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Application of A Robotic System with Mobile Manipulator and Vision Positioning

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Abstract—**This paper introduces a robotic system for electric energy meter detection, which is composed of AGV, RGV, 6-DOF manipulator and vision positioning. AGV is used to transport the electric energy meter from warehouse to transfer station for detection and send them back after detection. The manipulator is installed on a RGV and used to pick the electric energy meter to the detection platform with the help of RGV. All electric energy meters are placed back to their original position after detection. The manipulator end-effcecto r has three parallel pneumatic grippers that can grasp three meters at the same time. A camera and three barcode scanners are employed in the end-effector for positioning and reading barcode respectively. This system has been put into use in factory.**

I. INTRODUCTION

The electric energy meter detection is necessary before the electric energy meters are put into use. There are millions of newly produced electric energy meters waiting to be detected every year. This work is simple and boring but important and requires repeated manipulation to electric energy meters. Compared with picking and place, the detection takes much more time in this work [1]-[2].

The process of the electric energy meter detection needs to carry the meters from the warehouse to the platform, detect for more than an hour or even several hours (three phase meter), and send them back to the warehouse after detection. If all these operations are done by humans, the cost and efficiency will be both beyond expectation. So we employ a robotic system that includes AGV, RGV and manipulator to complete all of these tasks.

The industrial robots are mostly in the form of wheeled vehicles and manipulators. The wheeled vehicles, such as AGV and RGV, are usually used to transport materials for a long distance. The manipulators can machine surface, assemble parts, weld, spray paint and do many other complicated things. Those robots usually work together and complete all kinds of tasks coordinately, which can be called an integrated system in production.

Researchers have already done much work about AGV [3]-[4], and the critical point is how to achieve automatic guide or path planning during locomotion. The automatic guide is widely used in industry and achieved by laying out magnetic things at its scheduled path. The AGV can also have an executing mechanism to accomplish some more complicated functions.

RGV is just like AGV except that it needs a specified railway [5]-[7]. The positioning of RGV is much easier than AGV at the cost of flexibility. RGV is usually used in the automated assembly line and can carry manipulators from one station to another. The drive mechanism usually takes gear rack or wheels that include positioning sensors.

This paper introduces a robotic system. The system is used for electric energy meter detection and composed of AGV, RGV, manipulator and vision positioning. In addition, the precision of vision positioning is identified through experiment.

II. OVERALL ARCHITECTURE

The robotic system, integrated with several advanced technologies that are mature enough to be widely used, is used for detecting the electric energy meters, and this system has been put into use in factory.

A. System Components

This system can be divided into several components, and each component cooperates with each other with the help of task scheduling system. We show the robotic system in Fig. 1 and Fig. 2.

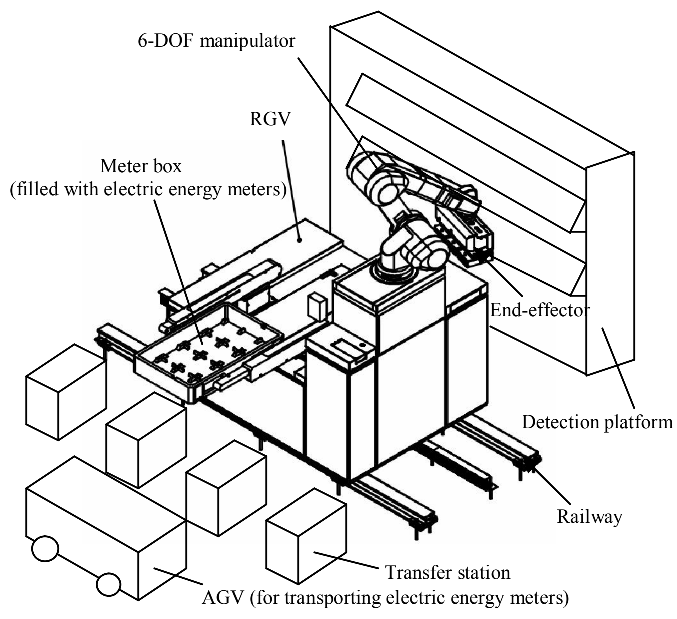

Fig.1 The wire frame model of the robotic system.

