Jurnal Sistem Komputer dan Informatika (JSON)
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001

PID-Controlled Gyroscopic Stabilization for Roll Balancing: A Simulation and Experimental Study

Padma Nyoman Crisnapati*, Putu Devi Novayanti, Ni Ketut Ira Permata Adi, I Putu Agung Mas Aditya Warman, Anak Agung Istri Cintya Prabandari, I Made Darma Susila

Computer System, Informatics and Computer, Institute of Technology and Business STIKOM Bali, Denpasar, Indonesia
Email: [1*]crisnapati@stikom-bali.ac.id, [2]devinovayanti@stikom-bali.ac.id, [3]220030624@stikom-bali.ac.id, [4]230010088@stikom-bali.ac.id, [5]220030230@stikom-bali.ac.id, [6]darma_s@stikom-bali.ac.id
Email Penulis Korespondensi: crisnapati@stikom-bali.ac.id*
Submitted: **09/08/2025**; Accepted: **01/11/2025**; Published: **31/12/2025**

Abstract− In marine engineering, stabilizing boat roll motion under wave-induced disturbances is a crucial problem where traditional approaches frequently have drawbacks in terms of responsiveness, energy efficiency, and adaptability. In this study, a PID-controlled gyroscopic stabilization system for boat roll balancing is designed, simulated, and experimentally validated. To capture the coupled dynamics of servo motor behavior, gyroscopic torque generation, and boat roll motion, a thorough dynamic model was created. Four gain configurations—Low, Moderate, High, and Very High—were evaluated using the model-guided PID parameter tuning that was implemented in Python. The mechanical system incorporates a gyroscopic flywheel driven by BLDC and mounted on a servo-controlled cradle. An ESP32 microcontroller processes real-time roll angle feedback from an MPU6050 sensor. According to simulation results, the ideal balance between rise time (~300 ms), overshoot (~2°), and settling time (~1 s) was reached with moderate PID gains. While High and Very High gains displayed instability because of unmodeled vibrations and sensor noise, a scaled physical prototype that was built and tested under controlled disturbances demonstrated strong alignment with simulation trends for Low and Moderate gains. The results show that moderate gains, which offer both quick stabilization and reliable performance, offer the most useful configuration for real-world applications. This work contributes a validated methodology for optimizing PID-controlled systems in dynamic environments by bridging the gap between theoretical modeling and practical implementation of marine gyroscopic stabilization.

Keywords: Dynamic Modeling; Gyroscopic Stabilization; PID Control; Roll Motion Balancing; Boat Balancing

1. INTRODUCTION

The ability to stabilize dynamic systems under external disturbances is a critical challenge in engineering, particularly in marine environments where wave-induced oscillations can compromise safety and functionality [1], [2]. Roll motion, a key destabilizing factor in boats, poses significant risks to stability, performance, and passenger safety [3], [4]. Conventional stabilization methods, such as ballast systems or active fins, have limitations, including response delays, high energy consumption, and inefficiency in varying environmental conditions [5], [6]. To address these issues, this research proposes a gyroscopic stabilization system, employing a PID-controlled gyroscopic flywheel integrated into a boat prototype [7], [8].

Gyroscopic stabilization relies on the principle of angular momentum, where a rotating flywheel generates torque to counteract roll disturbances [9], [10]. Previous studies have explored gyroscopic stabilization in various domains, including vehicle dynamics, drones, and marine systems. For instance, [11], [12], [13] developed gyroscopic stabilization systems for satellites, rotor systems, and bridge supports, demonstrating effective roll correction under turbulent conditions. In [14], a prototype boat roll stabilizer was developed using a gyroscope sensor and a control loop to address roll motion with two motors as stabilizers, but it did not implement gyroscopic stabilization. Similarly, [9] proposed a real-time roll motion control system using gyrostabilizers and a model predictive control (MPC) algorithm, but it remains in the simulation stage and is expected to consume significant memory. Likewise, [15] demonstrates the application of an $H\infty$ optimal control method for mitigating roll motion in a combatant warship, which is also still in the simulation stage and would require substantial memory resources. Despite these advancements, a robust solution that balances response time, energy efficiency, and stability across varying gain configurations remains an open challenge.

The objective of this research is to develop and validate a gyroscopic stabilization system specifically designed for roll balancing in boats. The study aims to address the primary limitations of existing methods, including excessive oscillations, poor alignment between theoretical models and real-world performance, and inefficiencies in tuning control parameters [16]. By integrating dynamic modeling, simulation, and physical prototyping, the proposed system aims to provide an effective solution for stabilizing roll motion in boats exposed to external disturbances [17].

Jurnal Sistem Komputer dan Informatika (JSON)
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001

The novelty of this research lies in the development of a dynamic model that captures the coupled dynamics of boat roll motion, gyroscopic torque generation, and servo dynamics. This research incorporates detailed mathematical formulations to simulate real-world conditions. The dynamic model serves as the foundation for PID tuning [18], [19], guiding the design of a physical prototype that demonstrates the practicality of the system. Furthermore, the study explores the impact of various PID gain configurations—Low, Moderate, High, and Very High—on the system's performance, providing valuable insights into the trade-offs between response time, overshoot, and stability.

