Jurnal
Teknologi

Full Paper

DEVELOPMENT AND EVALUATION OF TWO-PARALLEL CRAWLER ROBOT BY USING PROPORTIONAL CONTROLLER

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Article history
Received
15 May 2015
Received in revised form
1 July 2015
Accepted
11 August 2015

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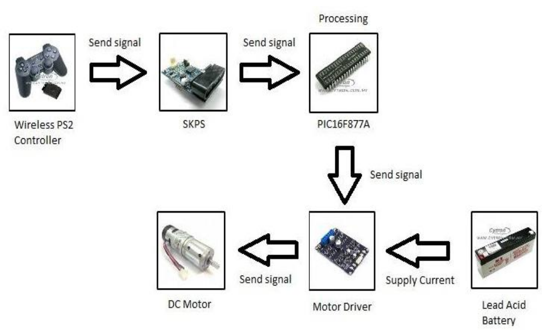
Graphical abstract



Abstract

Nowadays, the crawler type robots are widely used in rescuing and inspection missions. However, most of the existing crawler type robots available now are not moving consistently in one direction. This project aim on design and develop a crawler type robot which can pass through several types of terrain as well as to analyze and evaluate the performance of developed crawler type robot in term of its accuracy and repeatability by using Proportional (P) controller. Moreover, the terrains involved in this project are focused only on flat surface and rough surface respectively. The experiments are conducted in two methods which are lab test and field test. Lab test is conducted on flat surface while field test is conducted on rough surface. Then, the performance (accuracy and repeatability) of both experiments will be measured. As the results, the experiments which have been conducted on both methods by using Proportional (P) controller are implemented successfully.

Keywords: Crawler robot, proportional controller, irregular terrain

1.0 INTRODUCTION

Nowadays, mobile robots really play a significant role in our daily lives because it can assist us to solve the problems which cannot be solved directly from human beings. Besides that, it could also reduce the probability of human beings to get injured. Therefore, a research on mobile robots should be further studied in order to improve our future quality of life [1]. There are variety types of locomotion available for a robot to move and crawler is one type of it. Crawler type mechanism can be applied on various terrains, this is the reason why human is using crawler type robot to do the dangerous tasks in extreme condition such as rescuing and inspection missions.

Japan was recognized as one of the advanced countries nowadays due to its rapid development of technologies. But unfortunately, an unwanted incident occurred on March 11, 2011. The earthquake with Richter magnitude scale of 9.0 causes a tsunami which hit the Tohoku area in Japan. As a result, several nuclear plants were damaged and the radioactive materials were spread out widely nearby those areas. The extreme situation makes the rescue and inspection missions more difficult to be performed at that time due to high radiation environment. Therefore, they decided to use mobile robots to perform the tasks instead of human beings because human cannot be exposed to highly radioactive materials for long period of time.

The statistics of human and economic losses in Japan due to the disasters that happened since year 1980 to 2010 is increased. It shows that 157 of events were occurred within these 31 years and 8568 people were killed. Average people killed per year are about 276 people. However, the economic damage is about 208 billion US dollars over 31 years of natural disasters. There were nearly 6.7 million US dollars of economic damage per year in Japan due to the disasters [2].

S. Yokota *et al*., have done the researched about leg-type crawler robot on irregular terrain. They have proposed "leg-type crawler" mechanism for their robot which consists of crawler mechanism and walking mechanism. Therefore, it can switch the moving modes according to the terrain. However, it consists a lot of motors which could need a huge power supply for the operation. Therefore, the number of motors required need to be taken into consideration when design the crawler robot. Besides that, it takes time when climbing the stairs [3-4].

In addition, K. Tadakuma *et al*. mentioned about the omni-crawler with circular section. They have designed a new mechanism for the crawler type robot based on the concept of omni-directional mobile robot. With a conventional crawler robot, it has to turn round repeatedly to enter a narrow space. However, this kind of crawler type robot is differed from the conventional crawler robot. It can make a sideways movement easily, so it does not require too much energy to make the turning movement. Therefore, the energy loss can be greatly reduced by using this mechanism. Besides that, it could also perform step climbing, moving on and inside the pipe and moving on soft grounds [5].

