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Research Article

The Stability of the Model and Simulation, Control Issues for Ship System, Education, and Research

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This article deals with the study of mathematical models and the assessment of the stability of the motion of ships, investigating properties of the system such as kinetics and stability. This is essential for the selection of suitable control methods according to the requirements set out for the problem. Some control methods require the author to specify control parameters before the operation of the system can be started. Therefore, the survey of the article is useful for the above problem. Control methods through simulation results (PID controller, lag compensator, and lead compensator) give me results that reflect properties of the system (the stability of the operation cycle of the ship model). In addition, control methods for this model, which serve for research and education, are also presented below. Simulation is done by Matlab.

1. Introduction

A ship is an object that constantly moves on the surface of the sea. Ships are often large in size to serve the transport of goods, etc. Vessels are under a lot of pressure from fierce waves, tides, etc. So, navigating a ship is a challenge for the crew. The dynamics analyzed below are mainly laws. In particular, Newton's law is used in cases where a ship is considered to be a moving body in a fluid medium. The parameters of the liquid surface in this case are not taken into account. The equation describing the motion of the ship is a higher order differential equation. This equation contains many physical parameters. These parameters have correlation relationships with each other. Through previous studies, this object has full kinetic properties: the motion is calculated from the moment of the departure, the reserve of the stability is low [1] due to many effects of external forces, etc. Research reports show that the control of ships is aimed at the following purposes: the author stabilizes the ship's directions and improves the stability reserve of the system. The author adjusts the parameters so that the transition time is short. The aim of this paper is not beyond the above intentions. In the problems of stability of directions over a finite period of time, several other problems of stability of the trajectories of ships are known. These trajectories can be other objects' target tracking points. According to the requirements of the above problems, the stability of the systems is a topic of interest. This leads to a work that the author needs to do: the author evaluates the quality of the ship's kinematics through the parameters presented above. In addition, other factors include the costs to implement and the types of energy and their consumption to control a ship so that it operates in the most efficient way [2]. Another interesting work was lectures on hydrodynamics [3] for destroyers. Another novel theory is the use of techniques [4] for destroyers. A future research paper is investigating the dynamic characteristics for an aircraft carrier equipped with rocket launchers as referenced in [5]. Rudder roll damping experience [6] in Norway is a new research topic. Thrust losses associated with autopilot [7, 8] of a submarine are always welcome. The mechanical tests in [9] can be applied to a military submarine. Guidance and control [10] of military submarines in the ocean is interesting. The planar motion mechanism system [11, 12] for any type of ship is always useful to readers. The principles of architecture [13–15] for the design of a submarine are a new topic.

Probabilistic theory [16] of submarine dynamics has always been of interest to the author. Based on the reference of [17], the author can study the floating and sinking mechanism of submarines. Articles related to this topic are always helpful. On the coupled motion of steering and rolling [18] of a military submarine is a future work. The compatibility of solutions in [19] for a type of submarine can be considered by the researchers. The description of autonomous vehicles [20], including modern military vehicles underwater, is a novel topic in the early 21st century. Control strategies for unmanned underwater vehicles [21] including robotic submarines and robotic aircraft carriers are a fascinating topic. The Engineering Handbook [22] is necessary to mention the vehicles: robotic submarines and robotic aircraft carriers. The use of artificial neural networks for vehicles in [23] is of great interest. Optimal control for a surface combatant ship [24] /responding-type ship motion model [25] is a new research work. The Mathematical Model of Start [26] and this model can be controlled by a controller for consistency with its structure. Fatigue analysis of [27] is referenced for military ships. Ship-to-grid integration [28] can be advantageous for ships located far inland. The use of methods to detect ship radar signals [29] is a promising study. Electromagnetic compatibility [30] for the design of military ships is a special publication. Analysis on ship's underwater static electric field [31] was carried out with actual measurements for more accurate results. Intelligent decision support system of ship unsinkability design [32] in the final stages needs to be considered. This paper focuses on investigating the stability of the ship system through specialized control methods that have become popular for teaching activities in schools. The author has evaluated the effectiveness of these methods in the most detailed way that has not been thoroughly documented before.

2. Model of the Ship

Figure 1 depicts, in detail, the motion components and kinematic parameters of the ship (Figure 1) on axes in 6 degrees of freedom (DOF), specifically, as follows.

