Application of a SCARA Manipulator with a Visual System in Industries

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Abstract

Generally, robotic arms are applied to settled and repetitive processes or high-risk tasks. In recent years, the robotic arms combined with sensors are developed to support rapidly variable operations gradually. This study was intended to investigate the integration of a SCARA robotic arm and a conveying system. The idea is to allow the robotic arm to pick up an object accurately and place it at the predetermined location as the object is transported horizontally on a conveyor belt to approach the working range of the arm while the conveyor belt works independently. Two GS-2744B magnetic sensors and MGL-50 magnetic strips were used in the system as the visual system and the switch to activate and deactivate the SCARA arm. A coordinate conversion algorithm was used to locate the origin of the visual system and that of the robotic arm at the same location. The objects' planar coordinates were calculated and transmitted to the arm through a RS232 interface. At the end of the arm an MCHB-32 parallel gripper was installed to snatch objects. The actual experiment shows that the arm travelled steadily with the conveyer belt and performed gripping at various conveyer speeds. When an object to be identified was placed at a different location, the arm recognized and operated in a corrected angle. Ultimately, the arm was able to track the object, grip and place it at the designated location, and a very stable result was achieved as the arm travelled along the predetermined path.

Keywords: SCARA robot, Visual system, Encoder, Magnetic sensor, Conveyor tracking, Coordinate conversion algorithm.

1. Introduction

Because of the upgrading industrial technology in recent years, production equipment becomes automatic and intelligent gradually so to enhance productive efficiency and quality, and to reduce cost of human resource. The automated production is one of the essential factors. Basically, robotic arms are applied to settled and repetitive processes in a factory with constant environmental conditions, or tasks where operators have low willingness to carry out. One of the major changes is that robotic arms [1] are applied in manufacturing industries widely. Most of industrial robotic arms are applied in robots in manufacture and production. The kind of robot is equipped with a multiple degree-of-freedom automatic robotic arms. They are applicable to each kind of manufacturing and assembly tasks. Their operations are practiced in accordance with the fixed environment designed by people. They can support faster and more precise manufacturing requirements.

Robotic arms are often applied to industrial automatic processes. For example, the coating robotic arms [2] have been popular in the vehicle industry. Through image capture, feature recognition, corresponding three-dimensional coordinates and rotation angle estimation based on the image feature, and fast matching route planning, the robotic arms can move to the accurate position. However, the automatic combination, coating, welding, assembly, and other operations may be restricted by the limitation of surface structure of parts that may impact Therefore, introducing the visual identification to automatic process will become a key technology for traditional industries.

Nowadays, there are many types and sizes of industrial robotic arms, such as linear robotic arm [3], Delta robotic arm, SCARA arm [4], multi-axis articular robotic arm[5], and so on. According to the structure of joints, there are two major types: One is three-axis or less, and the other is four-axis or more. In addition, based on the moving principle, these robotic arms are divided into rectangular coordinate type [6], cylindrical type[7], polar coordinate type [8], multi-articular type [9], etc.

A robotic arm can only operate specific tasks repeatedly. These specific tasks should be defined first and will restrict the functions of a robotic arm. The research targets on a four-axis SCARA robotic arm integrated with a vision system, and aims to survey its object grasping and putting operations on a conveyor. The introducing of a vision system is the key point. Through flat-image capture by a CCD camera, visualization processes, binarization [10], edge detection [11], feature extraction [12], object size and center identification, and other steps, the spatial orientation of the object can be decided. Also, its coordinates and flat deflection angles, θ_X and θ_Y ,

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can be estimated. Moreover, the information can be sent to the robotic arm system so that the robotic arm can be instructed to achieve an ideal motion control.

