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Research And Design Of Guidance And Control System For Unmanned Surface Vessels

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Abstract

This asymed drone controller is indispensable for two components: Guidance and Controller. In which the Ministry of Guidance will receive waypoints from which to form an orbit then combine the data with the current location of the vessel, thereby calculating and also supplying the controller to drive the vehicle to follow the outlined trajectory. This article will use the Line Of Sight (LOS) algorithm to design the Guidance and Controller sets. The result as well as the effectiveness of the controller will be shown through matlab/SIMULINK simulation.

Keywords: *Guidance, Unmanned Surface Vessels, PID, Controller.*

1. Overview of guidance and control system

An asymed drone controller is a type of remote control that can be used to fly and maneuver an unmanned aerial vehicle This type of controller allows a pilot to control the drone without having to use a traditional joystick-style controller. Instead, the pilot uses a combination of buttons, switches, and sensors to control the drone’s movement. Asymmed controllers are becoming increasingly popular for UAVs due to their ease of use and the ability to provide hands-free operation. In this article we will focus on learning "guidance for path following". A lot of methods have been put to research for this problem, among which the most commonly seen methods are Line of Sight (LOS). Line of Sight is the simplest method, but many experiments and practical applications have proven its effectiveness in special road grip systems when used for surface boats. The L.A. [1] system is often combined with the heading autopilot system to calculate the appropriate steering wheel angle or rotation torque or, in other words, combined with the control system to create the corresponding moment force that can direct the vehicle to the desired heading angle, the entire system is then passed through the ship's dynamic model to return its position and velocity as figure 1[2].

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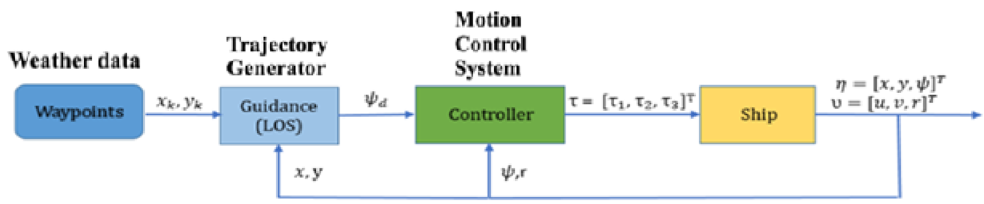

Figure 1. Guidance and control system block diagram

Table 1. Definition of variables in a six-order system of degrees of freedom

Freedom Tier	Description of motion	Force and moment	Linear velocity and angular velocity	Euler position and angle
1	Motion in *the x* (surge) method	*F*	*u*	*x*
2	Movement in *the* method (sway)	*Y*	*v*	*y*
3	Motion in *z-mode* (heave)	*Z*	*w*	*z*
4	Rotation around *the x-axis* (roll, heel)	*K*	*p*	ϕ
5	Rotation around *the y-axis* (pitch, trim)	*M*	*q*	θ
6	Rotation around *the z-axis* (yaw)	*N*	*r*	ψ

2. Research and design controllers for surface vessels

2.1 Directing in a straight trajectory

2.1.1 Clinging to the road on a horizontal plane.

When considering the means of transportation on the water or in other words, the cylinder horizontal plane, we will have the dynamic equation for the vessel when it will be [3].

$$\begin{cases} \dot{x} = ucos(\psi) - vsin(\psi) \\ \dot{y} = usin(\psi) + vcos(\psi) \\ \dot{\psi} = r \end{cases} \tag{1}$$

The total speed of the vessel is considered horizontally as

$$U = \sqrt{u^2 + v^2} \tag{2}$$

with $U_{\min} \leq U \leq U_{\max}, 0 < \mathrm{U}_{\min}$

Depending on the ship structure, the U velocity and R convergence radius are appropriately selected so that when the train moves through the waypoint there will be a small inerity, ensuring the deviation of the path is within the permitted range [4].