The motion components and kinematic parameters described on the shaft are as follows:

Sliding along the x-axis includes x_G, which isthe displacement of the ship's center vertically, u, which is the speed of longitudinal displacement, φ, which is the angle of the inclination, and $\dot{\varphi} = p$, which is the angular velocity of the roll

Sliding along the y-axis includes y_G, which is the displacement of the ship's center horizontally, v, which is the speed of horizontal displacement, θ, which is the angle of the difference, and $\dot{\theta} = q$, which is the angular velocity of longitudinal roll

Sliding along the z-axis includes z_G, which is the displacement of the ship's center in the vertical direction, v, which is the direction of the ship, and $\dot{\phi} = r$, which is the speed of the rotation

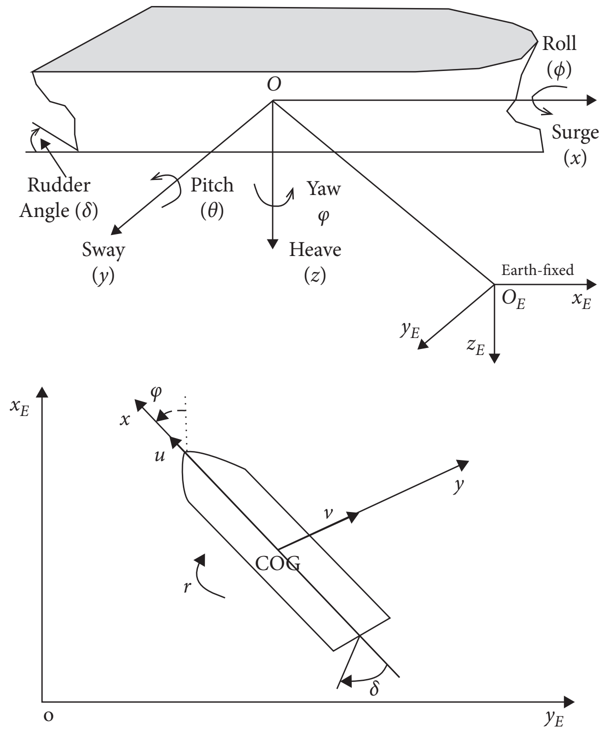

Figure 1: The motion components and kinematic parameters of the ship.

x_G, y_G, and z_G are coordinates of the center point of the ship

The motion of the ship at any position is shown as follows [1]:

$$M\dot{v} + C(v)v + D(v)v + g(\eta) = \tau, \tag{1}$$

where η is the vector specifying the position, which is used to orient with the reference frame on Earth, v is the direction velocity vector or the angular velocity vector, M is the inertial matrix, $C(v)$ is the Coriolis matrix, vector of the force, and moment of gravity, and $g(\eta)$ is the vector of the force and the moment of control signal.

The linear state-space model describing the dynamics of a ship without the effects of noise signals is shown as follows [33]:

$$\dot{x} = Ax + Bu, \tag{2}$$

where $x = [u \;\; v \;\; r \;\; p \;\; \varphi \;\; \phi]$, A and B are the coefficient matrices, $u = \tau$ is the control signal, and δ is the rudder rotation angle. Equation (2) can be written as

$$\begin{bmatrix} \dot{v} \\ \dot{r} \\ \dot{p} \\ \dot{\varphi} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v \\ r \\ p \\ \varphi \\ \phi \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ 0 \\ 0 \end{bmatrix} \delta. \tag{3}$$

Equation (3) is the ship's linear state-space equation used to synthesize the ship's controls without interference signals affecting the system. The parameters of a ship are as follows. The length of the ship is $L = 175$ (m), the width in the center of the ship is $B = 25.4$ (m), the expansion of the water is $W = 21222$ (m^3), and the maximum speed of the ship is $u = 14$ Knots. The value of *aij* and *bij* is calculated as in Table 1. The linear state-space equation of the ship:

$$\begin{bmatrix} \dot{v} \\ \dot{r} \\ \dot{p} \\ \dot{\varphi} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} -0.046 & -1.9614 & 0.2137 & 0.1336 & 0 \\ 0.0011 & -0.1326 & -0.1246 & -0.0331 & 0 \\ -0.001 & 0.0147 & -0.1163 & -0.0006 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v \\ r \\ p \\ \varphi \\ \phi \end{bmatrix} + \begin{bmatrix} -0.06 \\ -0.0035 \\ -0.0026 \\ 0 \\ 0 \end{bmatrix},$$
$$A = \begin{bmatrix} -0.046 & -1.9614 & 0.2137 & 0.1336 & 0 \\ 0.0011 & -0.1326 & -0.1246 & -0.0331 & 0 \\ -0.001 & 0.0147 & -0.1163 & -0.0006 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} -0.06 \\ -0.0035 \\ -0.0026 \\ 0 \\ 0 \end{bmatrix},$$
$$C = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \end{bmatrix}, D = 0. \tag{4}$$

The transfer function of the ship:

$$G(s) = \frac{-0.0035s^3 - 0.0003101s^2 + 6.363 \times 10^{-5}s + 9.869 \times 10^{-7}}{s^5 + 0.2949s^4 + 0.03167s^3 + 0.002041s^2 + 0.0001078s}. \tag{5}$$

From a model (3), the author generated a characteristic matrix A. The values of the coefficients, a_{ij} and b_{ij}, in this matrix are in an area in the distribution of poles in the complex plane. This leads to an undesirable phenomenon in the investigation of the dynamical properties of any system.

