Stabilization of Floating Roll by Fuzzy PID Controller Using New Concept of Internal Model

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Abstract–In this paper, the nonlinear modeling of ship roll angle movement in the presence of disturbances and its control through an adaptive method is investigated. One of the important issues in the control of vessels is to have a model of non-linear behavior, by using the dynamic equations of the ship's motion, the ship's roll motion equations is obtained in Third order dynamic equations. Another innovation presented in this paper is the design of a controller based on the input-output feedback linearization method and according to the proportional-integrator and derivative controller, which coefficients are adjusted by fuzzy logic to reject and reduce the sinusoidal disturbance effects. Therefore, another innovation of this paper is to minimize the effects of sinusoidal disturbance fluctuations in the roll angle of the ship in addition to achieving a zero degree roll angle. The results of the proposed method have been evaluated in MATLAB software and despite sinusoidal disturbances with a certain range, the proposed method has made the roll angle stable within an acceptable range and its effects on the roll angle of the ship have been eliminated.

Keywords: Ship movement-disturbance Rejection-feedback linearization

1. Introduction

Fluctuations in sea waves sometimes lead to ships leaving the main course of movement and re-correcting the course. The effects of these fluctuations in the roll angle of the ship can lead to unfavorable movement behaviors. To reduce these effects, during the past years, ship roll stability has received much attention [1]. In this regard, linear and non-linear controllers have been used to control the ship's roll motion [2-5]. Considering that the main model of the ship has a non-linear structure, therefore, the use of non-linear control method has been the focus of researchers, and the advantages and disadvantages of each are described. Reference [6] has presented a combination of predictive control method and an estimated model of input disturbance. In this article, in order to overcome the fluctuations caused by the sinusoidal disturbance in the ship, the predictive control method has been used. This method requires the data of previous moments and the amount of calculations is complex and time-consuming. The linear model of ship roll dynamics is presented in reference [7] and then the control method of the internal model to form the output sensitivity function in order to achieve the appropriate noise attenuation coefficient is investigated. The PID controller based on the linear model for dynamic roll stability has been investigated by reference [8]. To design the PID controller after linearization of the system, the model of sensors and actuators is added to the system model and then the PID controller is designed. A complete review of the performance of the PID controller on the ship's roll system has been reviewed in reference [9] and the obtained results have been evaluated. Several methods have been proposed to pi fuzzy rove the performance of the PID controller. One of these methods is the use of the backward step method, which is combined with PID and used to control the desired system. One of the non-linear control methods is the sliding model control method, whose control structure is in the form of a resistant structure and can be used despite the uncertainties and disturbances of the parameters (provided that the range of these uncertainties is and disturbances are known) [10]. It is possible to pi fuzzy lement this control method using infinite switching frequencies in theory and limited switching frequencies in practice in the control system [10-12]. Sliding mode control is a control algorithm and a powerful approach to control non-linear and non-deterministic systems, but due to the fact that switching is done in this method, the chattering phenomenon is listed as one of its disadvantages. Despite the sinusoidal fluctuations caused by disturbance in the system, it shows unstable effects [13]. Removing unknown disturbances in dynamic systems is a basic control problem for various models such

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as friction torque during oscillating movements [14], reduction of disturbances in gyroscopes, active noise control, disturbances of sine waves, vibration rejection in the structure of structures, The control of robot obstacles is the control of the rotation mechanism [15]. These fluctuations generally include constant frequency or variable frequency fluctuations. If the frequency of oscillations caused by the disturbance of the system is variable, it is inevitable to estimate or design the viewer to determine the frequency at every moment, which is presented in [15]. If the frequency of oscillations is evaluated as a constant value from the beginning, the process of removing it can be done more easily than in the case of variable frequency. This problem can usually be solved by using the concept of internal model, which is generally presented in [16] in the case of linear systems. PI fuzzy states that if the disturbance model can be accurately obtained and pi fuzzy lemented in the controller structure, disturbance in any form can be completely canceled. On the other hand, when no information about the disorder is available, PI fuzzy is no longer effective [17].

