TẠP CHÍ PHÁT TRIỂN KHOA HỌC VÀ CÔNG NGHỆ -
CHUYÊN SAN KỸ THUẬT & CÔNG NGHỆ, TẬP 1, SỐ 1, 2018

Research and manufacture of automated guided vehicle for the service of storehouse

Anh Son Tran, Ha Quang Thinh Ngo*

***Abstract*—In the logistics, the storehouse management plays an important role. It is difficult to handle a large warehouse only with human. Therefore, an implementation of path tracking AGV robot is investigated as an automated solution. The analysis of hardware design and software programming is performed in this work. Besides, overall system is scheduled to realize the components. The use of the nonlinear Lyapunov technique provides robustness for load and automated supervise. From the AGV robots, it is clarified the design and control approach which is proposed in this paper.**

***Index Terms*—Motion control, robotics, Lyapunov control**

1 INTRODUCTION

Although robotics system has been popular and applied widely in human society, it is still a key issue for researchers and practitioners to explore. Generally, it can be classified into two sub-class: legged robot and wheeled robot. The shape and attitude of humanoid robot mimic the human body and characteristics [1, 2]. This kind is hard to use in industry because the motion of humanoid robot is based on legs. Whilst the wheeled robots are driven by rotation motion, there are various driving types of mobile robots such as omnidirectional [3, 4], differential-drive [5, 6], car-like [7] or tractor-trailer [8]. Automated Guided Vehicle (AGV) is a kind of intelligent wheeled robot, which appears widely for material transportation in production line [9], warehouse logistics [10, 11] and other industrial areas. Existing researches related to AGV for logistics are quite limited. There are huge former investigations in AGV, for instance stable control [12], obstacle avoidance [13], navigation [14] or software programming [15]. However, it lacks research topics in logistics system, especially for specific distribution center. In this situation, robot is equipped with capable loading, flexible motion, path tracking, collision avoidance or navigation. Therefore, it is necessary to carry out the infrastructure design of specific AGV including mechanical and electrical components, operating software and control algorithm that are feasible to manipulate in warehouse.

In this research, a proposed AGV and control approach for tracking a reference trajectory is investigated. The operator orders vehicle to take a mission to carry cargo from start point to end point. The autonomous vehicle is moved automatically to track the reference path. The color of line following is different with the color of background in warehouse. Under the line, there are RFID cards to help AGV robot to determine the locations. Hence, the coordinates of the AGV along the reference trajectory obtained from cards is stored into memories. This data will be feedbacked to host via wifi communication. A trajectory tracking control method is also proposed for AGV based on Lyapunov technique. The rest of this paper is as following. The content of section 2 is about system description. In section 3, the hardware design and system specifications of proposed AGV robot is described. Several specifications of robot and load are defined in detail. Section 4 illustrates AGV's modeling and

Received: October 17th, 2017; Accepted: April 09th, 2018; Published: April 30th, 2018

The authors would like to thank Ngo Ha Gia Co. Ltd. for helping us to support finance and workplace to verify experiment. We also thanks editors and reviewers for their valuable comments.

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proposed controller design for path following of AGV. Several simulation results in section 5 are carried out to evaluate the effectiveness of the proposed controller. Finally, conclusion is mentioned for future development in section 6.

2 SYSTEM DEFINITION

Fig. 1 shows the controller system that is developed based on the integration of embedded processor. Two wheels are driven by DC servo motors (50W per each). The industrial DC servo drivers receives control signal from CPU and isolates the over-current. Simultaneously, the signals of line follower sensors are feedbacked to CPU to track the reference trajectory. Tiva C is a mainboard from Texas Instrument that plays an important role to handle the control algorithm. There are six proximity sensors around AGV robot to notify the obstacles. To lift up the shelves in warehouse, AGV robot is equipped the electric piston.

