Development of wall follower hexapod robot

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Abstract. This study aims to develop a six-legged robot that is able to walk in an arena that resembles a maze (maze wall) and is able to follow a wall (wall follower). This robot is competed in the Indonesian Robot Contest (KRI) in the Indonesian Fire Extinguisher Robot Contest (KRPAI) division which is held annually by the Directorate of Student Affairs, the Directorate General of Learning and Student Affairs, the Ministry of Research, Technology and Higher Education. The research design consisted of 4 stages, including: mechanical design, electronic design, joint movement design at the robot’s foot, and software design. The final result of this research was a six-legged robot design (hexapod) with robot dimensions of 29 cm x 29 cm x 25 cm (length x width x height). From several tests, the robot's success rate in completing the mission was 100%, with an average time of 16.73 seconds and the fastest time to complete the mission reached 15.85 seconds. Thus, the robot is expected to be included in the Indonesian Robot Contest (KRI) in 2020.

1. Introduction

A robot is a multifunctional machine that can be programmed and designed to be able to move materials, parts, or tools with certain specifics through programmed variable movements to do work from a variety of tasks [3]. Robots are designed to move materials, components, or special equipment through varied movements that are programmed to carry out various types of work [4]. Automatic robots have sensors as the eyes of the senses to determine the circumstances around them, and a microcontroller or Integrated Circuit (IC) as a robot control that can be programmed as required and needed.

Legged robot is a robot that can move freely because it has the ability to move to a movable position that is supported by the shape of the leg which is designed as a propulsion device. The use of legs and body shape is adjusted to the terrain that will be faced by robots [5]. Hexapod robot is a type of mobile robot that moves using six legs. Since statically a robot can move stably by using three legs, the hexapod robot certainly has a higher flexibility. When there is one leg that doesn't work, the robot can still walk. Not all legs are needed for stability, other legs can move freely to find a new footing in walking [4].

Hexapod robot has several advantages and disadvantages. The advantages, among others, are being able to move on several surfaces both rough and smooth. With the same number of legs on each side, the weight of the robot will be supported well. The position of the robot body is on the feet, so as to avoid friction or impact from the surface. While the shortcomings include the quite high research costs.
and relatively slow movements because it requires time to adjust the gaits that coordinate each of the servo [2]. The hexapod robot's leg structure consists of three main parts, namely Coxa, Femur and Tibia. Coxa or hips have a function to hold static body weight such as standing position and dynamic position when walking. Femur has a function as a connector between coxa and tibia. Femur provides support to the entire skeletal structure so that it helps in leg movements. The tibia or shin bone has the function of forming a hinge together with the femur called the knee so that it allows the robot to walk.

Gait is a pattern of joint movement, both in animals and humans. Gait in animals is formed based on the need for speed of movement, habitat conditions, and movement. In legged robots, there are several gait combination options, namely gait for 2 feet (Bipedal), 4 feet (Quadrupod), or 6 feet (Hexapod). Based on the gait movement pattern on the hexapod can be divided into several types, one of which is a tripod gait. A tripod gait is a gait that consists of the front and back legs and the middle leg on the other side, this gait steps with 3 legs or a tripod at a time. For each tripod, legs are raised, lowered, and moved back and forth simultaneously. When walking, the hexapod uses its two tripods to step from one foot to the other. Because 3 feet are always on the ground, the gait will always be stable.

Wall following is one of the navigation methods used to navigate the wall contours. This method is usually used by robots that have the ability to walk through walls or mazes to complete certain missions. Basically, this algorithm aims to keep the distance of the robot on the wall at the desired limit while the robot continues to move forward [1]. The way the wall following algorithm works is to set the distance of the wall with the robot to remain constant. If there is a change, the robot will move to then adjust the distance again. When the distance of the robot to the wall is too far, the robot will approach. Conversely, when it crashes or the distance is too close to the robot will stay away. This process will be repeated.

In a control system, we recognize that there are several types of control actions, including, proportional control actions, integral control actions and derivative control actions. Each of these control actions has certain advantages, where proportional control actions have the advantage of fast rise time, integral control actions have the advantage of reducing errors, and derivative control actions have the advantage of reducing errors or reducing overshoot/undershot. Therefore, we can produce output with rapid research and small errors, we can combine these three control actions into PID control actions. Proportional Integral Derivative (PID) controller parameters are always based on a review of the characteristics set (plant). Thus, no matter how complex a plant is, the behavior of the plant must be known before the PID parameter search is performed. Using a PID control means that it aims to process an error signal or error, the error value is processed by the PID formula to be used as a control signal or control signal that will be transmitted to the actuator.