In this article, the design of a controller that has the ability to control non-linear systems and guarantee their stability based on the Lyapunov method is discussed. In addition to this control method, a method to remove the disturbance is presented, which can be effective against the highly nonlinear dynamics of the ship model despite the existing environmental disturbances for the ship model in the oceans such as waves and winds. Since the input-output linear feedback controller by controlling the rotation angle of the ship while using the disturbance removal method can overcome the challenges for the ship model to a large extent, the error is expected to converge to zero and also shorten the transient response of the model output. This article is divided into 5 main parts, in the second part, the ship model is discussed in a non-linear way and based on the roll angle changes. In the third part, the proposed control method and disturbance removal method are presented. In the fourth part, the simulation of the control method is discussed, and in the fifth part, the results are evaluated.

2. Ship roll modelling

In this section by using dynamic equation of ship movement, new nonlinear model is extracted based on roll angel variations. In Fig. (1) rotation in different directions of coordinate axes is shown. In this article, one degree of freedom model is studied:

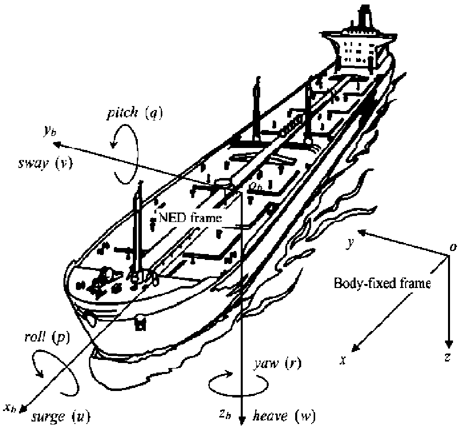

Fig.1. Roll movement structure for ship

In general, the dynamic equations of ship motion are expressed as the following general relationship:

$$\begin{cases} \dot{\eta} = J(\eta)v \\ M\dot{v} + C(v)v = \tau_h + \tau_c + \tau_d \end{cases} \tag{1}$$

In the above relation, considering the relationships with six degrees of freedom, $\eta = [x, y, z, \varphi, \theta, \psi]$ the motion vector is along the coordinate axes and the angles specific to each coordinate axis. $v = [u, v, w, p, q, r]$ The velocity vector is along the coordinate axis. J is the motion transfer matrix in the coordinate axes and M is the inertia matrix along the coordinate axes. C as the Coriolis matrix (body forces on a floating surface) and τ_h ,τ_c ,$\tau_d$as the component of hydrodynamic forces, the incoming force as control input and the considered forces as disturbances. In this research, the roll angle control ($\varphi = x_1$) is considered:

$$\begin{cases} \dot{\varphi} = p \\ I_x \dot{p} = \tau_h + \tau_c + \tau_d \end{cases} \tag{2}$$

In the above relationship, p as the roll angle change rate, Ix is the inertial component along the x ،τ_h,$\tau_c$and $\tau_d$as the component of hydrodynamics, control and disturbance of the ship. This relationship represents the model of the ship's roll angle ¬, and the fin related to the roll angle can be considered as the driver of the system. The relationships caused by the ship's fin are obtained according to [18]. The relationships related to the movement on the floating surface of the ship based on changes in the roll angle according to [18] have also been obtained in the form of the following relationship:

$$\begin{cases} (I_x - k_p)\varphi - k_p\dot{\varphi} + k_{p|p|}\dot{\varphi}|\dot{\varphi}| + c_1\varphi + c_3\varphi^3 + c_5\varphi^5 - k_d + \Delta_1 = k_\alpha \alpha \\ T_e\alpha + \alpha + \Delta_2 = k_\alpha \alpha_c \end{cases} \tag{3}$$

In the above relationship, kp and kα are considered as the constant coefficients of the ship, α c as the control input connected to the ship's fin and α as the angle of the fin. Te is also the time constant of the stimulus. The values of model parameters in this research are considered based on [18] . In this article, the dynamics of the ship and fin roll motion model considering the roll angle (φ) , angular velocity (φ̇) and roll angular acceleration (φ̈) as x1 , x2 and x3 state equations of the system and αc as The control input, the model is expressed as follows:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = x_3 \\ \dot{x}_3 = b_4 x_3 + b_3 x_2 + b_2 x_2 |x_2| + b_1 |x_2| x_3 + b_5 x_1 + b_6 {x_1}^3 + b_7 {x_1}^5 + \ldots \\ b_8 {x_1}^2 x_2 + b_9 x_2 {x_1}^4 + b_0 + b_u \alpha_c + b_d k_d \end{cases}$$
(4)

In the above relationship, bi is considered as the parameters of the ship. kd is the disturbance of the system. The ship model parameters are shown in table (1).

