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Hexapod Robot Movement Control for Uneven Terrain

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***Abstract*— Hexapod robot is a robot that has 6 legs with joints or structures that resemble insect legs. This study uses the inverse kinematic method with the aim of finding points and effectors of the robot's legs that will make the robot's legs pass through uneven obstacles such as uneven flor, stairs, bolong-bolong obstacles, bolong-non-obvious obstacles and non-objective obstacles. This inverse kinematic is accessed with the Open Cm 9.04 microcontroller to control the dynamixel servo on the robot leg. The results of testing the robot's movement using inverse kinematics have succeeded in overcoming uneven obstacles using the inverse kinematic method. For testing the stability of the robot it is still not stable enough because the mechanical part of the foot is still not precise. The conclusion of the study, from 6 trials that average and uneven obstacles were obtained in the range of 85% - 95%. The inverse kinematic method using a proximity sensor on the front of the robot, the average success that can be obtained is in the range of 80% - 90%.**

Keywords*— Uneven Terrain, INA221, Sharp Gp Sensor, Srf HC-SR04 Sensor, Arduino Due Controler

I. Introduction

The Indonesian Fire Fighting Robot Contest (KRPAI) is one of the regional and national level robot contests held annually by the Directorate General of Learning and Student Affairs, and the Ministry of Research, Technology and Higher Education (Kemenristekdikti). Since 2016 KRPAI has not been divided into two Wheeled Divisions and a Leged Division, but there is only a division with legged robots that move and walk on legs. The robot used is a six-legged robot or hexapod. The best robot will be submitted to Trinity as Indonesia's representative for the international championship. Trinity College Fire Fighting Home Robot Contest (TCFFHRC) is an international level robot contest organized by Trinity College, Hartford, Connecticut, USA, while the Indonesian Robot Contest contains several contest fields including KRAI (Indonesian Abu Robot Contest), KRPAI (Indonesian Fire Extinguisher Robot Contest) legged type, KRSTI (Indonesian Dance Robot Contest), and KRSBI (Indonesian Football Robot Contest) wheeled type. The competition regulations from the TCFFHRC are a reference for KRPAI competitions at both the regional and national levels, because the national winner will get a ticket from DIKTI to represent Indonesia at the TCFFHRC.

A robot is a mechanical device that is controlled by an electronic device and can work with human supervision or by using a program that has been defined in advance (artificial intelligence). Robots are items that are familiar to electrical students, especially the concentration of Control and Instrumentation. The development of robots is very rapid with a variety of new systems being discovered. One type of robot that has also been developed is the 6-Legged Robot (Hexapod). This robot moves based on the kinematic motion applied to each leg which is arranged by servo motors [1]. Robots participating in the Indonesian fire fighting robot contest have the main task of extinguishing fires and passing obstacles such as stairs and uneven flour in the competition arena.

One of the problems in KRPAI is that the robot has not been able to pass through the uneven surface of the stairs with a height of 6 cm which is in the middle of the track. Thus reducing the acquisition of bonuses in the Indonesian Fire Extinguisher Robot Contest competition regulations. The solution is the addition of the Sharp Gp sensor which has better readings for detecting uneven surfaces such as the surface of stairs. To move the robot's legs flexibly, several algorithms are needed to control a servo on a hexapod robot, namely inverse kinematic to determine the angle of each joint when the toe is at a certain coordinate and forward kinematic for a function that maps angles to positions [2]. The legged robot consists of motors which must be controlled at an angle to reach the desired position. The desired position can indeed be determined by using the trial-error method which we often call forward kinematic. To find out the movement of the hexapod robot, forward and inverse kinematics analysis is needed. Kinematic inverse refers to the robot kinematic equation that is used to determine joint parameters that will result in the movement of the robot so that the desired end or effector position is achieved or fulfilled, kinematic inverse is also known as motion planning. The hexapod robot uses ultrasonic sensors used in this robot to help in carrying out the task of detecting the distance in the room and the position the robot is in. From the development of legged robots it is still not significant. Therefore in this study will design a fire extinguisher hexapod robot that functions as a detector. Uneven surface detection using a sharp Gp sensor [3].

