International Journal of Fuzzy Logic and Intelligent Systems, vol. 6, no. 2, June 2006 pp. 95-99

# A Machine Vision System for Inspecting Tape-Feeder Operation

**Tai-Hoon Cho**

**School of Information Technology, Korea University of Technology and Education, Korea**

**Abstract**

A tape feeder of a SMD(Surface Mount Device) mounter is a device that sequentially feeds electronic components on a tape reel to the pick-up system of the mounter. As components are getting much smaller, feeding accuracy of a feeder becomes one of the most important factors for successful component pick-up. Therefore, it is critical to keep the feeding accuracy to a specified level in the assembly and production of tape feeders. This paper describes a tape feeder inspection system that was developed to automatically measure and to inspect feeding accuracy using machine vision. It consists of a feeder base, an image acquisition system, and a personal computer. The image acquisition system is composed of CCD cameras with lens, LED illumination systems, and a frame grabber inside the PC. This system loads up to six feeders at a time and inspects them automatically and sequentially. The inspection software was implemented using Visual C++ on Windows with easily usable GUI. Using this system, we can automatically measure and inspect the quality of all feeders in production process by analyzing the measurement results statistically.

**Key words** : Machine Vision, Surface Mount Device, Tape Feeder, Inspection System

## 1. Introduction

As electronic products are getting smaller due to rapid development of electronic and semiconductor technologies, Surface Mount Devices (SMDs) are widely used for electronic components such as resistors, capacitors, transistors, etc. These SMDs are mounted on a Printed Circuit Board (PCB) by SMD mounters. In a SMD mounter, a feeder is a device feeding surface mount components consecutively to the pick-up device of the mounter.

Types of component feeders include tube, vibration, tape & reel, tray, etc. Among these, tape & reel feeders are most widely used in general. A tape & reel feeder is shown in Fig. 1. Through tape & reel feeders, components are transferred at regular intervals to the component pick-up position. Components are placed within the carrier tape of the feeder. Usually a tape & reel feeder is composed of a reel holder, the mechanism of tape transport, and the mechanism of cover tape removal. The mechanism of tape transport is operated by vacuum, electrical, or mechanical methods. Transporting the carrier tape, peeling the cover tape, and exposing the component for pick-up occur simultaneously. The width of the carrier tape varies ranging from 8mm to 56mm. The mechanism of this tape & reel type feeding is appropriate for most production, in particular, for mass production [1].

Manuscript received Dec. 7, 2005; revised May. 25, 2006.
This work was supported by grant No. RTI04-01-02 from the Regional Technology Innovation Program of the Ministry of Commerce, Industry and Energy(MOCIE).

A SMD mounter picks up components fed by tape feeders using vacuum head, recognizes and compensates the posture (center and orientation) of the components using a camera, and mounts them on the PCB. (Initial reference position for picking-up components on a feeder is taught by an operator using a camera and stored inside the mounter.) Thus, successful component pick-up on the feeder is critical for accurate posture alignment by a camera, which can ensure precise mounting of components on the boards. In general, if components are large, feeding accuracy is not a major factor for successful component pick-up. However, extremely small components such as 1005 (1mm x 0.5mm) or 0603 chip are getting used recently and feeding accuracy should be very high for these components to be picked up successfully. If they are not fed to the pick-up position with the highest repeatability, they fail to be picked up correctly, which often causes problems in the posture alignment, thus making errors in mounting components.

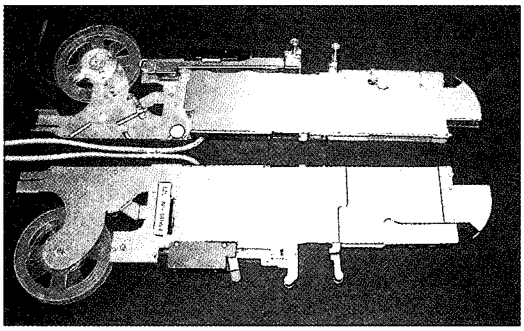

Fig. 1. A tape & reel feeder for a mounter

As components are getting much smaller, feeding accuracy of the feeder becomes one of the most important factors for successful component pick-up. Therefore, it is critical to keep the feeding accuracy to a specific level (normally, 0.1~0.2mm) in the assembly and production of tape feeders. However, in the feeder manufacturer, after the feeder assembly process, tape feeding operation has been often done manually and inspected by a human using images displayed on the monitor which are captured via a camera during the feeding operation test.

