Development of Hovercraft Prototype with Stability Control System using PID Controller

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Abstract— **Hovercraft is a mode of transportation as an alternative for users who stay on the river dan swamp surface. The problem with hovercraft is when uncertain weather and environmental condition, e.g. wind velocity and wave height disturb stability of hovercraft so as to endanger the driver. We propose a way to maintain the balance of the hovercraft by controlling center of gravity (CG) in the balance position. The controller controls the position of load to balance position. A 6-DOF IMU Sensor MPU 6050 was employed to generate data as a comparison with setpoint. PID control method was used. The test result shows that the prototype of hovercraft was able to keep its balance on the axis orientation of the roll although it was less effective in the pitch axis orientation.**

Keywords- Hovercraft, Stability, SetPoint, PID

I. INTRODUCTION

Indonesia is an archipelago country with more than 70% of its area consisting of waters and abundant river flow paths. Besides that, Indonesia has considerable risk from natural disasters, such as earthquake, flood, and even tsunami. Due to that geographic condition, Indonesia needs a vehicle which can move fast and reliable in many conditions, to use in transportation, emergency condition, coast guard, and search and rescue. Since the hovercraft can move in almost all terrain conditions, this vehicle is one of the solutions which can satisfy those requirements. A hovercraft, or Air-Cushion Vehicle, is an amphibious vehicle designed to travel over any sufficiently smooth surface – land or water – supported by a cushion of slowly moving, low pressure air, ejected downwards against the surface close below it. To produce the air cushion, the propeller is used to provide lift by keeping a low-pressure [1, 2]. One shortcoming of this hovercraft is its limited maneuvering. At the time of maneuver, movement will affect the orientation angle of hovercraft, due to changes in the slope on the rotary axis in hovercraft body. This hovercraft orientation angle change may result in the loss of stability in hovercraft body [3]. Therefore, control of hovercraft body is necessary to maintain in stable position so that the inclination of hovercraft can be stabilized and balanced.

One way to make the hovercraft body remains stable is to control the center of gravity of the hovercraft. Translational axis X, Y, Z and rotation angles of pitch, roll and yaw are commonly used as reference to control the center of gravity of the hovercraft [1,4]. In addition, the gravity and acceleration are necessary data as a comparison for corner setpoint. The 6-axis MPU-6050 module [5] is a combination of accelerometer and Gyroscope sensors that can be employed for this purpose. In addition, among many methods, PID [6,7] and fuzzy methods [8,9] have been used to provide the data setpoint and maintain hovercraft body tilt on the desired setpoint.

In this research, we propose a design of control system on the prototype of hovercraft with the purpose to maintain the hovercraft body position in stable state while on the move. The PID controller was selected due to its simplicity yet efficient, as it can be programmed with simpler microcontroller-based electronics.

II. METHODS

Mechanical systems in the prototype of hovercraft are very influential for stability when on the movement. Specifically, the design of hovercraft prototype must have the COG (Center of Gravity) approaching the orientation axes so that the movement in maintaining body stability could be done with less hassle. Fig. 1 shows the design perspective of the prototype. Moreover, the layout of mechanical components in the prototype is detailed in Fig. 2. The hovercraft prototype has technical components as described in Table 1, along with the corresponding weight. The numbers in Fig. 2 refers to the list of components in Table 1 as well. These components are useful to support the manufacturing of the hovercraft prototype. As can be observed from Fig.2, the layout and placement of components was selected to near symmetry in reference to x-axis.