To achieve the research objectives, a systematic methodology was employed. The initial phase involved mechanical design, focusing on the gyroscopic flywheel, servo cradle, and weight balancer bracket to ensure structural stability. The electronics design integrated components such as the MPU6050 IMU sensor [20], BLDC motor with an ESC [21], and ESP32 microcontroller [22] to facilitate real-time feedback and control. Software design incorporated a PID control algorithm to dynamically adjust the servo motor's position based on roll angle feedback [23]. A dynamic model was implemented in Python using the solve_ivp library, simulating system behavior under varying gain configurations [24]. Following the simulation, a physical prototype was developed and tested under controlled conditions to validate the dynamic model [25].

Preliminary results from the simulation indicate that moderate PID gains achieve the best balance between response speed and stability, with rise times of approximately 300 ms, minimal overshoot (~2 degrees), and rapid stabilization within 1 second. Experimental validation of the physical prototype showed good alignment with simulation trends for Low and Moderate gains but revealed significant noise and prolonged settling times for High and Very High gains due to unmodeled real-world factors such as vibrations from the BLDC motor and flywheel. In summary, this research contributes to the advancement of gyroscopic stabilization technologies by bridging the gap between theoretical modeling and practical implementation. The integration of a detailed dynamic model, robust simulation framework, and physical validation provides a comprehensive approach to solving the challenges of roll balancing in boats.

2. RESEARCH METHODOLOGY

2.1 Research Overview

The research methodology stages in this study are presented as shown in Figure 1. The process begins with the mechanical design, electronics design, and software design phases, where the system's structure, components, and control algorithms are developed. The methodology incorporates two key approaches: simulation and physical prototyping. These components are then assembled into a functional system, followed by comprehensive validation to evaluate the effectiveness of both the simulation and the prototype in maintaining stability.

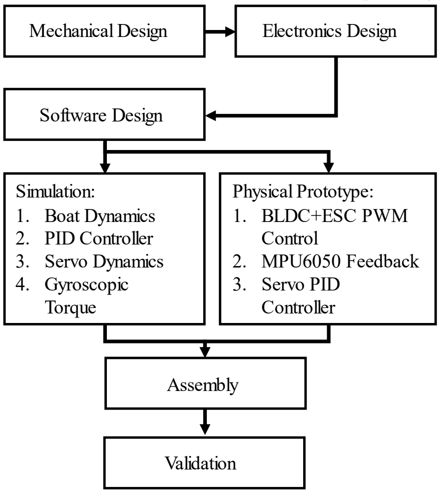


Figure 1. PID-Controlled Gyroscopic Stabilization for Boat Roll Balancing Research Methodology

2.2 Mechanical Design

The mechanical design presented in Figure 2 showcases a 3D CAD model of a gyroscopic stabilization system integrated into a boat prototype. This design highlights the key components and their interactions, which work together to maintain balance and stability under external disturbances such as waves. At the heart of the

Jurnal Sistem Komputer dan Informatika (JSON)
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001

system is the gyroscopic flywheel, driven by a brushless DC (BLDC) motor. The flywheel generates gyroscopic torque during rotation, which is essential for counteracting roll motions induced by external forces.

Mounted on a cradle structure supported by a weight balancer bracket, the flywheel operates with precise alignment and structural stability. The servo motor plays a critical role by dynamically controlling the angular orientation of the cradle. By adjusting its angular velocity, the servo motor directs the gyroscopic torque to stabilize the boat effectively. The support frame, illustrated in red and blue, provides the necessary rigidity and stability to the system, serving as the anchor for vital components such as the motor and cradle. The boat hull, serving as the base structure, interacts with external forces, inducing roll oscillations that the stabilization system is specifically designed to mitigate.

The blue circular arrows in the figure represent the rolling motion caused by external disturbances, while the green arrow illustrates the corrective force applied by the gyroscopic system to counteract these motions and restore the boat to a level position. The black curved arrows depict the rotational motion of the flywheel, demonstrating how its angular velocity and moment of inertia generate stabilizing torque.

