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Design and Development of a High Speed Sorting System Based on Machine Vision Guiding

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Abstract

In this paper, a vision-based control strategy to perform high speed pick-and-place tasks on automation product line is proposed, and relevant control software is develop. Using Delta robot to control a sucker to grasp disordered objects from one moving conveyer and then place them on the other in order. CCD camera gets one picture every time the conveyer moves a distance of *ds*. Objects position and shape are got after image processing. Target tracking method based on "Servo motor + synchronous conveyer" is used to fulfill the high speed porting operation real time. Experiments conducted on Delta robot sorting system demonstrate the efficiency and validity of the proposed vision-control strategy.

Keywords- automatic production line, machine vision, targets tracking, Delta robot

1. Introduction

As a comprehensive technology, machine vision has been used widely in various fields [1][2] including industrial fields making a significant contribution to ensuring competitiveness in modern industrial manufacturing[3]. On automatic sorting lines, machine vision is used to detect and track the moving target and guide sorting robot completing the sorting task. Much work was done about target recognition and dynamic objects' tracking. Wiehman W designed a computer device which recognized objects in time with a mobile camera [4]. Zhang realized the grasping task on a moving conveyer at about 300mm/s with dynamic visual feedback [5]. Allen designed a stereovision system tracking a moving target with the velocity of about 250mm/s [6]. Wilson realized the visual servo control of robots using Kalman filter estimates of relative pose[7]. Fu-Cheng YOU [8] proposed a system of combining specialized machine vision software platform and current development tool VC++ to recognize and sort out mechanical parts on

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the production line, which greatly improved development efficiency and running speed of the system. Dong xia[9] presents a moving target detection based primarily on inter-frame difference method using only visual sensing as input.

Based on the previous research, we propose a vision-based control strategy to perform high speed pick-and-place tasks on delta robot to control a sucker to grasp disordered objects from one moving conveyer and then place them on the other in order. The whole control system is composed of vision module and motion control module. The former gets the position and shape of the objects on the moving conveyer. The latter control the robot to complete the sorting tasks intelligently. Whether the robot can grasp the targets correctly depends on the image processing and target tracking which is the core of machine vision system. For the computational complexity reason, it is hard to fulfill the pick-and-place operation of the robot in real time, especially when the system runs in a high speed. “Servo motor + synchronous conveyer” is used to assistant the vision system to solve this problem. CCD camera gets one picture every time the conveyer moves a distance of *ds*. Objects’ position and shape are got through image processing methods. The real time positions of the objects depend on the conveyer velocity as they move with it. Then the velocity of the conveyer is planned and object’s picking position is calculated reference to the velocity of delta robot. Labview is select as the development environment and the vision-guide control software is developed.

2. System structure

As show in Figure 1, Delta robot is high speed, high precision performance 3-DOF parallel mechanism for pick-and-place operations. It has realized ±0.01mm repeat positioning accuracy in space, and can perform pick-and-place operations more than 120 times/min. Two conveyers are used for material transmission. CCD camera is fixed above conveyer Ⅰ with which disordered objects comes. Delta robot picks the disordered objects from it and places them on conveyer Ⅱ based on machine vision.

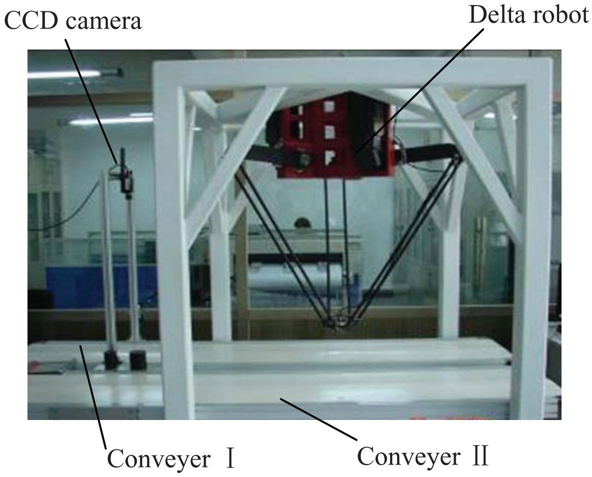


Figure 1. System structure

Vision module is composed of computer, image acquisition card, and CCD camera. Motion control module is composed of computer, motion control card, serve drivers and motors. The communication between vision module and motion control module is realized by using computer.