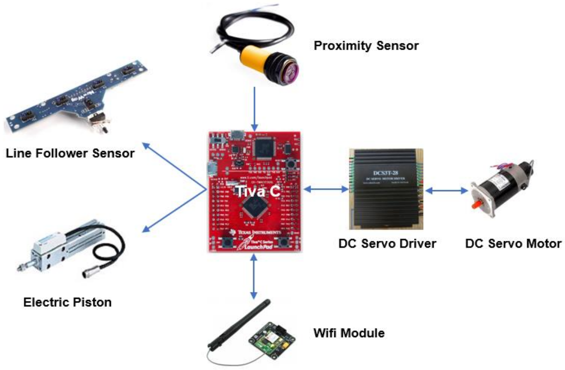

Figure 1. Diagram of the control system for AGV

Tiva C includes ARM Cortex M4F 32-bit microprocessor with 32 Kbyte of RAM memory and speeds up to 120 MHz. On average, this system can provide up to millimeter accuracy with an update rate up to 8 Hz. Whenever AGV robot receives the command from host PC, robot will output pulse to control DC servo motor and gets the signals from line follower sensors. Then, microprocessor based on the proposed algorithm calculates the signal control for next generation. If the obstacles occurs in front of robot, proximity sensor will notice AGV robot. The communication between robot and host PC is via wifi module that attached inside.

3 HARDWARE DESIGN AND SPECIFICATIONS

The AGV robot has rectangular-based shape with each rounded corner. It is made of 5mm steel to guarantee the reliability during the operation. The specifications of robot is listed in Table 1. To be able to lift up the load (approximately 20 kg), robot is equipped with electric piston and mobile-vertical platform. There are 6 proximity sensors that equally divided in head and tail of robot. From Fig. 2, head view of AGV robot is illustrated.

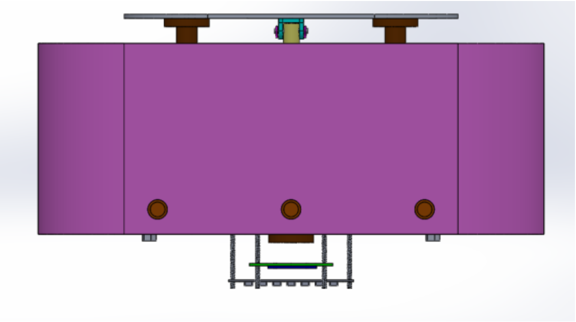

Figure 2. Head view of proposed AGV robot

In Fig. 3, the bottom view of AGV platform is designed to be able to work well in storehouse. A board of 7 line follow sensors is attached firstly to read the tracking error between command path and actual path. Besides, RFID module is at center of bottom platform to determine where robot locates.

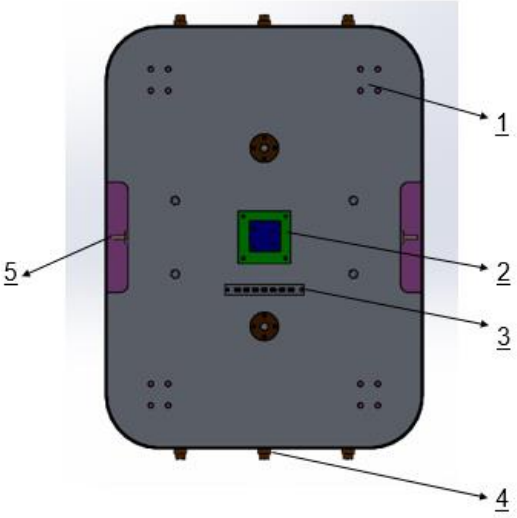

Figure 3. Bottom view of proposed AGV robot where 1. Castor wheel, 2. RFID reader, 3. Line following sensors, 4. Proximity sensor, 5. Driving wheel

When host PC gives out the order, the reference trajectory is planned. AGV start tracking the command line based on sensor. The embeded controller drives two centered orientable wheels to lessen tracking error. In each crossroad, there is a RFID card under the line. Therefore, RFID module returns the exact position of AGV to host PC. In multi robot control mode, server can specify which line is for one robot and others.

