Automated Inspection System for Assembled Printed Circuit Board Using Machine Vision

Harish O. Goupale, Neetu N. Gyanchandani, Pranay A. Chauhan, Sneha C. Kumbhare, Twinkle B. Bhaisare

Department of Electronics and Telecommunication, J D College Of Engineering and Management, Nagpur

Corresponding author: Harish O. Goupale, Email: hgoupale9119@gmail.com

The perfect Printed Circuit Board (PCB) plays a very important role in every electronic device as well as in automation systems. So, it is very important to find defects in the PCB before installing it to any system or any device. However, PCB Manufacturers use various inspection systems in the process of manufacturing PCBs for detecting various types of defects in the PCB. In this article, we present the Automated assembled PCB Inspection System. This system finds defects such as missing components and improper position of its components by using the Pattern matching Technique where a good known score of template image is matched with the score of the test image. This system gives results at each inspection within 10 Seconds and the result given by this system are passed or fail in the form of an array sheet. This automated inspection system is created by using NI Vision Builder AI and NI LabVIEW technology. Ni Vision Builder AI has been used to create the algorithm. And NI LabVIEW has been used to create the application.

Keywords: NI LabVIEW2020, NI Vision Builder AI 2020, Image Processing, Pattern Matching Technique.

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1. Introduction

In the modern world, infrastructures and industries turn towards automation where various types of PCBs play a very important role. The working of every electronic device and automation system depends on the functionality of PCBs. Due to misalignment and orientation during the manufacturing of PCB, various types of defects can occur. A very small defect in the PCB may cause the entire system failure, so before installing to any system, it is very important to check the functionality and working of PCBs in the last stage of PCB manufacturing units in the industry. Usually, many industries used various methods like manual inspection, electrical performance testing, Automated inspection systems, and Automated Visual Inspection Systems to find the various types of defects in the PCBs. PCB defects can be sorted into two parts: Functional defect and Cosmetic defect [15]. Opens, shorts, defective components, are the functional type of defects. And usually, functional defects can be tested by connectivity tests which affect the performance of the system [4]. Missing components, improper position of components is the cosmetic type of defects. And cosmetic defects affect the appearance of the PCB [15]. In general PCB algorithms can be classified into three types: referential approach, non-referential approaches, and hybrid approaches [15]. The referential approach involves the comparison between pixels in the test image and in a template image or reference image. The non-referential approach simply works on geometric shapes and verify the design rules. The hybrid approach is the combination of a referential approach and a non-referential approach. Most of the PCB manufacturing industries use machine vision technology, where a combination of hardware and software works together with a simple camera to acquire the image and by using pattern matching technique. Pattern matching in computer vision technology is the set of computational techniques that enable the localization of template patterns in a sample image. In the template matching algorithm, we have to pass the already reference image/template image to the algorithm, after that when the source image comes in, the template matching works by comparing each pixel value of the source image with the template one at a time. And then we get the output of an array of similarity values after comparing the template image. In this paper, the proposed automated inspection system is based on the referential approach. It is nothing but the pattern matching technique where the perfect assembled board is used as the template image, and inspecting images are considered as a test image. The proposed system finds defects such as missing components and improper position of components.

2. Literature Survey

Mukesh Kumar and colleagues [1] use an image enhancement algorithm to sharpen the edges of tracks in PCB, filter out the noise effectively with the help of National Instrument Vision assistant software. The average time ready to perform the proposed algorithm is 10 ms or 99.43 parts inspected per second

T. J. Mateo Sanguino et al. [2] The visual inspection system is used for automatic detection and classification for finding errors. The subtraction method is used for higher performance of defect detection and light intensity to get a more accurate classification. Through the use of statistical techniques, the system allows classifying a total of twelve types of detects and the algorithms are analytically compared and examined the performance.

Ziyin Li and colleagues [3] AOI technology are presented to detect the defects of PCB. The image enhancement, image denoising, pictures segmentation algorithm are used in this process. It detects wire gaps, voids, scratch defects as well short circuits, open circuit faults, and other types of defects. The system doesn't require any touch. The highest resolution of the design is 15μm and the detection success rate is over 95%.