II. Method

In research conducted by the AL-JAZARI hexapod robot using the kinematic inverse method, kinematic inverse is a theory about the movement of objects without taking into account the forces that cause the object to move [4]-[7]. This research will carry out the movement of the hexapod robot on uneven obstacles against objects of a certain color and be processed using Object Movements to detect the movement of the hexapod robot in video [8]-[12].

In designing this system, system design is used with two design stages, namely hardware design and software design. The first step is to make a hardware design block diagram, then make a robot hardware design. The second step is making a flow chart of the inverse kinematic formula and making a flow chart of the Sharp Analog Distance sensor, the design of the software used to find out how the hexapod robot works [13]-[15].

A. Hardware Design

The design of this tool uses a hexapod robot using 6 robot legs and each leg consists of 3 AX-18A servos, the hexapod robot consists of the Open Cm 9.04 microcontroller as the control of the hexapod robot legs, the sharp Analog Distance sensor functions as a replacement for the hexapod robot's movement patterns to ride on an uneven surface. The block diagram is shown in Fig. 1.

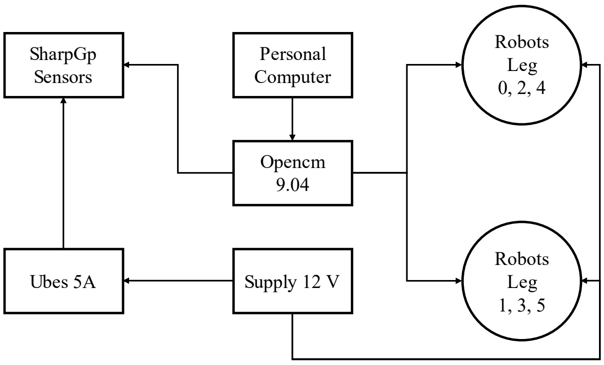


Fig. 1. Block diagrams

As in general for a robot, the system consists of mechanics, hardware, this research is on the development of hexapod robot movements, even so hardware design is very important for hexapod robots [16]. robot hardware design is shown in Fig. 2.

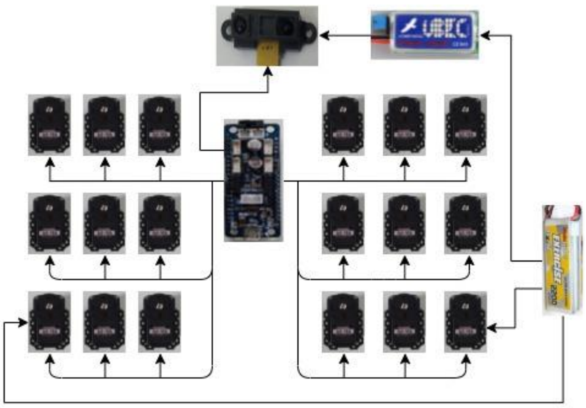


Fig. 2. Robotic hardware design

B. Software Design

In this research, the hexapod robot uses an Open CM software to send programs to the Dynamixel servo. In addition, the Open CM software is also equipped with a library to access the Dynamixel servo and sensors from ROBOTIS. This hexapod robot uses the structure of the C++ programming language, C++ programming which functions to send the inverse kinematic formula and sensors to the hexapod robot which will run as fully as possible according to the desired program.

The inverse kinematic flowchart starts with measuring the distance between the hexapod robot's legs from the coxa femure and tibia robot legs on the AX-18a servo first, then entering the X, Y, Z positions according to the desired position according to a certain hexapod robot leg position, then input the formula inverse kinematic robot like Fig. 3 [17]. Furthermore, after calculating the input numbers from the X, Y, Z values, they will be calculated from the kinematic inverse formula in Fig. 3, then the output will be declarations degree_1, degree_2, degree_3 and sent to the servo AX-18a. The inverse kinematic flow chart is shown in Fig. 3.

