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Design and Control of Material Transport System for Automated Guided Vehicle

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Abstract—**Automated guided vehicle (AGV) is used widely in many industrial applications to transport materials. A long-travel material transport system is designed and controlled in this paper for a unit load AGV to transfer the material pallet from AGV to the load stand and back, including a both-side three-level push-pull load-transfer mechanism and a programmable logic controller (PLC). AGV follows the path of the magnetic tapes in the floor, and locates itself according to the RFID tags beside the load stand. The PLC detects the docking position of AGV and the load stand, and controls the horizontal and vertical movement of the load-transfer mechanism by using a stepper motor and an electric push rod. The load transfer experiments of our AGV testify the performance of this material transport system.**

Keywords-automated guided vehicle; material transport; load transfer; mechanism control

I. Introduction

Automated guided vehicle (AGV) is a driverless, steerable, wheeled industrial vehicle that follows markers or wires in the floor, or uses vision or lasers. The largest consumer of AGVs is the automotive industry, yet AGVs are also common in other industries, including warehouses and distribution centers, paper, printing, textiles, and steel industries [1]. In these applications, AGVs have been found to increase routing flexibility, improve space utilization, ensure safety, and reduced overall operational cost [2].

According to the means of load transfer, AGVs can be classified as towing AGV, unit load AGV, pallet truck AGV, and fork truck AGV [3]. Towing AGV was the first type introduced and is still a very popular type today. It can tow single or multiple trailers by using hooks to provide traction. It has a simple structure and a capability of several times more materials than conventional unit load AGV. However, it has a difficulty to control the trailer position and has a larger turning radius. Unit load AGV is equipped with decks, which permits unit load transportation and often automatic load transfer. The decks can either be lift and lower type, powered or non-powered roller, chain or belt decks or custom decks with multiple compartments. Pallet truck AGV is designed to transport palletized loads to and from floor level, and it can eliminate the need for fixed load stands. Fork truck AGV is ideal for applications where automatic load pickup or delivery is required from floor or various height elevations. It has counterbalanced or straddled leg configurations depending on application requirements.

Initially, AGV paths are specified by electric wires placed approximately 1 inch below the ground [4]. It requires the expense of cutting the floor for the entire travel route, and it can not be easily removed and relocated if the course needs to change. Due to these disadvantages, Many AGVs begin to use tape in the floor as the guide path. The tapes can be magnetic, colored or other media. AGV uses the magnetic sensor to detect the magnetic tape and then follow the path [5], or uses the vision sensor (e.g. camera) to identify the colored tape [6-7]. In order to measure the position of AGV on the path, magnetic and visual coded signs can be used as artificial landmarks to express its absolute coordinates. Additionally, radio frequency identification (RFID) is regarded as a promising technology suitable for location and navigation of robot that can achieve a pervasive automation [8]. It can contain a large amount of data coded information compared to magnetic and visual signs.

We intend to design and develop an intelligent AGV guided by the magnetic tapes and located by the RFID tags to achieve the pervasive automation of materials transport and transfer, by combining the high guidance accuracy and setting convenience of magnetic taps with the high information capacity of RFID tags. The pervasive automation requires a close collaboration between vehicle guidance and material transport. This paper presents a long-travel material transport system for a unit load AGV having been equipped with the guidance control system. Section II proposes a material transport control methodology containing docking, retrieving and depositing for the unit load AGV. Section III designs a push-pull load-transfer mechanism that can pick up and down the material pallet in both sides. Section IV develops a PLC-based control system to detect the position of executive mechanisms and control their movements in the load transfer process. Section V presents the load transfer experiments, and a conclusion is given in section VI.

II. Load Transfer Methodology

Unit load AGV has many kinds of decks (e.g. lift, roller, chain, etc) to transport materials. In the consideration of the transfer requirements of automobile assembly production lines, we suggest a material transport control methodology to locate AGV beside the load stand accurately and retrieve and deposit the pallet automatically.

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A. Docking

A load stand is the fixed port where the material pallet is transferred from the AGV to the workstation and back. AGV movement near the load stand is controlled differently to its movement on the path since both a higher accuracy and a different obstacle avoidance technique are needed. In the close proximity to the load stand, AGV needs to navigate closer to obstacles and it must reach the designated point with greater precision. In order to achieve the accurate docking distance between AGV and the load stand, the real-time position of AGV needs to be updated continuously and AGV pose needs to be adjusted accurately.

