Humanoid Robot Balance System With 27 DOF Using MPU6050 Gyroscope Sensor

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Abstract – This study aims to discuss the design of the balance system in the balance system in the dancer humanoid robot. By using a MPU6050 gyroscope sensor and a STM32F103C8T8 microcontroller with an actuator in the form of an MX-28 servo so that it allows the robot to maintain balance when performing various dance movements and walking by passing obstacles that have been set at the Indonesian Robot Contest (KRI), especially the Indonesian Dance Art Robot Contest (KRSTI) in 2023. The study also discusses the importance of selecting the right parameters, such as the direction of rotation of the servo motor torque and angle setting to achieve optimal balance. Robots that have balance control are able to maintain stability in track field conditions that have a certain level of slope. From the results of the test, the percentage of success rate of the robot in a stationary condition with several angles of the slope plane and by using a balance system in the form of a MPU6050 sensor is 85%. The percentage of the robot's success rate in a stationary condition with several angles of the slope plane and without using a balance system in the form of MPU6050 sensors was 56%. From the results of all tests, it can be concluded that the design of the system that has been realized, the humanoid robot dancer can maintain balance and stability in various corners of the track field by using MPU6050 sensors.

Keywords: Humanoid robot, Indonesian Dance Art Robot Contest, Balance sensor, Gyroscope MPU6050.

I. INTRODUCTION

Developments in robotics technology can increase the productivity of a job. With robotics, jobs that were previously difficult and dangerous to do can now be done more easily and safely. Research in the field of robotics is also increasing, of course this is not without purpose. Thus, robot research, especially in humanoid robots, humanoid robots can carry out various human activities such as in security, sports, and the field of art. Humanoid robots are humanoid robots that are completely designed like humans, how to walk, move, and others.

others are designed to resemble humans who have a body with a head, two hands, and two legs [1]. In Indonesia itself, research or developers about humanoid robots are getting more rapid. This is because there are competitions, both at the Regional, National, and even International levels.

The Indonesian Robot Contest (KRI) is a competition activity organized by the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia (Kemenristek dikti). In KRI there are various divisions, one of which is the Indonesian Dance Art Robot Contest (KRSTI). This division is a competition for designing, manufacturing, and programming robots accompanied by elements of the nation's art and culture.

Indonesia, especially the art of dance, has been famous on earth[3]. The Indonesian Dance Robot Contest was held to improve the science and creativity of students in the field of robotics. In the Indonesian Robot Contest, students are required to be able to develop skills in the fields of mechanics, electronics, programming, strategy, the ability to research and write articles, as well as the development of discipline, sportsmanship, teamwork, mutual respect, and other soft skills[4]. In maintaining balance in the humanoid robot's walking process and balance when the humanoid robot performs dance movements, gyroscope and accelerometer sensors are used applied to the KRSTI humanoid robot. In addition to using gyroscope sensors and accelerometers, KRSTI humanoid robots also use STM32F103C8T6 or commonly referred to as STM32 bluepill as a microcontroller and CM-530 as a dynamixel controller to regulate movements on MX-28 servos and AX-12 servos. One of the factors that is very important and requires more attention in building a humanoid robot is the balance factor of the humanoid robot. Because the main task of a humanoid robot is to imitate natural movements made by humans, such as: walking forward, walking sideways, turning, waving, and dancing. Without having a good balance, humanoid robots will have difficulty performing these movements because the humanoid robot will easily fall[5].

The problem in this study is how to design a humanoid robot by adjusting the angle of each servo motor, the torque of the servo motor according to the weight of the robot, the control of the servo motor at each angle and the angle tilt position of the robot with a microcontroller[2]. By using the RoboPlus application, you can make movements on the MX-28 servo or on the AX-12 servo used on the robot's legs so that the robot can run according to the set mission. In the RoboPlus application connected to the CM-530 microcontroller that can regulate movements and act as a robot controller, where in each joint connected to the CM-530 microcontroller data can be taken from the gyroscope and accelerometer sensors which are then used to determine the direction of the robot's movement. The sensor used in the balancing robot is the MPU-6050 sensor, which is an integrated motion sensor module which is a 3-axis gyroscope as well as a 3-axis accelerometer or in other words (3-axis MEMS) gyroscope and 3-axis MEMS accelerometer that are integrated with each other. The sensor has an internal 16-bit ADC for each channel based on the X, Y and Z axes simultaneously at the same time[6].

