International Journal of Integrated Engineering, Vol. 9 No. 2 (2017) p. 71-77

Navigating an Auto Guided Vehicle using Rotary Encoders and Proportional Controller

Sung How Lee[1], **Kim Seng Chia**[1,*]

[1]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, MALAYSIA

Received 27 June 2017; accepted 21 December 2017, available online 21 December 2017

Abstract: Auto Guided Vehicle (AGV) is commonly used in industry to reduce labour cost and to improve the productivity. A few programmable devices are combined in an AGV to optimize the usage of time and energy. AGV is widely used to transport goods and materials from one place to another place. For the first generation of AGV was used the track to guide the AGV but it was not flexible enough. This study investigates an alternative to control an AGV using two rotary encoders and proportional controller. Arduino Mega 2560 was used as a microcontroller to receive and process the signals from the rotary encoders. Logic controller and proportional controller were implemented to control the AGV, respectively. The coefficient of proportional controller was optimized to improve the performance of the AGV during navigation process. Findings show that AGV with the proportional controller with coefficient 1.5 achieved the best performance during the navigation process.

Keywords: Auto guided vehicle, Rotary encoder, Proportional controller,

1. Introduction

The navigation system is a process monitoring and controlling of movement object from one place to another place [1]. Navigation is mainly separated into four categories, such as marine, land, space and aeronautic [2]. Auto guided vehicle (AGV) is commonly used in industry for transporting materials and goods. AGVs are nearly employed in every field, including medical, industry, hospitality and etc.

The AGV is commonly separated into two categories i.e. fixed path and free range AGVs [3][4][5]. For the fixed path AGV, its navigation system is guided by permanent path e.g. magnetic tape or colour tape that is installed at the early stage of the implementation of AGV [6][7]. The AGV contains various sensors e.g. infrared, colour, Hall Effect sensors to detect the path that fixed on or embedded under the surface of floor. The advantage of this fixed path AGV is the technology is well developed and it is early to be implemented. However, this technology requires a huge initial investment in terms of time and money to install the required fixed path. Additionally, it is inflexible in terms of the moving path of the AGV. Nevertheless, this technology is still popular due to its simplicity and reliability.

The free range AGV navigation system, on the other hand, provides greater flexibility in terms of the moving path modification. This is because there is no any significant installation prior to the implementation of the free range AGV navigation system. Generally, free range AGV navigation system can be classified into laser guided and inertial guided technologies. For laser guided AGV, the AGV will triangulate its current position by comparing the map of reflectors layout store in memory with environment information [8][9]. In contrast, inertial guided AGV uses various sensors e.g. accelerometer, gyroscope, and magnetometer to determine its position during navigation [10][11]. Even though the free range AGV is more flexible and does not require a huge initial installation cost in terms of installing the required fixed path, the navigation system of a free range AGV navigation system is much complex and expensive compared to the fixed path AGV. This is because the navigation system involves various expensive sensors and complex system to aggregate and analyse the signals from various sensors in order to navigate the AGV as required. Thus, an alternative of a free range AGV is worthy to be designed and investigated so that a compromise can be reached between complexity and flexibility.

This study investigates an alternative to navigate an AGV using two rotary encoders and proportional controller. The aim is evaluate the feasibility of the proposed system in navigating an AGV to move straight based on the reading from two rotary encoders. The proportional controller is chosen due to its simplicity and reliability in most cases.

2. Methodology

The Fig. 1 shows the block diagram of this project. The diagram clearly shown the components that used in this project. The components including Arduino Mega 2560, rotary encoder, motor driver, DC brushless motor, 12V and 24V.

---

*Corresponding author: kschia@uthm.edu.my

penerbit.uthm.edu.my/ojs/index.php/ijie

The Arduino Mega 2560 is a controller in this project. It generated pulse-width modulation (PWM) signal to control the motors motion. Besides that, brushless dc motors and motor driver are main component in this project. The function of motor driver is controlling the speed and direction of motors. Moreover, the rotary encoders are the main sensor of the project that used to measuring the distance travel by the AGV.

The 24V is main power source of the project and it supplied sufficient voltage to the motor drivers. The 12V power source is stepdown to 9V by voltage regulator and supplied to the Arduino Mega 2560.

