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Underwater Robot Trajectory Control Using Non-Singular Terminal Sliding Mode Controller

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Abstract

Sliding mode control is one of the most effective methods of controlling nonlinear systems with bounded uncertainty. Exponential convergence of tracking error is one of the most important problem of classic sliding mode control. One way to solve this problem is use of terminal sliding mode control. The great thing about terminal sliding mode control, is it's robustness in face of model uncertainty and external disturbances while can guarantee tracking error converge to zero in finite time simultaneously. Usually terminal sliding mode controller, is limited by singularity at the origin and infinite control signal. This article attempts to the singularity problem in controlling underwater robots and decreasing the convergence time by defining a new sliding surface for terminal sliding mode controller. simulation results shows the efficiency of proposed controller as it effectively improves the convergence time and accuracy in under water robots with are faced by structural and environmental uncertainties.

Keywords: Terminal sliding mode control, underwater robot, singularity, convergence

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1. Introduction

Sliding mode controller (SMC) is a powerful nonlinear control, which has been attracted attention of many researchers in recent years. This theory was firstly presented in 1950 by Eemelyanov and his colleagues and then widely developed. The main reasons to use this controller are its widespread usage and also its acceptable performance, stability and robustness. On the other hand, classical sliding mode controller is limited by its weaknesses. The first major limitation related to SMC is the problem of chattering, which can cause high frequency oscillation of the controller output [1]. Another disadvantage could be noted vulnerable to the noise and large initial value control signal [2]. In this article, for the first time, a new control method based on terminal sliding mode control is used to control an underwater robots path that has strongly nonlinear dynamics in horizontal plain and in the depth. The proposed controller causes time-limited stabilization of mechanical arms or in other words, helps system to deal with the uncertainties and external disturbances [3].

A) Controlling methods of submarine robot path:

The first category includes documents that have been presented based on smart methods.

In [4] a fuzzy controller have been used based on Sugeno to guidance screws and depth. Due to the gradual transition from maximum negative to positive stimulation, chattering decreased and the control is more robust than bang-bang control. However, to achieve better robustness, faster response must be sacrificed.

In [5] The Nero fuzzy cerebellar model articulation controller (FCMAC) have been used for tracking, guidance and depth control. Robust and better performance than PID controller and being insensitive to modeling uncertainties and external disturbances is some advantages of this controller.

The second category includes linear control methods of robots. The use of PID controller for underwater floating control is presented in [6]. Benefits of the mentioned controlling method is regarding to the mathematical model considered for disturbance modeling in floating mode and simplicity of controller design. Difficulty of access to the controlling parameters and lack of self-regulatory are disadvantages of this method.

In [7] a PD controller for each degree of freedom is defined to track the predetermined path. This method do not work properly in non-linear systems at low speed, which is a disadvantage of this controller.

The third category of papers is based on optimal control methods. The LQG optimal control and identification of system for yaw and depth is used in [8]. The advantage of this method is obtaining AUV model by identifying instead of engaging with complex modeling relationships using mathematics, but in this reference, noise of sensors or interruptions of signal in GPS was not considered.

Division of AUV system into several sub-systems using an optimal control chosen from database have been proposed in reference [9]. Resistant to noise ratio is an advantage for offered method and coupling effect that can cause instability by sudden change of depth and direction of AUV is the disadvantage of the proposed method.

The fourth category includes documents that have been used nonlinear control methods to control trajectory of robots. As an example, using nonlinear controller based on Lyapunov theorem and back stepping method has been presented in [10]. All over convergence of the real path to the desired path, overcoming to singularity problem and route followers in any way are its advantages, and non-causal relationship obtained in controller design, is one of its disadvantages.

Using nonlinear controller based on Lyapunove and back stepping method with nonlinear and coupled model has been proposed in [11]. Reduce of tracking error is the benefit of method and ignoring external disturbance and noise of sensors are some limitations of this algorithm.

The fifth category includes documents that have been used adaptive control methods for submarine robot control. Use of a DOB adaptive control includes a DOB as the inner loop and an adaptive non-recursive as outer loop controller has been proposed in [12]. No need to define parametric data and robustness to noise and undesirable changes of nominal model, are advantages of this method.

Using adaptive controller with neural network and SOM learning algorithms have been mentioned in [13].

The disadvantage of this method is that information of initial states during adaptive process, which reduces the impact of learning, disappears. In table 1, a comparison of these controlling techniques has been proposed.

Table.1.
Comparison of underwater robots controlling methods

Control Methods	***Sensitivity Uncertainty***	***Using toMathematical Relationships***	***Accuraciy***	***Speed***	***Mathematical model***
Intelligent Control [8-11]	No	Not always	Low	High	Commonly used
Nonlinear Control [12-13]	No	Usually	High	Average	Used
Optimal Control [10]	Yes	Usually	Low	Low	Used
Adaptive Control [13]	No	Sometimes	High	High	Commonly used
Linear Control [14]	Yes	Usually	Low	Low	Used

In this paper, we propose and apply terminal sliding mode controller. As it is mentioned, sliding mode controller, despite of high efficiency has numerous flaws. In this paper, a Terminal Sliding Mode controller (TSMC) is applied to reduce or eliminate the flaws that reduces the convergence time. Also in dealing with uncertainties in the model and external disturbances, TSMC is more robust and does not limited by singularity at the origin.