II. METHODS

Research Stages

This research was conducted with the aim of implementing a balance system in humanoid robots using MPU6050 gyroscope sensors. This stage of research is carried out in a structured manner to ensure that the results are in accordance with the expected plan.

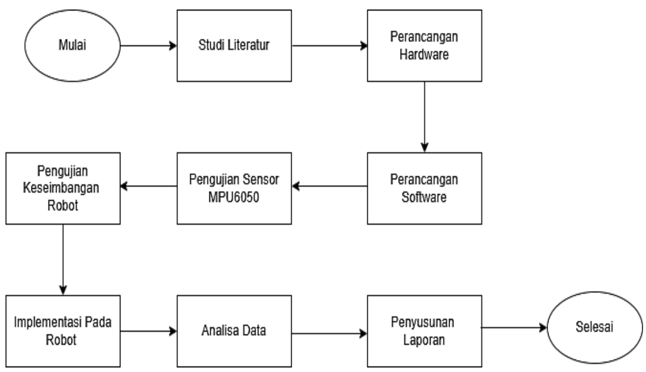

Figure 1. Research Stages

Figure 1 shows that the journey of the existing research stages at the initial stage is to identify the requirements. Furthermore, the characteristics related to the balance of humanoid robots with a slope of 0,2,4,6,8,10 degrees were analyzed. This analysis is supported by previous research and findings on the process of balancing robots against the slope plane as one of the obstacles in the Indonesian Robot Contest (KRI). The next step is to design a balance system and implement it on a humanoid robot. This process includes planning and selecting the right hardware, as well as setting up a structured test implementation. Testing and evaluation are carried out to measure the performance of the system in processing sensor data and compare it with setpoint values to then be implemented on the robot. The test results are thoroughly evaluated to ensure that the system functions according to the structure at the research stage.

Specifications

The components needed to support the research of balance systems in humanoid robots are shown in Table 1.

Table 1. Component Spesification

Component	**Specifications**
Controls	STM32F103C8T6
Balance Sensor	MPU6050
Stepdown	Ubec 5V, AMS1117 3,3V
Power Supply	3s 3300mah Lipo Battery

Hardware *Planning*

In the block diagram above, it can be seen that the balance control in this study uses the STM32F103C8T6 board as the main controller in the system. STM32F103C8T6 receives data from the ESP32 to then process the data and then sends commands to the servo to move the robot. The ESP32 is used as a subcontroller that connects the main controller's communication with the MPU6050 sensor where the sensor is used to communicate with the MPU6050 sensor and process the initial data obtained from the sensor. The data obtained from the sensor MPU6050 will be sent to the ESP32 as a sub-microcontroller for data processing. As sensors, MPU6050 are in charge of collecting data about the robot's position and movement.

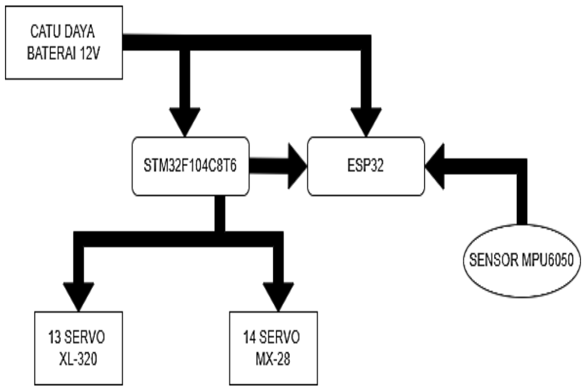

Figure 2. Hardware design block diagram

This data is in the form of information about the tilt and acceleration experienced by the robot at all times. The raw data from the MPU6050 is then sent to the ESP32 for further processing. The ESP32 will perform initial processing of the raw data from the MPU6050 sensor such as calibration and comparison with setpoint values before the data is sent to the STM32. If the data is in accordance with the pre-arranged database, the data will be sent from the ESP32 to STM32F103C8T6 as the main controller to drive the servos on the robot. In simple terms, the workflow of this system can be briefly explained, namely, the sensors MPU6050 collect data about the robot's position and movement, which is then sent to the ESP32 for processing. The ESP32 sends the processed data to the STM32F104C8T6. Then STM32F103C8T6 analyze the data and send commands to the servo to move the robot to keep it in a balanced position.

