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Editors:

Irawan

Hendri Irawan

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Efficient PID Controller based Hexapod Wall Following Robot

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Abstract— This paper presents a design of wall following behaviour for hexapod robot based on PID controller. PID controller is proposed here because of its ability to control many cases of non-linear systems. In this case, we proposed a PID controller to improve the speed and stability of hexapod robot movement while following the wall. In this paper, PID controller is used to control the robot legs, by adjusting the value of swing angle during forward or backward movement to maintain the distance between the robot and the wall. The experimental result was verified by implementing the proposed control method into actual prototype of hexapod robot.

Keywords— gait, hexapod, mobile robot, PID controller, wall following

I. INTRODUCTION

The locomotion control in mobile robots, such as wheeled robots [1]–[3] and walking robots [4]–[6], is an important task in some industrial applications. Unlike wheeled robots, legged robots have an ability to maneuver on different terrain, especially on uneven landscapes [7]. Among the various types of legged robots, a six legs robot configuration, known as hexapod robot, shows the advantages of more static stability and balance during walking, compared to biped and quadruped robots, due to the presence of three footrests while walking.

There are two main issues in controlling the movement of a hexapod robot, that is the coordination of the legs for forward movement and legs control for proper turning motion. Some evolutionary learning approaches has been proposed to generate the gait pattern to address the first issue [5], [8]–[11]. For the second issue, most studies have focused on gait control for trajectory following based on a predefined forward gait pattern. Inverse kinematics is the most popular approach to determine the control of degree of each leg [12]–[14]. This paper focuses on the second issue. The hexapod robot controller is designed to complete the wall-following task. To complete the task, a proportional-integral-derivative (PID) controller is proposed to improving the speed and stability of the hexapod robot movement while following the wall.

Several studies have been proposed in solving the wall following control problems of the mobile robot [1], [3], [23], [15]–[22]. Fuzzy logic controller (FLC) has become the most popular controller which is used to control the behaviour of the mobile robot movement. Some application of FLC for controlling the wall following task on mobile robot can be found on reference [5], [18]–[20], [23]–[26]. However, the FLC approach still has some limitation in controlling the mobile robot while conducting the wall following task.

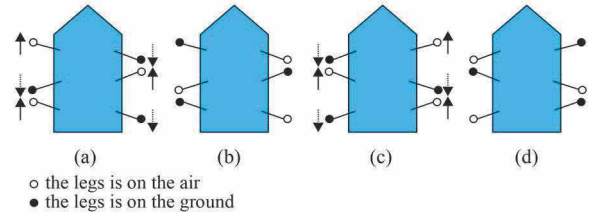


Fig. 1. The state of straightforward movement of hexapod robots

In the other case, the PID controller has been used to increase the stability and decrease the steady-state error [27]. PID controller is also the most popular techniques which are used in non-linear systems [28]. Many cases of mobile robots have used the PID controller to improve their performance [29]–[36]. In the case of wheeled based mobile robots, the PID controller is easier to implement because they are no need a complex control for actuator movement like a multi-leg robot.

In this paper, the design and implementation of a PID controller for the hexapod robot is proposed to improve its performance while conducting the wall following task. To verify the performance of the proposed controller, the anticipated algorithm is implemented and tested on an actual prototype of the hexapod robot and compared with the classic FLC approach.

This paper is organized as follows. Section 1 dealt with a brief introduction on hexapod robots and its various control algorithm methods. Section 2 describes the method for coordination control of hexapod robot gait. Section 3 introduces the design of PID control for wall following behaviour on hexapod robot. Section 4 presents an experimental result. Finally, section 5 presents the conclusion remarks.

II. HEXAPOD GAIT COORDINATION CONTROL METHOD

The hexapod robot has several advantage over another multi-legs robot, such as biped and quadruped robot [7], because it has more stability and balances while moving. To maintain the stability and balance of the hexapod robot, three legs should be always on the ground. The hexapod robot must have a minimum of two degrees of freedoms (DOF) per legs to complete the walking task. One DOF is used to control up or down motion, and the other DOF is used to control forward or backward motion. The optimal gait for forward movement can be controlled using a four-state finite state machine (FSM) [5]. Fig. 1. Shows the states of the six legs robot controlled using the FSM.