Our AGV navigates on the specified paths by following the magnetic tapes, as shown in Fig.1. A magnetic guide sensor is mounted in the lateral center of AGV body, and it can detect the lateral deviation between AGV and the desired paths. Path tracking control is used to eliminate this deviation and keep AGV on the path. When the load stands are placed accurately beside the paths, the lateral position between AGV and the load stand can be guaranteed by controlling the lateral deviation. On the other aspect, the longitudinal position from AGV to the load stand is also very important to the docking process. It can be controlled by dead reckoning that accumulates the traveling distance by supposing pure rolling of AGV wheels. In fact, dead reckoning data tends to drift due to wheel slippage. It is necessary to reset the dead reckoning counters according to some artificial landmarks before AGV enters the docking area. Here we put several RFID tags on the path near the load stands, as shown in Fig.1. The longitudinal position begins to sum up by using dead reckoning after AGV reads the RFID tags. The RFID sensor is installed in the head of AGV, which is designed as a semi-open structure in order to avoid the shielded metal environment that may block the RFID signals.

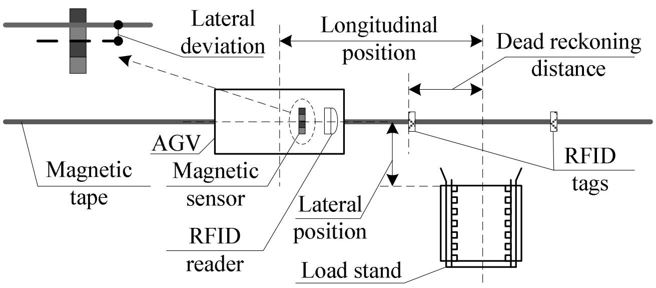

Figure 1. Materials transport path

B. Retrieving

Retrieving means AGV picks up the material pallet from the load stand. After AGV arrives at the accurate docking spot, it should check whether there is the designated pallet in the load stand. If it exists, AGV begins to pull it by using its load-transfer mechanism. AGV locates itself by making its side facing the front of the load stand, and the pallet needs to be pulled to AGV from its side. AGV should dock in the close proximity to the load stand in the lateral direction to reduce the transfer distance, as shown in Fig.2. Since the width of the load-transfer mechanism is no more than that of AGV body, the retrieving process is proposed as following actions.

(1) The mechanism moves downwards to make its convex blocks below the sockets of the pallet in the vertical direction.

(2) The mechanism moves towards the pallet to make its convex block 2 aligned with socket 1 in the lateral direction.

(3) The mechanism moves upwards to make its convex block 2 inserted into socket 1. At this time the load-transfer mechanism has grasped the pallet.

(4) The mechanism moves backwards to pull the pallet on AGV gradually. At this time block 2 (shown as the dashed lines) has aligned with the initial position of block 1 (shown as the solid lines) in the lateral direction.

(5) The mechanism moves downwards to release the pallet. At this time, the pallet has been placed on AGV.

(6) The mechanism moves towards the pallet to make its convex block 1 and 2 aligned with socket 1 and 2 respectively in the lateral direction. Note that at this time they are aligned on AGV.

(7) The mechanism moves upwards to make its convex block 2 inserted into socket 2 (block 1 also inserted into socket 1). So the load-transfer mechanism can hold the pallet firmly when the pallet is carried in the travel.

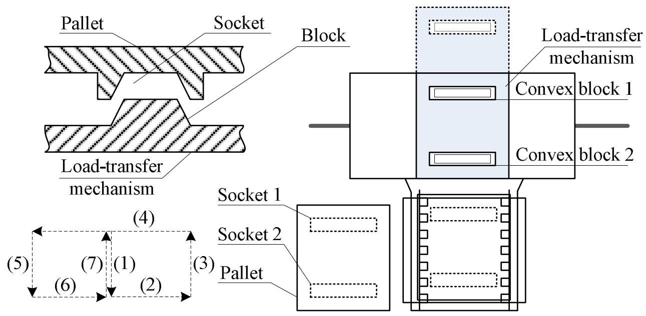

Figure 2. Load pickup approach

C. Depositing

Depositing means AGV puts down the material pallet to the load stand. AGV should contact the workstation and verify the load stand is free before the material delivery process starts. The pallet is pushed to the load stand from the side of AGV. It is a similar process of retrieving as following actions, shown in Fig.3.