Manasa H R and Anitha D B [4] Automated inspection system is used for improving quality of Printed

Circuit Board (PCB) production and rejection ratio. This system has been implemented using the template Matching method and it used a referential approach to inspect the assembled PCB, find missing components, verify the physical dimensions of the components, and generate a check report. This system is made for a particular PCB, so there is separate code that needs to be written for different PCBs.

Anitha D B, Mahesh Rao [5] The proposed work gives an automated approach for identifying defects related to the SMT components found in the assembled PCB. There are three different techniques 1. Contour Analysis 2. Optical Character Recognition 3, Pixel Subtraction. This technique is used for detecting the defects such as shifted components, placement of wrongly valued components, and missing components in the LabVIEW platform. Using this technique number of defects can be decreased and it takes very little time to identify other defects.

Hendawan Soebhakti and Farkhad Ihsan Hariadi [8] have developed automated optical inspection using surface mount technology to find missing components and defects during the PCB assembly process. They have found the solution developing AOI (automatic optical inspection) by employing neural networks and extracting histogram values from PCB images. When the system is inspecting a small size of components then it displays the result of an accuracy rate of 93%. By extracting histogram values from PCB images, the neural network can classify components under inspection as exit or missing. It classifies components available or not by using AOI and neural network technology.

Tejas Khare, Vaibhav Bahel, and Anuradha C. Phadke [9] The author name this proposed system as PCB Fire. The paper aims to solve the problem of missing components in PCB. They have used different techniques like Object detection, Image Subtraction Pixel manipulation algorithms, and neural
networks for detection and classification. A novel algorithm using image subtraction and pixel manipulation for detecting and classifying the missing components was proposed. In this system, the classification of the components is achieved by using the YOLO (You Only Look Once) algorithm. YOLO is a fully convolutional Neural network (CNN). They provide input image text size that is fed to be classified or detected by the network. This solution reduced the loss of capital and time incurred while identifying the fault. The model gave an accuracy of 75.48%.

Table 1. Comparison Table

No.	System Name	Technique used	Algorithm used	Software's used
[1]	Automated Optical Inspection System.	Patterns Matching Technique.	AOI system can quickly capture the focused pictures of inspected parts as well as record and compare their patterns with the perfect part or product.	NI Vision Assistant, Open CV library in LabVIEW Programming.
[2]	Automated Surface mount PCB inspection system.	Normalized Cross Correlation template matching technique.	The method developed is based on Template Matching and Genetic Algorithm search where a generalized grey model template is used for multiple target recognition.	Canny Edge Detection Algorithm Software.

[3]	Automated Optical Inspection System.	Neural Network Technique and Optical Character Recognition Method.	A threshold value is applied on acquired image to produce a binary image. Solder size can be calculated based on the number of white pixels in each of ROI.	LabVIEW and IMAQ function.
[4]	Automated Inspection System.	Template Matching Technique.	The perfect board is used as the reference board, inspecting PCB image is the test image. Test PCB is checked against the reference board using template matching technique.	NI Vision Development Module and LabVIEW Programming.
[5]	Automated Testing System	Bitwise XOR Operation	The captured RGB image is converted to grey scale. Grey scale image is then converted to binary form using Canny Edge Detection algorithm.	Canny Edge Detection Software.
[6]	Automated Optical Inspection	Contour Analysis, and Optical Character Recognition Technique, Pixel Subtraction Method.	Reference imageis compared with acquired image is being tried.	LabVIEW Programming, NI OCR Training Interface.
[8]	Automated Optical Inspection	Pixel theory and object detection technique, Image Subtraction Method. Convolutional neural network technique.	The detection and classification of component are achieved by using the (YOLO) You Only Look Once algorithm. (YOLO) is a fully Convolutional Neural Network (CNN). It is a neural network used for detection & classification Which has free open access.	PCB DSLR Dataset [online]

3. Identification of Tools

In the proposed Automated inspection System to construct the hardware structure, the 3MP Webcam has been used as shown in Figure 1. And we have created a Black box to set the camera in a static position as shown in Figure 2. Also, we have created a static position for inspection of PCBs as shown in Figure 3. and we have used two software to propose the whole Automated Inspection System which is NI LabVIEW and NI Vision Builder AI. NI LabVIEW version2020 has been used to build the application shown in Figure 4. and NI Vision builder AI 2020 has been used to create the algorithm shown in Figure 5.