Table 1. ship model parameters based on roll angle

parameter	value	relation
b_0	91.42	$\frac{k_\alpha^2}{T_e(I_x - k_{\dot{p}})}$
b_1	0.406	$\frac{2k_p\|p\|}{T_e(I_x - k_{\dot{p}})}$
b_2	0.104	$\frac{k_{p\|p\|}}{T_e(I_x - k_{\dot{p}})}$
b_3	0.176	$\frac{k_p + c_1}{(I_x - k_{\dot{p}})}$
b_4	-2	$\frac{-1}{T_e}$
b_5	0.060	$\frac{k_p + c_1}{T_e(I_x - k_{\dot{p}})}$
b_6	10^{-10}	$\frac{k_p + c_3}{T_e(I_x - k_{\dot{p}})}$
b_7	2×10^{-8}	$\frac{c_5}{T_e(I_x - k_{\dot{p}})}$
b_8	3×10^{-8}	$\frac{3c_3}{(I_x - k_{\dot{p}})}$
b_9	3×10^{-8}	$\frac{5c_5}{(I_x - k_{\dot{p}})}$
b_u	91.42	$\frac{k_\alpha^2}{T_e(I_x - k_{\dot{p}})}$
b_d	1	$\frac{1}{(I_x - k_{\dot{p}})}$

According to the model presented in the state space, it can be seen that the model is a non-linear model and has one output and one input. In this model, to measure the roll angle, an angle sensor is placed and feedback is taken from it as the output of the model. As mentioned, the optimal roll angle value for the stability of the ship is zero. On the other hand, for this model, a control input is designed as a torque force applied to the ship's fin, which can be designed by various non-linear methods. In the next section, the design method of the proposed controller is discussed.

3. Controller design

3.1 Feedback linearization control method

In a non-linear system, in order to design the input-output linear feedback control, first, by using the input-output feedback linearization method, the model is converted into a linear system, and then by designing the appropriate control input, according to the Lyapunov method, the stability of the system is guaranteed. In this section, in order to linearize the nonlinear model, the input-output linearization method is discussed. In order to design this method, the output dynamics of the model in the form of state space$x_1 = \varphi$is considered. The state space of the system according to the state space equations can be written in the following general form:

$\dot{x} = f(x)x + g\,u$ و $y = h(x)$ (5)

In this method, considering the use of derivation in terms of different functions, the definition of Lie derivative is used in order to spi fuzzy lify relations. Lie derivative is a mathematical operator defined as follows:

$L_f = \sum_{i=1}^{n} f_i(x) \frac{\partial}{\partial x_i}$ (6)

In order to design the linearizer method, it is necessary to derive a derivative from the output of the nonlinear model until the control input appears, and this process is obtained by considering the derivative relationships of Lee as follows:

$\dot{y} = \frac{\partial h}{\partial x}\dot{x} = \frac{\partial h}{\partial x} f_1 + \frac{\partial h}{\partial x} g_1(x)$ (7)

According to the relationships obtained, it can be concluded that by deriving the above expression, the control input appears and in order to design the linearizer input for the nonlinear system, the control input is equal to the opposite sign of the nonlinear expressions and summed with a control expression. V considered:

$$\dot{y} = L_f h(x) + L_g\, h(x) u \rightarrow u = \frac{1}{L_g L_f\, h(x)}(-L_f h + v) \tag{8}$$

In the examined model, an angle sensor is placed to measure the roll angle and it is taken as the output of the feedback model. As mentioned, the optimal roll angle value for the stability of the ship is zero. On the other hand, for this model, a control input is designed as a torque force applied to the fin of the ship, which can be designed by various non-linear methods. In this step, using the feedback linearization method, the output of the non-linear system is converted into a linear system. In feedback linearization, the output is derived from the output until a control input appears in it, then the control input is considered in such a way as to remove all the non-linear terms of the equation, and thus that control input is considered as linearization in the non-linear model. Taken. Now, considering the dynamic equations of the output of the ship model, it is designed in the form of the following relationship of the control input associated with the linearization of the nonlinear model. According to the dynamics of the system, the output of the system is considered as the roll angle:

$$y = x_1 = \varphi \tag{9}$$

To the number that a relationship is established between the system output and the control input of the system, derived from the output:

$$\dot{y} = \dot{x}_1 = x_2 = \dot{\varphi} \tag{10}$$

$$\ddot{y} = \dot{x}_2 = \ddot{\varphi} \tag{11}$$

Considering that the control input did not appear in the first derivative and the second derivative, the third derivative was taken from the output of the model, which is shown in the following relationship.