Software *Design*

The flowchart above begins with the data initialization process carried out by the robot after the robot is on and connected to the microcontroller. The initialization aims to set the points of the robot and the tolerance of the given error value. After initialization, the sensor MPU6050 will read the angle of the robot. When the robot is tilted, the sensor will give instructions to the microcontroller. The readings will be sent to the esp32 to process the sensor results and convert them to the MX-28 and XL-320 servos.

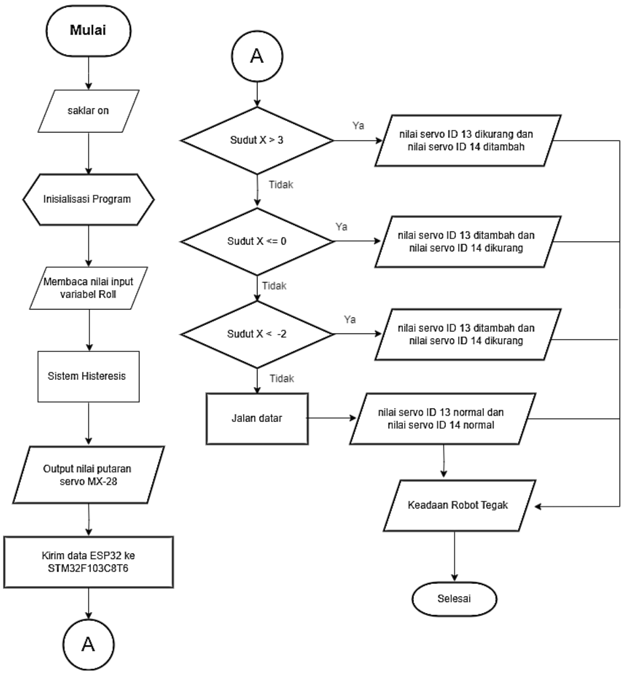

Figure 3. Flowchart designing software

In the test in this study with a range of trajectory angles between 0 degrees to 10 degrees, there are several sensor and arc values. Where the error value of the MPU6050 sensor can be known with the following formula:

$$\text{Error (\%)} = 100\% \times \frac{\text{Set Point} - \text{Nilai percobaan}}{\text{Set Point}} \quad (1)$$

Based on the results of the calculation of the error value, the average error value in each test can be known so that it can be known how much the error value of the drive system can be reached so that it can reach the predetermined angle.

In the humanoid robot's balance control algorithm, if the angle of inclination is more than 3 degrees forward, it means that the robot is too tilted forward by 3 degrees or more. Then the value of the servo ID 13 will be reduced (the servo motor will rotate backwards to straighten the position of the robot standing) and the value of the servo ID 14 will be increased so that the servo motor will rotate in the opposite direction to the servo ID 13 so that the robot position returns to the upright position (center). In the second condition, if the angle of inclination is less than 0 degrees, then the value of the ID 13 servo will be added (the servo motor will rotate forward to straighten the position of the standing robot) and the value of the ID 14 servo will be reduced so that the servo motor will rotate in the opposite direction to the ID 13 servo so that the robot position returns to the upright position (center).

The balance control algorithm in humanoid robots aims to keep humanoid robots standing upright and not fall when they are in a plane with a predetermined slope range. MPU6050 sensors play an important role in this system by providing data on the orientation and movement of robots in real-time.

The data is then processed and used to generate control signals that will be sent to the servo motor so that the robot performs corrective actions.

