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The stability of cannon position on tank prototype using PID controller

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ABSTRACT

Tank is a war vehicle made of steel that can be operated on various fields. With various fields and a large amount of terrain that the tank had to pass, this made it necessary for the tank to be able to stabilize the cannon so that the cannon be able to fire right on the target. This study discusses the stability of the position of the cannon on the tank prototype using the PID control system. PID values are obtained by using the Ziegler-Nichols tuning formula and simulink. The system using Arduino MEGA 2560 as microcontroller, gyroscope & accelerometer for the feedback sensor and cannon that driven using three servos that representing the x-axis, y-axis and z-axis. The highest average error value is 4.67 degrees with an overall average value of 2.29 degrees and an accuracy percentage of 98% when the tank tilted randomly on the x-axis, y-axis and z-axis.

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1. INTRODUCTION

The application of robotic technology is very helpful in terms of national defense [1] and one of the examples of its use is in tank vehicle. Tanks are war vehicles with robotic technology that can be operated in urban, rural, field and even desert areas [2]. With a large amount of terrain that the tank had to pass, this made it necessary for the tank to be able to stabilize the cannon so that the cannon be able to fire right on the target [3]. Various control systems can be applied to create stability in the tank cannon and one of them is the proportional integral and derivative (PID) control which is a classic control system. This classic control system can be used because of its stability and a good controller to reduce system oscillations [4]-[7].

The gyroscope sensor is a device used to measure the rotational speed or the rate of change in angles over time [8]-[11]. The accelerometer sensor is a device used to measure the value of acceleration, gravitational acceleration and also acceleration of motion [12]-[14]. The combination of the two sensor data can be used as a data source for the inertial measurement unit (IMU) [15]. This study used IMU 6 axes that consisting of 3 axes gyroscope sensor and 3 axes accelerometer sensor [16], [17].

PID controllers are very popular in the industrial section because of its reliability, applicability and simplicity [6], [18]. PID can be tuned using the Ziegler-Nichols (ZN) tuning method [19] which is the most popular method because of its ease of use among all of the PID tuning method [20]-[23]. PID can be used to stabilize DC motor [24]-[26] and servos [27]-[29].

In the previous search, researchers in conducting their research on tank servo systems are using one or two axes coordinate [29], [30], discuss about controlling cannon on the elevation axis using PID [31], using PID controller where the servo of cannon is able to pan left or right [1], [32], discuss about controlling tank using two axes coupling. To improve stability on the cannon, this study will discuss stabilizing cannon on yaw, pitch and roll coordinates when the tank moves from one place to another.

2. RESEARCH METHOD

2.1. System block diagram

This system was designed to create a stable position of the cannon on the tank prototype. This system consists of a controller in the form of Arduino MEGA 2560. Then an accelerator in the form of a cannon and also a gyroscope & accelerometer sensor for the feedback that is used for the PID control system. This system works by means of the user first determining the angular position of the *x*, *y* and *z* axes as a reference point of the cannon position. After that, the angular position will be converted to a pulse width modulation (PWM) value to move the servos as its actuator. Gyroscope & accelerometer sensor serves to check whether there are changes in the angle or position of the tank. The values from the gyroscope & accelerometer sensor in the form of degrees per second will later be converted into an angular position, and after that it will be compared with the reference of the angular position to see the difference value. If a different value is obtained between the gyroscope & accelerometer sensor readings and the reference of the angular position, the controller will do the calculation and correcting the value of the PWM to move the servos to a reference angle. This system block diagram can be seen in Figure 1.