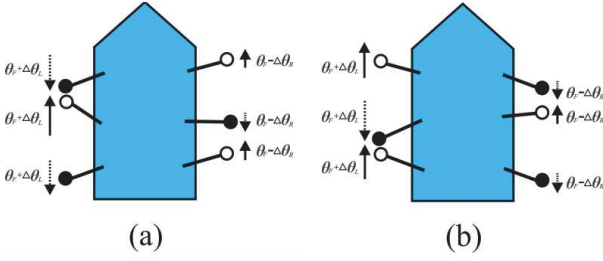


Fig. 2. The state of robot movement to make right turn

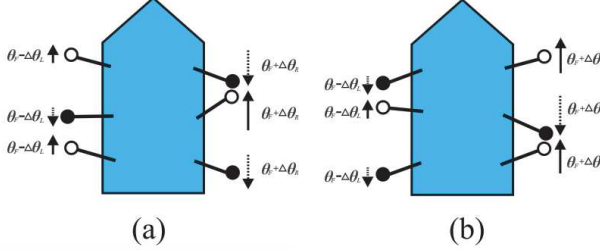


Fig. 3. The state of robot movement to make left turn

To ensure that the movement of the robot is straightforward, the swing angles (θ_F) of all legs are must be same in all states. Four states details of the legs control in each state are following:

- State 1 [fig. 1(a)]: Right-front, right-back, and left middle legs are the support legs. The actuator swings this leg backward, and the ground provides a reactive force to move the robot forward with a slight turn to the left side. The other three legs are on the air, with the actuator swinging that forward.
- State 2 [fig. 1(b)]: Actuators change the support legs in each state to support and up legs, respectively. That is, the up or support state of each leg in stage one is changed to the second state as seen in fig. 1(b).
- State 3 [fig. 1(c)]: The actuator swings three legs backward. The ground provides reactive power to move the robot forward with a slight turn to the right side, in compensation for turning left in state one; as a result, the robot moves straight forward. Then the actuator swings the other three legs forward.
- State 4 [fig. 1(d)]: The actuators change the support and up legs in state one to support and up legs, in this state. State one follows this state, and the FSM controls the robot moving straightforward.

In additional to the control of forward movement, it is also important to control the direction of the robot when carrying out the wall following tasks.

In this paper, the base algorithm that is used to coordinate the robot straightforward and turning motion is the same, the difference is only in the distance of forward or backward swing angle on the robot legs when making a turn so that the robot movement is expected to be controlled more easily. To make a right turn, the robot increases the swing angle of the left legs ($\Delta\theta_L$) and decreases the swing angle of the right legs ($\Delta\theta_R$). To makes a left turn, the robot increases the swing

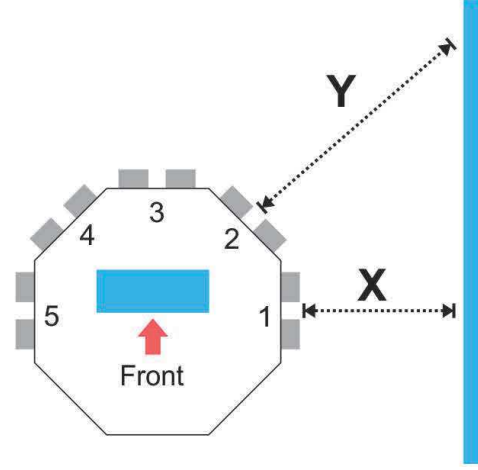


Fig. 4. Distance sensor configuration to measure the error

angle of the right legs ($\Delta\theta_R$) and decreases the swing angle of the left legs ($\Delta\theta_L$). Fig. 2. shows the states of legs swing angle change to make a right turn, and Fig. 3. shows the states of legs swing angle change to make a left turn.

As the autonomous robot, the hexapod robot must have an ability to determine the proper value of $\Delta\theta_R$ and $\Delta\theta_L$ automatically. To achieve this, the PID controller is proposed in this paper to control the movement of the hexapod robot while following the wall.

