System Design Warehouse Management AGV for Packages Sorting in Supporting Industry E-Commerce

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Abstract. The e-commerce industry has used a lot of goods sorting technology using AGV (Automated Guided Vehicle). Goods, moved automatically using an autonomous system can increase the effectiveness and efficiency of the process. The benefits of Sorting AGV are felt when a large number of goods (thousands to millions) must be delivered within a single day. For that we need an adequate autonomous AGV system that has the features to handle the job. This research focuses on mechanical design with mechanization that can support the entire system and the application of AGV motion control in order to run well from varying packet loads to be delivered. For fast movement and ease of control, the Differential Drive Mobile Robot (DDMR) model is chosen which is equipped with a flipping mechanism to drop the packet. The controller based on PID control is applied for first functional movement experiment to review the robot performance from transported various loads. From the preliminary experiment the robot is able to lift the load up to 42 kg and no significant different of position and velocity responds.

Keywords: AGV, DDMR, e-commerce industry, PID control.

1 Introduction

With the increasing flow of online e-commerce, warehousing and logistics industry are getting new challenges. Today's logistics and transportation systems are required to have more capabilities than before, such as delivering small items, categorizing more goods, and speeding up sorting which will ultimately have an impact on speeding up delivery of goods and lower logistics costs. To make it happen, it is necessary to build an efficient system to sorting goods according to the required categories[1].

A modern solution to overcome the above problems is to use Automated Guided Vehicles (AGVs), which run with an integrated system for the complete handling of logistics work in warehouses and factories in the future. In general, AGV systems are used to automatically transport, sort and unload goods from one place to another in an industrial environment[2].

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Automated Guided Vehicle is a mobile robot that moves along a line on the floor or uses vision or laser. With its capabilities, making AGV very useful in moving materials in the manufacturing or warehouse area. Some of the industrial reasons for its use include manually operated material handling, good response to labor shortages, lowering the rate of work accidents in industrial areas, as well as cost and time efficiency.

One company that massively implements AGV in all warehouse management activities is Amazon. Amazon has more than 200,000 robots that work in a systematic, integrated, simultaneous, and secure way to pick up and place millions of items in warehouses. Amazon robot developed by Kiva robotics system has been designed for the sake of meeting growing consumer demands in e-commerce by using a better system to provide order fulfillment solutions. Amazon robot example can be seen in **Figure 1.**

Fig. 1. Amazon Robot Navigation, tracks, and rack/ashtray carrying method [3]

The most advanced robot design of Amazon's Kiva picking system is that it can run accurately by following the identification code on the ground in distribution center to avoid mistakes caused by collision between each other. At the same time, among hundreds of thousands of the mobile robot, the robots are designed that there would be no more than 10 a robot fails at the same time in each working of the warehouse. Therefore, the working accuracy of the Amazon robots can reach to 99.99% [3]. Which could greatly reduce the probability of human error. When kiva robot receiving orders of picking, they will line up under setting rules and came to picking area and then pickers would remove the goods. Finally, Kiva robots follow the path back to the storage area to wait for the next picking work.

Their innovation of Kiva robots is to embed two cameras as a navigation monitoring tool which can be seen in **Figure 2**, and the purpose is to be able to read the code. Moreover, the camera above is used for navigation, and the QR code label is attached under the rack pod. The camera detects the code of the tracking sticker on the floor [4]. Then, Kiva robots will move ashtray read the information on the code line stickers on the floor to learn their coordinates in the warehouse. This control system regulates the robot to always follow parts of the stickers on the warehouse's floor forming a path so that the body does not exist from the center of the available path.

Fig. 2. Camera mounted for rack/ashtray detection and positioning [3]

Kiva robot equipped with Lifting mechanism with a large screw turns to raise racks in the inventory area. Meanwhile, the wheels rotate in the opposite direction of the lifter to keep the rack motionless. Collision-detection system infrared sensors and touch-sensitive bumpers stop the robot if people or objects get in its way. Driving system with two brushless DC motors control independent neoprene rubber wheels which allows the robots to move at 1.3 meters per second [5].

After the successful of Kiva robotics system implemented in Amazon, many industries are now begin to develop similar robot for the same or other application to handle huge task of product handling in e-commerce business. The era of sorting AGV to sort millions of packet to be sent to the customer emerged in many country. One of the most famous manufacturer is Tompkins Robotics as seen in **Figure 3.**, namely t-sort. T-sort is much smaller that Amazon robot as it’s used for smaller capacity of load sorted for different places of delivery.