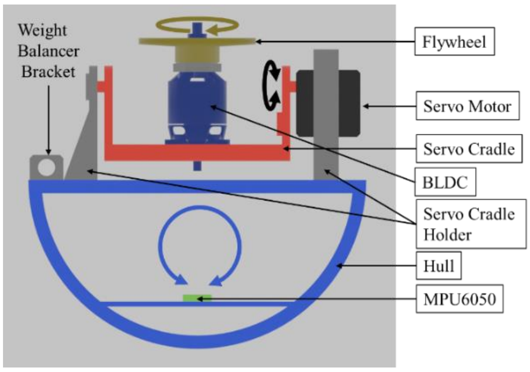


Figure 2. 3D CAD Mechanical Design

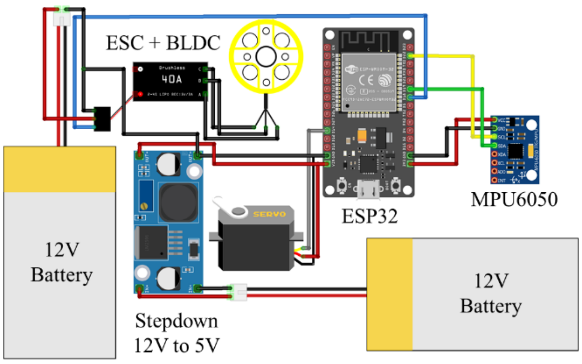


Figure 3. Electronics Wiring Diagram

2.3 Electronics Design

This stage focuses on designing the electronic components necessary for the system, such as the BLDC motor with its electronic speed controller (ESC), the servo motor, and the MPU6050 sensor for roll angle feedback. Figure 3 represents the electronics design phase of the gyroscopic stabilization system, highlighting the integration of various components and their connections. The system is powered by two 12V batteries, with one supplying energy to the ESC (Electronic Speed Controller) and BLDC (Brushless DC motor), while the other supports the ESP32 microcontroller and servo motor. A step-down module converts 12V to 5V, ensuring safe and efficient power delivery to the low-voltage components, including the ESP32. The MPU6050 IMU sensor provides real-time feedback on the boat's roll angle, which is processed by the ESP32. The ESP32 serves as the central controller, generating control signals based on the IMU feedback to dynamically adjust the servo motor's position and regulate the BLDC motor through the ESC. The servo motor is responsible for directing the gyroscopic stabilization torque by adjusting the cradle orientation of the flywheel system. Together, these components form a cohesive electronics design, enabling precise control and effective stabilization during external disturbances.

2.4 Software Design

To achieve a robust gyroscopic stabilization system for a boat prototype, an integrated approach combining sensor feedback, control algorithms, and dynamic modeling is essential. The core of this system lies in precise feedback from the IMU sensor, which continuously measures the roll angle of the boat. This data, combined with the desired target angle, enables the PID controller to calculate corrective actions based on proportional, integral, and derivative gains. These corrections are applied through the servo motor to dynamically adjust the gyroscopic flywheel's orientation, generating the necessary torque to counteract external disturbances. The underlying dynamics of the boat, including roll motion, gyroscopic torque, and servo behavior, are captured mathematically to ensure accurate simulation and control. The following sections provide a detailed explanation of the dynamic model and control system used as the foundation for this research.

The IMU feedback process involves measuring the roll angle of the boat, denoted as θ, which is provided in degrees or radians by the inertial measurement unit (IMU). The desired or target roll angle, referred to as θ_{ref},

Jurnal Sistem Komputer dan Informatika (JSON) Hal: 549-558
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001

is typically set to 0° to ensure the boat remains level. The error, eee, is calculated as the difference between the target roll angle and the measured roll angle, expressed as Equation 1 [26]. This error serves as the input for the PID controller to determine the necessary corrective action.

The PID controller calculates the command angle, ϕ_{cmd}, which dictates the position of the servo motor cradle to generate the required gyroscopic torque for stabilization (Equation 2). The controller operates based on three key gains: proportional (K_p), integral (K_i), and derivative (K_d) (Figure 4). The proportional gain, K_p, determines the controller's response based on the magnitude of the error e, providing immediate correction. The integral gain, K_i, addresses accumulated error over time by integrating $\int edt$, helping to eliminate any steady state offset. The derivative gain, K_d, considers the rate of change of the error, $\frac{de}{dt}$, predicting future behavior and adding damping to reduce overshoot [27].

The boat dynamics describe the roll motion caused by wave-induced disturbances and the corrective torque applied by the gyroscopic system (Equation 3). These dynamics are influenced by several factors, including I, the moment of inertia of the boat about the roll axis (X-axis), c, the damping coefficient representing resistance from water, and k, the stiffness coefficient corresponding to the restoring force from buoyancy. The corrective torque generated by the gyroscopic system is denoted as τ, while the roll angle of the boat is represented by θ (in degrees or radians). Additionally, $\dot{\theta}$ and $\ddot{\theta}$ denote the angular velocity and angular acceleration of the roll, respectively, capturing the boat's dynamic response to external disturbances and the stabilization efforts of the gyroscopic system [28].

The gyroscopic torque generated by the rotating flywheel is mathematically expressed as Equation 4, where J_f represents the moment of inertia of the flywheel, ω_f is the angular velocity of the flywheel in radians per second, and $\dot{\phi}$ denotes the angular velocity of the flywheel cradle, which is controlled by the servo motor. The flywheel provides both J_f and ω_f, while the servo-controlled cradle adjusts $\dot{\phi}$ to direct the torque effectively [13].

