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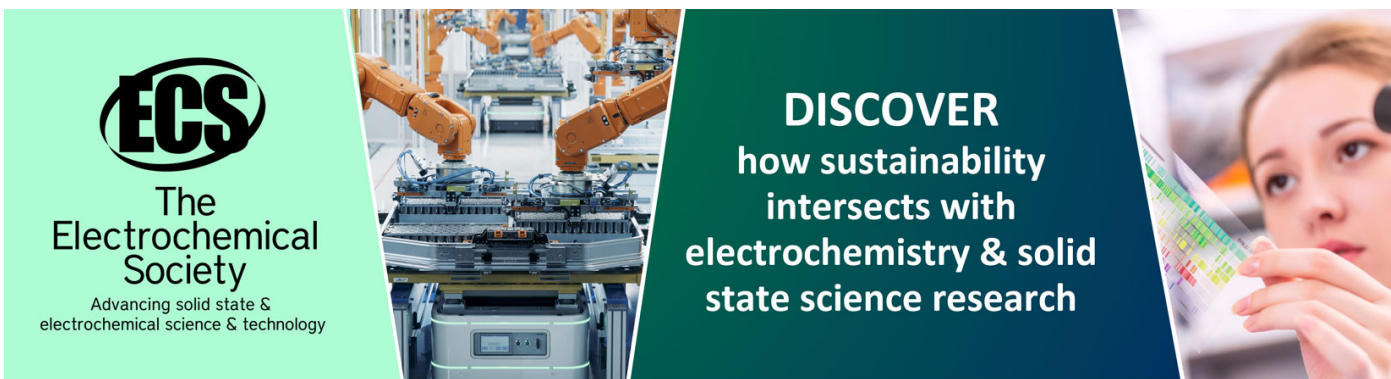
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Design of Fuzzy Sugeno Controller for Anti-Roll Stabilizer Using Flywheel

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Abstract. Ship stabilizers are still an interesting issue to develop. The ship changes a lot like the rolling motion caused by the waves. The scrolling effect of the ship causes passenger inconvenience and collisions. Therefore, a stabilizer is needed to reduce rolling so that the ship stays balanced. This stabilizer is mounted on the center of the ship to effect the rolling ship effect. This research developed an anti-roll stabilizer by utilizing the flywheel. The flywheel rotates on the stabilizer shaft producing Direction force and value magnitude. To control the flywheel speed, a fuzzy logic controller is used. The results of the study showed that the Anti-roll stabilizer was able to reduce rolling vessels by 26% from the front and rear directions of the ship, and 56% from the left and right directions.

Keyword : ship balancing, anti-roll stabilizer, flywheel, fuzzy logic controller

1. Introduction

The ship is a means of transporting passengers and goods at sea or river. Ships are also used in the military world, especially in the navy as a means of weaponry to maintain the security of a country's territory. In Indonesia, this means of transportation is needed because Indonesia is an archipelago [1]. In general, the motion of ships is divided into two types, namely translation and rotation. The translation movement is divided into three namely surge, sway, and heave, while the rotational movement is divided into three namely roll, pitch and yaw [2].

The main threat to the comfort and safety of ship transportation is ocean waves. There have been many ship accidents caused by ocean waves. Sea waves produce rolling ships that are large enough to defeat the moment of returning the ship. Rolling ships that occur continuously will result in ships not having the ability to stabilize the hull. Therefore a rolling stabilizer is needed so that the ship can reduce the effects of rolling caused by waves.

To reduce the effects of ship rolling, fishermen usually add balancing arms to the right and left sides of the ship. Tank stabilizers are the most popular stabilizers and are widely applied to ships [3]. Fin shaped boat stabilizers have also been made and are proven to reduce the effects of rolling due to ocean waves [4]. To maximize the performance of the fin-shaped anti-roll stabilizer, the angle of the fin is controlled so that it can adjust the incoming wave to dampen the rolling vessel [5].

