Visual Servo Technology Research of Industrial Palletizing Robot

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Abstract. With the wide application of palletizing robot in the field of logistics automation, the market is making higher demand for the adaptability and accuracy of the palletizing robot. In order to solve the problems of single function and poor adaptability for the ordinary palletizing robot, we combined the machine vision and palletizing robot control technology, built the palletizing robot visual servo control system platform, carried out the related graphic processing algorithms research. By test and verification, this palletizing robot visual servo control system platform can finish the detection, sorting and stacking for different goods fast and accurately. It can offer reference for the subsequent research of the palletizing robot visual servo technology.

Introduction

In the dual traction of the development of science and technology and market demand, the industrial palletizing robot has become the strong driving force to boost the logistics industry automation technology and equipment development. Compared with the manual handling, the palletizing robot is widely used because of its high efficiency, low cost, strong load capacity and many other advantages [1]. The application conditions of palletizing robots are becoming much more diversified, and the functional requirements are becoming more complex, which demands higher adaptability and accuracy of palletizing robots.

At present, the palletizing robots in industrial manufacturing adopt the Teaching-playing method to plan the grasping point, the stacking point and the trajectory in advance. The palletizing robot repeats the palletizing operation according to the teaching. In the face with the situation in which a single robot has to palletize different kinds of products or products from multiple production lines, such Teaching-playing obviously cannot meet the needs of the implementation. In order to improve the adaptability and intelligent level of palletizing robot, the research of visual servo technology was carried out. We used machine vision to identify and obtain the type and location of goods which was to cooperate with the palletizing robot to complete accurate goods grabbing and goods stacking according to their types, etc [2].

This paper proposed the building of the visual servo control system of the palletizing robot (see Figure 1), and studied the related image processing algorithms so as to accomplish the inspection, sorting and palletizing of the goods based on machine vision servo technology and eventually to improve the adaptability and accuracy of the industrial palletizing robot.

Palletizing Robot Visual Servo Control System

As shown in Figure 1, the visual servo control system of the palletizing robot was built on a 4-DOF industrial palletizing robot. The system is mainly divided into three functional units: image acquisition and processing unit, palletizing robot motion control unit and cargo transport unit.

Image acquisition and processing unit is mainly composed of an industrial computer, an IMPERX industrial camera and a NI PXIe-1427 image acquisition card. The industrial camera adopts eye-to-hand installation, acquire and process images in real time so as to obtain the type, coordinates of the mass center of goods.
Palletizing robot motion control unit is mainly composed of a palletizing robot arm, a motion control card, a signal transfer board and an industrial control [3]. The industrial PC interacts with the movement control cards via Transmission Control Protocol (TCP) communication. According to the control instruction, motion control card plans for trajectory and generate analog control signals to control axis movement of the palletizing robot in order to complete stacking movement.

Cargo transport unit mainly consists of goods, a conveyor belt and infrared sensors. The conveyor belt transports goods to the grasping area at a constant speed. After infrared sensors identify the goods are in place, the conveyor belt stops and the palletizing robot grasps and stacks goods according to the location of the goods which is instructed by the image acquisition and processing unit.
Image Acquisition and Processing

Camera Calibration

The main purpose of the camera calibration is to establish the relationship between the position of the camera image pixel and the location of the scene point so as to realize the 3D reconstruction. That is, the 3D coordinates of the spatial point are solved based on the 2D image [4]. The calibration process is to solve the model parameters of the camera based on the image coordinates of the known feature points and thus derive the transformation matrix between the two-dimensional image coordinate system and the world coordinate system. Due to the simple shape of goods and low precision of the palletizing robot, the conversion matrix can be deduced without considering the influence of camera lens distortion. The derivation of the transformation matrix is as follows:

Wherein:

\[ p_u \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \] —— Coordinates of target points in the two-dimensional image coordinate system

\[ w p \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} \] —— Coordinates of the target point in the world coordinate system

Sx, Sy, u0, v0, f —— camera intrinsic parameters

nx, ny, nz, ox, oy, oz, ax, ay, az, px, py, pz —— camera external parameters

As shown in Figure 3, according to the camera acquisition calibration plate picture, camera calibration is done using the NI Vision Assistant

![Image of calibration plate](image_url)

Figure 3. Industrial camera calibration.