$$\dddot{y} = \ddot{x}_2 = b_4 x_3 + b_3 x_2 + b_2 x_2 |x_2| + b_1 |x_2| x_3 + b_5 x_1 + b_6 {x_1}^3 + b_7 {x_1}^5 + \ldots b_8 {x_1}^2 x_2 + b_9 x_2 {x_1}^4 + b_0 + b_u \alpha_c + b_d k_d \tag{12}$$

Therefore, the order of the system is equal to 3. In order to design the input-output feedback controller, in the relationship of the third-order derivative of the output, all the non-linear expressions were removed by considering the appropriate control input, and as a result, the control input was designed as follows:

$$\alpha_c = \frac{1}{b_u}(V - b_2 x_2 |x_2| - b_1 |x_2| x_3 - b_6 {x_1}^3 - b_7 {x_1}^5 - b_8 {x_1}^2 x_2 - b_9 x_2 {x_1}^4 + b_0) \tag{13}$$

By considering the above control input, $\dddot{y} = V$ and obtaining the relationship between V and u , it is possible to design V considering the linear controller to ensure that the desired output value is reached. Now rewrite the relationship equations of the linearized model of the ship in the state space considering the new dynamics:

$$x^{\cdot} = Ax + BV \tag{14}$$

In the above relationship, the model state matrix and the input matrix are defined as follows:

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ b_5 & b_3 & b_4 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{15}$$

In this article, after linearizing the nonlinear model, the ¬PID control structure is used to design the controller. According to the above relationship, the equations are obtained in the form of a polynomial of the error and its derivatives, which can be guaranteed to converge to zero with the correct selection of their coefficients.

3.2 Fuzzy PID controller

In order to design a robust control method in line with the adaptive PI control method, a fuzzy controller is designed in this section. In this part of the design, we replace the PI controller with the fuzzy controller combined with the adaptive PI controller. Our system is not a fixed system and the coefficients are variable. It means that the PI that was designed at the beginning of the work will not be used until the end. If the system is unable to perform the control at different times, it causes undesirable changes to be shown in the system. Therefore, intelligent techniques can be used to obtain the desired response within a defined range. When you change the operating conditions and system parameters, the designed controller does not necessarily perform well. Now, using the fuzzy control structure, taking into account the rules and membership functions defined for the fuzzy controller, the control input is defined as the following relationship:

$$u = k_p e + k_i \int e\, dt + k_d \frac{de}{dt} \tag{16}$$

In the above relationship, the control input is applied to the system based on the combination of adaptive PID coefficients and the output of the fuzzy controller. In this way, the following relationship is used to achieve an adaptive controller:

$$k_p = \widetilde{k_p} + \acute{k}_p \tag{17}$$

$$k_i = \widetilde{k_\iota} + \acute{k_\iota} \qquad (18)$$

$$k_d = \widetilde{k_d} + \acute{k_d} \qquad (19)$$

In the above relationship, $\widetilde{k_p}$ is the PID controller coefficient with a fixed value and $\acute{k_p}$is the fuzzy value for the adaptive determination of the proportional coefficient. Other coefficients are determined in the same way. This structure has a combined state with a fuzzy controller that works online and adaptively. Using the self-regulating PI controller is a suitable solution for mastering new operational conditions. There are many smart ways to adjust controller parameters in fuzzy logic rules. Unlike the traditional PI method, in fuzzy PI, the value of PI control parameters will change during system control, and these values are carefully adjusted by fuzzy logic.

In order to design the fuzzy method for the industrial PI controller, a fuzzy structure is defined for each of the coefficients of the PI controller. The inputs of the fuzzy structure are two pi fuzzy ortant parameters in controller design, i.e. system error and error changes. In this case, for the inputs of the structure, different situations that happen in practice are assumed, and in these conditions, the design of the PI phase controller is presented. For each of the fuzzy inputs, there are 7 input modes, including NB, NM, NS, Z, PS, PM, PB, which represent very negative, medium negative, low negative, zero, low positive, medium positive, respectively, from left to right. And they are very positive. These seven membership functions are actually the minimum number of situations that can happen in the industry. Each of these membership functions is defined in specific ranges in the general range [2-2] according to the practical error of the ship model system, which is shown in Fig.s 2 and 3. We consider the structure of each membership function to be Gaussian, taking into account that the closer the input data is to the center of the membership function, the higher the membership ratio will be.

