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Open Source Automated SMD Pick and Place Machine

Gokulnath A R*, Chandrakumar S, Sudhakar T D

St.Joseph's college of Engineering, OMR, Chennai-119, India.

Abstract

Surface Mount Device (SMD) is widely used in an automated Printed Circuit Board (PCB) assembling plant. Soldering SMD is a tedious and time-consuming process when it is done using bare hands. Industries require bulk production and hence it cannot be achieved by manual labour. For this fully automated SMD Pick and Place (P&P) machines are available in the market but the cheapest one starts at INR 15 Lakh (Yamaha yv-100x—Refurbished) and they are proprietary. Start-ups especially India based, find it difficult to afford such machine. In this paper, this issue is addressed and built an automated SMD P&P machine which is open source and far cheaper than the cheapest one in the market. However, the algorithm of the developed SMD P&P Machine and the one in the market remains the same but it functions differently and the steps are as follows; (i) Component are loaded onto the feeder tray (ii) Centroid file(machine file in ASCII format which comprise reference designator, X, Y , rotation, top or bottom side of the PCB board) is fed to the machine (iii) From the feeder tray component is picked by placement head using vacuum suction (iv) If the component is available in the placement head then correcting of component's orientation and alignment using image processing is done else placement head is made to re-pick the component from feeder tray (v) Properly aligned and oriented component is placed on the PCB by releasing the vacuum. The proposed model is open source in both hardware (Raspberry Pi & Arduino) and software which is user friendly and easy to customize as per requirements.

Keywords: Computer Vision (CV), Pick and Place (P&P), Surface Mount Device (SMD), Surface Mount Technology (SMT), Printed Circuit board(PCB), Components Per Hour(CPH);

1. Introduction

Our task as an Engineer is to design and implement the most optimized system for P&P assembly process. But there is a subtle difference between general purpose robotic P&P machine and Surface Mount Technology (SMT) P&P machine. A lot of research works are undergoing into the general P&P [1] but the SMT version is still in an evolving stage. Our intention is to provide a most affordable machine for Indian start-ups and it has to be an open

* Corresponding author. Tel.: +91-9884562945.
E-mail address: argokulnath@yahoo.co.in, t.d.sudhakar@gmail.com.

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source mechanism so that it can be easily customized according to the user needs. The system is built based on above intentions and it is heavily customizable and can be modified anytime according to the needs. The process is divided into 3 steps. First being recognizing the placed PCB onto the assembly tray and adjusting the offset values by using CV. Second being the placement head which picks up the component and the object feature extraction/ Object recognition is done and component is rotated/compensated for the linear offset positions. Third being moving to its corresponding positions as mentioned in the Centroid file and placing the component onto the PCB. The generalized SMT Physical look is shown in the Fig 1.

Fig. 1. Basic SMD P&P Machine.

SMT Technology evolves in early 1980's and it brought a tremendous change towards how a PCB is constructed and overall cost reductions. It does need a machine to assemble the parts onto the PCB. This machine is also called as called chip shooters, which places simple components such as resistors and capacitors. The most advanced one of this time can do only 53K Components Per Hour (CPH) and this trend hasn't changed much since then. At Present certain low budget machines which are under 15Lakh INR is not well equipped to perform certain basic procedures which are necessary for Indian needs and new technology aren't implemented too. They can do certain things which are basic and mentioned below:

- Pick and place process
- Feeder assembly is present
- Reflow oven (separate machine)

And some possible changes of the process are for image recognition the new vision systems [2] proposed by ICOS vision system can be used. Since SMD technology evolves continuously, its sizes and new designs need an entirely new method of image processing which requires classifier parameters, resizing images with the loss of pixel data [3] etc. And their performance should meet the requirement standards. In the assembly process, the usage of different type placement head is also required in order to achieve concurrent high speed P&P process [4]. The processing speed is also affected by the frequent nozzle changes for different sized SMD components. A special algorithm can be implemented to reduce the maximum possible frequency of nozzle changes [5]. Finally, all those above mentioned algorithms can be used to fully optimize the P&P process [6].