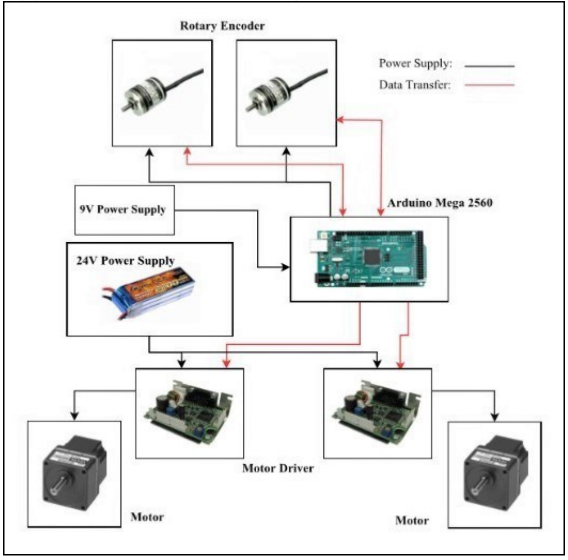


Fig. 1 Block diagram of the project

2.1 Hardware Assembly

An existing body frame are used to carry this project with dimension 350mm×480mm×450mm. The body frame made by aluminium, perspex, and high alloy steel. However, a connector shaft is printed by 3D machine to combine the omni-wheel and rotary encoders together. The Fig. 2 shows the connector shaft printed by 3D machine.

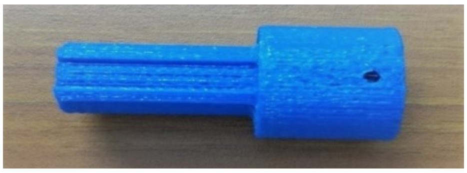


Fig. 2 Connector shaft printed by 3D machine

Moreover, a flexible holder is made by aluminium bar to hold the two rotary encoders. The holder allows the encoders to move vertically to avoid major damage from physical environment. The holder attached at the bottom of AGV and let the rotary encoders always touch the ground. Fig. 3 shown the actual position of encoders on the AGV and the flexible holder.

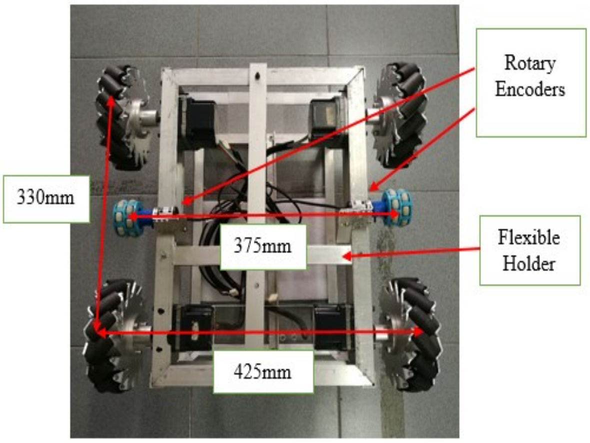


Fig. 3 The actual position of encoders and holder on the underside of AGV

2.2 Control System of AGV

The control system is important in navigation process. The control system requires information in order to make the AGV go straight. The errors of the AGV are the difference between distances at the right (a.k.a. distanceR) and the left (a.k.a. distance) that happen along the navigation process. Fig. 4 shows the control system of AGV.

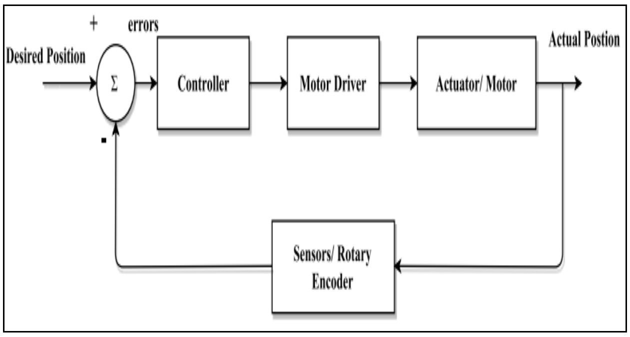


Fig. 4 Control system of the proposed AGV

2.3 Control System

i. Logic control system

The logic control system chooses which set of commands and operations to be executed based on a condition. When a condition is fulfilled, the given operation will be executed and vice versa. The logic control system is straight forward. However, this control strategy may not be suitable in some practical applications because the system may unable to reach a desired steady state.