In second section, we will discuss the mathematical model of system, control design is presented in the third section and in the fourth section, the simulation results are illustrated.

2. Phoenix dynamic system introduction

In this paper, to control the robot path in the horizontal plane that is an example of nonlinear MIMO systems, the variables of location and position of a two-dimensional model of a MIMO AUV called Phoenix Build in NPS Research Center is considered in horizontal plane. Two steering wheels in the front and rear of the vehicle are used as control input. The inertial coordinate frames of system can be seen in Fig1.

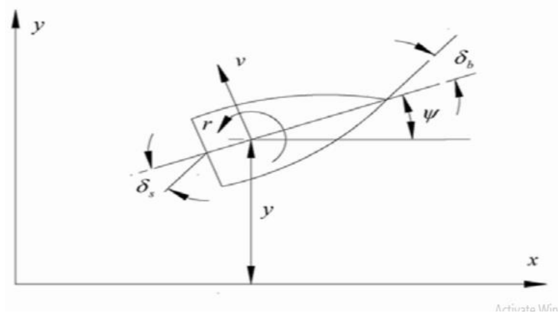


Fig. 1. Inertial coordinate frame of Phoenix system

Later, in this paper, a system with nonlinear SISO equations is considered for depth control of robot.

A) Mathematical model-AUV equations of motion in horizontal plane

In horizontal plane, mathematical model contains Sway (horizontal motion to the longitudinal axis of the body) and Yaw (rotational motion to the vertical axis) equations of motion. Which according to [14] can be expressed as follows:

$$\dot{v}[\mathrm{m}-\mathrm{Y}\dot{v}]+\dot{r}[\mathrm{m}x_G-\mathrm{Y}\dot{r}]=Y_{\delta s}\delta_S u^2+Y_{\delta b}\delta_b u^2-d_1(\mathrm{v},\mathrm{r})+Y_v\,\mathrm{uv}+(Y_r-\mathrm{m})\,\mathrm{ur} \quad (1)$$

$$\dot{v}[\mathrm{m}\,x_G-\mathrm{N}\dot{v}]+\dot{r}[I_z-\mathrm{N}\dot{r}]=N_{\delta s}\delta_S u^2+N_{\delta b}\delta_b u^2-d_2(\mathrm{v},\mathrm{r})+N_v\,\mathrm{uv}+(N_r-\mathrm{m}x_G)\,\mathrm{ur} \quad (2)$$

Where d1 (v, r) and d2 (v, r) are hydrodynamic coefficients which are defined as follows and within maritime patrol their amounts are small and can be ignored.

$$d_1(\mathrm{v},\mathrm{r})=\frac{\rho}{2}\int_{tail}^{nose} c\,D_y\,\mathrm{h}(\varepsilon)\,\frac{(v+\varepsilon r)\text{^}3}{|v+\varepsilon r|}\,\mathrm{d}\varepsilon \quad (3)$$

$$d_2(\mathrm{v},\mathrm{r})=\frac{\rho}{2}\int_{tail}^{nose} c\,D_y\,\mathrm{h}(\varepsilon)\,\frac{(v+\varepsilon r)\text{^}3}{|v+\varepsilon r|}\,\mathrm{d}\varepsilon \quad (4)$$

By substituting the following parameters in equation (1), (2) and regardless of d1 and d2 complete equations of motion in the horizontal plane can be obtained.

Table.2.
Values of parameters

Moreover, the equations of motion in the horizontal plane as follows.

$$\begin{aligned}
&\dot{v}=a_{11}\,\mathrm{uv}+a_{12}\,\mathrm{ur}+d_v(\mathrm{v},\mathrm{r})+b_{11}u^2\delta_S+b_{12}u^2\delta_b\\
&\dot{r}=a_{21}\,\mathrm{uv}+a_{22}\,\mathrm{ur}+d_r(\mathrm{v},\mathrm{r})+b_{21}u^2\delta_S+b_{22}u^2\delta_b\\
&\dot{\psi}=\mathrm{r}\\
&\dot{x}=\mathrm{u}\cos\psi-\mathrm{v}\sin\psi\\
&\dot{y}=\mathrm{u}\sin\psi+\mathrm{v}\cos\psi
\end{aligned} \quad (5)$$

Where a_{ij} and b_{ij} are coefficients calculated by setting the parameters in v̇ and ṙ equations. In addition, their amount are:

$$a_{ij}=\begin{bmatrix}-1.4776 & -0.3083\\ -1.8673 & -1.2682\end{bmatrix}\ b_{ij}=\begin{bmatrix}0.2271 & 0.1454\\ -1.9159 & 1.2112\end{bmatrix}$$