Assume that a vehicle is being converged to a two-point reference point connector (way-point) $wp_{t_k} - wp_{t_{k+1}}$, error along track (x_e) and cross track (y_e) of the vessel then defined by the:

$$\begin{bmatrix} x_e \\ y_e \end{bmatrix} = R^T(\alpha_p) \begin{bmatrix} x - x_k \\ y - y_k \end{bmatrix} \quad (3)$$

In it x_k, y_k is the location of the kth waypoint in the coordinate system NED (k = 1 … N); x, y is the current position of the ship in the coordinate system NED; R^T is the inerity matrix in coordinate transfer, defined by the formula:

$$R(\alpha_p) = \begin{bmatrix} cos(\alpha_P) - sin(\alpha_P) \\ sin(\alpha_P)\, cos(\alpha_P) \end{bmatrix} \in SO(2) \quad (4)$$

When deployed, we will have:

$$x_e = (x - x_k)\, cos(\alpha_P) + (y - y_k)\, sin(\alpha_P)$$
$$y_e = -(x - x_k)\, sin(\alpha_P) + (y - y_k)\, cos(\alpha_P) \quad (5)$$

With $\alpha_P$is a route angle defined by the formula

$$\alpha_p = \text{atan2}(y_{k+1} - y_k, x_{k+1} - x_k) \quad (6)$$

The purpose is to control cross track errors within the permitted limits or in other words:

$$\lim_{t\to\infty} y_e(t) = 0 \quad (7)$$

Note that for those applications where its algorithm has a time constraint we need to further limit errors along track (x_e) about the convergence radius and if we only consider the path following problem, we only need to control (y_e).

2.1.2 Guidance algorithm LOS.

Depending on the purpose of the application, means of use or navigation methods, L.A. vectors can be defined in a variety of ways. Specifically in the path following application for overwater vehicles, LOS is considered as a vector with an initial point placed at the center of the boat and an end point located at a point (x_{los}, y_{los}) on a 2-point tangling waypoint p_k và p_{k+1}. Point position (x_{los}, y_{los}) will be a perpendicular projection point of the train on the tang route (intersection point y_e and desired line) a distance Δ > 0. Depending on the dynamic characteristics of the vessel or the concern is the accuracy or performance we choose Δ appropriately [5]. Considering Δ is a constant, the smaller the Δ value, the faster the vehicle converges to the desired trajectory, but the heading angle will change continuously many times, requiring the angle of the steering wheel or rotational torque to change continuously accordingly, the system can respond not in time and the increased response time prolongs the process of going through the trajectory of the vehicle [6]. To solve the above problem, one can consider Δ value changes over time from small to large [7].

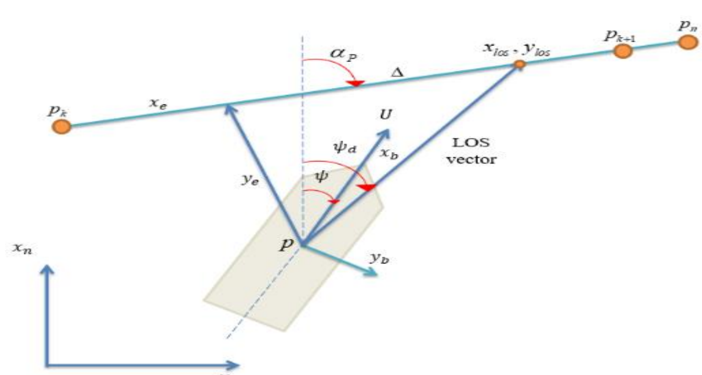

Figure2. Model for L.A. vector of ship in case of no angle considerationsideslip β

As figure 2, we can determine the desired heading angle of the vessel according to the formula:

$$\psi_d = \alpha_p + arctan(\frac{-y_e}{\Delta}) \quad (8)$$

Note: in reality, when the train moves, there will be external forces such as wind, flow ... or unwanted interference that makes the vessel should have moved in the way of the heading angle will be deviated from adding a small angle component sideslip β [8].

Then the formula (8) becomes:

$$\psi_d = \alpha_p + arctan(\frac{-y_e}{\Delta}) - \beta \quad (9)$$

with β defined as $\beta = atan2(v, u)$ We will assess the impact β external forces from the environment (namely, wind, flow) on the quality of the system in the simulation below.

