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Design and Implementation the Stability and Direction of Hexapod Robot Motion

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Abstract

Robotics technology has developed rapidly and applied to various fields of work that cannot be done by humans. Many forms and types of robots used include the hexapod robot. The purpose of this research is to regulate the direction of the hexapod robot's motion and be able to avoid obstacles to maintain the stability of its motion using a PID control system. In establishing a good control system, various types of sensors are used, those are ultrasonic and inertial measurement unit sensors. The shape of the hexapod robot is made to be integrated with the robot's legs. Each leg of the robot consists of 3 joints, joined by a servo motor. There are 18 servo motors. Eight ultrasonic sensors are used to detect surrounding objects, run well, and ability to avoid obstacles. The main orientation of the hexapod robot motion is to move forward, but if there are obstacles, it will find a solution to turn using ultrasonic sensors. An inertial measurement unit sensor is used to maintain the robot's body's stability.

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1 Introduction

Today's robot technology has developed rapidly and is widely used to help humans work. In general, robots are categorized into two types, namely robots that can move, known as mobile robots, and robots that cannot move or known as manipulator robots. The robot’s motion is adjusted to the medium in which it moves, such as a ground robot, a water robot (submarine robot), and a flying robot (aerial robot). Land robots (ground robots) are grouped into two types, namely wheeled robots and legged robots. Legged robots have an advantage over wheeled robots because they can move well on uneven surfaces. One type of legged robot that is widely developed is the hexapod robot. The hexapod robot must have high stability, and the way of walking also varies according to the pattern of steps. In general, the hexapod robot step is divided into three step patterns, those are metachronal, ripple, and tripod. The metachronal step pattern is to move the robot's legs alternately one by one, while the ripple step pattern is to move two robot legs simultaneously and continue with the other two legs alternately, for the tripod step pattern, which is to move three robot legs simultaneously and continue with three legs that are others in turn.

To increase the reliability of the hexapod robot, either in the form of stability or speed, and to determine the direction of the robot's movement, an electronic sensor device is needed. The sensor that can be used to maintain the stability of the movement of the hexapod robot is the inertial measurement unit (IMU) sensor. The IMU sensor is part of the navigation system to estimate a relative position and acceleration of a movement. The IMU sensor can perform measurements such as gyroscope and accelerometer and other conditions. The Gyroscope data can be used to maintain an approximate angular orientation of the motor. The angular rotational speed of a gyroscope is stated in degrees per second (^{O}/S). Data from the accelerometer is used to generate servo motor rotation to obtain the desired position. The motion is generated by the rotation of the servo motor which is integrated with a mechanical device in a certain form and will produce several movements known as the degree of freedom. In the 3-dimensional plane, the direction of angular movement is divided into three parts, namely pitch (ϕ), roll (θ), and yaw (ψ), the acceleration of movement referring to the x, y, and z axes.

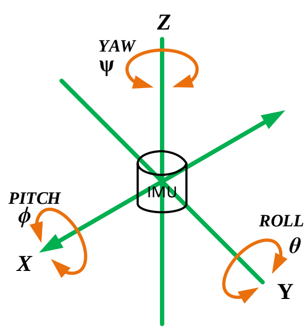

Figure 1. IMU sensor movement direction 6 DOF

A servo motor is an electromechanical device that produces a rotating motion based on a given digital signal. This instruction is in the form of a digital signal that will drive the servo motor output at a certain angle with the desired rotational speed. The servo motor rotation output will produce a mechanical movement that will move the hexapod robot leg as desired. In order to adjust the rotation speed and angle of the servo motor, a PID control system is utilized. All ultrasonic and IMU sensors will be used as input data to determine the rotation direction and speed of the servo motor.

2 Materials and Methods

The robot designed in this study is a 6-legged robot known as the Hexapod robot. The hexapod robot device consists of a driven device in the form of a mechanical robot and an electronic device as a robot motion control system. Mechanical devices can be part of a place to store electronic devices and can also be objected to that are mentioned electronically to obtain the desired robot movement. In order to adjust the motion of the hexapod robot, forward kinematic and inverse kinematic analyses are used. Forward kinematic is a robot movement analysis system to get position coordinates (x, y, z) if the angle of each joint of the robot leg is known, on the other hand, inverse kinematic is used to analyze the kinematic movement of the robot to get the angle of each joint if it has data. Position coordinates (x, y, z). The determination of the size of each joint angle is carried out by a servo motor, each link is always connected to a servo motor, and the end of the last link is known as the end-effector. The end-effector hexapod robot is also known as the leg base because it is the end of the robot's leg that will determine the position of the hexapod robot.