Fig 1(a). Blazon Webcam , HD, 3MP Image Resolution, Frame Rate30fps

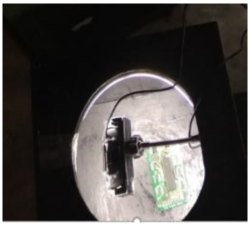


Fig 1(b) Wooden Box to set the camera

Fig 2. Static Position of PCB

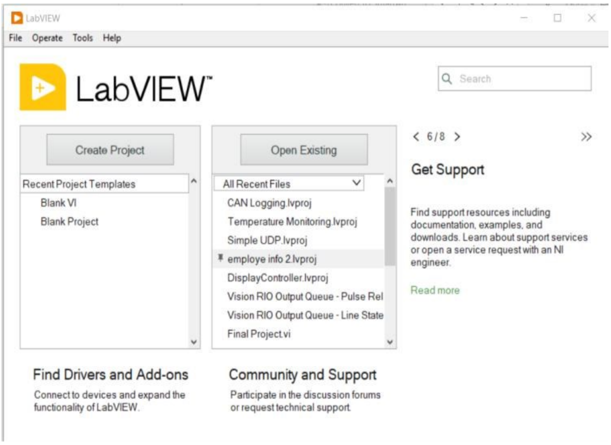


Fig 3. NI LabVIEW

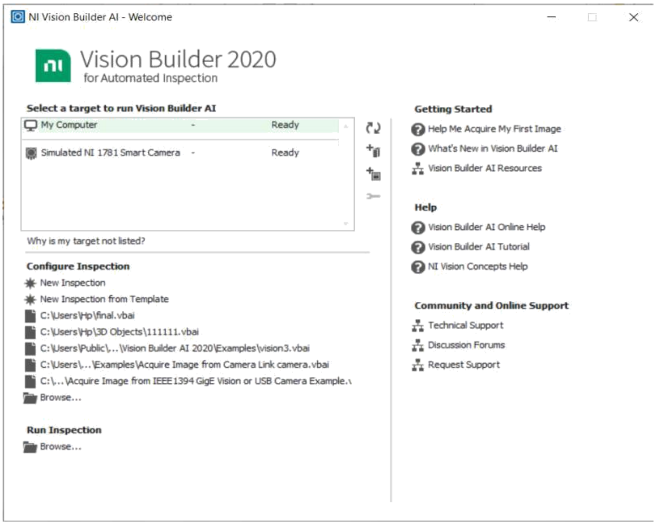


Fig 4. NI Vision Builder AI

4. Implementation of the Algorithm

The proposed Automated Inspection System for Assembled Printed Circuit Board has been implemented using pattern matching technique and to create the algorithm the software tool used is NI Vision Builder AI shown in Figure 6. The template images are matched with the test images. The perfect assembled PCB is considered as the template image shown in Figure 7. Every manufacturing PCB is considered as the test image shown in Figure 8. If the match score of the test image is less than the template image then the test image is considered as a fail. Figure 9 Flowchart of Proposed Automated Inspection System Shows the overall flow of the inspection in the following 5 steps.