Take the derivative of y_e in a formula (5) I can:

$$\begin{aligned} \dot{y}_e &= -\dot{x}\, sin(\alpha_p) + \dot{y}\, cos(\alpha_p), \\ &= -(u\, cos(\psi) - v sin(\psi))\, sin(\alpha_p) \\ &\quad +(u\, sin(\psi) + v\, cos(\psi))\, cos(\alpha_p), \\ &= u\, sin(\psi - \alpha_p) + v\, cos(\psi - \alpha_p) \end{aligned} \quad (10)$$

Transform the formula (9) in the form of the phase amplite we receive:

$$\begin{aligned} \dot{y}_e &= \sqrt{u^2 + v^2}\, sin(\psi - \alpha_p + \beta) \\ &= U\, sin(\psi - \alpha_p + \beta) \end{aligned} \quad (11)$$

If you consider that the actual heading angle is almost following the desired heading angle, we can consider:

$$\dot{y}_e = U_h \frac{-y_e}{\sqrt{{\Delta_h}^2 + {y_e}^2}} \quad (12)$$

Select function Lyapunov $V_1 = \frac{1}{2}{y_e}^2$

Take the derivative we have

$$\dot{V}_1 = U_h \frac{-y_e}{\sqrt{{\Delta_h}^2 + {y_e}^2}} < 0 \quad \text{với } U_h > 0 \quad (13)$$

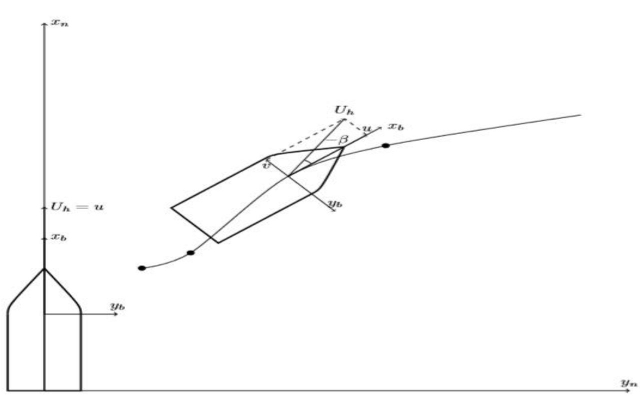

Figure3. Angular component sideslip when there is an external force

We can solve the problems that Δ network distance as mentioned above by building Δ as a variable with values that change over time:

$$\Delta = (\Delta\, e^{-K_\Delta y_e^2} +_{min} min_{max} \quad (14)$$

In it Δ_{max}, Δ_{min} and constants that show convergence rate K_Δ can choose from ship model or experimental word.

2.2 Curved orbital navigation

Assume that the media is converging on the drawn reference curve with coordinates $x_d(\theta)$, $y_d(\theta)$ error along track (x_e) and cross track (y_e) of the vessel then defined by the formula [9]:

$$\begin{bmatrix} x_e \\ y_e \end{bmatrix} = R^T(\alpha_p) \begin{bmatrix} x - x_d(\theta) \\ y - y_d(\theta) \end{bmatrix},$$

In it $x_d(\theta)$, $y_d(\theta)$ is the coordinates of the drawn curve according to the inferning that from this coordinate we can build a tang route to identify the remaining components; x, y is the current position of the ship in the coordinate system NED; R^T is the inverse matrix of the rotation matrix in the coordinate system transfer, defined by the formula [10]:

$$R(\alpha_p) = \begin{bmatrix} cos(\alpha_p) - sin(\alpha_p) \\ sin(\alpha_p)\, cos(\alpha_p) \end{bmatrix} \in SO(2),$$

When deployed, we will have:

$$x_e = (x - x_d(\theta))\, cos(\alpha_p) + (y - y_d(\theta))\, sin(\alpha_p),$$
$$y_e = -(x - x_d(\theta))\, sin(\alpha_p) + (y - y_d(\theta))\, cos(\alpha_p),$$

For each point on the curve, we can identify a tangent vector of it, when dividing the curve into very small segments, we can see it as a straight segment that coincides with the method of the tangent vector. At that time $tan(\alpha_p)$ is the angle of vector tangential or otherwise is the 1st derivative of y in x at 1 point on the curve. As defined by the combined derivative, we define the angle α_p as follows [11].

$$\alpha_p = \text{atan2}(y_d'(\theta), x_d'(\theta)) = arctan(\frac{y'_d(\theta)}{x'_d(\theta)})$$