2. Research Methods
The robot frame used was made of acrylic with a thickness of 5 mm and 3 mm, consisting of a body frame, leg frame, and robot head. Servo motors used, namely the type of digital titanium gear servo motor as many as 18 pieces of Hitec HS-7955TG. Arduino used consisted of 2 pieces, namely Arduino Nano master and slave. The master functions as a controller and processor of sensor data, and the slave as a controller of the navigation system and pulse generator to control servo movements. Servo controller circuit consisted of 3 arduino pro mini integrated with each other through serial communication, its function is to provide pulses to 18 servo motors that function as robotic drives. The designed power supply circuit is a circuit for microcontroller and servo power supplies. The power supply circuit consisted of a battery and a switching regulator. The input for the allowed microcontroller power supply was 5 Volts, while the power supply was on the 9-12 Volt servo. 16 x 2 LCD Display was used to display the distance value of the robot's ultrasonic proximity sensor, which then processed by a microcontroller to determine the type of control and response or robot motion pattern. The 7.4 V battery was used as an Arduino power supply and sensor, while the 11.4 V battery was used as a servo motor power supply. 5 Ping Parallax sensors were used. This sensor works to detect objects around the robot by capturing the reflection of the signal emitted. As an actuator or robot drive, it consists of 18 servo motors, each foot consists of 3 servo motors.
After collecting data relating to the object to be examined; both in the form of relevant references, datasheet components and manuals, the next step was to design the system. The study design was made with a system block diagram. This block diagram was used in software and hardware design. The whole system block diagram can be seen in Figure 1.

![Figure 1. Block Diagram of Overall System Design.](image1)

The design of the robot used was a six-legged robot (hexapod). The design of the robot design with the hexapod type was based on a robotic motion pattern that is more stable and faster in making displacement, the following is the robot design used:

![Figure 2. The design of hexapod robot legs for vertical motion [3].](image2)

![Figure 3. The design of hexapod robot legs for horizontal motion [3].](image3)
Figure 4. The design of a whole hexapod robot mechanic [3].

The following figure shows the position of the Ping Parallax sensor used as an input parameter to determine the behavior of the robot in tracking walls, and also to determine which sensor will be used as an error gauge in the built PID control system.

Figure 5. Ping Parallax Position Sensor.

The motion pattern used in the design of this robot was a tripod gait type motion pattern where 3 robot legs are used to support the robot's body to remain standing, while the other 3 legs will move forward in accordance with the input provided. Step motion of the tripod gait is shown in Figure 6.

Figure 6. Illustration of hexapod robot foot movements in the tripod gait method [3].

3. System Testing
System testing can be done after the design process is complete, in this process the system was tested whether it can work in accordance with their respective functions and tasks. The stages to be carried out were electronic testing and mechanical testing.
Electronic testing aims to test the voltage used for the mini system power supply and 18 servo pieces on the robot. The testing was done by testing the input point of the power supply circuit connected to the battery and at the output point of the servo power supply circuit connected to the mini system and servo motor using a multimeter. The target of this test was a stable and accurate voltage value in accordance with the desired input and output. Ping Parallax sensor testing was conducted to determine the characteristics of the Ping Parallax sensor readings to the objects around it displayed on the 16x2 LCD display, then measure and compare the results of the distance sensor reading with the actual distance and measure the elevation angle of the Ping Parallax sensor. The target of this test was to get accurate results from the reading of the proximity sensor so that it can improve system performance. Testing the set point PID wall following was done to find the set point distance setting for the PID that will be applied to the robot. The target of this test was to obtain the most appropriate PID setting to be applied to the wall following robot. Testing the set point multiposition controller wall following setting was done to test and compare the robot's performance by using the PID control based multiposition controller wall following method.

Robot mechanical testing aims to show the results of hexapod robot mechanics that have been made, in the form of testing the results of robot mechanical design, and testing the degree of freedom of each robot joint. Robot movement speed testing was also done to determine the speed of the robot. The test was carried out in a straight path with a length of 200 cm to make it easier to measure the speed of the movement of the robot when tracing the wall.

**Figure 7.** Front view of the hexapod robot [3].

**Figure 8.** Top view of the hexapod robot [3].

**4. Results**

Testing of power supply circuits for the Arduino system mini circuits was done by providing an input voltage to the UBEC TurnA 5A switching regulator. The voltage source used a 7.4 V / 1300 mAh battery. The testing used a digital multimeter to determine the voltage in the circuit.
Table 1. Input / output voltage regulator and mini system.

| Point | Connection Line | Voltage (V) | Description     |
|-------|-----------------|-------------|-----------------|
| 1     | Input           | 8.22        | Input Baterai   |
| 2     | Output          | 5.05        | Output UBEC     |
| 3     | Input           | 5.05        | Input Arduino   |

Tests on the servo power supply circuit were done by giving the input voltage to the Turnigy UBEC 15A switching regulator. The voltage source used 11.1 Volt / 2700 mAh battery. The test was carried out on the Turnigy UBEC 15A input voltage and output switching regulator. The circuit output was tested by using a digital multimeter to determine the voltage generated by the regulator. The magnitude of the regulator output voltage and test results can be seen in Table 2.

