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GAIT CONTROL APPLICATIONS ON FOUR LEGGED ROBOT

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ABSTRACT

A common problem faced by four-legged robots is when they encounter obstacles that have structures that force the robot to lift its legs higher than the robot's ability limit and can disrupt the robot's balance, so it is necessary to add a gait control method. This research has resulted in controlling the movement of a four-legged robot using the wave gait control method to pass obstacles in the form of stairs and uneven floors, where the movement of the robot by lifting one leg at a time makes the balance of the robot very awake. So that the robot can make decisions if the robot encounters obstacles in the form of stairs and uneven floors, the role of the ultrasonic sensor is very decisive in reading the environment. The way for the robot to climb stairs and not fall backwards is to slide the robot's hind legs back so that each robotic footstep will form a triangle. When the robot detects the presence of a stairs, the robot will lift its legs by 50^{o,} while when it detects an uneven floor, the robot's legs will lift its legs by 40^{o}. Based on the results of research conducted with 4 experiments, namely the success of the robot in passing through the trajectory without obstacles by 100%, the success of the robot in crossing the uneven floor by 60%, the success of the robot in passing the stairs by 50%, while the success of the robot in passing the stairs and the uneven floor by 70%.

Keywords: *four legged robot, ultrasonic, gait control, stairs, uneven floor*

1. INTRODUCTION

The legged robot is one of the technologies that can be applied in industry to assist human work in conducting surveillance [1]. In addition, it can also help complete dangerous missions [2].

The legged robot structure is built using a servo motor on each leg [3]. For the movement of the legged robot, it imitates the motion system of a spider which is more flexible and more suitable for uneven terrain [4] such as rocks, stairs and *uneven floors*, so that the movement of the four-legged robot uses different movement methods to produce a robot movement mechanism, appropriate has been investigated [5].

Most cases that occur in legged robots are difficulties in identifying and passing obstacles in the form of stones, stairs and *uneven floors*, resulting in the robot's legs getting stuck. For this reason, a four-legged robot must be equipped with sensors to detect the height of the obstacle so that the robot can easily navigate autonomously to pass through the obstacle [6][7][8]. Research on the control system and the application of algorithms in the form of movement accuracy which is applied to a four-legged robot to produce a maximum movement pattern has been produced [9], so that the robot can pass through uneven terrain [10].

This research proposes a gait control method for a four-legged robot using wave gait and ripple gait. The purpose of this study is to produce a gait control system for the movement of a four-legged robot when passing obstacles in the form of stairs and uneven floors so that it can shorten the travel time to the target or finish.

2. LITERATURE

2.1 Gait Control

This four-legged robot or *quadpod* is a robot that has a leg structure like a four-legged animal, namely a cat or dog. The movement pattern of this robot is also the same as that of a four-legged animal. This legged robot has the advantages of being able to move on several rough or smooth surfaces, the robot design is slimmer than the hexapod robot and the robot is more able to maintain its balance compared to a *tripod. Quadpod* robot can use two gait controls, namely the Wave gait method and the Ripple gait method [11].

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2.1.1 Wave Gait

Wave gait is a movement control method by moving the robot's legs one by one when walking. By using this method at a time there is only one leg raised and the other three feet on the ground so that the robot is more stable when moving, but in the wave gait method This robot moves slowly, so it takes a long time to reach the target or finish [12].

2.1.2 Ripple Gait

Ripple gait is a movement control method by moving two legs at a time, the moving legs are on different sides. For example, if the front right foot moves, the back left foot also moves, otherwise when the front left foot moves, the rear right foot also moves. The use of the method *ripple gait* makes the robot move faster than the method, *wave gait* but the stability of the robot is very difficult [13].

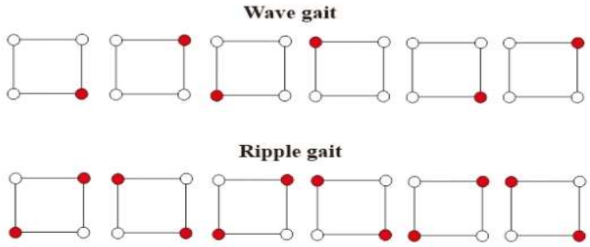

Figure 1. Illustration of the movement of a four-legged robot using the wave gait and ripple gait methods.

2.3 Servo Motor

Servo motor is a motor that is able to work in two directions where the direction and movement of the rotor can be controlled only by setting the signal duty cycle PWM on the control pin [14]. This motor consists of a DC motor, gear, potentiometer and control circuit. The potentiometer is used to determine the angular limit of the servo rotation. While the angle of the servo motor axis is set based on the width of the pulse sent through the signal leg of the motor cable. This servo motor rotates slowly, which is usually indicated by a slow rotation route but has a very strong torque due to the influence of the internal gear. This servo motor has 3 cable lines namely power, ground, and control.