During system development, the moving velocity of conveyor should be considered. Too fast moving velocity will cause that the response time of magnetic sensor is not enough. It impacts the image fetching timing of a vision system, and then may cause that the robotic arm grasps nothing, presses targeted object, or practices other mistake operations. The end jaws can fetch objects by air-pressure conduction. No force-sensitive [13] sensor and other related sensors are used to protect objects. During the processing of the robotic arm, the speed of conveyor, rotation angle of objects, and other initial parameters should be set accurately. In the research system, the moving velocity of conveyor is set 2.9 meters/minute, 4.1 meters/minute, 5.2 meters/minute, and 5.8 meters/minute, respectively, to practice the object grasping and categorizing.

Section 2 will introduce the system architecture, section 3 will describe the test procedure and methods based on the system, and section 4 will discuss the test results and analysis. Finally, section 5 will conclude each characteristics and advantages of software and hardware in the research.

2. System Architecture and Design

As Figure 1, the system is controlled by PC, and two magnetic sensors [14] are set on the conveyor. When the first magnetic sensor reads the magnetic strip, it will trigger CCD camera to fetch images, and then send the images to the controller through RS232 for object identification. After the second magnetic sensor reads the magnetic strip, it will trigger the robotic arm to grasp objects, and to put the objects at the designated position. Through the encoder, the robotic arm gets pulse and converses the pulse to real unit value. The value is used to correct the displacement of a robotic arm for object tracking. Moreover, the contact wheel of an encoder should be ensured to contact the conveyor. The pulse number of the encoder is 4000 per cycle, and the diameter of contact wheel is 50mm.

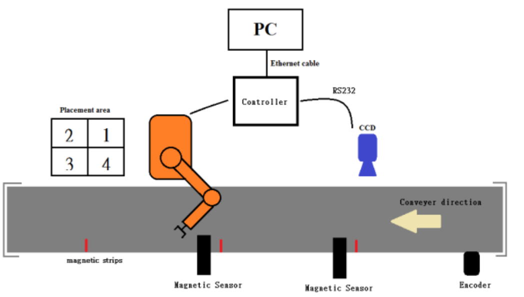


Figure 1: System Architecture Illustration

2.1 System Construction

1). Step1

There are two ways to set up the image server. One is to set up at a fixed position, and the other one is to set up on the robotic arm. The research selected the first way, and set up the CCD camera on the top of a conveyor. It is worth noting that the direction of CCD and SCARA should be fixed as Figure 2. The front of CCD should aim to the front of SCARA, and the CCD lens should parallel the SCARA.

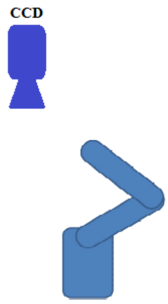


Figure 2: CCD Len Parallels SCARA

2). Step2

As Figure 3, the CCD lens will construct a real image frame with A4 size. It is used to correct the positioning function. In the system, the distance between the CCD camera and objects should keep 25cm.

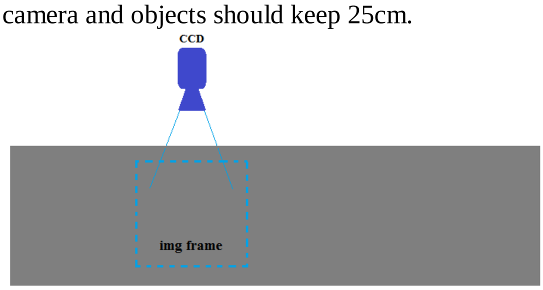


Figure 3: Image Frame Construction

3). Step3

After constructing the size of image frame, it is used to determine the fixed position of CCD sensor as shown in Figure 4.

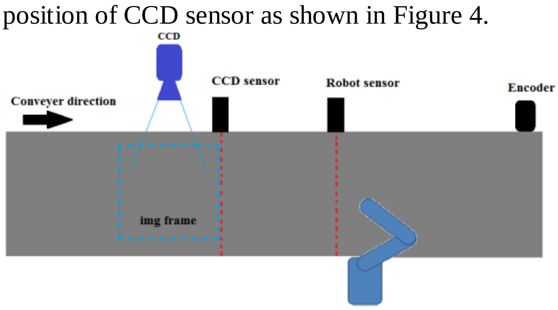


Figure 4: Fixing the Position of CCD Sensor

4). Step4

After fixing the CCD sensor, put the image frame on the conveyor temporarily. Move the conveyor and stop it when the SCARA touches left-top corner of the image frame. The purpose of the setting is to overlap the X and Y of the Cartesian coordinate of the robotic arm and the image frame. Then the robot sensor should be fixed at the right edge of the image frame as shown in Figure 5.