ii. Proportional control system

The proportional control system is a type of linear feedback control system. The output of the proportional controller is proportional to the product of signal error and proportional gain [12][13][14]. The equation below shows the calculation of output of proportional controller using in coding.

$$Pout = Kp * e(t) + po \qquad (1)$$

Where

- Pout : Output of proportional controller
- Kp : Proportional gain
- e(t) : Instantaneous process errors at time t
- po : Output controller with zero error

2.4 Performance Analysis

The performance of the proposed AGV navigation system was investigated based on the capability of the AGV to move straight with three different speeds. When the AGV is moving straight, the readings from the two encoders are same. Thus, by minimizing the different between these two readings from encoders, the AGV can be navigated to move straight. The readings from the encoders were recorded in a laptop computer that allocated on the AGV via serial communication using a USB cable.

Two control strategies i.e. logic control and proportional control systems were compared and discussed. Additionally, the effect of three different speeds were investigated. A good controller should maintain minimum steady state error with a smaller overshoot and fewer or zero oscillation during the navigation testing.

3. Results and Discussion

3.1 Testing of Rotary Encoders

The rotary encoder is the main component of this project. It is a highly sensitive and precision sensor. There are 2 rotary encoders installed on the AGV. Both of the encoder are placed at the left-hand side and right-hand side. The rotary encoders are used to detect the distance travel by the AGV. By comparing the values of both encoders, the AGV able to go straight and reach the target position.

AGV is manually navigated about 1 meter and the values of both encoders directly send to the serial monitor of Arduino IDE software. The distance travel of the AGV can be calculated with the 2 formulas given below.

Formula given below used to calculate the circumference of omni-wheel:

$$Circumference = \pi d \qquad (2)$$

where d is the diameter of omni-wheel

Substituted (2) into formula (3) below to calculate the distance travel by the AGV:

$$Distance\ Travel = Counter * \frac{\pi d}{Pulse\ per\ Revolution\ of\ Rotary\ Encoder} \qquad (3)$$

Fig. 5 shows the values of the difference of distanceR and distanceL with 1000 mm. The performance of rotary encoders was good enough because that actual values were kept between 990 mm and 1010 mm.

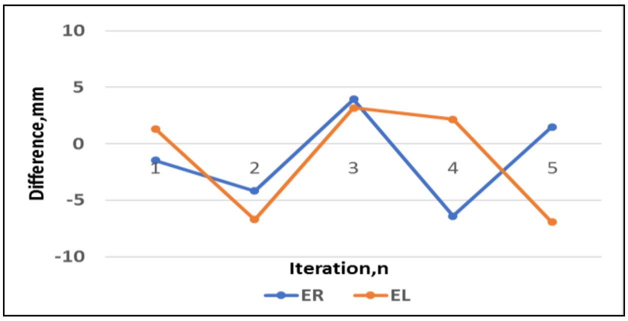


Fig. 5 The difference of distanceR and distanceL with 1000 mm

3.2 Testing on Repeatability of AGV

A target has been set for the AGV. The AGV had to moving forward for 5000mm within 3 tiles. The width of tiles was about 890mm. The stability of the AGV during the navigation was observed and recorded. The AGV navigated with minimal overshoot and oscillation was considered a good performance. Figure 6 shows the real situation when the testing was carried out.