Furthermore, J. Nagase, K. Suzumori and N. Saga have done the cylindrical crawler robot using worm rack mechanism. They have claimed that cylindrical crawler robot is able to move in confined space such as under rubble or thin pipe compared to conventional crawler robots. However, it can only move in forward and backward directions, but not in lateral movement. Omni-crawler mechanism actually can be implemented in cylindrical crawler unit but it is quite difficult due to its complicated structure [6]. Besides that, T. Yamawaki, T. Omata and O. Mori proposed the parallel mechanism on mobile robots with 4 and 5 degree of freedom in their study. They did the integration of parallel mechanism with the crawler mechanism in mobile robot. The combination of these two mechanisms brings advantages such as move over the vertical bump by controlling its center of gravity and carrying a load by transforming its shape [7].

In the paper written by G. P. Lan, S. G. Ma and K. Inoue, they have proposed the crawler robot for irregular terrain purpose. They introduced a rotatory crawler mechanism for mobile robot in order to move on irregular terrains. Normally crawler-type robots are better than wheeled or leg-type robots because it has off-road capability. Planetary gear reducer was used in this invention because it can provide two different outputs with one actuator only [8]. In addition, crawler type mechanism is kept improving so it can be applied on various type of terrains with better performance. However, the crawler type robot is not easy to be developed because it requires the use of fundamental mechatronics engineering knowledge, especially on irregular terrains. Most of the existing crawler type robots available now are not moving consistently in one direction. In other words, it cannot move according to our desired direction properly.

In other words, the speed of both motors is different from each other even though the output power for both motors is the same, which means the motors speed for both side are not synchronize together. Besides that, it might be due to the miss-alignment of the crawler belt. As a result, the robot will move slightly deviate from the desired route. If this condition is still persisting, then it might affect the overall performance and efficiency of the robot and also might bring a hazard to human. Therefore, it needs to be improved its accuracy and repeatability or maintain the speed for both sides of motors during the operation of robot. Some studies have been done to implement the control system such as PID controller or PSO algorithm or Fuzzy algorithm in the system is done [9-16]. The study on the obstacle detection and navigation system for the crawler robot to be fully autonomous also been done [17-22].

This project aim on design and develop a crawler type robot which can pass through several types of terrain as well as to analyze and evaluate the performance of developed crawler type robot in term of its accuracy and repeatability by using P controller. Here, the only P controller is used in order to simplify the developed system with simple method and low cost. Moreover, the terrains involved in this project are focus only on flat surface and rough surface respectively. The experiment conducted here consists of two methods which are lab test and field test. Lab test is conducted on flat surface while field test is conducted on rough surface. Both of the experiments measure the performance (accuracy and repeatability). As the results, the experiment of crawler robot is conducted on both methods which are lab and field test and the P controller are implemented successfully.

2.0 DEVELOPED CRAWLER ROBOT

2.1 Robot Construction

Figure 1 shows the conceptual design of crawler type robot. This crawler type robot design basically consists of four main items which are direct current (DC) motors, crawler belts, pulleys and body structure. The body structure of the crawler type robot was constructed using L-bar or angled bar which is made of aluminum material. The total weight of this crawler robot is 3.7 kg and the dimension is 470(L) x 315(W) x 160(H) (mm). Figure 2 shows the developed crawler robot by applying the conceptual design. However, the body cover of the robot was made using transparent PVC sheets. The purpose of using transparent PVC sheet is to give a clear visualization inside the robot. Therefore, it is easier for the troubleshooting task. Besides that, a plastic pulleys were used instead of using metal pulley because plastic material is much lighter than metal. The last component was the crawler belt, which using rubber material because it can provide a sufficient friction and grip force to make the robot moves and climbs the stairs without slippage.

