Advances in Technology Innovation, vol. 2, no. 2, 2017, pp. 40 - 45

Position Control and Novel Application of SCARA Robot with Vision System

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Received 02 February 2016; received in revised form 27 April 2016 accepted 02 May 2016

Abstract

In this paper, a SCARA robot arm with vision system has been developed to improve the accuracy of pick-and-place the surface mount device (SMD) on PCB during surface mount process. Position of the SCARA robot can be controlled by using coordinate auto- compensation technique. Robotic movement and position control are auto-calculated based on forward and inverse kinematics with enhanced the intelligent image vision system. The determined x-y position and rotation angle can then be applied to the desired pick & place location for the SCARA robot. A series of experiments has been conducted to improve the accuracy of pick-and-place SMDs on PCB.

Keywords: SCARA, pick-and-place, forward and inverse kinematics, vision system

1. Introduction

Industrial heavy duty manipulator such as Selective Compliance Assembly Robot Arm (SCARA) is an automatic device which is capable to carry and move components/devices/ parts in the manufacturing process. The first SCARA robot was invented by Professor Hiroshi Makino from University of Yamanashi, Japan in 1978 [1]. Fig.1 demonstrates the basic structure includes kinetic 4-axis and 4-DOF, translation on X, Y, Z and rotation about vertical Z-axis. Two-link compliant arms with rotated wrist behave somewhat like the human arm that joints allow the arm to move vertically and horizontally in a limited space. SCARA was specially designed for precision devices

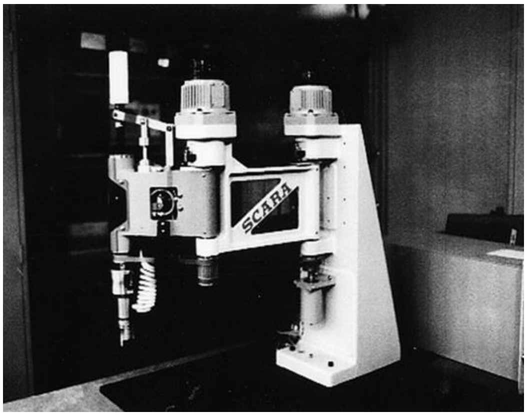

Fig. 1 The first SCARA robot by Hiroshi Makino [1]

assembly, especially place a pinned component in a hole.

A typical SCARA robot is a stationary robot arm including base, elbow, vertical extension and tool roll and comprising both rotary and prismatic joints. SCARA robots may vary in size and shape but they all are consistent in a unique 4-axis motion [2]. With this distinguished feature, SCARA particularly fits the pick-and-place surface mount devices on PCB (printing circuit board) and move-to-take delicate silicon wafers or glass panels on magazine. SCARA robot was introduced in SEIKO watch assembling lines in 1981 and since then industrial SCARA robot has been widely used in electronic, semiconductor, automobile, electronic, plastic, food and pharmaceutical factories [3] all over the world.

SCARA robot is the principle use of robotics field and most of the domain of robotics field is on industry and academia. The control system of industrial SCARA robot is a highly non-linear,

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strong coupling and time-varying systems [4]. Kinematics modeling is one of the key technologies to verify the model. Many researchers and engineers [5-6] have presented the manipulating ability of robotic mechanisms in positioning and orienting end-effectors and propose a measure of manipulability. The motion trajectory of a robot arm is calculated using the geometric analysis. The PID control techniques [7] have been proposed to solve the nonlinearity issue with acceptable results to control the movement of robot arms. The motion trajectory of a robot arms is calculated using the geometric analysis with Matlab software.

The performance of industrial heavy duty robots working in unstructured environments can be improved using visual perception and learning techniques [7-10]. The object recognition is accomplished using an artificial neural network (ANN) architecture. A novel technique used in the assembly lines integrates computer vision to capture the shape of the objects, online grasp determination based on that shape, and image-based control for grasp execution. Visual servoing system [8] consists of high-speed image processing, kinematics, dynamics, control theory, and real-time computing to control the position and orientation of a robot with respect to an object. Furthermore, the color of objects could also be considered and included in the image-base system. The developed image processing and workpiece recognition algorithm is based on LabVIEW Vision Development Module [9]. Later, like two eyes on human, two cameras are developed to detect the robotic arm movement in 3-D space. In this system, the robotic arm is controlled and moved, and after mathematic calculations the precise position of the motors is calculated to reach the designated position [10].