(1) The mechanism moves downwards to depart from its initial position, shown as step (1) in Fig.3.

(2) The mechanism moves away from the pallet to make its convex block 2 aligned with socket 1 in the lateral direction, shown as step (2) in Fig.3.

(3) The mechanism moves upwards to make its convex block 2 inserted into socket 1. At this time the load-transfer mechanism has grasped the pallet, shown as step (3) in Fig.3.

(4) The mechanism moves towards the load stand to push the pallet on it gradually, shown as step (4) in Fig.3.

(5) The mechanism moves downwards to release the pallet. At this time, the pallet has been placed on the load stand, shown as step (5) in Fig.3.

(6) The mechanism moves backwards to align itself with AGV body in the lateral direction, shown as step (6) in Fig.3.

(7) The mechanism moves upwards to return its initial position that is always kept when AGV follows the paths.

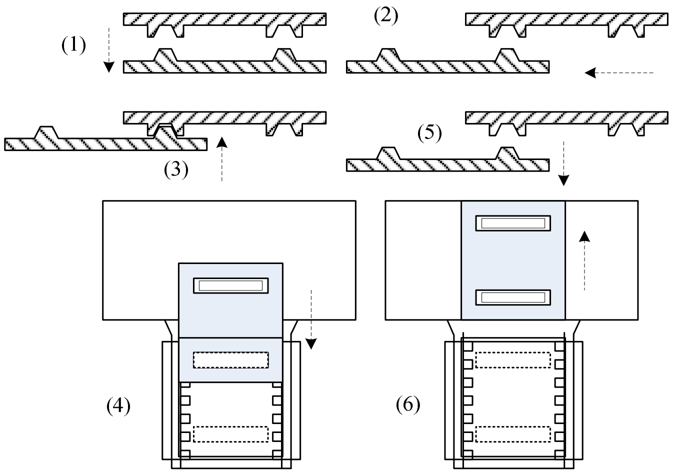

Figure 3. Load putdown approach

III. LOAD-TRANSFER MECHANISM DESIGN

In order to execute the retrieving and depositing behaviors required in the long-travel materials transport process, a both-side three-level push-pull load-transfer mechanism is designed. This mechanism contains a lifting module and a translational module, as shown in Fig.4.

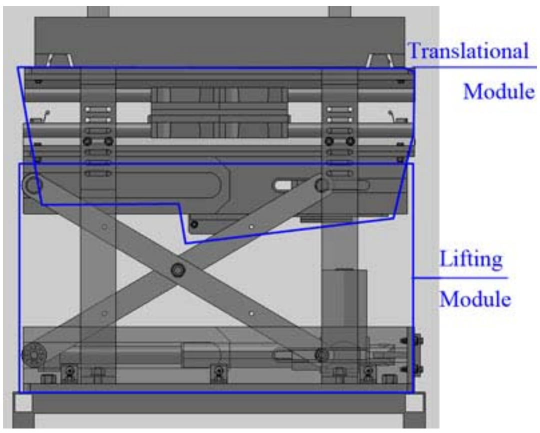

Figure 4. Load-transfer mechanism

A. Lifting module

Lifting module is able to change the vertical height of the platform by using a cross-shaped mechanism, as shown in Fig.5. Two rods are linked at the middle point by using a hinge 3 to form a cross shape. Hinge 1 and rail 1 are fixed on the upper surface of AGV body. Hinge 2 and rail 2 are fixed on the lower surface of the platform. An electric push rod mounted on AGV surface impels slider 1 to make it move forwards and backwards along rail 1. When slider 1 moves forwards, hinge 3 is pulled to move along arc 1, slider 2 to move along arc 2, and hinge 2 to move downwards in the vertical direction, shown as dashed shapes in Fig.5. As a result, the platform follows their movements and lowers itself. When slider 1 moves backwards, these parts moves in reverse trajectories, and their movements lift the platform consequently. In order to control two limit positions of the platform in the vertical direction, two travel switches can be placed at two ends of rail 1 accurately.