In addition, fixed variable u is equal to three. Taking time derivative of the equation ψ̇ and ẏ and substituting the equation v̇ and ṙ in them, desired equation is obtained in terms of acceleration as follows:

$$\ddot{y}=\mathrm{u}\,\dot{\psi}\cos\psi+(a_{11}\,\mathrm{uv}+a_{12}\,\mathrm{u}\dot{\psi}+b_{11}u^2\delta_S+b_{12}u^2\delta_b)\cos\psi-\mathrm{v}\,\dot{\psi}\sin\psi \quad (6)$$

$$\ddot{\psi}=a_{21}\,\mathrm{uv}+a_{22}\,\mathrm{ur}+b_{21}u^2\delta_S+b_{22}u^2\delta_b$$

The matrix form of equations is as follows:

$$\binom{\ddot{y}}{\ddot{\psi}}=\begin{bmatrix}a_{11}\mathrm{u}\cos\psi-\mathrm{r}\sin\psi & \mathrm{u}\cos\psi+a_{12}\mathrm{u}\cos\psi\\ a_{21}\,\mathrm{u} & a_{22}\,\mathrm{u}\end{bmatrix}\binom{v}{r}+\begin{bmatrix}b_{11}u^2\cos\psi & b_{12}u^2\cos\psi\\ b_{21}u^2 & b_{22}u^2\end{bmatrix}\binom{\delta_S}{\delta_b} \quad (7)$$

In the above equation as control inputs are δs and δb .

B) Mathematical model-Dynamic model of robot in depth plane:

In equations of motion in depth plane due to large centres of buoyancy and gravity, amount of roll (∅) and screw (θ) angles are almost zero and this features makes separate vertical motion of vehicle from its motion in horizontal plane. Thus, equations of motion in the depth plane has the following form.

$$\mathrm{M}\,\ddot{z}+\mathrm{c}\dot{z}|\dot{z}|+\mathrm{d}=\mathrm{u} \quad (8)$$

$$\ddot{z}=m^{-1}.(\mathrm{U}-(\mathrm{C}.\dot{z}.|\dot{z}|+\mathrm{d})) \quad (9)$$

Where u is control input (motive force), d is disturbance created by external forces, c defines hydrodynamic coefficient of damping and m is the mass of vehicle with added mass. Moreover, we consider the following assumptions:

Assumption 1: m (t) is time variant, unspecified but limited and positive
$0<\mathrm{m}_{\min}\le \mathrm{m}(t)\le \mathrm{m}_{\max}$

Assumption 2: c (t) is time variant, unspecified but limited
$c_{\min}\le c(t)\le c_{\max}$

Assumption 3: d(t) is time variant. In addition, the values of parameters in the model are:
m=55kg , m=m(1+0.5sin(0.1πt) and C=270kg/m , C= C (1+0.5sin(0.1πt)

3. Terminal sliding mode control method

Consider the following second order multiple-input-multiple-output nonlinear system:

$$\ddot{x}(t)=f(x,\dot{x},t)+g(x,\dot{x},t)\cdot u(t)+d(t) \quad (10)$$

Where x and ẋ are measurable state variables, u(t) is control signal and d(t) is external noise. d(t) is unspecified but its amplitude is limited. Also, time variant nonlinear functions f (x,(x,) ̇t) and g (x,(x,) ̇t)are uncertain. Physical causes of uncertainty and uncertainty can be, for example, the crime problem or hydrodynamic coefficients device. Uncertainty and uncertainty in the system, can be done in different initial conditions, as well as changing the parameters can also be an undetermined cause that is supposed to do, and with a low frequency sinusoidal variations are taken into account, ie if parameter P changes in P (t) = P + asin ωt is shown.

A) Horizontal motion control using terminal sliding mode control:

With the aim of tracking the optimal path [y_d , ψ_d]= [2 sin t ,sin t] new sliding surfaces $S_1$and S_2 are selected as follows:

$$S_1(t) = e_1(t) + \beta|\dot{e}_1(t)|^{\gamma}\, \text{Sign}(\dot{e}_1(t)) = 0 \quad (11)$$

$$S_2(t) = e_2(t) + \beta|\dot{e}_2(t)|^{\gamma}\, \text{Sign}(\dot{e}_2(t)) = 0$$
$$\text{As } 1<\gamma<2,\ \beta>0,\ e_1 = y - y_d,\ e_2 = \psi - \psi_d \quad (12)$$

Moreover, sliding surface dynamics is selected as follows:

$$\dot{s}_1 = -K_1 S_1(t) - K_2\, \text{Sig}(S_1)^P \quad (13)$$

$$\dot{s}_2 = -K_1 S_2(t) - K_2\, \text{Sig}(S_2)^P$$
$$0 < P < 1,\ \text{Sig}(S)^P = |S|^P\, \text{Sign}(S) \quad (14)$$

And switching gains, Ki must be chosen such that guarantee level achievement in limited time, so Ki s in equations aboveshoud satisfy the following condition[*]:

$$\text{Min}(K_i) \geq \|F - F_o + (G - G_o)u\| + \|d\| + \eta \quad (15)$$

As d is disturbance, Go and Fo are nominal values and G, F, η are constant values.(so $K_1 > 0$, $K_2 > 0$)
Terminal sliding mode controller of two parts:

- Stage level of the equation $\dot{s} = -k_1 s(t) - k_2 sig(s)^p$ is obtained and correction control or the law is, and when comes in that mode separated from the system.
- Stage slip on the surface of the equation $s = 0$ is obtained and the control of the state is called into action when the system is on. Now based on proposed sliding surface , Robust Control rule will be defined as follows :

$$U_1 = b_1^{-1}(y, \dot{y}, t)\,(-f_1(y, \dot{y}, t) - d_1(t) + \ddot{y}_d(t) + \beta^{-1}\gamma^{-1}\, \text{sig}(\dot{e}_1)^{2-\gamma} + k_1 s_1 + k_2\, \text{sig}(s_1)^P) \quad (16)$$

$$U_2 = b_2^{-1}(\psi, \dot{\psi}, t)(-f_1(\psi, \dot{\psi}, t) - d_2(t) + \ddot{\psi}_d(t) + \beta^{-1}\gamma^{-1}\, \text{sig}(\dot{e}_2)^{2-\gamma} + k_1 s_2 + k_2\, \text{sig}(s_2)^P) \quad (17)$$

B) Depth control of vehicle by using of terminal sliding mode control

Sliding surface S whit aim of tracking desired path z_b = 0.5 . (1-sin(0.1 . π .t)) is described as:

$$S(t) = e(t) + \beta\, |\dot{e}(t)|^{\gamma} \text{sign}(\dot{e}(t)) = 0$$
$$1 < \gamma < 2,\ \beta > 0,\ e = z - zb \quad (18)$$

In addition, dynamic of level sliding achievement have been selected as follows:
$\dot{s}(t) = -K_1 S(t) - K_2\, sig(S)^p$

Where
$K_1 > 0$, $K_2 > 0$, $0 < P < 1$, and $\text{Sig}(S)^P = |S|^P\, \text{Sign}(S)$

Now, based on sliding level and dynamic of sliding level achievement, Robust Control Act of attention to what was said will be defined as follows.

$$U = b^{-1}(z, \dot{z}, t)(-f(z, \dot{z}, t) - d(t) + \ddot{z}_b + \beta^{-1}\gamma^{-1}\, \text{sig}(\dot{e})^{2-\gamma} + k_1 s + k_2\, \text{sig}(s)^P \quad (19)$$

4. Simulation and results

In this section with regardless of input noise, the results for two controlling methods will be investigated, at first we consider classic sliding mode controller and after that, we discuss the results with terminal sliding modes controller.

A) Simulation results of classic sliding mode controller with regardless of noise, for horizontal motions defined in figures 2 to 4.

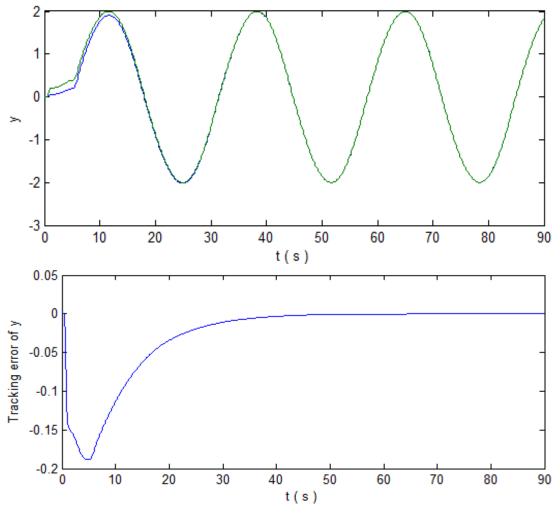


Fig. 2. Motion in direction of y and The tracking error in initial state of y(0) = 0 , ψ (0) = 0

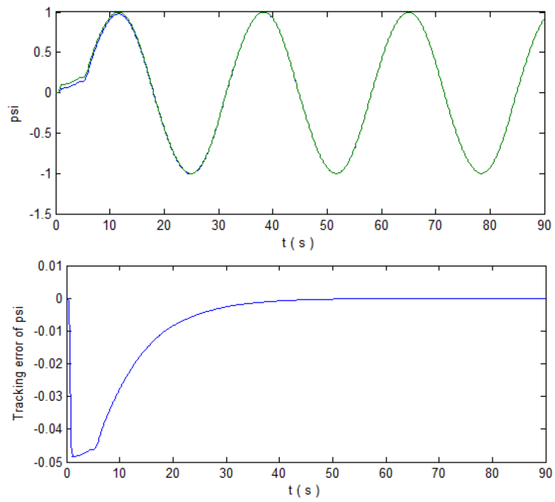


Fig. 3. Yaw angular position along error in initial state of y(0) = 0 , ψ (0) = 0

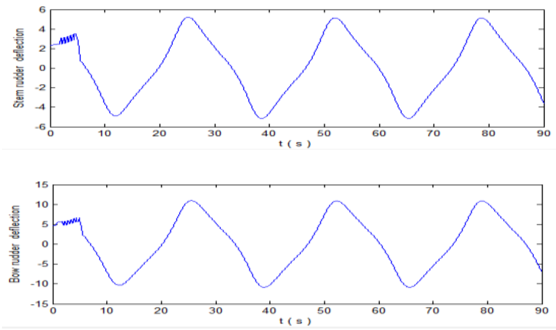


Fig. 4. Deviation of steering wheels in front and rear of the vehicle in initial state of y(0)=0 , ψ (0)=0

According to Figure 2 and 3, the optimization results of applying the sliding mode controller with boundary layer noise regardless of the initial conditions of zero can be seen. The tracking error direction y, after 30 seconds and the tracking error of the yaw angular position after 35 seconds follow the desired path. With respect to Figure 4, which shows the deflection of the rudder front and rear of the vehicle as control inputs are considered, it is observed that there are fluctuations in the first control signal that is not appropriate.