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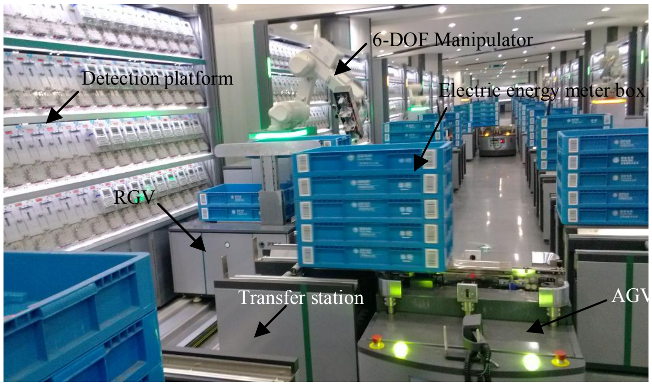


Fig. 2 The robotic system in factory. 6-DOF manipulator, RGV and AGV compose the main parts of this robotic system. There are also some auxiliary components, such as transfer station, detection platform and electric energy meter boxes.

AGV works between the transfer station and warehouse, its tasks are to transport the electric energy meters to the transfer station for detecting and send them back to the warehouse after detection. The ground is arranged with magnetic nails on the planned lines, which can be used for the automatic guide of AGV.

The AGV system has three main parts, motion mechanism, transmission mechanism and sensors. The transmission mechanism has a two-stage lateral drive and a two-stage vertical drive, which can be used to accomplish the transfer of boxes that are full of electric energy meters. The magnetic sensor works with the magnetic nails to achieve automatic guide, and the supersonic sensors are to detect barriers for the sake of safety.

The AGV will rest at specified areas if there are no more tasks, and it can go to the power supply station automatically for charging if the battery runs out. Workers can also control the AGV with the controller stored on it in case of emergency.

There are three transfer stations, the left one is used for the electric energy meters that are to be detected, the middle one is used for the empty boxes, and the last one is for the electric energy meters that have already been detected. Each manipulator is responsible for four to six detection platforms, which needs a transfer station for empty boxes. The left transfer station has a buffer mechanism to center the placement of boxes.

All electric energy meters are detected on the detection platform, and the tables that are on the platform can be adjusted by rotating theirs axes to best adapt to the manipulator. There are also some feature points pasted on the table corresponding to every meter position for the vision sensors. The station layouts some auxiliary lights to compensate the brightness of feature points and installs photoelectric sensors to detect whether there are meters or not.

The task scheduling system is installed in the server and runs all the time. AGV communicates with server via WLAN, and RGV communicates with server indirectly with the help of a PLC. The manipulator uses both Ethernet and PLC to interact with server. The status of each component is sent to the server, and then the task scheduling system can assign mission to every component without interference.

B. Working Flow

The main points of this system are meters-up flow (how to put the meters up to the detection platform) and meters-down flow (how to send them back to the boxes). These two processes are similar. Fig. 3 introduces the meters-up working flow.

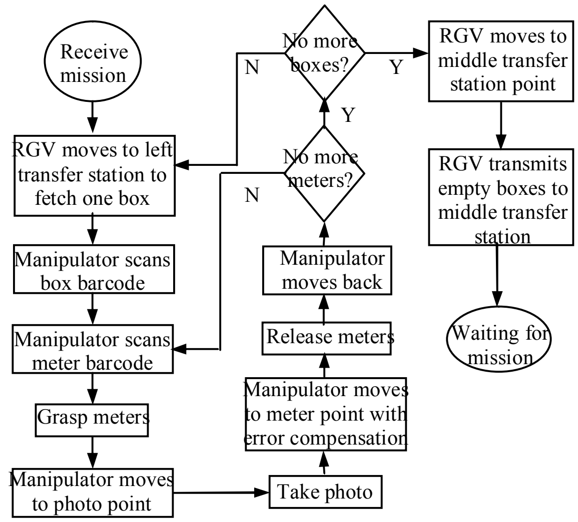


Fig. 3 The meters-up working flow. If the scanner (installed on the End-effecter) fails to get the barcode information during the working flow, the manipulator will adjust its position, and then the scanner will try again and again until it successfully gets the code. The manipulator will send an alarm to the server if the scanning times exceed the specified value. The same is true when the camera takes photos.

There are all kinds of sensors to detect the status of the meters-up working flow, only when one step finishes can the next one take action. The I/O information is mainly processed by PLC. Some information may be transmitted by Ethernet, such as position error compensation values and code.

