Balancing Control System for Humanoid Robot using Pressure Sensor

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Abstract: Balancing the control system becomes one of the important topics in special robots is a humanoid robot. The sensors used for balance control mostly use the inertia measuring unit (IMU) sensor. The sensor can detect the value and level of the tilt, displacement, and gravity of the robot. By using the reference from the sensor data, the value of the data in the balance control system will be made to make the humanoid robot can walk and move in a balanced manner. Not only the IMU sensor can be used in the application for balance control, one of which is to use a pressure sensor. The working system of this sensor is the pressure force received from the sensor that will be used as a reference for the balance data values in the robot humanoid balance control system. So that the humanoid robot can adjust to the conditions of the road being passed while maintaining its balance and not falling. the pressure sensor will be placed on the foot of the humanoid robot foot as the pedestal and the reading of the tilt data each foot of the robot will be installed 2 pressure sensors to get the value of the slope data which is in the position of the direction forward and back when the humanoid robot moves and steps. Through a series of testing processes of the balance control system in the humanoid robot, it was found that the robot can maintain its equilibrium position in the incline to 15 degrees, and the average error value obtained from reading the data on the pressure sensor is 0.13%.

1 INTRODUCTION

One of the most important things to make a humanoid robot is balancing control system. It can determine the success of a humanoid robot in carrying out movements such as stabilizing the body in an inclined plane, walking and dancing. Without balancing control system, the robot will have difficulty making movement and can cause the robot fall also fail to do something. Until now, balancing control system of humanoid robots is still developed, such as static balance, dynamic even the ability to determine movement when there is a loss of balance. To make it real about balancing control system of humanoid robot there needs a control system can control the actuator of the robot in order to realize a balanced condition (Riananda, 2018). Kind of sensors are usually used for balancing control system is gyroscopes, accelerometers, and magnetometers. Now, 3 kind of that sensor be combined into a more complex sensor module known as IMU (Inertial Measurement Unit) Sensor.

IMU sensor can't use in humanoid robot because the balancing control system difficult to get data sensor while this robot walking and dancing. The degree of the sloped surface is set to vary from 5° to the maximum extent of robot ability. The test results show the addition of the balance control system gives ERISA robot capability of walking on the sloped surface up to 10 degree (Alasiry, 2018).

To resolve this problem, in this research using pressure sensor and will placed on both sole of foot the robot to balancing control system. This sensor consists of load sensor and pressure sensor where every difference condition in load and pressure of this sensor will produce different resistance value. From these differences, it can be used as a reference in regulating the balance of the robot by means of each pressure sensor that will be placed on the two legs of the robot. On each leg there are 2 sensors that function to measure the load and pressure at the 2 outer points of the foot to be able know the compressive force at each point. From that we can draw the resultant force from each of these points. Result of processing from the resultant force to these 2 points will bring up a

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coordinate of the fulcrum on the soles of the robots. From the displacement of the fulcrum it is used as a robot balance system.

Figure 1: Humanoid Robot.

2 ROBOT DESIGN

2.1 Mechanical Design

Total Dof (Degree of Freedom) from Robot is 29 and parts detail from that DoF in Table 1. Robot was made from CAD software to make the design from the leg until the neck. And also using CAM software to make generate code (G-Code) from that design to realization the model using machine CNC. To make all of parts from Robot using type of motor is servo dynamixel MX-28:

Table 1: DoF Part Detail of Humanoid.

No	Body Part	Number of DoF
1	Head	3 (Neck)
2	Stomach	1 (Stomach)
3	Waist	1 (Waist)
4	Hand	6 (Shoulder)
		2 (Elbow)
		4 (Wrist)
5	Feet	6 (Waist)
		2 (Knee)
		4 (Ankles)
Total Number of DoF		29 DoF

2.2 Electrical Design

To control the overall performance, use ARM microcontroller, it has frequency up to 168MHz. To calculate value of kinematic and accessing the sensor also communicate with PC, robot use the main controller that is ARM SFM32F4. The data read from FSR sensor. Since the reading result is analogue data, it needs to be converted to get the angle value using ADC.

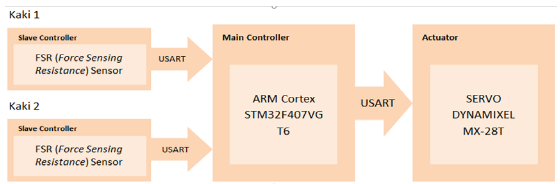


Figure 2: Electrical System Diagram.