Fig 5. Image of Template PCB

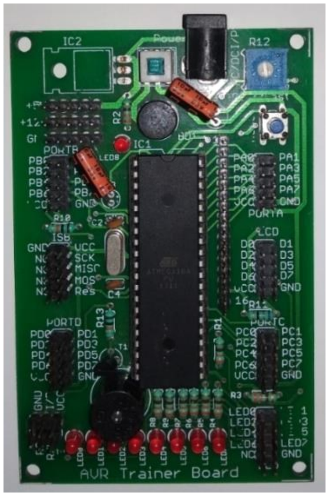


Fig 6. Image of Test PCB

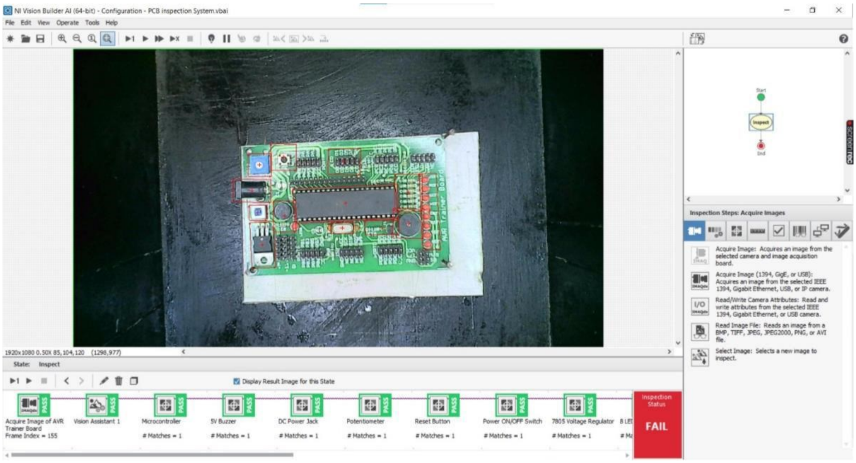


Fig 7. Algorithm of Automated PCB inspection system

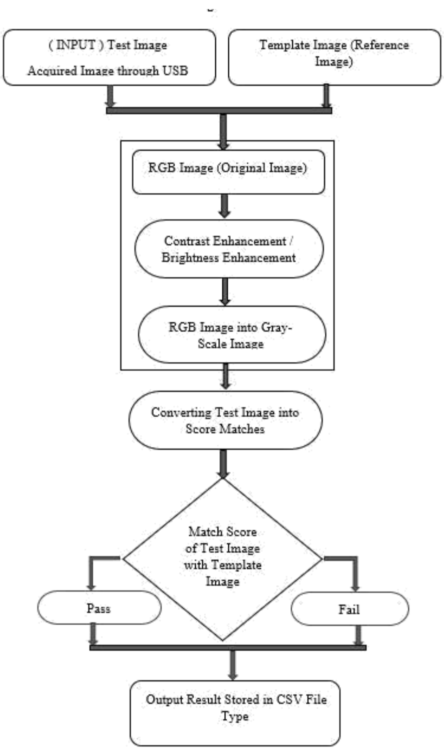


Fig 8 . Flowchart of Proposed Automated Inspection System

Step 1: This is the Image Acquisition step. This is the first step of the algorithm. In this step, the proposed system acquired the image of the AVR Trainer Board through a USB cable from a 3MP Webcam Camera.

Step 2: This is the Image Enhancement step. In this step there is a new window open called as NI Vision Assistant window where we have performed image enhancement on AVR Trainer Board shown in Fig.10. it improves the quality and information content of original data before processing. It includes Brightness enhancement where it alters the brightness which refers to the overall lightness or darkness of the image. Also, it includes contrast enhancement which is the difference in brightness between objects or regions. and gamma enhancement that preserves the mean brightness of an image that produces natural-looking images by the choice of an optimal gamma value. And this is the first step of the image enhancement step. now the second step of the image enhancement step is Color Plane Extraction. in this step we can extract the three-color planes such as Red, Green, Blue (RGB), Hue, Saturation, Luminance (HSL), Value, (HSV) from an image. From all the extraction operations, we have used the green plane extraction which extracts the green plane from an RGB image. And the third step of image enhancement step is Gray Morphology. In this step we can modify the shape of objects in an image in various morphological operations like Erode, Close, Open, Proper closed, Proper open, and Auto median. From all these morphological operations, we have set the open gray morphology operation on AVR Trainer Board.