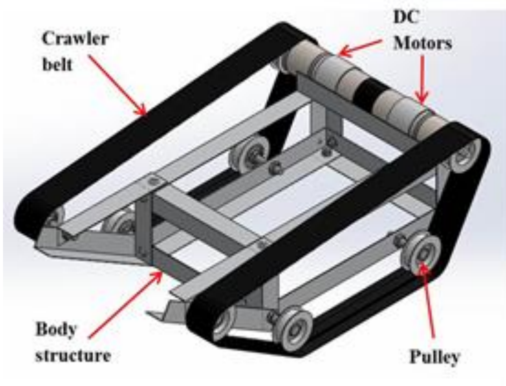


Figure 1 Designed crawler robot

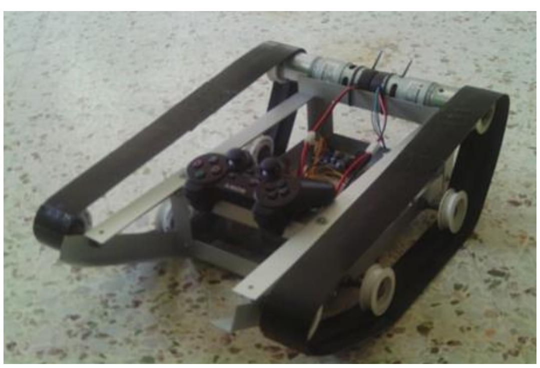


Figure 2 Developed crawler robot

2.2 System Configuration

In order to make the developed crawler robot can be run successfully, the system configuration which is illustrated such in Figure 3 is implemented. Here, the wireless PSR controller is used just to give the straight run command to the crawler robot. In other words, the PS2 is function like a switch to the crawler robot. Then, the input signal form the wireless PS2 controller receives by controller receiver (SKPS module) and processed by using PIC microcontroller (PIC16F877A). Then, PIC will send the signal to the motor driver in order to drive both of DC motor for left and right motor. All the system are powered by 12V (2300mAH) Sealed Lead Acid battery as a power supply. Table 1 shows the specification of the DC geared motor which is used in the developed crawler robot.

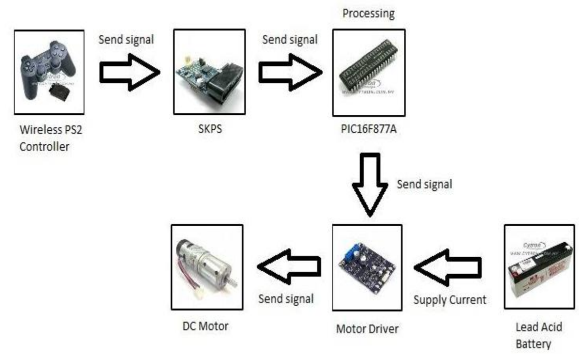


Figure 3 System configuration

Table 1 Specification of DC geared motor

Descriptions	Specification
Voltage	12V DC
Torque	1200 mN.m
Speed	24 RPM
Current	0.9 A
Gear ratio	264:1
Encoder Output	1848 pulses per rotation, single channel output

2.3 Proportional Controller

In order to compensate the error which are occurred when conducting the experiment, the control system by using proportional controller (P controller) is proposed. The principle of using P-controller for this robot is shown in Figure 4. From this block diagram, the speed of slowest motor would be the desired input or reference value for the system. An encoder could be used to determine or read the speed of the motor. Basically, the pulse width modulation (PWM) is generated by PWM port inside the PIC microcontroller. The value of the PWM signal also can be set through programming and the the duty cycle will be implemented to the DC geared motor. The rotational speed of the DC geared motor will be generated depend on the set PWM value in the programming downloaded.

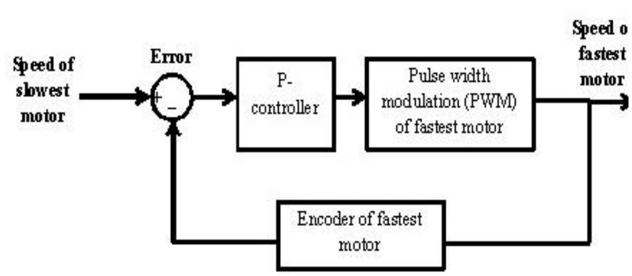


Figure 4 Block diagram of P-controller

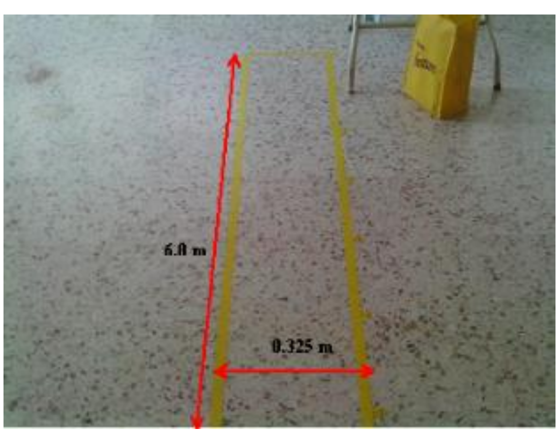
Meanwhile, the encoder of fastest motor would be read the speed and provide feedback into the system. The difference between the desired value and actual value would be the error for the input of P-controller. The error would be converted to PWM by Kp gain in P-controller. Therefore, a new PWM will be generated to control the speed of the fastest motor. In other words, the fastest motor would be slow down to achieved same speed as the slowest motor. By using this method, the robot could be achieved better performance in terms of its accuracy and repeatability by moving toward desired direction without deviate too much from its desired route.