The complex number form is expressed as follows: $s = a + b * j$, where the value of "a" is the real part and the value of b is the imaginary part. Factors that affect the stability of the system include the properties of the dynamics. All state variables are dynamic representations of the system. These variables include important parameters such as tilt angle and yaw speed, affecting the stable quality of the ship system. Therefore, these two parameters are always interested. Another parameter is the magnitude of the rudder angle that affects how much energy is consumed during the steering of the ship. This parameter plays a key role in keeping the direction of a ship's movements for a long period of time. The analysis of the above factors is necessary for the selection of controllers to control the operation of the ship in different purposes.

3. Controller Design Using PID Strategy

PID controllers are commonly used to regulate the time domain behavior of many different types of dynamic plants [35]. The transfer function of PID control is given by

$$G_{PID} = K_P + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_P s + K_I}{s},$$
$$= \frac{K_D\left[s^2 + (K_P/K_D)s + (K_I/K_D)\right]}{s}. \tag{6}$$

4. Controller Design Using Lead and Lag Compensators

Lead compensator is a soft approximation of the PD controller; the PD controller, given by $G_{PD}(s) = K_P + K_D s$, is not physically implementable, since it is not proper, and it would differentiate high frequency noise, thereby producing large swings in output. To avoid this, the PD controller is approximated to the lead controller of the following form:

$$G_{PD}(s) \approx G_{\text{Lead}}(s) = K_p + K_D\frac{P_s}{s + P}. \tag{7}$$

The large the value of P, the better the lead controller approximates PD control; rearranging gives

$$G_{\text{Lead}}(s) = K_P + K_D\frac{P_s}{s + P} = \frac{K_P(s + P) + K_D P_S}{s + P},$$
$$G_{\text{Lead}}(s) = \frac{(K_P + K_D P)s + K_P P}{s + P},$$
$$G_{\text{Lead}}(s) = \left(K_p + K_D P\right)\frac{s + \left[K_P P/K_P + K_D P\right]}{s + P}. \tag{8}$$

Now, let

$$K_C = K_P + K_D P \tag{9}$$

and

$$Z = \left[\frac{K_P P}{K_P + K_D P}\right]. \tag{10}$$

The following approximated controller transfer function of the PD controller is obtained and is called the lead compensator:

$$G(s) = K_C\frac{s + Z}{s + P}. \tag{11}$$

Table 1: The value of a_{ij} and b_{ij} [34].

No.	Coefficient	Value	No.	Coefficient	Value
1	a_{11}	−0.046	9	a_{31}	−0.0010
2	a_{12}	−1.9614	10	a_{32}	0.0147
3	a_{13}	0.2137	11	a_{33}	−0.1163
4	a_{14}	0.1336	12	a_{34}	−0.0006
5	a_{21}	0.0011	13	b_1	−0.0600
6	a_{22}	−0.1326	14	b_2	−0..0035
7	a_{23}	−0.1246	15	b_3	−0.0026
8	a_{24}	−0.0331			

If $Z < P$, this controller is called a lead controller (or lead compensator). If $Z > P$, this controller is called a lag controller (or lag compensator). The transfer function of the lead compensator is given by

$$G_{\text{lead}}(s) = K_c \frac{(s + Z_0)}{s + P_0}, \quad P > Z. \tag{12}$$

The lag compensator is a soft approximation of the PI controller, and it is used to improve the steady state response, particularly, to reduce the steady-state error of the system; the reduction in the steady-state error is accomplished by adding equal numbers of poles and zeros to systems:

$$G_{PI}(s) \approx G_{\text{lag}}(s) = K_P + \frac{K_I}{s} = \frac{K_P s + K_I}{s} = K_P \frac{(s + (K_I/K_P))}{s}. \tag{13}$$

Since the PI controller by itself is unstable, I approximates the PI controller by introducing value of P_0 that is not zero but near zero, the smaller I makes P_0, the better this controller approximates the PI controller, and the approximation of the PI controller will have the form:

$$G_{\text{lag}}(s) = K_c \frac{(s + Z_0)}{s + P_0}. \tag{14}$$

5. Simulation Results and Discussion

Diagrams of the system using the PID controller, LEAD compensator, and LAG compensator are shown in Figures 2–4 , and simulation results using the PID controller, LEAD compensator, and LAG compensator are shown in Figures 5–16 .

Figure 8 shows that impulse response for the closed system (highlighted in red) is worse than the open system (highlighted in green Figure 6). The value of amplitude of the oscillation of the closed system in this case is large, and the closed system does not reach a steady state. For the PID controller, the closed system does not respond well. The value of amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state.

Figure 7 shows that step response for the closed system (highlighted in blue) is worse than that for the open system (highlighted in red Figure 5). The value of amplitude of the oscillation of the closed system in this case is large, and the closed system does not reach a steady state. For the PID controller, the closed system does not respond well. Meanwhile, the open system cannot respond well. In general, for the PID controller, the system does not respond well.