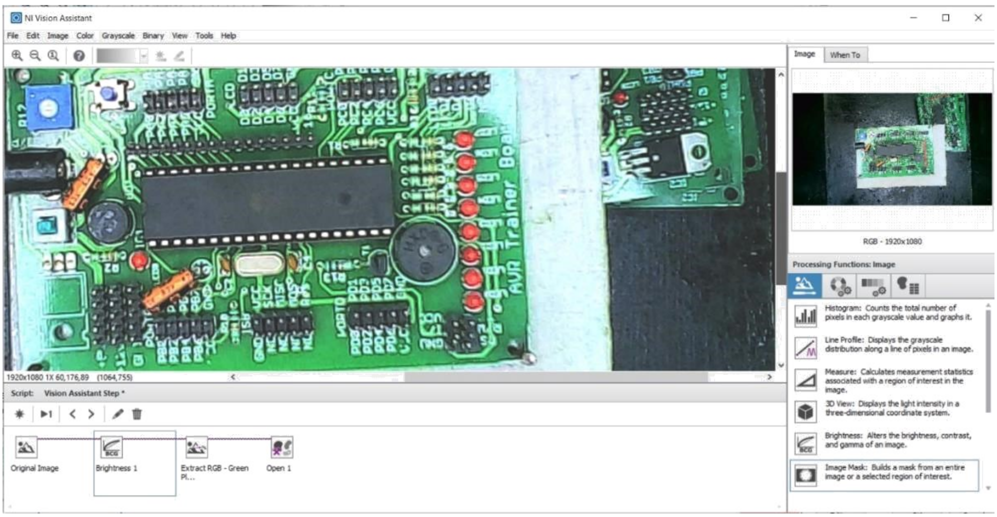


Fig 9. NI Vision Assistant for Image Enhancement

Step 3: This is the pattern matching inspection step. This step is the main step of the algorithm. In this inspection technique, we create a template image of the object for the inspection. This is also called as template matching technique. This template matching technique is a high-level machine vision technique of NI Vision Builder AI that identifies the parts of an image that match a predefined template. This technique is flexible and relatively straightforward to use which makes them the most popular method of object localization. Specifically, in this step we have created a template that represents the object for which we are searching. after that when we run the algorithm then the inspection step searches for the pattern in each acquired image. Then in every inspection, it calculates the score of every match. the score of every match depends on the following number of matches. X number of pixel (X(pixel)), Y number of pixel (Y(pixel)), X Calibrated position X(M), Y Calibrated position Y(M), Angle, Angle Calibration and Score. The score relates how closely the instances of the template match the pattern. We have set the minimum score limit of every template image up to 800. If the new test image achieved less than 800 scores in the pattern matching step then the test image is considered a fail. We have implemented this inspection step / Technique on the AVR Trainer Board which is a complete starter kit for the AVR Flash Microcontroller. We have implemented this technique to the components of the AVR Trainer Board such as given in the following list. ATMEGA 16 Microcontroller, DC Jack, Trimming Potentiometer, Power ON/OFF Switch, Reset Switch, Onboard 8 LED array, Onboard 5V Buzzer, Onboard 12MHZ Crystal Oscillator, 7805 Voltage Regulator, Transistor, W04 Bridge Rectifier Diode, 6Resister of 220 Ohms, and 2 electrolytic capacitors. The template image of the ATMEGA 16 Microcontroller is shown in Figure 10. The template image of DC Jack is shown in Figure 11.