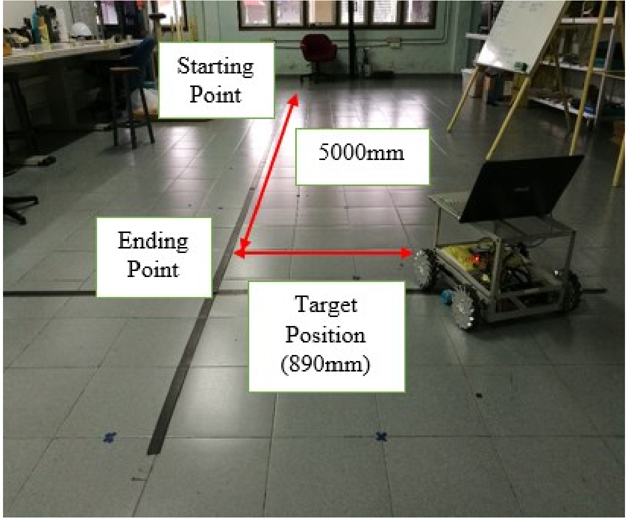


Fig. 6 Real situation when testing was carried out

i. PWM 100 without control

Fig. 7 shows the difference between distanceR and distanceL against time taken. Both motors of the AGV are running with the speed of PWM 100 without any control. The graph above shows that the errors are accumulated until every run is complete. The AGV cannot performed well under the condition without control. Moreover, the AGV performed in a curve motion and it was unable to reach the target position.

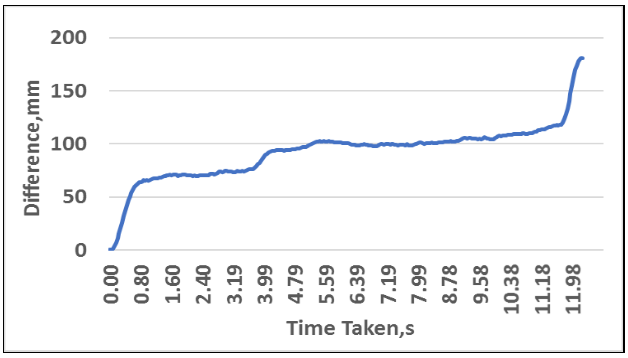
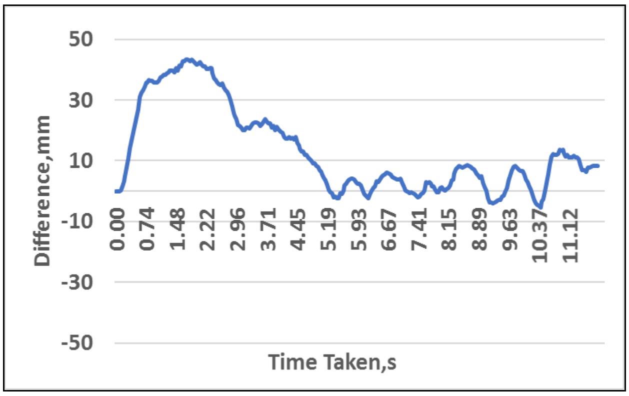


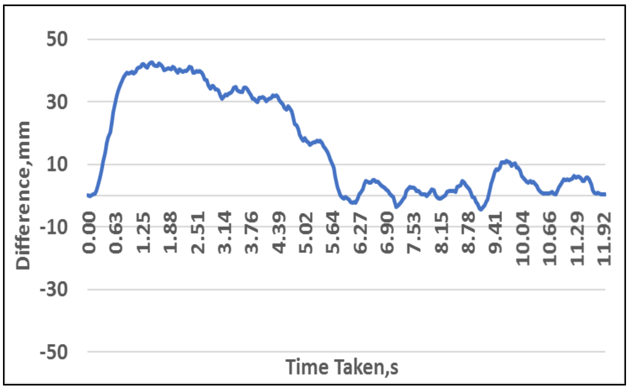
Fig. 7 The difference between distanceR and distanceL with condition of PWM100 without control

ii. Logic control system

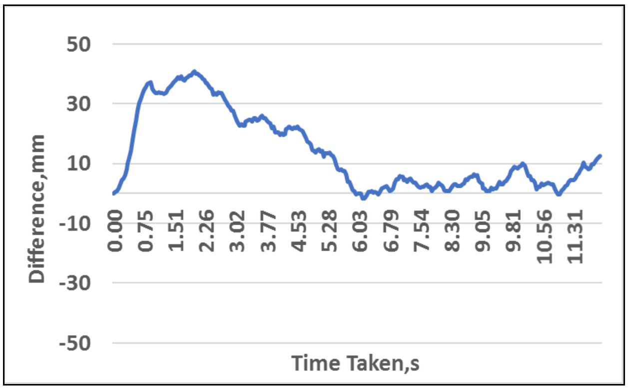
The AGV managed to reach the target position by using logic control system. The function of the logic control system was to minimize the difference between distanceR and distanceL that happened during the navigation process. The AGV minimized the difference by increasing the speed of the motor of one side while maintaining a constant speed on the other side. Fig. 8 shows the difference between distanceR and distanceL that the AGV navigated under adjustment PWM 110 with different react distance. The AGV that navigated under adjustment PWM 110 did not oscillate obviously but it only made some minor error correction. The oscillations of AGV happened between 20mm to -10mm.