The servo motor dynamics, which govern the motion of the cradle and its ability to adjust the flywheel orientation, are described by the Equation 5. Here, ϕ is the cradle angle controlled by the servo motor, ϕ_{cmd} is the command angle provided by the PID controller, ζ is the damping ratio of the servo system, and ω_n is the natural frequency of the servo system. Additionally, $\dot{\phi}$ and $\ddot{\phi}$ represent the angular velocity and angular acceleration of the cradle, respectively. The servo-controlled cradle implements these dynamics to adjust ϕ, while the PID controller supplies ϕ_{cmd} as the input, ensuring precise control of the stabilization process [29].

$$e = \theta_{ref} - \theta \tag{1}$$

$$\phi_{cmd} = K_{p^e} + K_i \int edt + K_d \frac{de}{dt} \tag{2}$$

$$I\ddot{\theta} + c\dot{\theta} + k\theta = \tau \tag{3}$$

$$\tau = J_f \omega_f \dot{\phi} \tag{4}$$

$$\ddot{\phi} + \zeta\omega_n\dot{\phi} + \omega_n^2(\phi - \phi_{cmd}) = 0 \tag{5}$$

After the dynamic model and control system calculations for the simulation were completed, the next step was formulating the pseudocode to be implemented into the physical prototype. The hardware implementation involves controlling the BLDC motor and servo via PWM signals, utilizing feedback from the MPU6050 sensor for roll angle measurements, and tuning the PID controller to achieve the desired stabilization.

2.5 Assembly

Jurnal Sistem Komputer dan Informatika (JSON)
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001

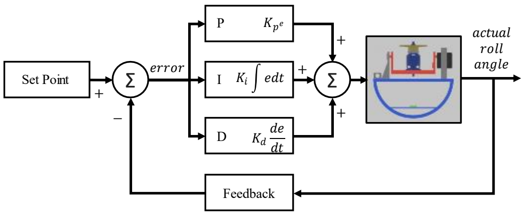


Figure 4. PID Closed Loop Control System

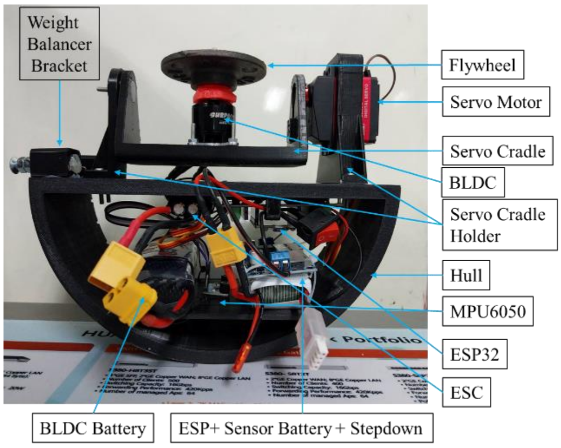


Figure 5. Final Prototype Assembly

The assembly phase integrates the mechanical, electronic, and software components into a unified system designed for gyroscopic stabilization, as shown in Figure 5. Key components include the weight balancer bracket for maintaining structural balance, the gyroscopic flywheel driven by a BLDC motor to generate stabilization torque, and a servo motor that dynamically adjusts the cradle orientation to counteract disturbances. The MPU6050 sensor provides real-time roll angle feedback to the PID controller, while the ESC and power distribution modules regulate energy for the BLDC motor, servo motor, and ESP32 microcontroller, which orchestrates the system's operations. Dual 12V batteries supply power to ensure uninterrupted performance. After precise alignment and calibration, the assembled prototype was tested under simulated conditions to validate its functionality and effectiveness in stabilizing roll motion.

2.5 Validation

The final step involves validating the system's performance by comparing simulation results with the physical prototype's behavior under real-world conditions (Table 1). The validation process assesses the gyroscopic stabilization system's performance under four PID gain configurations (Low, Moderate, High, and Very High) in both simulation and physical prototype environments. Each configuration tests the system's response to external disturbances, focusing on rise time, overshoot, and settling time. Low gains prioritize stability with slower corrections, moderate gains balance stability and response speed, high gains emphasize rapid corrections with increased overshoot, and very high gains test system limits with aggressive but unstable responses. This comprehensive approach ensures the alignment of simulation results with real-world behavior, enabling refinement of both the control algorithm and physical design for optimal stabilization performance.

Table 1. Experimental PID Gain Configurations and Parameter Values

Gain Config	K_p	K_i	K_d
Low	0.2	0.01	0.001
Moderate	0.6	0.03	0.001
High	1	0.1	0.05
Very High	10	1	0.5

3. RESULTS AND DISSCUSSION

3.1 Dynamic Model Implementation and Simulation Results

The dynamic model was implemented in Python using the solve_ivp library to simulate the system’s response under several paramaters configurations (Table 2). The simulation accurately replicates the coupled dynamics of the boat, flywheel, and servo system. Key performance metrics, including rise time, overshoot, and settling time, were evaluated. Simulation results informed the design and tuning of the physical prototype and validate the prototype under real-world conditions.

