Cost-effective, Reliable, and Precise Surface Mount Device (SMD) on PCBs

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Abstract. Automated Pick-and-Place (P&P) machines offer a new prospective for the assembly of Surface Mount Devices (SMDs) on Printed Circuit Boards (PCBs), owing to their advantages of time-effectiveness and precision. SMDs are widely used to improve production efficiency and reduce common defects. However, these machines are quite expensive and not easily available for the local market. This study is based on the design of a P&P machine model that incorporates principles of machine learning theory. The model has been developed in such a way that it can be introduced to the local market in a more cost-effective manner without compromising on its precision and accuracy.

1. Introduction
Assembly of components onto the Printed Circuit Board (PCB) uses mainly two techniques; the first, more prevalent method being the one that employs through-hole technology and the second, relatively advanced method employs Surface-Mount Technology (SMT). As no component leads must be inserted through holes in the PCB during assembly, Surface Mount Devices (SMDs) are well suited for high speed, reliable placement, miniaturization and low cost [1]. SMT facilitates large volume production by simplifying the integration of electronic circuits and simultaneously allows higher component density [2]. Due to the precision of the machine, small errors in component placement are corrected automatically as the surface tension of molten solder pulls components into alignment with solder pads.

The SMD assembly process can be classified in three categories [3]: Picking (the component is picked with a vacuum), Alignment (of the component relative to the board), and Placement. The accuracy with which components are to be placed on the PCB is a very crucial step in the assembly process [4]. Therefore, automatic machines, namely Pick and Place (P&P) machines, have been developed to precisely place various electronic components such as capacitors, resistors and Integrated Circuits (ICs) onto PCBs with high precision.

During the 1980s and 1990s two different P&P machines were placed in sequence for the assembly process. They were built around a single turret design where the they were used together for the placement of the components onto the board from a tape feeder. Owing to the huge cost of the two machines, their inflexibility and the speed limitations of the chip shooters, manufacturers shifted to an all-in-one modular, multi-headed and multi-gantry machine from the 20th century onwards. Nowadays, there are various kinds of SMD placement machines available, such as Sequential P&P, Rotary Disk Turret, Concurrent P&P etc. [5].
The P&P machines provide an easy and accurate method of assembling SMDs on PCBs but owing to their high cost, they are not affordable for industries. They must send their Gerber files for fabrication of PCBs to companies or markets that specifically employ these machines further increasing the cost and time required to get the desired product.

This study has been undertaken to fabricate a cost-effective P&P machine for the assembly of SMD without compromising precision and accuracy. The success of this project will have a huge impact on the growth of our local electronic industry.

2. Proposed Method
The initial steps of the design process included the study of automated commercial products of P&P machines already present in the market. Keeping in view the overall cost and time-effectiveness, it was concluded that the model design should be based on automatic P&P machines to cut the extra labour cost.

2.1. System Modelling
The system has been modelled as shown in Figure 1. The body of the machine comprises primarily of three axes, X, Y and Z, that are to be controlled using a MACH-3 controller connected to a computer. The X and Y axes have screw rods with timing belts that travel using Nema-17 stepper motors connected to wheels mounted on the timing belt. The Z axis is made of linear sliders mounted on the travelling plate of the X axis. Two Z axes are being used according to our design; one for paste dispensing and the other for the P&P action.

![Figure 1. System Model of SMD assembly machine.](image1)

The P&P machine was programmed with the information about component positions, developed through Gerber File. The machine, after determining the position of a component through the program developed using computer vision, picks up electronic components, ICs, from the feeder tray (holds the components before they are placed onto the PCB). The ICs are picked through the vacuum nozzle connected to a hollow shaft, Nema-8 stepper motor through a header. Before the IC is placed onto its respective position on the PCB, a drop of high-quality solder paste is dispensed onto the corresponding location through a pressure control kit with its air outlet connected to a syringe.

The design for this model also includes two cameras mounted on the machine. One camera has been placed between the two Z axes to help with the precise placement of the components on the PCB. The other camera is faced upwards and has been installed on the platform. It is used to correct the
orientation of component in the case that it is not deposited in the correct position from the feeder tray. Both the cameras have been programmed using machine learning principles through OpenCV.

### 2.2. Mathematical Modelling

An important feature of the P&P machine, included in our model, is the paste dispensing module responsible for dispensing small drops of solder paste onto the PCB before an IC is placed onto it. It consists primarily the paste dispenser kit, AD982 and the 12V piston compressor (100 psi) with the final dispensing taking place through a syringe. High viscosity industrial solder paste has been used to better control the velocity and flow of the paste that exits the dispensing nozzle.