The purpose is to control cross track errors within the permitted limits or in other words:

$$\lim_{t\to\infty} y_e(t) = 0,$$

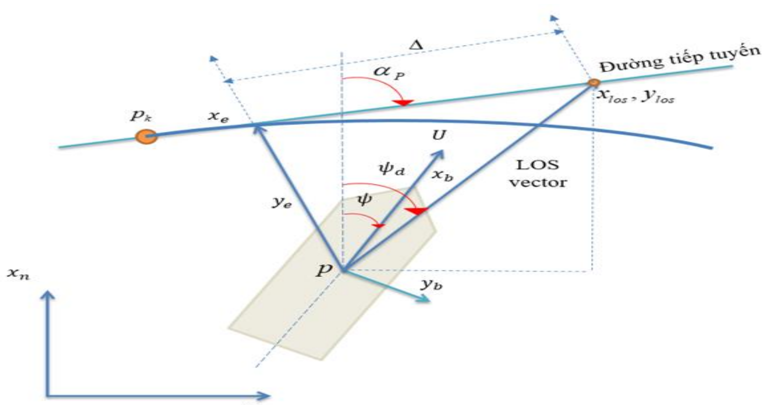

Figure 4. The model for the L.A. vector of boats does not take into account the angle component β

As figure 4, we can determine the desired heading angle of the vessel according to the formula:

$$\psi_d = \alpha_p + arctan(\frac{-y_e}{\Delta}) \quad (15)$$

Note: in reality when the train moves there will be wind components or undesirable external forces that make the vessel should have moved in the direction of the heading angle will be deviated by a small corner component sideslip β [12].

Then the formula (15) becomes:

$$\psi_d = \alpha_p + arctan(\frac{-y_e}{\Delta}) - \beta$$

With β is defined as$\beta = \text{atan2}(v, u)$

3. Perform simulations in combination with controllers and evaluations

Matlab is one of the most popular software used for analysis, design and simulation of automatic control systems. In this experiment, students use Matlab's commands to analyze the system such as considering the stability of the system, transient characteristics, set errors. We in turn apply navigation algorithms to the controllers designed above for simulation and evaluation of results. Choose an orbit that is a generalized zig-zac line and the desired velocity is 1m/s.