Fig. 3. Tompkins Robotics, a division of Tompkins International [6]

Knowing that sorting or warehouse type AGVs require operating in very large numbers of robot to be able to run all tasks, they need decision rules for robotic mobile fulfillment systems, so that the system can run simultaneously without any collision among robots [7]. According to research [8], avoiding obstacles (obstacles) automatically is the goal of mobile robot movement. Knowing environmental information with the help of sensors, becomes a very important aspect. The sensor that can be used is the proximity sensor. Sensor characteristics are still susceptible to interference or noise. The ultrasonic sensor is one of the most popular proximity sensors, because it has a fairly strong accuracy in detecting obstacles, this sensor is able to provide clear environmental knowledge to the robot [9].

While there are plenty of AGV shorting robot that have been researched, this paper provides detailed development of shorting AGV robot for specific load mass up to 40Kg. The robot is built based on DDMR system for ease of movement. In research [10], The Line Follower Controller using PD Method is an effective method to make the robot follow the line well, namely by designing the quantification of the error when the line position hits the sensor. Thus other AGV shorting robot, the design proposed in this paper have additional PID controller integrated inside for adjusting the actuator speed. This can ensure the robot capable to move at stable speed when carrying different load mass. The benefit from using this kind of speed feedback is it can help the robot to move efficiently as it can reduce the effect of speed slowdown due to increased load mass

2 Differential Drive Mobile Robot

Differential Drive Mechanism is mostly used for warehouse AGV system. It gives advantages in many aspects such as easy and flexible design, easy to control, and maneuverability. For mobile robot this system is called Differential Drive Mobile Robot (DDMR). It has illustration shown in **Figure 4.**

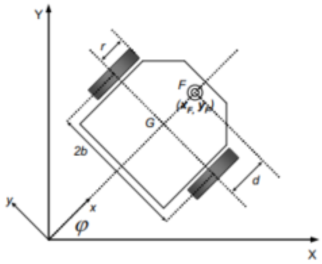


Fig. 4. DDMR in 2D cartesian [6]

The mobile robot discussed in this study is assumed to move in a horizontal plane, and to drive two left-right wheels which are driven separately (differentially driven mobile robot, abbreviated DDMR). The robot is assumed to be in a 2D region at coordinates XY Cartesian. The parameters are:

φ	Robot direction's angle
2b	Width of the robot measured from the centerline of the wheel to the wheel
r	radius of left or right wheel
d	distance between center point and 2 caster wheels
(x,y)	The reference coordinates of the robot body are in the center of the robot body

The robot moves around the Instantaneous center of curvature (ICC) or instantaneous center of rotation (ICR). By changing the speed of the 2 wheels, the ICC will move and a certain trajectory will be formed. At each time the left and right wheels rotate in a trajectory around the central axis of the ICR with the same average angular velocity. The movement trajectory can be seen in **Figure 5.**

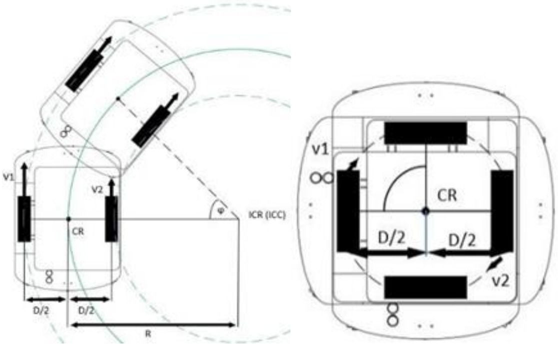


Fig. 5. (a) Robot trajectory (b) robot pivots

with DDMR turning condition $\omega = \frac{dP}{dt}$

$$\omega . \mathrm{R} = v_{CR}$$
$$\omega . \left(R + \frac{D}{2}\right) = v_1 \quad (1)$$
$$\omega . \left(R + \frac{D}{2}\right) = v_2$$

v_1 in equation (1) is the speed of the left wheel, and v_2 is the speed of the right wheel. D is the distance between the right and left wheels, and R is the calculated distance from the ICC to the midpoint of the distance between the two wheels or the turning radius to the ICC. Also note that v_1, v_2 and R are functions in time. To get R and ω, in equation (2, 3):

$$R = \frac{v_2 + v_1}{v_2 - v_1} . \frac{D}{2} \quad (2)$$

$$\omega = \frac{v_2 - v_1}{D} \quad (3)$$

For the speed of the CR point (the midpoint of the distance between the two wheels), it can be calculated as the average of the speeds v_1 and v_2 in equation (4)

$$v_{CR} = \frac{v_2 + v_1}{2} \quad (4)$$

The relationship $v_{R,L}$ with the angular speed of the right and left wheels is shown in equation (5).