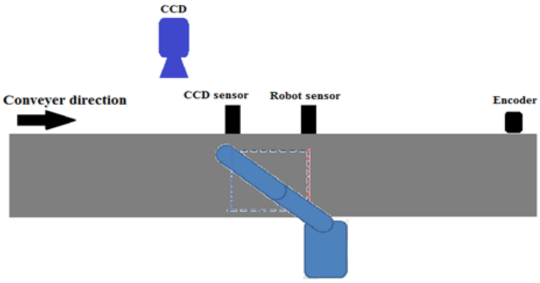


Figure 5: Fixing the Position of Robot Sensor

5). Step5

The contact wheel of an outer encoder should be ensured to contact the conveyor.

2.2 Magnetic Sensor

The research adopts magnetic sensors to trigger the robotic arm and CCD camera. The GS-2744B magnetic sensor and MGL-50 magnetic strip are adopted to the major detecting devices in the system. In addition, a 50mm×30mm magnetic strip is constructed, and the height between the magnetic sensors and magnetic strip is 10mm as shown in Figure 6. Moreover, the distance between the two magnetic strips should be more than the distance between the two magnetic sensors. Also, only one object can be put between the two magnetic strips.

Figure 6: Magnetic Sensor

The four modes of the magnetic sensors are listed in Table 1. The modes can be switched by changing the SEL1 and SEL2 pins. Since the conveyor operates straight, the straight mode should be selected to be the switch of CCD lens and the robotic arm. Through the GATE pin, the magnetic sensors transfer a low potential to form a loop for detection of the magnetic strip as shown in Figure 7.

Table 1: Mode Setting of Magnetic Sensor

Mode	SEL1	SEL2
Straight	L	L
Right branch	L	H
Left branch	H	L
Not selected	H	H

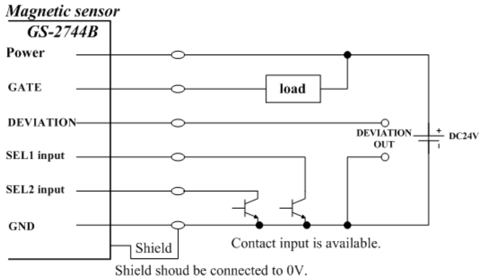


Figure 7: Connection Diagram of Magnetic Sensor

2.3 Encoder

Because the conveyor cannot be stopped during the operation, an incremental encoder is selected for system requirement as shown in Figure 8. The output format of the encoder adopts A/B-phase pulse input. For example, for an encoder with 4000 pulses per cycle, the diameter of contact wheel is 50mm for pulse count.

$$\frac{50\times\pi}{4000}=0.039\left(\frac{mm}{pulse}\right)$$

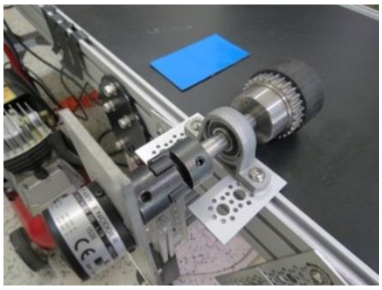


Figure 8: External Encoder Illustration

Based on the pulse of external encoders[15], a robotic arm can align the moving position, speed and route path of end-effector to objects, and then carry out the function of object tracing. Without any external encoder, a robotic arm can only move to the original point of the object captured by the CCD camera instead of the accumulated y-coordinates. In Figure 9, the robotic arm without any external encoder can only be applied to operations under condition of constant and static moving trajectory.