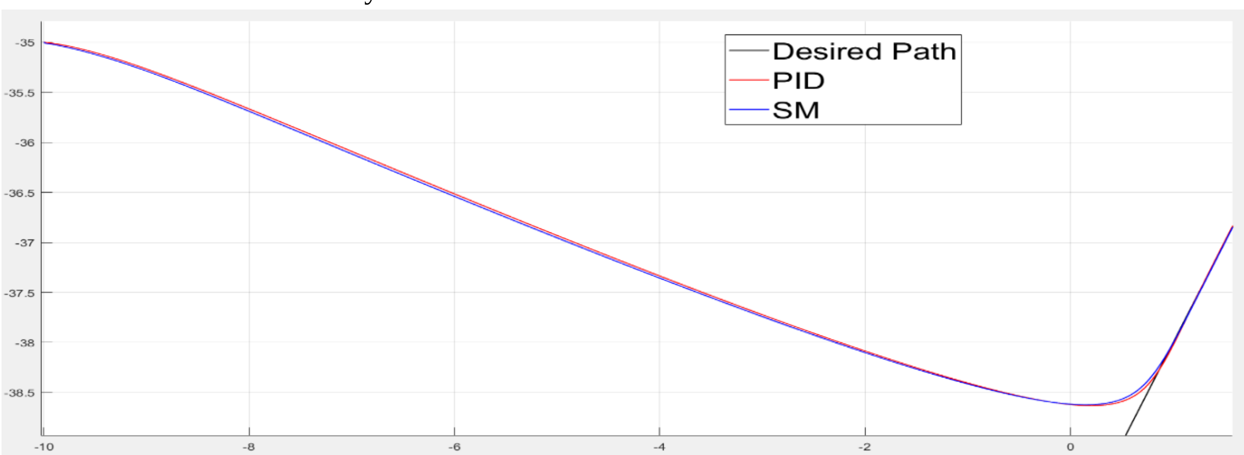

Figure 5. Compare the convergence of lines between controllers

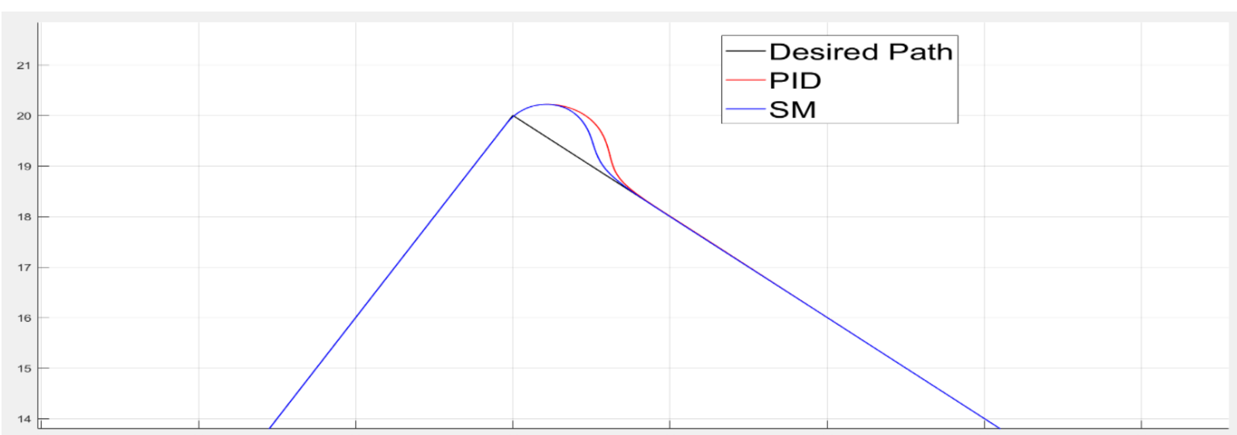

Figure 6. Compare the trajectory of the vessel at the waypoint point to the line between the controllers

Both methods have good road grip, especially SM is for better quality at the point transfer stage. The trajectory of the vessel at the waypoint point will be compared to the line between the controllers by analyzing the direction, speed, and distance of the vessel from the waypoint point. The vessel will have to travel in the same direction as the line between the controllers, maintain the same speed, and stay within a certain distance from the waypoint point in order for the comparison to be accurate.

