On-Line Enhancement of the Stencil Printing Process

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The number of defects in stencil printing can be reduced by using feedback control based on AOI measurements of the deposited solder paste bricks.

According to estimates, 50 to 70 percent of the total defects in surface-mount assembly lines are related to the stencil printing process, and approximately 30 to 50 percent of the total manufacturing cost is due to test and rework expenses.[1,2] Many factors affect the quality of the stencil printing process, including squeegee pressure, printing speed, solder paste viscosity and rheology, and air temperature and humidity within the production environment.

Efforts have been made to enhance the performance of the printing process by using on-line feedback control, where automatic optical inspection (AOI) measurements of deposited solder paste bricks are used to adjust machine settings such as squeegee pressure and printing speed. However, the success that has been achieved in using on-line feedback control in existing surface-mount lines appears to be rather limited. Some new stencil printers do include a closed-loop controller to maintain desired squeegee pressures and printing speeds in both printing directions. However, these controllers do not ensure that the deposited bricks will have desired characteristics such as the correct volume.

The limited use of feedback control of the stencil printing process in existing surface-mount lines is most likely due to the complexity and the high degree of natural variability of the process. To apply a conventional approach to controller design, the functional relationships must be determined between stencil printer parameters and AOI measurements of the deposited solder paste bricks such as height and area. But due to the process' complexity and variability, precise analytical relationships between stencil printer parameters and AOI measurements are very difficult to generate.

To overcome this difficulty, an approach to controller design for the stencil printer was developed using neural networks and fuzzy logic, which are well suited for highly complex and uncertain applications. Neural networks can be used to determine the membership functions for a fuzzy logic controller and to emulate the process for control signal verification. A fuzzy logic controller can also be used to incorporate knowledge (heuristics) from machine operators in the generation of the control signal.

Process Analysis

The first step in designing a controller was the collection of data relating stencil printer parameters and measurements of deposited solder paste bricks for the various pad types on the board. The printer parameters chosen were squeegee pressure and printing speed, and the deposited bricks were characterized in terms of their height and area.

Run Parameters

No. of Boards	Squeegee Pressure (Lb/in.^{2})	Printing Speed (in./sec.)
48	10, 25, 40	0.5
52	6,10,12,14,20,30,40	1
22	12	0.5,1,1.5,2,4
20	12	1
22	16	0.5,1,2,4
18	16	1

TABLE 1: Pressures and speeds for the board runs.

Pad Type Distribution

Pad Type	No.	Pad Type	No.
BGA	134	RC0805	94
MELF0805	94	RC1206	44
RC0402	94	SO50	68
RC0603	94	TSOP	100
		TOTAL	722

TABLE 2: Pad types on each board.

Data were collected for 182 boards that were run through the surface-mount assembly line in the Center for Board Assembly Research (CBAR) at the Georgia Institute of Technology. Table 1 shows the different values of pressures and printing speeds that were used for the various board runs.

The pad types on each board are shown in Table 2. In all of these runs, the snap-off distance was set to zero inches and the snap-off speed was set to 0.05 in./sec. A metallic 12-inch blade squeegee was used in all runs. Softer blades were not used because they have the tendency to print erratically in fine-pitch applications. The stencil thickness was 5 mils.

A three-dimensional laser inspection tool was used to measure the height and area of the deposited solder paste bricks. Data were collected showing the relationship between the mean and standard deviation of the height of the deposited solder paste bricks as a function of print speed and squeegee pressure. Data were also collected showing the relationship between the mean and standard deviation of the normalized area of the solder paste bricks as a function of print speed and squeegee pressure.

As an example of the results, Figure 1 shows the mean value of the height of the deposited bricks as a function of the print speed for a fixed value of the squeegee pressure. The height increased as the speed increased, and the height differed for the two print directions.

Figure 2 shows the standard deviation of the height as a function of the print speed. The standard deviation, and thus the degree of variability, also increased as the speed increased and was different for the two print directions.

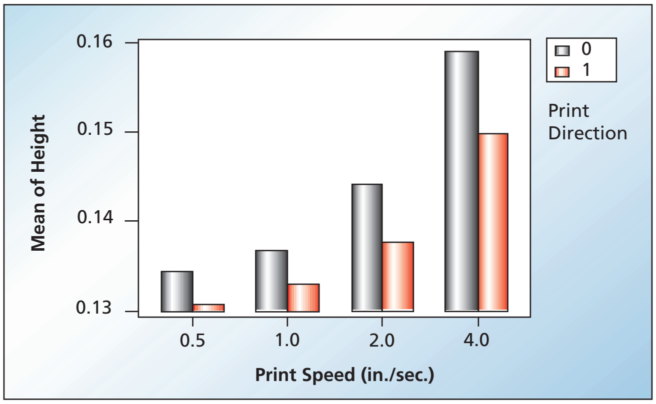

FIGURE 1: Mean of deposited brick height as a function of print speed.