The automation in surface mount precision assembly lines often consists of SCARA robots equipped with grippers, image vision system and linked by motorized conveyances. In this system, the combination of high performance motion control with integrated vision guidance and conveyor tracking are demonstrated. The robotic arms are used for the pick-and-place of the SMT components. The placement system on printed circuit board (PCB) is mainly influenced by the surface mount device (SMD) robots and the production environment in assembly line. Temperature on the reflow process is often above 250^{O}C which easily distorts the tray. The deformed tray would result in misalignment of the placement system. The yield rate is consequently descended and the cost would be enormous.

The purpose of this paper is to improve the accuracy of the placement system on PCB during surface mount process. Coordinate auto-compensation technique on deformed tray is developed to control the position of SCARA robots equipped with image vision system. Robotic movement and position control are calculated based on forward and inverse kinematics.

2. Theoretical Development

Fig. 2 illustrates the coordinate system of random point located on PCB (x, y) with respect to robotic arm.

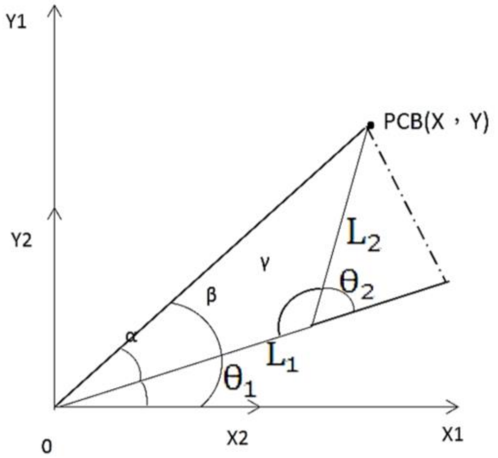

Fig. 2 Random point (x, y) on PCB

2.1. Forward Kinematics

Location of end effector can be determined by the length of robotic arm and rotation angle of each axis

$$X = L_1 cos\theta_1 + L_2 cos(\theta_1 + \theta_2) \quad (1)$$

$$Y = L_1 sin\theta_1 + L_2 sin(\theta_1 + \theta_2) \quad (2)$$

where L_1, L_2 are robotic arm length, and θ_1, θ_2 are rotation angle of each axis

2.2. Inverse Kinematics

Rotation angle of each axis can be determined by the coordinate system of end point.

$$\theta_2 = \cos^{-1}\frac{X^2+Y^2-L_1^2-L_2^2}{2L_1L_2} \quad (3)$$

$$\theta_1 = \beta - \alpha$$
$$= \tan^{-1}\left(\frac{Y}{X}\right) - \tan^{-1}\left(\frac{L_2(sin\theta_2)}{L_1+L_2(cos\theta_2)}\right) \quad (4)$$

2.3. Compensation for Image and Distance Coordinate

Fig. 3 demonstrates the captured image of pixel with respect to distance (1 pixel equals to 0.01 mm). The origin of distance coordinate is located in the center of image coordinate and then pixel (320, 240) would be the same as distance (3.2mm, 2.4mm).

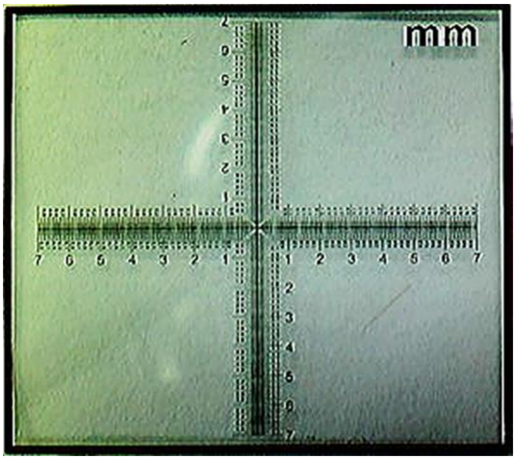

Fig. 3 Image/distance coordinate system

2.4. Compensation for deformed PCB Tray Coordinate

Fig. 4 presents the compensation for deformed PCB tray coordinate. Assuming the PCB tray offset 1 mm due to thermal induced warpage, the coordinate of random point in image capture system is determined.