3.0 EXPERIMENTAL SETUP

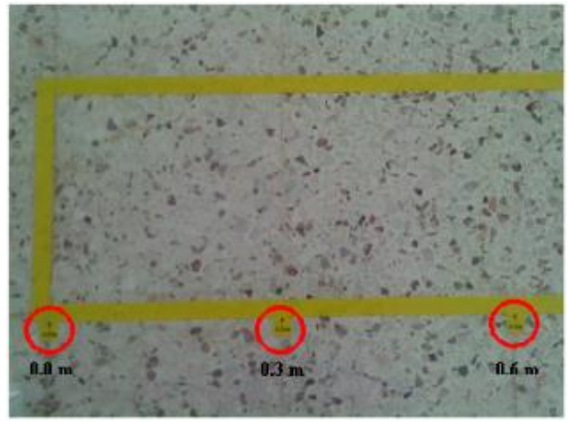
In project evaluation phase, the project will be evaluated based on its performance in term of its accuracy and repeatability. The design parameters would be the speed of the robot, while the performance parameters would be the accuracy and repeatability. The methodology used for this research or project was the experiment which consists of lab test and field test. Lab test was conducted on flat surface while field test was conducted on the rough surface.

3.1 Laboratory Test (Regular Terrain)

In order to measure the accuracy and repeatability of the robot's movement, a track or a reference line is needed to perform this test. Therefore, a 6 meter long and 0.325 meter wide yellow line track was setup on the flat surface floor using yellow tape as shown in Figure 5. The purpose of using yellow line as the reference line is due to its contrast of the colour. Yellow is the most visible colour from a certain distance if compared to other colours. Therefore, measurement is taken easily from this yellow reference line. Then a measurement along one side of the track was written down for every 0.3 meter interval using measuring tape and permanent marker pen. In other words, there will be 20 intervals along this yellow line.



(a) Vertical view



(b) Horizontal view

Figure 5 Field setup on flat terrain

Next, the robot was programmed to 25% of robot's full speed (PWM=64). The value of PWM=64 which is mentioned is referred to the value of PWM which will be set in the program of microcontroller. The developed crawler type robot was placed on the long yellow line track at starting point (0.0 m). The right hand side of the crawler belt of the robot must be placed in line with the yellow line to calibrate the measurement at the beginning. The purpose of this approach is to eliminate any unwanted error that occurs at the beginning of this experiment. Finally, the robot was then started to move using PS2 controller and stopped at each 0.3 meter interval until it finished at the end of the track (6.0 m). The deviation of the right hand side crawler belt from the yellow line track was measured using ruler and recorded for every 0.3 meter interval. The above steps were repeated for three times to get the average values so the reliability of the data will be higher. After finished with 25% of the robot's full speed, the experiment was continued with 50% (PWM=128), 75% (PWM=192) and 100% (PWM=255) of robot's full speed. After that, P-controller with different values of Kp was tested to the robot to figure out which value of Kp is most suitable to compensate the error. The speed level of the robot using for this test was 100%. The robot was moved from starting point until the finishing point and the deviation error data was collected to study the relationship between Kp value and the deviation error. The most suitable Kp value will be chosen for the next experiments.

3.2 Field Test (Irregular Terrain)

Moreover, the field test is conducted to study the performance of the fabricated crawler type robot in terms of its accuracy and repeatability on irregular terrain. Besides that, its goal also to analyse the data collected from the experiment for further improvement. A suitable irregular terrain was found at outdoor as shown in Figure 6. The irregular terrains could be the grass, stone or road. But in this case, the grass terrain was chosen and certain area of this irregular terrain which is suitable for this experiment was selected. Then the initial point and desired final point was marked on the irregular terrain and the distance between two points was measured using measuring tape as shown in Figure 6. The distance between two points was assigned to 1 meter. The developed crawler robot needs to finish the course with success by follow the reference line with less error.