Jurnal Sistem Komputer dan Informatika (JSON)
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001

Table 2. Parameter Values for Gyroscopic Stabilization System Equations

Parameter	Value	Unit
θ_{ref}	0	degrees
θ	*	degrees/radians
ϕ_{cmd}	*	degrees/radians
e	$e = 0 - \theta$	degrees/radians
I	0.025	kg·m^2
c	0.5	-
k	10.0	N·m/rad
τ	*	N·m
J_f	2.94×10^5	kg·m^2
ω_f	117.27	rad/s
$\dot{\phi}$	*	rad/s
θ	*	degrees/radians
ζ	0.7	-
ω_n	10.0	rad/s
*Dynamic (from system)		

The simulation results show how changing the PID tuning parameters affects system performance in terms of rise time, overshoot, and settling time. Each configuration has its own set of trade-offs between response speed, stability, and convergence. Low PID gains cause a slow rise time and little overshoot because corrections are made carefully. However, they also take a long time to settle, so they are best for situations where stability is more important than speed. Moderate PID gains give a well-balanced response that greatly speeds up rise time while keeping overshoot under control and settling time shorter. This makes them perfect for real-world uses where both speed and accuracy are important. Higher gains make rise time even shorter by making more aggressive corrections, but they also make overshoot and oscillations worse. These changes may make settling time shorter, but they could also make things less stable in dynamic environments. Very high gains make rise times very fast, but they also cause too much overshoot and undershoot, which can lead to long or unpredictable settling times and, in some cases, complete destabilisation. This shows how dangerous it can be to tune too aggressively. The comparative study shows how important balanced tuning is. Moderate gains provide the best balance between rise time, overshoot, and settling time, allowing the system to behave quickly but steadily. In the future, improvements could include adaptive PID tuning methods that automatically adjust to changing conditions to make the system work better.

Table 3. PID Simulation Configuration Performance Comparison Results

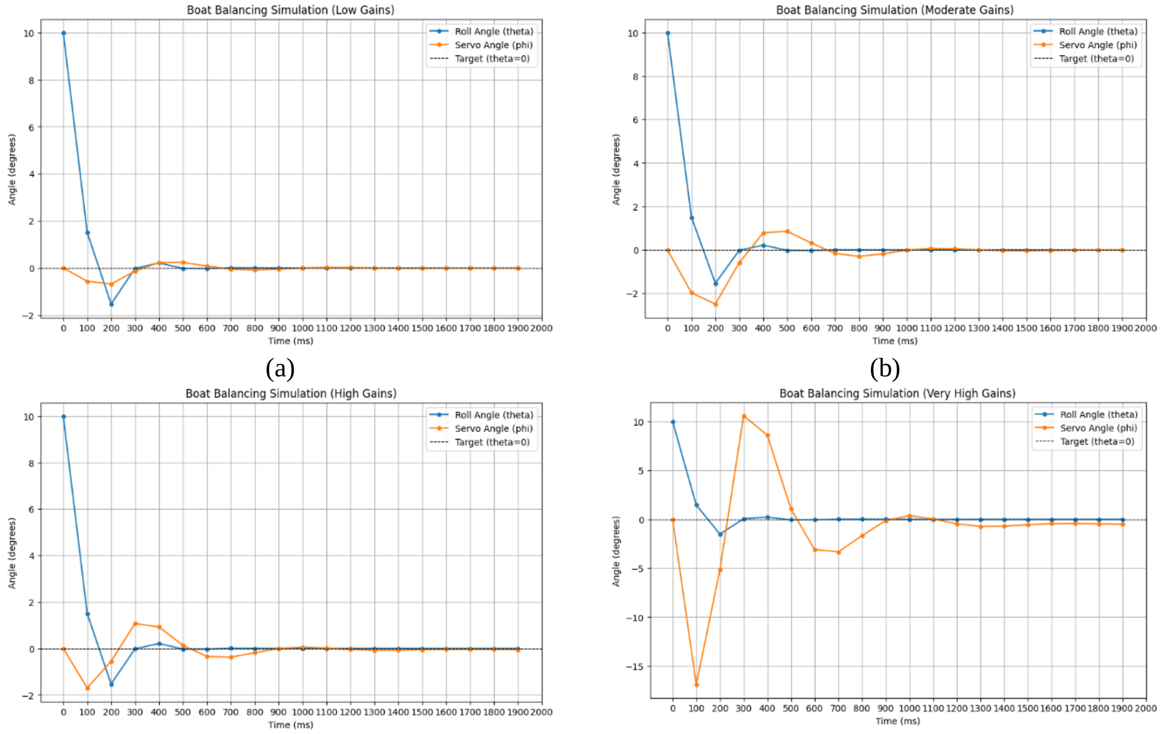
Gain Type	Rise Time (ms)	Overshoot (degrees)	Settling Time (ms)	Descriptions
Low Gains	400	~0	1800	Gradual response with no overshoot, prioritizing stability over speed.
Moderate Gains	300	~2	1000	Balanced response with minimal overshoot and faster stabilization compared to Low Gains.
High Gains	200	~4	800	Faster response but introduces noticeable overshoot, requiring trade-offs in stability.
Very High Gains	100	~7	1500	Rapid response but exhibits significant overshoot and oscillations, compromising overall stability.

3.2 Physical Prototype Implementation and Experimental Results

A scaled prototype was made based on the best simulation setup, and outside forces were added to make the system roll back and forth. This let us test how well it worked with different gain settings. Table 4 shows a comparison of these scenarios that gives us information about how the stabilisation system works in the real world and how it changes over time. When the gains are very high, the servo angle swings too much between positive and negative extremes, and the roll angle shows uncontrolled high-frequency oscillations. This means that the system isn't stabilising properly because of aggressive corrective actions and too much overshoot. This instability not only makes things less efficient, but it also raises safety concerns, which shows how dangerous it is to use very

Jurnal Sistem Komputer dan Informatika (JSON)
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001

high gains. High gains, on the other hand, make the servo work better and stabilise the roll better than very high gains, but oscillations are still there. High gains make things happen faster than low gains, but the overshoot and longer settling time that come with them make them less useful in real life. This shows how important it is to carefully tune the system to find the right balance between speed and stability.