Table 2. Servo regulator Input and Output Voltage.

| Point | Connection Line | Voltage (V) | Description     |
|-------|-----------------|-------------|-----------------|
| 1     | Input           | 12.48       | Input Baterai   |
| 2     | Output          | 5.05        | Output UBEC     |
| 3     | Input           | 5.05        | Input Servo     |

Degree of Freedom (DOF) testing of each robot joint was intended to find out how far the freedom of each joint is at the robot's feet so that it can facilitate the design of the robot's motion patterns. The test was carried out with a manual measurement method where each robot joint was checked for maximum and minimum DOF used with reference to the position of the default / home robot as a 0 degree point for each joint / servo.

Table 3. The results of testing the Degree of Freedom (DOF) of the robot.

| Leg Number | Servo Number | Joints | Degree Min (°) | Degree Max (°) |
|------------|--------------|--------|----------------|----------------|
| 1          | 1            | Coxa   | -70            | 90             |
| 1          | 2            | Femur  | -27            | 70             |
| 1          | 3            | Tibia  | -55            | 85             |
| 1          | 4            | Coxa   | -60            | 60             |
| 2          | 5            | Femur  | -27            | 70             |
| 2          | 6            | Tibia  | -55            | 85             |
| 2          | 7            | Coxa   | -75            | 60             |
| 3          | 8            | Femur  | -27            | 79             |
| 3          | 9            | Tibia  | -55            | 85             |
| 3          | 10           | Coxa   | -60            | 60             |
| 4          | 11           | Femur  | -27            | 70             |
| 4          | 12           | Tibia  | -55            | 85             |
| 4          | 13           | Coxa   | -60            | 60             |
| 5          | 14           | Femur  | -27            | 70             |
| 5          | 15           | Tibia  | -55            | 85             |
| 5          | 16           | Coxa   | -75            | 60             |
| 6          | 17           | Femur  | -27            | 79             |
| 6          | 18           | Tibia  | -55            | 85             |
Ultrasonic sensor testing aims to measure the distance of the robot to the object, as an input to determine the error value on the applied PID control. Ping Parallax sensor testing was divided into 2 stages, namely sensor accuracy testing and sensor elevation angle testing. The distance testing method of the Ping Parallax sensor was done by displaying the sensor readings by the microcontroller on the LCD Display mounted on the robot. Table 4 shows the results of testing the Ping Parallax sensor by comparing the actual distance with the distance read on the LCD.

| Testing to-n | Reading Distance (cm) | Distance Read (cm) |
|--------------|-----------------------|--------------------|
| 1            | 5                     | 5                  |
| 2            | 10                    | 10                 |
| 3            | 15                    | 15                 |
| 4            | 20                    | 20                 |
| 5            | 25                    | 25                 |
| 6            | 30                    | 30                 |
| 7            | 35                    | 35                 |
| 8            | 40                    | 40                 |
| 9            | 45                    | 45                 |
| 10           | 50                    | 50                 |
| 11           | 55                    | 55                 |
| 12           | 60                    | 60                 |
| 13           | 65                    | 65                 |
| 14           | 70                    | 70                 |
| 15           | 75                    | 75                 |
| 16           | 80                    | 80                 |
| 17           | 85                    | 85                 |
| 18           | 90                    | 90                 |
| 19           | 95                    | 95                 |
| 20           | 100                   | 100                |

Table 5. The measurement results of the Ping Parallax sensor elevation angle.

| Testing to-n | Measurement Distance | Measurement Angle (°) |
|--------------|----------------------|-----------------------|
|              | 5 10 20 30 40 50     |                      |
| 1            | 10                    | ✓ ✓ ✓ ✓ ✓ X           |
| 2            | 15                    | ✓ ✓ ✓ ✓ ✓ X           |
| 3            | 20                    | ✓ ✓ ✓ ✓ ✓ X           |
| 4            | 25                    | ✓ ✓ ✓ ✓ ✓ X           |
| 5            | 30                    | ✓ ✓ ✓ ✓ ✓ X           |
| 6            | 35                    | ✓ ✓ ✓ ✓ X X           |
| 7            | 40                    | ✓ ✓ ✓ X X X           |
Subsequent tests were carried out to compare the results of the PID control-based wall following design with the multiposition controller wall following method by providing different set point parameters so that later it can be seen the range of errors obtained from the test results. The test was carried out with 3 different SP (Set Point) parameters, namely 5, 10, and 15. Each was done 10 times to determine the best performance of the robot.