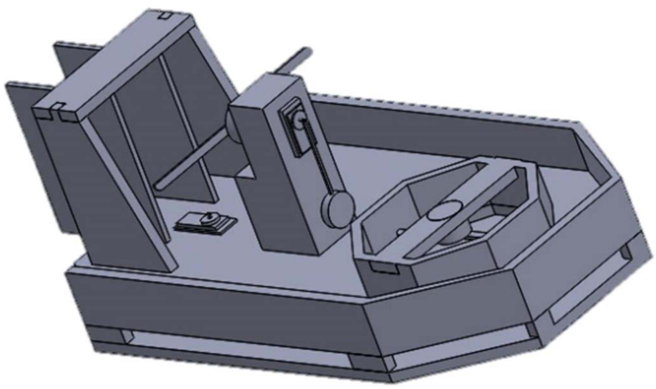

Fig. 1 Hovercraft prototype design using Solidworks 2015

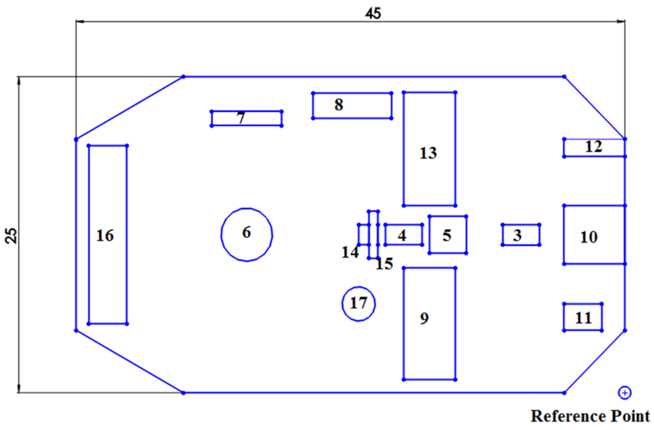

Fig. 2 Layout and placement of prototype's component

TABLE I. COMPONENTS OF HOVERCRAFT PROTOTYPE

No	Component	Weight (gram)
1	Frame of prototype	577
2	Hull + Skirt	250
3	Rudder Servo	55
4	Actuator Servo	55
5	Trust Fan	65
6	Lift Fan	65
7	Electronic Speed Controller (ESC)1	45
8	Electronic Speed Controller (ESC)2	45
9	Battery (Lipo 3S 11,1 1000 MAh)	93
10	Receiver - PS2 Joystick	19
11	Lipo Checker	15
12	Bluetooth HC-05	7
13	Mikrocontroller + MPU-6050	21
14	Arm Servo	28
15	Load actuator	73
16	Additional load 1	76
17	Additional load 2	37
	Total component weight	1542

With the reference to the placement and weight of each component, the center of gravity (COG) can be calculated. The COG calculation is required because in order to get static stability, the load must be distributed evenly across the surface area of the hovercraft prototype [2]. To meet that requirement, the COG must be placed near the center of the prototype body, therefore makes it easy to make movement in any angle or direction. The symmetry between left and right side of body along the center line is crucial in the balance of the system while moving forward. In addition, the reference point (0, 0) is selected at the downright point in Fig. 2.

Components with their respective weight in Table 1 were distributed so the weight of all the components can be centered in the middle of prototype at coordinate (12.5, 22.5) in order to facilitate the design of control system on a hovercraft prototype's balance. The reference point is the starting point for determining the distance of each component.

After the components were put in right place, then the next step is to calculate the coordinates of the center of gravity. It is noteworthy that each component was assumed as point mass body to simplify the calculation of the center of gravity. Table 2 shows the calculation of the COG of the hovercraft prototype. Variables X and Y are the relative position from reference point. The weight is calculated from W = m.g, with m as mass and gravity g = 9.8 ms^{-2}.

TABLE II. CALCULATION OF CENTER OF GRAVITY (COG)