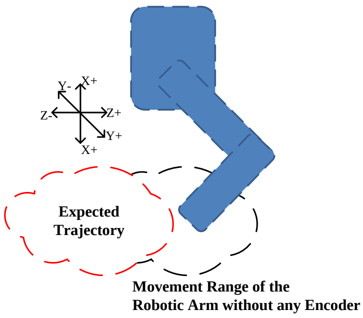


Figure 9: Illustration of Aligned Trajectory of the Robotic Arm

2.4 End-Effector Jaw

A jaw is set up on the arm end for object grasping. The jaw is controlled by air-pressure for open and close actions. The I/O port of controller sends potential to the coins of electromagnetic valve to change internal channels. The open/closed function of a fluid channel is controlled by the electromagnetic valve through the up/down operations of internal armature. Moreover, the operation of internal armature is controlled by the coin through make/break operations. The internal structure is illustrated in Figure 10.

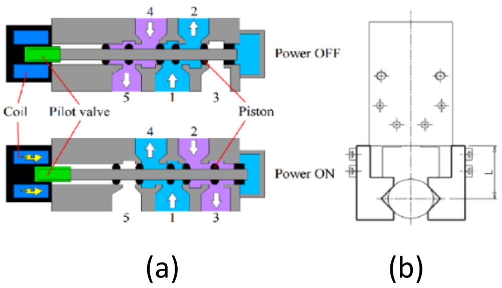


Figure 10: (a) Electromagnetic Valve Principle (b) Parallel Jaw[16]

3. Test Procedure and Methods

In addition to the system construction, the image identification aims to the PET bottle caps for the grasp/put operations of a robotic arm. First, an original image is saved, and processed through gray-scale, filtering, binarization, and so on. Then the origin of the PET bottle under the CCD camera is calculated to deduce the coordinate value for object grasping by the robotic arm. During the process, each fetched image is saved in the computer for image identification and comparison. The required rotation angle of the object can be calculated real time, and fed back to the robotic arm for angle correction as shown in Figure 11.

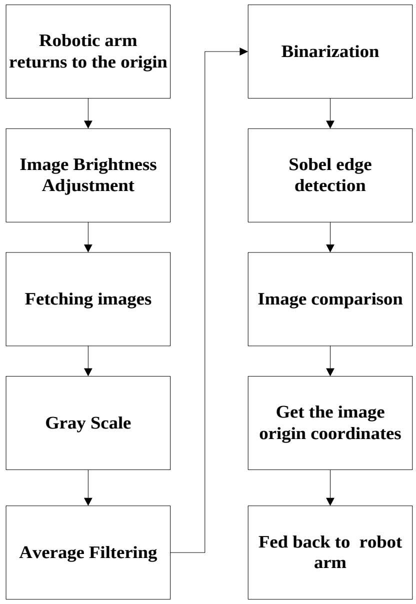


Figure 11: Test Procedure of Image Identification

An 800-thousand-pixel CCD camera is adopted for image identification. Through image processing, the images fetched by the camera in fixed height and search area are used to deduce the real coordinate value of object in images. Then the coordinate value is sent to the robotic arm for object grasping. In the system, the pixel of camera is 1024*768, the X coordinate value is 0 ~ 1023.99, and the Y coordinate value is 0 ~ 767.99.

(a) Image Brightness Adjustment

Since there is no automatic brightness adjustment function in the CCD camera, the brightness should be set up in accordance with the system environment for operation. To make gray-scale images more clear, the part required to enhance the contrast should be taken for the inclined lines in the images. Then the gray-scale images should be expanded based on the equation with the minimum value, a, and the maximum value, b, in the part:

$$Z' = \frac{255-0}{(b-a)} Z + 0$$

(b) Gray Scale

Gray-scale images are different from the black and white pictures. In machine vision field, there are only black and white colors in black and white pictures. In a gray-scale image, however, there are many colors with different gray degrees. In general, gray-scale images used for display are often saved in 8-bit per pixel. Therefore, there are 256 gray-degree colors to avoid distortion as shown in Figure 12.