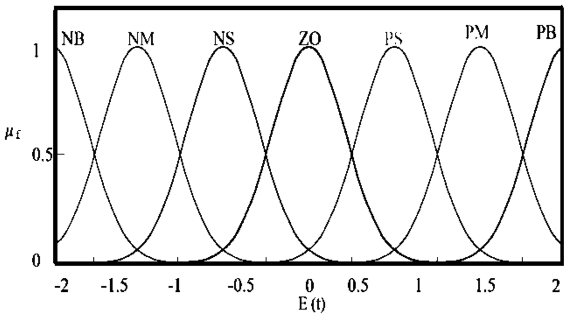

Fig.2. Structure of fuzzy controller membership functions for error input

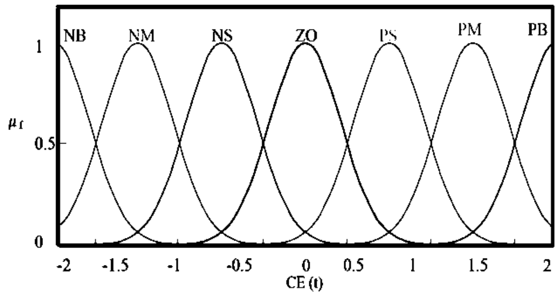

Fig.3. Structure of membership functions of fuzzy controller for input of error changes

In order to design suitable rules for the PI controller, we consider Fig. 4 as a structure of the real model. According to Fig. 4, it can be seen that there are different states for error and error changes, and for each state, the coefficient $\acute{k_P}$ must have a descriptive or fuzzy value. In the general structure of the PI controller, by increasing the value of $\acute{k_P}$, the response range increases, and by reducing it, the output range can be reduced. According to this point, the coefficient $\acute{k_P}$can be increased or decreased according to the error state of each moment of the system, which is defined as a law for the fuzzy structure. By changing the coefficient $\acute{k_\iota}$ in the structure of the PI controller, the fluctuations and the error of the permanent state of the system can be changed optimally at any moment.

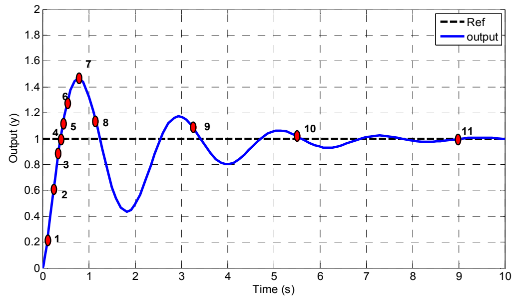

Fig.4. Different states for error and error changes in PI-fuzzy controller design

Mode 1: It is assumed that the system error is high at the beginning of the operation and the output has not yet reached the desired value. In this case, the slope of the error is also high. In this case, the error sign (e-eref) is a negative value and the error slope has a positive sign. Therefore, in order to achieve the desired response, the value of Kp should be increased to a large or moderately positive value (because the slope is in the direction of reducing the error).

Mode 2: In this state, the slope is still high and the system error has an average value, and the sign of each is similar to state 1. Here, the Kp coefficient should have a medium or small positive value (because the slope is in the direction of error reduction).

Mode 3: In this state, the slope is still high and the system error is small, and the sign of each is similar to state 1. Here, the Kp coefficient should have a small positive value or zero (because the slope is in the direction of error reduction).

Mode 4: In this state, the slope is still high and the system error is zero, and the error change sign is similar to state 1. Here, the Kp coefficient must have a value of zero or a small but negative value (because the slope is in the direction of reducing the error).

Mode 5: In this situation, the slope is still high and the system error is small, and the error sign has a negative sign and the error change is positive. Here, the Kp coefficient should have a small negative value or a moderate negative value.

Mode 6: In this situation, the slope is still high and the system error has a medium value, and the error sign has a negative sign and the error change is positive. Here, the Kp coefficient should have a moderate negative value or a large negative value.

Mode 7: In this condition, the slope of the error is still zero and the system error has a large value and the error sign has a negative sign. Here, the Kp coefficient must have a large negative value.

Mode 8: In this situation, the error slope is still high and the system error is medium, and the error sign has a negative sign and the error change is negative. Here, the Kp coefficient should have a medium negative or small negative value.