An fully automatic P&P machine with full image recognition and offsetting capability runs into the upwards of 30Lakhs INR and some affordable ones aren't equipped to do component recognition, offset correction for nozzle head, integrated soldering methods, single headed optimisation (one size fits all), open source hardware and software, All machines are Chinese made and no after sales support, heavy import duty (44% to 125%).

So the need of the hour is the fully automated P&P machine with full image recognition and offsetting capability at lower cost for Indian requirements. For which a low cost machine with all these facilities are proposed. The cost is reduced by using open source in, (i) hardware design, (ii) controllers and (iii) OpenCV library. Further the cost is reduced by using the stepper motor in its place of servo motor.

2. Proposed Methodology

To overcome the above limitations following proposed system is explained and basic functional changes are also described. Mechanical system i.e. the proposed SMD machine is built based on the direct shaft-driven XY mechanism as compared to conventional CoreXY and similar systems (H-Bot, D-Bot, etc.). Usage of linear flat bearing has significantly improved mechanical stability by reducing torsional disturbances as compared against conventional usage of circular bearing in P&P machines. Usage of stepper motor without position encoder has shown a significant drop in overall capital price. The accuracy of about 0.01mm in x-direction and the y-direction remains complete intact with the system. Vision system is based on contour feature extraction algorithm whereas HAAR training algorithm needs to High capital to train the machine on image processing. Usage of open source hardware and software in this machine helps P&P developers to work directly in customizing according to their need. The firmware is embedded with Arduino which is placed in firmware layer. Users who wish to customize this machine can work directly in customizable layer which has access to adding new components, creating remote access etc. The Basic Block diagram and the Software architecture diagram is shown in the Fig. 2.

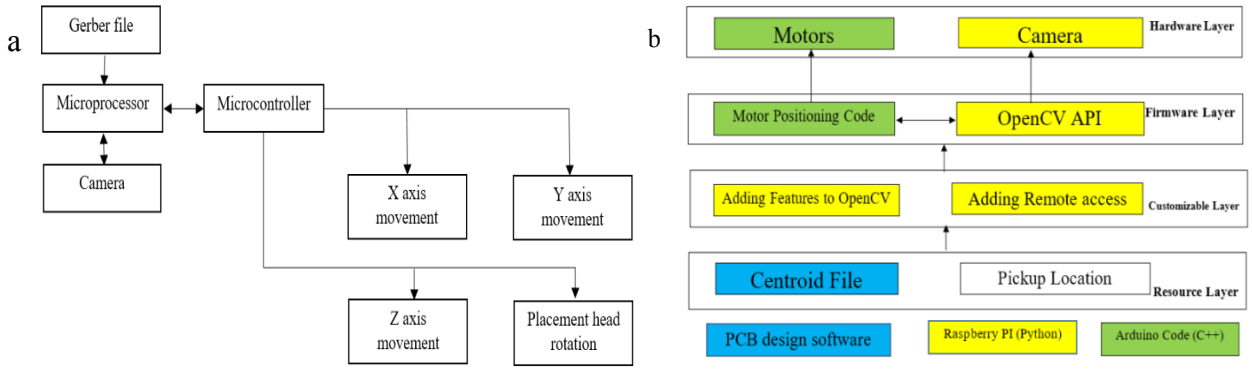

Fig. 2. (a) View of Basic block diagram; (b) Software Architecture diagram.

2.1. Algorithm

The working algorithm is explained in consecutive order. Centroid file generated from any PCB design software should be uploaded into the machine. Decoding and extraction of placement location is extracted from the centroid file [7]. This location is being used by the machine to place the components. To pick the component another file which is similar to the format of Gerber file and is show in the Table 1 must be provided. Raspberry PI sends command to Arduino to pick the component. Once the placement head is moved to that particular position and picks up the component and then Raspberry Pi sends command to move the machine to the camera location. Camera uses Contour feature [8] algorithm as in OpenCV library to understand about the properties of component.