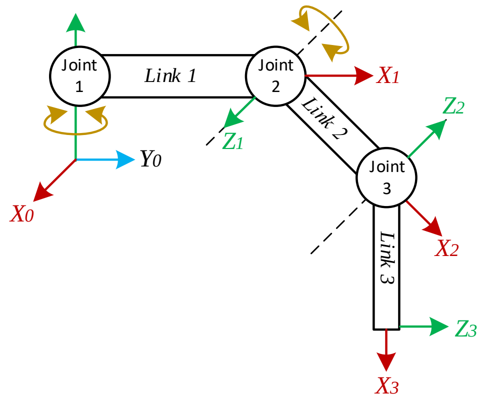

Figure 2. Angular movement of the robot's legs

The block diagram of the electronic device used can be seen in Figure 3. The battery is a direct current power source used to power the robot, and the nominal voltage range of the battery used ranges from 7-12VDC. In the hexapod robot, there are electromechanical components, namely servo motors, there is also a control system device in the form of a control module, to provide energy sources separately, and the distribution of direct current power sources is carried out. The separation of the direct current power source is done to anticipate interference from the servo motor on the control signal from the main controller module and the sensor module. The DC to DC Converter 1 module is used to maintain the stability of the direct current power source from the battery which will be distributed to the ultrasonic sensor module, the inertial measurement unit (IMU) sensor module, and the main controller unit module. The DC to DC Converter 2 module is useful to distribute direct current power sources to the servo motor driver module and 18 servo motors.

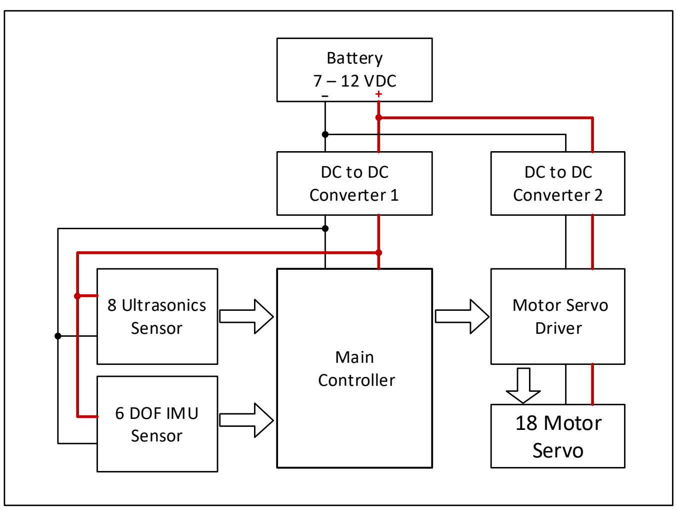

Figure 3. Block diagram of the hexapod robot electronic system

The hexapod robot consists of 6 legs that can be controlled using a servo motor, the number of servo motors used depends on the number of joints desired in each robot leg. In general, three servo motors are used on each leg of the robot, so 18 servo motors are needed for all the driving components. When using three servo motors for each robot leg, they will produce three degrees of freedom for each leg movement of the robot. In this study, three servo motors will be used for each leg of the robot, and the type of servo motor used can produce an angle of 180^{O}.

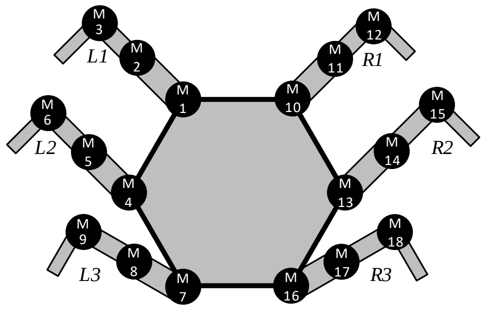

Figure 4. Construction of placement of 18 servo motors on a hexapod robot

In the picture above, you can see the basic construction of the hexapod robot foot placement using 18 servo motors. For the movement of the hexapod robot, a tripod gait step pattern can be used, by using a tripod gait pattern the robot can walk with a combination of the initial movements of the legs L1, R2, and L3 being lifted simultaneously at a certain angle and speed, after the initial position of the motion is carried out and has reached the position desired, then lift the legs R1, L2, and R3. This movement pattern is carried out continuously to move the robot. The construction realization of the shape and pattern of the hexapod robot steps can be recognized in the image below.

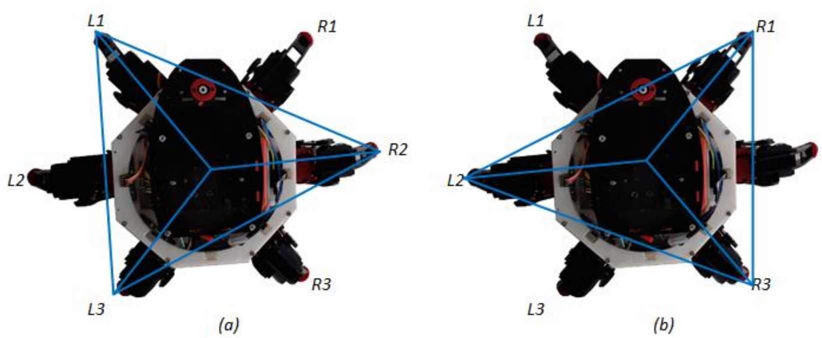

Figure 5. The pattern of steps (a) first step, (b) second step

The main motion of the hexapod robot is to move forward, the robot will stop moving or can change direction according to the ultrasonic sensor reading. So that the robot can run well and can avoid obstacles that are around it, the robot is equipped with eight ultrasonic sensors. Ultrasonic sensors are installed in 8 different directions to obtain data on surrounding objects. All ultrasonic sensors will send data on the object around them continuously according to their coverage area.