$$V_R = r . \dot{\theta}_R \ ; V_L = r . \dot{\theta}_L \quad (5)$$

From the above equation is the basic kinematic equation related to the linear velocity (v) and angular velocity of the DDMR mobile robot. Meanwhile, the distance traveled by the left wheel S_L and the right wheel S_R can be seen in equation (6,7).

$$S_R = \varphi \frac{c + 2b}{2} \ ; \ S_L = \varphi \frac{c - 2b}{2} \quad (6)$$

$$S = \frac{S_L + S_R}{2} \quad (7)$$

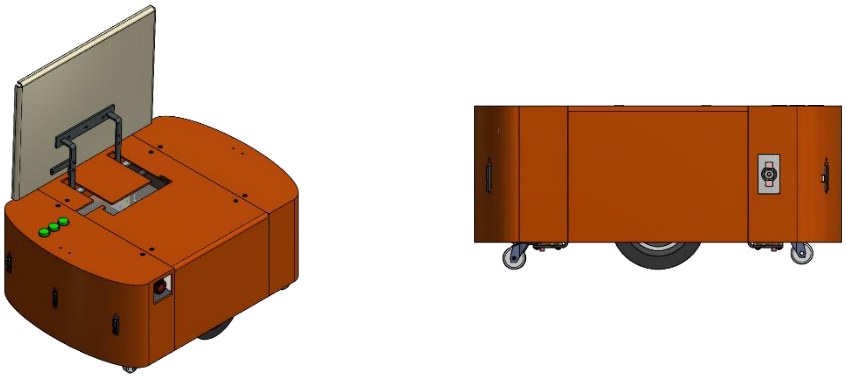
By subtracting the values of S_L and S_R, the following equation (8) is obtained:

$$S_R - S_L = \varphi\, 2b\,;\ \varphi = \frac{S_R - S_L}{2b} \quad (8)$$

3 Robot System Design

3.1 Mechanical Design

The robot is designed with basic principle model as described above. The robot frame design is made of several parts using iron plates with a thickness of 3mm and 4mm as the bottom main base. The robot has 4 caster wheels to hold the balance of the robot and 2 driving wheels, and has a spring as a suspension system when carrying a load which is located above the robot tray. the tray can be tilted by the inverting motor when the packet to be sent has arrived at the destination point of sorting. The design is shows in **Figure 6.**



‘(a) Sorting AGV Mechanical Design (b) Wheel and caster

Fig. 6. DDMR AGV robot design

3.2 Drive actuator spesification

The driving motor used has a gear ratio of 10:1. Rotational speed of 3000 rpm, so that the output speed of the motor axle is 300 rpm. The torque of the drive motor is 1.1 Nm, so the total torque is 2.2 Nm considering the type of robot is DDMR. Table 1 and Table 2 shows the detail of drive specification and general robot specification.

Table 1. Motor Drive Specification

Rated Output Power (w)	50
Power Source	24 VDC
Rated Input Current (A)	2,5 A
Maximum Input Current (A)	3,5 A
Torque	1,1 N.m
Permissible Overhungload (N)	300 N
Permissible Thrustload (N)	100 N
Maximum Speed (r/min)	300 r/min
Rated Speed (r/min)	250 r/min

Table 2. General Robot Specification

Dimension	410 × 300 × 185 (mm)
Controller	Raspberry PI + *Arduino* Mega, *Arduino* Nano
Flip Motor	DC motor 12V,1:55, 5 rpm, 18 kg.cm
Maximum load	40 Kg *(drive)*
Guidance	Line guidance, QR code & camera
Security	Infrared Sensor 60 cm (obstacle detection)
Line sensor	Led, photodiode
QR Code reader	Camera

3.2 Electronic System Design

To fulfill the robot's function, an electronic system is designed that is able to process several tasks simultaneously. These tasks are line detection, obstacle detection, QR Code reading, and robot control. The electronic system can be shown in **Figure 7.**