Table 1. An Overview of a Pickup location file

Name of component	X position (in mm)	Y position (in mm)
R1	5580	16790
R2	5500	16790
R3	5420	16790
L1	5580	16700
L2	5580	16610
L3	5580	16520

After any offset is detected it is adjusted by rotating the component to desired position as mentioned in Gerber file coordinates. Thus, the component is moved to the particular position to place it in the PCB board. This process is done until all the component gets placed onto the PCB.

3. Working of This Machine

The machine working remains the same for SMD Packages 1206, 1210, 1806, 1812, 2010 and 2512. These numbers are Universal standard of Imperial Codes for SMD which denotes SMD Component sizes. Testing is successfully completed for LED, Resistor and capacitor in SMD packages. Detailed explanation of all these packages has been shown below. P&P mechanism involves 2 distinct methodologies as stated below.

- Mechanical movement
- Image processing

3.1. Mechanical Movement

The working algorithm for the mechanical movement (machine) is described in step by step procedures below. Pick and place centroid file is generated using PCB design software a like Eagle, Web View (This is called Gerber file [7]). A Sample view of Gerber file and PCB design layout is shown in the Fig. 3. It is fed to Raspberry PI and it decodes into machine readable format which is done by a python code. (Raspberry Pi is also known as RPI). Then RPI checks for the availability of pick and place machine. RPI initializes the pick and place machine. Coordinates from where to pick components, are given to RPI using an excel file. RPI sends signal to Arduino to move motor using motor driver. Then placement head is moved to corresponding X Y locations to pick the component (here we use 3 LEDs and 3 resistors of 1kohm). Using suction cup (vacuum) the head picks up the component. Then it is moved to the camera position and check for alignment and orientation which is explained in the next process (image processing). After offsetting and alignment complete, placement head moves to corresponding position for that component which is taken from the Gerber file. The head is lowered and vacuum is released to place the component. Procedure 6 to procedure 10 is repeated until all components are placed. Thus, the head moves to initial position and would be ready for next batch.

a.

	A	B	C	D	E
1	Reference Designator(s)	X	Y	Rotation	Side
2	R1	25.4	21.59	0	Top
3	R2	7.62	21.59	180	Top
4	R3	16.51	11.43	270	Top
5	LED1	16.51	25.4	90	Top
6	LED2	11.43	16.51	240	Top
7	LED3	21.59	16.51	300	Top
8					

b.

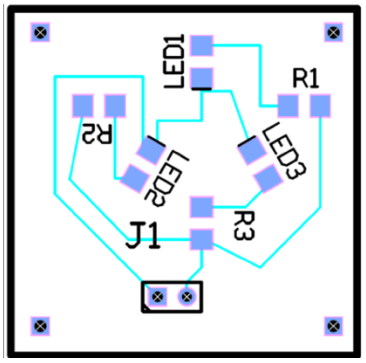

Fig. 3. (a) View of Software generated Gerber file; (b) Sample PCB final layout.

3.2. Image Processing

The working algorithms for image recognition are explained in step by step procedures below. Placement of the components must be done in the exact orientation as specified in the Gerber file. In order to achieve that, OpenCV is being used to process the image to find the current angle and centre of the chip. First the placement head along with the picked chip is moved to the exact center of the camera as hard coded according to the machine. Then image is

captured using the camera attached to the raspberry pi, converting the image to Grayscale format. Now using Gaussian blur filter removing the texture present in the lead of the chip. Using Thresholding technique [9] the noises present in the image are removed. Using Canny edge detection [10] technique borders of the image are detected. Areas of the border and if the areas are greater than 10000 pixel it is evident to be a chip are found. Using contour features [8] angle and center of the chip are founded. Return it to the calling function. The working screenshot of image processing is shown in the Fig. 4. Green borders represent the chip and Centres of the chip is given in the terminal in X, Y format. Since actual image is a part of video clip where the chip gets rotated then centres are continuously printed. Angle of orientation is mentioned inside the chip.