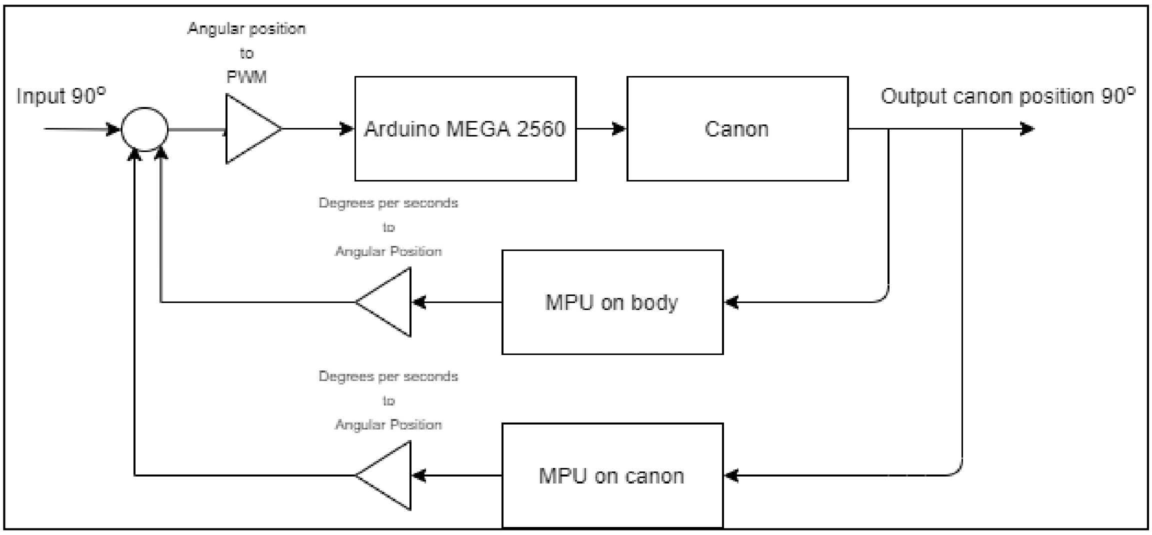

Figure 1. System block diagrams

2.2. System flowchart

The system will perform the initialization process first. In the initialization process, there is a setpoint value from each axis position (*x*-axis, *y*-axis and *z*-axis) which will become the reference value. Then, the gyroscope which works as a position sensor will check whether the position of the *x*-axis is having the same value as the reference value or not. If the difference in value is obtained, the controller will perform the calculation of the kp, ki and kd for later use of these as the PID value on the servo. After that, the system will check the position of the *y*-axis and the *z*-axis. If there is a difference with the reference value, the controller will perform the same process as mentioned above. This process will be carried out repeatedly so that the position of the cannon through the *x*-axis, *y*-axis and *z*-axis will always be stable at a predetermined reference value. An explanation of the flowchart can be seen in Figure 2.

2.3. Hardware design

This study using Arduino MEGA 2560 as a microcontroller that controls the entire cannon position stability system on the prototype tank. Then the actuators are using servo motor MG996R servos for each x, y and z axes. For the feedback sensors, it uses two MPU6050 (gyroscope & accelerometer) sensors that are placed on the body of the tank and on the tip of the cannon. Those sensors are connected to the I2C pin on the Arduino MEGA 2560 as shown in Figures 3-5.