In this study an anti-roll stabilizer was installed in the upper hull to maintain the balance of the ship by utilizing the momentum force that occurs in the flywheel. The force of momentum that occurs in the flywheel produces direction and value and will react to the direction of the interference that comes. The disturbance is detected by the gyro sensor and processed using a microcontroller. Furthermore, the microcontroller provides the value of the action on the motor as a flywheel driver,



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and this flywheel movement will produce a force that has a value and direction (vector). Fuzzy method is used to adjust the rotation speed of the flywheel based on changes in ship angle caused by interference.

2. Methods

Anti-roll stabilizer is a roll damping system equipment installed on the upper hull of the ship which serves to maintain the balance of the ship. This anti-roll stabilizer makes use of the flywheel rotating force. Flywheel has two forces namely centrifugal force and centripetal force based on Newton's Law III. F_s is the force acting on an object that moves in a circle where the direction of F always goes to the center of the environment, so that it produces equations 1, 2, and 3 [6][7].

$$F_s = m \cdot a_s \quad (1)$$

$$F_s = \frac{m \cdot v^2}{R} \quad (2)$$

$$F_s = \frac{m \cdot \omega^2}{R} \quad (3)$$

$$F_{sf} = + \frac{m \cdot v^2}{R} r \quad (4)$$

In this case, the stabilizer utilizes centrifugal force which can be changed in the direction of the style as shown in Figure 1 [8]. The direction of the centrifugal force on the flywheel is away from the center of the force and is perpendicular to the direction of rotation and produces equation 4. The (+) sign indicates that the direction of the force is away from the center of the circle.

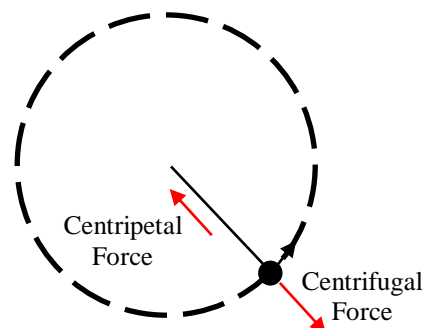


Figure 1. Centrifugal and Centripetal Forces

Centripetal and centrifugal forces are not action-reaction pairs, they are acting on the same thing. When the flywheel rotates counter-clockwise (CCW), the flywheel rotation direction (ω) in the forward direction, angular momentum (L) goes to the axis (x) so that the torque (τ) goes to the axis (y). The force on the flywheel can provide force according to its speed and weight, causing this tool to work as a stabilizer [9]. Therefore, the anti-roll stabilizer will utilize the flywheel and be applied to the hull. Flywheel torque can be determined based on equation 5. Flywheel as an anti-roll, depends on the mass of the flywheel and the flywheel speed, so it must use a DC brushless motor with the calculation of the torque in equation 6.

$$\tau = I_g \cdot \omega \cdot \ddot{\theta} \cdot \cos \theta \quad (5)$$

$$P = \tau \cdot \omega \quad (6)$$

Good mechanical design will support anti-roll movement for the better. Therefore the anti-roll frame must be made symmetrical and sturdy so that it can be held in the direction of the hull to be filled. The mechanical design and anti-roll block diagram can be seen in Figure 2. The anti-roll mechanic has a flywheel, MPU-6050, BLDC, servo, battery and arduino. Servo placed on the horizontal and vertical anti-roll, laying the servo is used to move the y axis of the flywheel. Servo movements are compiled by reading data generated by MPU-6050. Laying mechanical anti-roll at landing by a center of gravity (middle of the weight) that depends on the ship. In Figure 4 Answer The direction of the servo force is in accordance with the direction of the waves coming. The configuration of arm motion used on the flywheel is motion y. At rest, servo x does not work. The starting position of the servo is 90° , so that the movement is faster than the starting position of the servo 0° . Servo Y will work when the waves come from the front or back direction. When the waves come from the front direction, the Y servo will work according to the height of the incoming waves.