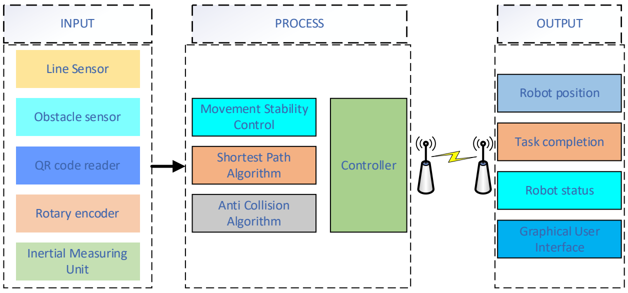


Fig. 7. System electronics design

Input data/sensors are processed in a controller-based microcontroller or embedded PC which functions for the stability of the robot's motion, finding the shortest path, and methods of avoiding obstacles. In addition, the electronic control must also be able to store a map of the work area so that the search for the shortest path can be carried out locally by each robot. The robot is equipped with a wireless communication system for robot status reports and receiving server commands or settings by the operator. For fast robot motion performance considering the large number of packets to be sent, a controller or processor with fast computing capabilities is needed, for example for reading QR Codes and related processes.

4. Path and Guidance

The path or trajectory of the robot is designed so that it is in the form of a grid with intersections where a QR Code is installed as a marker of the robot's position in the field or the location of the drop-off point. The robot work area must also consider a docking area for charging, a parking area, and an area for feeding goods to the robot which is automatically dropped on the tray above the robot. For more complex systems where the number of robots can reach thousands or tens of thousands of robots, the buffer area, transit, charging area, etc. other requirements need to be considered. A basic illustration of the existing maps and our experimental plan is as follows (**Figure 8.**)

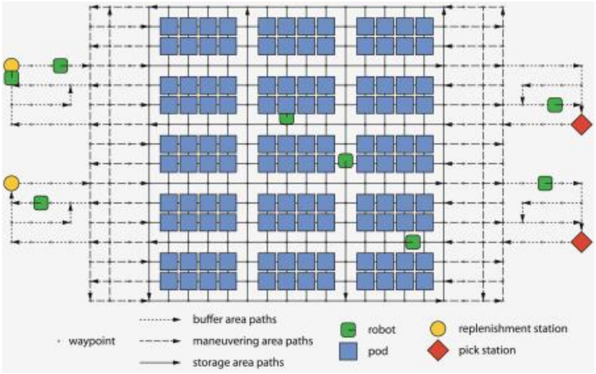


Fig. 8. A top view of an RMFS layout. The lines indicate the directed graph used for robot navigation [8]

In this research, the working area for experiment purpose is simplified as shown in **Figure 9.** The working are is design in grid composition where each crossroads is attached with QR Code for position and orientation of current robot status. In carrying tasks, robots operate by following commands and guidelines. In some conditions, based on information from the server, the robot must be able to make its own decisions, such as when the power state is reduced, the robot must park, transit to wait, and other states that have been comprehensively defined to avoid possible failures. To be able to move towards the destination precisely and stably, the robot was purchased with a guiding system, namely path guidance, position correction on the work area map based on QR Code, and motion stability guidance system based on IMU and odometry. To process all these processes, a computer system with high computational capabilities and good algorithms is required, especially if a large number of multi-robots are operated together.

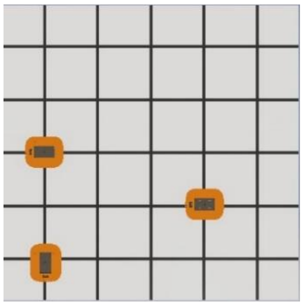


Fig. 9. Sorting AGV path or workspace

5. Controller Design

In this initial study, we tested a simple robot control system as a function test of the AGV system for sorting goods in a warehouse. We use PID control with feedback in the form of a rotary encoder sensor combined with a line sensor. The number of sensors installed in the line sensor package and the width of the line size also greatly affect the stability of the robot. The control system is also designed so that the robot is able to control the speed at the same time as the robot must also achieve the right and accurate position. The basic control block diagram that we implement in the robot is shown in **Figure 10.**