B) Simulation results of applying terminal sliding mode controller with regardless of noise, for horizontal motion is considered and illustrated in figures 5 to 7.

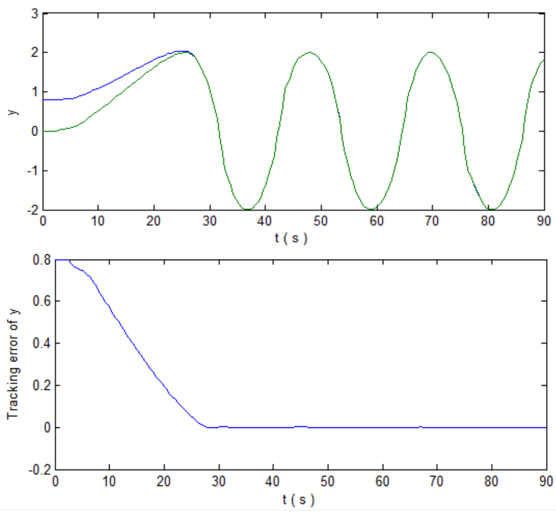


Fig. 5. The tracking error in y axis direction with initial states y(0) = 0 and ψ (0) = 0

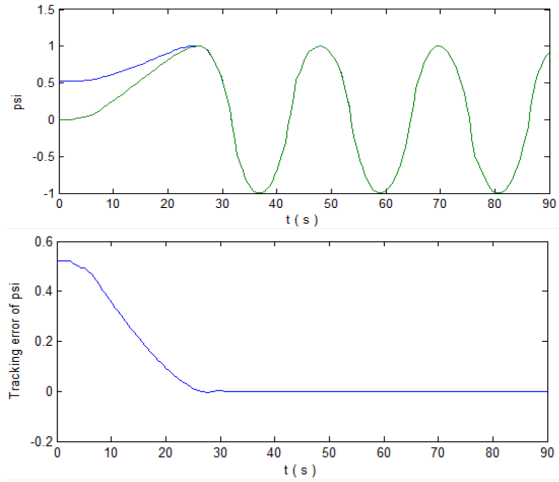


Fig. 6. Yaw angular position and its related tracking error for initial state of y(0) = 0 , ψ (0) = 0

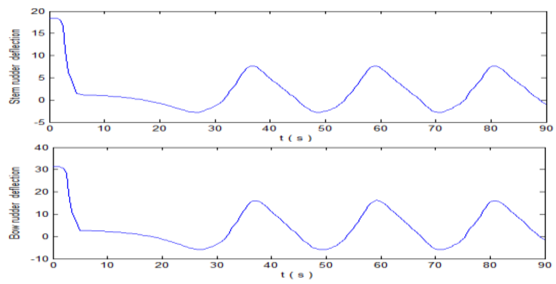


Fig. 7. Deviation of steering wheels in front and rear of the vehicle for initial state valuesy(0)=0 , ψ (0)=0

According to Figure 5 and 6, thereby optimizing control of the terminal sliding mode regardless of the noise in the initial conditions of zero can be seen. As can be seen, the tracking error direction y, after 20 seconds and the tracking error of the yaw angular position after 15 seconds, which follow the desired path of the sliding mode controller, has better performance classic. Also with respect to Figure 7, which represents the deviation of the front and rear wheels as a control input device are considered, it is observed that at the beginning of the control signal oscillations is reduced and the control performance has been improved.

Considering that in addition to external disturbances to the system, the system also creates unspecified parameters in the system. This section examines the noise and chaos of the system and the ability of the classical sliding mode controller and sliding mode control terminal in the face of uncertainty and discuss uncertainties and noise. To move horizontally, up to 0.03 domain y (to the vehicle) and ψ (angular position) is applied, as well as for vertical movement (depth) with a range of 0.03 to noise z (depth displacement) is applied.

