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Experiment study of an automatic guided vehicle robot

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ABSTRACT

This paper presents the design and control of an autonomous robot-automation guided vehicle (AGV) with a load of 50 kg and a DC motor in theory and experiment. This robot has the function of transporting tools and equipment in the factory. This robot is designed and built control system including hardware and software. In which microcontroller type STM32F407VG is selected to control the primary system. The AGV robot is controlled to move according to the required trajectory. A PID controller controls the DC motor. The AGV robot moves precisely according to the routes set in the factory. At the same time, the AGV has good obstacle avoidance. The results of the proposed solution are proven through simulation and experiment.

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1. INTRODUCTION

Robot AGV is an innovative solution for the future in the era of digitization and industry 4.0. Automation guided vehicle (AGV) robot ensures the certainty and flexibility of the product. At the same time, it makes it easier to move goods inside factories and warehouses. Besides, AGV robots also improve automation and solve production continuity problems [1]–[3]. The AGV robot wants to move automatically. Therefore, it needs to solve three main issues: positioning, trajectory planning, and motion control in navigation for AGV [4]–[6]. In particular, the motion control system of the AGV robot plays a crucial role in moving from the starting point to the destination [7]. In addition, [8]–[10], the AGV robot is determined by the feedback signal for sensors to assess information. The controller for the robot's motion will determine the speed and direction of action for the AGV robot. Therefore, the time and the moving distance are optimized, and the motion control system is stable for the AGV self-propelled robot.

There has been researching, designing, and manufacturing of AGV robots. This robot is increasingly improved and enhanced according to actual requirements [11]–[15]. In 2019, Joo [15] proposed a control system design for AGV based on a 2-layer controller structure. In this design, the controller uses STM32robot, so the AGV robot has improved motion quality. Lee and Jung [16] designed the controller for the AGV robot using modular design ideas to achieve communication and control between modules. In another study, based on [17] developed an AGV forklift truck with a laser-based control system. The central controller uses a PLC to control and plan the path of the AGV. Experiments verify the correctness of the solution. In addition, an ARM (advanced RISC machine) microprocessor to control the magnetic field [18]. Real-time robot control system. With this, the AGV robot can precisely move along the specified path, park the vehicle in an emergency, and safely avoid obstacles. However, most AGV robots are from abroad and geared towards light load equipment. AGV robots in the Vietnamese market are developing slowly due to high costs and unspecialized working environments in factories and enterprises [19]–[26]. This article deals with the design, control, and development of the AGV robot system with the dimensions of 750 (mm) long, 450 (mm) wide, and 270 (mm) high, corresponding to the details used. Capable of carrying loads up to 100 (kg). This robot is designed with a control system using microcontroller STM32F407GV with low cost, simple and effective installation. Therefore, the AGV robot meets the needs of factories that tend to develop specialization and modernization with a fully automatic AGV system.

The article consists of 5 main sections. In which an overview of the design and control of the AGV robot is presented in part 1. Next, the paper presents the control structure and modeling of the AGV robot system to design and build the AGV robot system in part 3. Finally, the experimental model evaluation of the AGV robot and the development direction to improve the robot's motion stability are given in sections 4 and 5.

2. CONTROL STRUCTURE AND MODELING OF AGV ROBOT SYSTEM

2.1. Control structure

The article mentions that the four-wheel self-propelled robot AGV with two front driving wheels and two rear guiding wheels, as shown in Figures 1 and 2. Figure 2 shows the structure of the controller for the AGV vehicle. First, ports and communication methods feed sensor signals into the central control unit. Then, based on the call from the sensor block, the main control unit will calculate to determine the moving state of the AGV. Then, the primary control block will output a pulse width modulation (PWM) pulse signal from those states to control the motors through the motor control power circuit. It will help the AGV move on its own in a predetermined trajectory.