There is no need to scan the meters during meters-down working flow, which is the main difference between these two processes. The manipulator will put all the meters back to their original position in the box after the meters' detection is finished, and the order is determined by user. The RGV will rest at one position after it finishes one mission or move to other working stations waiting for the next mission.

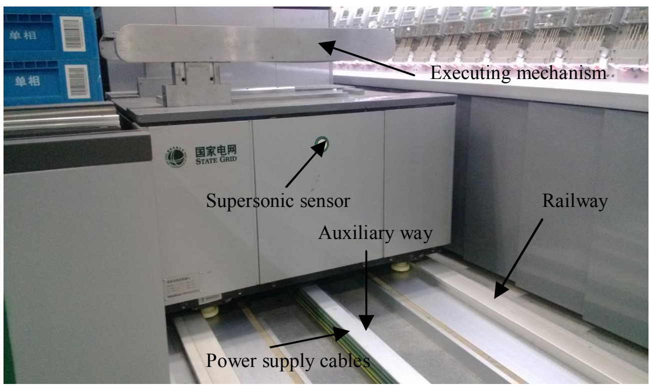
III. MOBILE PLATFORM

The manipulator is usually fixed on the ground, which can ensure the repositioning accuracy. But the manipulator workspace is limited under this condition. The more manipulators a system has, the more unreliable and costly it is. If a manipulator is responsible for several working stations, it would be better to fix the manipulator on a mobile platform.

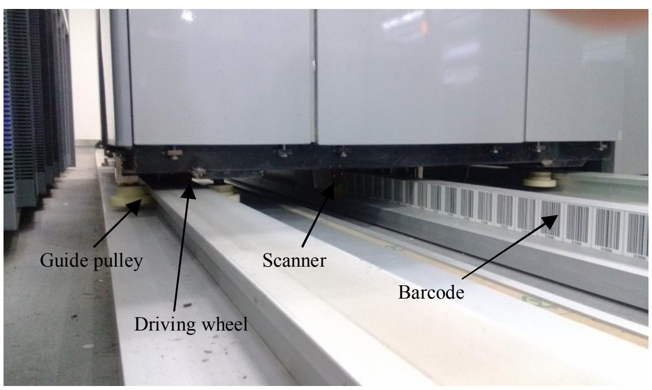
This system takes RGV as the mobile platform. The RGV not only transports the manipulator, but also has an executing mechanism that can work coordinately with the manipulator to accomplish each task. The mass distribution should be carefully considered to make the manipulator more stable during work.

A. *RGV Structure*

The RGV system is mainly composed of motion mechanism, executing mechanism and sensors. We show the detailed distribution in Fig. 4.



a) The executing mechanism of the RGV



b) The motion mechanism of the RGV

Fig. 4 The components distribution of the RGV system

Two supersonic sensors are installed on the both sides of the RGV respectively to ensure security in case of people or other barrier, as shown in Fig. 4 a). The power supply cables, composed of positive pole, negative pole and GND, are installed on the auxiliary way. These cables are connected with RGV by an electric brush, which can free the RGV from cable connection and improve the stability.

The executing mechanism has vertical and lateral motions with two-stage to save space and can reach as far as possible. The vertical motion is driven by an AC servo motor, and transmitted by belt and worm that can self lock to resist the gravity of meters. The lateral motion is driven by two AC servo motors (each motor drives one fork, one of the motors is active, and the other one follows up) and transmitted by steel wire ropes.

There is also a photoelectric sensor at the end of the fork to detect the number of boxes and whether there is a box available. Four fixture blocks are switched on by pneumatic drive after the forks reach to the box position, and then the forks can carry the box from the transfer station to RGV to be ready for the manipulator.

The locomotion of RGV is driven by an AC servo motor executed by two wheels, as shown in Fig. 4 b). So there may be slide of the wheels during running, which will cause an error to positioning. To decrease the error as small as possible, the auxiliary way lays out a series of barcode bands for position feedback. The barcode bands are numbered every four serial number, and work with the scanner that is installed on the RGV. The optical barcode image positioning technology, based on barcode recognition and machine vision, has been widely applied in photoelectric automatic measurement fields [8]-[12].

The guide pulleys are arranged around the railways on both sides, which are used to avoid the RGV running out the railway (caused by the differential speed of the driving wheels or other perturbations). There are also baffles on both ends of the railway for safety.