C) Simulation results of using classic sliding mode control considering the noise, for horizontal motion

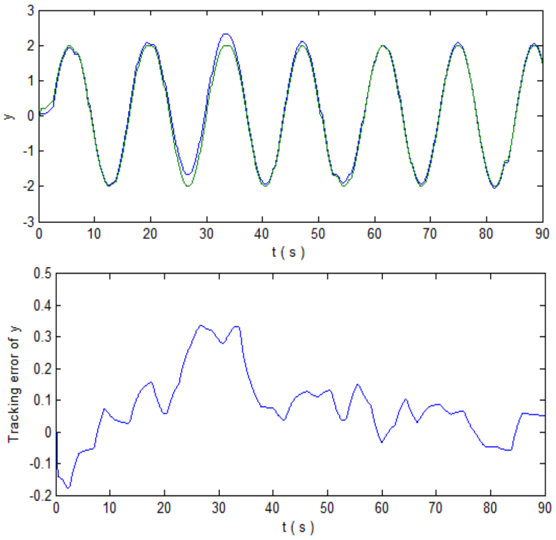


Fig. 8. Motion in direction of y and The tracking error along with noise in initial state of y(0) = 0 , ψ (0) = 0

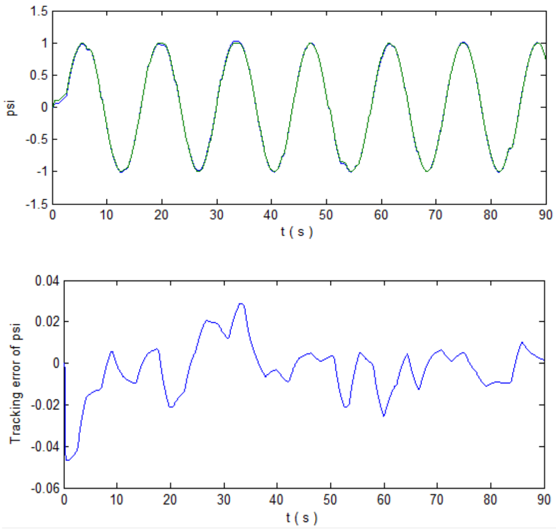


Fig. 9. Yaw angular position along with error and noise in initial state of y(0) = 0 , ψ (0) = 0

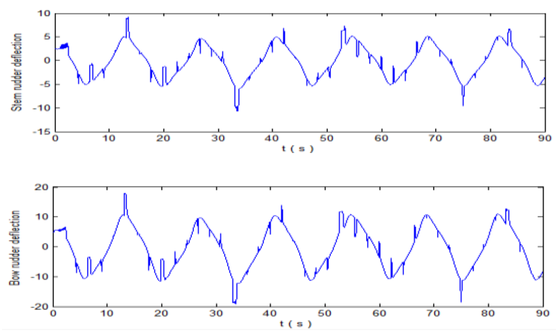


Fig. 10. Deviation of steering wheels in front and rear of the vehicle along with noise in initial state of y(0)=0 , ψ (0)=0

When the noise logged in results in the form of the initial conditions of zero (according to Fig. 8 and 90), the tracking error for the direction y has caused major distortions in the range of 0.6. The tracking error of the yaw angular position has distortion as well as the range is 0.08 to Figure 10, the control signal is a high volatility. Therefore, the optimal path tracing performed correctly reflects the weakness of the controller against noise.

D) Simulation with use of terminal sliding mode control with regard of noise, for horizontal motion

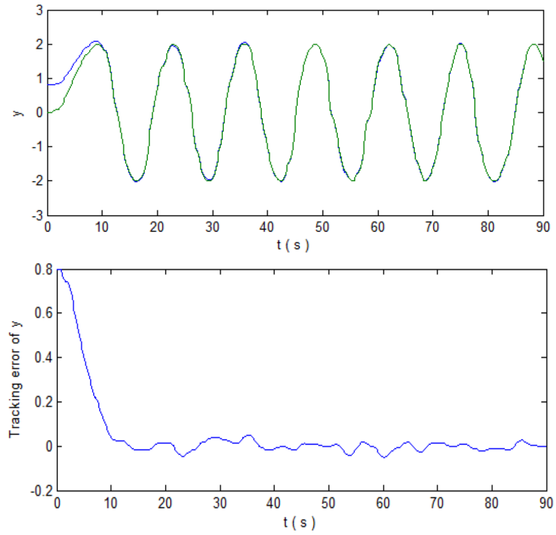


Fig. 11. Motion in direction of y and The tracking error along with noise in initial state of y(0) = 0 , ψ (0) = 0

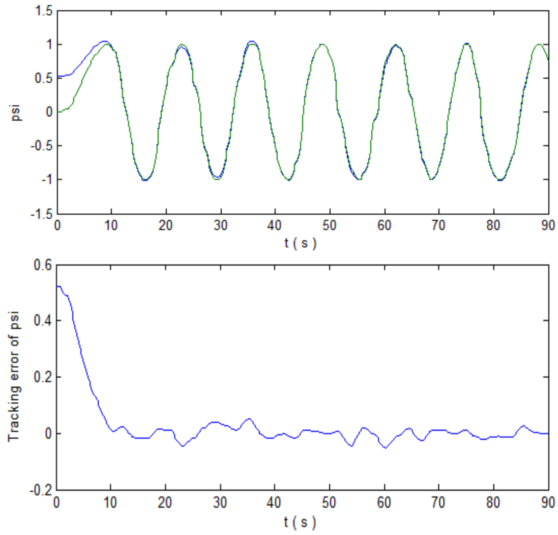
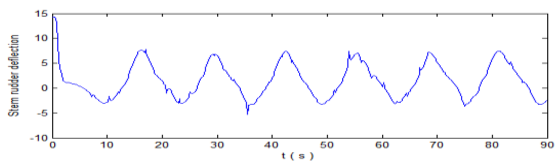