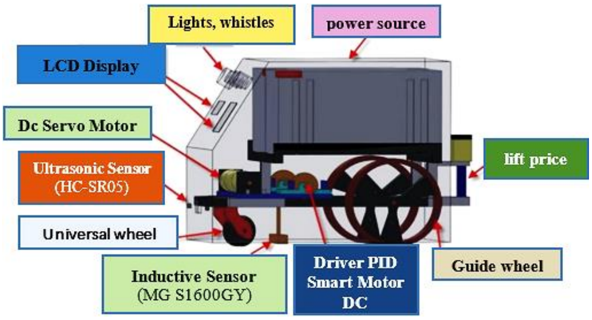

Figure 1. Model of a robot AGV

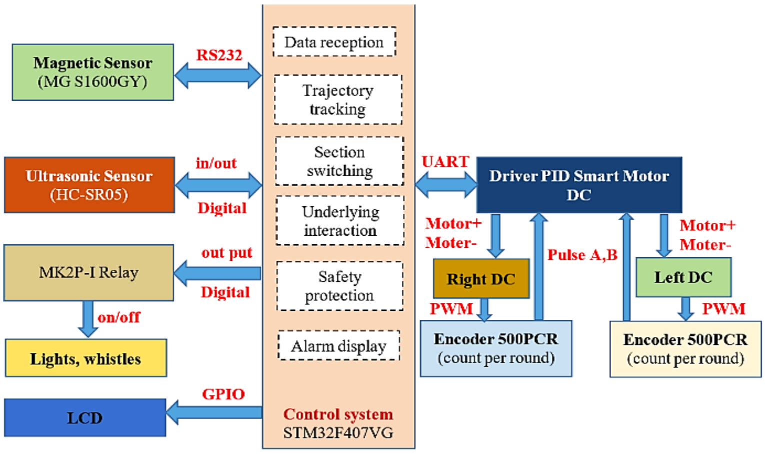

Figure 2. Control structure of a robot AGV

In the AGV robot, the control block plays a significant role. The system includes a central processing circuit that is a microcontroller STM32F407VG. Here the system will receive and process the data sent from the sensors. The magnetic field sensor returns a digital signal to be sent to the controller via the RS232 interface. After receiving the signal from the magnetic field sensor, the microprocessor will process the signal and send it to the driver circuit through the universal asynchronous receiver-transmitter (UART) interface. The DC motor is controlled through the power driver by PWM pulses from the microcontroller. Feedback speed and angle of rotation to the power driver circuit through 2 channels A and B of the optical encoder built into two geared DC motors. To increase safety during the operation of the AGV robot, we use sensors to determine the distance of the vehicle from the obstacles on the moving vehicle. The central control unit will affect the car's speed when this distance is within the danger zone. This helps the vehicle avoid collisions with obstacles. Alarms are displayed via lights and buzzers communicated via the microcontroller's GPIO output.

2.2. Modeling of an AGV robot system

2.2.1. The kinetic model of an AGV

The modeling of an AGV robot system is expressed in Figure 3. Where: v (m/s): is the linear speed of the vehicle; $v_L; v_R$ (m/s): are linear velocities of left and right wheels; R (m): is the radius of the active wheel; $\omega_L; \omega_R$ (rad/s): is the angular speed of the left and right wheels; θ (rad): is the orientation angle of AGV.

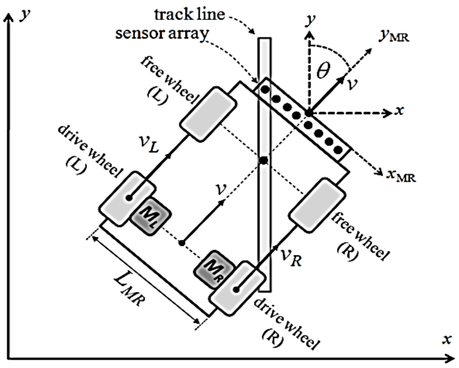

Figure 3. The modeling of an AGV robot system

Figure 3 shows the linear velocity of the two rear control wheels. The linear speeds of the left and right wheels can calculate according to the radius of the wheel R. The angular momentum of each spin is written by (1).

$$v_R = \omega_R R; v_L = \omega_L R \tag{1}$$

The linear velocity of the AGV is calculated by the average of the rates of the left and right wheels. Hence, it is called the forward kinematics model of linear acceleration.

$$v = \frac{v_R + v_L}{2} \Leftrightarrow v = \frac{(\omega_R + \omega_L)R}{2} \tag{2}$$

Velocity components $\dot{x}$ and $\dot{y}$ in the coordinate system:

$$\dot{x} = v \sin\theta \,; \dot{y} = v \cos\theta \tag{3}$$

Substituting the linear velocity component of (2) into the velocity component of procedure (3):

$$\dot{x} = \frac{(\omega_R + \omega_L)R}{2} \sin\theta \,; \dot{y} = \frac{(\omega_R + \omega_L)R}{2} \cos\theta \tag{4}$$