This paper describes a tape feeder inspection system that was developed to automatically measure the feeding accuracy of a tape feeder using machine vision. Using this system, we can automatically measure and inspect the quality of all feeders in production process and analyze the results statistically. Thus, in this way, we can not only monitor operating status of feeders, but also strengthen product competitiveness considerably through reforming feeder assembly process.

## 2. The Tape Feeder Inspection System

### 2.1 System Configuration

The tape feeder inspection system consists of a mechanical part where feeders are loaded and controlled in the same way as in the real SMD mounter, an image acquisition system, and a computer for processing acquired images and performing inspection. (See Fig. 2.)

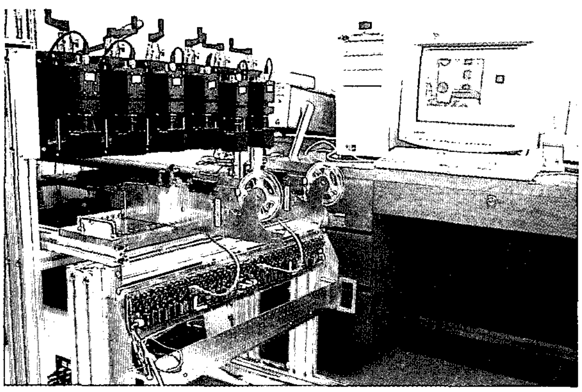

Fig. 2. The feeder inspection system

The mechanical part utilizes a feeder base and a control board used in the real mounter and provides the same operational environment as in the mounter. The control board that is connected to the inspection computer makes feeders move successively and reports operational status of feeders in response to the computer's commands.

The image acquisition system is composed of inspection cameras with lens, a frame grabber, and an illumination system. Cameras are installed right above the feeders loaded on the feeder base. Their field of view (FOV) is adjusted as wide as possible so that the position of a component fed is clearly and largely seen on the image acquired. Cameras acquire images of feeders at the position of component feeding and send them to the frame grabber inside the inspection computer. In the inspection system, 6 cameras were installed and can inspect up to 6 feeders at a time. The illumination system consists of 6 red LED modules, with each module located just below each camera and around the lens. We used cameras of EIA type with the resolution of 768(H) X 494(V) and a frame grabber that can acquire 640x480 images from 6 input channels, one at a time.

The inspection computer monitors loading status of feeders by communicating with the feeder control board via a RS-232 serial port, controls feeders under inspection, and acquires appropriate images through the frame grabber to perform inspection. PC was used for the inspection computer and the inspection software was implemented using Visual C++ on Windows with easily usable GUI.

### 2.2 System Operation

For inspection of feeders, instead of real tapes, a specially manufactured inspection template is used and loaded into the feeder and images of the template are acquired and analyzed to measure the feeding accuracy. The template used for the measurement is a plain stainless steel tape, where a square area of 1x1 mm on the component position is etched with high accuracy in black to appear distinctly compared with the template background color (Fig. 3). The use of the inspection template enables repetitive use for a long time, thus reducing inspection' cost. It also gives the advantage of maintaining consistent measurement accuracy.