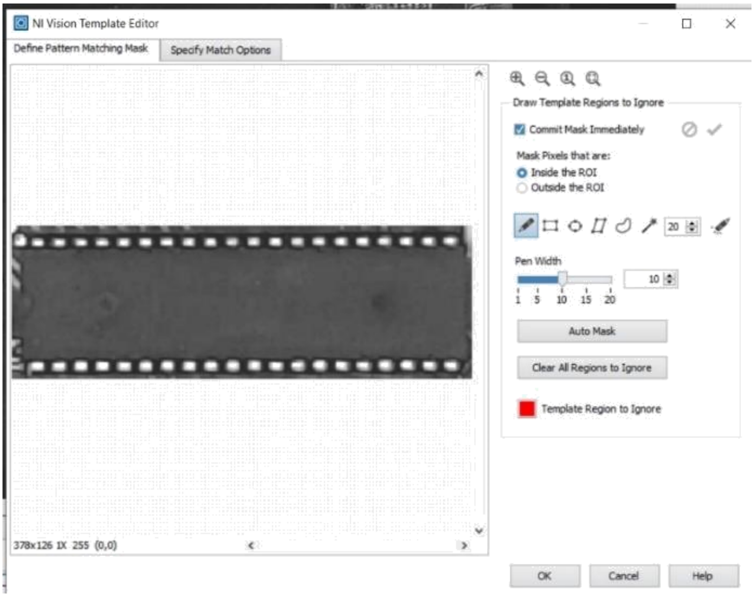


Fig 10. Template image of ATMEGA 16 Microcontroller

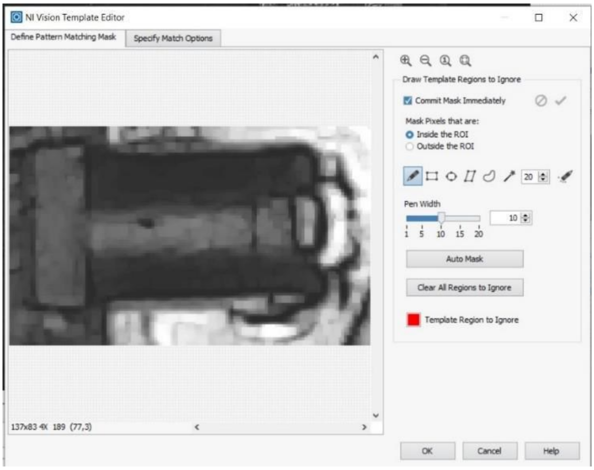


Fig 11. Template Image of DC Jack

Step 4: This is the Set Inspection Status step. In this step, we can set up the inspection status of the whole algorithm. We can select the inspection status from the already given status for our algorithm. we have selected the status such as, set to FAIL if any previous step fails or if the current value of Inspection Status is FAIL. because our whole algorithm is totally based on the status of previous steps.

Steps 5: This is the data logging step. In this step, we can enter the overall inspection results into a file on the local hard drive or to a remote FTP server. The following data logging control is located on the data logging step, like Measurements Logged Tab and Destination Tab. In the measurements logged Tab, we have set the "Always Logged Measurements" Which means, all the selected measurements of every inspection step are logged when the step executes. And in the Destination Tab, we have set the "Logged to Local Drive" Which means the measurement results are saved to a 'local storage device'. And the 'local storage device' is one of the Comma Separated Value (CSV) File Type shown in Figure 12, Figure 13, and Figure 14.

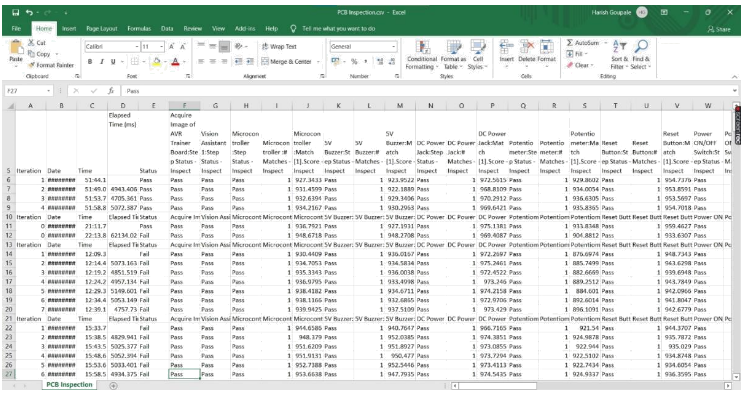
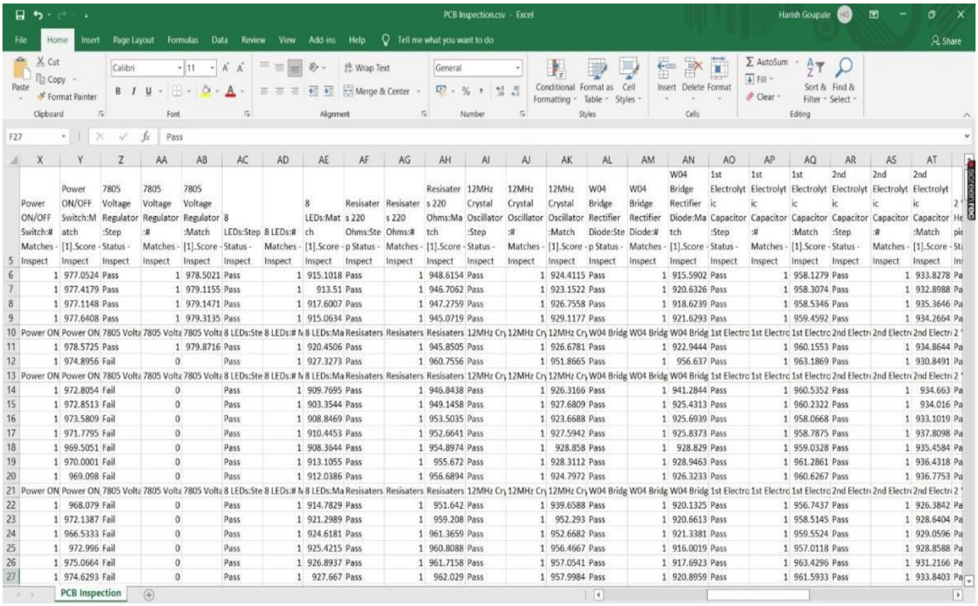