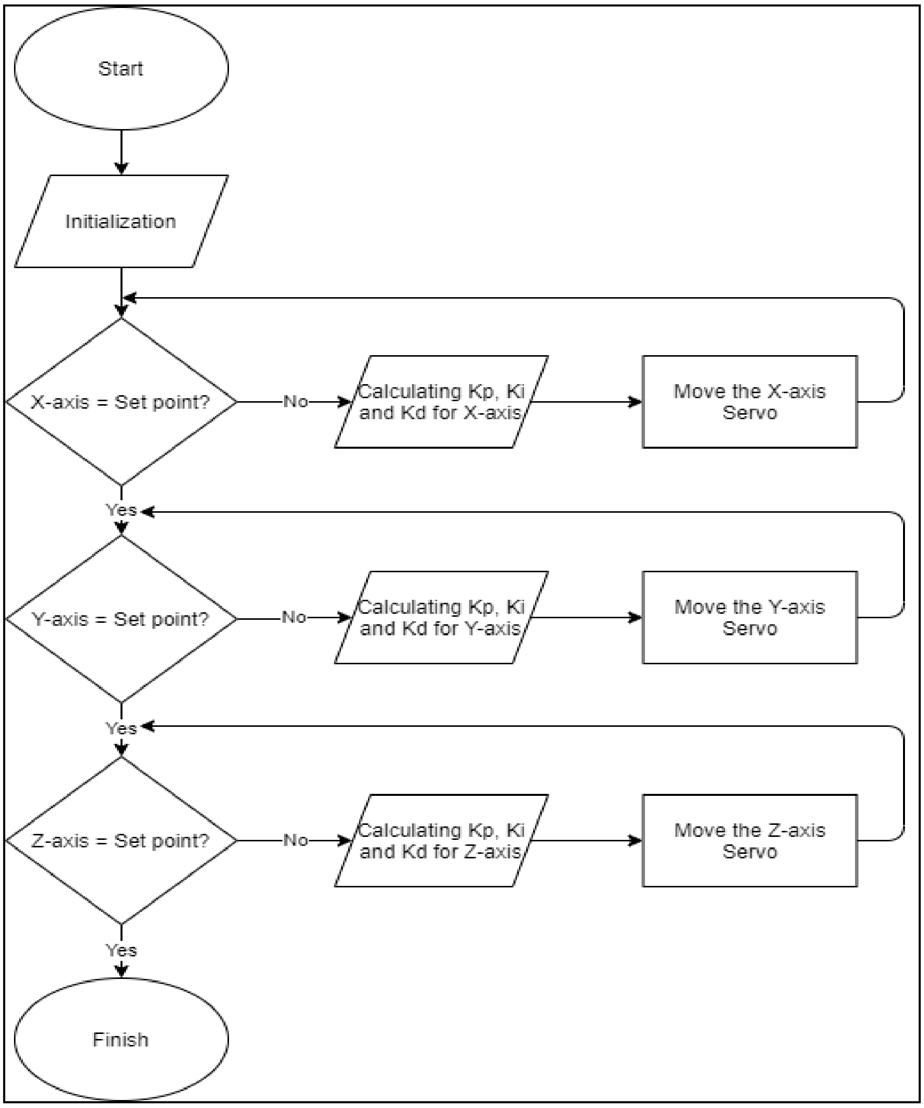

Figure 2. System flowchart

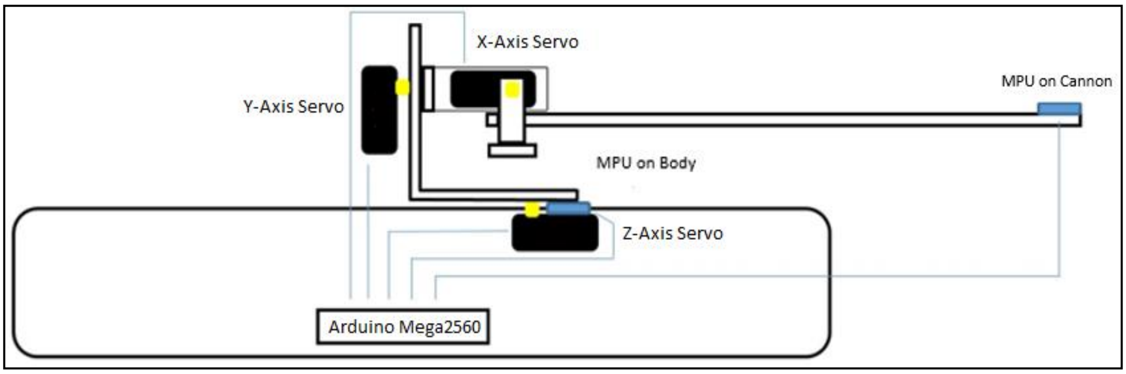

Figure 3. Control mechanism on the tank prototype (side view)

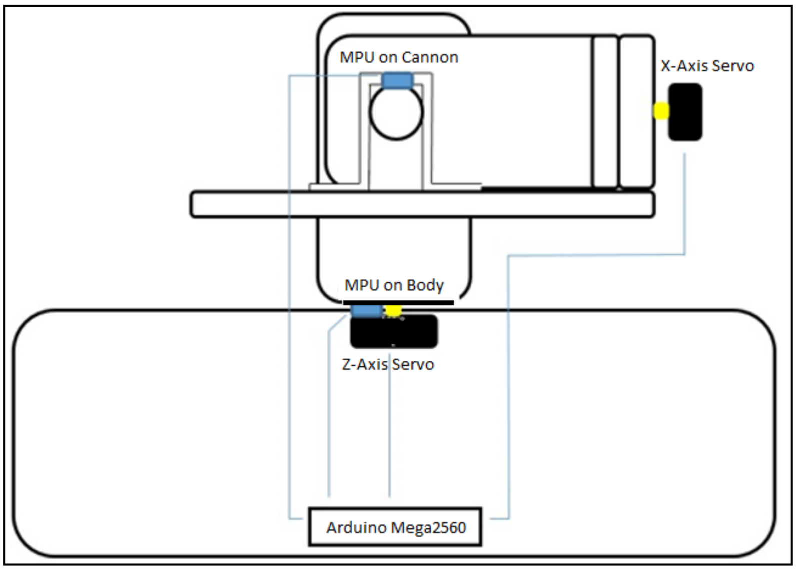

Figure 4. Control mechanism on the tank prototype (front view)