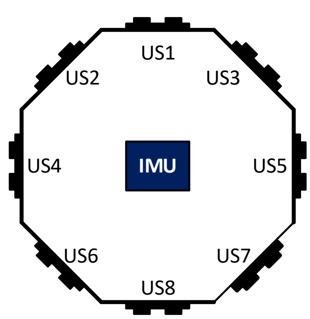

Figure 6. Construction of the placement of 8 ultrasonic sensors

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The hexapod robot must be able to move stably in order to maintain its stability of the hexapod robot, it is equipped with an inertial measurement unit (IMU) sensor which features 6 degrees of freedom (6 DOF). On the IMU sensor, 6 degrees of freedom is divided into two parts, namely accelerometer 3 DOF, and gyroscope 3 DOF. All sensor data generated will be read by the control system device so that it can be processed into a balanced robot motion.

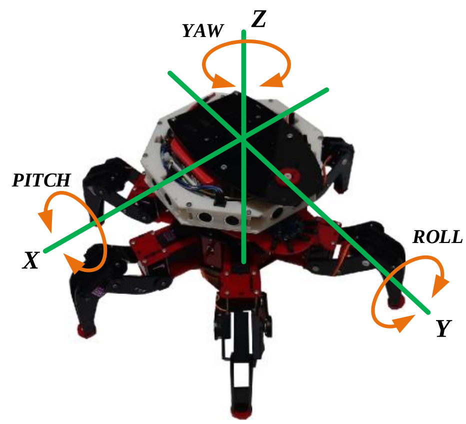

Figure 7. The direction of movement generated by the hexapod robot

Data from this sensor will be processed on the controller module and sent to the servo motor by providing input in the form of pulse width modulation (PWM), this PWM value will determine the angle of each robot leg joint. To produce an angle of 180^{O} at the servo motor output it takes a period of 20ms. The pulse width value will determine the duty-cycle and finally produce the PWM value for the servo motor.

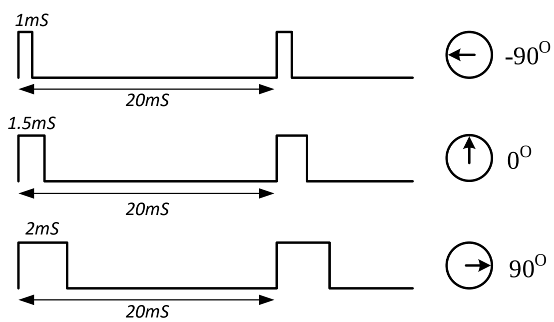

Figure 8. Angle setting on a servo motor

The design of the moving method is carried out so that the robot's motion becomes dynamic and can move in various directions. The method used for the movement of the robot's legs is the inverse kinematic method, with this method the desired robot position will be obtained according to the angular movement of the servo motor. To support the inverse kinematic method, a proportional integral derivative (PID) control system is used.

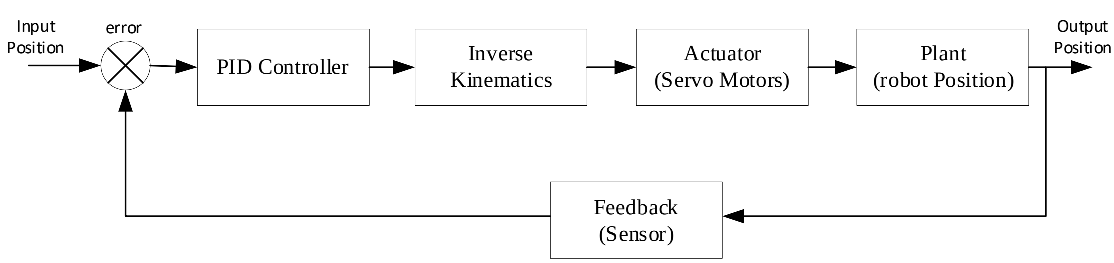

Figure 9. PID Control design

Figure 9 shows the basis for designing PID control on a hexapod robot. The PID control hexapod robot is applied to the inverse kinematic method. The value generated from the control system will be given to the driving device, namely the servo motor, then the servo motor will move the robot's legs so that the robot's position is obtained. For the robot to run properly, the control system is equipped with ultrasonic sensors and IMU sensors. Data from all sensors will be used as feedback to maintain stability and monitor the direction of the robot's motion (Artanayasa & Giri, 2019; Sumba et al., 2020).

3 Results and Discussions

The hexapod robot is made proportionally with a maximum dimension of 56 cm long, 56 cm wide, and 30 cm high. The image below shows the dimensions of the hexapod robot that has been created.

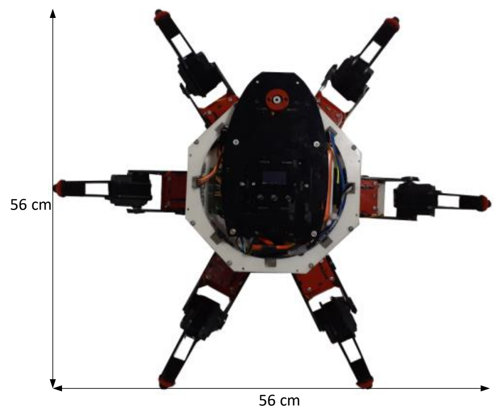

Figure 10. Dimensions of the hexapod robot

The test is carried out on a flat plane with a certain height which will be the reference height (href) to regulate the stability of the robot. When the robot is first to run, the robot must move at a reference point. This reference height is the benchmark for the movement of the hexapod robot. The hexapod robot test was carried out in several stages including determining the angle of the servo motor output, the mechanical movement of the robot's legs, ultrasonic sensor readings, and IMU sensors.