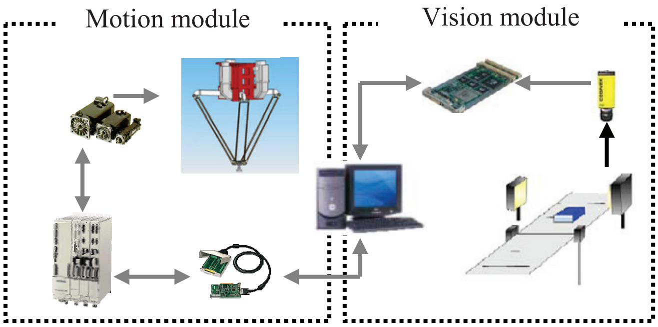


Figure 2. The whole control system

Vision system is used to acquire objects' information for the motion control of the system. A UNIQ UP680CL Channel Link digital camera is chosen as the vision input device. This video camera used is digital, monochrome unit with a (6.8mm×4.8mm)CCD and a resolution of 659×494 pexels. The vertical distance of the camera and the conveyer is 600mm with a visual field about 280×180mm. NI PCI-1428 Camera Link image acquisition card is chosen and the vision development module IMAQ-Vision is used. The motion control module is based on NI PCI-7356 motion control card which provides a 64kB Buffer. In the Contouring control mode, the motor rotate one ring per 10000 pulses. The computer white the track points into the Buffer and the motion control card read the data from the Buffer and drives the motor in real time.

3. Machine vision system

3.1 Image acquisition and processing

In the real image acquirement system, image quality gets worse in the process of image formation, transmission and reception. It is difficult to acquire the effective information. Image processing is used to make the image easily for the computer to analysis and recognize targets. In this system computer vision system is used to recognize different rings, image processing concludes image pretreatment and image segmentation. The image changes to a binary image after image processing, the region of 1 means the target objects, and 0 means the background.

In binary image, object area can be easily defined as the number of pixels that object boundary surrounds and it is related as the size of itself. Define the target (p×q)image matrix[7]

$$m_{pq} = \sum_{i=1}^{M}\sum_{j=1}^{N} i^p j^q B(i,j) \qquad (1)$$

Where M、N means the length and width of target region. means pixel value（0 or 1）. The formula used to calculate is:

$$A = \sum_{i=0}^{n-1}\sum_{j=0}^{m-1} B[i,j] \qquad (2)$$

And the centroid of target object is

$$\begin{cases} u = \dfrac{\sum_{i=1}^{M}\sum_{j=1}^{N} iB(i,j)}{\sum_{i=1}^{M}\sum_{j=1}^{N} B(i,j)} \\ v = \dfrac{\sum_{i=1}^{M}\sum_{j=1}^{N} jB(i,j)}{\sum_{i=1}^{M}\sum_{j=1}^{N} B(i,j)} \end{cases} \tag{3}$$

Figure 3 shows the image acquisition and image processing program by Labview software. With the calibration program of Labview software, the coordinate of the object in world coordinate system   is got.

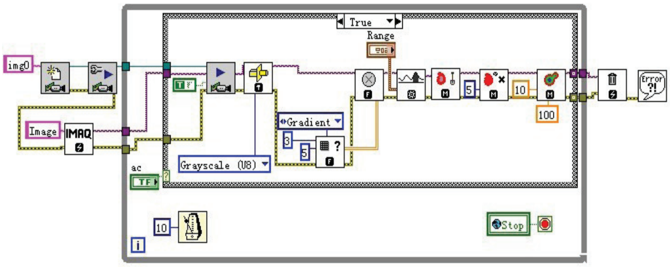


Figure 3. Machine vision module

3.2 Dynamic target tracking

In order to fulfill the high speed pick-and-place operation of the robot in real time, "Servo motor + synchronous conveyer" is used to assistant the vision system. Through image processing, we get objects' information at the moment when we acquire an image. The conveyer is controlled by a serve motor, the position pulse of which can be read from the code disc in time. So serve motor position pulse parameter can be used for the tracking of dynamic objects in real time when the objects move with the conveyer. With this parameter, the object can be recorded as $(x_n \;\; y_n \;\; A_n \;\; c_n)^T$, and with the movement of the conveyer, the position of the object is