Thus, the acceleration component for the AGV according to the coordinate system is calculated by (5):

$$\ddot{x} = \frac{(\dot{\omega}_R + \dot{\omega}_L)R}{2} \sin\theta \,; \ddot{y} = \frac{(\dot{\omega}_R + \dot{\omega}_L)R}{2} \cos\theta \tag{5}$$

The position coordinate system of a AGV robot is shown in Figure 4. Where: L_{MR} (m): is the distance between the two active wheels; L_R (m): is the length of the right arc; L_L (m): is the length of the left arc; R_T (m): is the radius of motion of the AGV

Figure 4 shows the difference in the AGV position concerning the line. Since the coordinate system of the AGV is x_{MR1}, y_{MR1} for the first position and x_{MR2}, y_{MR2}] for the second position, the orientation angle θ of the AGV is different between MR1 and MR2. Therefore, a curve or length of the line AGV moving L_T is calculated as the average of the left arc L_L and the right arc L_R:

$$L_T = \frac{L_R + L_L}{2} \tag{6}$$

the orientation angle θ of the AGV is linear. It can be described as:

$$\theta = \frac{L_L}{R_T - \frac{L_{MR}}{2}} \tag{7}$$

Left arc road L_L and right arc road $L_R$are calculated by determining the radius of motion R_T, L_MR, and orientation angle θ of AGV according to the (8).

$$L_R = (R_T + \frac{L_{MR}}{2})\theta; L_L = (R_T - \frac{L_{MR}}{2})\theta \tag{8}$$

The orientation angle θ of the AGV is shown in (9).

$$\theta = \frac{L_R - L_L}{L_{MR}} \tag{9}$$

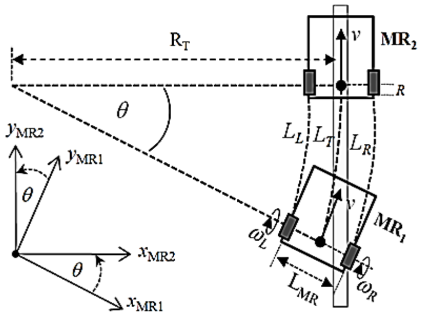

Figure 4. The position coordinate system of AGV

The directional angular derivative of the AGV leads to the angular velocity determined as (10).

$$\dot{\theta} = \frac{v_R - v_L}{L_{MR}} \Leftrightarrow \dot{\theta} = \frac{(\omega_R - \omega_L)}{L_{MR}} R \tag{10}$$

The angular speed of AGV is a function of the angular derivative concerning time. This derivative is divided into two parts as (11).

$$\dot{\theta} = \frac{d\theta}{dt} = \frac{d\theta}{dL}\frac{dL}{dt} \tag{11}$$

Since the component dθ/dL is $1/R_T$ and the linear velocity *v* is equal to dθ/dL, (11) can be transformed into:

$$\dot{\theta} = \frac{v}{R_T} \Rightarrow v = \dot{\theta} R_T \tag{12}$$

the derivative gives the angular velocities of both the left and right wheels:

$$\omega_R = \frac{v_R}{R} = \frac{\dot{L}_R}{R}; \omega_R = \frac{v_L}{R} = \frac{\dot{L}_L}{R} \tag{13}$$

substitute (9) into two (13), so the result is as (14):

$$\omega_R = \frac{(R_T + \frac{L_{MR}}{2})\dot{\theta}}{R}; \omega_L = \frac{(R_T - \frac{L_{MR}}{2})\dot{\theta}}{R} \tag{14}$$

substitute (12) into two (14), so the result is as follows:

$$\omega_R = \frac{(R_T + \frac{L_{MR}}{2})v}{R_T.R}; \omega_L = \frac{(R_T - \frac{L_{MR}}{2})v}{R_T.R} \tag{15}$$

$$\Leftrightarrow \omega_R = (1 + \frac{L_{MR}}{2R_T})\frac{v}{R}; \omega_L = (1 - \frac{L_{MR}}{2R_T})\frac{v}{R} \tag{16}$$

the inverse kinematics model of the vehicle is shown in (17). The angular speed of both the right and left wheels is determined by the linear velocity of the motion AGV.

$$\omega_{R/L} = (1 \pm \frac{L_{MR}}{2R_T})\frac{v}{R} \tag{17}$$

2.2.2. The kinetic model of a DC motor

The DC motor model is written according to the Laplace transform as the (19):

$$\frac{(J.s+b).\omega(s)}{K}.(L.s + R) = U(s) - K.\omega(s) \Leftrightarrow \omega(s).\left[\frac{(J.s+b).(L.s+R)}{K} + K\right] = U(s) \tag{18}$$

$$\Leftrightarrow \frac{\omega(s)}{U(s)} = \frac{K}{(J.s+b).(L.s+R)+K^2} = \frac{K}{L.J.s^2+(J.R+L.b).s+(b.R+K^2)} \tag{19}$$