(a)



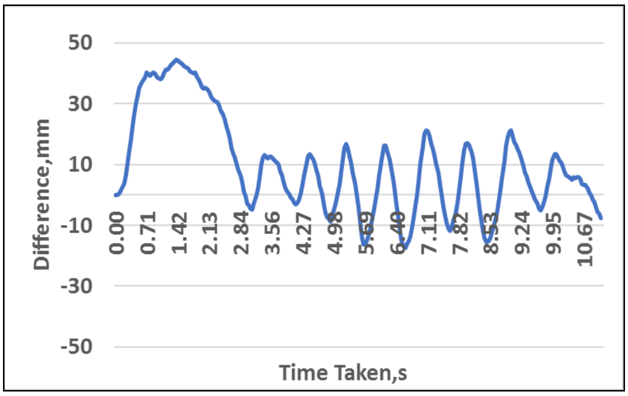
(b)



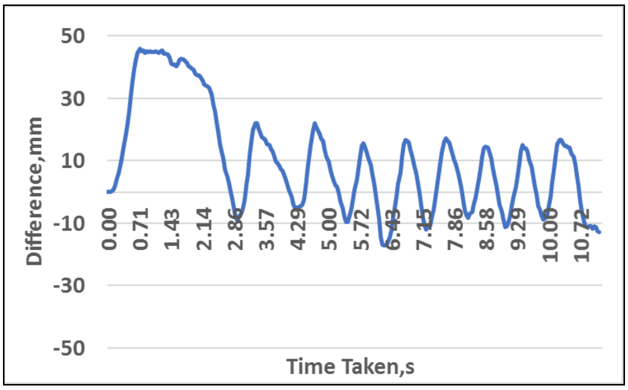
(c)

Fig.8 The difference between distanceR and distanceL that AGV navigated under adjustment PWM 110 for (a) react distance -1 to 1, (b) react distance -2 to 2 and (c) react distance -5 to 5

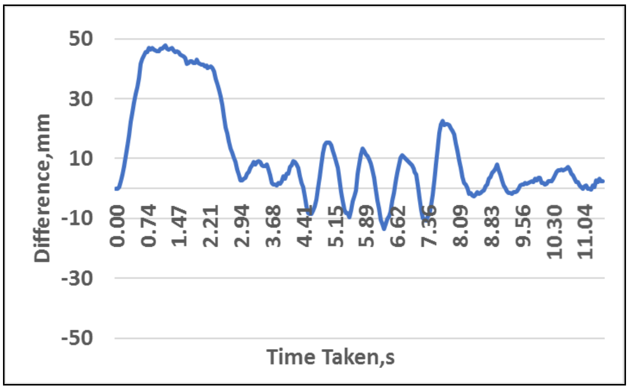
Fig. 9 illustrates the difference between distanceR and distanceL that the AGV navigated under adjustment PWM 130 with different react distance. The AGV that navigated under adjustment PWM 130 was oscillating and the oscillations happened after the huge difference between distanceR and distanceL. The oscillations happened of AGV that navigated under adjustment PWM 130 between 30mm to -20mm.