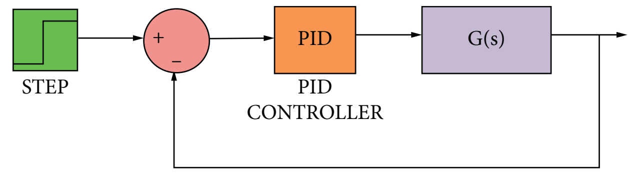

Figure 2: Simulink model of the PID controller $G(s)$: $K_p = 56.71$, $K_i = 46.1$, and $K_d = 562.44$.

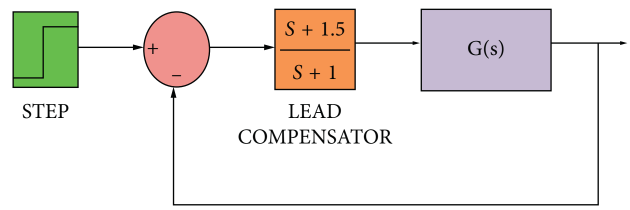

Figure 3: Simulink model of the lead compensator $G(s)$.

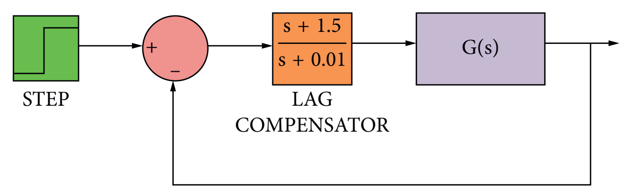

Figure 4: Simulink model of the lag compensator $G(s)$.

Figure 12 shows that impulse response for the closed system (highlighted in green) is worse than the open system (highlighted in green Figure 10). The value of amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For the lead compensator, the closed system does not respond well. The value of amplitude of the oscillation of the open system in this case is zero and the open system reaches a steady state.

Figure 11 shows that step response for the closed system (highlighted in red) is better than that for the open system (highlighted in blue Figure 9). The value of amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For the lead compensator, the closed system does not respond well. Meanwhile, the open system cannot respond well. In general, for the lead compensator, the system responds well.

Figure 16 shows that impulse response for the closed system (highlighted in red) is worse than the open system (highlighted in red Figure 14). The value of amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For the lag compensator, the closed system does not respond well. The value of amplitude of the oscillation of the open system in this case is −1.4 and the open system reaches a steady state.

Figure 15 shows that step response for the closed system (highlighted in green) is better than that for the open system (highlighted in blue Figure 13). The value of amplitude of the

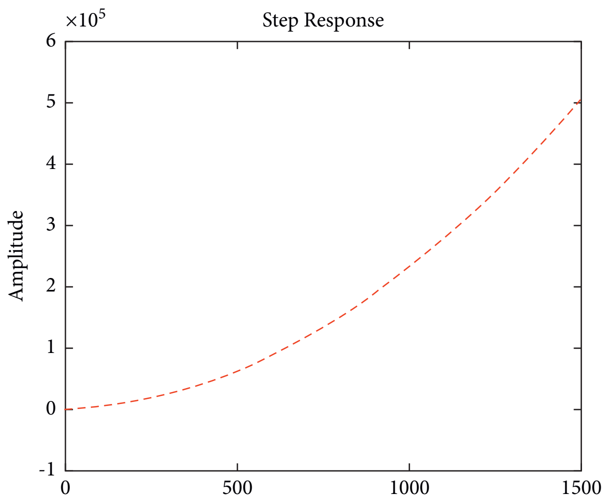

Figure 5: Step response for the open system "G (s)."

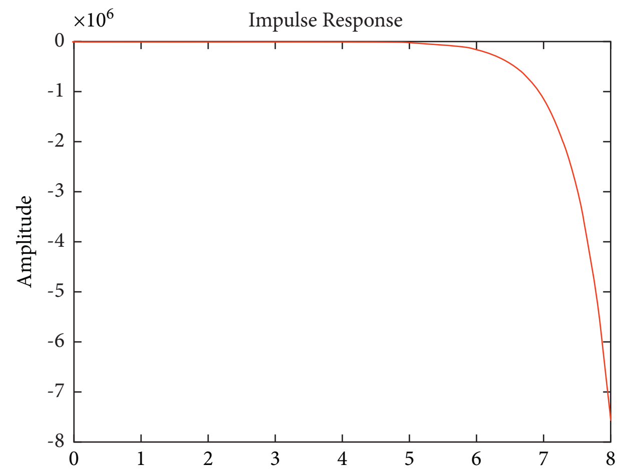

Figure 8: Impulse response for the closed system "G (s)."