Mode 9: In this situation, the slope of the error still has a medium value and the system error has a small value, and the error sign has a negative sign and the error change is negative. Here, the Kp coefficient should have a small negative or zero value.

Mode 10: In this situation, the slope of the error is still small and the system error is small, and the error sign has a negative sign and the error change is negative. Here, the Kp coefficient must have a value of zero.

Mode 11: In this situation, the slope of the error is still zero and the system error is zero. In this situation, the Kp coefficient must have a value of zero.

In the same way, with 7 membership functions (adjectives) for error and 7 membership functions (adjectives) for error changes, 49 rules can be defined for the system that adjust the coefficients $\acute{k_p}$ and $\acute{k_\iota}$. According to the description of the coefficients $\acute{k_p}$ and $\acute{k_\iota}$ in the fuzzy structure, it is designed as Table 2 and 3:

Table.2 Fuzzy controller rules according to linguistic variables $\acute{\boldsymbol{k}}_{\boldsymbol{p}}$

c e/e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	PB	PB	PM	PM	PS	ZE	**ZE**
NM	PB	PB	PM	PS	PS	ZE	**NS**
NS	PM	PM	PM	PS	ZE	NS	**NS**
ZE	PM	PM	PS	ZE	NS	NM	**NM**
PS	PS	PS	ZE	NS	NS	NM	**NM**
PM	PS	ZE	NS	NM	NM	NM	**NB**
PB	ZE	ZE	NM	NM	NM	NB	**NB**

Table .3 Fuzzy controller rules according to linguistic variables$\acute{\boldsymbol{k}}_{\boldsymbol{\iota}}$

c e/e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NS	NS	**ZE**
NS	NB	NB	NB	NS	NS	ZE	**PS**
NS	NB	NB	NS	NS	ZE	PS	**PS**
ZE	NB	NS	NS	ZE	PS	PS	**PB**
PS	NS	NS	ZE	PS	PB	PB	**PB**
PS	NS	ZE	PS	PS	PB	PB	**PB**
PB	ZE	PS	PS	PB	PB	PB	**PB**

4. Simulation

In this section, the simulation of the model resulting from the ship's roll movement despite disturbances is discussed. For this purpose, MATLAB software has been used for fuzzy pi modeling and control. In this part of the simulation, in order to eliminate the effects of disturbance caused by waves on the ship, fuzzy PI method is used. In all the simulations, the perturbation has been applied in the form of sinusoidal summation with the input of the model. In this regard, fuzzy PI disturbance removal method has also been used and the simulation has been carried out by considering the frequency of sinusoidal disturbance. The simulation has been done to remove the effects of disturbance in the Simulink space. At first, it is assumed that the disturbance frequency has a constant value of f=0.5. The mathematical relationship of the disturbance is applied to the control input in the form of summation throughout the simulation period as follows.

$$d(t) = 0.6 \sin{(2\pi f t)} \tag{20}$$

Now, the simulation is performed in two cases: pi fuzzy and without this block. The sinusoidal disturbance signal is shown in Fig. 5. In Fig. 6, taking into account the proper performance of the mode feedback method, the effects of sinusoidal disturbance in this system are investigated with and without the presence or absence of fuzzy PI section.

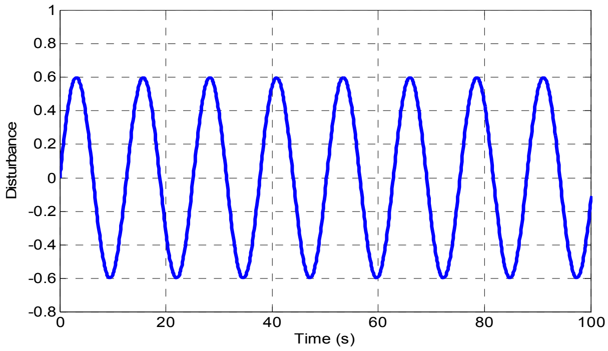

Fig.5. sinusoidal disturbance signal at the input of the model

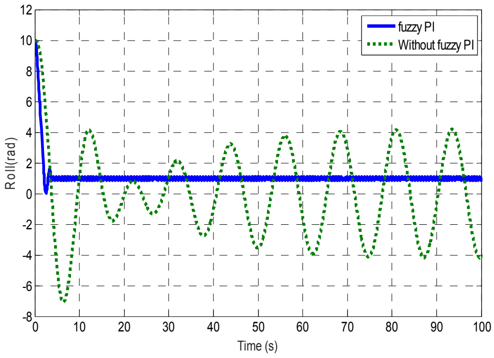

Fig.6. roll angle output using state feedback controller and fuzzy PI disturbance removal