To increase accuracy of results, standard thermodynamic principles for the calculations of time have been made as in equation (1).

\[
\dot{m} = \rho AV ; t = \frac{m}{\rho AV}
\]

where \( \dot{m} \) is the mass of paste dispensed, \( \rho \) is the density of the solder paste, \( A \) is the area of the nozzle that dispenses paste, and \( V \) is the velocity of the that exits the nozzle.

### 2.3. Algorithm Development

The code for the microcontroller, object detection and scaling programs have been written and tested through OpenCV. Detection of the corner points and the centre of the IC was a crucial step for their precise placement on the PCB as seen in Figure 2. This was achieved using Algorithm 1:

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**Algorithm 1: Algorithm for IC Size Calculation**

```python
1: for c in cnts:
2:     if cv2.contourArea(c) < 100:
3:         then
4:             (tl, tr, br, bl) = box
5:             (tltrX, tltrY) = midpoint(tl, tr)
6:             (blbrX, blbrY) = midpoint(bl, br)
7:             (tlblX, tlbly) = midpoint(tl, bl)
8:             (trbrX, trbrY) = midpoint(tr, br)
9:             dA = dist.euclidean(tltrX, tltrY), (blbrX, blbrY)
10:            dB = dist.euclidean(tlblX, tlbly), (trbrX, trbrY)
11:            if pixelsPerMetric is None:
12:                 pixelsPerMetric = \frac{dB}{args[\text{width}]}
13:            dimA = \frac{dA}{pixelsPerMetric}
14:            dimB = \frac{dB}{pixelsPerMetric}
15:        end for
```
Figure 2. Schematic diagram for SMD assembly process.

3. Results and Analysis
We aim to bring a commercially available product to the local market, various design parameters were analysed and adjusted for the model of the P&P machine accordingly. The final design of the model has been curated after taking into consideration the challenges faced along the way.

The equipment required for the design includes a 12V, 40A and 3-channel DC supply to power the machine, Nema-17 stepper motors together with A4988 stepper drivers, a 12V piston compressor, an AD982 dispenser, a 12V vacuum pump to assist in the P&P action, a 5V solenoid valve, 2-channel 5V relay, a BT100 SMT header and Nema-8 hollow shaft stepper motor used together with a DQ542MA stepper driver to perform the picking action.

Initial testing of the paste dispensing module was conducted using a mechanical relay. However, after carrying out several tests, it was concluded that switching to a solid-state relay would make the process more efficient as it provided a faster switching speed (less than 400ms). The relay is controlled by the microcontroller with the help of an 8-inch jack that sends input signal to the dispenser via an aux cable.

The data used to plot the graphs in Figure 3 was obtained from a set of experiments carried out to establish relationships between parameters crucial to the design process. Fig. 3(a) represents a non-linear relation between the velocity of the paste dispensed and the switching time of the relay. As can be seen from the figure, change in switching time controls the velocity of the paste dispensed. Fig. 3(b) represents a linear relationship between the diameter of the dispensing nozzle and the volume of the paste dispensed. Choosing an effective nozzle group (or a nozzle) is important since a nozzle change operation is time consuming [6]. Different sets of nozzles were used during the experiment to determine which one provided the best control over the volume of the paste dispensed as this had to be very accurate. Greater or lesser volume dispensed could lead to inaccurate placement of ICs on the PCB. A decrease in nozzle diameter allows greater control over dispensed volume.
Figure 3. (a) depicts the relationship for the velocity of the paste dispensed and the time required; (b) depicts relationship of volume of paste dispensed and the diameter of nozzle.

4. Conclusion
With this study, we have proposed and implemented the design model for a P&P machine that operates on the principles of Machine Learning Theory. The model was completed within 18-20% of the cost of a commercially available P&P. With the study that was conducted, we have been able to reduce the cost factor and provide an alternate solution that can be introduced to the local market without compromising on the accuracy and precision required to complete the assembly process.

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References
[1] G. Burel, F. Bernard and W.J. Venema, “Vision Feedback for SMD placement using neural networks,” Proceeding IEEE, pp.1491, 1995.
[2] Lifei Bai, Xianqiang Yang and Huijun Gao, “Corner point-based coarse-fine method for surface mount component positioning,” IEEE Transactions on Industrial Informatics, vol.14, issue 3, March 2018.
[3] Ivo Van RIJSSEL, “User requirements of the Galatea vision work package dedicated to SMD placement”, Galatea Report (European Esprit project no 5293), April 15th, 1991.
[4] Huanca, J. and Spence, R.” A new statistical algorithm for fault location in tolerance analogue circuits,” Proceedings IEE, vol. 30, part G, pp. 1148-1151, 1983.
[5] Gastel, 2002; Grotzinger, 1992; Khoo and Loh, 2000.
[6] M.Ayob and G. Kendall, “A nozzle selection heuristic to optimize the hybrid pick and place machine,” IEEE Conference on Cybernetics and Intelligent Systems, pp.1260, 05 July 2005.