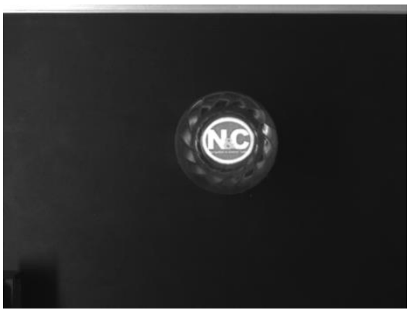


Figure 12: Gray-Scale Effect Illustration

(c) Average Filtering

Filtering operation is used to fetch some visual characters in images, to remove noise, to fetch character point, to reassembly images, and so on. The research adopts filtering operation to remove noises. Although noises removing may cause image blurring, it can remove noises in the system environment efficiently as shown in Figure 13.

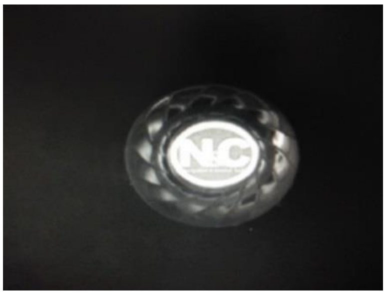


Figure 13: Filtering Effect Illustration

(d) Binarization

Binarization is a method for image cutting. The threshold value can be divided into fixed type and adaptive type in according with selected values. In general, there are two gray degrees in an image. It means that a gray degree value is selected. All pixels with higher gray degree than the value are set as light spots, and the others are set as dark spots. Hence, the image can be transformed as a binary image. Suppose m is the binarization threshold value, the equation is described as follows:

$$m = \sum_{i=1}^{m} f(x, y)$$

Where f is the input image, n is the number of all pixels, and $f(x, y)$ is the gray value of coordinate value (x, y).

Figure 14: Binarization Effect Illustration

(e) Sobel Edge Detection

Marking the object after binarization, the Sobel edge detection is adopted to search the character pixels fulfilling the image edge. Moreover, the Sobel mask is adopted to detect pixels with the most variation. The Sobel mask consists of a pair of 3*3 masks. One mask is used to detect the pixel with the most variation in X direction, and the other one is used to detect the pixel in Y direction. Figure 15 indicates these two masks.

-1	-2	-1
0	0	0
1	2	1

(a) Grey change of y direction

-1	0	1
-2	0	2
-1	0	1

(b) Grey change of *x* direction

Figure 15: Sobel mask

The equation for calculation of variation is listed as follows:

$$|G| = |Gx| + |Gy|$$

The results detected by Sobel edge are shown in Figure 16:

Figure 16: Sobel Result

(f) Object Origin Identification

Through pre-processing, the specific object can be identified in the designated search area. Also, the coordinate value of the object origin can be fetched. Then the coordinate value is sent to the robotic arm through RS232 for object grasping.

(g) Conveyor Tracking

For synchronizing the robotic arm and the object, the moving velocity and position of the object and the speed of the robotic arm should be considered as shown in Figure 17, where the black line indicates the conveyor, the blue line indicates the robotic arm, Δt^{synch} is the time for robotic arm to touch the object, and Δt_g^{synch} is the speed for robotic arm to touch the object.

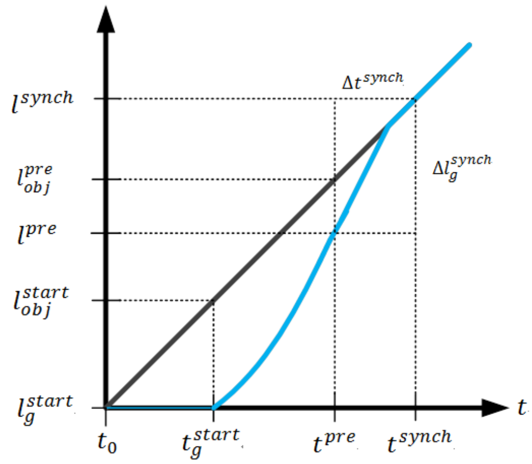
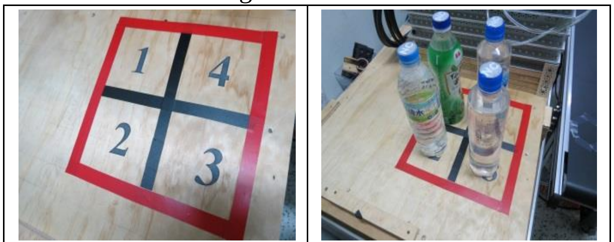