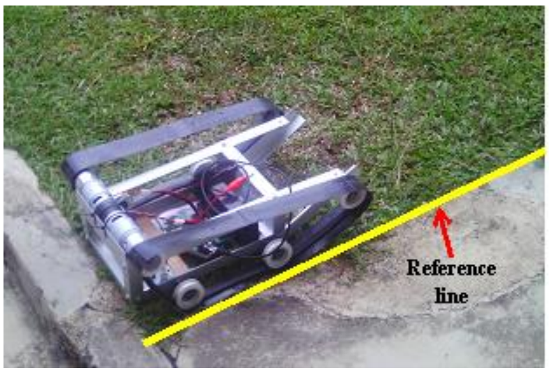


Figure 6 Field setup on irregular terrain

Next, the robot was programmed with 100% of robot's full speed (PWM=255) first before conducting the experiment. The fabricated crawler type robot was then placed on the initial point as shown in Figure 6 and it was started to move to the desired final point using PS2 controller. The crawler belt of the robot had to be placed in line with the reference line to eliminate unnecessary error at the beginning of the experiment. After the robot was reached the desired final point, then the deviation error was measured from the reference line using measuring tape and the reading was then recorded. The above steps were repeated for 10 times to get the average values so that the reliability of data is higher.

4.0 EXPERIMENTAL RESULTS

In order to evaluate the validity and the performances of the developed crawler robot, some experiments have been conducted like what have been mentioned in previous section. Figure 7 shows the deviation error of the robot's movement is inversely proportional to the speed of robot. In other words, the lower speed will contribute to greater deviation error. Besides that, other findings show most of the deviation errors are skewed to negative side, which mean the robot are moving more to the left hand side even though it was programmed to move straight forward. Moreover, Figure 7 shows the graph of error against displacement for different level of robot's full speed. Based on these results, the mean of the data for each level of robot's full speed are -164.87 mm (25%), -250.05 mm (50%), -90.28 mm (75%) and -77.38 mm (100%). However, the standard deviation of the data for each level of robot's full speed are 156.57 mm (25%), 229.58 mm (50%), 82.48 mm (75%) and 69.62 mm (100%). In other word, 100% of robot's full speed contributes higher accuracy and repeatability compared to lower level of robot's full speed.

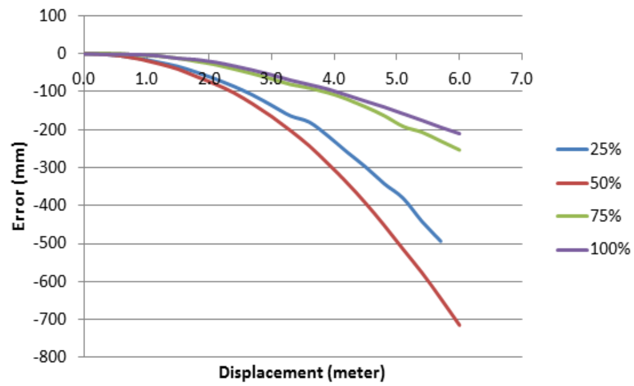


Figure 7 Relation of error and displacement for different level of robot's full speed

Besides that, Figure 8 shows the graph of error changes versus displacement for different level of robot's full speed while applying the P controller. Based on these results, the peak values for each level of robot's full speed are -61.00 mm (25%), -70.33 mm (50%), -28.00 mm (75%) and -18.34 mm (100%). However, the minimum values for each level of robot's full speed are given 0.33 mm (25%), -0.67 mm (50%), ±1.33 mm (75%) and -0.33 mm (100%). Figure 9 shows the graph of error versus Kp value for 100% of robot's full speed with P-controller. From this finding, the negative deviation error was gradually decreased when the Kp gain was increased up to 0.8 value of Kp. Beyond this value could increase the positive deviation error. Among these 10 times of Kp gains values was tested starting from 0.1 until 1.0 and the Kp gain value of 0.8 is the most suitable value to implement inside the P-controller since it has the smallest deviation error with the average of -3.33 mm.