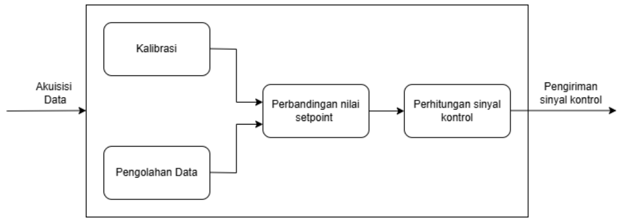

Figure 4. Balance control algorithm

The explanation of the flow chart in figure 4 is:

1. Data Acquisition
   Namely the reading of the acceleration and angular velocity values on the x-axis of the MPU6050 sensor which then converts the raw data into angular values in degrees per second.
2. Calibration
   The offset value and sensitivity of the sensor are calibrated to obtain accurate data and eliminate bias in the sensor.
3. Data Processing
   By converting the raw data value to the angle in degrees, namely by integrating the gyroscope value (angular velocity) using the euler method to obtain the angle in degrees per second.
4. Comparison with Setpoint Value
   Comparing the measured angle with the desired angle (setpoint) and then calculating the error value as the difference between the actual value and the setpoint value
5. Control Signal Calculation
   The calculation of the control signal will determine how much the motor must move to correct the robot's position.
6. Control Signal Transmission
   The control signal will be sent to the actuator (servo motor) on the robot which then the servo motor will move to correct the position of the robot so that the robot will return to the balanced position.

III. RESULT AND DISCUSSION

Testing of robot balance systems

At the time of testing the humanoid robot's balance system, it was carried out with a technique that was carried out to ensure that the humanoid robot could stand as well as return to an upright position when given obstacles that affected the balance level of the humanoid robot. The tests carried out involve Gyroscope and Accelerometer sensors which are used to measure rotation and linear movement to detect changes in the orientation and position of the robot where in this study a gyroscope sensor MPU6050 used. The purpose of applying a gyroscope sensor MPU6050 is to be able to measure the tilt rotation of the robot so that the servo motor can move the humanoid robot's joints to adjust the position and posture of the humanoid robot as needed so that it can restore the robot's position in an upright state.

The balance testing of the robot in this study uses the Disturbance Rejection Test method which is a testing method to test the ability of humanoid robots to maintain balance when facing disturbances that can affect the balance level of humanoid robots when standing upright. This test method is very important to determine that the robot can stand balanced despite obstacles that can affect the balance level of the dancer's humanoid robot.

The implementation of the balance level test of the dancer humanoid robot with several stages, including preparation, namely by ensuring that all sensors and servo motors are functioning properly and have been calibrated with maximum accuracy. Furthermore, the simulation stage, namely by testing the control system algorithm and simulation in the form of simulations to identify and fix algorithm and programming problems before applying them directly to the robot. The physical testing stage, namely by testing directly on the physical humanoid robot and identifying and trying directly the results of responses to disturbances that can disturb the balance level of the humanoid robot. The last stage is the stage of analyzing the data that has been collected during testing the system as well as the weaknesses and problems experienced when testing and identification.

Hysteresis Control System

A hysteresis control system is an on-off control system that has a deadband at a value range of 11 reference limits (setpoints). In this device, the hysteresis control system is designed using MPU6050 sensor as the balance controller and the MX-28 servo as the output regulated by the microcontroller[15]. The hysteresis control system is designed to control the level of balance, namely by regulating the value of servo rotation with several predetermined conditions. This control is designed by adding a hyperesis condition to the setpoint value

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$$y = \begin{cases} 1, \frac{dx}{dt} > 0 \\ 0, \frac{dx}{dt} \leq 0 \end{cases}$$

Figure 2. Hysteresis Control System Condition Abstract

Where y is the output of the result of the servo rotation value and is the change in the input value to time. With this control, the instability of the sensor reading when it is at the setpoint will not cause a rapid displacement effect (chattering) on the results of servo rotation $\frac{dx}{dt}$[15].

In an on-off control system, the generating element only has two states, namely on and off. Because of its on-off operation, the result of the control of the on-off control will cause the process variable to ripple as shown in figure 3 below.

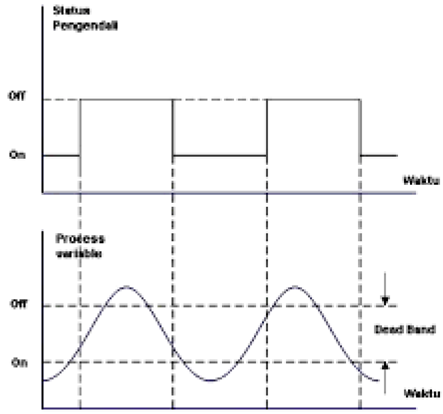


Figure 3. on-off control system

On-off control systems are relatively simple and inexpensive and in this case are very widely used in industrial as well as domestic control systems. For this reason, this research also makes use of an on-off control system.