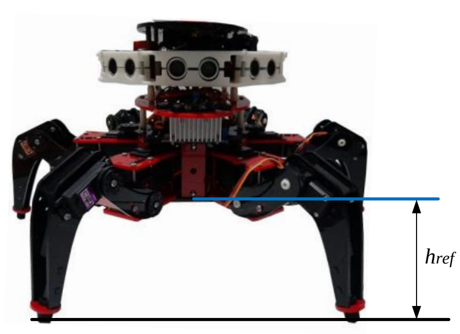

Figure 11. Hexapod robot reference height position

IMU Sensor

In the initial condition of the hexapod robot moving, the robot must stand at a certain height and become the reference height (href), then the IMU sensor is used to make the robot body parallel to the surface plane. The position of the IMU sensor can be used as a reference to make the robot's body flat. The reference point (href) on the

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robot is determined based on the value of the position of the lower body of the robot, for the reference point is 5 cm. After the reference point has been determined, the hexapod robot must be limited to the lowest and highest distances from the robot body to the surface area on which the robot stands. The lowest value from the bottom of the robot to the surface is 1cm, and the farthest value is 10 cm. The value of the IMU sensor test results on the hexapod robot at the lowest distance and the reference point and the farthest distance can be seen in the table below.

Table 1
IMU sensor test results at the initial reference point of the hexapod robot

Angle	Angle on Lowest Distance	Angle on Reference Distance	Angle on Farthest Distance
Pitch (ϕ)	0.5	0.6	0.7
Roll (θ)	0.8	0.9	1.0
Yaw (ψ)	0.6	0.7	0.8

Based on the results of testing the angles on the pitch, roll, and yaw of the hexapod robot, it is known that the higher the distance of the hexapod robot's body from the surface, the greater the error generated. This error occurs due to several things, including the uneven placement of the IMU sensor and the robot's mechanical construction is not very precise, but with a small error value compared to the angle of the robot's movement, this error can be ignored (Polizzi et al., 2007; Allen & Wood, 2006).

Hexapod Robot Motion

In the initial conditions, the hexapod robot moves, the robot must stand at a certain height based on a predetermined reference distance. The height value from the bottom of the robot body will determine the angle of the servo motor mounted on each robot leg. Determination of the servo motor angle at the reference point, the lowest distance, and the highest distance from the lower body of the robot must be carried out because the value of this angle is the limit for the angular movement of the robot. The servo motor used is capable of producing a maximum angle of 180^O, but the 0^O angle of the servo motor is in the middle, so the range of motion of the servo motor angle is from -90^O to 90^O.

Figure 12. The angular motion of the servo motor on the hexapod robot leg

The hexapod robot has 6 legs and each leg has 3 servo motors so the total servo motors used are 18 servo motors. The table below is the servo motor angle value when the lower body of the robot is at its furthest distance (Mott, 2004; Najmurrokhman et al., 2018; Niku, 2020; Nonami et al., 2014; Rudy & Lukas, 2018; Siegwart et al., 2011). The highest distance from the lower body of the hexapod robot to the designed surface is 10 cm. At the highest distance of the hexapod robot, each leg of the robot has a determined angle, the desired angle for servo motor 1 (joint 1) is 90^O, the angle for servo motor 2 (joint 2) is 90^O, and the angle for servo motor 3 (joint 3) is 45^O. The table for testing the farthest distance from the lower body of the robot can be seen in the table below.

Table 2
Servo motor test results at the highest distance

Robot Leg	Servo Motor /Joint	Servo Motor Angle	Links	Angle Link
Leg 1 (L1)	Servo Motor 1	0	1	90
	Servo Motor 2	89	2	90
	Servo Motor 3	45	3	89
Leg 2 (L2)	Servo Motor 4	0	4	90
	Servo Motor 5	89	5	90
	Servo Motor 6	44	6	89
Leg 3 (L3)	Servo Motor 7	1	7	90
	Servo Motor 8	90	8	90
	Servo Motor 9	45	9	90
Leg e (L4)	Servo Motor 10	1	10	89
	Servo Motor 11	89	11	90
	Servo Motor 12	44	12	89
Leg 5 (L5)	Servo Motor 13	0	13	90
	Servo Motor 14	90	14	90
	Servo Motor 15	45	15	90
Leg 6 (L6)	Servo Motor 16	1	16	89
	Servo Motor 17	89	17	90
	Servo Motor 18	44	18	89

Based on testing when the lower body of the robot is at its highest point, it produces a different angle value on each servo motor or the joint, but this difference is not a problem because the difference is not too large and can still be tolerated (Jazar, 2010; Kurniawan et al., 2018; Lawrence et al., 2021). Next will be tested at the reference height. This reference point is the midpoint of the robot body. The distance of the lower body reference point of the hexapod robot to the surface is 5 cm. At the reference point of the hexapod robot body, each leg of the robot has been determined the angle, the desired angle on the servo motor 1 (joint 1) is 90^{O}, the servo motor 2 angle (joint 2) is -45^{O}, and the servo motor 3 angle (joint 3) is -65^{O}. The test results at the reference points can be seen in the table below (Henning & Rautenberg, 2006; Gil et al., 2007).