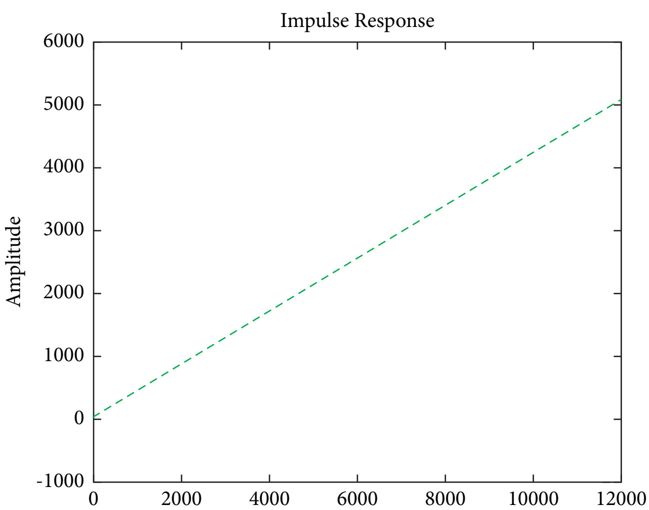

Figure 6: Impulse response for the open system "G (s)."

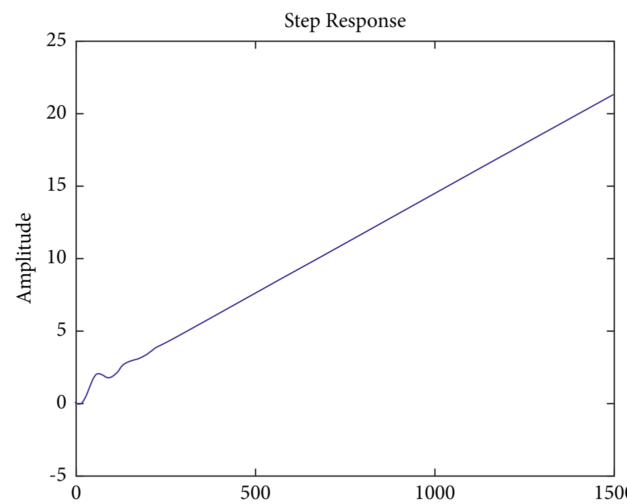

Figure 9: Step response for the open system "G (s)."

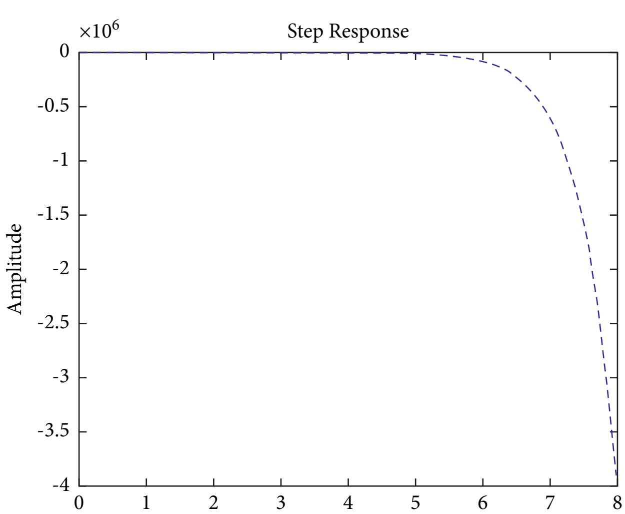

Figure 7: Step response for the closed system "G (s)."

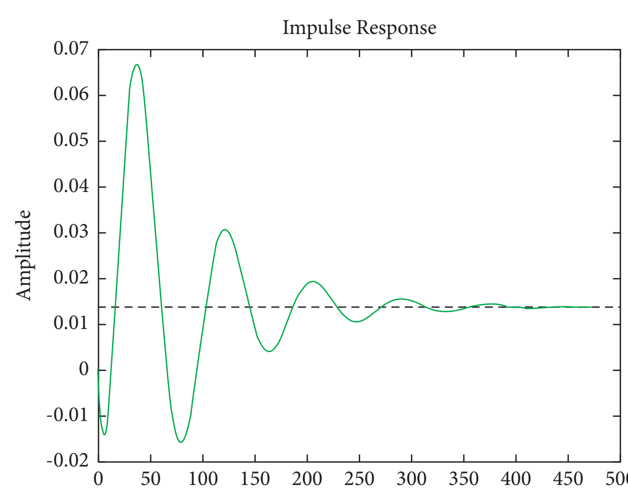

Figure 10: Impulse response for the open system "G (s)."