(a)



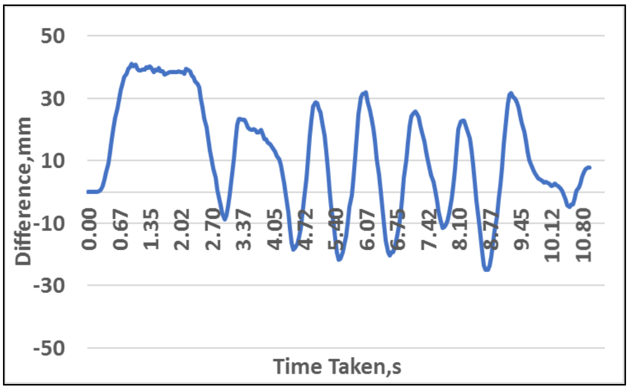
(b)



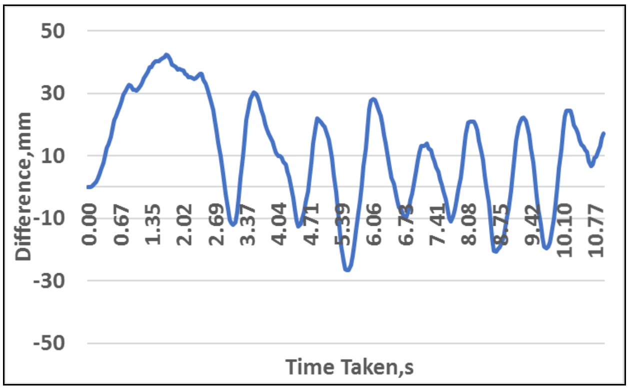
(c)

Fig. 9 The difference between distanceR and distanceL that AGV navigated under adjustment PWM of 130 for (a) react distance -1 to 1, (b) react distance -2 to 2 and (c) react distance -5 to 5

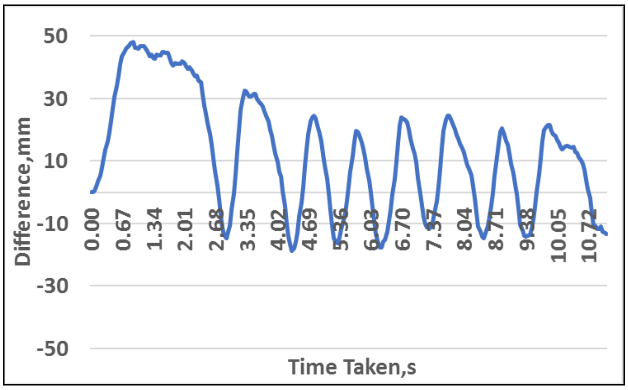
Fig. 10 illustrates the difference between distanceR and distanceL that the AGV navigated under adjustment PWM of 150 with different react distance. The AGV that navigated under adjustment PWM of 150 was oscillating and oscillation happened after the large difference between distanceR and distanceL. The oscillation of the AGV happened between 40mm to -30mm. However, the oscillation of the AGV that navigated under react distance 5 to -5 fell between 40mm to -20mm.



(a)



(b)



(c)

Fig. 10 The difference between distanceR and distanceL that AGV navigated under adjustment PWM of 150 for (a) react distance -1 to 1, (b) react distance -2 to 2 and (c) react distance -5 to 5

A large difference occurred at the starting point of every graph above due to the difference in time response of motors. The time response of right-hand side motor was slightly faster and caused a large positive difference in the graph. The AGV running under adjustment speed PWM of 130 and 150 minimized the difference in a shorter time. This was due to the AGV running under adjustment speed PWM of 130 and 150 had faster reaction compared to PWM 110. However, the AGV that had faster reaction caused oscillations and overshoot during the navigation process and at the same time also caused a large offset in the graphs. Increasing the reaction distance was able to reduce the offset in the graphs caused by the oscillations. Nevertheless, it was not so significant.

The AGV navigated under adjustment speed PWM 110 was able to go straight in a much smoother manner. Besides that, the AGV took a longer time to minimize the difference. At the same time, the offset of the graphs with adjustment speed PWM 110 is reduced when compared with different adjustment speed but same react distance.