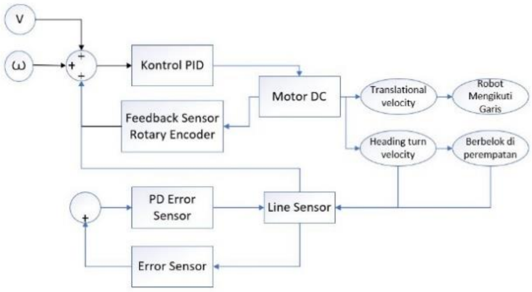


Fig. 10. Controller design

5.1 Flip test

This test is carried out to find out how much the robot's ability to carry goods with an estimated mass. Based on the calculation of the motor torque in section 3, the motor drive is capable of carrying a robotic load of up to 40 Kg with a torque equal to the required motor torque and specifications for both motors. And also to find out how the robot moves when following the line and turning. The test procedure can be seen in **Figure 11.**

Fig. 11. Flip Test

5.2 Pivot test

Before the robot goes to point x and point y, the first step that must be done is to test the direction of the face or rotation of the robot when making a rotation. The robot is rotated from 0 degrees to 90 degrees and vice versa. Then the robot is rotated back to a semi-circle, either turning right or turning left

Based on the direction of rotation or facing the robot, there are 4 kinds of rotation that can be done by the robot. The first test is that the robot is rotated to the left, i.e. the rotation is from 0 degrees to -90 degrees (to the left), then the robot is rotated to the right, i.e. the rotation is from 0 degrees to 90 degrees (to the right), and then the robot is rotated back to the right, namely the rotation from 0 degrees to +180 degrees (to the right). The test procedure can be seen in **Figure 12.**

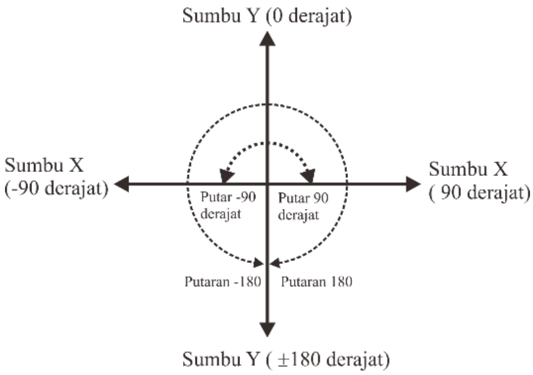


Fig. 12. Rotational direction of the robot

There are three ways the robot can rotate, the first is the robot rotates using feedback from the line sensor, the second is the robot rotates using feedback from the rotary encoder sensor, and the third is the robot rotates using feedback from the combination of the two sensors (linear) and rotary encoder.

When the robot rotates or rotates using feedback from the line sensor, the robot will detect the position of each sensor that detects the line. For a 90 degree rotation (facing left and right), the robot will rotate until the center sensor on the line sensor detects the line then the robot stops. As for the 180 degree rotation, the robot will rotate until the center sensor detects the line twice and then the robot stops rotating.

When using line sensors as feedback when the robot rotates, in the experiment the robot sometimes rotates not completely 90 degrees or even the robot rotates more than 90 degrees. Therefore, a combination of line sensors and rotary encoder sensors is used to increase accuracy when the robot rotates or changes its face direction. When the robot rotates, the robot will check the number of pulses generated by the rotary encoder by using a calculation for each desired rotation (the number of pulses needed to rotate) and simultaneously the robot will also check the position of the sensor affected by the line. To find out the number of pulses needed to rotate 90 degrees and 180 degrees, it can be obtained form I/O functional test during programming of the mobile robot. To test the direction of the robot's face or rotation when using a combination of feedback from the line sensor and the encoder rotary sensor, see the following **Figure 13.** In can be seen that the robot is performing correctly for its basic function movement while during the task. On the contrary, the robot is not preforming precisely as its really depend on density line guided sensor.

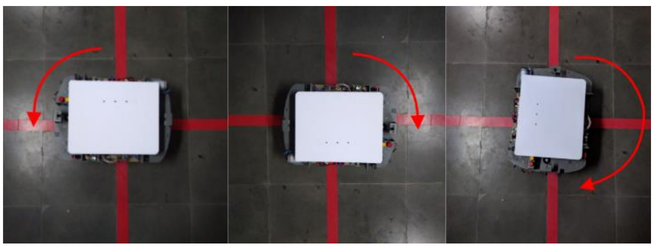


Fig. 13. Robot rotates -90º (left facing), +90º (right facing) and 180º

5.3 XY position test

The robot is tested on an actual work area, which is a grid that requires x and y positions to move. The test is done by providing input coordinates of the destination in the form of x and y positions, then the robot goes to the destination position by carrying goods and then placing the goods. After the robot puts the goods, the robot will return to its initial position, which is coordinates 0.0 in **Figure 14.**