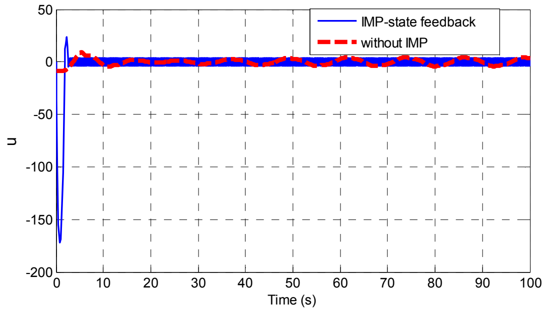

Fig.7. Control input using state feedback controller and fuzzy PI disturbance removal

According to the obtained results, it can be seen that by using the fuzzy PI method and considering the design theory presented according to the reference article, the sinusoidal disturbance applied to the system has been removed by this method and its effects on the output response of the model have disappeared, which shows It means that we have achieved the design goal in this part of the simulation. In the rest of this section, taking into account the desired results in the case of constant frequency sinusoidal disturbance, the simulation of the system with variable frequency is discussed. In this case, it is assumed that the frequency of the sinusoidal signal has different values at different moments, and its function is considered as follows:

$$d(t) = \begin{cases} 0.6\sin\left(2\pi(0.5)t\right) & t < 30 \\ 0.6\sin\left(2\pi(0.8)t\right) & 30 < t < 60 \\ 0.6\sin\left(2\pi(0.3)t\right) & t > 60 \end{cases} \qquad (21)$$

Now, considering the relation (21), we perform the simulation in the two cases of taking into account the fuzzy PI disturbance removing part and without it in the state feedback control loop for the linearized model of the ship's roll angle. The results of the simulation are shown in Fig.s (8) and (9) in the form of roll angle output and applied control input:

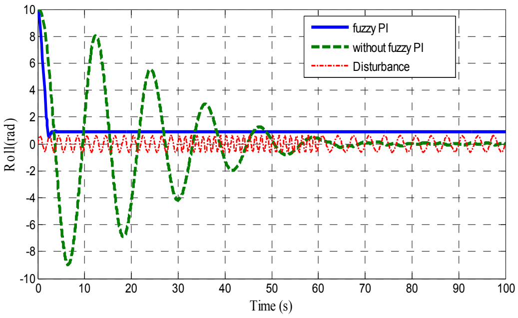

Fig. 8. Roll angle output using state feedback controller and pi fuzzy disturbance removal

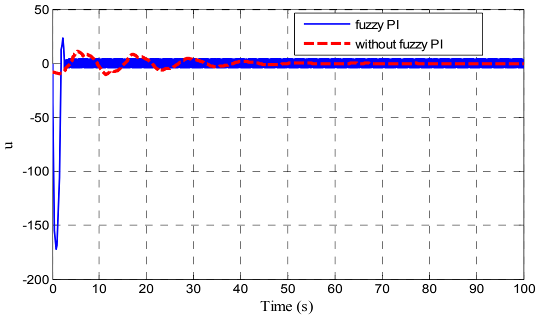

Fig. 9. Control input using state feedback controller and fuzzy pi disturbance removal

Based on the results obtained in Fig. (8), it can be seen that the state feedback control loop for the linearized model of the ship's roll angle with the presence of the disturbance removing part has a very good performance compared to the absence of this structure and can be Changes in the frequency of disturbance signal fluctuations, the PI fuzzy disturbance elimination method was evaluated as appropriate.