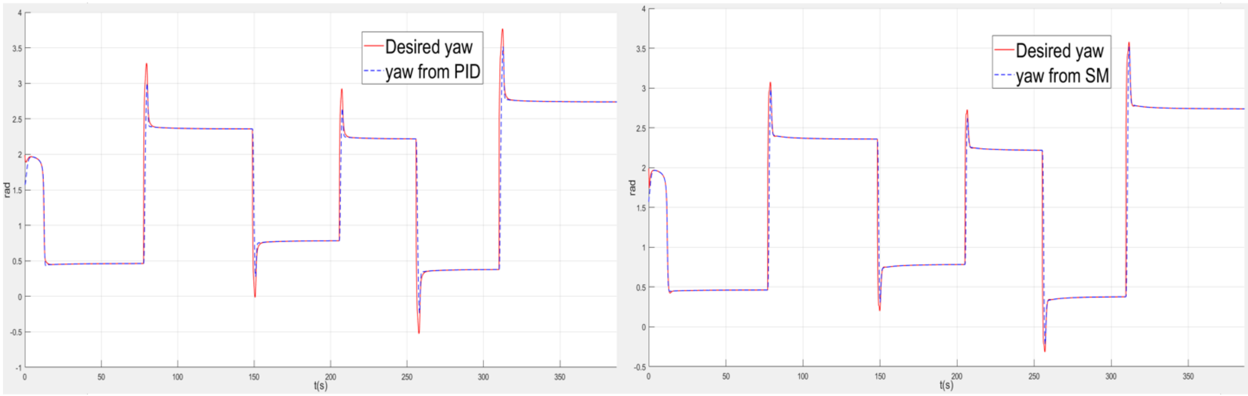

Figure 7. Compare yaw angle responses between controllers

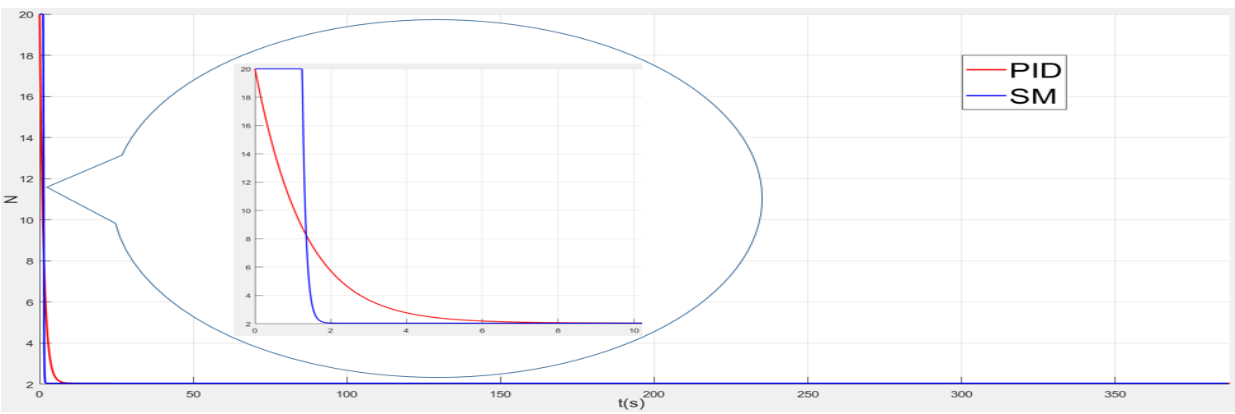

Figure 8. Compare the thrust to be supplied between controllers

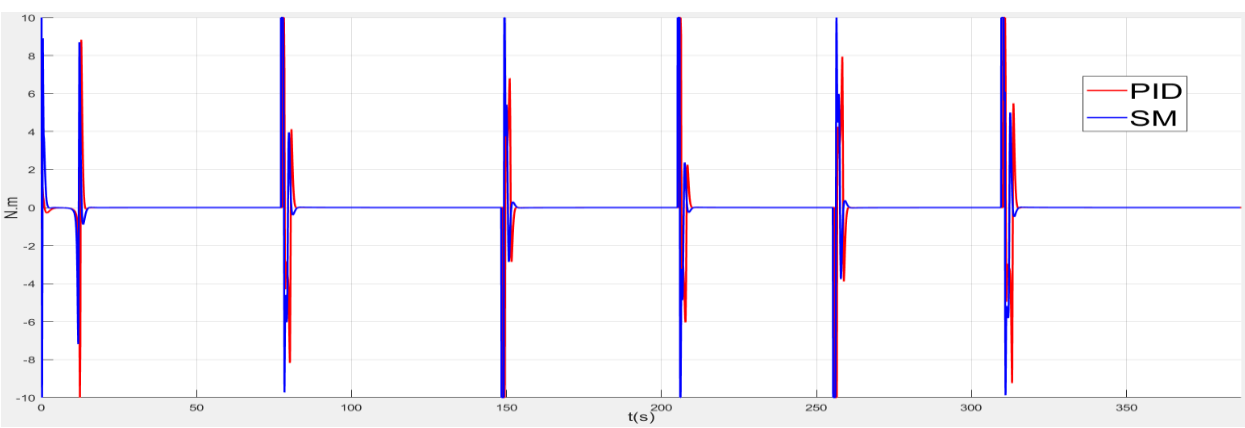

Figure 9. Comparison of rotation torque to provide between controllers

The response of Sliding mode is better than PID. Sliding mode's velocity response is faster without spikes, and the rotation torque needs to provide a smaller amplit margin of change than PID.

3.2 LOS curves and controllers

We have a simulation scheme to create curves, while calculating and delivering values x_d, y_d and for the L.A. algorithm for calculations. We can use both of these simulation files into a single Guidance file, but here we separate to understand that these are two separate stages.

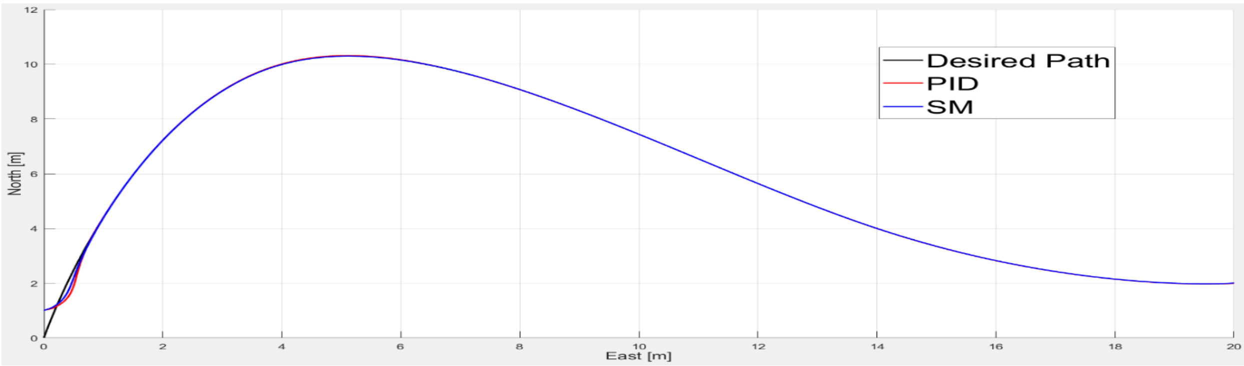

Figure 10. The result simulates the trajectory of the controllers when combined with the guide