MPU6050 Sensor Testing

In the sensor test, MPU6050 was carried out with 2 trials, namely in a flat plane and in a sloped plane. In the flat field test, it was carried out with a range of 90° to -90° where the results of the inclination value of the sensor MPU6050 displayed on the monitor series. The results that have been obtained are as follows:

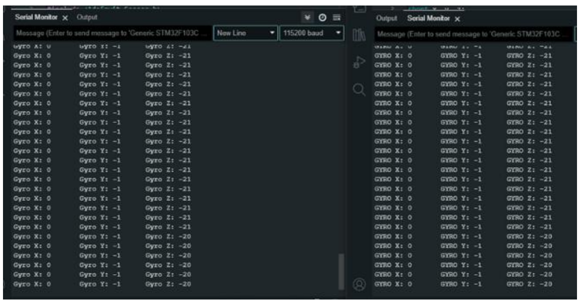


Figure 4. Data Print Result of MPU6050 Sensor Testing

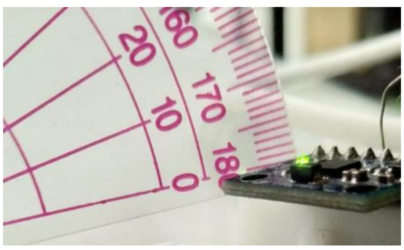


Figure 5. MPU6050 sensor test results at 0° field angle

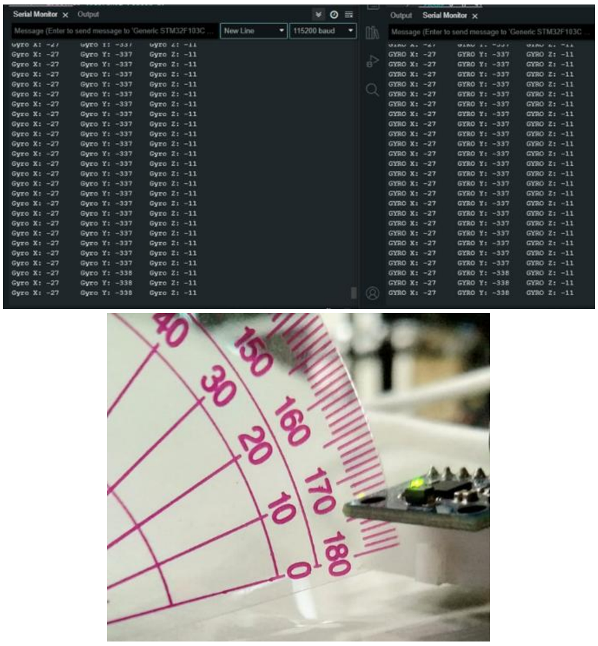


Figure 6. MPU6050 sensor test results at a 5° field angle

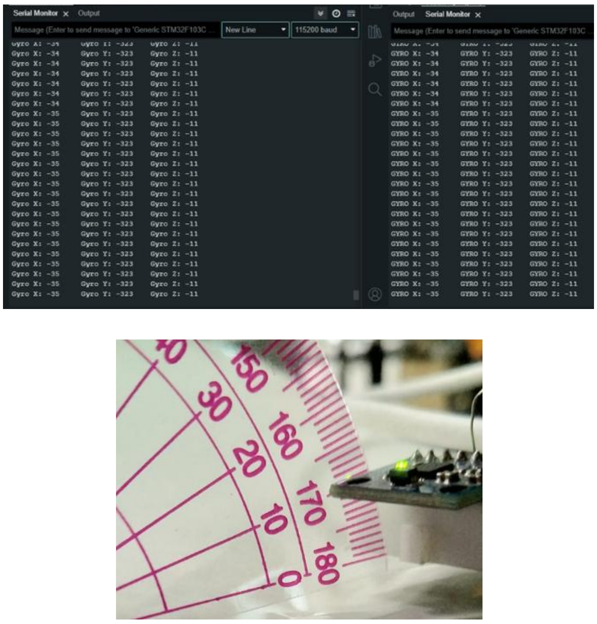


Figure 7. MPU6050 sensor test results at a 10° field angle

The sensor test results MPU6050 at track plane angles of 0° to 10°. At the angle of the 0° track plane (flat plane) a pitch angle of 0° is obtained, because the robot is in a stable state. Meanwhile, at a track plane angle of 10°, that is, at a steeper track plane angle, it shows a pitch angle of -29° to -32°, which means that the robot's position is increasingly tilted.