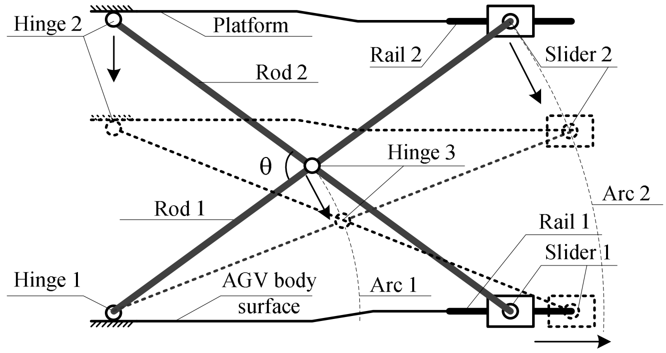

Figure 5. Lifting module

B. Translational module

Translational module is fixed on the platform and moved by lifting module upwards and downwards. This module is responsible for the lateral movement of their convex blocks by using a three-level planar mechanism, as shown in Fig.6. The low-level plane is the platform, and a stepper motor is installed on its lower surface. Gear 1 is linked with the motor shaft by using a key, and gear 2 is supported by a stationary mandrel. On its upper surface, rail 1 is fixed near the right border, and rack 2 is in its middle line. The middle-level plane (plane 2) has slider 1 and slider 2 fixed on its upper and lower surfaces symmetrically, and has gear 3 supported by another stationary mandrel in the center of its upper surface. The high-level plane (plane 3) has rail 2 mounted near the right border on its lower surface, and rack 3 in its middle line. Convex block 1 and 2 are located on its upper surface, as shown in Fig.2.

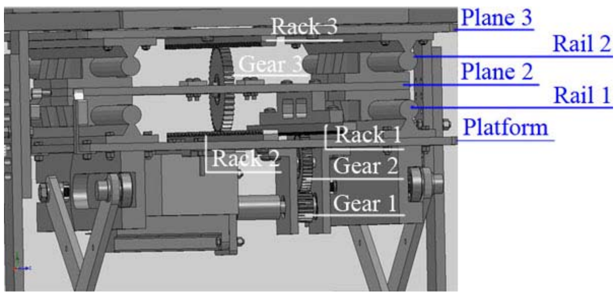

Figure 6. Translational module

The stepper motor drives gear 1 via the connecting key, and then gear 1 makes gear 2 roll on rack 1 by engaging tooth. Since the platform is fixed with lifting module, plane 2 moves relatively to the platform in the lateral direction. Gear 3 is pushed forwards by plane 2, and it rolls on the lower rack 2 of the platform and on the upper rack 3 of plane 3 simultaneously. If plane 2 is selected as the reference coordinate system, plane 2 and plane 3 have an opposite translational movement with the same speed rate. Therefore, when the platform is stationary, if plane 2 has a translational speed and displacement in one direction, plane 3 will have a double speed and displacement in the same direction. It is the basic principle on which the large-travel translational movement is implemented based by using the three-level planar mechanism with gears and racks. In order to control two limit positions and one initial position of plane 3 in the lateral direction, three travel switches can be placed at two ends and in the middle of rail 1 accurately.

IV. CONTROL SYSTEM DEVELOPMENT

A Siemens PLC S7-224XP CN is adopted as the controller of the material transport system, in charge of controlling the lateral movement of translational module by using the stepper motor, regulating the vertical movement of lifting module by using the electric push rod, and communicating with the on-board controller of AGV, as shown in Fig. 7.

The PLC has two high-speed impulse output ports Q0.0 and Q0.1, which can generate a PWM pulse or a PTO pulse. PWM means the duty cycle is variable by fixing pulse cycle and changing pulse width. They are accumulated by counters with the maximum value of 65535 and based on time unit of micro-second or millisecond. PTO is a pulse sequence of square wave with a fixed duty cycle of 50%. Their pulse number can change in the range of 10~65535μs or 2~65535ms. The stepper motor is controlled by a PTO pulse from Q0.0 and a direction signal from Q0.1. The PLC sends a pulse to make the stepper motor rotate over a step angle, and then checks whether the switch is triggered by the translational module.