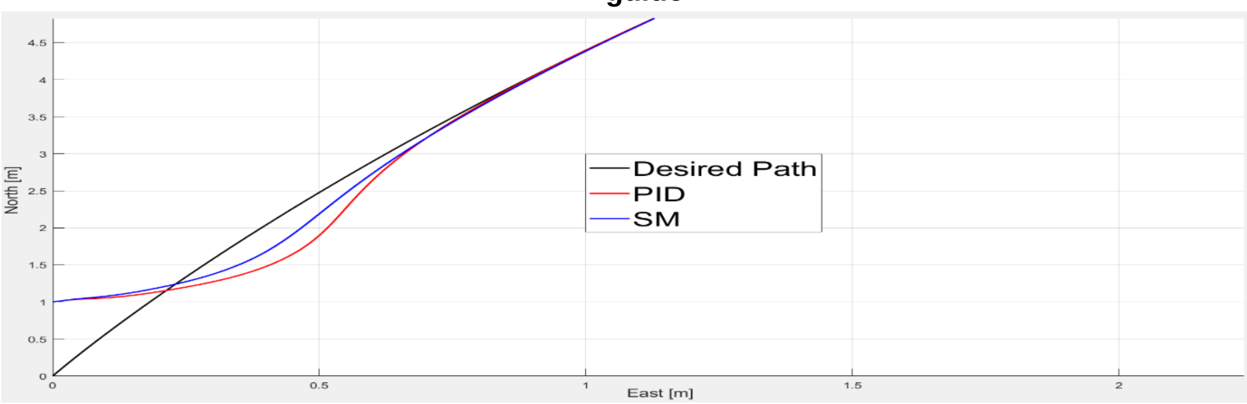

Figure 11. Compare the convergence of lines between controllers

Review: Similar to straight lines, the controllers are all good grip and Sliding mode is of better quality, converging on fast lines and good grip.