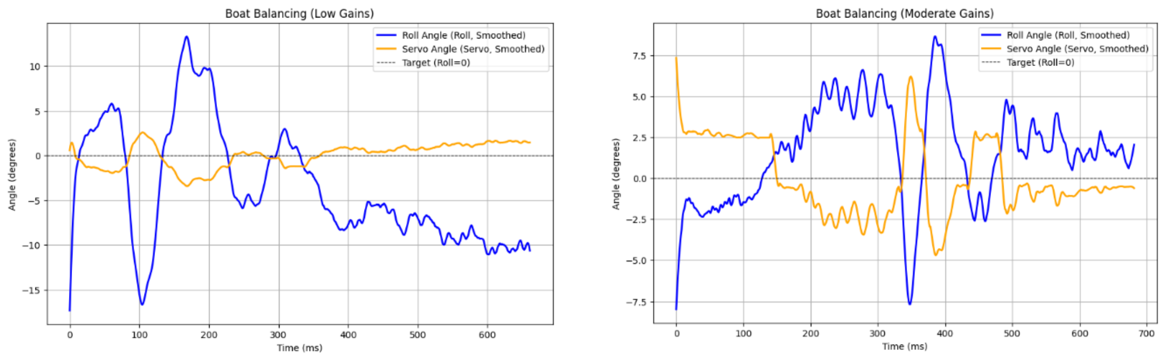


(a) (b) (c) (d)

Figure 6. Dynamic Model Simulation Results with Different Gain Types: (a) Low (b) Moderate (c) High (d) Very High.

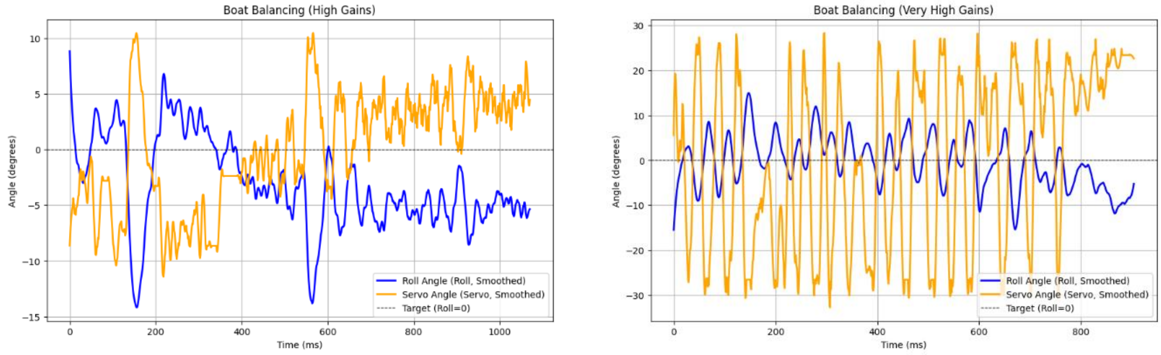
Conversely, low gains prioritize stability over speed, resulting in a roll angle that stabilizes slowly along a smoother trajectory without aggressive oscillations. The servo angle remains steady, with minimal oscillations, indicating controlled and gradual corrections. While low gains achieve a highly stable system, the slower response times make this configuration more appropriate for calm water conditions or applications where energy conservation is critical.

Finally, moderate gains offer the best balance between response time and stability. The roll angle exhibits a quick response with minimal oscillations, stabilizing effectively after some initial fluctuations. The servo angle dynamically adjusts within reasonable bounds, avoiding excessive oscillations and maintaining system control. Moderate gains emerge as the most practical configuration for real-world applications, where both quick stabilization and system reliability are paramount.



(a) (b)

Jurnal Sistem Komputer dan Informatika (JSON)
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001



(c) (d)

Figure 7. Pysical Prototype Experimental Results with Different Gain Types: (a) Low (b) Moderate (c) High (d) Very High.

Table 4. PID Configuration Performance Comparison Results

Gain Type	Rise Time (ms)	Overshoot (degrees)	Settling Time (ms)	Descriptions
Low Gains	~200	Minimal	~600	Gradual response with minimal oscillations, prioritizing stability over speed.
Moderate Gains	~150	~3	~500	Balanced response with minimal overshoot and faster stabilization.
High Gains	~100	~5	~400	Faster stabilization with noticeable overshoot and oscillations, sacrificing some stability.
Very High Gains	~50	>15	Unstable	Excessive overshoot and oscillations, failing to stabilize effectively, highlighting system instability.