Figure 2. Servo motor.

2.4 Ultrasonic

The ultrasonic sensor consists of a transmitting unit and a receiving unit. The signal is emitted by an ultrasonic transmitter with a frequency of 40 kHz – 400 kHz. The emitted signal will then propagate as a signal/sound wave with a speed of about 340 m/s. When hitting an object, the signal will be reflected by the object. After the reflected wave reaches the receiver, the signal will be processed to calculate the distance of the object. The object distance can be calculated using equation (1).

$$s = \frac{340xt}{2} \qquad (1)$$

Where s is the distance between the sensor and the object, while t is the difference between the time the wave is emitted by the transmitter and the time when the reflected wave is received by the receiver [15]. Figure 3 is how the ultrasonic sensor works.

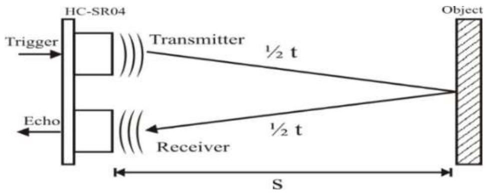

Figure 3. Ultrasonic works as a transmitter and receiver.

The calculated time starts from the moment the transmitting unit is active until the receiver circuit receives the reflected wave from the transmitter. If it exceeds a certain time limit, the receiver circuit does not receive the input signal, then it is considered that there is no obstacle in front of the robot.

3. RESEARCH METHODOLOGY

3.1 Hardware Design

System configuration on this robot to be able to pass stairs and uneven floor consists of input, microcontroller, and output. Of the three parts there are hardware and software. On the input side, there are 8sensors ultrasonic mounted on the robot body. As for the control, there is an Arduino DUE type microcontroller. For the output there is an LCD and a servo motor. The software used to program the microcontroller is using the software Arduino default.

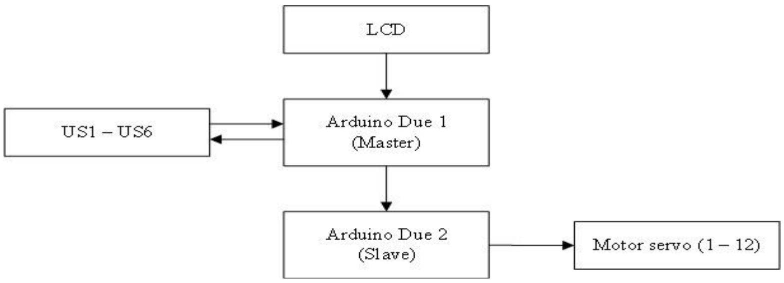

Figure 4. Hardware block diagram.

Figure 4 shows a block diagram of the system of a four-legged robot consisting of 2 parts of the microcontroller, namely *slave* and master. The slave *is* used to control the output of the robot drive in the form of a servo motor using the Arduino DUE microcontroller. While the master is used as the control center of the robot which is directly connected to the ultrasonic sensor. Communication on these two microcontrollers uses serial communication.

3.2 Robot Leg Structure

Structure of this legged robot consists of three main parts namely the coxa, femur, and tibia. Coxa or hips have a function to support body weight when standing or walking. The fremur or thigh bone has a function as a connector between the coxa and the tibia or shin bone. The fremurs provide support to the entire skeletal structure, thus assisting in foot movement. The tibia functions to form a hinge with the thigh bone called the knee, allowing the robot to walk, run and climb stairs. Figure 5 is an analogy of the legs on a four-legged robot that is designed

Figure 5. Analogy of legs on a robot.

3.3 Software Design

The system design on a four-legged robot is made with the aim that the robot can pass several obstacles in the form of stairs and uneven floors using the wave gait control method. The movement of this legged robot is based on the performance of ultrasonic sensors that provide environmental readings. At the first time the robot goes straight forward until the robot encounters an obstacle and when the robot encounters an obstacle the robot will perform its actions according to what was previously ordered. Figure 6 is a flowchart of the robot movement system.

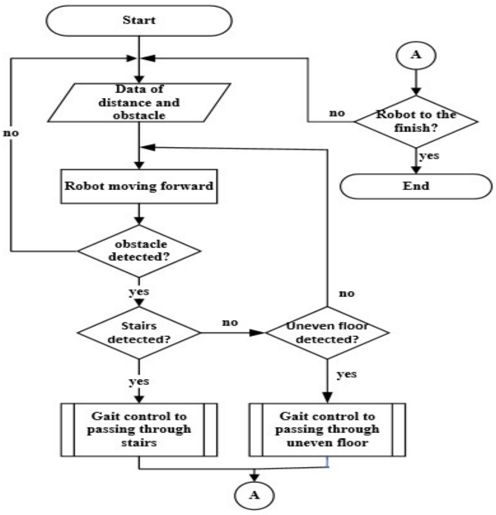

Figure 6. *Flowchart* of robot movement.