5. Conclusion

In this paper, according to the zeroing of the ship's roll motion in the conditions of sea water wave fluctuations, the nonlinear dynamic equations of the ship's roll motion have been modeled and a control method has been designed along with the anti-disturbance section. The model of this structural process is based on changes in the roll angle of the ship, which is controlled by input-output linearizer feedback to linearize the mathematical model of the roll motion. Fuzzy PI controller is used in the control part of this process. One of the features of the proposed method is to reduce the disturbance effects by adjusting the controller coefficients based on fuzzy logic in disturbance conditions. For this purpose, using the linear control method, the designed control input has been simulated in the presence of sinusoidal disturbances in two modes of constant frequency and variable frequency. According to the results obtained in the MATLAB software environment, the output of the roll angle has reached the desired value of 0 degrees in 3 seconds, and according to the output results, the effects of sinusoidal disturbances are minimized and eliminated in a short period of time. This structure has been compared with the PI controller and the results show the proper performance when achieving the desired value of the ship's roll angle and removing the disturbance effects in the proposed control method. As suggestions for future research, it is possible to express the development of the controller to estimate the frequency of oscillations and adapt the conditions of the controller using neural network or adaptive methods.

References

[1] T. Perez, M. Blanke, “Ship roll damping control,” IEE Proceedings on Control Theory and Applications. *Rev. Control*, 2012.

[2] C.-H. Chung, M.-S. Chen, “A robust adaptive feedforward control in repetitive control design for linear systems,” *Automatica* 48 (1), pp. 183–190, 2012.

[3] I. Houtzager, J.-W. van Wingerden, M. Verhaegen, “Rejection of periodic wind disturbances on a smart rotor test section using lifted repetitive control,” *IEEE Trans. Control Syst*. Technol. 21 (2) pp. 347–359, 2013.

[4] G. Fedele, A. Ferrise, D. Frascino, “Multi-sinusoidal signal estimation by an adaptive SOGI-filters bank,” *IFAC Symposium on System Identification*, pp. 402–407, 2008.

[5] F. Alarçin, H. Demirel, M. Ertugrul Su, and A. Yurtseven, “Modified pid control design for roll fin actuator of nonlinear modelling of the fishing boat,” *Polish Marit. Res.*, 2014.

[6] C. Holden, R. Galeazzi, T. I. Fossen, T. Perez, “Stabilization of parametric roll resonance with active u-tanks via Lyapunov control design,” *International Journal of Adaptive Control and Signal Processing*, 2018.

[7] R. Skjetne,. N. Smogeli, T. I. Fossen, “A Nonlinear Ship Manoeuvering Model: Identification and adaptive control with experiments for a model ship,” *Model. Identif. Control*, 2004.

[8] M. H. Moradi. M. R. Katebi, “Predictive PID Control for Ship Autopilot Design,” *IFAC Proc.* vol. 48, 2017.

[9] L. Liang, P. Zhao, S. Zhang, “Roll reduction control during ship turns using fin stabilizers with PID controller based on Monte Carlo optimization*,” IEEE Trans. Control Syst,* vol. 35, pp. 48–55, 2018.

[10] J. Pan and Y. Wang, “Internal model based active disturbance rejection control,” in *Proceedings of the American Control Conference*, vol. 2016-July, pp. 6989–6994, 2016.

[11] M. Moradi, H. Malekizade, “Robust adaptive first-secondorder sliding mode Control to stabilize the uncertain fin- roll dynamic,” *Ocean Eng.* 69, 18-23, 2014.

[12] P. Yang, J. Ma, W. Sun, L. H. Liang, and G. Bin Li, “Simulation and research of the fuzzy sliding mode controller of the ship test bed,” in *Proceedings of the 2006 International Conference on Machine Learning and Cybernetics*, vol. pp. 457–462, 2017.

[13] J. M. Larrazabal and M. S. Peñas, “Intelligent rudder control of an unmanned surface vessel,” *Expert Syst. Appl.*, vol. 55, pp. 106–117, 2016.

[14] K. J. Burnham, A. J. Koshkouei, and Y. Law, “A comparative study between sliding mode and proportional integrative derivative controllers for ship roll stabilisation,” *IET Control Theory Appl.*, 2007.

[15] C. C. De Wit, H. Olsson, K. J. Astrom, and P. Lischinsky, “A newmodel for control of systems with friction,” Automatic Control, IEEE Trans on, vol. 40, no. 3, pp. 419–425, 1995.

[16] F. Zhang, E. Keikha, B. Shahsavari, and R. Horowitz, “Adaptivemismatch compensation for vibratory gyroscopes,” in Inertial Sensorsand Systems (ISISS), 2014 International Symposium on. IEEE,pp. 1–4, 2014.

[17] C. E., Kinney, R. A. de Callafon. "The internal model principle for periodic disturbances with rapidly time-varying frequencies." *International Journal of Adaptive Control and Signal Processing*, pp. 1006-1022, 2017.