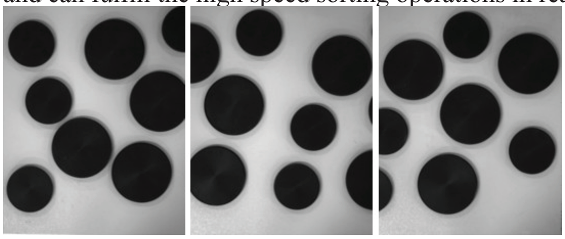
$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x = x_n + (c - c_n)\cdot dc \\ y = y_n \end{pmatrix} \tag{4}$$

Where c is the code disc of the serve motor in real time,   is the length the conveyer moves per pulse.

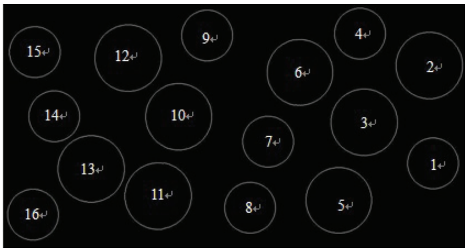
In order to decrease the computer load and not leaving out a target, CCD camera gets one picture every time the conveyer moves a distance of *ds*

$$ds = M - \varphi - \zeta \tag{5}$$

Where *M* is the length of the camera field of view in the direction of the conveyer, φ is the maximum length of object. ζ is used to avoid missing objects. At last, compare the objects in this image with in the former one and delete the repeated objects as shown in figure 4. This object tracking strategy decreases calculation amount largely and can fulfill the high speed sorting operations in real time.



(a)Three continuous images



(b) Terminal result

Figure 4. Dynamic targets recognition strategy

4. Sorting Control Strategy

4.1 Control strategy of Delta robot

In industry application, high speed sorting robot usually runs a "door" path as shown in figure 5(dashed line) including three line segments[10]: $\overrightarrow{P_1P_2}(S_1)$, $\overrightarrow{P_2P_3}(S_2)$ and $\overrightarrow{P_3P_4}(S_3)$ with the acceleration as shown in Eq.(6). In order to improve the efficiency of the robot, the second state begins at P_5 and the third state begins at P_7. Then the robot runs to P_6 when the first state finishes, and it runs to P_8 when the second state finishes (solid line). P_5 is the middle point of P_1P_2, and P_8 is the middle point of P_3P_4.

$$a = \begin{cases} a_{\max}\sin(\frac{4\pi}{T}t) & (0 \le t \le \frac{T}{8}) \\ a_{\max} & (\frac{T}{8} < t \le \frac{3T}{8}) \\ a_{\max}\cos\left[\frac{4\pi}{T}(t-\frac{3T}{8})\right] & (\frac{3T}{8} \le t \le \frac{5T}{8}) \\ -a_{\max} & (\frac{5T}{8} \le t \le \frac{7T}{8}) \\ -a_{\max}\cos\left[\frac{4\pi}{T}(t-\frac{7}{8}T)\right] & (\frac{7T}{8} \le t \le T) \end{cases} \tag{6}$$