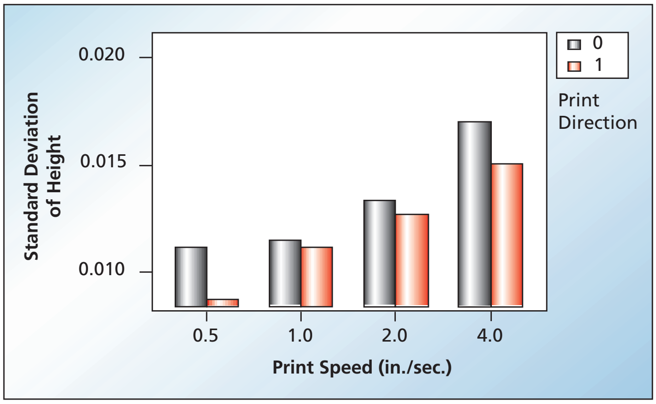

FIGURE 2: Standard deviation of deposited brick height as a function of print speed.

Fuzzy Logic Controller

Figure 3 depicts a stencil printer with the feedback control configuration. The block labeled *SPC* was a software package that performed various statistical calculations such as the mean and standard deviation of AOI measurements stored in the database. In the figure, the arrows from the fuzzy logic controller to and from the printer represented the two-way communication path between the controller and the printer. A software platform was used for the communications that provides a Java framework for implementing the GEM standard. The software allows the controller to change on-line any equipment variables and equipment constants.

Figure 4 depicts the stencil printer and the components of the fuzzy logic controller (FLC). The FLC was designed by first using the data relating the printer parameters and the mean and standard deviation of the height and area of the deposited bricks to generate membership functions for the FLC. An adaptive neuro-fuzzy inference system (ANFIS) tool automatically clustered the data to define the membership functions for the fuzzification stage of the FLC.

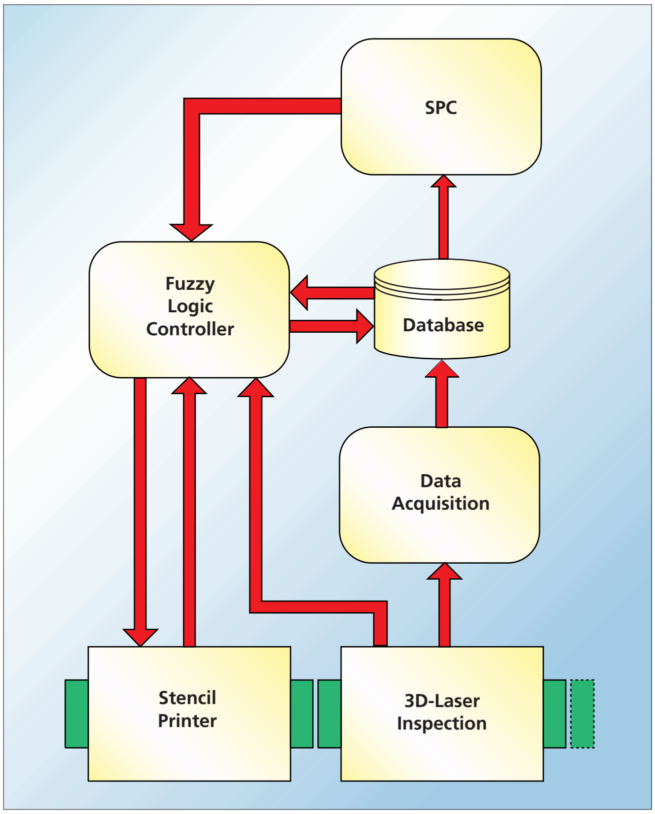

FIGURE 3: Stencil printer with feedback control configuration.

As an example of this process' output, the variable equal to the mean of the height was "fuzzified" into the sets denoted by low, normal, medhi, hi and veryhi, with the membership functions shown in Figure 5.

In addition to the mean of the height, fuzzy sets and membership functions were also generated for the standard deviation of the height, mean of the area, squeegee pressure, print speed, output pressure and output speed. Then the rules for the FLC were generated. The current version of the FLC consists of 18 rules, the first five of which are given below:

- If (Speed is not Fast) and (HeightStDev is Small) then (OutPressure is Med)(OutSpeed is Med)
- If (Speed is Med) and (HeightStDev is not Big) then (OutPressure is MedHi)(OutSpeed is Fast)
- If (Speed is Med) and (HeightStDev is Big) then (OutPressure is MedLow)(OutSpeed is Slow
- If (Speed is Fast) and (HeightStDev is Big) then (OutPressure is Med)(OutSpeed is Med)
- If (Speed is Fast) and (HeightMean is VeryHi) then (OutPressure is not Hi)(OutSpeed is Med).