No	Mass (gram)	Weight, W (N)	X (cm)	Y (cm)	XW (Ncm)	YW (Ncm)
1	577	5.65	12.5	22.5	70.68	127.23
2	250	2.45	12.5	22.5	30.62	55.12
3	62	0.61	12.5	10	7.6	6.08
4	62	0.61	12.5	18	7.6	10.94
5	65	0.64	12.5	14.5	7.96	9.24
6	65	0.64	12.5	31	7.96	19.75
7	45	0.44	23	22.7	10.14	10.01
8	45	0.44	21	29.8	9.26	13.14
9	93	0.91	6.3	16.6	5.74	15.13
10	19	0.19	12.5	2.8	2.33	0.52
11	15	0.15	6.7	3.6	0.98	0.53
12	7	0.07	19.7	2.8	1.35	0.19
13	21	0.21	19.7	17	4.05	3.5
14	28	0.27	12.5	20.8	3.43	5.71
15	73	0.72	12.5	20.6	8.94	14.74
16	76	0.74	12.5	43.6	9.31	32.47
17	37	0.36	5.7	24.8	2.07	8.99
TOTAL		15.09			187.97	324.29

The center of gravity in terms of X and Y coordinates are calculated as following:

$$\overline{X} = \frac{\sum XW}{\sum W} = \frac{187.97}{15.09} = 12.45 \text{ cm}$$

$$\overline{Y} = \frac{\sum YW}{\sum W} = \frac{324.29}{15.09} = 21.49 \text{ cm}$$

By distributing the loads into selected positions, the value of the center of gravity is very close to the position of balanced actuator servo. The error value $\Delta X = 0.05$ cm and $\Delta Y = 0.01$ cm were found which are very small.

In the prototype, the balance is controlled using a PID controller. The error of set point is generated from the sensor data and then calculated into PID. In general, controller block diagram is shown in Fig. 3 that shows that the 6 DOF IMU sensor produces roll and pitch angles. This angle is compared with the input set point. Angle error is fed into PID controller input. Error is then calculated to generate the PWM signal output.

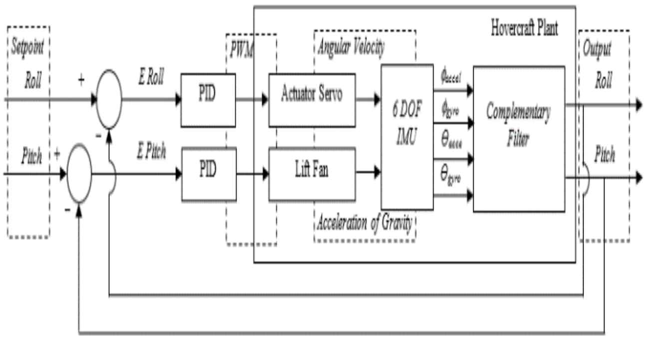

Fig. 3. Block Diagram of system

As important part of the system, 6 DOF MPU-6050 is a combination of two kinds of sensors: accelerometer and gyroscope sensor manufactured by InvenSense with I2C communication interface. The MPU-6050 combines accelerometer and gyroscope in a single board [5]. These sensors can detect acceleration in three axis (x, y, and z) and the angular velocity in three axis (x, y, and z).

The two inputs bring noise, each of which is high and low frequency noise. Therefore, two kind of filters were employed. The signal with high frequency noise was filtered by the low-pass filter, while the input containing low frequency noise was filtered with high pass filters. The output reconstruction of both signals after filters produces signal without noise previously associated with sensor. Fig. 4 illustrates the complementary filter diagram of the rotation angle. According to the figure, the angle calculation with the combination of complementary filter for each sensor, i.e accelerometer and gyroscope, is formulated as following:

$$\phi = (K_{gyro}) \times \left(\phi + \dot{\phi}_{Gyro} \times dt\right) + (K_{Act}) \times (\phi_{Act})$$

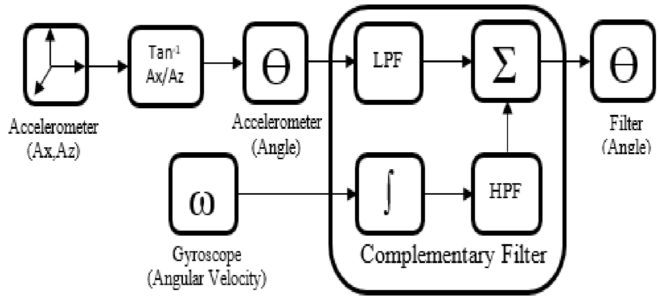

Fig. 4. Complementary filter diagram of rotation angle.