Table 3
Test results of servo motors and at the reference point of the hexapod robot body

Robot Leg	Motor Servo/Joint	Servo Motor Angle	Links	Angle Link
Leg 1 (L1)	Servo Motor 1	0	1	90
	Servo Motor 2	-44	2	-44
	Servo Motor 3	- 65	3	20
Leg 2 (L2)	Servo Motor 4	1	4	89
	Servo Motor 5	-44	5	-44
	Servo Motor 6	-65	6	20
Leg 3 (L3)	Servo Motor 7	1	7	90
	Servo Motor 8	-44	8	-44
	Servo Motor 9	-64	9	21
Leg e (L4)	Servo Motor 10	1	10	89
	Servo Motor 11	-45	11	-45
	Servo Motor 12	-65	12	20
Leg 5 (L5)	Servo Motor 13	0	13	90
	Servo Motor 14	-45	14	-45

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	Servo Motor 15	-64	15	21
Leg 6 (L6)	Servo Motor 16	0	16	90
	Servo Motor 17	-44	17	-44
	Servo Motor 18	-64	18	21

The results of the angle test on each servo motor at the reference point can be seen that the resulting angle has several differences in almost every joint and link angle on the robot leg. But the difference is still in the tolerance stage. The position at the lowest point needs to be tested as well, the lowest distance of the lower body of the hexapod robot is 1 cm (Chairunnas, 2017; Ding & Yang, 2016; Dzulfiqar & Widodo, 2019). At the reference distance of the hexapod robot body, each leg of the robot has a determined angle, the desired angle on the servo motor 1 (joint 1) is 90^{O}, the servo motor 2 angle (joint 2) is -65^{O}, and the servo motor 3 angles are large. (joint 3) is -20^{O}. The test results for the lowest point can be seen in the table below.

Table 4
Motor servo test results at the lowest distance

Robot Leg	Motor Servo/Joint	Servo Motor Angle	Links	Angle Link
Leg 1 (L1)	Servo Motor 1	0	1	89
	Servo Motor 2	-65	2	-65
	Servo Motor 3	-20	3	25
Leg 2 (L2)	Servo Motor 4	0	4	90
	Servo Motor 5	-64	5	-64
	Servo Motor 6	-20	6	25
Leg 3 (L3)	Servo Motor 7	1	7	89
	Servo Motor 8	-65	8	-65
	Servo Motor 9	-20	9	25
Leg e (L4)	Servo Motor 10	1	10	89
	Servo Motor 11	-65	11	-65
	Servo Motor 12	-21	12	24
Leg 5 (L5)	Servo Motor 13	0	13	90
	Servo Motor 14	-75	14	-65
	Servo Motor 15	-20	15	25
Leg 6 (L6)	Servo Motor 16	1	16	89
	Servo Motor 17	-64	17	-64
	Servo Motor 18	-21	18	24

From the results of testing the angle on each servo motor at the lowest point, it can be seen that the joint angle and link angle produced are slightly different in almost every joint and link of the robot leg.

Ultrasonic Sensor

One way to determine the direction of movement of the hexapod robot is to use ultrasonic sensor data. Testing of 8 ultrasonic sensors is carried out by providing obstacles with a certain distance on each ultrasonic sensor. The results of sensor readings will be compared with distance measurements so that the error that occurs in each ultrasonic sensor is obtained (Gökrem et al., 2020; Beatty Jr, 1986; Asrofi et al., 2015). The unit of distance generated by the ultrasonic sensor is expressed in cm. The direction of the robot's movement is prioritized on moving forward, the robot can walk forward if the ultrasonic sensor US1 is more than 15 cm away. The robot will move to the right when the US4 sensor is smaller than 15 cm, the robot will move to the left when the US5 sensor is smaller than 15 cm. The orientation of the direction of movement will be carried out when one of the sensors has reached the nearest predetermined distance. If all sensors do not reach the nearest predetermined distance, the robot will move forward. The robot will walk backward when all sensors except the US8 sensor have reached a predetermined distance limit. The robot will turn right when the US1 sensor value is less than 15 cm and the US2 sensor is further than 15 cm, the robot will turn left when the US1 and US2 sensors are smaller than 15 cm (Washabaugh et al., 2017; Li et al., 2010).

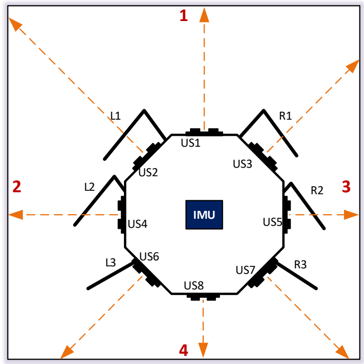

Figure 13. Robot given barrier wall 1

The picture above is an illustration of the position of obstacles in the form of 4 walls in the entire area around the robot (Abdulridha & Jasem, 2017; Arif & Kurniawan, 2013; Wijayanto et al., 2020). The US1 ultrasonic sensor is placed on the front of the robot body, the US2 ultrasonic is between the US1 ultrasonic sensor and the US4 sensor, the US3 sensor is between the US1 sensor and the US5 sensor, and the US4 sensor is the sensor on the left of the robot body, the US5 sensor is on the right side of the robot body, the sensor The US6 sensor is located between the left side sensor and the back sensor of the robot, the US7 sensor is between the right side sensor and the rear sensor, and the ultrasonic sensor US8 is placed on the back of the robot body (Yang et al., 2012; Chen & Gong, 2017). The results of the first test on all ultrasonic sensors are shown in the table below.