$$X_2 = PCB\ X + Pixel\ X \quad (5)$$

$$Y_2 = PCB\ Y + Pixel\ Y \quad (6)$$

where X_1=28.2, Y_1=52.4 are system default parameters. After mathematical calculation, the placement coordinates are

$$X = X_2 - X_1 \quad (7)$$

$$Y = Y_2 - Y_1 \quad (8)$$

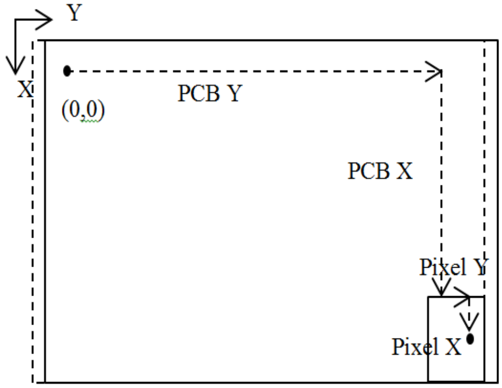

Fig. 4 Schematic illustration of PCB coordinate system

2.5. Image Processing

Grayscale digital image is a range of shades of gray without apparent color. The reason for differentiating gray images is that only specify a single intensity value for each pixel, i.e. less information for each pixel. In order to reduce the complexity of post-processing grayscale image scheme is applied to capture the characteristic image.

The Hough transform is a technique which can be used to isolate features of a particular shape, such as line, circle, ellipse, etc., within an image. Based on Hough transform, circular detection on LabVIEW Vision Assistant is applied to determine the precise position on deformed PCB.

3. Structure of Improved Placement System

3.1. Hardware Description

A Toshiba SCARA robot (#SR-424SHP) with control card (#PISO-PS400) shown in Fig.5 is employed in this study. Fig. 6 illustrates SMD components placed on PCB with tray (carrier). The placement system on trial run conveyer is presented in Fig. 7.

Fig. 5 Toshiba SCARA robot (#SR-424SHP)

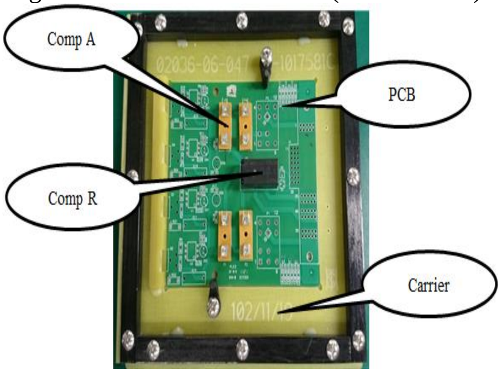

Fig. 6 SMD components on PCB with tray (carrier)

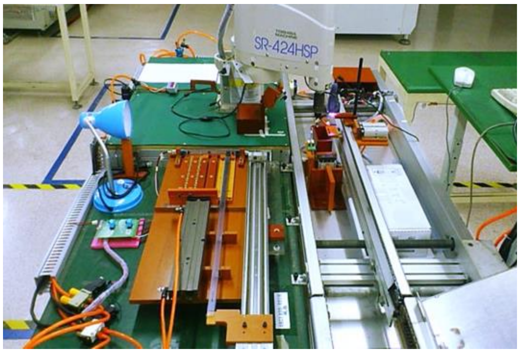

Fig. 7 Placement system on trial run conveyor

The overall placement system also consists of trial run conveyor for PCB tray, SMD components feeder, buzzer, 3 cylinders (baffle, push and charge-in). 2 cameras (coordinate auto-compensation and poka-yoke), 3 sensors with Arduino UNO and a lighting system (top and broadside). All SMD components are held in specific trays which are loaded in upstream vibratory parts feeding stations.