Image Processing

**Edge Detection.** Edge detection is an important part of image analysis and recognition. Edge detection algorithm can accurately identify the edge features of the goods. At present, the commonly used edge detection algorithm is based on differential operator, such as Sobel operator, Prewitt operator, Canny operator and Laplace operator. Canny operator, which has a good signal-to-noise ratio, high edge location performance and better detection in noisy environment, is suitable for edge detection in different environments [5].

The operator first smooths the image using the first derivative of the two-dimensional Gaussian function, calculates the magnitude and direction of the gradient for the smoothed image and performs non-maxima suppression, and finally detects and connects the edge.

**Image Matching.** Image matching is the process of recognizing points of the same name
between two or more images by matching algorithm \(^6\). In this paper, invariant moment matching algorithm is used to match the target image according to the seven feature moment invariants of the image. If the invariant moment of the target image is \( M_i (i=1,2...7) \), the similarity matching formula between the two graphs is as follows:

\[
R(u,v) = \frac{\sum_{i=1}^{7} M_i N_i(u,v)}{\left[ \sum_{i=1}^{7} M_i^2 \sum_{i=1}^{7} N_i^2 (u,v) \right]^{1/2}}
\]

(1)

Wherein:
- \( R(u,v) \)——The correlation values of invariant moments at the test locations \( (u,v) \)
- \( N_i (u,v) \) \((i=1,2...7)\)——Matching moment invariants.

Using pattern matching algorithm can effectively distinguish the types of goods placed in order to achieve a multi-product stacking operations.

**Centroid Calculation.** For the extracted object, by calculating the center of gravity method the location of the target object image can be easily calculated \(^7\):

\[
\begin{align*}
\hat{x} &= \frac{\sum x_i}{S} \\
\hat{y} &= \frac{\sum y_i}{S}
\end{align*}
\]

(2)

Wherein:
- \( x, y \) ——The calculated X and Y coordinates of the center of gravity
- S——Area
- \( x_i, y_i \)——X and Y coordinates of each pixel in the target image area.

**Palletizing Process**

The upper control software of the visual servo control system of the palletizing robot is developed by LabVIEW (see Figure 4). It is mainly composed of initialization module, image acquisition module, image processing module, motion control module and status display module.

![Figure 4. Upper control interface.](image-url)
The palletizing robot visual servo control system workflow is shown in Figure 5. When the palletizing robot starts to work, the system initializes and the robot moves to the starting zero position. When the conveyor belt transports the goods to the capture area, the industrial camera with the image acquisition card completes the real-time acquisition of goods image. The upper control software processes the image of the acquired goods, obtains the information such as the length and width of the goods to determine the kind of the goods placed and calculates the coordinates of the centroid of the goods in the world coordinate system. According to the centroid coordinates of the goods, motion control instructions are generated to control the palletizing robots so as to accurately capture the goods and distinguish them according to their types.

In this paper, two different sizes of mineral water containers were selected as the target cargo. The palletizing robots grasped and placed two types of goods respectively. The test shows that the palletizing robot visual servo platform performed well in goods identification and grasping and placed goods to different zones according to their different types.

Figure 5. Working process of palletizing robot visual servo control system.
Summary
This paper proposed a visual servo control system of a palletizing robot based on 4-DOF palletizing robot, and developed the related image processing algorithm. The test verified that the visual servo control system can correctly identify the type of goods, accurately capture and put the goods which meets the demand of multi-product or multi-production-line stacking tasks. The visual servo control system and related servo algorithm of the palletizing robots explored in this paper can provide reference and basis for the research of the visual servo technology of the subsequent palletizing robots.

References