B. *RGV Control*

The RGV works with the manipulator independently and coordinately, which all owes to the task scheduling system. So the RGV needs to communicate with the task scheduling system (runs on the server) to get missions and send its working status. We show the communication mode of each component in Fig. 5.

The server creates two networks to cover the whole factory. One network is for normal use, and the other one is for reserving to ensure the stability of the automation system. Each RGV has installed a wireless AP that plays the role of communication between RGV, manipulator and the server.

The manipulator and AGV join in the wire network through a Hub that connects with the wireless AP, as shown in Fig. 5. All the sensors connect with PLC through the I/O ports and can directly transmit the signals to PLC for processing. The PLC has joined in a PROFIBUS with DP protocol that can control the scanner directly and servo drivers indirectly. All servo drivers compose a CAN bus with CANOpen protocol, and connect with PROFIBUS through gateways.

The wireless AP is fixed on the AGV making use of the attractive force of magnetic iron, which can be removed easily for repairing or substitution. Both the PLC and servo motor drivers are put in the RGV. The heavier the RGV is, the more stable the RGV can hold for the manipulator. But the load of the locomotion motor and energy consumption will largely increase under this condition. So we should compromise considering these two factors.

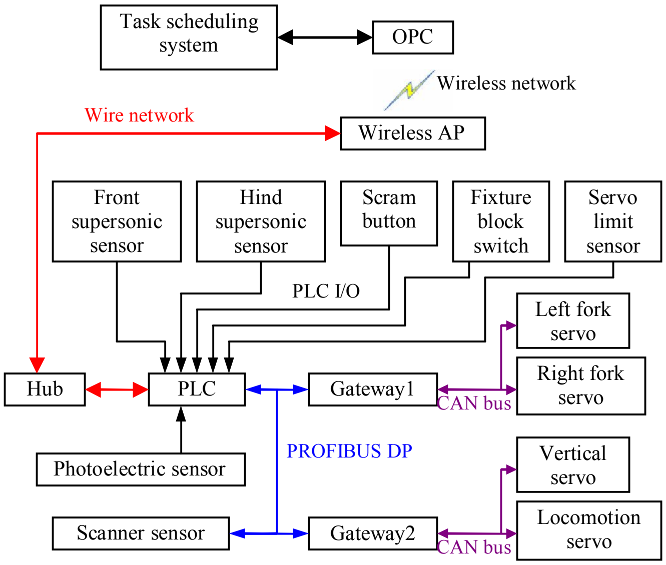


Fig. 5 The communication of RGV

IV. MANIPULATOR WITH GRIPPERS

The manipulator repositioning accuracy is the most important factor during point-to-point working process. The meters-up and meters-down working processes only need point to point control and allow a relatively small error.

A. Manipulator Structure

Researchers have done much about manipulator control [13]-[16]. We divide the manipulator into two components in the robotic system, the manipulator itself and the end-effector, as shown in Fig. 6.

The manipulator in Fig. 6 is a 6R (rotation joint) system, and each joint has mechanical limit for safety. The software system integrates the inverse kinematics and dynamics [17].

The manipulator can be controlled through trajectory planning and teach. The trajectory planning is used in surface machining or other continuous motion situations. We only need point-to-point mode of motion in the meters-up and meters-down working flow, so we teach the manipulator to get each coordinate by teaching box. The repositioning accuracy affects the performance greatly, but it's an intrinsic parameter of the manipulator and can't be changed.

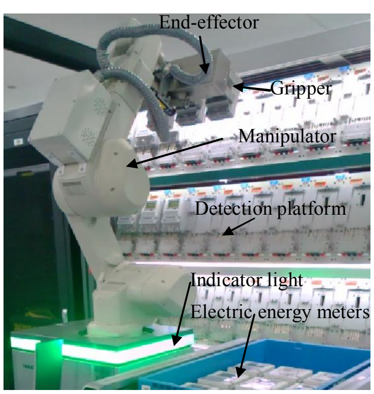


Fig. 6 The components of the manipulator. The manipulator is composed of mechanical system and software system. The mechanical system can be divided into manipulator and end-effector.

The indicator light has three statuses, green, yellow and red. The green light means that the manipulator is under normal work, the yellow light means that the manipulator is waiting for mission, and if the light turns to red, the manipulator is in fault status. If the light flashes when it's yellow, the manipulator is suspended by human. It's an unrecoverable fault when the light flashes with red color, and we can only reset the system to restore it under this condition.