Figure 17: Relationship Diagram of Moving Velocity and Position

4. Experiment Results

First, the research constructs the placement area for the robotic arm and four PET bottles filled with water as shown in Figure 18.



(a) (b)

Placement area and Object for Identification.

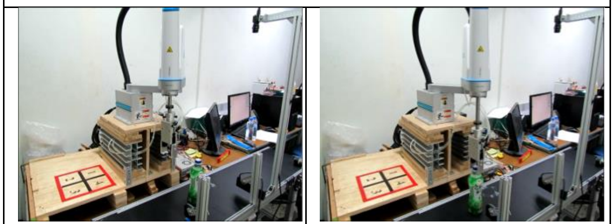
Figure 18: Placement Area of Objects

In the moving path of the robotic arm systems, the research sets four points: the origin point, operating point, temporary point, and the placement point. The robotic arm will operate each process through the four points in sequence. The origin point is the position where the robotic arm is waiting; the operating point is the origin coordinate of object captured by the CCD camera; the temporary point is set for protection, and there are four locations for the placement point where the robotic arm will put objects in a straight movement.

When the procedure starts, the robotic arm returns to the origin and waits for triggers issued by the magnetic sensors. After detecting a magnetic strip, the first magnetic sensor triggers the CCD camera to fetch an image. The image is processed in a series of image processes, and fed back to the computer. At that time, the robotic arm stays in waiting state. When second magnetic sensor detects the magnetic strip, it triggers the operations of robotic arm. According to the coordinate value calculated by the image process, the robotic arm will move to the position and operates object grasping. Then it will put the PET bottles at the four designated placement areas. After completing the process, the robotic arm returns to the origin and waits until the procedure ending. The procedure is illustrated in Figure 19. Moreover, the temporary point is set to avoid the end of robotic arm to crash the seat in the straight movement.

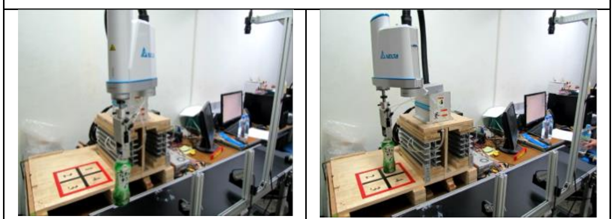
(a) (b)

Procedure Start: Fetching images when the 1st magnetic sensor detects a magnetic strip.



(c) (d)

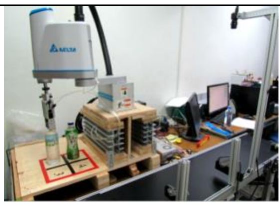
After detecting the magnetic strip, the robotic arm moves to operating point from the origin.



(e) (f)

The robotic arm moves to the temporary point, and then moves to the designated position to put the PET bottle.

(g)



(h)

The robotic arm returns to the origin. and waits for trigger to put PET bottles in sequence.

Figure 19: Full Test Procedure

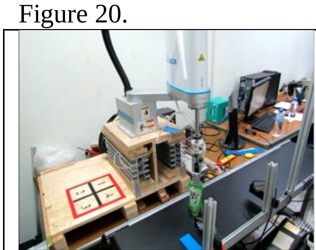
Finally, the research tests the grasping stability of a robotic arm. 10 times of the procedure are practiced for each moving velocity. Each procedure is successful if the robotic arm puts the four PET bottles in the four designated positions. The experiment results are listed as Table 2.