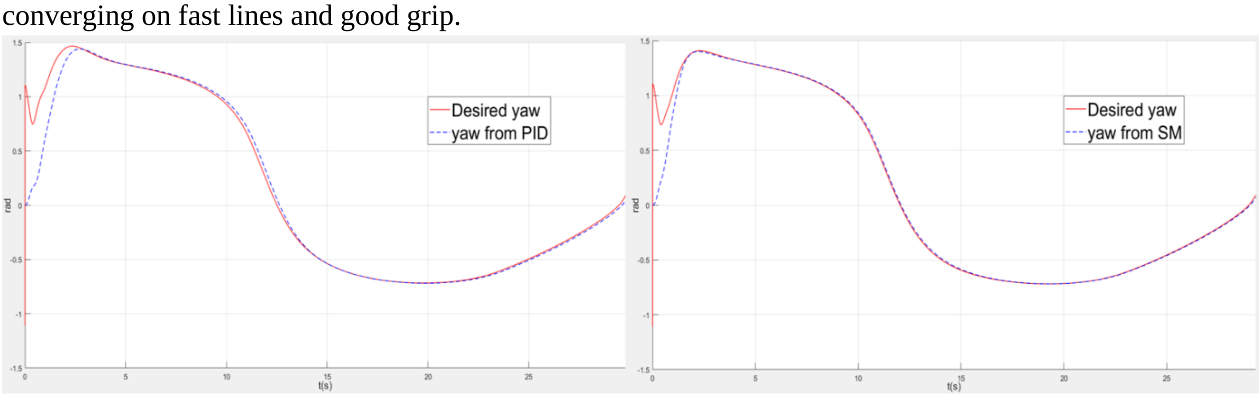

Figure 12. Compare yaw angle responses between controllers

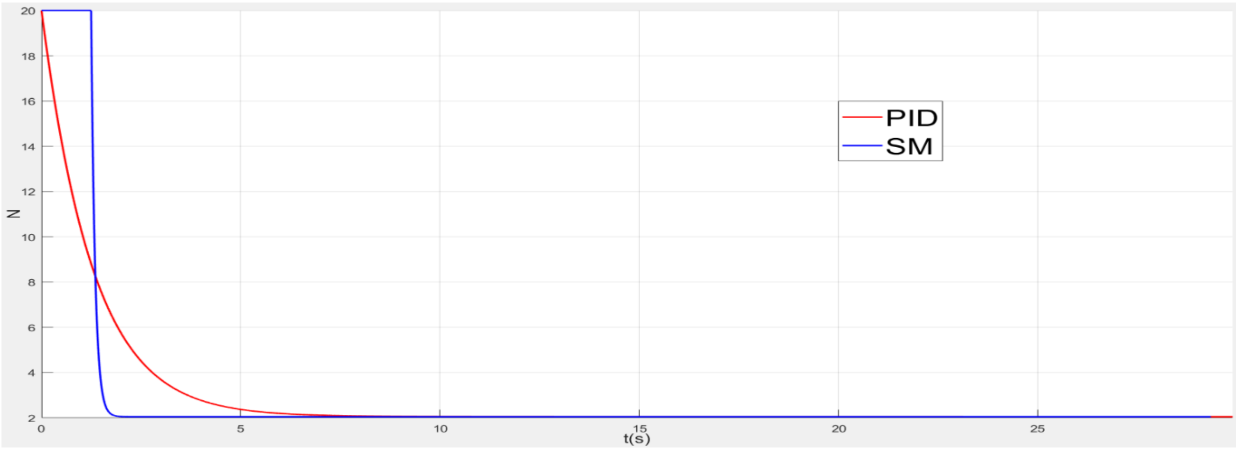

Figure 13. Compare the thrust to be supplied between controllers

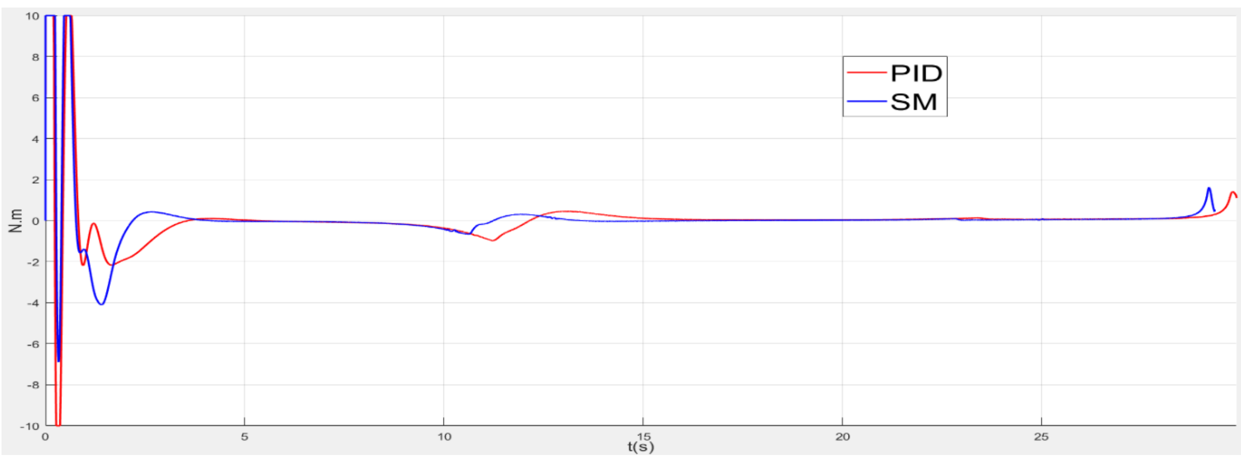

Figure 14. Comparison of rotation torque to provide between controllers

From Figure 14, it is clear that the yaw angle of Sliding mode is much better than PID. Similar to the straight line, which meets the speed of the Sliding mode faster and does not leap, the time to go the full distance is also shorter than that of the PID. In terms of force and torque to provide, it is possible to consider the quality of both controllers equally.

In summary, the simulation results show that the combination of the guide and the controller has solved the core problems in the problem of self-driving for the ship. The results obtained are very positive and practically consistent.

4. Conclusions

In this study, we raised two main issues for an autonomous vessel, heading autopilot and velocity indicators during travel, and also presented the direction of solving and designing the Guidance and Controller for it. The results obtained through simulation are consistent and positive with reality. The ability to converge on the desired line and stay on it as well as the good grip velocity according to the set value shows the accuracy of the Guidance and the quality of the Controller.

In addition, comparing the impact of the components in the guide, as well as the optimization between control algorithms to orbital quality, will help the designer understand the nature of the parameters to fine-tune them accordingly and achieve the desired criteria that are also clearly presented in the simulation.

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