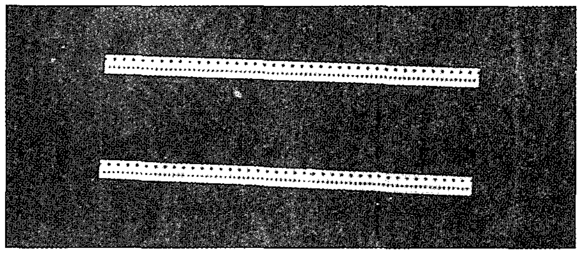

Fig. 3. An inspection template

If the inspection computer gives a command for component feeding to the feeder control board via a serial port, the inspection template proceeds by a fixed step. Then an image of the template is acquired to measure its position. Fig. 4 shows an example of an image acquired. In this image, black circle areas on the left are holes of sprockets needed to move the template. The position and size of each sprocket hole are identical to those of a real tape. The black squares on the right are made with the length of 1mm for a side by etching.

As a feeder moves this template to the next component position at a time, the position of the black square is measured.

This measurement is repeated a specified times for each feeder, and finally pass/fail decision and measurement results including mean, maximum, minimum, and standard deviation are outputted in text data and graph on the printer. Once the feeding accuracy test is completed for a feeder, next feeder is under inspection in turn automatically until all the feeders loaded on the feeder base are went through the inspection.

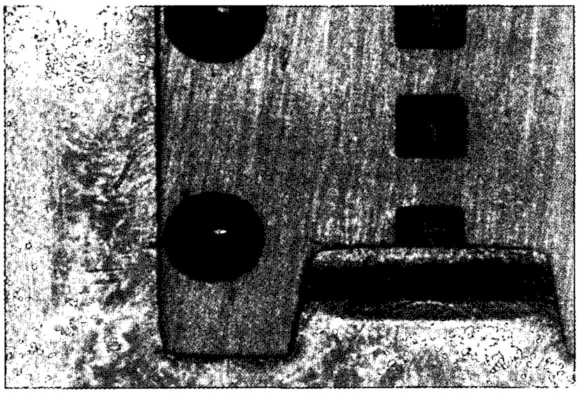

Fig. 4. An image obtained with an inspection template on the feeder

### 2.3 Inspection Methodologies

Image processing and analysis techniques that were used as inspection methodologies in this system are pattern matching and camera calibration based on edge detection [2][3][4][5][6][7].

First, to measure feeding accuracy, from an image acquired at the component position, a square pattern on the template is searched using pattern matching and its position on the image is measured. As a pattern matching method, a normalized correlation search [5][7] was used and a subpixel algorithm [3] using interpolation was used for better accuracy. In the setup phase, the image of a square pattern on the template is saved as the *model* on the computer.

Normalized correlation R at pixel (u,v) is given as follows.

$$R(u,v)=\frac{N\sum_i I_iM_i-(\sum_i I_i)(\sum_i M_i)}{\sqrt{(N\sum_i I_i^2-(\sum_i I_i)^2)(N\sum_i M_i^2-(\sum_i M_i)^2)}} \quad (1)$$

where, $I_i$ is the image intensity at ($u+x_i$, $v+y_i$), $M_i$ is the intensity value of the corresponding model pattern pixel at relative offset ($x_i$, $y_i$), and N represents the number of pixels of the model. R approaches to 1 as matching between the image and the model becomes better. First, the position with maximum R value inside the search area, that is, the position matching best with the model is found at pixel level. Then, the matching position in subpixel is calculated accurately using quadratic interpolation. In the 1-d correlation case, if R(u) becomes maximum at $u=u_0$ among all integer positions, $R(u_0-1)$ and $R(u_0+1)$ are used to estimate $u'$ in subpixel, where $R(u')$ is maximum, by the following quadratic interpolation.

$$u'=u_0-\frac{R(u_0+1)-R(u_0-1)}{2(R(u_0+1)-2R(u_0)+R(u_0-1))} \quad (2)$$

For the 2-d correlation in the image, this equation can be used in the x axis and y axis direction independently.

Fig. 5 shows a screen of parameter setting and trial execution of pattern matching. The rectangle in dotted lines on the image represents a ROI(Region of Interest), within which pattern matching is performed. The purpose of the setting of the ROI is to reduce the probability of detecting adjacent rectangles and to increase the search speed. Inside the ROI, there is a smaller rectangle in solid lines, which represents an image of the model registered for pattern matching. Since the image of the model is distinct from others inside the ROI, pattern matching errors may barely occur. Actually, during the operation of the system for a long time, this type of error never happened.