The rules were evaluated using an inference engine and then the control inputs to the stencil printer were generated via a defuzzification scheme (Figure 4). A Mandami controller was used for the inference engine and for the defuzzification stage of the FLC. A very readable explanation of fuzzy sets and the Mandami fuzzy logic controller is available on the Web.[3]

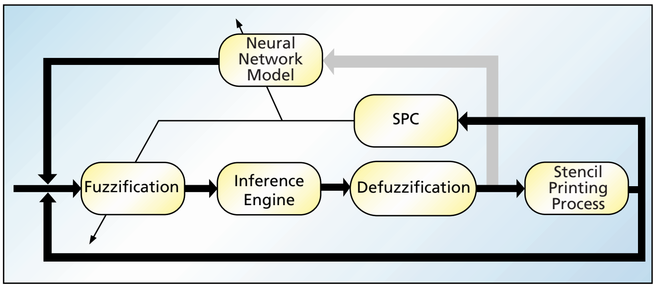

FIGURE 4: Stencil printer and the components of the fuzzy logic controller.

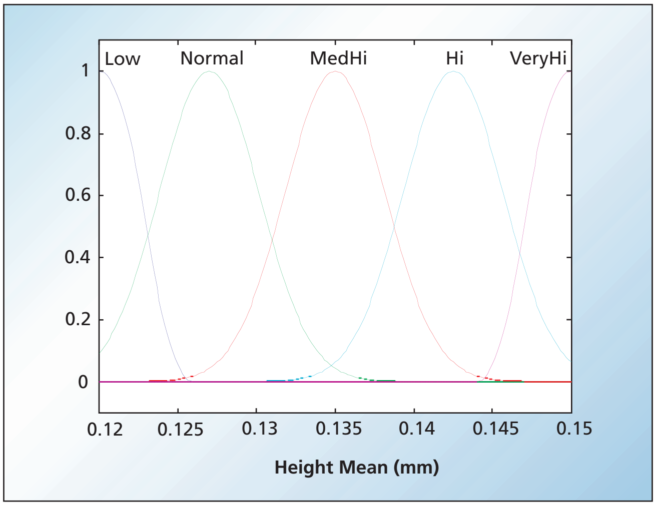

FIGURE 5: Membership functions for the fuzzification of the mean of the height.

In the on-line operation of the FLC, data from the most recently processed board was used to generate inputs to the FLC using the methodology summarized above. The FLC output consisted of the pressure and print speed values to be used in processing the next board. The generated values for pressure and speed were "verified" for accuracy, and tuned if necessary, by feeding the values back through a neural network model (emulation) of the printing process (Figure 4). The arrows through the neural network model and fuzzification blocks in Figure 4 indicate that these components can be tuned during production to track time variations in the stencil printing process.

Controller Performance

An example of controller performance is shown in Figure 6. Here the objective was to vary the printing speed if necessary to keep the height of the deposited bricks at 0.15 mm. As shown, the mean value of the height was close to the desired value for the first five boards, but then dropped substantially for the sixth board. The sudden decrease in height was due to changing the squeegee pressure from 16 lb/in.^{2} to 12 lb/in.^{2}, which represented a major disturbance in the process.

As shown, the controller automatically increased the print speed which then caused the height to return to the desired value beginning with the eighth board. However, the "overshoot" in the height for the seventh board was larger than desired, but this overshoot was due to the large magnitude of the disturbance. Efforts are underway to refine the controller by adding additional rules to produce an acceptable transient response over a wide range of disturbances.

Based on the surface-mount line at CBAR, an evaluation is planned to determine the effectiveness of the fuzzy logic controller in reducing the number of defects that occur in a board run. This project will correlate the occurrence of defects such as open or short circuits after reflow with the mean and standard

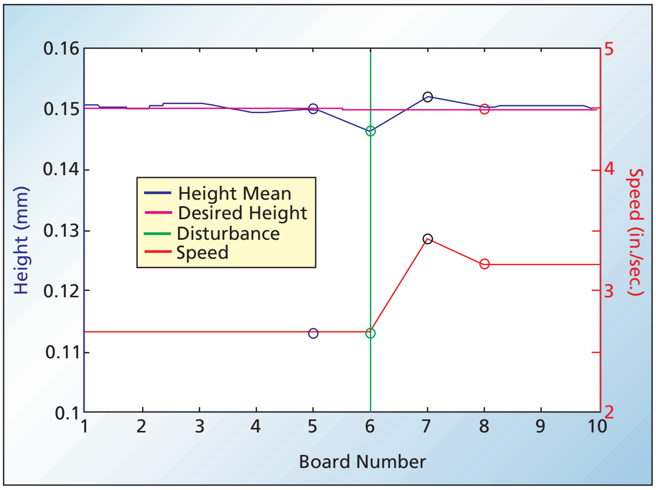

FIGURE 6: Controller performance in response to a major disturbance.

deviation of the height and normalized area of the deposited solder paste bricks after printing.

Conclusion

The opportunity exists for enhancing the stencil printing process by using feedback control, based on AOI measurements of the deposited solder paste bricks after printing. Due to the complexity and uncertainty in the process, a fuzzy logic framework may provide the best methodology for generating reliable control signals for adaptively adjusting printer tool parameters on a board-to-board basis. A specific goal of ongoing work is to show that the fuzzy logic controller described in this article can reduce the percent of defects that result from the stencil printing process. ■

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