III. Results and Discussion

The hovercraft prototype was tested for several procedures. The first test was moving the prototype in straight line over the ground, and the second was flying over the water. Data of position and angle were sent via Bluetooth to the computer terminal for analysis purpose.

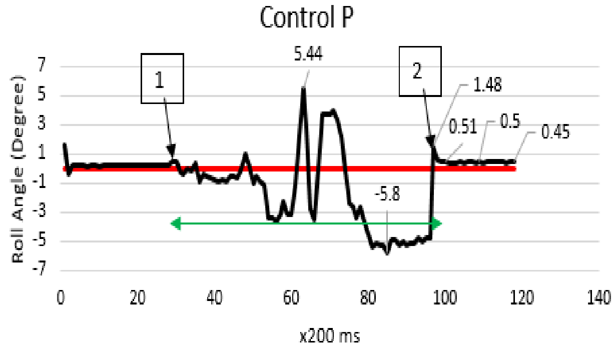

Fig. 5. Roll angle response of the prototype moving above the ground due to disturbance

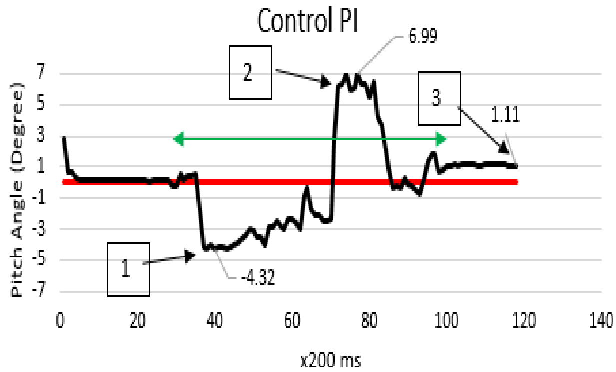

Fig. 6. Pitch angle response of the prototype moving above the ground due to disturbance

A. Movement test above the ground

Fig. 5 reveals obtained data of the roll angle when the system was subjected to disturbance (box 1). The angle deflected away from the setpoint for a few seconds and then returned back to the setpoint. The maximum roll angle deflections were 5.44 ° and -5.8 ° for each part. In this case the PWM duty cycle for servo motors was compensated to arrive at the set point. Until the end of the disturbance (box 2), the speed increased because of the excess PWM duty cycle for up to a few seconds. Afterwards, the speed went down and followed the setpoint, but a slight error of 0.51° was found. The small deflection is an indication that system running in PID control went well for the roll angle response.

On the other hand, Fig. 6 shows the pitch angle when the system is subjected to disturbance (box 1) for lack of mechanics and aerodynamics of hovercraft prototype. This in turn makes hovercraft prototype suffer from the downforce to the surface with the offset of maximum -4.32°. At the time of the affected system disturbance (box 2) in the form of an uneven path, the system drifted away from the setpoint by 6.99° but a few seconds later, the system was able to return to stable condition. A setpoint error of 1.11° from zero position was found (box 3). The time required by the system to stabilize is shown along the line green. The system requires about 14.2s to reach stability. Table 3 shows the time it takes the system to achieve stability when moving forward along straight line above the ground for several times. The test resulted in an an average time of 16.96 seconds when the system given the disruption of the bumpy track 2 times at a distance of 38 meters.