3. DESIGN AND BUILD AN AGV ROBOTIC SYSTEM

3.1. Mechanical system for AGV

3.1.1. Design of chassis:

Based on the mechanical requirements, the design is suitable for the needs of the job. The paper gives the AGV robot frame drawing such as Figure 5. The AGV robot has parameters:

- The chassis requires a high load capacity, easy to assemble with the vehicle's wheel modules and circuit modules. The selected dimensions are length 750 (mm), width 450 (mm), and height 270 (mm), corresponding to the parts used. Capable of carrying loads up to 100 (kg).
- The body must be designed so the circuit and sensor modules can easily mount firmly on the vehicle.

3.1.2. Design of the wheel part

a) Motivational wheel

The motivational wheel frame is expressed in Figure 6. The driving wheel needs to be well loaded, and the friction between the wheel and the workshop floor must be significant to avoid slipping when moving, causing instability of the vehicle during work. Based on the above requirements and the size of the AGV, the paper chooses the driving wheel size as wheel diameter 100 (mm). The wheel has a cast iron inner core structure so that it can withstand loads very well; two wheels can bear loads of up to 200 (kg). The outside is covered with a layer of PU plastic 15 (mm thick), so it is very cool to be close to the workshop floor.

b) Lifting module

The lifting module frame drawing is expressed in Figure 7. It includes the following components:

- The module is required to lift and lower a specific volume of goods, up to 50 (kg).
- Ensure stability so that the goods are safe during transportation.
- The ability to lift and lower smoothly to facilitate picking control

Figure 5. The AGV robot frame drawing

Figure 6. Motivational wheel frame drawing

Figure 7. Lifting module frame drawing

3.1.3. Design of controller

The motion control program for the AGV robot as shown in Figure 8. Figure 8 shows the specific details of the operation process of the AGV robot. The AGV robot will start at the starting position; the AGV will go to the cargo area to lift and then transport to the required location. During the transportation process with case 1, if it encounters an obstacle or someone passes by, the AGV robot will stop and warn. In case 2, if the robot deviates from the line, the robot will automatically catch the line or suppress the warning depending on the case.

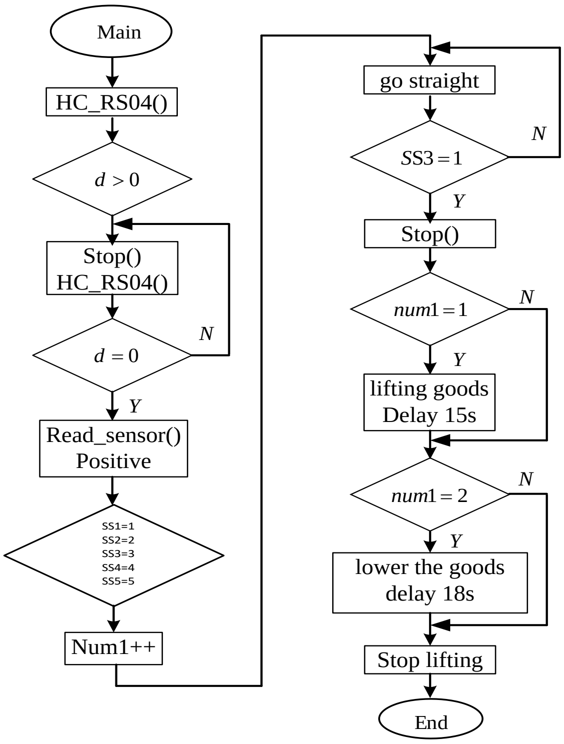

Figure 8. The AGV robot control algorithm diagram

4. EXPERIMENTAL MODEL RESULTS AND EVALUATION

4.1. AGV robot model evaluate

The model can achieve the following criteria: i) The mechanical design is a solid AGV model; the operation is relatively stable and flexible; ii) Analyze the kinematic model of the vehicle, and the velocity relationship between the two driving wheels to the vehicle's direction of movement at this moment, providing a control method; iii) Designed a practical cargo lifting module, ensuring the safety of goods and can lift goods to 50 (kg); iv) Complete the active two-wheel assembly with enough load capacity and a good grip on the road during travel; v) Know how to use some machines at the factory during processing such as drilling machines, lathes, welding machines, cutting machine; vi) Proficient and effective use of solid works design software, auto CAD, and other programming software; vii) The parameters of PID controller with K_p=0.7; K_I= 0.6; K_D= 0.01.