III. DESIGNING PID CONTROL FOR WALL FOLLOWING TASK OF HEXAPOD ROBOT

This section described the design of PID controller to end the wall following task of the hexapod robot. The objective of the proposed PID controller in this paper is to improve the speed and stability of the hexapod robot movement while completing the wall following task.

Basically, the PID is a three-term controller that is used to increase stability and decrease steady-state error. The discrete function of the PID controller is given by:

$$PID = K_p e_k + K_i T \sum_0^k e_k + \frac{1}{T} K_d (e_k - e_{k-1}) \quad (1)$$

Where K_p is the proportional gain, K_i is the integral gain, K_d is the derivative gain, T is the integral time constant and e_k is the accumulation of error parameter.

In the case of a wall-following task, the PID controller can be implemented by configuring the distance of sensors to accumulate the error parameter. Following the fig. 4. the error is given by:

$$PV = \min(X, Y*0.5);$$

$$Error = SP - PV; \quad (2)$$

Where X is the distance between the sensor number 1 and the wall, Y is the distance between the sensor number 2 and the wall, SP is the set-point parameter.

To get the proper values of $\Delta\theta_R$ and $\Delta\theta_L$, the error parameter that has been obtained from Equation (2) is substituted in the **PID** transfer function Equation (1), value of PID is estimated and used with the base swing angle (θ_F). Thus the value of swing angles for left and right legs are obtained as;

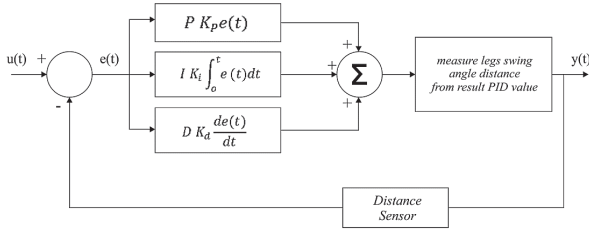


Fig. 5. Proposed PID controller diagram

$$\Delta\theta_L = \theta_F - \text{PID} \quad (3)$$

$$\Delta\theta_R = \theta_F + \text{PID} \quad (4)$$

The block diagram of the proposed PID controller in this paper is shown in fig. 5.

Finally, the method to determine the value of K_p , K_i , and K_d gain parameters of the PID controller is using the *trial and error* method. The tuning value is starting from 0 until 20 for each gain parameters. The best value of the PID gain parameters that we get is shown in table 1.

TABLE I. THE BEST PID VALUE FOR THE PROPOSED CONTROLLER

Gain parameters	K_p	K_i	K_d
Value	18	16	19

IV. EXPERIMENTAL RESULT AND DISCUSSION

To verify the performance of proposed PID controller, the algorithm was implemented to an actual prototype of the hexapod robot. Fig. 6. showed the real prototype of the hexapod robot that had been used. The dimension of the robot is, 23,5cm x 24,5cm x 25cm, for the length, width, and height, respectively. The main controller of the robot was using Arduino Due. The main of the robot actuator used digital Dynamixel AX-18A smart servo with 18 DOF. The sensor used HC-SR04 ultrasonic sensor with the configuration of the sensor shown in fig. 4.

Experimental sets were divided into two steps, first was balance and stability test and the second was speed test. For the balanced and stability test, the performance of robot was tested on the unique wall pattern. For the speed test the robot testing on a straight wall with 150cm length. The proposed controller method was compared with a conventional wall following method using FLC approach [37].