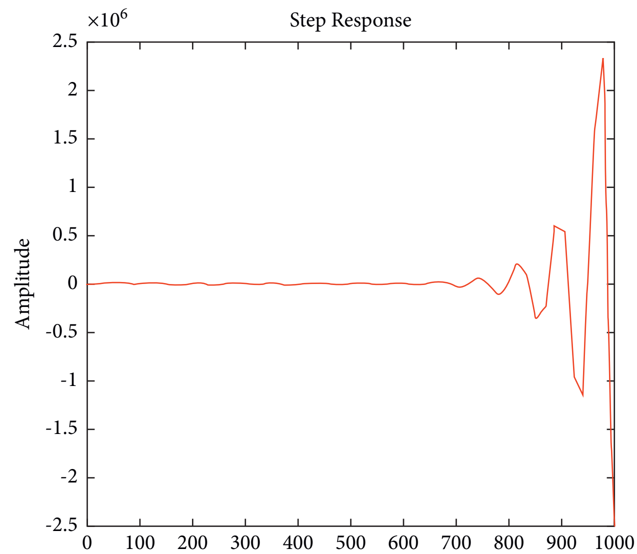

Figure 11: Step response for the closed system "G (s)."

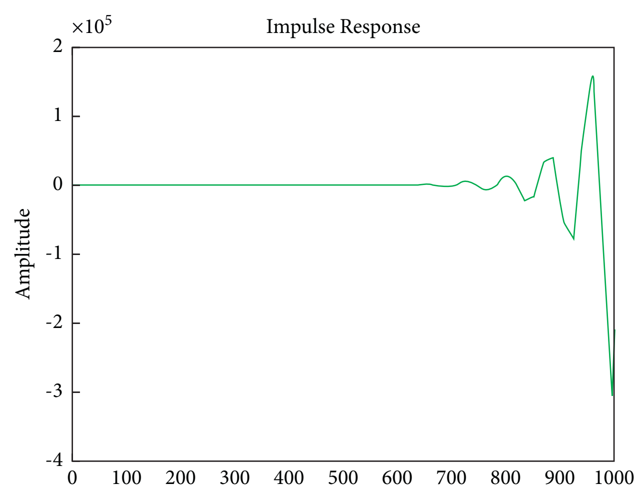

Figure 12: Impulse response for the closed system "G (s)."

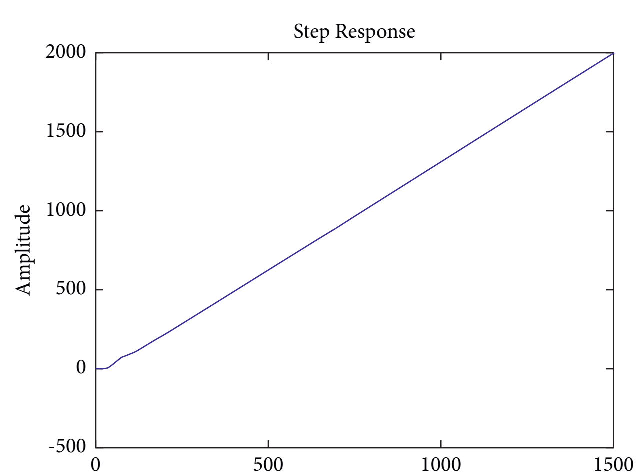

Figure 13: Step response for the open system "G (s)."

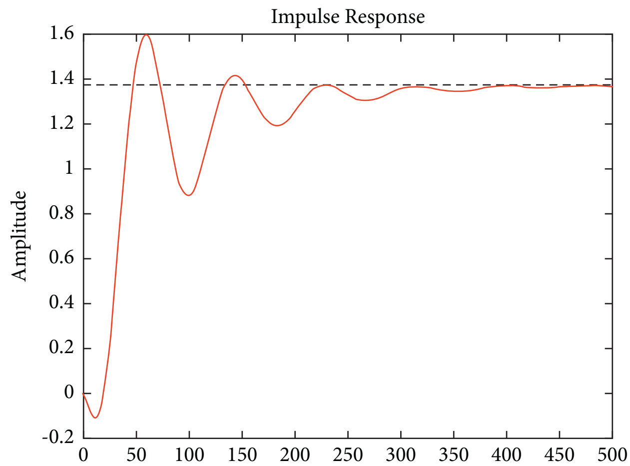

Figure 14: Impulse response for the open system "$G(s)$."

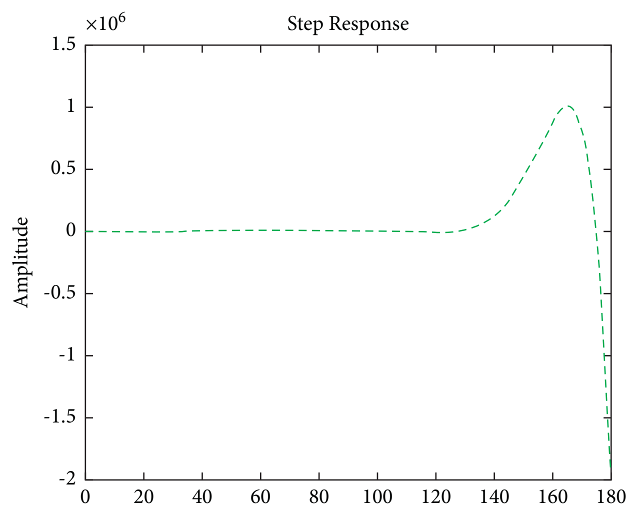

Figure 15: Step response for the closed system "$G(s)$."