3.3 Discussion

Comparing the results of the dynamic model simulation to the results of the physical prototype experiment gives useful information about how the system works. The simulation does a good job of showing how the boat stabilisation system would work in theory with different gain settings (Low, Moderate, High, Very High). The experimental results, on the other hand, show that real-world factors like vibration and mechanical flaws make things more complicated. One of the best things about this is that the behaviour trends are consistent. Both the simulation and the prototype show that low gains lead to slower but stable responses, while high gains lead to faster responses with more oscillations. There is a strong agreement between the simulation and the experiment in the Moderate gain configuration, which shows that the model can reliably predict the best performance. The simulation also accurately predicts trends in rise time and overshoot, which makes it a good tool for initial PID tuning. The physical prototype, on the other hand, has a lot of noise and oscillations at High and Very High gains because the BLDC motor and flywheel vibrate. This isn't shown in the model, which makes settling times longer and damping lower. So, even though the dynamic model is a strong theoretical framework for Low and Moderate gains, it becomes less accurate at higher gains because of real-world factors that aren't modelled, like vibration, actuator delays, and sensor noise. Adding these factors to the model, along with more experimental validation and the possible use of adaptive or machine learning-based methods for PID tuning, can make it more robust and make the results of the simulation match the real-world performance better.

4. CONCLUSION

A PID-controlled gyroscopic stabilization system for reducing roll motion in boats exposed to outside disturbances was effectively developed and validated in this study. The study showed that it is possible to bridge the gap between theoretical modeling and practical implementation by combining physical prototyping with a comprehensive dynamic model. A strong framework for PID tuning and performance prediction was offered by the simulation phase, which was based on the coupled dynamics of roll motion, gyroscopic torque, and servo behavior. Consistent patterns emerged from a comparison of simulation and experimental data, especially in the Moderate gain configuration, which struck the best balance between stability, overshoot, and rise time. Moderate gains provided the best performance for real-world applications, while low gains guaranteed high stability with a slower response and high or very high gains caused instability because of overshoot and vibrations. The study emphasizes the significance of balanced PID tuning and the necessity of taking into consideration practical elements like sensor noise, actuator delays, and mechanical vibrations. To further improve stabilization effectiveness and resilience in a range of environmental circumstances, future research may investigate adaptive or machine learning-based control strategies.

REFERENCES

[1] P. Corigliano, F. Frisone, C. Chianese, M. Altosole, V. Piscopo, and A. Scamardella, "Fatigue Overview of Ship Structures under Induced Wave Loads," *J Mar Sci Eng*, vol. 12, no. 9, p. 1608, Sep. 2024, doi: 10.3390/jmse12091608.

[2] S. Hirdaris, *Elements of Ship Dynamics and Hydromechanics*, vol. 1. Helsinki: Aalto University, 2022.

[3] Y. Feng *et al.*, "Prediction of the severity of marine accidents using improved machine learning," *Transp Res E Logist Transp Rev*, vol. 188, Aug. 2024, doi: 10.1016/j.tre.2024.103647.

[4] Y. Wu, T. Wang, and S. Liu, "A Review of Path Planning Methods for Marine Autonomous Surface Vehicles," May 01, 2024, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/jmse12050833.

[5] K. Luo, L. Yan, Z. Zhu, Z. Wang, H. Wang, and F. Jiang, "Application of Bionic Technology in Marine Cruise Equipment: Research Progress and Development Trends," May 01, 2024, *Springer*. doi: 10.1007/s42235-024-00483-w.

[6] Z. Sun, A. Feng, J. Yu, W. Zhao, and Y. Huang, "Development of autonomous sailboat sails and future perspectives: A review," Jan. 01, 2025, *Elsevier Ltd*. doi: 10.1016/j.rser.2024.114918.

[7] Z. H. Yap, H. H. Tang, S. Kang, L. K. Quen, and T. Nur, "Roll motion compensation by active marine gyrostabiliser," 2021.

[8] P. Sumislawski and M. Abdel-Maksoud, "Advances on numerical and experimental investigation of ship roll damping," *Journal of Hydrodynamics*, vol. 35, no. 3, pp. 431–448, Jun. 2023, doi: 10.1007/s42241-023-0044-9.

[9] L. Hu, M. Zhang, X. Yu, Z. M. Yuan, and W. Li, "Real-time control of ship's roll motion with gyrostabilisers," *Ocean Engineering*, vol. 285, Oct. 2023, doi: 10.1016/j.oceaneng.2023.115348.

[10] M. A. Tofigh, M. J. Mahjoob, M. R. Hanachi, and M. Ayati, "Fractional sliding mode control for an autonomous two-wheeled vehicle equipped with an innovative gyroscopic actuator," *Rob Auton Syst*, vol. 140, Jun. 2021, doi: 10.1016/j.robot.2021.103756.

[11] G. F. Giaccu and L. Caracoglia, "A gyroscopic stabilizer to improve flutter performance of long-span cable-supported bridges," *Eng Struct*, vol. 240, Aug. 2021, doi: 10.1016/j.engstruct.2021.112373.

[12] J. Zhao, X. Zhong, K. Yu, and M. Xu, "Effect of gyroscopic moments on the attitude stability of a satellite in an elliptical orbit," *Nonlinear Dyn*, vol. 111, no. 16, pp. 14957–14976, Aug. 2023, doi: 10.1007/s11071-023-08639-9.