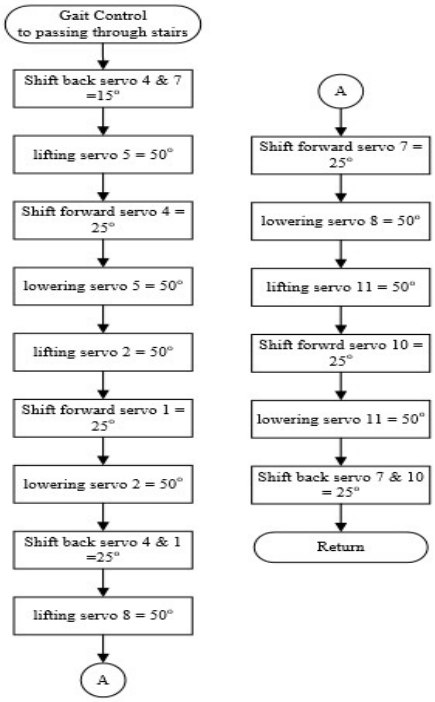

Figure 7. Flowchart for gait control to passing through the stairs.

3.3.1 Gait Control to Passing through Stairs

When the robot is walking and the ultrasonic sensor reads in the track or track there is a ladder in front of it. Then the robot will advance until the front foot touches a stairs first, after which the robot will lift its foot according to the height of the stairs. After the robot has reached the top of the stairs, the robot will change its movement to go down the stairs by lowering its legs. The flowchart for the gait control program through the stairs is shown in figure 7.

3.3.2 Gait Control to Passing through Uneven Floor

If the robot detects an uneven floor then the robot will lift the right rear leg by 40^o, then change the right front leg is lifted by 40^o, after that the left rear leg is lifted with a height of 40^o, then the left rear leg is lifted by 40^o and the robot's speed will decrease compared to walking straight. After the robot has successfully climbed the uneven floor, then the robot will go down the uneven floor. By lifting the leg by 35^o and the robot's speed is slower. Figure 8 shows a flowchart of gait control to across the uneven floor.

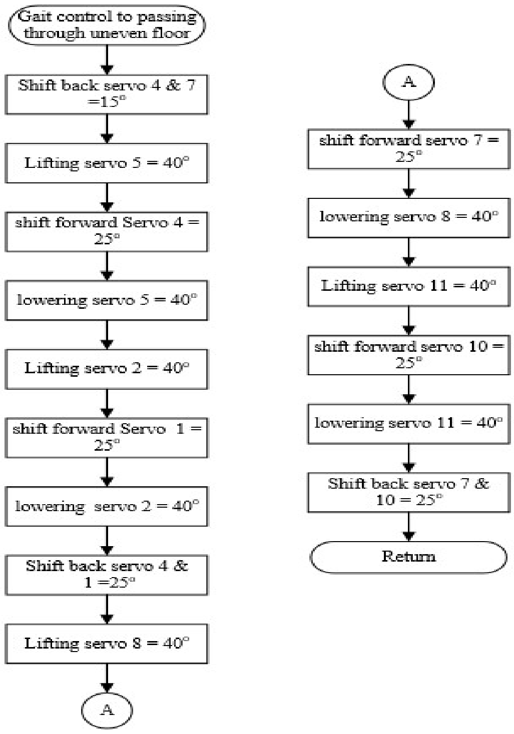

Figure 8. Flowchart of gait control to passing through uneven floor.

4. RESULT AND DISCUSSION

4.1 System Testing

The testing in this four-legged robot research includes ultrasonic sensor testing and robot travel time testing. Testing the robot's journey to pass stairs and uneven floors which are 110 cm apart. The experiment was carried out with 4 trials with different obstacle shapes. System testing is divided into 3 tests, namely: (1) running without obstacles; (2) the robot passing through the stairs; (3) the robot passing through the uneven floor. The test of this system is as shown in Figure 9.

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Figure 9. Robot testing trajectory.

4.2 Gait Control Testing Without Obstacle

The gait control test of the robot without any obstacle was carried out 10 times. Where the length of the track used in this experiment is 110 cm. In the experiment running without this obstacle the success rate of the robot is 100% successful. The results of this experiment can be seen in table 1.

Table 1. Testing the robot without obstacle using the method wave gait.