Fig. 12. Yaw angular position alongwith error and noise in initial state of y(0) = 0 , ψ (0) = 0



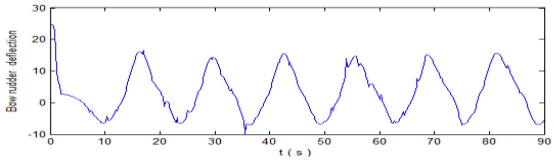


Fig. 13. Deviation of steering wheels in front and rear of the vehicle along with error in initial state of $y(0)=0$, $\psi(0)=0$

According to Fig. 11 and 12 can be seen that the initial conditions of zero tracking error for the direction of travel as well as the tracking error of the angular position of the yaw also distorted, but the distortion is reduced and, respectively, 0.03 and 0.02 as well as the in Figure 13, the control signal is fluctuating. However, the number of fluctuations decreased, which indicates the robustness of the sliding mode controller blocks in front of the noise.

E) Simulation with use of classic sliding mode control with regardless of noise, for depth motion

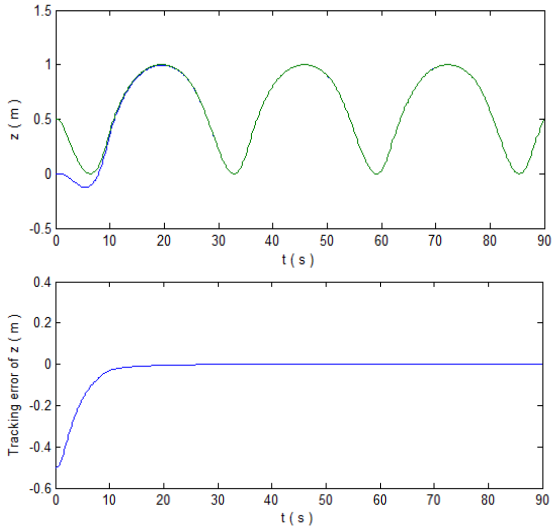


Fig. 14. Figure14: vertical motion (depth) along with tracking error with regardless of noise in initial state of z (0)= 0

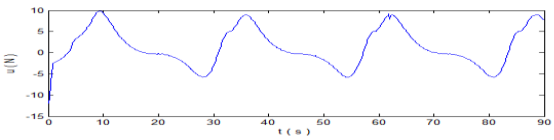


Fig. 15. Controlling input (motive force) in initial state z (0)= 0

The initial conditions zero according to the 14 observed that the tracking error of the displacement depth z (m) After 20 seconds of zero and response system to follow the desired path. Also due to figure 15 can be seen that the control signal control performance is acceptable but there is a buzz in the beginning a little signal, which is not appropriate.

F) Simulation with use of terminal sliding mode control with regardless of noise, for depth motion

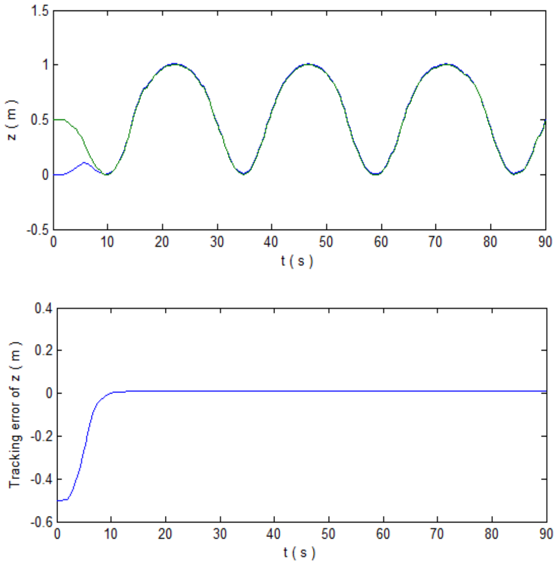


Fig. 16. vertical motion (depth) along with tracking error in initial state of z (0)= 0

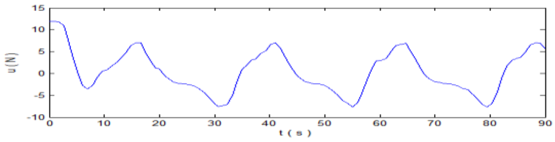


Fig. 17. controlling input (motive force) in initial state z (0)= 0

The initial conditions zero according to the 16 observed that the tracking error of the displacement depth z (m) After 15 seconds of zero and response system to follow the desired path. Moreover, due to figure 17, the control signal has an acceptable control performance and signal the beginning of fluctuation is reduced.