Table 5
First test results on ultrasonic sensor

Ultrasonic Sensor	Sensor Reading Distance (cm)	Measurement Results (cm)	Error (%)
Ultrasonic 1 (US1)	14,75	14,85	0,67
Ultrasonic 1 (US2)	23,10	23,35	1,07
Ultrasonic 1 (US3)	16,40	16,60	1,20
Ultrasonic 1 (US4)	13,10	13,20	0,76
Ultrasonic 1 (US5)	8,70	8,75	0,57
Ultrasonic 1 (US6)	13,90	14,05	1.07
Ultrasonic 1 (US7)	14,20	14,35	1,05
Ultrasonic 1 (US8)	7,30	7,35	0,68

Error testing on the ultrasonic sensor can be done by comparing the distance readings generated by the ultrasonic sensor with the actual distance measurement. The unit of distance used for ultrasonic sensor testing is cm. From the results of sensor readings and testing, it can be seen that the smallest error is 0.57% and the largest error is 1.2%. When the readings of all sensors are averaged, the resulting error is 0.88%. This error can still be tolerated to produce a hexapod robot movement control system. To test the stability of the ultrasonic sensor, another measurement is carried out by being given an obstacle with a greater distance than the previous test (Delcomyn & Nelson, 2000; Espenschied et al., 1996).

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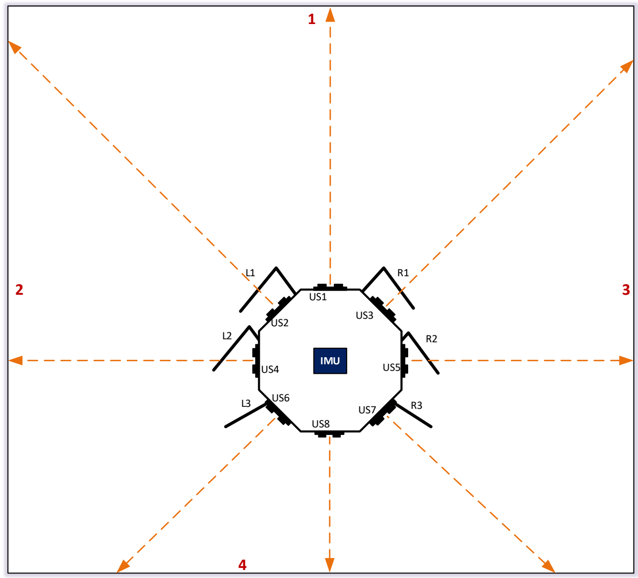

Figure 14. Robot given barrier wall 2

The image above shows the position of the hexapod robot against a barrier wall that serves as an obstacle for the ultrasonic sensor (Thilderkvist & Svensson, 2015; Taghirad, 2013; Wahyudi et al., 2017).

Table 6
The results of the second test of the ultrasonic sensor

Ultrasonic Sensor	Sensor Reading Distance (cm)	Measurement Results (cm)	Error (%)
Ultrasonic 1 (US1)	35,50	35,85	0,98
Ultrasonic 1 (US2)	47,80	48,35	1,14
Ultrasonic 1 (US3)	44,75	45,30	1,21
Ultrasonic 1 (US4)	31,25	31,55	0,95
Ultrasonic 1 (US5)	28,90	29,15	0,86
Ultrasonic 1 (US6)	28,70	29,05	1.20
Ultrasonic 1 (US7)	29,45	29,80	1,17
Ultrasonic 1 (US8)	17,50	17,65	0,85

Error testing on the second ultrasonic sensor is done by comparing the reading distance produced by the ultrasonic sensor with the actual measurement. From the results of sensor readings and measurements, it can be seen that the smallest error is 0.85% and the largest error is 1.21%. When the readings of all sensors are averaged, the resulting error is 1.05%. From the results of testing all ultrasonic sensors, it can be seen that the farther the distance measured, the higher the error generated. The image below shows a comparison graph of test 1 and test 2 on all ultrasonic sensors (Wajiansyah et al., 2021; Wibowo et al., 2021; Yunardi et al., 2019).