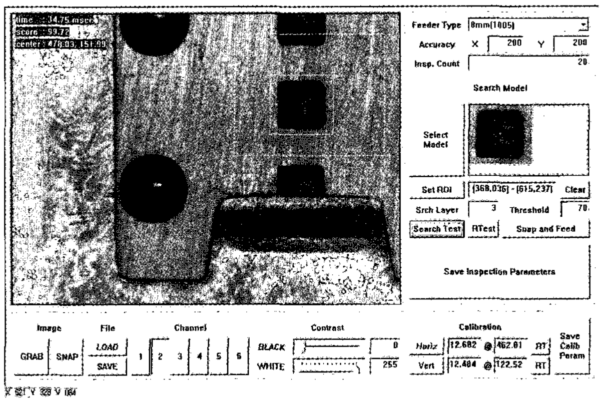


Fig. 5. A screen of pattern matching parameter setting

Next, in order to convert image coordinates extracted from the pattern matching to real world coordinates, an adequate camera calibration method is necessary. Due to the operational environment, this system requires a different calibration method from those normally used in machine vision systems. That is, circumstances where calibration is needed may frequently occur in this system, but this system has a structure difficult for placing general calibration tools appropriately. Thus, we used a black square mark etched on the inspection template for the calibration as well as pattern matching. The length of the square mark is measured horizontally and vertically using edge detection in subpixel and these values in pixels are compared with the real distance 1mm, and scale conversion factors (real distance per pixel) at both x axis and y axis are computed and saved on the computer.

This calibration method enables both calibration and measurement using the same template, allowing easy and convenient inspection process. Also, since the measurement is done on a specific area rather than the whole image area, this can be a simple but effective camera calibration method, assuming that the template is made with high accuracy in dimension and edge detection is done accurately. Fig. 6 shows a screen that measures horizontal length of the square mark on the inspection template by extracting edges at both ends.

The edge detection method used is as follows. Edge detection window in a strip form is placed on the square pattern and gray-level projection of the pixels inside the window is performed along the shorter side direction. The positions with locally maximum absolute slope value of the projection profile are considered as edge positions, as shown in Fig. 7. The edge positions are also estimated accurately in subpixel using the quadratic interpolation explained above. The distance between the two edge positions corresponds to the real distance 1mm.

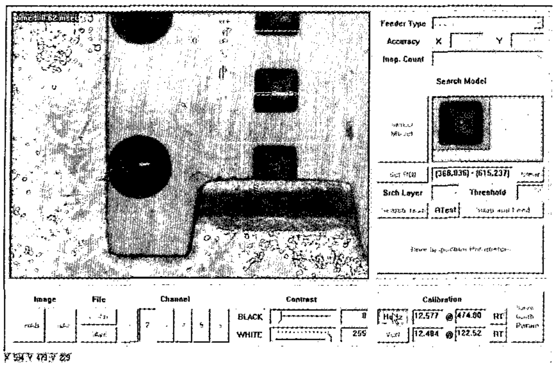
Fig. 6. Edge detection for camera calibration