3 CONTROL SYSTEM DESIGN

To keep stabilize balancing of using control system. This control system will maintain the value COG from body robot to make the body robot become upright and stable. This is the basis of stability system so the robot able to compensate for external influences (Saputra, 2016). The kinematic model of pitch and roll position control from show on figure 3. The kinematic model can be described as two inverted pendulum which servo motor position in stomach of robot as roll compensator, and then servo motor position in the waist of robot as pitch compensator (Zafar, 2016). Servo motor place in roll position compensate the right and left. And to control front and back falling direction is servo position in the pitch.

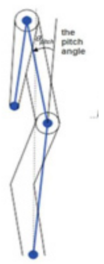


Figure 3: Kinematic Model of pitch pose control system.

3.1 Pressure Sensor and Design

Pressure sensors applied in humanoid robots use the FSR400 FSR model. This FSR is the main sensor used to measure the force caused due to the pressure acting on each FSR sensor later. The use of this FSR sensor is very easy. Because basically the FSR sensor has an output in the form of an obstacle that changes with the changing forces acting on this sensor so that by using the voltage divider circuit this sensor can be read the output voltage.

3.1.1 Placement of Pressure Sensors on the Robot Root

The design of the FSR placement design on robot foot is in figure 4. From figure 4, it appears that on each foot there are 2 pieces of FSR attached. This FSR is placed at the end of each foot. The purpose of laying 2 FSR on the ends of the foot is that the distribution of the center of pressure is easy and can know the condition of the pressure sensor that is not tread when on an uneven surface. The laying of the FSR at the end of the foot will provide information on the condition of the robot's pressure when standing.

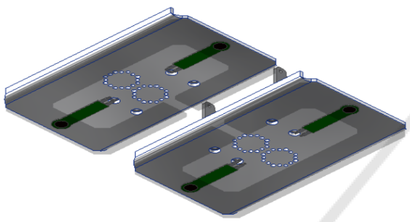


Figure 4: Layout Design Place of Sensors on the Robot Root.

From the results of the design, FSR placement on robot foot was carried out. The results of the realization of the FSR placement on robot foot are in figure 34. It appears that in one foot requires 2 FSR, so that in one robot it requires 4 FSR to get information on robot pressure. In the design, the area of foot is made with maximum dimensions. Determination of the maximum area of robot foot is determined based on the height of the robot and the height of the center of mass on the body of the robot.

3.1.2 Pressure Sensor Control Design

From the 2 sensors in each leg the data center pressure on the foot is then processed to become the center of pressure on the robot. And then the data will be used as a parameter for robot balance control.

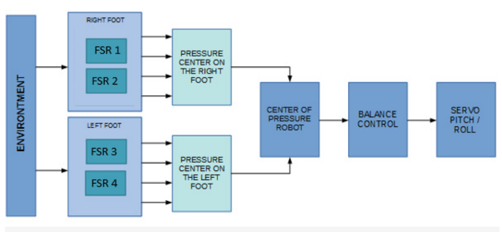


Figure 5: Layout Design Place of Sensors on the Robot Root.

3.1.3 Positioning of the Centre of Pressure on The Foot

To get the center of pressure on the robot, each foot is calculated first on the value of the pressure pressed by each foot. After obtaining this value, then the center of pressure is sought on one of the foot. To get the center of pressure on one of the foot can use equations (1) for the position of coordinates for the left foot and equations (2) for the position of coordinates for the right foot. Figure 6 shows the position of each size.

$$Ycopr = \frac{(F1.Y1 + F2.Y2)}{F1 + F2} - Y1/2 \qquad (1)$$

$$Ycopl = \frac{(F1.Y1 + F2.Y2)}{F1 + F2} - Y1/2 \qquad (2)$$

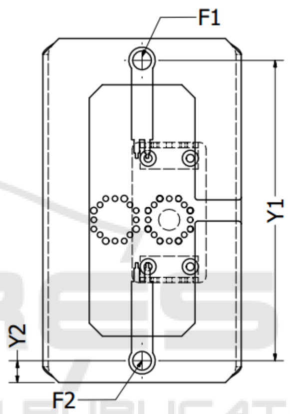


Figure 6: Positioning of the centre of pressure on foot.

3.1.4 Determining the Position of the CoP Robots

The location of Center Of Position (COP) can evaluate the stability when humanoid robot walking. In this section, how to measurement COP of humanoid robot is discussed in detail. Style movement walking of Humanoid robot use single or multiple support phase and because of that the COP measurement discussions cover both of them. COP be an important role for the stability of walking humanoid robot (Sukha, 2015). The force under the feet during the walking robot can be estimated by the vertical force reflected from the ground. More dynamic phenomena needed for ZMP as long as humanoid robots increase complications increase gait. Therefore, this study proposes to simplify the evaluation of stability by using force sensors to measure COP.