3.2. *Software Development*

The control software used in this study is LabVIEW 2012 and LabVIEW Vision Assistant 2012.

4. Results and Discussion

Coordinate compensation system for SMD placement and starved feeding (queliao) auto-detection system have been developed in this paper. In the first, anchor point on PCB was shot by camera and the offset amount on PCB was then calculated by compensation of the image and distance coordinate. The precise location on PCB for components placement was then determined. For queliao and those parts did not place in the desired position, the developed system can also sound a buzzer signal on the control annunciator panel and warn the upstream feeding stations to load SMD components.

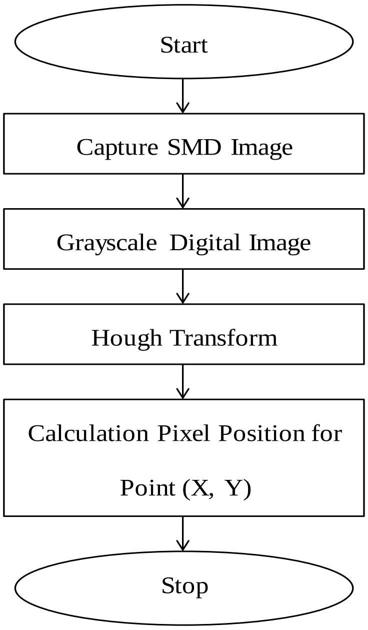

Fig. 8 Flow chart of coordinate compensation system for SMD placement

Fig. 8 and Fig. 9 present the flow chart for coordinate compensation system and queliao auto-detection system, respectively. Fig. 10 demonstrates the accuracy of SMD components pick-and-place improved by the developed algorithm. The accuracy on auto assembly (99.73%) has been dramatically improved after teaching mode (78.66%).

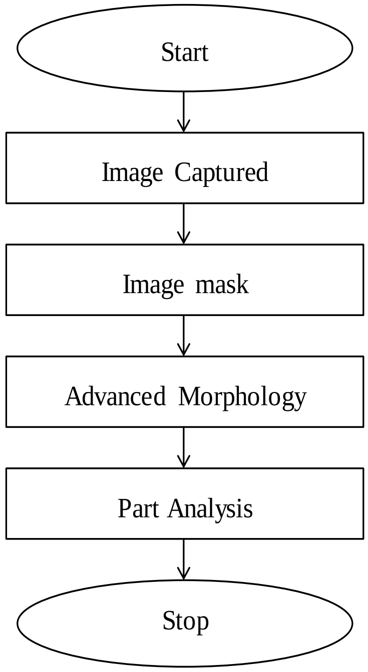

Fig. 9 Flow chart of queliao auto-detectionsystem

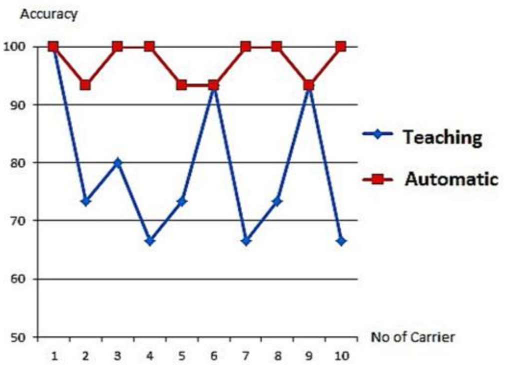

Fig. 10 Accuracy of SMD components pick-and-place

5. Conclusions

In this paper, an improved pick-and-place SMD on PCB system has been accomplished by using SCARA robot and machine vision. The result has shown that 97.33% yield rate was achieved and more than 2% of error could be eliminated by improving the hardware of system. Besides top lighting camera, anchor point on the skewed PCB tray can be calibrated and revised by a broadside webcam. Remote operation using wireless network is feasible.

Acknowledgement

The authors would like to express their appreciation to Ministry of Science and Technology, Taiwan, ROC, for financial supports under project No. MOST103-2221-E-214-018 and MOST104-2221-E-214-051. Appreciation is also extended to Oriental Semiconductor Electronic, Ltd. for carrying out all the experiments.

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