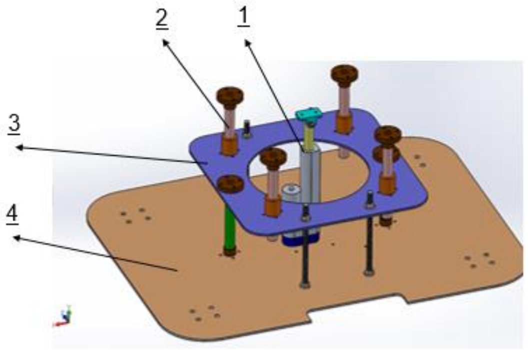

Figure 4. Inside architecture of proposed AGV robot where 1. Electric cylinder, 2. Linear slider, 3. Middle layer, 4. Base platform

The electric piston is located at center of AGV robot as shown in Fig. 4. In each direction, there are 4 rails to guide the mobile-vertical platform when load is lifted up.

Table 1. Specifications of designed AGV robot

Length (mm)	760
Width (mm)	640
Height (mm)	410
Weight (kg)	30
Wheels	4 (2 driving wheels, 2 castor wheels)
Velocity (m/s)	0.5
Driving motors	EC212A-4 (Ametek)
MCU	Tiva-C (Texas Instrument)
Power	2 battery 12VDC-28Ah
Navigation	RFID technology
Sensors	7 line following sensors, 6 proximities sensors

4 SYSTEM MODELING

Fig. 5 shows the AGV architecture and its symbol for its kinematic modeling. It is assumed that geometric centre C and the centre of gravity coincide. $q=[x,y,\theta]^T$ is defined as a position vector of AGV, v and ω are defined as linear and angular velocities of the platform, and L is the AGV inter-wheel distance.

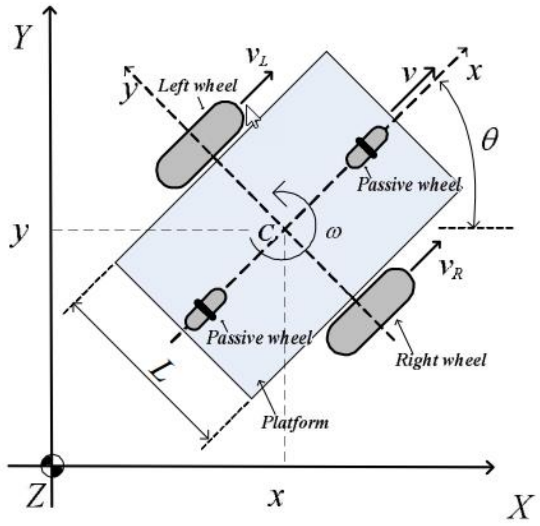

Figure 5. Symbol and structure of AGV robot

The kinematic equations of the AGV are as follows:

$$\dot{q}=Su \tag{1}$$

Where $u=[u_1 \quad u_2]^T=[v \quad \omega]^T$ is a velocity vector of AGV and $S=\begin{bmatrix}\cos\theta & 0\\ \sin\theta & 0\\ 0 & 1\end{bmatrix}$.

The velocities of the right and the left wheels of the AGV are:

$$v_R=v+\frac{\omega L}{2} \tag{2}$$

$$v_L=v-\frac{\omega L}{2} \tag{3}$$

Reference point is determined from desired trajectory in time $(x_d(t),y_d(t))$, desired velocity $v_d(t)$ and desired angular velocity $\omega_d(t)$ will be computed from path reference.

The desired velocity is expected as following.

$$v_d(t)=\pm\sqrt{\dot{x}_d^2(t)+\dot{y}_d^2(t)} \tag{4}$$

The sign of equation (4) depends on the direction movement of robot (forward or backward).