[13] A. De Felice and S. Sorrentino, "Damping and gyroscopic effects on the stability of parametrically excited continuous rotor systems," *Nonlinear Dyn*, vol. 103, no. 4, pp. 3529–3555, Mar. 2021, doi: 10.1007/s11071-020-06106-3.

[14] E. Sitompul, A. S. Prabowo, H. Tarigan, and A. Suhartomo, "Design of an Arduino-Based Boat Roll Stabilizer System Prototype Using MPU6050 Sensor," *Circuit: Jurnal Ilmiah Pendidikan Teknik Elektro*, vol. 8, no. 2, p. 217, Aug. 2024, doi: 10.22373/crc.v8i2.23124.

[15] M. Taskin and A. O. Ahan, "Input saturated H∞ optimal control to mitigate DTMB 5415 combatant roll motion using anti roll gyro stabilizer," *Ocean Engineering*, vol. 305, Aug. 2024, doi: 10.1016/j.oceaneng.2024.117913.

[16] H. Bao, Y. Zhang, M. Song, Q. Kong, X. Hu, and X. An, "A review of underwater vehicle motion stability," Nov. 01, 2023, *Elsevier Ltd*. doi: 10.1016/j.oceaneng.2023.115735.

[17] C. V. Amaechi, F. Wang, J. Ye, and G. García, "Mathematical Modelling of Bonded Marine Hoses for Single Point Mooring (SPM) Systems, with Catenary Anchor Leg Mooring (CALM) Buoy Application-A Review," *Marine Science and Engineering* , vol. 9, no. 1179, pp. 48–49, 2021, doi: 10.3390/jmse91.

[18] O. A. Somefun, K. Akingbade, and F. Dahunsi, "The dilemma of PID tuning," Jan. 01, 2021, *Elsevier Ltd*. doi: 10.1016/j.arcontrol.2021.05.002.

[19] V. Vartika, S. Singh, S. Das, S. K. Mishra, and S. S. Sahu, "A Review on Intelligent PID Controllers in Autonomous Vehicle," in *Lecture Notes in Electrical Engineering*, Springer Science and Business Media Deutschland GmbH, 2021, pp. 391–399. doi: 10.1007/978-981-15-7675-1_39.

[20] M. Pokydko, O. Oliinyk, and V. Tymchenko, "MEMS Gyroscope Based on MPU-6050 Sensor and ATmega328 Microcontroller," in *2024 IEEE 7th International Conference on Smart Technologies in Power Engineering and Electronics, STEE 2024*, Institute of Electrical and Electronics Engineers Inc., 2024. doi: 10.1109/STEE63556.2024.10748180.

[21] M. Palraj and P. Rajamanickam, "Motion control of a barge for offshore wind turbine (OWT) using gyrostabilizer," *Ocean Engineering*, vol. 209, Aug. 2020, doi: 10.1016/j.oceaneng.2020.107500.

[22] D. Hercog, T. Lerher, M. Truntič, and O. Težak, "Design and Implementation of ESP32-Based IoT Devices," *Sensors*, vol. 23, no. 15, Aug. 2023, doi: 10.3390/s23156739.

[23] H. Feng, W. Ma, C. Yin, and D. Cao, "Trajectory control of electro-hydraulic position servo system using improved PSO-PID controller," *Autom Constr*, vol. 127, Jul. 2021, doi: 10.1016/j.autcon.2021.103722.

[24] J. Sundnes, *Solving Ordinary Differential Equations in Python*, vol. 15. Heidelberg: Springer, 2024.

[25] S. Li, Z. Xu, J. Liu, and X. Hu, "Towards the Testing and Validation of Autonomous Ships: Design of a Variable Stability Ship Control System," *J Mar Sci Eng*, vol. 11, no. 7, Jul. 2023, doi: 10.3390/jmse11071274.

[26] J. Juchem, M. Loccufier, and A. Chevalier, "Towards a Controlled Orthosis for Sit-To-Stand Support in Independently Living Elderly: Model Development," in *IFAC-PapersOnLine*, Elsevier B.V., Jul. 2023, pp. 6471–6476. doi: 10.1016/j.ifacol.2023.10.861.

Jurnal Sistem Komputer dan Informatika (JSON)
Volume 7, Nomor 2, Desember 2025
e-ISSN 2685-998X
DOI 10.30865/json.v7i2.9001

[27] J. Kim, H. You, and C. Kim, "Shock-capturing PID controller for high-order methods with data-driven gain optimization," *J Comput Phys*, vol. 508, Jul. 2024, doi: 10.1016/j.jcp.2024.113015.

[28] Z. yun Huang, Z. liang Gao, and S. ming Xu, "Numerical study on roll dynamics of damaged ship in beam waves and calm water," *Journal of Hydrodynamics*, vol. 35, no. 3, pp. 482–497, Jun. 2023, doi: 10.1007/s42241-023-0041-z.

[29] Y. Q. Guo, X. M. Zha, Y. Y. Shen, Y. N. Wang, and G. Chen, "Research on PID Position Control of a Hydraulic Servo System Based on Kalman Genetic Optimization," *Actuators*, vol. 11, no. 6, Jun. 2022, doi: 10.3390/act11060162.