Tilt Testing

The test results on the slope plane were carried out by taking data as many as 24 test result data, including 4 data at each slope with a range of 0°, 2°, 4°, 6°, 8°, and 10°.

Table 2. Test data with slope

Field Angle (°)	Pitch Angle (°)	Servo ID 13 value	Servo rated ID 14	Note
0	0	1788	2547	Stable robot without correction
0	0	1788	2547	Stable robot without correction
0	0	1788	2547	Stable robot without correction
0	0	1788	2547	Stable robot without correction
2	-2	1742	2603	Small corrections forward
2	-1	1741	2606	Small corrections forward
2	-3	1743	2602	Small corrections forward
2	-9	1744	2608	Small corrections forward
4	-5	1890	2621	Correction is ahead
4	-7	1895	2627	Correction is ahead
4	-4	1897	2625	Correction is ahead
4	-14	1894	2628	Correction is ahead
6	-18	1325	2550	Major corrections ahead
6	-10	1329	2553	Major corrections ahead
6	-16	1326	2558	Major corrections ahead
6	-22	1327	2556	Major corrections ahead
8	-19	1432	2285	Maximum correction in the future
8	-20	1437	2289	Maximum correction in the future
8	-21	1434	2284	Maximum correction in the future
8	-27	1439	2287	Maximum correction in the future
10	-24	1491	2131	Full correction forward
10	-29	1496	2133	Full correction forward
10	-26	1493	2136	Full correction forward
10	-28	1495	2134	Full correction forward

Based on the table above, it explains how the humanoid robot reacts to changes in the angle of inclination in the inclined plane by using pitch angle data measured by MPU6050 sensors and servo positions to make balance corrections.

The field angle column shows the slope of the field where the robot is tested, with ranges of 0°, 2°, 4°, 6°, 8°, and 10°, the larger the plane angle, the greater the balance level challenge that the robot must overcome. The pitch angle column shows the robot's tilt angle detected on the X axis (pitch angle) due to changes in the plane angle. In flat conditions (0°) the pitch angle is almost zero or even close to zero because the robot is in a stable state. At a larger angle of field, the pitch angle increases, reflecting the tilted position of the robot. In the column of servo value ID 13 and servo value ID 14, it shows that the servos ID 13 and ID 14 are in charge of moving the robot's body parts (abdomen and hips) to adjust the balance of the robot so that the roots remain in a balanced state at the angle of the inclined plane.

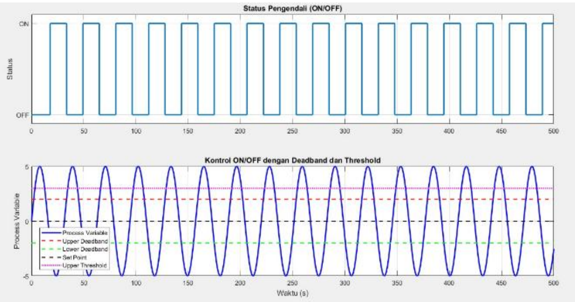
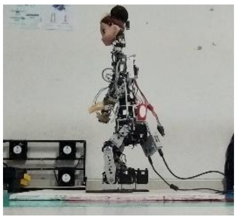


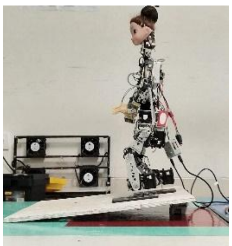
Figure 8. Test Graph with slope


(a)


(b)


(c)


(d)


(e)

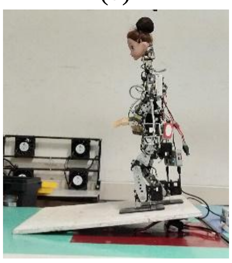

(f)

Figure 9. Static testing of robots (a) tilt angle 0°, (b) tilt angle 2°, (c) tilt angle 4°, (d) tilt angle 6°, (e) tilt angle 8°, (f) tilt angle 10°,