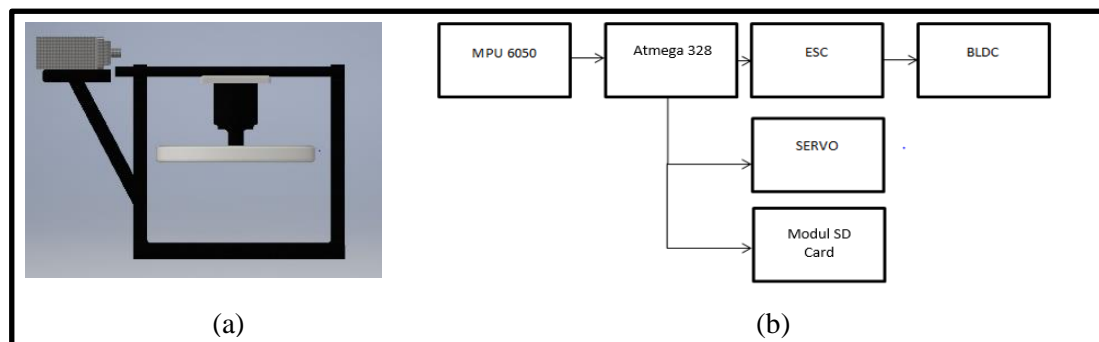


Figure 2. (a) Anti-roll Design (b). Block Diagram System

The anti-roll system works by receiving data from the MPU-6050 sensor which is then connected to the microcontroller. Data from this sensor is used to move the actuator in the form of a servo and motor. Gyro sensors have x, y and z values. The values used on this sensor are only x and y values, i.e. horizontal and vertical values, (ignoring z values). In this case, motor speed is controlled using Fuzzy Sugeno which has a linear equation output, the process consists of fuzzification, fuzzy inference and defuzzification[10][11]. Fuzzy system used is embedded in the microcontroller. In this method, the Arduino microcontroller is used as an intermediary for system input and output. A simple work system can be seen in Figure 3.

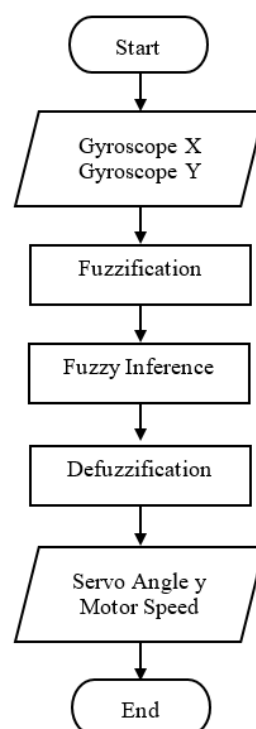


Figure 3. Anti-roll Stabilizer Control System

In the initial stage, what is done is the reading of the x-axis and y-axis gyroscope produced by MPU 6050. After getting the data generated by the sensor, the process is continued with fuzzification. Fuzzification requires the establishment of a rule base. Rule base is a fuzzy method stage in which there are input and output membership. Implications used are max value implications, this value will be used as a defuzzification input which the final stage is the angular control of the servo and BLDC speed.

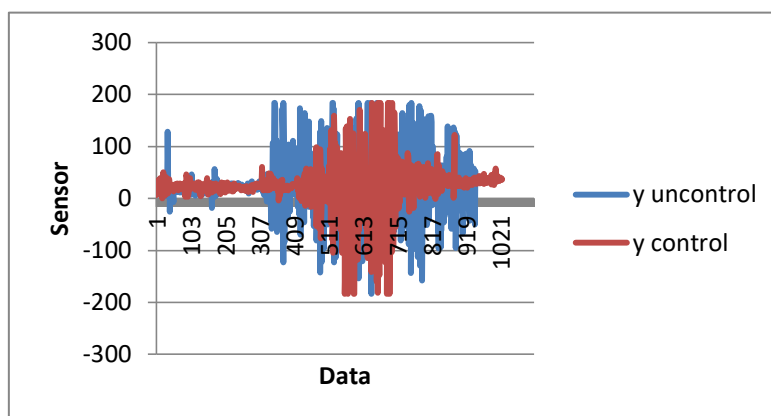
3. Result and Discussion

Before testing the anti-roll stabilizer, the first thing to do is to calibrate the gyro x and y sensors. Calibration is done by comparing manual measurements and measurements produced by sensors. This is done to ensure that fuzzy works as desired. If the difference is not too significant then it is certain that fuzzy will run well, so the anti-roll stabilizer also works well. Based on measurements for gyro y of 0.03% and gyro x 0.05% as in the Table 1.