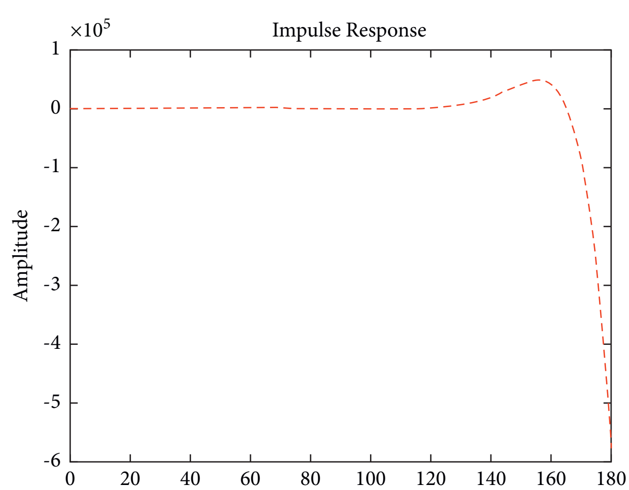

Figure 16: Impulse response for the closed system "$G(s)$."

oscillation of the closed system in this case is large and the closed system does not reach a steady state. For the lag compensator, the closed system does not respond well. Meanwhile, the open system cannot respond well. In general, for the lag compensator, the system responds well.

The efficiency of the above control methods in descending order:

(1) Lead compensator
(2) Lag compensator
(3) PID controller

6. Conclusions

Through the investigation of the stability of the system, the author had the next treatment direction in the following research works: the author used this property to evaluate the effectiveness of using specialized controls for the system mentioned above. In the future, the use of powerful control algorithms can be applied to the above model such as neural control. Comparing the efficiency of the controllers helped me understand the essence of the problem for ship models in particular and other automatic models in general. The simulation results of this paper can be a rich source of reference for the selection of new control methods for ships in the future.

Data Availability

The data used to support the findings of the study are cited as references within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] T. I. Fossen, *Guidance and Control of Ocean Vehicles*, John Wiley & Sons, Hoboken, NJ, USA, 1994.

[2] Ю. А. Лукомский and В. Г. Пешечонов, Скорочод Д. А. НавиГация и уПравление движением судов. - СПб, Ллмор, 2002.

[3] M. A. Abkowitz, "Lectures on ship hydrodynamics- steering and manoeuvrability," *Technical Report Rep. No. Hy-5. Hydro Og Aerodynamisk Laboratorium*, Lyngby, Denmark, 1975.

[4] M. Blanke and A. Christensen, "Rudder roll dumping autopilot robustness to sway-yaw-roll couplings," in *Proceedings of 10th SCSS*pp. 93–119, Ottawa, Canada, 1993.

[5] M. Blanke and A. G. Jensen, "Dynamic properties of container vessel with low metacentric height," Technical Report Doc. No. R-1997-4173, Dept. of Control Engineering, Aalborg University, Copenhagen, Denmark, 1997.

[6] M. Blanke, P. Haals, and K. K. Andreasen, "Rudder roll damping experience in Denmark," in *Proceedings of the IFAC Work Shop CAMS'89*, Lyngby, Denmark, August 1989.

[7] M. Blanke, *Ship propulsion losses related to automatic steering and prime mover control*, PhD thesis, Servolaboratory, Tecnical University of Denmark, Lyngby, Denmark, 1981.

[8] M. S. Chislett, "The addition of heel-roll servo mechanism to the dmi horizontal planar motion mechanism," in *Proceedings of the of MARSIM and ICSM*, Tokio, Japan, June 1990.