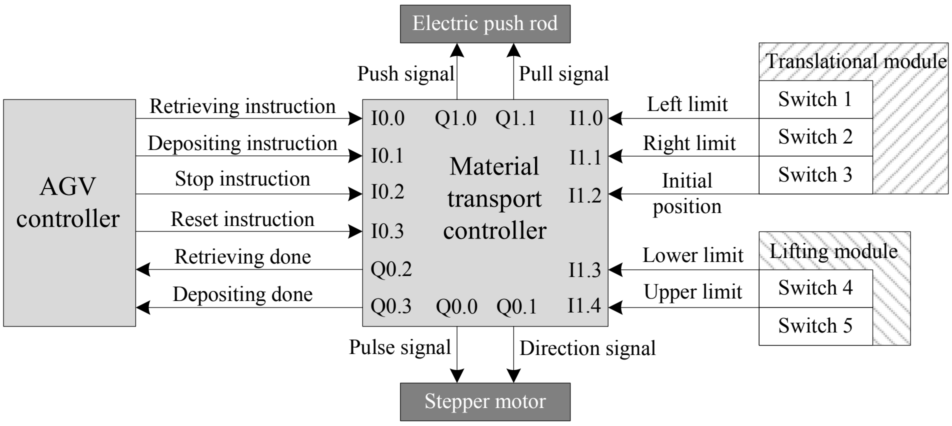

Figure 7. Material transport control system

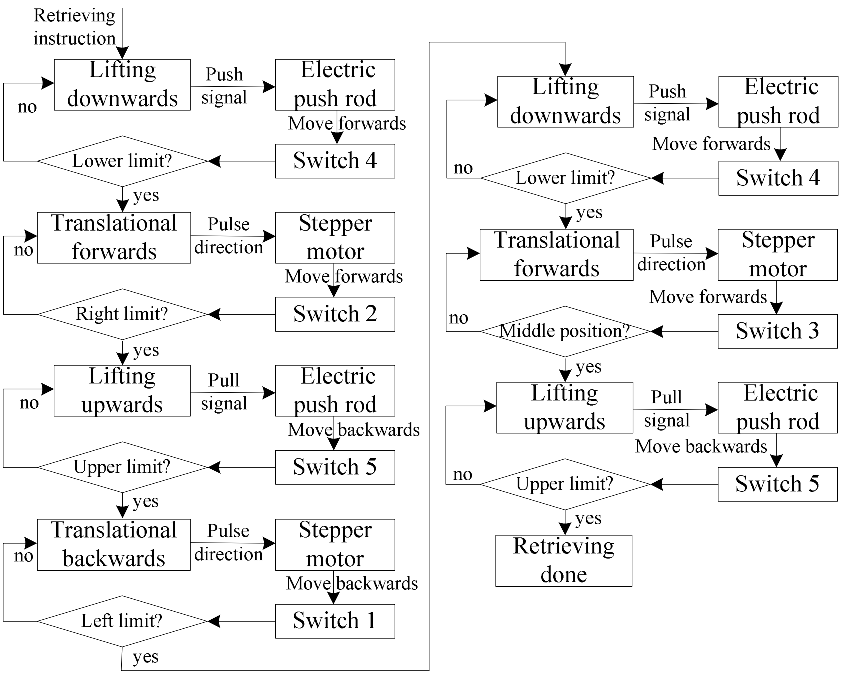

Figure 8. Retrieving control diagram

After AGV arrives at the accurate docking spot and checks its pallet target, AGV controller sends a retrieving instruction to the PLC that starts the entire control process, as shown in Fig8. Firstly, the PLC gives a push signal to the electric push rod, and it pushes sliders forwards to lower lifting module. When switch 4 sends a lower limit signal back to the PLC, it stops the push rod, and the convex blocks have moved below the sockets. Secondly, the PLC gives a forward pulse sequence to the stepper motor. The motor drives plane 2 and 3 towards the load stand. When switch 2 sends a right limit signal back to the PLC, it stops the stepper motor, and convex block 2 has aligned with socket 1. Thirdly, the PLC gives a pull signal to the electric push rod, and it pulls sliders backwards to raise lifting module. When switch 5 sends an upper limit signal back to the PLC, it stops the push rod, and convex block 2 has inserted into socket 1. Fourthly, the PLC gives a backward pulse sequence to the stepper motor. The motor drives plane 2 and 3 backwards AGV. When switch 1 sends a left limit signal back to the PLC, it stops the stepper motor, and block 2 has aligned with the initial position of block 1 in the lateral direction. Fifthly, the PLC gives a push signal to the electric push rod until switch 4 feeds back a lower limit signal. Convex block 2 has retracted from socket 1 and plane 3 has released the pallet. Sixthly, the PLC gives a forward pulse sequence to the stepper motor until switch 3 feeds back a middle position signal. Convex block 1 and 2 has aligned with socket 1 and 2 respectively in the lateral direction. Lastly, the PLC gives a pull signal to the electric push rod until switch 5 detects an upper limit signal. Convex block 1 and 2 has inserted into socket 1 and 2, and plane 3 has grasped the pallet again.