Table 2: Robotic Arm Grasping Test

	M/minute			
Success Times	2.9M	4.1M	5.2M	5.8M
	10	10	10	8

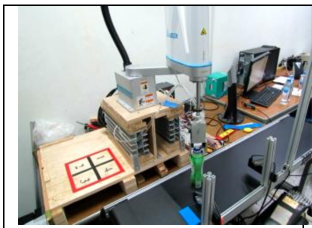
The research performs the robotic arm under a various moving velocity. According to Table 2, the robotic arm can put the PET bottles at the designated position stably and precisely if its moving velocity is set between 2.9M and 5.2M. If the moving velocity is set up to 5.8M, there are some unstable results. In the twice of these fail results, the robotic arm cannot grasp the PET bottle exactly. They are caused by the response time of magnetic sensors. Since the response time of magnetic sensors is too short to delay the start time of robotic arm, the robotic arm cannot be synchronized with the conveyor. If an industrial sensor, such as a photoelectric sensor or a proximity sensor, can replace the original magnetic sensor, the robotic arm should provide more stable performance.

According to the placements of PET bottles and the change of rotation angles based on flat Cartesian coordinate, the end-effector jaw can process the coactive rotation function. The function can enhance the capability of a robotic arm to fetch not only circle objects but also other types of ones, as shown in Figure 20.



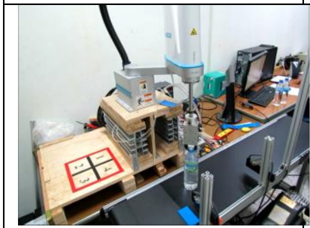
Object Rotation 35° CW

Object Rotation 90° CW

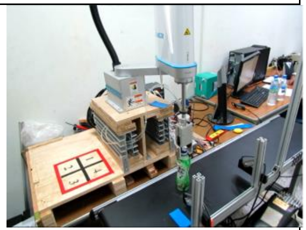


Object Rotation 125° CW

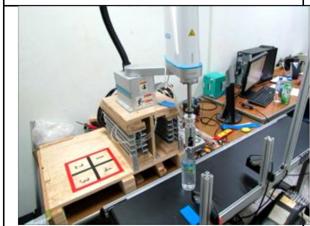
Object Rotation 179° CW



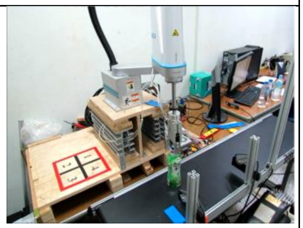
Object Rotation 35° CCW



Object Rotation 90° CCW



Object Rotation 125° CCW



Object Rotation 179° CCW

Figure 20: Rotation Angle Test

5. Conclusions

The research integrates the CCD camera, SCARA robotic arm, and the GS-2744B magnetic sensors to construct a conveyor tracking system. In the system, the object grasping operation of the robotic arm can be stable. Since the robotic arm can complete the object grasping in various moving velocities, it is appropriately applied in product lines to reduce the cost of human resource. In addition, the robotic arm is controlled by programming software. First, the images fetched by the CCD camera should be processed in a series of image processes to enhance the readability and stability. Moreover, the coordinate value of the object origin can be calculated, and fed back to the robotic arm for object grasping precisely. Therefore, the image processing is an essential part in the system. Moreover, the system is easy to output in various operation environment for conveyor tracking.

Restricted by the mechanism of the end-effector jaw, directly introducing the object rotation to the system is inappropriate. In this article, the object rotation is used for test majorly. The movement routes of a robotic arm are controlled in straight lines. It is the most efficient that the end jaw is controlled to face the PET bottles. If the end-effector jaw rotates 90 degree to fetch the object during the movement, it is easy to press the surface of PET bottle cap in the moving process. Therefore, the success rate of operation will be reduced significantly.

Acknowledgment

The research is completed based on the devices lent by Delta Electronics Inc. and supported by the Model University of Technology Program of Ministry of Education. Authors would like to extend their sincere gratitude to all of supports.

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