The angle of reference point in the desired trajectory is as following.

$$\theta_d(t) = \arctan 2\left(\dot{y}_d(t), \dot{x}_d(t)\right) + k\pi \quad (5)$$

If the direction movement is forward, then k = 0 and otherwise.

By taking derivative of equation (5), the desired angular velocity can be obtained.

$$\omega_d(t) = \frac{\dot{x}_d(t)\ddot{y}_d(t) - \ddot{x}_d(t)\dot{y}(t)}{\dot{x}_d^2(t) + \dot{y}_d^2(t)} = v_d(t)k(t) \quad (6)$$

Where k(t) performs the curvature of trajectory.

Using path planning $\left(x_d(t), y_d(t)\right)$ in advance, the kinematic parameters $\left(x_d(t), y_d(t), \theta(t), v(t), \omega(t)\right)$ to track the profile can be achieved absolutely.

The control algorithm is applied to drive AGV robot to follow the desired trajectory. Hence, the error modeling $e = \left[e_1, e_2, e_3\right]^T$ of AGV robot is considered in Fig. 6 as following.

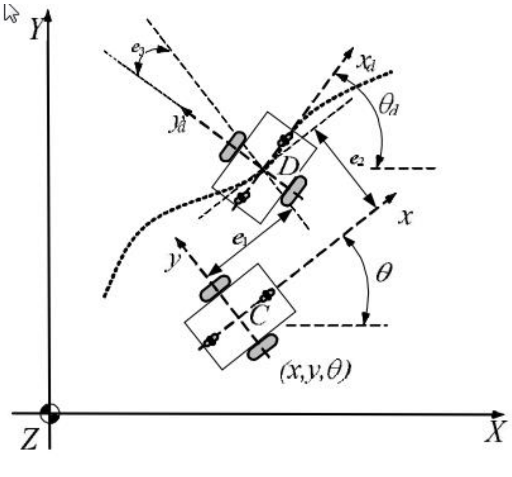

Figure 6. Error modeling of AGV robot

$$e = A\left(q_d - q\right) \quad (7)$$

Where

$$A = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_d - x \\ y_d - y \\ \theta_d - \theta \end{bmatrix} \quad (9)$$

The following error dynamics is illustrated.

$$\dot{e} = Bu_d + Cu \quad (10)$$

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = \begin{bmatrix} \cos\left(e_3\right) & 0 \\ \sin\left(e_3\right) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_d \\ \omega_d \end{bmatrix} + \begin{bmatrix} -1 & e_2 \\ 0 & -e_1 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (11)$$

The designed controller for AGV robot is formed.

$$u = \begin{bmatrix} v \\ \omega \end{bmatrix} = \begin{bmatrix} u_{r1}\cos\left(e_3\right) \\ u_{r2} \end{bmatrix} - \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \quad (12)$$

Where $u_{r1}\cos\left(e_3\right)$ and u_{r2} are feed-forward input signals, v_1 and v_2 are obtained from closed-loop scheme.

The differential equation that described relationship among deviation of error $\dot{e}$, tracking error e, desired signal u_d and adaptive signals $\left[v_1 \quad v_2\right]^T$.

$$\dot{e} = De + Eu_{d1} + Gv \quad (13)$$

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = \begin{bmatrix} 0 & u_2 & 0 \\ -u_2 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} + \begin{bmatrix} 0 \\ \sin\left(e_3\right) \\ 0 \end{bmatrix} v_d + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \quad (14)$$

By linearizing equation (14) at 'operating point', $e_1 = e_2 = e_3 = 0$, $v_1 = v_2 = 0$, linear modeling is demonstrate as following.

$$\dot{e} = Fe + Gv \quad (15)$$

Where

$$F = \begin{bmatrix} 0 & u_{d2} & 0 \\ -u_{d2} & 0 & u_{d1} \\ 0 & 0 & 0 \end{bmatrix} \quad (16)$$

Therefore, the closed-loop controller is as bellow.

$$v = Ke \tag{17}$$

Where

$$K = \begin{bmatrix} -k_1 & 0 & 0 \\ 0 & -\operatorname{sgn}(u_{d1})|u_{d1}|k_2 & -k_3 \end{bmatrix} \tag{18}$$

5 RESULTS OF SIMULATION AND EXPERIMENT

Several simulations are done on AGV system with parameters such as length L = 0.6m, system gains $k_1 = k_3 = 2.4$ and $k_2 = 39.2$. The initial information is listed in Table 2.