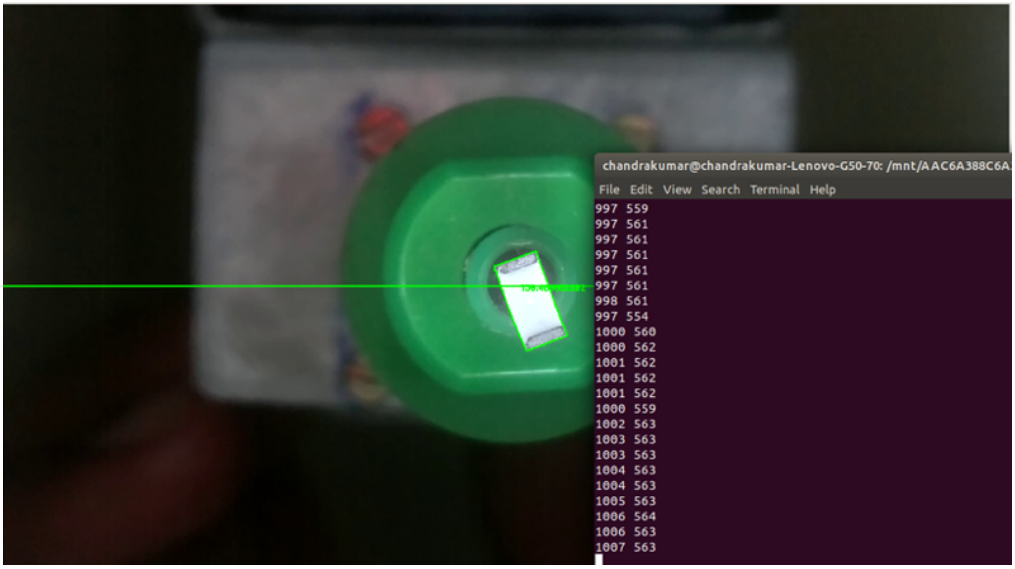

Fig. 4. A view of image recognition algorithm returning the center coordinates of the object to its right during run time.

4. Results and Discussion

The machine is successfully tested for resistor, LED and capacitor. The final assembled pic of the PCB is shown in the Fig. 5. Industrial grade materials are used and build cost is about INR 40,000. Thus, the overall cost of the machine is far lower than the current available machine in the market (15L – 3Cr.). Thus, Indian startups can afford P&P machine at their industries by using open source Software and Hardware.

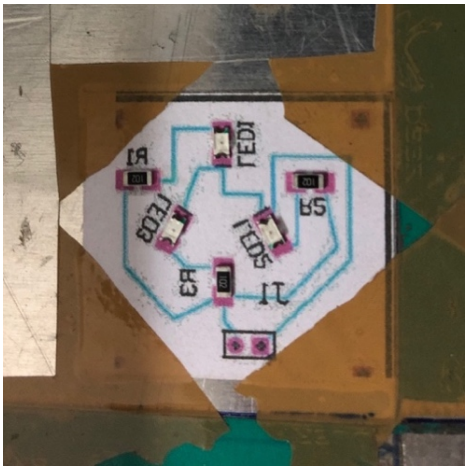

Fig. 5. View of fully assembled PCB by the P&P Machine

4.1. Features of this Machine

The features of this machine are fully described below. Open Source in both hardware and software. Image processing remains the same irrespective of the SMD package used. Uses flat bearing and guide rather than circular bearing. This allows us to have torsion stability in this machine at a low cost rather than using dual beam structures. High torque dc geared stepper motors are used which doesn't contain encoder and any other form feedback mechanisms, though this machine is highly stable. Only one placement head is required and optimized to place SMD component of packages 1206, 1210, 1806, 1812, 2010 and 2512 as in imperial codes, which means no need of nozzle changing for these packages. A view of the placement head and the whole machine is shown in the Fig. 6. Working accuracy of about .01mm in X direction and Y direction is in intact with the machine always.

Low power consumption as stepper motors are used which requires 2A for one motor driver. Aluminium is used as build materials. Machine can reach 240 Components Per Hour (CPH) as in current configuration and if feedbacks are introduced CPH as high as 10,000 can be achieved.