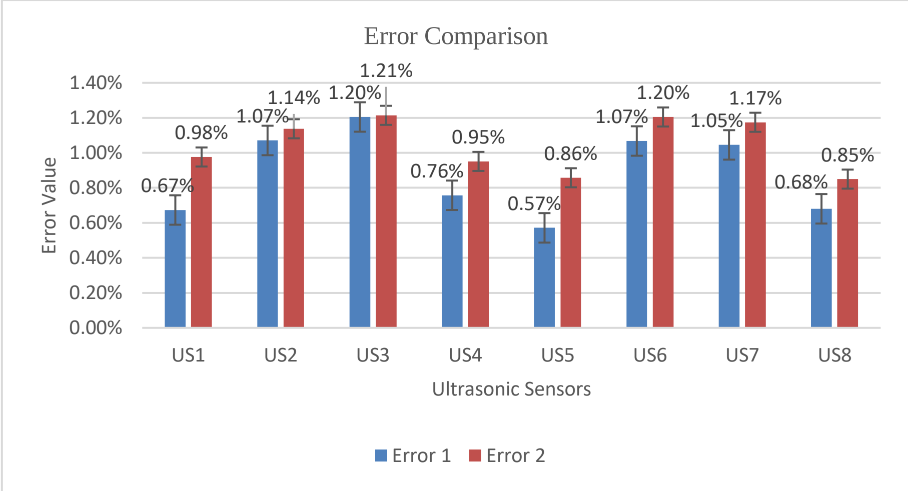

Figure 15. Error comparison of ultrasonic sensors

4 Conclusion

The construction of an electromechanical device on the hexapod robot is designed to move and step well. The hexapod robot is made by using 18 servo motors as its propulsion, each leg of the robot is equipped with 3 servo motors as its driving source to produce 3 degrees of freedom on each leg of the robot. So that the robot can move well and when walking does not hit objects that block it, 8 ultrasonic sensors are used which are arranged in an octagonal shape. Data from this sensor will be used by the control system device to determine the direction of movement and speed of the hexapod robot. The main orientation of the hexapod robot movement is to move forward, the robot will turn left and right according to the comparison of the ultrasonic sensor, and the robot will move backward if there are obstacles on the front and sides of the robot. To increase the stability of the robot body so that the robot can move in balance, the hexapod robot is equipped with an inertial measurement unit sensor. By using an inertial measurement unit sensor, the robot can move faster because its balance is well maintained. To drive the servo robot, a proportional integral derivative (PID) control system is applied. Data from all ultrasonic sensors and IMU sensors will be processed by the control system device to be used as a determinant of the shift angle at the servo motor output. The mechanics of the robot's legs will move according to the angle and rotational speed of the servo motor.

Conflict of interest statement
The authors declared that they have no competing interest.

Statement of authorship
The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

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References

Abdulridha, H. M., & Jasem, H. N. (2017). Planning of motion strategy for hexapod robot using biogeography based optimization. *Journal of University of Babylon*, *25*(5), 1870-1883.Andika, J., Salamah, K.S. (2018), Analisis kinematik pada robot hexapod, Jurnal Teknik Elektro, 9(2), 83-91.

Allen, W. A., & Wood, G. (2006). Defining and achieving financial stability. *Journal of financial stability*, *2*(2), 152-172. https://doi.org/10.1016/j.jfs.2005.10.001

Arif, Y. M., & Kurniawan, F. (2013, November). Implementation of multi sensor system for MSR-H01 hexapod robot.

Artanayasa, I. W., & Giri, M. K. W. (2019). Learning models and authentic assessment on football skill learning achievement. *International Journal of Physical Sciences and Engineering*, *3*(1), 22–31. https://doi.org/10.29332/ijpse.v3n1.246

Asrofi, M., Sumardi, S., & Setiyono, B. (2015). Stabilisasi Robot Berkaki 6 (Hexapod) Pada Bidang Miring Menggunakan 9 DOF IMU Berbasis Invers Kinematic. *Transient: Jurnal Ilmiah Teknik Elektro*, *4*(1), 97-105.

Beatty Jr, M. F. (1986). *Principles of engineering mechanics: Kinematics—the geometry of motion* (Vol. 32). Springer Science & Business Media.

Chairunnas, A. (2017). PENERAPAN ALGORITMA TRIPOD GAIT PADA ROBOT HEXAPOD MENGGUNAKAN ARDUINO MEGA128 APPLICATION OF ALGORITHM OF THE TRIPOD GAIT ON A HEXAPOD ROBOTS USING ARDUINO MEGA128. *Jurnal Penelitian Pos dan Informatika*, *7*(1).

Chen, S. Y., & Gong, S. S. (2017). Speed tracking control of pneumatic motor servo systems using observation-based adaptive dynamic sliding-mode control. *Mechanical Systems and Signal Processing*, *94*, 111-128. https://doi.org/10.1016/j.ymssp.2017.02.025

Delcomyn, F., & Nelson, M. E. (2000). Architectures for a biomimetic hexapod robot. *Robotics and Autonomous Systems*, *30*(1-2), 5-15. https://doi.org/10.1016/S0921-8890(99)00062-7

Ding, X., & Yang, F. (2016). Study on hexapod robot manipulation using legs. *Robotica*, *34*(2), 468-481.

Dzulfiqar, M. D., & Widodo, N. S. (2019). Implementasi PID Navigasi Pelacakan Titik Api dengan Sensor Flame Array pada Robot Hexapod untuk Kontes Robot Pemadam Api Indonesia. *Buletin Ilmiah Sarjana Teknik Elektro*, *1*(3), 131-143.