G) Simulation with use of classic sliding mode control with regard of noise, for depth motion

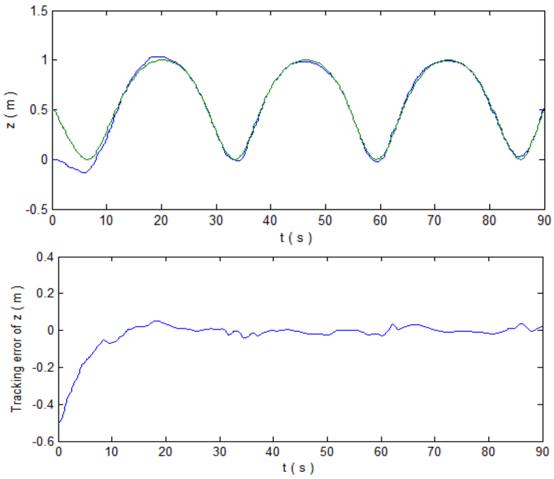


Fig. 18. vertical motion (depth) along with tracking error and regard of noise in initial state of z (0)= 0

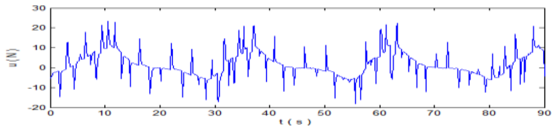


Fig. 19. controlling input (motive force) along with noise in initial state of z (0)= 0

When the noise to the system applies the results is that the initial conditions of zero according to the 18 tracking error of the displacement depth z (m), with distortion and approximately after 20 seconds the optimal path to follow that practice not the right track. In addition, according to the 19 observed that the control signal does not have high volatility and good control performance. This high volatility reflects the weakness of the controller to deal with the noise.

H) Simulation with use of terminal sliding mode control with regard of noise, for depth motion

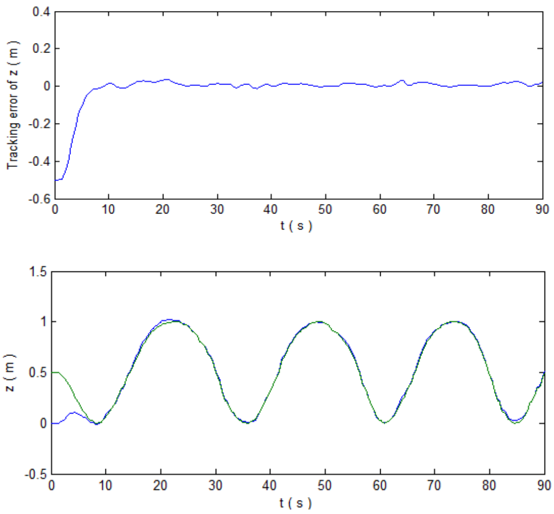


Fig. 20. vertical motion (depth) along with tracking error and noise in initial state of z (0)= 0

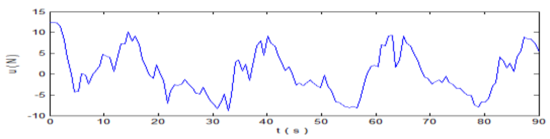


Fig. 21. controlling input (motive force) along with noise in initial state of z (0)= 0

The initial conditions of zero, according to the 20 observed that the tracking error of the displacement depth z (m) has a distortion. Nevertheless, the range of distortions of the classic fashion Asladyng dropped controller and system response after 10 seconds Msyrmtlvb motivation to pursue better tracking performance than classical sliding mode. As well as with regard to the 21 observed that the control signal has lower volatility, but volatility of classic fashion sliding controller. In addition, to control classical sliding mode control function is more acceptable.

5. Conclusions

Sliding mode control signal is composed of two parts: New equation obtained and correction control or the law separated from the state system. Feature is that it affects the turbulence on. Moreover, the next phase slip on the surface of the equation called into action when the system is on. This feature is that it does not affect the noise.

According to the results, and as previously stated, terminal sliding mode controller of the classic sliding mode controller, in the face of uncertainties in model and more resistant to external disturbances as well as convergence error

Track toward zero, the more limited guarantees. The main difference between the classical sliding mode controller and sliding mode control terminal is the optimum route convergence time in the terminal sliding mode controller, the faster the classical sliding mode controller and the reason is that the sliding mode controller Classical equation slip plate so that the answer is a structural view. In other words, the dynamics of an error when placed on the screen, when you reach the desired point of view of their structure. However, the terminal sliding mode controller, the slip texture deficit equation page, and proved to be a mathematical proof that dynamic error when placed on the surface. When you reach the desired point of view not as optimal route convergence time, will be faster.

In this paper, the robustness of the sliding mode control terminal of the classic sliding mode controller against noise, correction control. In this case, when the noise correction control is affected, then the time to reach the lower level is unaffected by the noise is lower, resulting in higher system robustness against noise.

Since the sliding mode controller terminal's structural deficit, one of the main problems with the terminal sliding mode controller, Syngvlaryth control signal at the origin or the source is infinite. In this paper a new sliding surface with Sign gamma limit between one and two (one $<\gamma<$ two) has been solved. Also due to the structure of the control signal, Syngvlaryth of origin will not happen again. Moreover, it is the first time that control a robot for underwater path of a terminal using sliding mode controller.

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