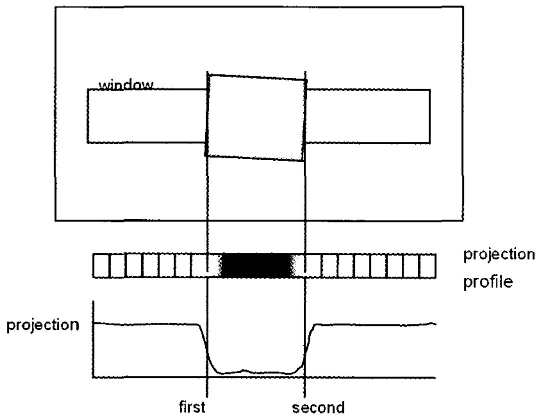

Fig. 7. Edge detection method

Once models for pattern matching and camera calibration parameters are registered on the computer, inspection stage proceeds. Fig. 8 shows a screen of performing real inspection. The position of the pattern model (square mark) that is extracted using pattern matching on the image under inspection is converted to real world coordinates using camera calibration parameters and printed in a dot on the left graph. After the inspection of pre-specified times for each feeder is completed, pass/fail decision and data needed for quality control are computed and outputted through statistical processing. The data computed include mean, standard deviation, maximum, and minimum in both horizontal and vertical directions.

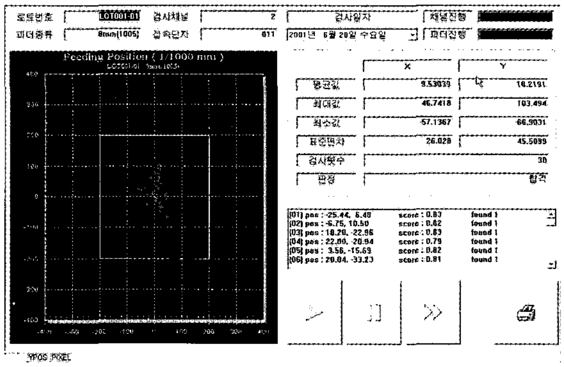
Fig. 8. A screen of feeding accuracy measurement

## 3. Experimental Results

First, we tried to measure the repeatability of the image processing methods employed in this inspection system. Test methodology is to apply each image processing method 100 times with image acquisition environment (feeder, camera, illumination, etc.) unchanged and to examine the deviation of the results. This repeatability test was performed 10 times as feeding proceeds. This test was done for both pattern matching and camera calibration. The standard deviation (σ) measured is shown in Table 1.

Table 1. Repeatability(standard deviation) (unit: pixel)

| trial | pattern matching | | camera calibration | |
|---|---|---|---|---|
| | x | y | x | y |
| 1 | 0.0274 | 0.0081 | 0.0277 | 0.0248 |
| 2 | 0.0145 | 0.0217 | 0.0339 | 0.0203 |
| 3 | 0.0129 | 0.0239 | 0.0371 | 0.0269 |
| 4 | 0.0107 | 0.0119 | 0.0375 | 0.0291 |
| 5 | 0.0114 | 0.0141 | 0.0301 | 0.0270 |
| 6 | 0.0081 | 0.0163 | 0.0598 | 0.0175 |
| 7 | 0.0091 | 0.0093 | 0.0404 | 0.0277 |
| 8 | 0.0087 | 0.0094 | 0.0348 | 0.0285 |
| 9 | 0.0091 | 0.0062 | 0.0330 | 0.0218 |
| 10 | 0.0078 | 0.0056 | 0.0454 | 0.0214 |

The pattern matching has the maximum standard deviations of 0.0274 and 0.0239 pixel and the 3σ repeatability of 0.08 and 0.07 pixel in x axis (horizontal) and y axis (vertical) direction, respectively. The maximum standard deviations of the camera calibration are 0.0598 and 0.0291 pixel, and thus 3σ repeatability will be 0.18 and 0.09 pixel in x and y, respectively. In the current FOV of the camera, a side of the square mark of 1x1mm corresponds to 79~80 pixels, thus one pixel representing 12~13um approximately. Therefore, the camera calibration method has the repeatability of 0.18 pixel, 2.3um in the maximum. In conclusion, maximum 3$\sigma$ repeatability of this system including pattern matching and camera calibration will be approximately 0.08*13+0.08*13*(2.3/1000)=1.04 um.

To measure the feeding accuracy of the feeder, with the inspection template loaded on the feeder, the position of the square mark on the template was measured 30 times to yield mean and standard deviation as the template moves up step by step. In measuring the position of the square, the position of the model registered was used as the origin. Then the feeder was unloaded and reloaded again, and the above experiment was repeated 10 times. The results are shown in Table 2.