TABLE III. THE RESPONSE ON FORWARD MOVEMENT TEST OVER THE GROUND

Test #	Time (s)
1	14.2
2	18.4
3	17.4
4	17.2
5	17.6
Average	16.96

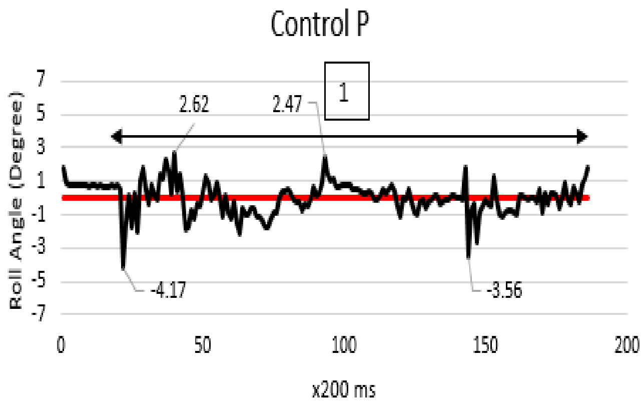

Fig. 7. Roll angle response of the prototype moving above the water due to disturbance

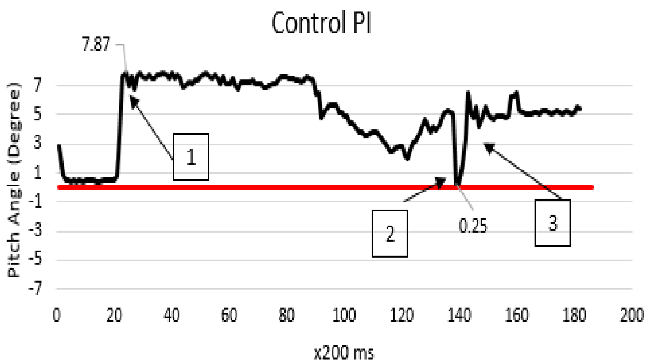

Fig. 8. Pitch angle response of the prototype moving above the water due to disturbance

B. Movement test above the water

Movement tests on water were conducted in a swimming pool which has a depth of 0.5 meters. Testing was conducted by flying the prototype on straight line of 20 meters. Figs. 7 and 8 show the results of testing.

Fig. 7 shows the roll angle response when the system is subjected to continuous disruption (box 1) due to waves of water at the time of testing that always fluctuates. This caused the system to oscillate with the greatest error of 4.17°. The disturbance was not fully overcome by the PID control on pitch angle as the angle oscillated in more than 70s. On the other hand, Fig. 8 shows the results of flying testing above the water in regards of pitch angle when the system was running with the condition of fan trust on 100% duty cycle conditions. Box 1 is the start of disturbance that produce large pitch angle offset of 7.87°. The aerodynamics of the prototype made the direction of the produced thrust skewed downward because of the frictional forces skirt. In addition, the pressure loss on the front side of the skirt hovercraft due to the nature of water affected the COG to move forward from its initial position while on the water. As a consequence, the oscillation was not being able to overcome by PID control on the pitch angle. When the speed of the fan trusts decreased (box 2), offset on the pitch angle was able to decrease to 0.25° because the COG is shifted back to the initial coordinates and pressure distribution on the hovercraft skirt back to normal. However, when the fan speed is increased again to full trust (box 3), the offset on the pitch angle was observed again. Therefore, the PID control above the water needs extra consideration on the speed limitation. With moderate speed, the existing PID control can overcome the disturbance with only slight deflection while moving above the water.

IV. CONCLUSION

The hovercraft prototype has been developed with the PID controller to maintain its stability. The load balance mechanism was employed with the concern on the center of gravity in order to compensate any change of pitch and roll angle. The testing results revealed that the hovercraft could move forward above the ground easily, and in the presence of disturbances, it could recover to its stable position. Angle errors were found for about 0.51° and 1.11° in roll and pitch angles, respectively. The average time to reach stability was 16.96 seconds. On the other hand, disturbance test above the water produced greatest error on the roll and pitch angles of 4.17° and 7.87°, respectively. Oscillation of pitch angle while on testing above the water was not able to be addressed by the PID control due to shortcomings in terms of aerodynamics. The water waves affect shifting of COG forward when the hovercraft prototype running above water which causes the error on a large pitch angle. Speed limitation with thrust control is found to be a solution for reducing the oscillation for movement over the water.

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