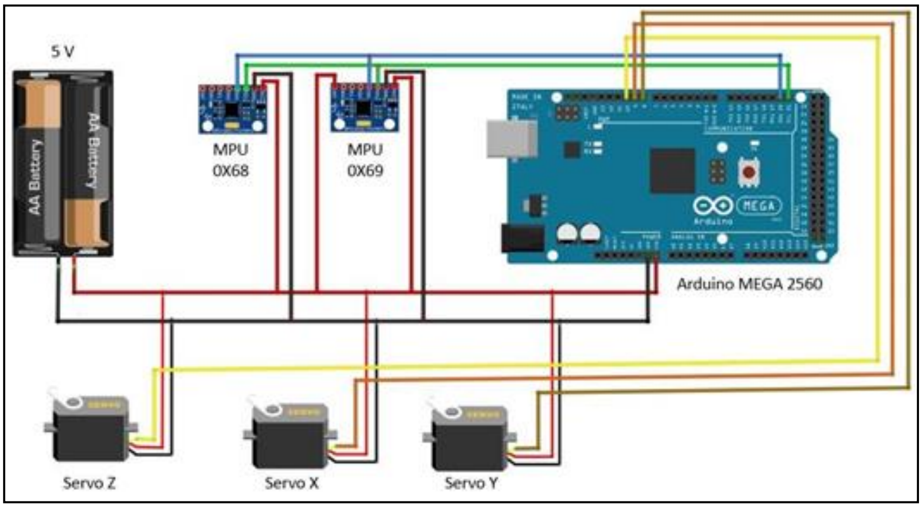

Figure 5. Circuit diagram of tank prototype

2.4. Transfer function of DC servo motor

The transfer function of the DC servo motor that is applied in block Simulink and illustrated in figure 6 are obtained by modifying the equation from Widhiada [33].

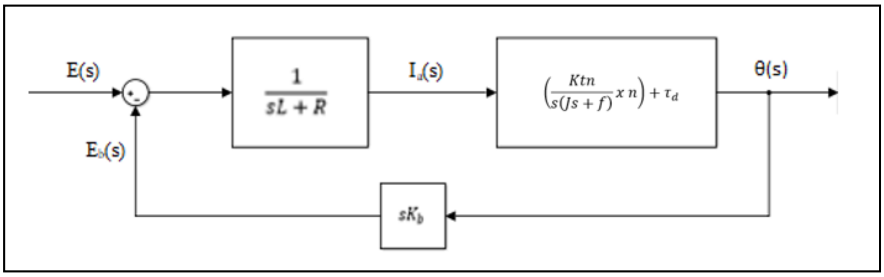

Figure 6. The transfer function of DC servo motor

where,
R = armature resistor (Ω)
L = armature inductance (H)
i_a = armature current (A)
J = moment inertia motor (Kgm^2)
f_o = coefficient viscous motor and load ($\frac{Nm}{rad/sec}$)
K_{tn} = motor torque constant
τ_d = disturbance torque

Then by entering the values for those parameters that are shown in Figure 6, the transfer function value of each servo is shown in (1) to (3).

$$\text{TFx-axis servo} = \frac{0.000003234\,s^2 + 0.00008085s + 0.117}{0.000002545\,s^3 + 0.0001636\,s^2 + 0.00484\,s} \quad (1)$$

$$\text{TFy-axis servo} = \frac{0.0000008154\,s^2 + 0.00002038s + 0.117}{0.000002486\,s^3 + 0.0001624\,s^2 + 0.00484\,s} \quad (2)$$

$$\text{TFz-axis servo} = \frac{0.000005272\,s^2 + 0.0001318s + 0.117}{0.000002585\,s^3 + 0.0001646\,s^2 + 0.00484\,s} \quad (3)$$

Then by using the ZN tuning formula [19] and Simulink, the Kp, Ki and Kd (PID constant) values are obtained as shown in the Tables 1 to 3 and Figures 7 to 9.