Fig. 7 performs the command line and actual line of AGV. The command trajectory has five parts with three straight line parts and two curved line segments. The radius of the first curve is 1.5m and the radius of the second one is 2m. In Fig. 8-10, the position error e_1, e_2 and e_3 are tested correspondingly. It can be seen that AGV robot tracks well in straight line parts and slightly inclines from command path has been. The tracking error e_1 in Fig. 8 performs how center point of robot tracks reference trajectory. In initial time, AGV may deviate from middle point of following line. After several seconds, the design algorithm controls robot back to reference path. In the corner, the tracking error e_1 of robot peaks at turn movement of 90°. Then, it decreases gradually.

Table 2. Parameters of system simulation

x_0(m)	y_0(m)	θ_0	ω_0	v_d	ω_{d0}
1	1	0	0	40	0

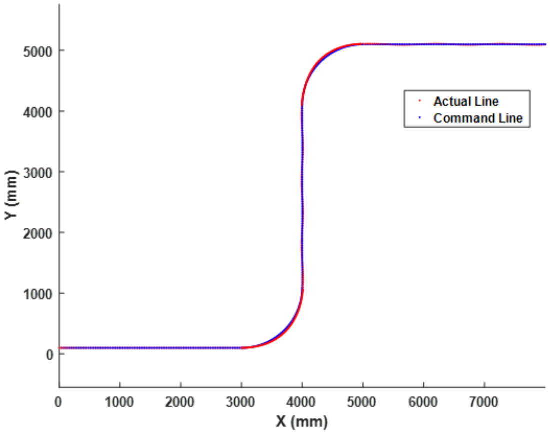

Figure 7. Error modeling of AGV robot

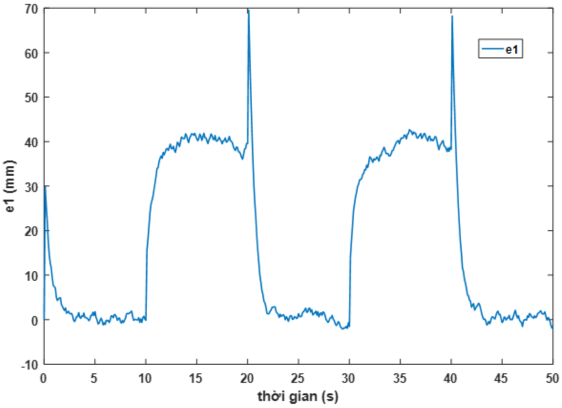

Figure 8. Error modeling e_1 of AGV robot

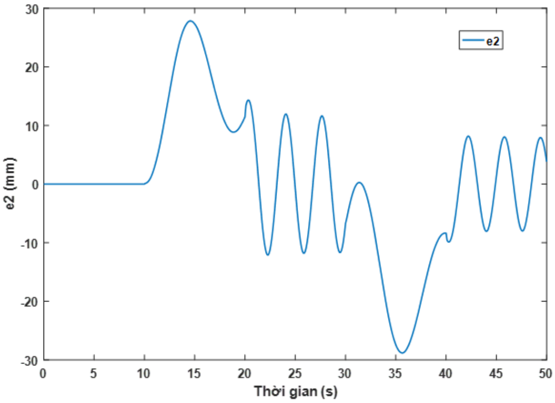

Figure 9. Error modeling e_2 of AGV robot

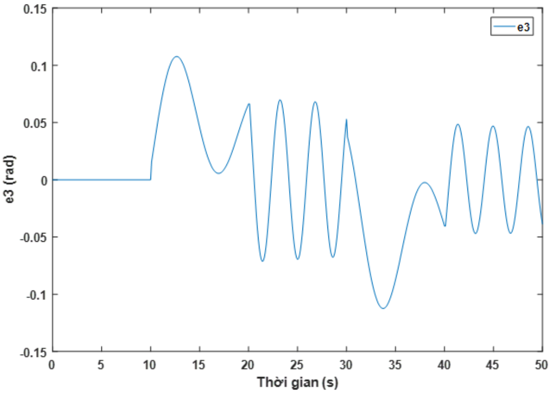

Figure 10. Error modeling e_3 of AGV robot