When the position of the center of pressure on each foot is obtained, then the data is sent to the controller on the robot body. The data is then processed to obtain the position of the center of pressure on the robot that is retracing the current conditions. In addition to the position data center of pressure, the pressure data on each sensor is also sent to ensure if there is a data transmission error. In finding the position of the center of pressure on the robot you can use Equations (3) for y coordinates. Figure 7 shows the position of the center of pressure obtained on the robot.

$$Ycop = Yo\left(\frac{(F1 + F2 + F3 + F4) * dY}{Ftotal}\right) \quad (3)$$

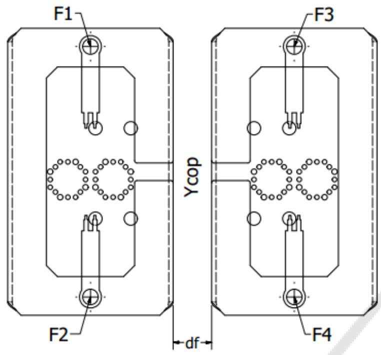


Figure 7: Determining the Position of the CoP Robots.

3.2 Balancing Control System

The position of the robot pressure center is in a balanced condition which is at the position of coordinates (0; 0) (Al-Shuka, 2016). In these conditions the robot is at the center of the mass and gravity of the robot. So that the coordinate point (0;0) is the setpoint value of the robot.

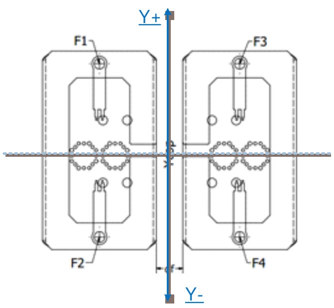


Figure 8: Centre of pressure Robot.

When the position from the robot's center of pressure is not in the position of coordinates (0; 0), the condition of the robot would be unstable. The position of the center of pressure that is read will be reduced by coordinates (0; 0) which is the setpoint on the robot, so that the error value is obtained, which will then be entered into the PID controller as shown in figure 9. In the PID control tuning Kp, Ki and Kd is done to get a fast response to reach steady state.

As the concept of the Inverted Pendulum PID control will drive ID servo 3 and 9 on the ankle part of the robot. When the position of the robot COP from the sensor is in front of the sole of the foot, which means that the robot is leaning forward, the servo will move backwards so the robot does not fall. Opposite from that, when the position of the robot COP from the sensor is behind the sole of the foot, which means that the robot is leaning backwards, the servo will move forward so the robot does not fall.

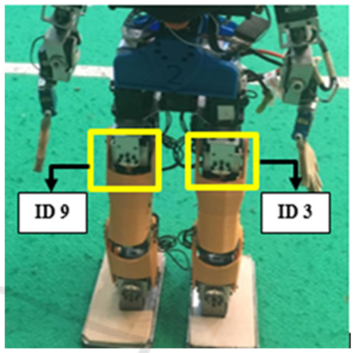


Figure 9: Servo ID.

When the position of the robot's center of pressure is not in the position of coordinates (0;0), the robot will be in an unbalanced condition. So it is necessary to determine the back movement so that the robot returns to a balanced position. To get back movement can be calculated using the PID control so that the response of the given back motion becomes smoother for the movement of the robot. The position of the center of pressure that is read will be reduced by coordinates (0;0) which is the setpoint on the robot, so that the error value is obtained. The PID control will determine the back motion which will then be calculated with the default servo position data to control the value of the new servo movement. In the PID control tuning Kp, Ki and Kd is done to get a fast response to reach steady state.

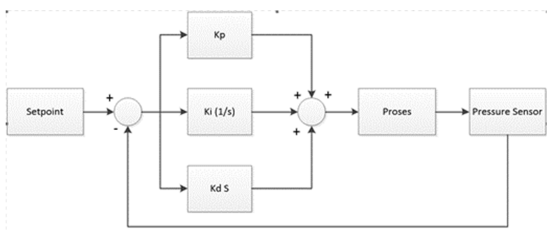


Figure 10: Control PID Diagram.

4 EXPERIMENTAL RESULT

Chapter of system testing and analysis, will be explained about the data obtained from the results of testing the pressure sensor on the robot during the process, and analysis of the data obtained.

4.1 Testing the Centre of Pressure in One Foot

For Testing the center of pressure on one foot in this case to compare the center pressure data obtained with the center pressure data obtained through calculations in Equations (1) and Equations (2). Testing in this section is done by placing the object on each FSR with known pressure. Then the error is calculated between the calculation results and the results obtained. Table 2 show the results of testing the center of pressure on one right foot.

Table 2: Test Results on Right Foot Tread.