The end-effector has three grippers that can grasp three meters at the same time, and each gripper is driven by pneumatic actuator. The interval of the meter box is smaller than the working station, so we use an auxiliary air cylinder to adjust the interval of the grippers. The end-effector has three scanners to get the box and meter information, and it also has a camera to get the error value of the grasp or release point.

B. Manipulator Control

The manipulator needs to communicate with the PLC at each manipulation to work coordinately and safely. The meter and box information also need to transmit to the database. Fig. 7 shows the communication mode.

All scanners communicate with the server directly through Ethernet. The box and meter information can be transmitted to database and offer guidance to pick out unqualified meters. The camera is also controlled by the Ethernet and transmits the error information to the manipulator for compensation.

The manipulator communicates with PLC through PROFIBUS with DP protocol, and it controls the camera light and grippers directly through its I/O ports. When the grippers and interval pneumatic actuator have finished their work, the electromagnetic sensor will send information to manipulator.

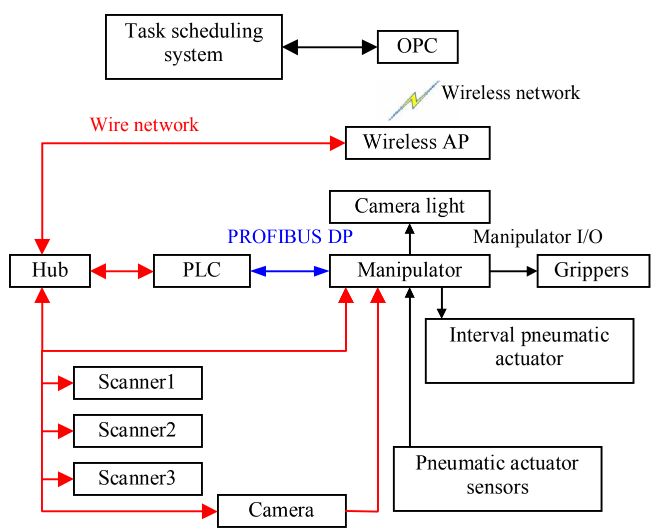


Fig. 7 The communication of the manipulator

V. Vision Positioning

The repositioning accuracy of the manipulator is extremely important in point-to-point working mode, and the error mainly results from the RGV and manipulator itself. So we add a camera to improve the repositioning accuracy. The effect of other uncertain perturbations to repositioning accuracy can also be decreased by the camera.

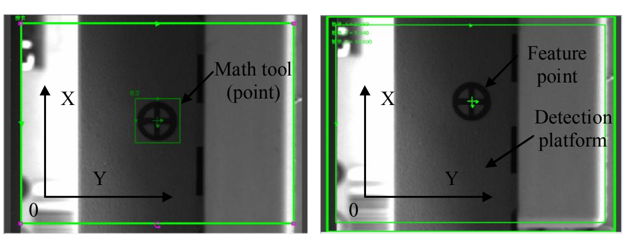
The vision system in Fig. 6 is composed of light, camera and lens. The camera has integrated the data processing chip to calculate the result and output to the manipulator. The light is used to compensate for the brightness in case that the scene is too dark, and the brightness of the light should be adjustable in case that the scene is too bright after compensation.

The camera communicates with the manipulator via Ethernet, as shown in Fig. 7, and it should be fixed rigidly on the end-effector to ensure the accuracy of the result. The camera also has software to form the template and define the output variables, and then the project can be downloaded to the memory of the camera.

Firstly, we need to form the template. We should connect the camera with a computer and make sure that the communication is correct. The camera should be located at the working height, and the height can't be changed, or else the template is invalid. Then we need to make a paper that is filled with point figures (the relative position is known) and paste the paper on the detection platform. After that, we turn on the camera to take a photo that includes those point figures. The software can recognize those points and mark them. We select those needed points and input the actual position values. After all these have been done, we save the project as a calibration file.

Once we've get the calibration file, we turn on the camera again to take a photo that includes the feature point and make the camera be the offline status. Then we circle the feature point with a mathematic tool, input the allowable matching rate, define the output variables, select the calibration file and save the project as a template file. Finally the camera can work in the manipulator project through the specified commands.

We conduct an experiment on the manipulator about the vision positioning. The template image and the actual gathering image are shown in Fig. 8.



a) The template image b) The image with offset

Fig. 8 The comparison between the template and actual image

The position that forms the template is the standard point that the manipulator refers to during the actual work. The camera takes photo after the end-effcetor gets to the photo point, and then the camera calculates the error (relative to the standard point). The manipulator will compensate for the error at the meter release or grab point.