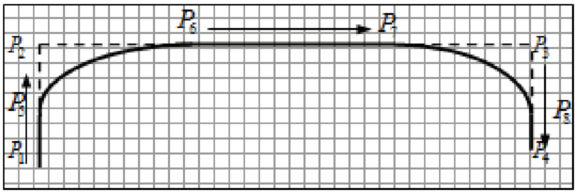


Figure 5. Robot running path

Where v_{max} means the maximum acceleration of the robot, T is the total time the robot finishes running one line segment. Then the time the robot runs from v_1 to $v_2(v_2 > v_1)$ is

$$t = T_1 / 2 + T_2 + T_3 / 2 \tag{7}$$

Where

$$T_i = \sqrt{\frac{S_i}{(\frac{1}{8\pi} + \frac{1}{8})a_{max}}} \quad (i\text{=1-3})$$

4.2 Velocity of the conveyer

On automatic sorting line, objects on the conveyer come with different densities. The conveyer should move faster when there is a lower density, and slower when there is a higher density to fit the work cycle of sorting robot and ensure a higher sorting efficiency without leaving out any object. The next-picking object's position is used to plan the velocity of conveyer as shown in Figure 5.

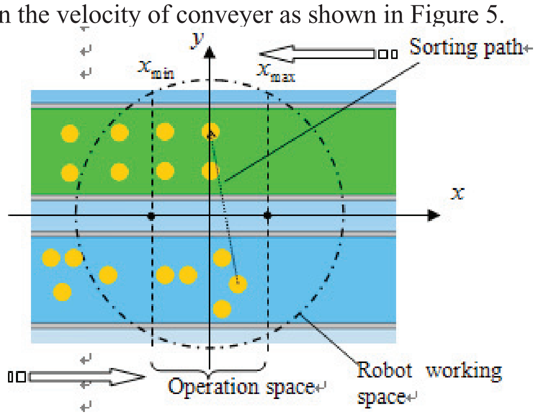


Figure 5. Velocity control of the conveyer

The maximum velocity of the conveyer is v_{max}, (x_{min} , x_{max})is the operation space of the system (depending on the robot working space). The position of the next-picking object is (x, y) when the robot begins to move, v_t is the velocity of the conveyer at the moment. Then in the process of the movement of robot, the conveyer moves at a speed of

$$v = \begin{cases} v_{\max}, & x \le 0 \\ v_{\max}(x_{\max} - x)/x_{\max}, & 0 < x \le x_{\max} \\ 0, & x_{\max} < x \end{cases} \tag{8}$$

In order to decrease the impact to the system of the conveyer-velocity change, sine rule is used in the velocity-change process. The maximum acceleration of the conveyer is $a'_{\max}$, it changes from v_1 to $v_2 (v_2 > v_1)$ during a time of . Then during this time, the acceleration of the conveyer is

$$a' = (1 + a_{\max}{}' \sin(\frac{2\pi t}{T'} + \frac{3\pi}{2})) \tag{9}$$

As we know , so

$$T' = \frac{v_2 - v_1}{a_{\max}{}'} \tag{10}$$

4.3 Pick position calculation

With the conveyer moves in the direction of axis x, the real time position of the object is

$$\begin{cases} x = x_n + \int_0^t v dt \\ y = y_n \end{cases} \tag{11}$$

Where (x_n, y_n) is the position coordinate of the target at the time the robot begins to run to grasp it, v is the velocity of the conveyer. Eq. (7) and Eq. (11) leads to

$$x = x_n + \frac{v_2 + v_1}{2}\frac{v_2 - v_1}{a_{\max}{}'} + v_2(\frac{1}{2}\sqrt{\frac{S_1}{(\frac{1}{8\pi} + \frac{1}{8})a_{\max}}} + \sqrt{\frac{\sqrt{(x - x_0)^2 + (y - y_0)^2}}{(\frac{1}{8\pi} + \frac{1}{8})a_{\max}}} + \frac{1}{2}\sqrt{\frac{S_3}{(\frac{1}{8\pi} + \frac{1}{8})a_{\max}}} - \frac{v_2 - v_1}{a_{\max}{}'}) \tag{12}$$

Eq. (12)is too complex to solve directly, Newton's dichotomy is used here. Figure 6 shows the curve of Eq. (7) and Eq. (11)