Table 1. Diffence Measurement

Y Value			X Value		
Sensor Measurement	Manual Measurement	Different Value	Sensor Measurement	Manual Measurement	Different Value
32°	30°	2	48°	45°	3
61°	60°	1	23°	20°	3
24°	20°	4	27°	25°	3
92°	90°	2	92°	90°	2
43°	40°	3	53°	50°	3
48°	50°	2	74°	70°	4
15°	15°	0	62°	60°	2
Different Value (%)		0.03%	Different Value (%)		0.05%

After calibration, an anti-roll stabilizer experiment was conducted with the results shown in Figure 4 and Figure 5. In the 406th sampling data, the uncontrolled gyro value is 111 while the controlled gyro value is 28, we can observe that the resulting difference reaches 74% or 83. The difference in value is also in the 387th data, the uncontrolled gyro is 104 and the controlled gyro is 17, so the difference in both values is 83% or 97. From the two data it can be ascertained that the control anti-roll stabilizer is very influential to reduce shocks.

**Figure 4.** Gyro Y Anti-roll Stabilizer Result

Whereas on gyroscope x, in the 414th data, the controlled gyro x is 9 and the gyro x is not controlled 17, so the difference between the two values is 40% or 8. The 773th data also shows a significant difference, the controlled x value value of 11 while the value of x is not controlled value of 137, so the difference from that value is 90% or 126. The gyro x value is generated by the anti roll. from this experiment we can conclude that the anti-roll stabilizer has the role of providing a force in accordance with the wobble of the ship can be damped by the force exerted by the anti roll on the hull. From the test data, the anti-roll stabilizer can reduce ship shock 26% on the y axis and 56% on the x axis

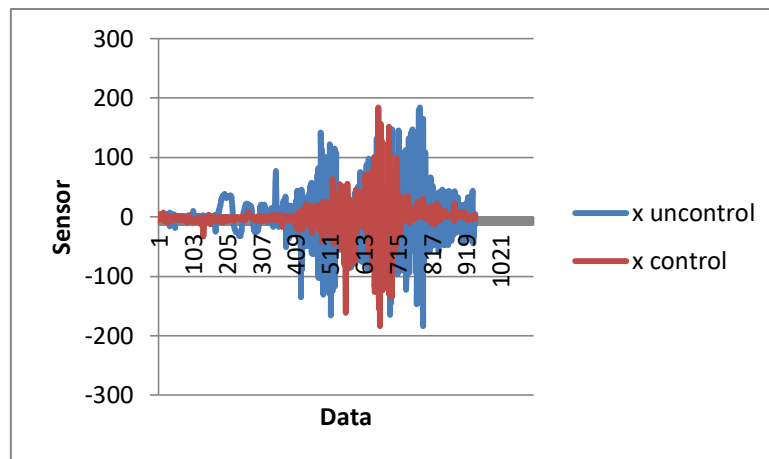


Figure 5. Gyro X Anti-roll Stabilizer Result

4. Conclusion

After conducting several tests, it can be concluded that:

1. It is not recommended to use a servo, because it causes delays in action so that the ship causes more rocking
2. Using a motor that is not noisy, but has the power like BLDC, noise pollution caused by BLDC can not be muted perfectly even though using rubber tires.
3. The MPU sensor value of 6050 has a difference in value between manual measurement and sensor measurement results of 0.05% on the x axis and 0.03% on the y axis.
4. Anti-roll can reduce the waves that hit the ship by 56% on the x axis and 26% on the y axis.

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