Table 1. ZN type 2 for servo x

Type	Kp	Ki	Kd
Classical PID	1.772280	25.872701	0.030350
P	1.476900	0.000000	0.000000
PI	1.329210	11.642715	0.000000
PD	2.363040	0.000000	0.040467
Some Overshoot	0.984600	14.373723	0.044963
No Overshoot	0.590760	8.624234	0.026978

Table 2. ZN type 2 for servo y

Type	Kp	Ki	Kd
Classical PID	1.663398	24.283182	0.028486
P	1.386165	0.000000	0.000000
PI	1.247549	10.927432	0.000000
PD	2.217864	0.000000	0.037981
Some Overshoot	0.924110	13.490657	0.042201
No Overshoot	0.554466	8.094394	0.025321

Table 3. ZN type 2 for servo z

Type	Kp	Ki	Kd
Classical PID	1.889279	27.989324	0.031882
P	1.574400	0.000000	0.000000
PI	1.416960	12.595196	0.000000
PD	2.519039	0.000000	0.042509
Some Overshoot	1.049600	15.549625	0.047232
No Overshoot	0.629760	9.329775	0.028339

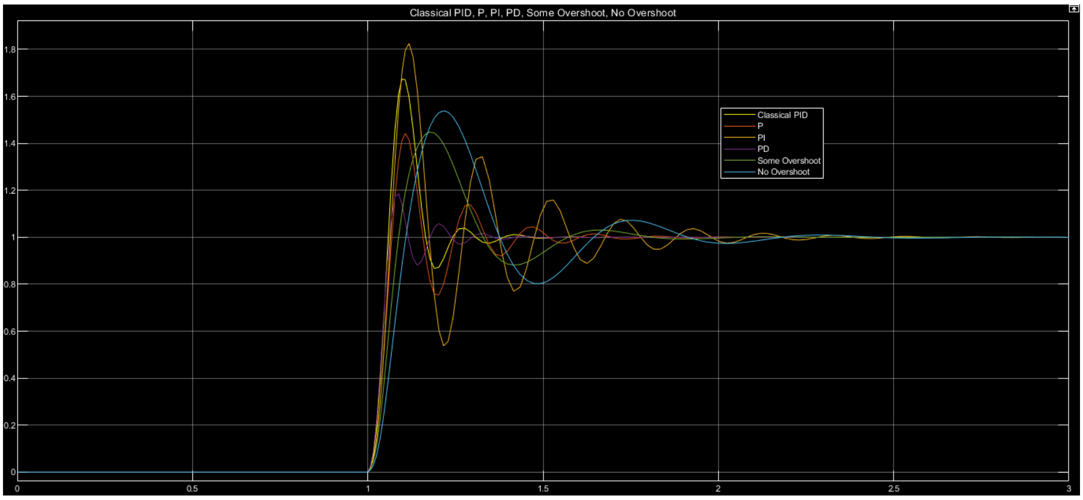

Figure 7. Response of ZN type 2 for servo x

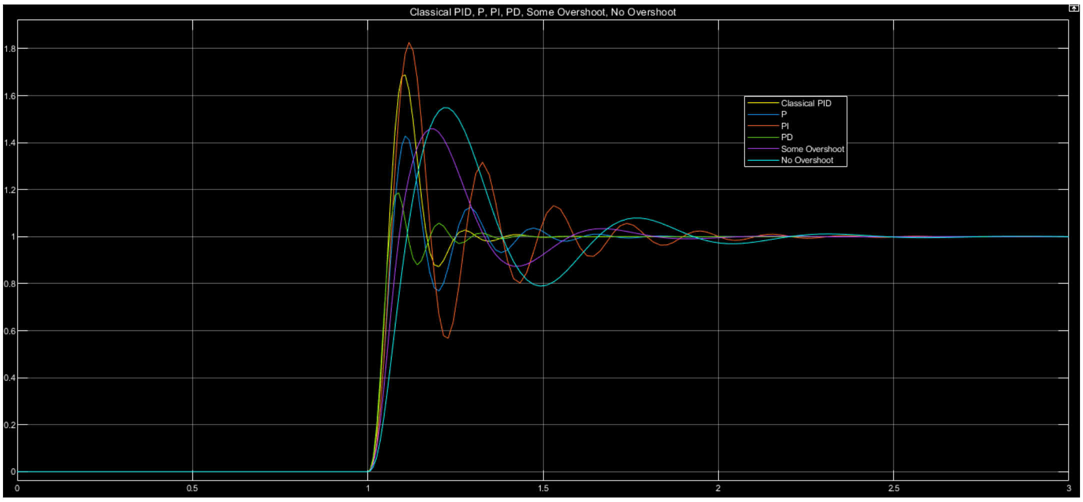

Figure 8. Response of ZN type 2 for servo y

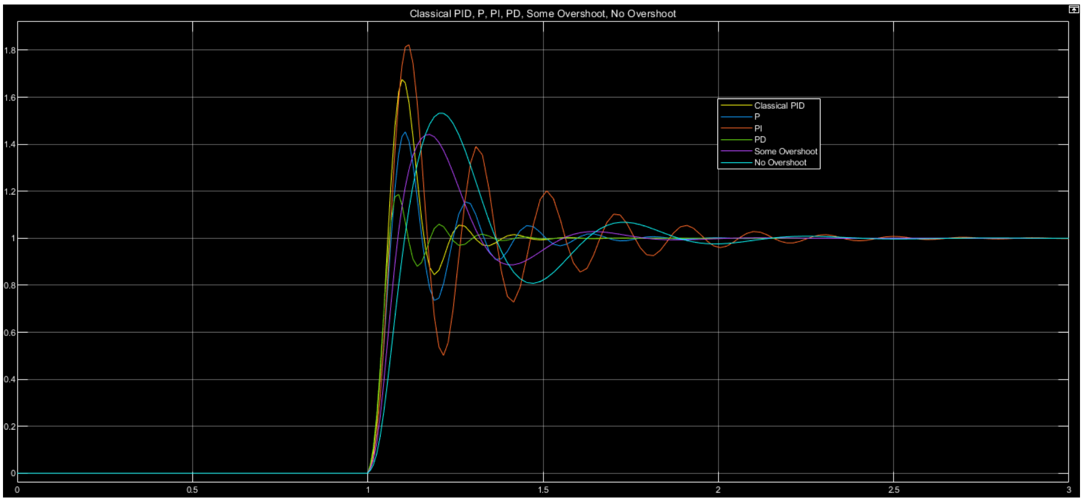

Figure 9. Response of ZN type 2 for servo z

3. RESULTS AND ANALYSIS

The testing of this system is carried out with 4 different tests. Testing on the *x*-axis only, *y*-axis only, *z*-axis only, and the whole servo. When test on the *x*-axis only, first the value of servo x is adjusted according to the PID value. Then the value of servo y and servo z is set with a reference value of 90 degrees (respect to gravity). After the whole servo value is set, the position of the body of the tank is tilted every 5 degrees and the output position value of the tip of the cannon is recorded to see the stability of the system. Then, the output value of each axis is seen whether it remains at the reference position or there is a change. The same steps and procedure are carried out in the testing on the *y*- & *z*-axis only.