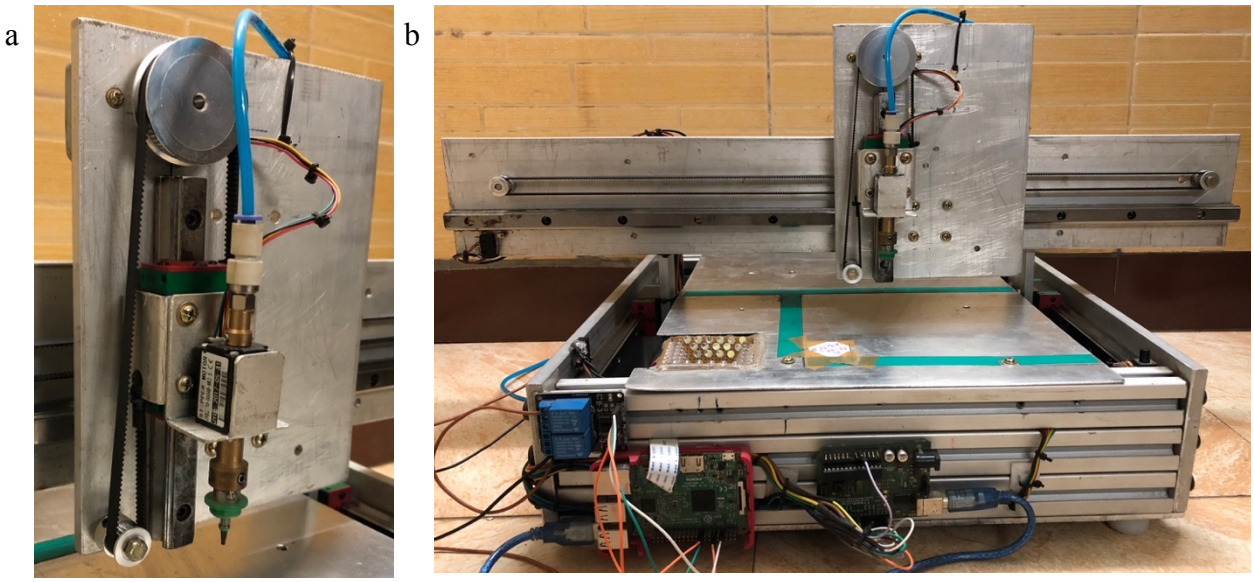

Fig. 6. (a) side view of the Placement head; (b) Front full view of the complete machine.

4.2. Difficulties faced

The following are the difficulties faces during the construction of this machine. This machine uses linear XY movement mechanism. This increases the stress for X movement when compared to Y movement. Since feedback is not used here, this machine needs to be initialized to (0, 0) for X, Y axis in order to maintain the accuracy of the machine after 5 successive placements which further decreases the CPH value. This machine at times fails to drop the component at the exact position due to presence of partial vacuuming even when the vacuum motor is switched off. Placement head Mechanism is not very efficient which needs total redesign.

5. Conclusion and Future Advancements

5.1. Conclusion

Low cost Automated SMD pick and place (P&P) machines are designed. The cost reduction of the machine is achieved by using the open source hardware. For which the coding is developed and used for the hardware design, controllers and image recognition. The main advantage of the machine is the reduced control circuit, as it works on

the open loop control. The final reason for the cost reduction is the selection of the motor. In the proposed work the stepper motors are used instead of servo motors. By using all these parameters, the cost of the machine is drastically reduced.

5.2. Future Advancements

The following advancements can be made to this proposed machine to further elevate its effective process. We suggest using H-Bot or D-Bot for building the mechanical movement assembly. Feedbacks like linear encoders can be used for mechanical movement in order to increase the CPH. However, we suggest using stepper motor (NEMA 23) with built in encoders for the X and Y axis motors. Pneumatic directional valve needs to be used in addition to suction valve to place the component in the proper position. Laser soldering can be done. This eliminates the cost for a soldering reflow oven and overall time spent. Multiple placement heads (like Circular, Turret type etc.) [2] can be used to increase CPH. USB camera can be connected at the placement head to achieve automatic picking of component from the feeder and Feeder tray irrespective of their orientation at the tray. Finally, Motion Stability and dynamic analysis can be done and based on the results the design can be tweaked.

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