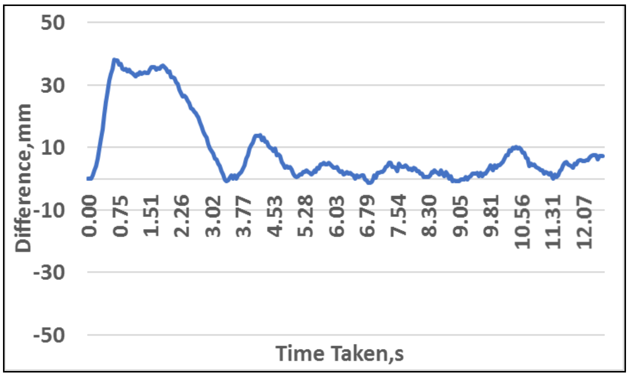
Overall, the AGV ran under react distance 5 to -5 with adjustment speed of 110. It performed best in this configuration compared to all 9 conditions. Next, the proportional controller is introduced to the AGV to improve the performance of logic control system.

iii. Proportional controller

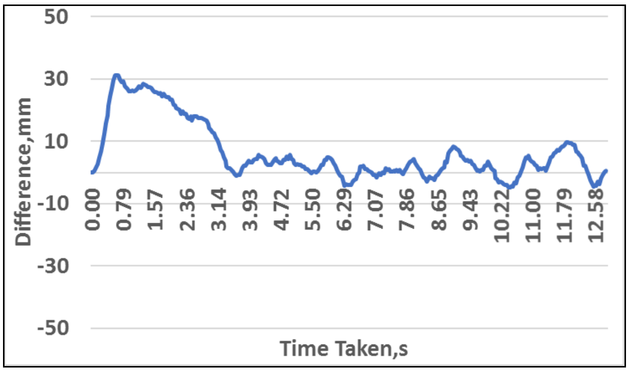
The proportional controller output is proportional to the error signal, which is the difference between the setpoint and the process variable. The function of proportional controller is to minimize the difference by regulating both of the motors speed. The AGV will minimize the difference by increasing the speed of motor on one side while decreasing the speed of motor on the other side.

Fig. 11 shows the difference between distanceR and distanceL that the AGV navigated under proportional controller with different coefficients. A large positive difference in distance occurred at the starting point of each graph due to faster time response of the right-hand side motor of the AGV. The AGV navigated under proportional controller was able to reduce the effect of faster time response brought by right-hand side motor. This was due to the adjustment of proportional controller more effective when compared with the best performance of logic control system. AGV was able to navigate in a much more stable manner and only resulted in small offset on the graphs.

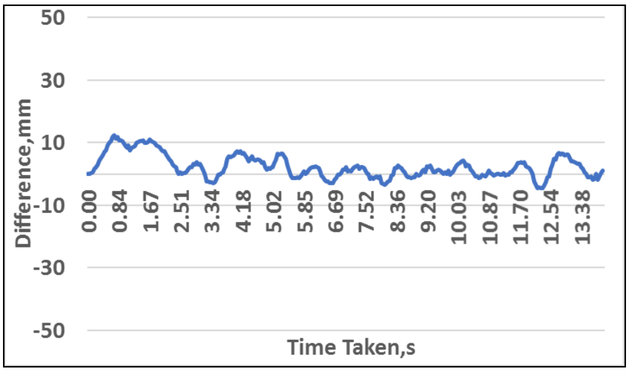
On the other hand, the proportional controller with coefficient 2 navigated the AGV under unstable condition. The result of the proportional controller with coefficient 2 was totally different with other because it deviated from the regular patterns. The response of the AGV was too fast that caused the AGV to oscillate more frequently. Overshoot happened more often during the navigation process which resulted in large offset on the graph as shown in Fig. 11(d).



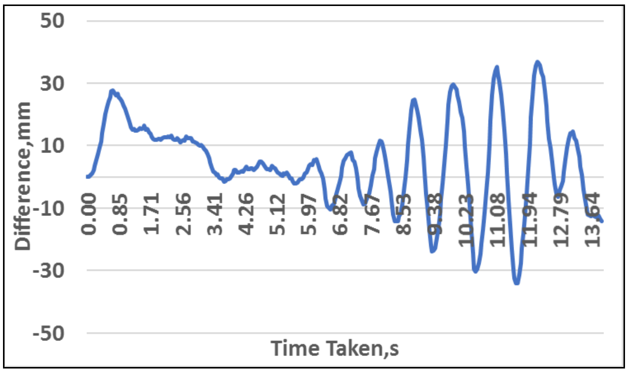
(a)



(b)



(c)



(d)

Fig. 11 The difference between distanceR and distanceL that AGV navigated under proportional controller with different coefficients for (a) 0.5, (b) 1, (c) 1.5 and (d) 2

The overall, the AGV navigated under proportional controller with coefficient 1.5 shown in Fig. 10(c) presented the best performance among the several different conditions. However, the offset occurred in the proportional controller can be stabilized by using PI controller but that could be done for future work.