No.	Force Data		Calculation Result	Testing Result	Error
	F1 (N)	F2 (N)	Ycop	Ycop	
1	0,55	5,34	-46,15	-46,13	0,05%
2	0,26	4,38	-50,39	-50,36	0,06%
3	0	10,16	-56,75	-56,75	0,00%
4	0,18	9,05	-54,54	-54,6	0,12%
5	2,03	5,01	-24,02	-24,06	0,16%
6	5,04	0	56,75	56,73	0,04%
7	5,97	1,2	37,75	37,75	0,01%
8	3,35	2,65	6,62	6,65	0,44%
9	4,59	1,73	25,68	25,65	0,12%
10	5,23	3,56	10,78	10,75	0,30%
Error Average					0,13%

4.2 PID Control Response

This PID control test aims to determine the system response after applying the PID control to the system. The test is testing using the PID control where from several tests that have been carried out the results of the PID control response as shown in figure 11. From figure 11 explain about the respon system to reach set point value using PID parameter. To get the value of PID parameter using trial and error method, which this method input value parameter from zero until get the best respon from system to reach set point was declared. From the experiment get the best PID parameter for this system is Kp = 0.2, Kd = 0.018 and Ki = 0.0001. With this control method that is PID control, control system can be more stabilize and no more oscillation when the robot in condition unstable.

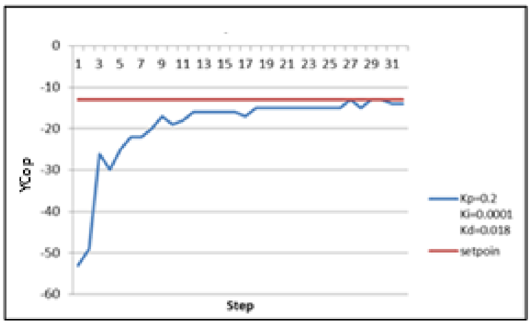


Figure 11: PID Control Response.

4.3 Balancing Control using Pressure Sensor

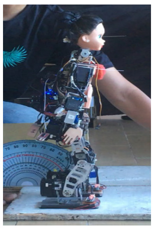
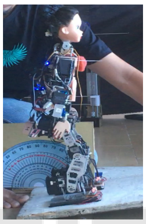
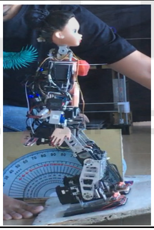
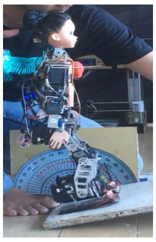
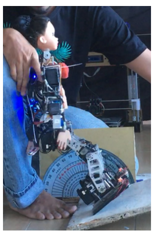
The next test is testing the balance of the robot. Testing in this case is to find out whether the robot is able to balance itself when it is in a sloping and uneven field condition with information from the pressure center or Center Of Pressure (COP). In this test the test was carried out to see the robot's response when it was in the inclined plane. When tilted the value of Ycop will be displayed through the serial monitor on the PC / laptop. In the previous research the balance of the robot using the IMU sensor. The feedback used to control the balance of the robot lies in the hand. This is because the hand response is more efficient to make the robot stable in walking without interfering with walking planning in walking. But in the Dance Robot hand movements are very varied and are needed in beautifying the dance so that in the art robot the feedback dance with hand control becomes inefficient. In these conditions robotic testing is carried out in standing in a sloping condition. Table 3 shows the results of testing the condition of the robot when in the inclined plane with no balance and with the balance of the hand when tilted towards the front and back.

Table 3: Test Results Robots Without Balancing Control.

No	Slope Angle	Notes
1	0	Not Falling
2	5	Not Falling
3	10	Falling
4	15	Falling
5	20	Falling

From the results of these tests, it can be seen that in conditions without balance, the robot can only stand up to a slope of 5 degrees. From these data, changes in the robot's response were made using the foot response. After that, testing the slope of the robot is carried out with a balance of information on the position of the center of pressure. The next test is by testing the inclined plane, but it is done by using the Control with robotic pressure center information. Table 4 shows the results of testing the robot's response when tilted with a balance from the information position of the robot pressure center.

Table 4: Test Results Robot with Balancing Control.

No	Slope Angle	Robot Condition	Ycop	Notes
1	0		1	Not Falling
2	5		-14	Not Falling
3	10		-29	Not Falling
4	15		-42	Not Falling
5	20		-56	Falling

5 CONCLUSIONS

From testing canter of pressure on the right and left foot with the result an average error of 0.13% using FSR sensor can be declared to work well. The use of the FSR Sensor to measure any pressure on the sole of the robot's foot can be done and can be implemented for balance data the robot beside of using IMU Sensor. With balancing control system using PID control method, robot can stand and adaptation by itself during difference slope from the plane until 15 degrees. Result from this research can be another sensor option for the balance of humanoid robots. It is hoped that the development of humanoid robots can be combined with other inertial sensors to become a better balancing control system.

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If any, should be placed before the references section without numbering.

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