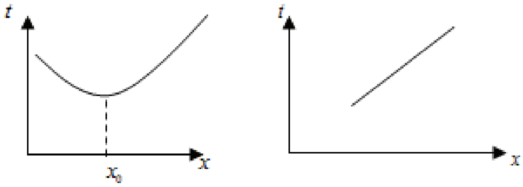


Figure 6. Curve of Eq. (7) and Eq. (11)

Construct function as follow

$$F(x) = x_n + \frac{v_2 + v_1}{2}\frac{v_2 - v_1}{a_{\max}'} + v_2\left(\frac{1}{2}\sqrt{\frac{S_1}{(\frac{1}{6\pi} - \frac{1}{6} + \frac{1}{4})a_{\max}}} + \sqrt{\frac{\sqrt{(x - x_0)^2 + (y - y_0)^2}}{(\frac{1}{10\pi} - \frac{1}{10} + \frac{1}{4})a_{\max}}} + \frac{1}{2}\sqrt{\frac{S_3}{(\frac{1}{6\pi} - \frac{1}{6} + \frac{1}{4})a_{\max}}} - \frac{v_2 - v_1}{a_{\max}'}\right) - x \quad (13)$$

Eq. (12) changes to $F(x) = 0$. There are 4 theoretical solutions exist. But in the space of operation space, there are three situations based on Figure 6

a) Only one solution and $x < x_0$

b) Two solutions and $x_1 < x_0, x_2 > x_0$

c) Only one solution and $x > x_0$

When situation 2 happens, the first solution is used in order to improve efficiency of the system. Define a micro amount ξ, when $|F(x)| < \xi$, regard the x as the solution needed. Newton's dichotomy is used as follow

Step 1: If $x_n < x_0$, let be $x_1 = x_n, x_2 = x_0$, then $F(x_1) > 0$, if $F(x_2) < 0$, let be $x_2 = x_{\max}$;

If $x_n > x_0$, let be $x_1 = x_n, x_2 = x_{\max}$

Step 2: Let be $x_3 = \frac{x_1 + x_2}{2}$, if $|F(x)| < \xi$, x_3 is the solution we need. Or else go to step 3

Step 3: If $F(x_2) > 0$, let be $x_1 = x_3$, if $F(x_2) < 0$, let be $x_2 = x_3$ and return to step 2

4.4 System process and experiment

In order to ensure the system work fluently, target data

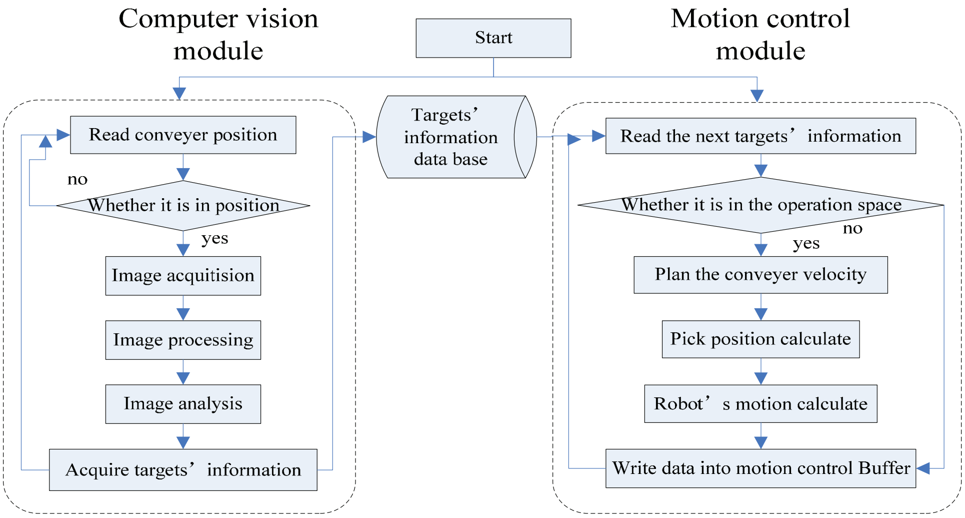


Figure 7. System control flow

base is used to exchange information between computer vision module and motion control module. Targets' information is written into the data base by computer vision module. Motion control module read targets' information from the data base and control the motion of the whole system realizing the sorting tasks in high speed. Figure 7 shows the whole process of the system. When it is applied, define the maximum velocity of the conveyer 400mm/s, and , he maximum acceleration of the robot , the system realized the sorting task of two different pieces at more than 120 times/min as shown in figure 8.