From Fig. 9, the error e_2 can be achieved from line following sensors. It measures horizontal distance between line and following sensors. At first time, the error e_2 of robot can be perfect. Later, the magnitude of e_2 is maximum when AGV changes direction. After two corners, robot can be stabilized regularly. Fig. 10 shows that the error e_3 is the most expensive one. In order to evaluate correctly, it is necessary to receive signal from laser sensor. From the values of angular error, controller have information of deviated angle of current location.

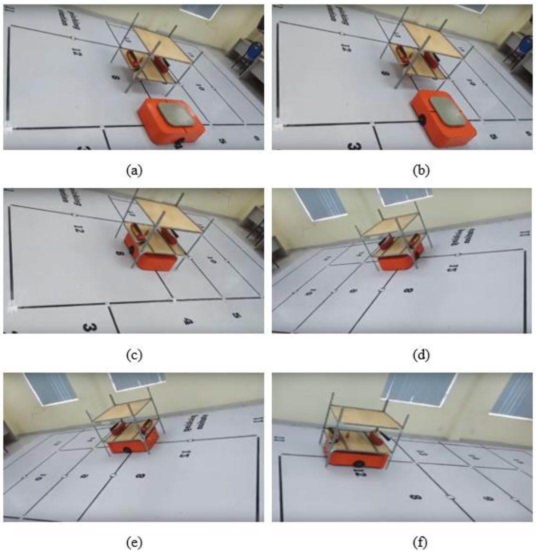
(a) (b) (c) (d) (e) (f)

Figure 11. Experimental test of loading task

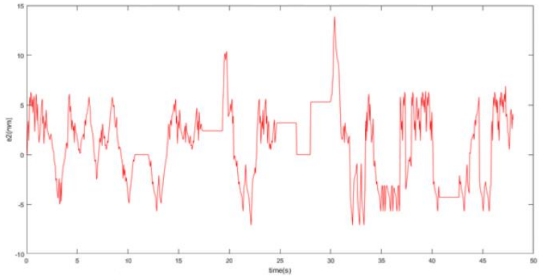

Figure 12. Experimental result of tracking error e_2

To validate the feasibility and capability of proposed design, several experiments are done in practical scenario tests as Fig. 11. The proposed design has been improved to meet the requirements of industrial automation. In Table 3, it is evaluated to implement the enhancements regarding to previous design. From Fig. 11, the signals from line following sensors feedback to controller to provide information of existing status. These signals imply particularly that controller is able to lessen the tracking error. The velocities of left and right wheel are demonstrated in Fig. 13. Due to differential drive structure of vehicle, the direction depends on gap among speeds. Whenever vehicle moves far from reference trajectory, control scheme drives to back by adjusting velocities of wheels.