We make end-effector of the manipulator move 5mm along the positive direction of the X axis in the experiment, and then we can get the calculated value by the camera. We have measured this value for ten times by moving the end-effector forward and back repeatedly. The experiment data is shown in Table 1.

TABLE I
THE EXPERIMENT DATA OF VISION SYSTEM

Time	Data (mm)					
	x1	x2	△x	y1	y2	△y
1	1.097	5.950	4.853	1.026	0.875	-0.151
2	1.067	5.956	4.889	0.968	0.893	-0.075
3	1.080	5.947	4.867	1.015	0.879	-0.136
4	1.071	5.963	4.892	0.993	0.902	-0.091
5	1.075	5.955	4.880	0.993	0.897	-0.096
6	1.078	5.967	4.889	0.998	0.892	-0.106
7	1.085	5.932	4.847	1.010	0.899	-0.111
8	1.073	5.947	4.874	1.003	0.880	-0.123
9	1.080	5.961	4.881	0.993	0.897	-0.096
10	1.086	5.948	4.862	1.005	0.880	-0.125
Ave	1.079	5.953	4.874	1.000	0.889	-0.111

The red data in Table 1 is got by calculating, and the black data is obtained from the camera. x1 and y1 are the values of the first point position, x2 and y2 are the offset values. Ave denotes the average value, △x and △y is the difference of those two points. The matching rate in each measurement is between 92 % and 93 %, much bigger than the allowable matching rate in template (50%). This high matching rate means that the experiment data is reliable.

The theoretical △x and △y values are 5 mm and 0 mm respectively. The average △x value in the experiment is 4.874 mm, and it's -0.126 mm smaller than the theoretical value. The average △y value in the experiment is 0 mm, and it's -0.111 mm smaller than the theoretical value. The motion of the end-effector is repeated, so we can get the conclusion that the backlash errors of the manipulator are about 0.126 mm in X direction and 0.111 mm in Y direction. The difference between the X and Y direction may be caused by the difference of moving joints. We should make a compensation for the manipulator during the reciprocating motion

We can know that the repositioning error is about 0.01mm by comparing the average value with each measurement value. The backlash error is a system error that can be decreased by compensation, while the repositioning error is a random error that can't be compensated. These two errors have not considered the data image processing error.

VI. Implementation

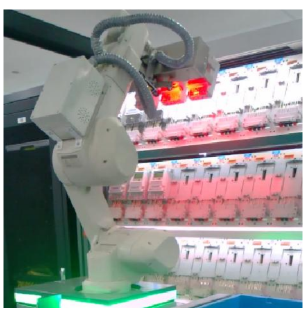
We apply this robotic system in electric energy meter detection to substitute for the human labor. The manipulator has three parallel pneumatic grippers that can grasp three single-phase meters at the same time. Fig. 9 shows the snapshots of the meters-up working flow.

a) Fetching one box

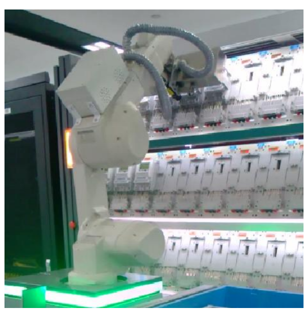
b) Scanning box barcode

c) Scanning meter barcode

d) Grasping three meters



e) Vision positioning



f) Releasing meters

Fig. 9 Snapshots of the meters-up working flow.

The end-effector and camera take remarkably important roles in the robotic system, and they work coordinately with RGV and manipulator. All this system concentrates on the meters-up and meters-down working flow.

The barcode scanner may fail to read the barcode, and the camera may also fail to achieve positioning in factory. We add an error processing program in the project to process these two accidents. If the error processing process still fails to handle them, manual handling is necessary.

VII. Conclusion

The whole robotic system can work well in factory. But there are still some problems that often appear accidently. The biggest problem is the reliability of the structure, especially the executing mechanism of RGV. The wireless network is also unstable at some time. We should pay more effort to these problems in the future work.

The main error of the manipulator is the backlash error. The RGV may also cause a relatively big error during its motion, and this error can also be detected by the camera and compensated together with the error from manipulator. In fact, if the total error value is within the acceptable one, the camera is only needed in teaching.

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