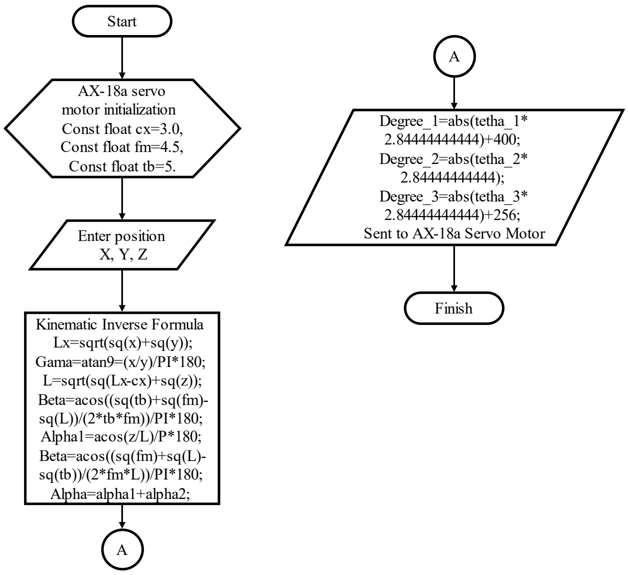


Fig. 3. Kinematic inverse formula flowchart

The sharp Analog Distance Sensor flowchart functions to find out if there is an uneven surface, the first step is to set the sharp sensor value then the sensor reads the height of the uneven surface, then the sharp sensor detects the uneven surface with a value <= 11 if this value has not been fulfilled then it will back again to the surface level reading process if yes then it will change the movement pattern of the hexapod robot on an uneven surface. The sharp Gp sensor flowchart is shown in Fig. 4.

C. Equation

The equation for the movement of the hexapod robot using the inverse kinematic method is as follows:

$$L1 = \sqrt[2]{x^2 + y^2} \quad (1)$$

Information: $L1$ = foot length of $coxa$ to $tibia$
$x = x\ coordinate$
$y = y\ coordinate$
$\gamma = tan^{-1}$
Information: γ = gamma is a fulcrum angle that functions to move the robot's legs forward and backward.

$$L = \sqrt[2]{(L1 - cx)^2 + z^2} \quad (2)$$

Information:
L = toe distance *tb* with hinges between *fm* dan *cx*
$z = z\ coordinate$

$$L = \sqrt[2]{(L1 - cx)^2 + z^2} \quad (3)$$

Information:
β = beta is an angle that serves to find a wide angle and stretch the tibia leg.
$cx = coxa$
$fm = femur$
$tb = tibia$

$$\alpha 1 = acos\left(\frac{Z}{L}\right) \quad (4)$$

$$\alpha 2 = cos^{-1}\left((fm^2 + L^2 - tb^2)/(2 \times fm \times L)\right) \quad (5)$$

$$\alpha = \alpha 1 + \alpha 2 \quad (6)$$

Information: $\alpha =$ alpha is an angle that helps the movement of the femur leg to run the up and down angle position of the leg.

D. Algorithm

The flowchart of the algorithm explains the first process, namely walking straight ahead using the invert kinematic method, until the sensor knows which is uneven. If the conditions are yes, then the robot's legs will change motion patterns to climb stairs or those that are not level. If not, then the robot will carry out the process of walking straight ahead until the sensor detects an uneven surface. After that, it goes into the research of controlling the movement of the hexapod robot for uneven surfaces, moving the leg positions 0,2,4 to the top and forward positions together, then moving the leg positions 0,2,4 to the bottom and forward positions together, movement foot position 0,2,4 to the back position, Move the foot position 1,3,5 to the top and forward position together, Then move the foot position 1,3,5 to the bottom and forward position together, Move the foot position 1, 3.5 to the rear position then the process is repeated until the process is complete [18]. Algorithm flow chart is shown in Fig. 5.

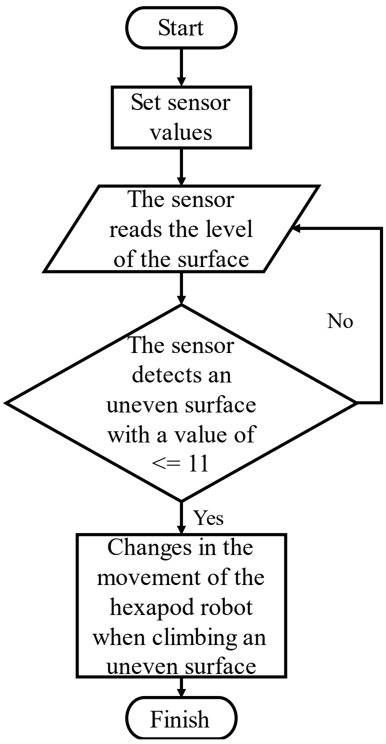


Fig. 4. Proximity sensor flow chart (sharp analog distance)