Table 3. Comparison of current research and previous works

Previous works	Current Research
[9]: ☐ Fork-lift truck, three electrical motors for traction, steering and lift ☐ Laser navigation, embedded computer ☐ Controlled by joystick, cargo on pallet ☐ Local path planning ☐ Obstacle avoidance by laser scanner	☐ Differential drive, two driving wheels by motors, lifting by electric cylinder ☐ RFID-based navigation, embedded computer ☐ Controlled by host PC, cargo on shelves ☐ Global path planning ☐ Obstacle avoidance by proximity sensor
[16]: ☐ Differential drive, two driving wheels, one castor wheel ☐ Guidance by color sensor ☐ No loading capability ☐ MCU: Arduino-uno	☐ Differential drive, two driving wheels, two castor wheels ☐ Guidance by color sensor ☐ Loading capability ☐ MCU: Tiva-C

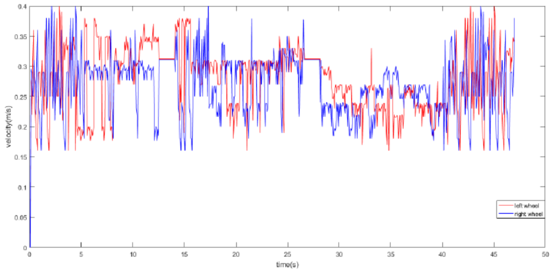

Figure 13. Experimental result of velocities in left and right wheel

Table 4. Comparison result of tracking error e_2 in simulation and experiment

Description	Simulation result	Experimental result
Average	3.721	4.684
RMS	4.935	6.103

Table 5. Comparison results of linear and circular tracking error e_2 in simulation and experiment

	Linear Trajectory	Circular Trajectory
Simulation	2.23%	4.15%
Experiment	3.77%	5.58%

Owing to signals from line following errors, the results of tracking error e_2 in experiment are compared to simulation in Table 4. It is easily seen that the proposed control scheme is feasible and robust to drive vehicle. In reality, the trajectory is complex and multipart. As a result, the test scenario must include linear path and circular path. Table 5 shows comparison results between linear and circular motion in simulation and experiment. From these results, the errors have bigger changes in curved line than in straight line due to shape of trajectory.

6 CONCLUSION

In this paper, an industrial AGV specializing for logistics field is developed. The proposed design has been improved lifting actuator, suitable physical dimension, similar loading capability, flexible motion and effective execution. First, the design of mechanical components and hardware are illustrated. Later, the modeling of AGV system is simulated to estimate performance. After that, the proposed controller for trajectory tracking is implemented to drive AGV. Finally, the results of experiments and simulations verify that the proposed design is able to achieve good performance. It is indicated that the proposed AGV is feasible and appropriated for distribution logistics center.

REFERENCES

[1] Henze B., Dietrich A., Ott C., “An Approach to Combine Balancing with Hierarchical Whole-Body Control for Legged Humanoid Robots”, *IEEE Robotics and Automation Letters*, vol. 1, no. 2, pp. 700-707, 2016.

[2] Teachasrisaksakul K., Zhang Z.-Q., Yang G.-Z., Lo B., “Imitation of Dynamic Walking with BSN for Humanoid Robot”, *IEEE Journal of Biomedical and Health Informatics*, vol. 19, no. 3, pp. 794-802, 2015.

[3] Huang J.-T., Hung T.-V., Tseng M.-L., “Smooth Switching Robust Adaptive Control for Omnidirectional Mobile Robots”, *IEEE Transactions on Control Systems Technology*, vol. 23, no. 5, pp. 1986-1993, 2015.

[4] Terakawa T., Komori M., Matsuda K., Mikami S., “A Novel Omnidirectional Mobile Robot with Wheels Connected by Passive Sliding Joints”, *IEEE/ASME Transactions on Mechatronics*, vol. 23, no. 4, pp. 1716-1727, 2018.

[5] Chen X., Jia Y., “Input-constrained formation control of differential-drive mobile robots: geometric analysis and optimization”, *IET Control Theory & Applications*, vol. 8, no. 7, pp. 522-533, 2014.