Espenschied, K. S., Quinn, R. D., Beer, R. D., & Chiel, H. J. (1996). Biologically based distributed control and local reflexes improve rough terrain locomotion in a hexapod robot. *Robotics and autonomous systems*, *18*(1-2), 59-64. https://doi.org/10.1016/0921-8890(96)00003-6

Gil, E., Escolà, A., Rosell, J. R., Planas, S., & Val, L. (2007). Variable rate application of plant protection products in vineyard using ultrasonic sensors. *Crop Protection*, *26*(8), 1287-1297. https://doi.org/10.1016/j.cropro.2006.11.003

GÖKREM, L., CAN, M. S., & AYDIN, S. (2020). Hexapod Robot Design and Performance Comparison of Fuzzy and PID Control Methods. *Balkan Journal of Electrical and Computer Engineering*, *8*(1), 88-97.

Henning, B., & Rautenberg, J. (2006). Process monitoring using ultrasonic sensor systems. *Ultrasonics*, *44*, e1395-e1399. https://doi.org/10.1016/j.ultras.2006.05.048

Jazar, R. N. (2010). *Theory of applied robotics*. Springer Science+ Business Media, LLC.

Kurniawan, I. A., Feriyonika, F., & Pramono, S. (2018, October). Inverse dan Body Kinematics pada Robot Hexapod. In *Prosiding Industrial Research Workshop and National Seminar* (Vol. 9, pp. 115-123).

Lawrence, N. F., Qurthobi, A., & Barri, M. H. (2021). Perancangan Dan Implementasi Kendali Lingkar Tertutup Gait Robot Hexapod Untuk Mendeteksi, Menaiki Dan Menuruni Tangga. *eProceedings of Engineering*, *8*(5).

Li, Q., Young, M., Naing, V., & Donelan, J. M. (2010). Walking speed estimation using a shank-mounted inertial measurement unit. *Journal of biomechanics*, *43*(8), 1640-1643. https://doi.org/10.1016/j.jbiomech.2010.01.031

Mott, R. L. (2004). *Machine elements in mechanical design*. Pearson Educación.

Najmurrokhman, A., Wibowo, B. H., & Rafanca, N. A. (2018). Desain dan Implementasi Robot Heksapoda dengan Misi Pemadaman Api. *JUMANJI (Jurnal Masyarakat Informatika Unjani)*, *1*(1), 1-9.

Niku, S. B. (2020). *Introduction to robotics: analysis, control, applications*. John Wiley & Sons.

Nonami, K., Barai, R. K., Irawan, A., & Daud, M. R. (2014). Hydraulically actuated hexapod robots. *M], Springer Japan*.

Polizzi, K. M., Bommarius, A. S., Broering, J. M., & Chaparro-Riggers, J. F. (2007). Stability of biocatalysts. *Current opinion in chemical biology*, *11*(2), 220-225. https://doi.org/10.1016/j.cbpa.2007.01.685

Rudy, R., & Lukas, L. (2018). Pergerakan Jalan Stabil Robot Hexapod di Atas Medan yang Tidak Rata. *TESLA: Jurnal Teknik Elektro*, *19*(2), 211-220.

Siegwart, R., Nourbakhsh, I. R., & Scaramuzza, D. (2011). *Introduction to autonomous mobile robots*. MIT press.

Sumba, E. F. S., Sumba, A. V. S., Castillo, G. A. L., & Rodríguez, J. A. P. (2020). Impact of distributed generation in the electrical system of Ecuador. *International Journal of Physical Sciences and Engineering*, *4*(1), 1–10. https://doi.org/10.29332/ijpse.v4n1.389

Taghirad, H. D. (2013). *Parallel robots: mechanics and control*. CRC press.

Thilderkvist, D., & Svensson, S. (2015). Motion control of hexapod robot using model-based design.

Wahyudi, Y. R., Hadi, M. S., Handayani, A. N., & Sendari, S. (2017). Implementasi Sistem Kendali PD (Proportional Derivative) Pada Navigasi Wall Follower Robot Berkaki Enam (Hexapod).

Wajiansyah, A., Supriadi, S., Gaffar, A. F. O., & Putra, A. B. W. (2021). Modeling of 2-DOF Hexapod Leg Using Analytical Method. *Journal of Robotics and Control (JRC)*, *2*(5), 435-440.

Washabaugh, E. P., Kalyanaraman, T., Adamczyk, P. G., Claflin, E. S., & Krishnan, C. (2017). Validity and repeatability of inertial measurement units for measuring gait parameters. *Gait & posture*, *55*, 87-93. https://doi.org/10.1016/j.gaitpost.2017.04.013

WIBOWO, I. K., PREISTIAN, D., & ARDILLA, F. (2021). Kontrol Keseimbangan Robot Hexapod EILERO menggunakan Fuzzy Logic. *ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika*, *9*(3), 533.

Wijayanto, A., Karim, K., & Pradana, S. (2020). Rancang Bangun Modul Praktikum Penggunaan Fotovoltaik. *PoliGrid*, *1*(2), 39-48.

Yang, N., Li, D., Zhang, J., & Xi, Y. (2012). Model predictive controller design and implementation on FPGA with application to motor servo system. *Control Engineering Practice*, *20*(11), 1229-1235. https://doi.org/10.1016/j.conengprac.2012.06.012

Yunardi, R. T., Muchadin, A., Priyanti, K. L., & Arifianto, D. (2019). Inverse Kinematics and PID Controller Implementation of Hexapod Robot for Wall Follower Navigation. *INAJEEE (Indonesian Journal of Electrical and Electronics Engineering)*, *2*(2), 57-62.