4. Conclusion

The proposed auto guided vehicle (AGV) navigation system that used two encoders coupled with proportional controller with coefficient 1.5 achieved the best performance among that used proportional controller with other coefficient values and that used logic controller. With this optimal coefficient value, the AGV was able to be navigated with more stable manner and smaller offset. The maximum overshoot of the AGV with optimal performance was 12.28mm and its offset was between 10mm to -10mm. Finding indicates that AGV with the proposed navigation design and proportional controller was able to go straight and reached the target position. In future works, we aim to investigate other controllers to possible enhance the AGV performance and the feasibility of the design for different free range AGV navigation studies.

Acknowledgement

This study was sponsored by Faculty of Electrical and Electronic Engineering (FKEE), Universiti Tun Hussein Onn Malaysia (UTHM). Authors would like to acknowledge FKEE, UTHM for providing facilities for this study.

References

[1] N. Bowditch, “The American Practical Navigator,” *Deffense Mapp. Agency Hydrogr.*, no. 9, p. 882, 2002.
[2] B. Hofmann-Wellenhof, K. Legat and M. Wieser, *Navigation*, 1st ed. Wien: Springer, 2003.
[3] G. Ullrich, The History of Automated Guided Vehicle Systems, Springer Berlin Heidelberg, 2014.

[4] M. v. d. Z. a. G. L. Mark B. Duinkerken, "COMPARISON OF ROUTING STRATEGIES FOR AGV SYSTEMS USING SIMULATION," in *Proceedings of the 2006 Winter Simulation Conference*, 2006.

[5] M. v. d. Z. a. G. L. M.B. Duinkerken, "Dynamic Free Range Routing for Automated Guided Vehicles," in *Networking, Sensing and Control, 2006. ICNSC '06*, 2006.

[6] V. S. R. B. P. V. V. V. Prof. Ashraf Siddiqui, "International Journal of Computer Science Trends and Technology (IJCST)," *Automated Guided Vehicle with ARDUINO Using Magnetic Sensor,* vol. 5, no. 2, pp. 91-93, 2017.

[7] S. K. Das, "IJSTE - International Journal of Science Technology & Engineering," *Design and Methodology of Line Follower Automated Guided Vehicle-A Review,* vol. 2, no. 10, pp. 9-13, 2016.

[8] J. J. A.-J. a. H. M.-B. David Herrero-Pérez, "International Journal of Advanced Robotic Systems," *An Accurate and Robust Flexible Guidance System for Indoor Industrial Environments,* vol. 10, 2013

[9] P. T. D. S. S. P. H. K. K. S. B. K. Thanh Luan Bui, "Internat. J. of Sci. and Eng," *AGV Trajectory Control Based on Laser Sensor,* vol. 4, no. 1, pp. 16-20, 2013.

[10] S. W. J. K. J. D. S. K. S. B. Jungmin Kim, "International Journal of Precision Engineering and Manufacturing," *Inertial navigation system for an automatic guided vehicle with Mecanum wheels,* vol. 13, no. 3, pp. 379-386, 2012.

[11] M. M. R. Mr. Aditya Dhanvijay, "International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering," *Intelligent Autonomous Automated Guided Vehicle,* vol. 4, no. 12, pp. 97-100, 2016.

[12] D. S. S. Saurabh Dubey, "International Journal of Innovative Research in Computer and Communication Engineering," *A PID Controlled Real Time Analysis of DC Motor,* vol. 1, no. 8, pp. 1965-1973, 2013.

[13] S. Sheilza Jain, "International Research Journal of Engineering and Technology," *PID Controller for Longitudinal Parameter Control of Automatic Guided Vehicle,* vol. 3, no. 6, pp. 3010-3016, 2016.

[14] K. S. C. a. X. Y. Yap, "A Portable PID Control Learning Tool by Means of a Mobile Robot," iJOE, vol. 12, no. 6, pp. 54-57, 2016.