Table 2. Measurement of feeding repeatability of a feeder (unit: um)

| trial | mean | | standard dev. | |
|---|---|---|---|---|
| | x | y | x | y |
| 1 | 9.5 | 18.2 | 26.0 | 45.5 |
| 2 | 11.7 | 17.8 | 28.2 | 44.2 |
| 3 | -30.4 | 27.5 | 25.0 | 46.6 |
| 4 | 6.2 | 11.6 | 21.2 | 50.2 |
| 5 | -61.7 | 28.3 | 27.7 | 44.6 |
| 6 | 21.8 | 10.5 | 19.7 | 51.2 |
| 7 | -20.6 | 30.9 | 27.9 | 44.6 |
| 8 | -20.6 | 9.7 | 20.0 | 51.5 |
| 9 | -44.6 | 28.8 | 28.4 | 46.9 |
| 10 | -82.5 | 5.4 | 18.8 | 52.1 |

The maximum deviations of the mean are 104.3um (-82.5~21.8um) and 25.5um (5.4~30.9um) in x axis and y axis, respectively. These deviations come from positional errors occurring in loading the feeder on the feeder base. We can see that these positional errors are much larger in horizontal direction than in vertical direction. The maximum standard deviations are 28.4um and 52.1um in x axis and y axis, respectively, thus 3$\sigma$ repeatability being 85.2um and 156.3um in the maximum. Notice that the error in vertical direction (that is, feeding direction) is larger than that in horizontal direction. This can be expected from the mechanical structure of the feeder.

## 4. Conclusion

This paper describes a tape feeder inspection system that was developed to automatically measure feeding accuracy of tape feeders using machine vision. It consists of a feeder base, an image acquisition system, and a PC. Feeders are mounted on the feeder base up to six feeders. The image acquisition system is composed of a CCD camera with lens, a LED illumination system, and a frame grabber inside the PC. This system inspects up to six feeders automatically and sequentially, one camera being mounted above each feeder. The PC controls movement of feeders being inspected and acquires feeder images through the frame grabber and performs inspection. A pattern matching method based on normalized correlation search and a camera calibration method using edge detection were used in this system. The inspection software was implemented using Visual C++ on Windows with easily usable GUI.

Using this system, we can automatically inspect the quality of all feeders in production process and use the measurement results statistically. Thus, by this way, we can not only monitor operating status of feeders, but also strengthen product competitiveness considerably through productivity improvement by reforming feeder assembly process.

## References


[1] http://www.smtman.com/process/feeder.htm

[2] E.R. Davies, *Machine Vision*, Academic Press, 2nd ed., 1997.

[3] R.M. Haralick and L.G. Shapiro, *Computer and Robot Vision*, vol. 1&2, Addison-Wesley, 1993.

[4] J.C. Russ, *The Image Processing Handbook*, 3rd Ed., CRC Press, 1998.

[5] R.C. Gonzalez and R.E. Woods, *Digital Image Processing*, Addison-Wesley, 1992.

[6] W.K. Pratt, *Digital Image Processing*, 2nd Ed., John Wiley & Sons, 1991.

[7] D.I. Barnea and H.F. Silverman, "A class of algorithms for fast digital registration", *IEEE Trans. Comput.* C-21, pp.179-186, 1972.


**Tai-Hoon Cho**

He received the B.S. degree in electronics engineering from Seoul National University in 1981, and the M.S. degree in electrical and electronic engineering from KAIST(Korea Advanced Institute of Science and Technology) in 1983. In 1991, he received the Ph.D. degree in electrical engineering from Virginia Polytechnic Institute & State University. From 1992 to 1997, he was a Senior Researcher at LG Industrial Systems R&D Center. In 1998, he joined the School of Information Technology, Korea University of Technology and Education, Chonan, Korea, where he is currently an associate professor. His research interests include computer vision, image analysis, and neural networks.