V. Load Transfer Experiments

In order to test the material transport system of AGV, the load transfer experiments are carried out in our laboratory. A ring closed path is laid out in the floor by using magnetic tapes. One load stand is placed on a designated spot accurately beside the path, which is used as a load pickup workstation as well as a load delivery workstation. Firstly, AGV starts at an arbitrary point of the path and moves towards the load stand. After it arrives at the accurate docking spot, it picks up the pallet from the load stand automatically. Then it continues to run on the ring path and comes back to the load stand when it finishes the circle of path. After it checks the load stand is free, it delivers the pallet to the load stand automatically, as shown in Fig.9. Fig.9.(a) shows the grasp operation that plane 3 holds the platform by inserting convex block 2 into socket 1 when the electric push rod pulls sliders backwards to raise lifting module. Fig.9.(b) shows the push operation that plane 3 pushes the platform to the load stand when the stepper motor drives rack 1 and 3 move forwards.

In the load transfer experiments, retrieving and depositing operations of AGV are executed continuously in a periodic way up to 8 hours. This satisfactory experiment result can only be achieved when the material transport system already has two control capacities at the same time. One is that AGV can locate itself accurately on the same spot beside the load stand at each time. So the longitudinal position and the lateral position between AGV and the load stand can be guaranteed strictly. Usually, the longitudinal position error is less than ±15mm, and the lateral position error is less than ±10mm. The other is that the load-transfer mechanism can arrive at the precise position to grasp the platform, push the platform to the correct position of the load stand, and pull the platform back to itself accurately. The experiments show that the translational module has a position error less than ±1mm, and the lifting module has a position error less than ±3mm. It is seen that the performance of the material transport system can be guaranteed by the high repeatable accuracy of AGV and its load-transfer mechanism.

(a) grasping the platform

(b) pushing the platform

Figure 9. Load transfer experiments

VI. Conclusions

This paper designs a long-travel material transport system for a unit load AGV. AGV follows the path of the magnetic tapes in the floor, and locates itself according to the RFID tags beside the load stand. A load transfer methodology containing docking, retrieving and depositing is proposed firstly. A push-pull load-transfer mechanism is then designed to pick up and down the pallet in both sides, including a lifting module that changes the vertical height of the platform and a translational module that moves their convex blocks in the lateral direction. Thirdly, a PLC-based control system is developed to detect the position of executive mechanisms and control their movements. Lastly, the load transfer experiments of our AGV testify the performance of this material transport system.

References

[1] I.F.A. Vis. "Survey of research in the design and control of automated guided vehicle systems," European Journal of Operational Research, 2006, vol. 170, pp. 677–709.

[2] T. Ganesharajah, N.G. Hall and C. Sriskandarajah. "Design and operational issues in AGV-served manufacturing systems," Annals of Operation Research, 1998, vol. 76, pp. 109-154.

[3] A. Kelly, B. Nagy, D. Stager and R. Unnikrishnan. "An infrastructure-free automated guided vehicle based on computer vision," IEEE Robotic and Automation Magazine, 2007, vol. 14, pp. 24-34.

[4] Chen C, Wang B and Ye Q T. “Application of automated guided vehicle (AGV) based on inductive guidance for newsprint rolls transportation system,” J. of Dong Hua Univ. (Engl. Ed.), 2004, Vol. 21, pp. 88-92.

[5] F. Tomoya, O. Jun, A. Tamio and et al. "Semi-guided navigation of AGV through iterative learning," IEEE Int. Conf. Intell. Rob. Syst., 2001, vol.2, pp. 968-973.

[6] G Beccari, S Caselli, F Zanichelli and et al. “Vision-based line tracking and navigation in structured environments,” IEEE Int. Symposium on computational intelligence in robotics and automation, 1997, pp. 406-411.

[7] Wu X, Lou P H and Tang D B. “Integrated motion control of path tracking and servo control for an automated guided vehicle,” Chinese J. of Mech. Eng., 2011, vol. 47, pp. 43-48.

[8] T. Deyle, N. Hai, M. S. Reynolds and et al. “RFID-guided robots for pervasive automation,” IEEE Pervasive Comput., 2010, vol. 9, pp. 37-45.