[9] M. S. Chislett and J. Støm-Tejsen, "Planar motion mechanism tests and full scale steering and maneuvering predictions of a mariner class vessel," Technical Report Rep. No. Hy-6, Hydro Og Aerodynamisk Laboratorium, Lyngby, Denmark, 1965.
[10] T. I. Fossen, *Guidance and Control of Ocean Marine Vehicles*, John Wiley & Sons, New York, NY, USA, 1994.
[11] A. Goodman and M. Gertler, "Planar motion mechanism system," US patent 3052120, 1962.
[12] A. G. Jensen, "Fluid dynamic derivatives: marine and wind engineering approaches," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 69, no. 71, pp. 777–793, 1997.
[13] N. A. Hamlin, "Principles of naval architecture vol 1," in *Stability and Strength*, E. V. Lewis, Ed., Society of Naval Architecture and Marine Engineers, New York, NY, USA, third edition, 1988.
[14] J. D. Van Manen and P. Van Oossanen, "Principles of naval architecture vol II: resistance," in *Propulsion and Vibration*, E. V. Lewis, Ed., Society of Naval Architecture and Marine Engineers, New York, NY, USA, third edition, 1988.
[15] R. F. Beck, W. E. Cummins, J. F. Dalzell, P. Mandel, and W. C. Webster, "Principles of Naval Architecture Vol III," in *Motions in Waves and Controllability*, E. V. Lewis, Ed., Society of Naval Architecture and Marine Engineers, New York, NY, USA, third edition, 1988.
[16] W. C. Price and R. E. D. Bishop, *Probabilistic Theory of Ship Dynamics*, Chapman & Hall, London, UK, 1974.
[17] Sname, "Nomenclature for treating the motion of a submerged body through a fluid," Technical Report Bulletin 1-5, Society of Naval Architects and Marine Engineers, New York, NY, USA, 1950.
[18] K. H. Son and K. Nomoto, "On the coupled motion of steering and rolling of a high-speed container ship," *Journal of the Society of Naval Architects of Japan*, vol. 152, pp. 180–191, 1982.
[19] J. Van Amerongen, *Adaptive steering of ships - a model reference approach to improved maneouvering and economic course keeping*, PhD Thesis, Delft University of Technology, Delft, The Netherlands, 1982.
[20] D. Richard Blidberg, "The development of autonomous underwater vehicles (AUV)," *A Brief Summary*, Autonomous Undersea Systems Institute, 2000.
[21] P. J. Craven, R. Sutton, and R. S. Burns, *Control Strategies for Unmanned Underwater Vehicles*, University of Plymouth, Plymouth, England, 1998.
[22] F. El-Hawary, *The ocean engineering Handbook, The Electrical Engineering Handbook Series*, CRC Press, Boca Raton, FL, USA, 2001.
[23] R. Cristi, F. A. Papoulias, and A. J. Healey, "Adaptive sliding mode control of autonomous underwater vehicles in the dive plane," *IEEE Journal of Oceanic Engineering*, vol. 15, no. 3, pp. 152–160, july 1990.
[24] A. Vicenzutti, G. Trincas, V. Bucci, G. Sulligoi, and G. Lipardi, "Early-Stage design methodology for a multirole electric propelled surface combatant ship," in *Proceedings of the 2019 IEEE Electric ship Technologies Symposium (ESTS)*, Washington, DC, USA, August 2019.
[25] Y. Tian, L. Huang, L. Chen, J. Mou, Y. He, and K. Zhang, "System identification based parameter identification of responding type ship motion model," in *Proceedings of the 2019 5th International Conference on Transportation Information and Safety (ICTIS)*, Liverpool, UK, July 2019.
[26] A. V. Vyngra, B. A. Avdeyev, R. F. Abdurakhmanov, V. V. Yenivatov, and I. K. Ovcharenko, "Mathematical model of Start for a piston compressor electric drive of a ship refrigerator," in *Proceedings of the 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*, Moscow, Russia, January 2019.
[27] C. Liu, J. Huang, S. Zhao, S. Guo, and H. Zhang, "Fatigue analysis of ship-borne modular skid-mounted equipment," in *Proceedings of the 2021 7th International Symposium on Mechatronics and Industrial Informatics (ISMII)*, Zhuhai, China, January 2021.
[28] A. Vlachokostas, J. Prousalidis, D. Spathis et al., "ship-to-grid integration: environmental mitigation and critical infrastructure resilience," in *Proceedings of the 2019 IEEE Electric ship Technologies Symposium (ESTS)*, Arlington VA, USA, August 2019.
[29] C. Wang, L. Xiao, and C. Ni, "On the detection performance analysis of ship radar under interference environment," in *Proceedings of the 2017 International Applied Computational Electromagnetics Society Symposium (ACES)*, Firenze, Italy, March 2017.
[30] V. H. J. González, "Electromagnetic Compatibility in ships design and construction," in *Proceedings of the 2013 IEEE Electric ship Technologies Symposium (ESTS)*, Arlington, VA, USA, August 2013.
[31] Y. Ding-Feng, G. Pan, X. Zheng-Xi, and T. Chen, "Analysis on ship's underwater static electric field with physical scale model," in *Proceedings of the 2016 11th International Symposium on Antennas, Propagation and EM Theory (ISAPE)*, Guilin, China, October 2016.
[32] Y. Hou, P. Jin-Yun, and C. Xiao-Hong, "Intelligent decision support system of ship unsinkability design in the first design stage," in *Proceedings of the 2009 WRI Global Congress on Intelligent Systems*, Xiamen, China, May 2009.
[33] T. Perez and M. Blanke, *Mathematical Ship Modeling for Control Applications*, Technical Report Dept. of Electrical and Computer Engineering The University of Newcastle, Newcastle, 2308, Australia, 2002.
[34] T. I. Fossen, *Marine Control Systems - Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles Marine Cybernetics*, Springer, Berlin/Heidelberg, Germany, 3rd edition, 2002.
[35] R. D. Doncker, D. W. J. Pulle, and A. Veltman, *Advanced Electrical Drives: Analysis, Modeling, Control*, Springer, Berlin, Germany, 2011.