For testing on the whole servo, each of the servos is adjusted with each PID value. After the whole servo value is set, the position of the body of the tank is tilted randomly 30 times and the output position value of the tip of the cannon is recorded and compared with the reference value to see the stability of the system. The result of the whole test can be seen in Tables 4 to 6.

3.1. Testing on the *X*-axis

Based on the test on the *x*-axis only which can be seen in Table 4 above, the following results were obtained:

- The largest error value on the *x*-axis, with an error value of 3 degrees is obtained when the tank body is tilted at a position of 100 degrees. Then the average error on this axis is 1.3 degrees.

- The largest error value is on the *y*-axis, with an error value of 1 degree obtained when the tank body is tilted at a position of 75 and 110 degrees. Then the average error on this axis is 0.2 degrees.
- The largest error value is on the *z*-axis, with an error value of 3 degrees obtained when the tank body is tilted at a position of 115 degrees. Then the average error on this axis is 0.9 degrees.
- The largest error value is obtained when the tank body is tilted by 100, 115 and 120 degrees. The average error value is 1.33 degrees in the three positions.
- Overall, this test has a maximum error value of 3 degrees and an average error value of 0.8 degrees.

Table 4. X-axis results

Body-X	X						Max.	Avg.
	X		Y		Z			
	Cannon	Error	Cannon	Error	Cannon	Error		
75	90	0	91	1	90	0	1	0.33
80	91	1	90	0	90	0	1	0.33
85	92	2	90	0	90	0	2	0.67
90	90	0	90	0	90	0	0	0
95	92	2	90	0	90	0	2	0.67
100	93	3	90	0	89	1	3	1.33
105	92	2	90	0	89	1	2	1
110	90	0	91	1	88	2	2	1
115	91	1	90	0	87	3	3	1.33
120	92	2	90	0	88	2	2	1.33
Max.	93	3	91	1	90	3		
Avg.	91.3	1.3	90.2	0.2	89.1	0.9		

3.2. Testing on the *Y*-axis

Based on the test on the *y*-axis only which can be seen in Table 5 above, the following results were obtained:

- The largest error value is on the x-axis, with an error value of 1 degree obtained when the tank body is tilted at a position of 85 and 115 degrees. Then the average error on this axis is 0.17 degrees.
- The largest error value is on the y-axis, with an error value of 3 degrees obtained when the tank body is tilted at a position of 65 degrees. Then the average error on this axis is 0.58 degrees.
- The largest error value is on the z-axis, with an error value of 3 degrees obtained when the tank body is tilted at a position of 60 and 65 degrees. Then the average error on this axis is 0.92 degrees.
- The largest error value is obtained when the tank body is tilted by 65 degrees. The average error value is 2 degrees at that position.
- Overall, this test has a maximum error value of 3 degrees and an average error value of 0.56 degrees.

Table 5. Y-axis results

Body-Y	Y						Max.	Avg.
	X		Y		Z			
	Cannon	Error	Cannon	Error	Cannon	Error		
60	90	0	91	1	87	3	3	1.33
65	90	0	93	3	87	3	3	2
70	90	0	91	1	88	2	2	1
75	90	0	90	0	88	2	2	0.67
80	90	0	91	1	89	1	1	0.67
85	91	1	90	0	90	0	1	0.33
90	90	0	90	0	90	0	0	0
95	90	0	90	0	90	0	0	0
100	90	0	90	0	90	0	0	0
105	90	0	90	0	90	0	0	0
110	90	0	90	0	90	0	0	0
115	89	1	89	1	90	0	1	0.67
Max.	91	1	93	3	90	3		
Avg.	90	0.17	90.42	0.58	89.08	0.92		

3.3. Testing on the *Z*-axis

Based on the test on the *z*-axis only which can be seen in Table 6 above, the following results were obtained:

- The largest error value on the x-axis, with an error value of 3 degrees is obtained when the tank body is tilted at positions 5, 10, 15, 20, 25, 30 and 35 degrees. Then the average error on this axis is 0.77 degrees.
- The largest error value is on the y-axis, with an error value of 3 degrees obtained when the tank body is tilted at a position of 30 and 150 degrees. Then the average error on this axis is 0.83 degrees.
- The largest error value is on the z-axis, with an error value of 2 degrees obtained when the tank body is tilted at positions 5, 15, 45, 60, 155, 170 and 175 degrees. Then the average error on this axis is 0.89 degrees.
- The largest error value is obtained when the tank body is tilted by 30 degrees. The average error value is 2.33 degrees in that position.
- Overall, this test has a maximum error value of 3 degrees and has an average error value of 0.83 degrees.

Table 6. Z-axis results

Body-Z	Z						Max.	Avg.
	X		Y		Z			
	Cannon	Error	Cannon	Error	Cannon	Error		
5	87	3	90	0	88	2	3	1.67
10	87	3	89	1	89	1	3	1.67
15	87	3	89	1	88	2	3	2
20	87	3	89	1	88	2	3	2
25	87	3	88	2	89	1	3	2
30	87	3	87	3	89	1	3	2.33
35	87	3	89	1	90	0	3	1.33
40	88	2	89	1	89	1	2	1.33
45	88	2	90	0	88	2	2	1.33
50	89	1	90	0	88	2	2	1
55	89	1	89	1	89	1	1	1
60	90	0	90	0	88	2	2	0.67
65	90	0	90	0	89	1	1	0.33
70	90	0	90	0	89	1	1	0.33
75	90	0	90	0	89	1	1	0.33
80	90	0	90	0	90	0	0	0
85	90	0	91	1	90	0	1	0.33
90	90	0	90	0	90	0	0	0
95	90	0	90	0	90	0	0	0
100	90	0	90	0	90	0	0	0
105	90	0	90	0	90	0	0	0
110	90	0	90	0	90	0	0	0
115	90	0	90	0	90	0	0	0
120	90	0	90	0	90	0	0	0
125	90	0	91	1	90	0	1	0.33
130	90	0	92	2	90	0	2	0.67
135	90	0	92	2	90	0	2	0.67
140	90	0	92	2	89	1	2	1
145	90	0	92	2	89	1	2	1
150	90	0	93	3	89	1	3	1.33
155	90	0	92	2	88	2	2	1.33
160	90	0	92	2	89	1	2	1
165	90	0	91	1	89	1	1	0.67
170	90	0	90	0	88	2	2	0.67
175	90	0	90	0	88	2	2	0.67
Max.	90	3	93	3	90	2		
Avg.	89.23	0.77	90.2	0.83	89.11	0.89		