TABLE II. SPEED TEST RESULT

Attempt	Time (s)	
	PID	FLC
1	5,27	5,59
2	4,99	5,99
3	4,94	5,85
4	5,14	6,18
5	5,20	6,26
Average Time (s)	5,108	5,974
Average speed (cm/s)	29,37	25,11

As shown in fig. 7. the line trajectory of the hexapod robot while following the wall with the proposed PID

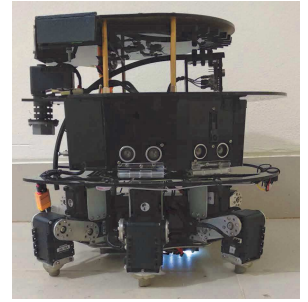
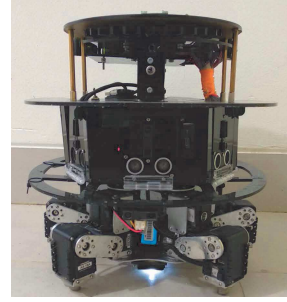


Fig. 6. Hexapod robot prototype

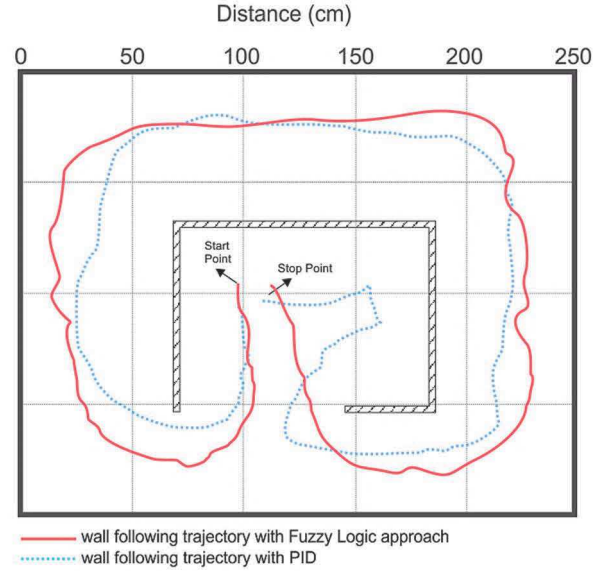


Fig. 7. Line trajectory of tested robot while following the wall

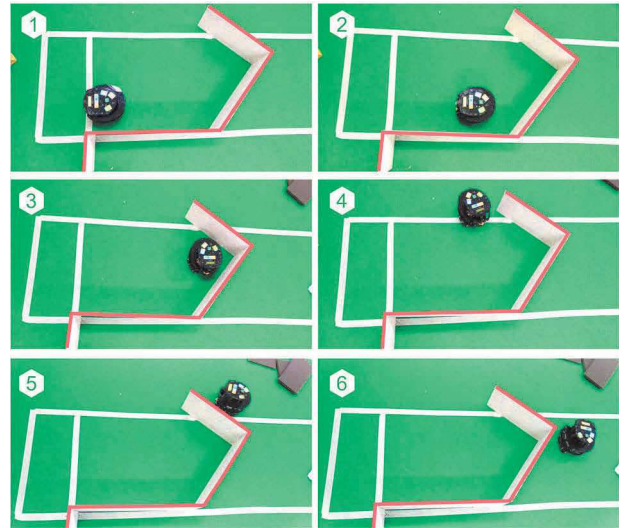


Fig. 8. Snapshot of the real hexapod robot while testing on unique environment

controller experienced more balance, straight, and close to the wall, when compared to the wall following algorithm using FLC method. That is the effect the steady-state error decrease and balance increase of a PID controller. Finally, speed test is performed on the straight wall, with 150cm length and was conducted by 5 attempts to get the average speed of the proposed method. As seen in table 2. speed of the hexapod robot while using the PID controller algorithm

was faster than using the conventional wall following algorithm.

In industrial application, the hexapod robot wall-following behavior can be used to move an object along the wall with an uneven floor. In other cases, hexapod robots also can be used to handle the emergency case, such as fire cases, natural disasters, etc., which requires a vehicle with the ability to move along the uneven landscapes that can't be passed by cars or another wheeled vehicle. Fig. 8. showed the snapshot of successful experimental of the hexapod robot while testing on a unique environment.

V. CONCLUSION

This paper had proposed a PID controller to improve the wall following performance of a hexapod robot. The PID controller is proposed to control right legs and left legs swing angles for the forward and backward movement. The proposed control method was verified by direct implementation to the actual hexapod robot. The result showed that the proposed PID controller can be used to improve the performance of the hexapod robot while conducting the wall following task.

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