5. Conclusions

A vision-based control strategy to perform high speed pick-and-place tasks in automation product line has been proposed. Vision system is used to get the position and shape of objects and "Servo motor + synchronous conveyer" is used to assistant the target tracking to fulfill the pick-and-place operation of the robot in real time, motion control system coordinate and plan the robot's movement with the conveyer to complete the sorting task. Experiments conducted on Delta robot sorting system demonstrate the efficiency and validity of the proposed control strategy.

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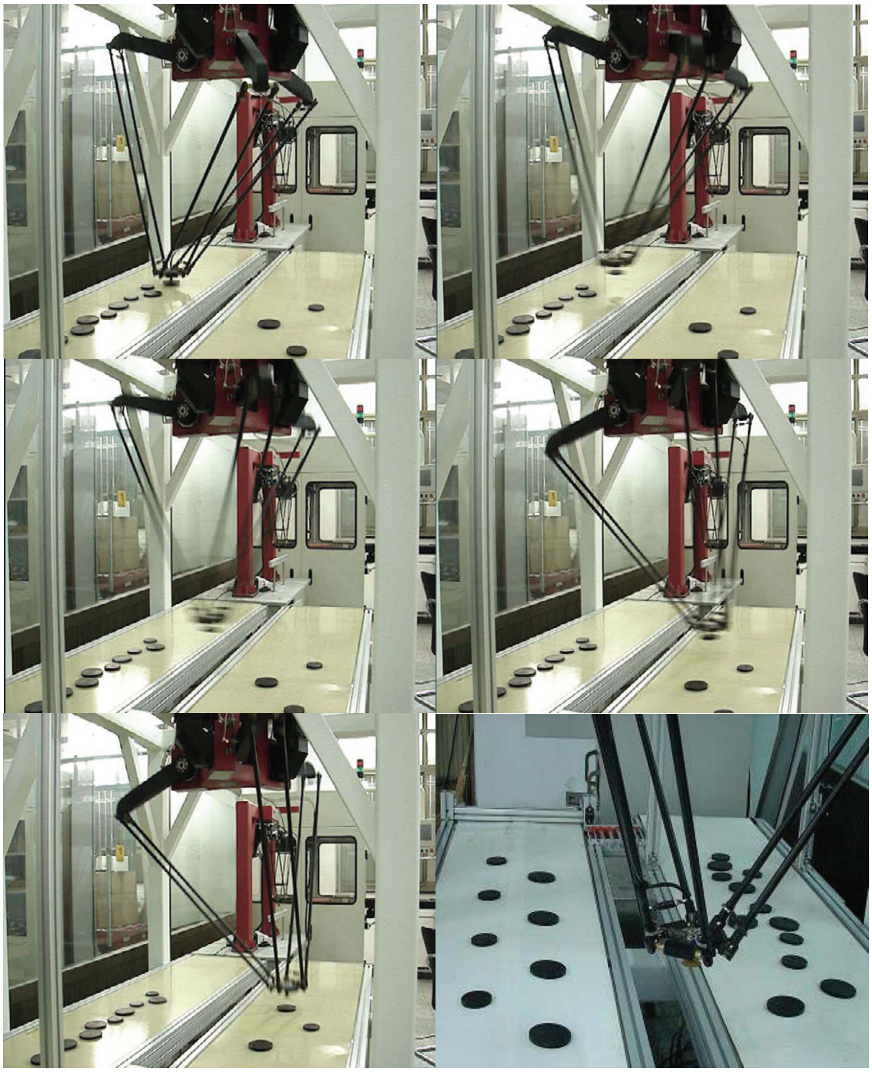

Figure 8. Sorting experiment

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