4.2. Experimental results

– Case of L_T is unchanged

Consider the case of the AGV robot without load and with the load. The simulation results are shown in Figures 9 and 10. The experimental results of Figures 9 and 10 show that the AGV robot is idling and loading, with the oscillation line error being more minor. Thus, the AGV robot moves precisely and quickly as required.

– Case of L_T is changed

The experimental results of Figures 11 and 12 show that when the error parameter L_T changes, the AGV robot's speed response will change, leading to the incorrect displacement of the robot. In the article, the parameter $L_T = 0.25(m)$was selected to help the AGV robot respond quickly to the slightest line error, in line with the requirements.

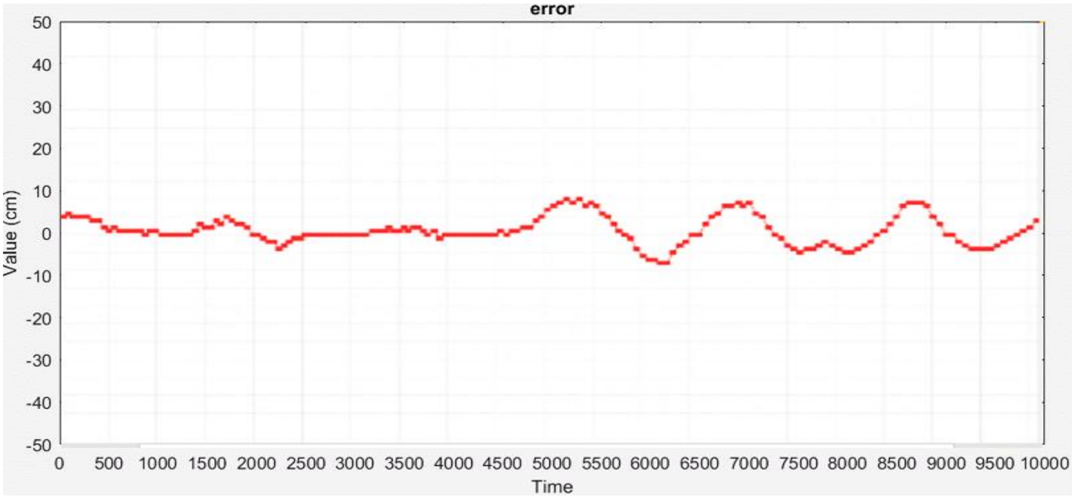

Figure 9. Line error chart when AGV without load

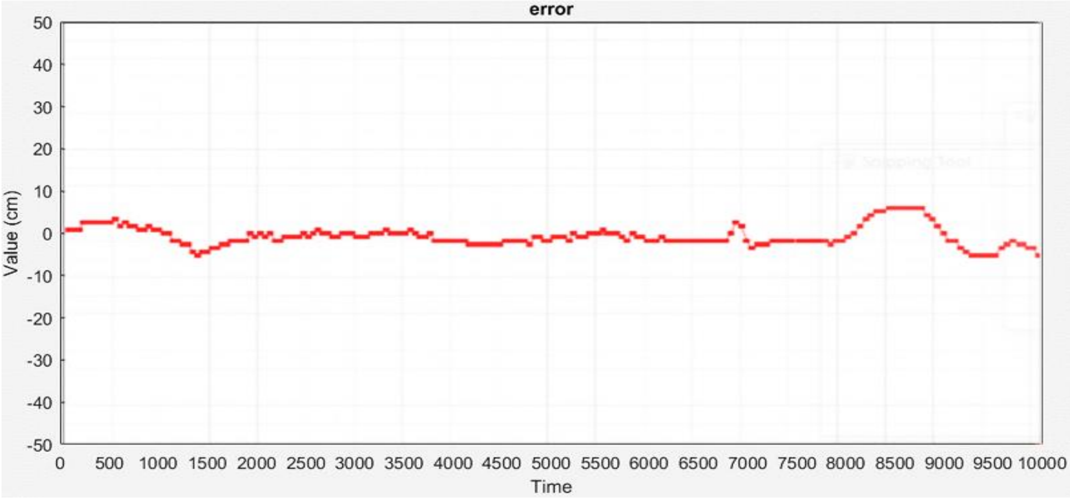

Figure 10. Line error chart when AGV runs a load of 50 kg

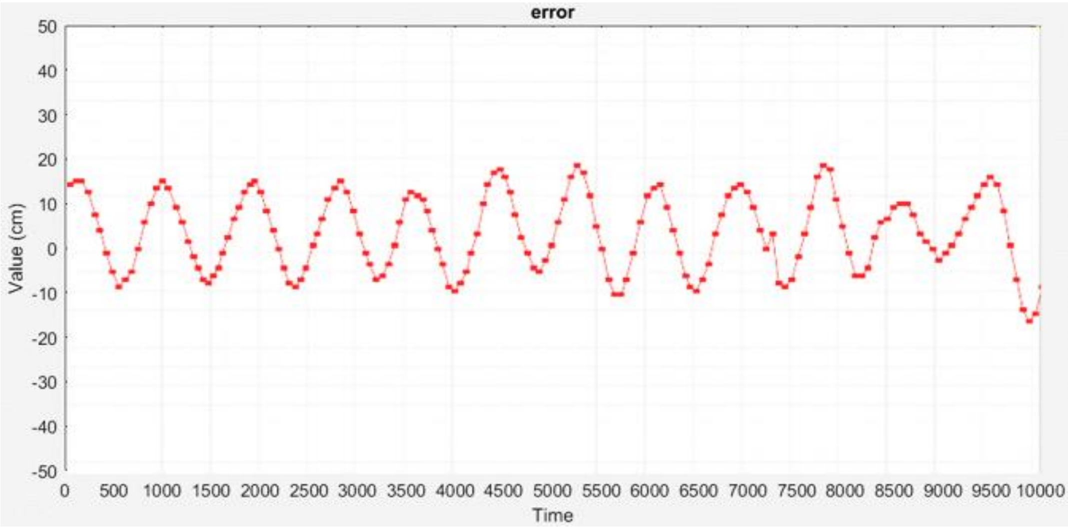