Table 6. The results of testing the PID setting with the parameter SP = 5 cm.

| Testing to-n | Time (s) | Closest Distance (cm) | Collision with a wall (x) |
|--------------|----------|-----------------------|--------------------------|
| 1            | 22.5     | 7                     | 2                        |
| 2            | 21.3     | 6                     | 3                        |
| 3            | 23.5     | 7                     | 3                        |
| 4            | 22.3     | 7                     | 2                        |
| 5            | 23.7     | 6                     | 3                        |
| 6            | 24.4     | 6                     | 3                        |
| 7            | 25.6     | 6                     | 4                        |
| 8            | 25.3     | 6                     | 3                        |
| 9            | 23.1     | 7                     | 2                        |
| 10           | 22.9     | 6                     | 2                        |
| Amount       | 234.6    | 64                    | 27                       |
| Average      | 23.46    | 6.4                   | 2.7                      |

Table 7. The results of testing the PID setting with the parameter SP = 10 cm.

| Testing to-n | Time (s) | Closest Distance (cm) | Collision with a wall (x) |
|--------------|----------|-----------------------|--------------------------|
| 1            | 22.6     | 10                    | 0                        |
| 2            | 19.6     | 9                     | 0                        |
| 3            | 22.3     | 8                     | 0                        |
| 4            | 21.3     | 9                     | 0                        |
| 5            | 24.1     | 10                    | 0                        |
| 6            | 20.4     | 9                     | 0                        |
| 7            | 20.1     | 8                     | 0                        |
| 8            | 19.5     | 9                     | 0                        |
| 9            | 21.5     | 8                     | 0                        |
| 10           | 22.8     | 9                     | 0                        |
| Amount       | 214.2    | 89                    | 0                        |
| Average      | 21.42    | 8.9                   | 0                        |
Table 8. The results of testing the PID setting with the parameter SP = 15 cm.

| Testing to-n | Time (s) | Closest Distance (cm) | Collision with a wall (x) |
|--------------|----------|------------------------|--------------------------|
| 1            | 23.4     | 13                     | 0                        |
| 2            | 21.5     | 14                     | 0                        |
| 3            | 23.6     | 13                     | 0                        |
| 4            | 22.4     | 12                     | 0                        |
| 5            | 24.7     | 14                     | 0                        |
| 6            | 21.8     | 14                     | 0                        |
| 7            | 24.6     | 13                     | 0                        |
| 8            | 25.6     | 12                     | 0                        |
| 9            | 24.4     | 12                     | 0                        |
| 10           | 23.7     | 13                     | 0                        |
| Amount       | 235.7    | 130                    | 0                        |
| Average      | 23.57    | 13.0                   | 0                        |

This robot movement speed test was carried out to review the robot's performance and stability when walking through walls. This test was carried out on a straight line along the 200 cm divided into 10 barriers to facilitate the calculation of the robot's movement speed.

Table 9. The results of testing the speed of the robot movement with the PID wall following algorithm.

| Testing to-n | Distance (cm) | Time (s) | Speed (cm/s) |
|--------------|---------------|----------|--------------|
| 1            | 20            | 1.21     | 16.53        |
| 2            | 40            | 2.38     | 16.81        |
| 3            | 60            | 3.43     | 17.49        |
| 4            | 80            | 4.59     | 17.43        |
| 5            | 100           | 6.08     | 16.45        |
| 6            | 120           | 7.57     | 15.85        |
| 7            | 140           | 8.68     | 16.13        |
| 8            | 160           | 9.40     | 17.02        |
| 9            | 180           | 10.75    | 16.74        |
| 10           | 200           | 11.88    | 16.84        |
| Amount       |               |          | 167.29       |
| Average      |               |          | 16.73        |

5. Conclusion
The application of the PID control-based wall following algorithm on the robot has been successfully carried out and was able to make the robot run stably without crashing into the wall. From 10 times of trial, the success rate of completing the mission was 100%, with an average time of 16.73 seconds and the fastest time to complete the mission reached 15.85 seconds.

The application of PID control in the wall following robot navigation has been able to increase the stabilization and speed of the robot in tracing the wall, so as to shorten the robot's travel time in completing missions. Thus, the robot is expected to be included in the Indonesian Robot Contest (KRI) in 2020.
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