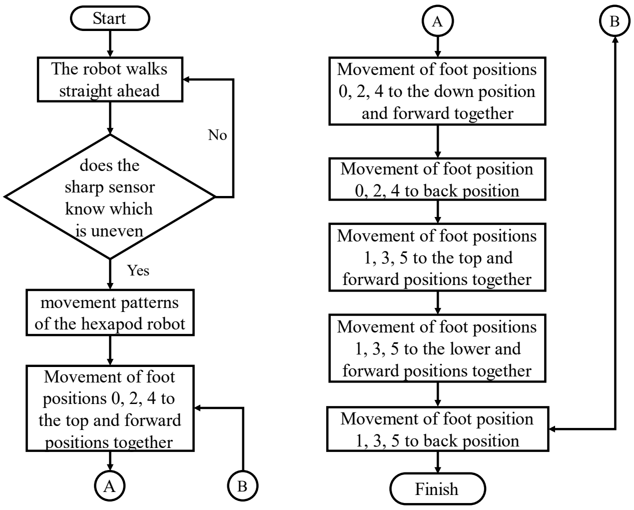


Fig. 5. System algorithm flowchart

III. Result and Discussion

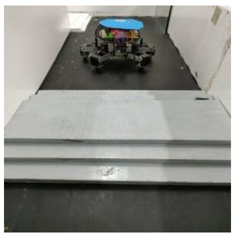
A. Sensor Testing

Data testing was carried out by means of a hexapod robot walking towards an uneven surface so that the sharp Analog Distance sensor can detect stairs or unevenflour to change the movement pattern of the hexapod robot. The sensor can read uneven surfaces automatically with calculations [19]-[20], these calculations can be seen in Predictions 1 and 2. The sensor has been programmed to function with reading the maximum value according to the sensor when it detects an uneven surface. Shown in Table 1. The data can be searched by equations 1 and 2.

$$sensorValue = analogRead(sensorIR) \quad (7)$$

$$Cm = 4192.936\ x\ (Sensor\ Value^{-1}) - 3.937 \quad (8)$$

Table 1. Sharp GP sensor testing for uneven surfaces

Sensor Value Before Surface Detection	Picture
Value :Cm:13.15| Not yet detected Value :Cm:13.10| Not yet detected Value :Cm:13.31| Not yet detected Value :Cm:13.12| Not yet detected Value :Cm:13.17| Not yet detected Value :Cm:13.11| Not yet detected Value :Cm:13.20| Not yet detected	
Sensor Value After Detected Surface	**Picture**
Value :Cm:10.09| Detected Value :Cm:9.94| Detected Value :Cm:9.94| Detected Value :Cm:9.98| Detected Value :Cm:9.91| Detected Value :Cm:9.91| Detected Value :Cm:9.98| Detected	

Based on Table 1 the results of the calculation of the Sharp Gp sensor with uneven surface readings and flat surface readings can be seen in the graph shown in Fig. 6 and Fig. 7.

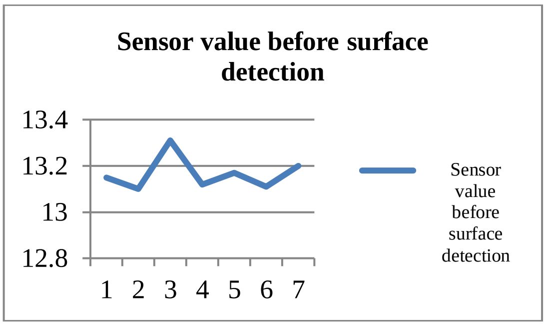


Fig. 6. Graph of sensor values before surface detection

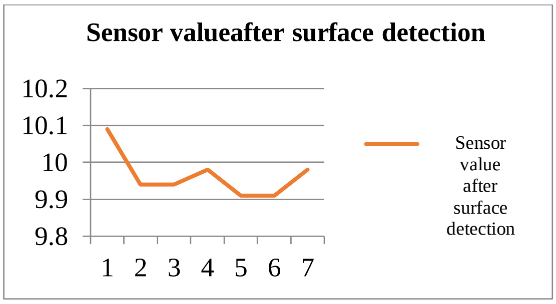


Fig. 7. Graph of sensor values after surface detection

B. Motion Testing of the Hexapod robot

Testing is carried out by recording the movement of the hexapod robot when walking in the arena track with the robot walking straight, the robot detecting an uneven obstacle, the robot when climbing an uneven surface, stairs, hollow obstacles, protruding obstacles

a. Kinematic inverse straight path testing

In testing the kinematic inverse straight path, the value of the kinematic inverse coordinate point is determined (7.5, 6.5, -5) to reach the coordinate point reaching the top point so that it can walk straight as desired, shown in Fig. 8:

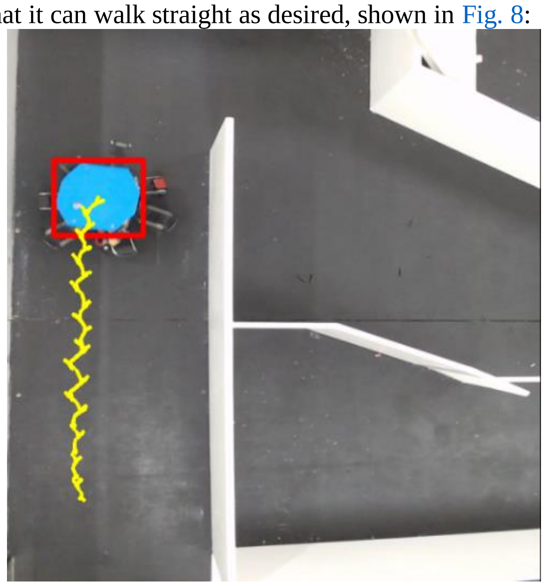


Fig. 8. Kinematic inverse straight path testing

From the test, it was found that the value of the kinematic inverse coordinate points was inputted and the results obtained were the angle values X/Gama = 40.91 Y/alpha = 153.30, Z/beta = 127.99. For the results of the straight road movement shown in Fig. 9.

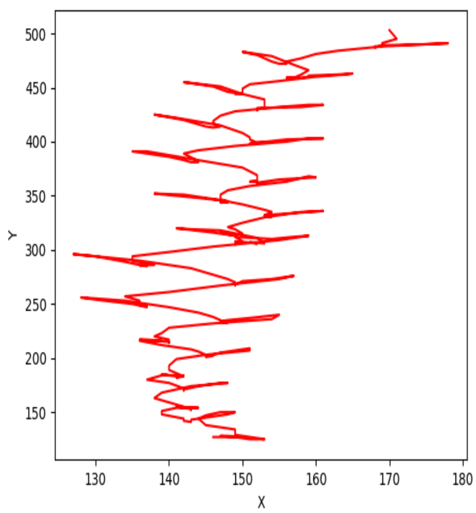


Fig. 9. Kinematic inverse straight path graph results

b. Testing the way up the uneven obstacles

In the Road Climbing the uneven obstacle test, the value of the kinematic inverse coordinate point (7.5, 7.5, -5) is determined to reach the coordinate point to reach the top point so that you can walk up the uneven obstacle as desired, shown in Fig. 9.

C. System Testing

System testing can be done after the design process is complete. System testing in this study is as follows:

1. Test walking straight ahead to find out the application of the movement method using the inverse kinematic method on the hexapod robot that has been designed, besides that to find out whether the robot can move until the hexapod robot's movement pattern changes.
2. The robot will be equipped with a Shap GP sensor which will be used to change the motion pattern of the hexapod robot.
3. Testing after changing the robot's movement pattern with the kinematic method then testing the accuracy of the robot's leg movement pattern that falls on an uneven surface.

IV. Conclusion

Based on the research results on the hexapod robot using the inverse kinematic method, it has been successfully carried out with the research results that the robot can be run on race tracks or outside race tracks. The following results of the conclusions obtained from researchers can be seen as follows.

1. The robot manages to walk straight using the inverse kinematic method.
2. The robot successfully detects uneven surfaces to change the movement pattern of the hexapod robot.
3. The robot succeeds in passing uneven surfaces such as uneven floors, stairs, perforated obstacles, perforated obstacles and bumpy obstacles using the inverse kinematic method.
4. This kinematic inverse method can control the movement of the hexapod robot's legs for uneven surfaces so that when the robot is on an uneven surface the robot's feet are at the coordinates we specify.

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