Figure 11. Line error chart with LT = 0.15 (m)

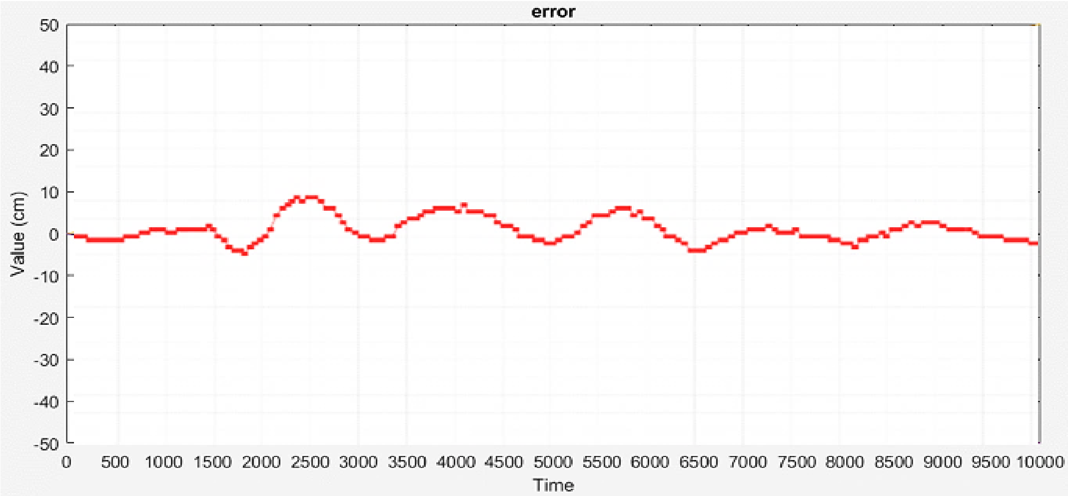

Figure 12. Line error chart with LT = 0.5 (m)

5. CONCLUSION

The article has successfully designed and built an AGV self-propelled robot with a PID control algorithm to control the speed of the AGV robot. They realize that the robot model AGV offers is compact, with low investment costs but high efficiency. Besides, the robot has followed the predetermined line, but there is still a line error when moving. To improve the control quality for the AGV robot in the factory, we can upgrade to use higher monitoring control devices such as AI cameras or upgrade control algorithms to make the system more and more accurate. Then fuzzy control, neuron. In addition, it is also possible to integrate communication capabilities for AGV robots via WIFI and Bluetooth by creating a closed working process with high expertise.

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