3.4. Testing on the *X*, *Y* and *Z* axes

Based on the test in Table 7 above, the following results were obtained:

- The largest error value on the x-axis, with an error value of 6 degrees was obtained when the tank body was tilted in the 12th, 16th and 27-30th experiments. Then the average error on this axis is 2.77 degrees.
- The largest error value on the y-axis, with an error value of 8 degrees was obtained when the tank body was tilted in the 20th experiment. Then the average error on this axis was 2.9 degrees.
- The largest error value on the z-axis, with an error value of 4 degrees was obtained when the tank body was tilted in the 16th experiment. Then the average error on this axis was 1.2 degrees.

- The largest error value is obtained when the tank body is tilted by 90 degrees on the x-axis, 102 degrees on the y-axis and 112 degrees on the z-axis. The average error value is 4.67 degrees at that position.
- Overall, this test has a maximum error value of 8 degrees and has an average error value of 2.29 degrees.

Table 7. Results of X, Y and Z axes

No	Body-X	Body-Y	Body-Z	X		Y		Z		Max.	Avg.
				Cannon	Error	Cannon	Error	Cannon	Error		
1	86	93	86	92	2	90	0	90	0	2	0.67
2	86	95	81	90	0	92	2	90	0	2	0.67
3	85	96	75	89	1	92	2	90	0	2	1
4	85	100	74	87	3	91	1	90	0	3	1.33
5	87	91	80	90	0	92	2	89	1	2	1
6	90	90	83	90	0	92	2	89	1	2	1
7	87	80	85	90	0	92	2	89	1	2	1
8	85	79	93	90	0	89	1	89	1	1	0.67
9	87	74	100	90	0	90	0	90	0	0	0
10	83	81	111	90	0	87	3	89	1	3	1.33
11	89	89	111	93	3	83	7	88	2	7	4
12	90	102	112	96	6	83	7	89	1	7	4.67
13	89	90	98	93	3	87	3	88	2	3	2.67
14	96	81	83	95	5	89	1	87	3	5	3
15	100	82	77	94	4	91	1	87	3	4	2.67
16	98	72	69	96	6	92	2	86	4	6	4
17	97	87	61	90	0	91	1	87	3	3	1.33
18	100	80	52	93	3	97	7	87	3	7	4.33
19	95	92	50	85	5	92	2	88	2	5	3
20	96	80	40	94	4	98	8	87	3	8	5
21	94	90	57	87	3	92	2	90	0	3	1.67
22	93	75	60	93	3	94	4	89	1	4	2.67
23	86	86	71	89	1	90	0	91	1	1	0.67
24	95	90	97	88	2	85	5	90	0	5	2.33
25	97	106	107	90	0	85	5	91	1	5	2
26	100	91	110	85	5	87	3	90	0	5	2.67
27	99	93	95	84	6	91	1	91	1	6	2.67
28	106	91	86	84	6	93	3	90	0	6	3
29	95	79	85	84	6	95	5	91	1	6	4
30	97	74	96	84	6	85	5	90	0	6	3.67
		Max.		96	6	98	8	91	4		
		Avg.		89.83	2.77	90.23	2.9	89.07	1.2		

4. CONCLUSION

The values of Kp, Ki and Kd that obtained from the Ziegler Nichols type 2 method can be implemented in the system and stabilize the tank cannon. The amount of load on each servo also can affect the value of the transfer function which causes differences in the PID value of each servo. The test was conducted with 4 schemes which are tilted on the *x*-axis only, *y*-axis only, *z*-axis only, and when the tank is tilted randomly on those three axes. The result has shown that the average error value is 0.8 degrees with an accuracy percentage of 99% when the tank is tilted on the *x*-axis only, the average error value of 0.56 degrees with an accuracy percentage of 99% when the tank is tilted on the *y*-axis only, the average error value of 0.83 degrees with an accuracy percentage of 99% when the tank is tilted on the *z*-axis only, and the average error value of 2.29 degrees with an accuracy percentage of 98% when the tank tilted randomly on the *x*-axis, *y*-axis and *z*-axis. As future works, there are several suggestions that can be given to developing the system so that it can be implemented on the real size tank. First, by using a motor that has a large speed and torque with clear specifications so that the transfer function can be calculated precisely. Then use a sensor with better specifications so that it can provide more accurate and faster results. And a controller with high specifications that can control the whole system so that it can be applied in future work.

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