	Z	NS	NM
PS	PS	Z	NS	NM	NB
PM	Z	NS	NM	NB	NB

VI. SIMULATIONS

Software MATLAB/SIMULINK used in this study to simulated the system. The sample in order to simulation was 1000 second to result the respons vessel from maintain position (0,0) and heading angle (0^o) with wave disturbance. Fuzzy logic have a purpose to manipulating vessel thruster which a changes the internal control of trhuster. The fuzzy logic controller can be design based on experience of researcher. And than studying cause and effect relation of input forces and moment vessels against position and heading angle to known about behavior of USV.

Table 3. Gains of Wave Disturbance

Gains	**Value**
Kx_w	1
Ky_w	1
Kn_w	1

Table 4. Parameter Wave Simulations

Parameter	**Value**
σ	0.5
ω_o	1.25
λ	0.1
f	0.707

Table 5. Principle Dimention USV

Parameter	**Value**
Lpp	12,1 m
U	18,0056 m/s
B	3,55 m
T	0,75 m
C_B	0,439
X_G	1,5
A_δ	0,197 m^2
m	14500 kg

Wave disturbance simulation use parameter in the table 3. The simulate of wave disturbance to show a wave consistent in the sea. The wave disturbance already simulated by MSS from Fossen[8].

VII. RESULTS

The figures 7, figure 8 and figure 9 is show a result how step response consisted the movement of vessel in surge, sway and yaw motion. The output of three controller is a signals thrust and momen to produce the vessel is maintain the position (0,0) and heading (0^o). The results can seen in the figure 10 until 12. The step response in fuzzy controller output is an effort the vessel to stabilise the position from wave disturbances.

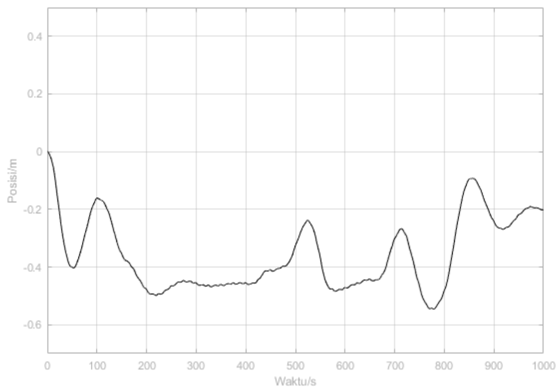

Fig. 7 Respon Position in Surge

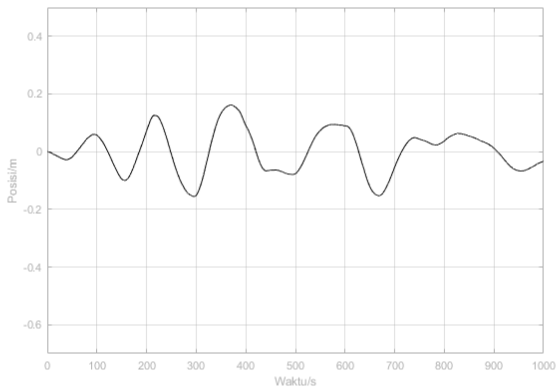

Fig. 8 Respon Position in Sway

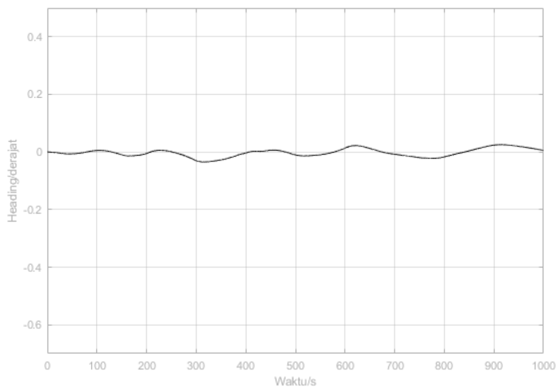

Fig 9. Respon Ship Heading in Yaw

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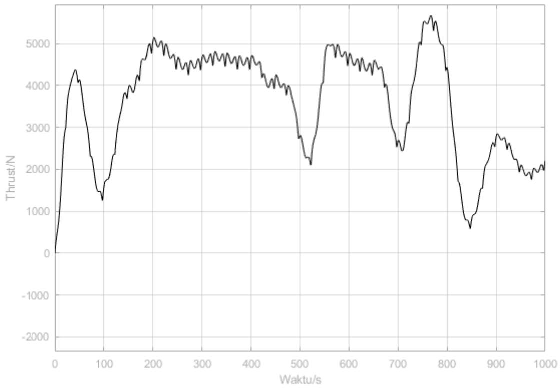

Fig. 10 Output of Surge Controller

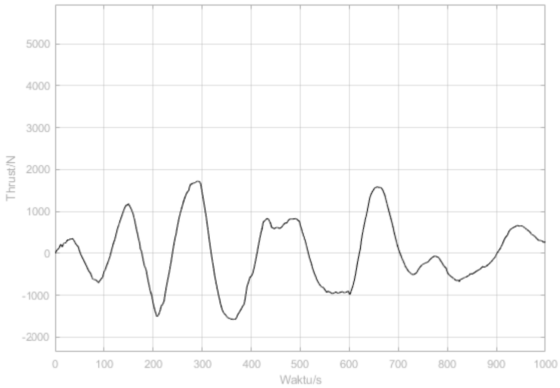

Fig. 11 Output of Sway Controller

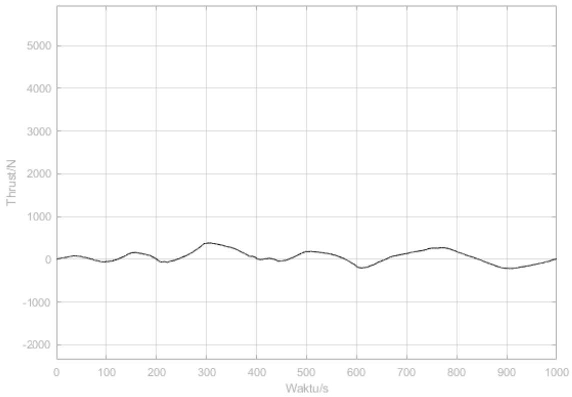

Fig. 12 Output of Yaw Controller

The capabilities of three fuzzy logic controller attempt to understand in movement and control the dynamic and model vessel. The results shows the capabilties controller can maintain a position and heading vessel. The output of thrust in surge motion have a large value than the sway motion. The wave disturbances direction that’s can be consisted in surge motion. But the vessel can correct the control position. Whitout comparative study in this paper, the fuzzy logic controller can be overcomes the contrast result of thrust in surge motion. And the fuzzy logic controller is also successfully resists the wave disturbances

VIII. CONCLUSION

In this paper, fuzzy logic controller of DP system show the results which the numerical and mathematical models. The environmental load use the wave disturbance to opposed the vessel force in the system. Design a fuzzy logic controller for USV dynamic positioning system, have a good control to back the position (0.0) and heading angle (0^o). So the design of controller can be maintain vessel position and heading. From the inverse response at the last in surge, a need correction in algorithm system to maintain surge position. Since the simulations in the MATLAB/SIMULINK are carried out, filter measurement of environment not be calculated. But all the matrix states parameter of USV are correctly by approach the numerical model. In the state space representation of USV allocation of thrust and inverse mapping are directly absorbed in thrust matrix of input. But the effect of maintain ship position and heading can be achieve from the fuzzy controller design.

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