Trial to	Robot travel time (s)	Robot success	Robot's Arrive
1	181	succeed	Finish
2	183	succeed	Finish
3	183	succeed	Finish
4	182	succeed	Finish
5	184	succeed	Finish
6	181	succeed	Finish
7	181	succeed	Finish
8	180	succeed	Finish
9	182	succeed	Finish
10	183	succeed	Finish

4.3 Gait Control Testing passing through Uneven Floor

The gait control testing of this robot uses a track length of 110 cm, where the robot runs straight and there are 2 floors in front of it uneven with different shapes. Where one uneven floor is flat while the other is in the form of triangular waves. The data from the gait control test can be seen from the travel time of the robot and its success rate as shown in table 2.

Table 2. The travel time of robot to passing through uneven floor.

Trial to	Robot travel time (s)	Robot success	Robot's Arrive
1	41	failed	Uneven floor 1
2	210	succeed	Finish
3	52	failed	Uneven floor 1
4	131	failed	Uneven floor 2
5	206	succeed	Finish
6	207	succeed	Finish
7	207	succeed	Finish
8	56	failed	Uneven floor 1
9	206	succeed	Finish
10	207	succeed	Finish

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From the robot's experiment when it crosses the uneven floor of In 10 experiments, there were failed experiments and the failed was due to inaccurate ultrasonic sensor readings so that the gait displacement was not correct so that the robot's feet were stuck on obstacles on the track, this makes the robot unable to continue its journey to the finish point.

In experiments 1, 3, and 8 the robot failed on the uneven floor in the form of waves. Meanwhile, the failure of the robot in the 4th experiment occurred on uneven floor the flat. So most robot failed to occur on the uneven floor in the form of waves which result in inaccurate ultrasonic sensor readings at the obstacle distance. The percentage of success in testing the robot in crossing the uneven floor is 60% success.

4.4 Gait Control Testing Passing through Stairs

The gait control testing to passing through stairs uses a track length of 110 cm, where the robot goes straight and there are obstacles in front of 2 stairs of the same shape and size. The travel time and success rate of the robot in climbing two stairs can be seen in table 3.

Table 3. The robot's travel time to passing throughover stairs.

Trial to	Robot travel time (s)	Robot success	Robot’s Arrive
1	42	failed	First stairs
2	47	failed	First stairs
3	210	succeed	Finish
4	42	failed	First stairs
5	211	succeed	Finish
6	212	succeed	Finish
7	129	failed	Second stairs
8	131	failed	Second stairs
9	212	succeed	Finish
10	211	succeed	Finish

In the experiment of the robot when it passed the stairs that had been carried out 10 times, it could be seen that there was a failed in the experiment. The failed was due to inaccurate ultrasonic sensor readings so that the movement would be wrong which resulted in the robot getting stuck on the stairs obstacle in front of it. So the robot can not continue until the finish line. The percentage of success of the robot in passing the stairs is 50% successful.

4.5 Gait Control Testing Passing through Stairs and Uneven Floor

The gait control testing to over stairs and uneven floor uses a track length of 110cm, where the robot runs straight and there are two obstacles in the form of stairs and an uneven floor. Gait control test data when passing stairs and uneven floor are shown in table 4.

Table 4. The Robot travel time to over stairs and uneven floor.

Trial to	Robot travel time (s)	Robot success	Robot’s Arrive
1	203	succeed	Finish
2	50	failed	Uneven floor
3	45	failed	Uneven floor
4	196	succeed	Finish
5	198	succeed	Finish
6	196	succeed	Finish
7	126	failed	Stairs
8	201	succeed	Finish
9	200	succeed	Finish
10	201	succeed	Finish

In the last experiment the robot was required to pass through two obstacles, namely stairs and uneven floor. In this experiment there was also the same failure in the previous experiment. Where the ultrasonic sensor readings are inaccurate, so that the movement of the robot's legs is not correct and causes the robot's feet to get stuck on obstacles on the track. The success rate of the robot when passing through obstacle stairs and uneven floor is 70%.

5. CONCLUSION

The control of the movement of the four-legged robot using the wave gait method through obstacles in the form of stairs and uneven floors to produce a robotic balance has been produced in this study. Where based on the results of the algorithm design on this legged robot, when the ultrasonic sensor detects the height of the stairs, the robot will lift its legs by 50°, while when the ultrasonic sensor detects an uneven floor height, the robot will lift its legs by 40°. Based on the results of research conducted with 4 experiments, namely the success of the robot in crossing the trajectory without obstacles by 100%, the success of the robot in crossing uneven floors by 60%, the success of the robot in passing stairs by 50%, while the success of the robot in passing stairs and floors that are uneven by 70%.

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