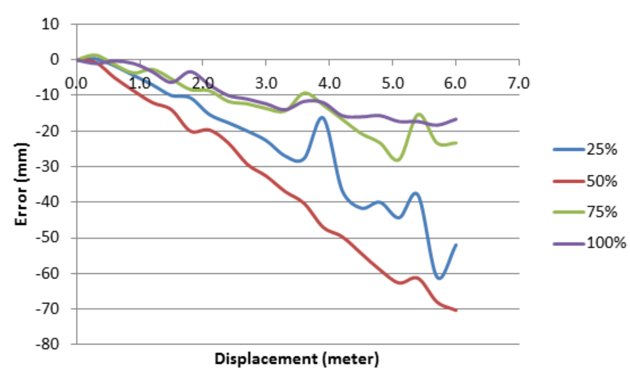


Figure 8 Relation of error and displacement for different level of robot's full speed using P controller

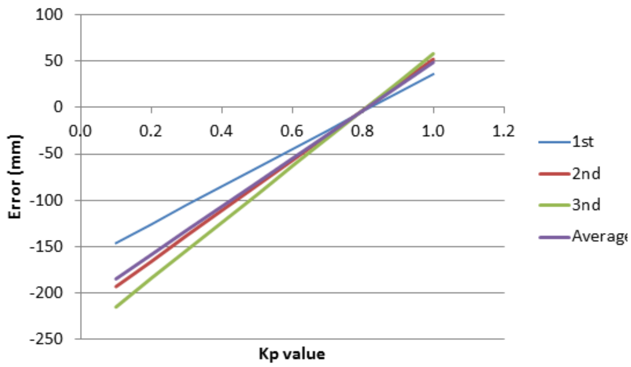


Figure 9 Adjustment of Kp value for 100% of robot's full speed with P-controller

On the other hand, field test was conducted in this project to determine the performance of the crawler type robot on rough surface or irregular terrain in term of its accuracy and repeatability. From the result illustrated in Figure 10, it shows the movement of the robot was not so consistent on irregular terrain. The average value or mean of the data was given -66.10 mm while its standard deviation was 56.17 mm. However, the peak value of the data collected was -153 mm while the minimum deviation error was 12 mm. The reason of large deviation error on irregular terrain compared to regular terrain was the uneven surface of irregular terrain which causing the robot hard to move in one direction consistently. Even it was equipped with P-controller, but it still deviate from the desired route. When a robot moves on an irregular terrain, there are many factors need to be considered in order to make the robot move in desired route. One of the factors could be the friction force between the rough surface and the crawler belt. Besides that, the design of this robot was too low, so the friction force not only acting on the crawler belt, but also the beneath surface of the robot. Therefore, the grass drags the movement of the robot and affects the overall performance in terms of its accuracy and repeatability too.

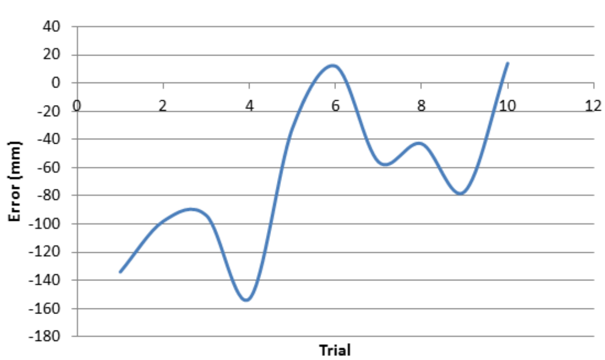


Figure 10 Relation of error and no. of trial for field test

5.0 CONCLUSION

The study was undertaken with the aim to design and develop a crawler type robot which can pass through several types of terrains as well as to analyze and evaluate the performance of fabricated crawler type robot in term of its accuracy and repeatability. The findings of this project were based on the data collected during the experiments. It shows the deviation error is inversely proportional to the speed of the robot. In other words, deviation errors will be increased when the speed level of robot's motors is decreasing. Besides that, by implementing P-controller inside the system, the error managed to decrease compared to the uncompensated system. However, the compensated system only works effectively on regular terrain, and not so effective in grass terrain. The suitable Kp gain for this controller was 0.8. The weight of the developed crawler type robot also too light which make the robot easy to slip away from the reference line. The balance between weight of the developed crawler robot with the power consumption and DC geared motor torque also need to be considered in the future. Besides, the advanced image processing method by using camera also recommend for the next step in order to study the implementation of the developed crawler robot in unknown field and far from the operator.

Acknowledgement

This research is a collaboration project between Tokushima University and Universiti Teknikal Malaysia Melaka.

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