In the initial condition (0°) the servo position is at the value of (1788) for ID 13 and (2547) for ID 14, i.e. in the balanced position of the robot standing. As the plane angle increases, the servo position changes proportionally to compensate for the pitch angle. The note column shows the position of the robot when it is in the angle of the plane that has been determined, when the robot's stable position in a flat plane (0°) the robot is in a stable state without the need for significant correction. In the position of the robot in the forward correction condition, that is, when the angle of the plane begins to tilt (2° or more), the robot will lean forward so that the servo adjusts the position to pull the body back to achieve balance. In the robot position in the maximum correction condition, i.e. when the angle of the inclined plane is steeper (8° to 10°) the servo position reaches the maximum limit, indicating the robot's efforts to maintain balance.

Robot Control Testing

The robot control test was carried out to find out how the robot responds to the given obstacle, namely in the slope range between 0°, 2°, 4°, 6°, 8°, and 10°.

Table 3. Robot control test data

Robot Position	Pitch Angle	Servo ID 13 value	Servo ID 14 Value	Time (ms)	Note
0°	0	1788	2547	0	The initial position of the robot in balance
2°	-4	1742	2603	500	The position of the robot began to tilt forward
4°	-10	1890	2621	1000	The position of the robot began to tilt forward
6°	-18	1325	2550	1500	The position of the robot began to tilt forward
8°	-22	1432	2285	2000	The position of the robot began to tilt forward
10°	-29	1491	2131	2500	The position of the robot began to tilt forward

Performance Evaluation of Humanoid Robot Balance System

This test is carried out by providing a tilt angle in the track plane of 0° to 10°, with the results of the entire test when the root is at rest will be carried out an average process to determine the percentage of success rate when the robot is stationary in the track plane using a balance system (Using MPU6050 sensors) or without a balance system (Without using MPU6050 sensors).

Table 4. Sensor performance evaluation data

No	Field Angle (°)	Success Percentage (%)	
		With balance system	Without a balance system
1	0	100	100
2	2	100	100
3	4	100	68
4	6	100	50
5	8	60	20
6	10	50	0
Average		**85**	**56**

From the table data, the average value of the percentage of success rate of robot testing using MPU6050 sensors and without using MPU6050 sensors in the robot position in a stationary state and tied at an angle in the track plane of 0° to 10° is 85% and 56%. From the results of the comparison of the average values in the table, it can be concluded that after the robot is added, MPU6050 sensors can help to maintain the balance and stability of the humanoid robot in the condition of the track plane angle with a slope of 0° to 10°.

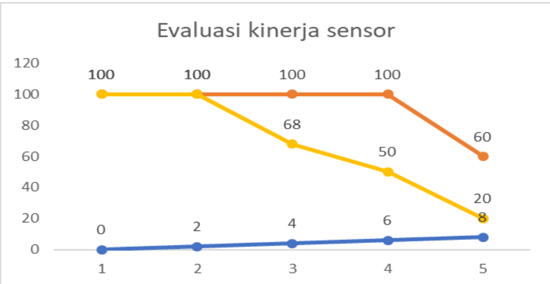


Figure 10. Sensor Performance Evaluation Graph

IV. CONCLUSION

This study successfully tested and analyzed two main aspects, namely testing the MPU6050 gyroscope sensor and testing the control response of humanoid robots to the angle tilt of the track plane. The MPU6050 sensor test shows the realization of testing the balance system and stability of humanoid robots with the result that the MPU6050 sensor has an increasing level of balance as the slope angle of the track plane increases. Testing of the balance and stability system of the humanoid robot using MPU6050 sensors showed success with a 100% percentage at the track tilt angle of 0° to 6°. Meanwhile, testing the balance and stability system of humanoid robots without the use of MPU6050 sensors showed success at a track plane tilt angle of 0° to 2°. Thus, it can be concluded that the robot can maintain balance and stability when standing at an angle of 0° to 10° tilt plane by using MPU6050 sensors.

ACKNOWLEDGMENT

In the testing of the balance and stability system of humanoid robots, further analysis is needed on factors that can affect the failure to reach the equilibrium point at the angle of inclination of the track plane above 10°.

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