[6] Sun D., Feng G., Lam C.-M., Dong H., “Orientation control of a differential mobile robot through wheel synchronization”, *IEEE/ASME Transactions on Mechatronics*, vol. 10, no. 3, pp. 345-351, 2005.

[7] Akhtar A., Nielsen C., Waslander S.-L., “Path Following Using Dynamic Transverse Feedback Linearization for Car-Like Robots”, *IEEE Transactions on Robotics*, vol. 31, no. 2, pp. 269-279, 2015.

[8] Yuan J., Sun F., Huang Y., “Trajectory Generation and Tracking Control for Double-Steering Tractor-Trailer Mobile Robots with On-Axle Hitching”, *IEEE Transactions on Industrial Electronics*, vol. 62, no. 12, pp. 7665-7677, 2015.

[9] Humberto M.-B., David H.-P., “Development of a flexible AGV for flexible manufacturing systems”, *Industrial Robot: An International Journal*, vol. 37, no. 5, pp. 459-468, 2010.

[10] Wang T., Ramik D.-M., Sabourin C., Madani K., “Intelligent systems for industrial robotics: application in logistic field”, *Industrial Robot: An International Journal*, vol. 39, no. 3, pp. 251-259, 2012.

[11] Ngo H.-Q.-T., Nguyen T.-P., Le T.-S., Huynh V.-N.-S., Tran H.-A.-M., “Experimental design of PC-based servo system”, *International Conference on System Science and Engineering*, pp. 733-738, 2017.

[12] Hwang C.-L., Yang C.-C., Hung J.-Y., “Path Tracking of an Automated Ground Vehicle with Different Payloads by Hierarchical Improved Fuzzy Dynamic Sliding-Mode Control”, *IEEE Transactions on Fuzzy Systems*, vol. 26, no. 2, pp. 899-914, 2018.

[13] Tian D., Wang S., Kamel A.-E., “Fuzzy controlled avoidance for a mobile robot in a transportation optimization”, *International Conference on Fluid Power and Mechatronics*, pp. 868-972, 2011.

[14] Beji L., Bestaoui Y., “Motion generation and adaptive control method of automated guided vehicles in road following”, *IEEE Transactions on Intelligent Transportation Systems*, vol. 6, no. 1, pp. 113-123, 2005.

[15] Moura F.-M., Silva M.-F., “Application for automatic programming of palletizing robots”, International Conference on Autonomous Robot Systems and Competition, pp. 48-53, 2018.

[16] Hazza M.-H.-F.-A., Bakar A.-N.-B.-A., Adesta E.-Y.-T., Taha A.-H., “Empirical Study on AGV Guiding in Indoor Manufacturing System Using Color Sensor*”, International Symposium on Computational and Business Intelligence*, pp. 125-128, 2017.

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Nghiên cứu và chế tạo phương tiện tự hành có dẫn hướng dành cho công tác nhà kho

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Ngày nhận bản thảo: 17-10-2017; Ngày chấp nhận đăng: 09-4-2018; Ngày đăng: 30-4-2018

***Tóm tắt* – Trong lĩnh vực logistics, việc quản lý kho đóng vai trò quan trọng. Việc này khó khăn trong công tác quản lý kho quy mô lớn chỉ với yếu tố con người. Do đó, việc ứng dụng robot tự hành có dẫn hướng vào nghiên cứu như một giải pháp tự động hóa. Phần phân tích thiết kế phần cứng và lập trình phần mềm được trình bày lần lượt trong bài báo này. Ngoài ra, toàn bộ hệ thống được hoạch định để hiện thực hóa các thành phần. Kỹ thuật phi tuyến Lyapunov được sử dụng để cung cấp tính tự động hóa cho tải và giám sát tự động. Từ mô hình robot tự hành có dẫn hướng, thực nghiệm hướng thiết kế và điều khiển khả thi được trình bày trong bài báo này.**

***Từ khóa* – Điều khiển chuyển động, hệ thống robot, điều khiển Lyapunox.**