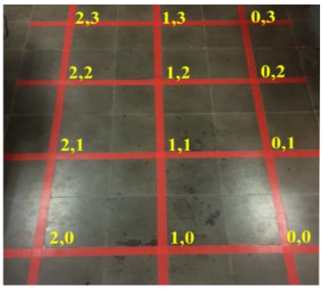


Fig. 14. Workspace of sorting AGV and coordinates system

In this test, the robot's work area is limited only to the x,y coordinates, which is 2,3. There are 3 goal positions in the robot's work area, the first position is at coordinates 2,3, then the second goal is at coordinates 1,2 and the third goal is at coordinates 0,3. The test starts with the robot carrying the goods in the initial position which is at coordinates 0,0 and moving towards the destination coordinates. After arriving at the destination coordinates, the robot will put the goods and then return to the initial position, namely at coordinates 0,0 as shown in **Figure 15.**

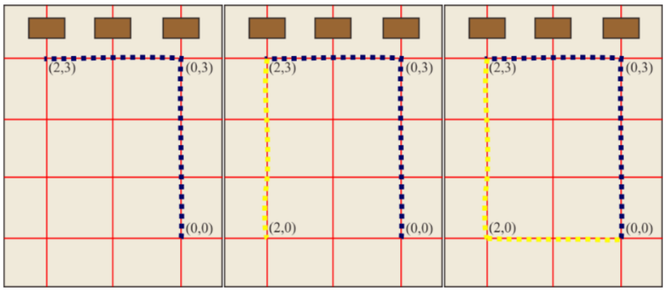


Fig. 15. Sorting AGV test at specified coordinates
(yellow line: information, blue line: robot trajectories result)

Based on the results of testing the robot to the position of the x and y coordinates, it can be concluded that the robot can move to the desired destination position properly. After the robot arrives at the destination position, the robot puts the luggage in the space provided and the robot returns to the starting position properly

5.4 Load test

This test is performed to show how consistent the robot able to maintain speed stability with different load. The first test is position test which is done by giving the robot set point coordinate and measure how long the time for the robot needed to reaches the destination. For the second test is velocity test which is done by testing the robot speed when carrying different load. The loads in this test are vary from 5 to 42 kg. The experiment is only applied for load carrying method not for flip mechanism as it’s very rare for sorting AGV would transfer the load up to 10 kg by flipping mechanism but conveyor system. From multiple experiment conducted, the optimum PID constant achieved respectively is P=4, I=9, D=0.1 for the robot to perform very good performance where no significant affection of velocity and position responds as it shown in **Figure 14.**

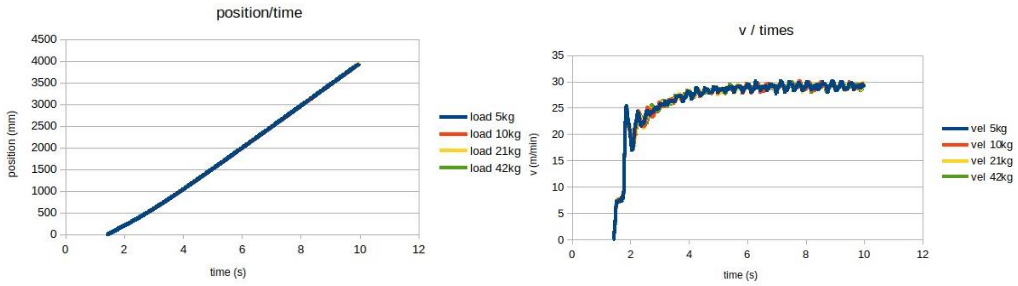


Fig. 14. Position and velocity test

6. Conclusion

This paper reports the results of research on the design of AGV systems for the needs of goods sorting in the e-commerce industry. The system has been designed, built and realized for small scale and to fulfill functionality. Basic experiments such as items dropping, turning pivots, testing the X Y position, and load carrying test have been performing according to the functionality. For load testing the robot has performing its ability to lift the load up to 42 kg with great performance in positioning and velocity. Next, further large scale simulations and experiment need to be more comprehensively and continuously performed to approach field realization.

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