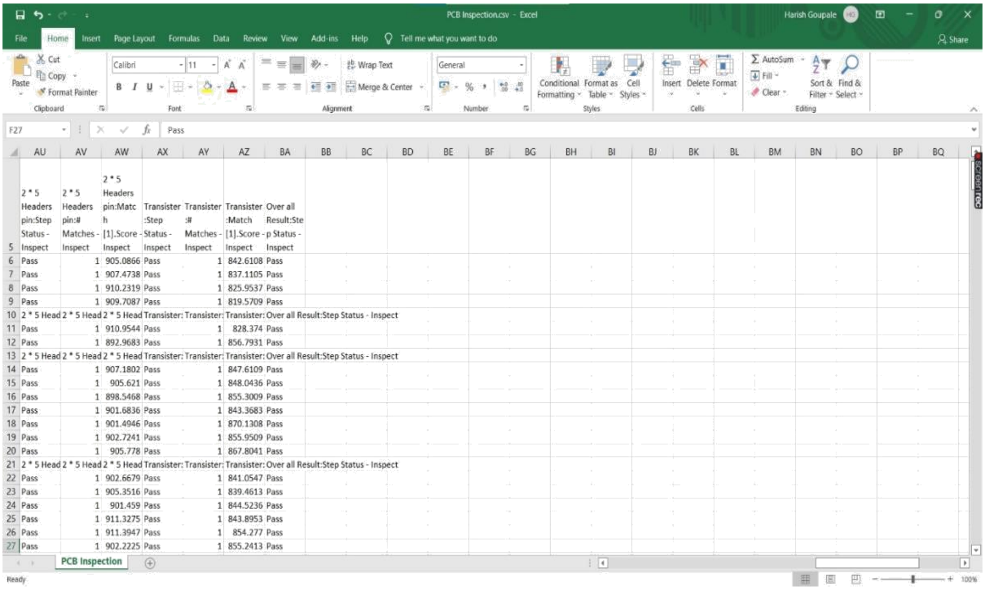
Fig 12. PCB Inspection Result



	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH
5	Power ON/OFF Switch:# Matches - Inspect	Power ON/OFF Switch:Match [1].Score - Inspect	7805 Voltage Regulator :Step Status - Inspect	7805 Voltage Regulator :# Matches - Inspect	7805 Voltage Regulator :Match [1].Score - Inspect	8 LEDs:Step Status - Inspect	8 LEDs:# Matches - Inspect	8 LEDs:Match [1].Score - Inspect	Resisaters 220 Ohms:Step Status - Inspect	Resisaters 220 Ohms:# Matches - Inspect	Resisaters 220 Ohms:Match [1].Score - Inspect
6	1	977.0524	Pass	1	978.5021	Pass	1	915.1018	Pass	1	948.6154
7	1	977.4179	Pass	1	979.1155	Pass	1	913.51	Pass	1	946.7062
8	1	977.1148	Pass	1	979.1471	Pass	1	917.6007	Pass	1	947.2759
9	1	977.6408	Pass	1	979.3135	Pass	1	915.0634	Pass	1	945.0719
10	Power ON	Power ON	7805 Volta	7805 Volta	7805 Volta	8 LEDs:Ste	8 LEDs:# M	8 LEDs:Ma	Resisaters	Resisaters	Resisaters
11	1	978.5725	Pass	1	979.8716	Pass	1	920.4506	Pass	1	945.8505
12	1	974.8956	Fail	0		Pass	1	927.3273	Pass	1	960.7556
13	Power ON	Power ON	7805 Volta	7805 Volta	7805 Volta	8 LEDs:Ste	8 LEDs:# M	8 LEDs:Ma	Resisaters	Resisaters	Resisaters
14	1	972.8054	Fail	0		Pass	1	909.7695	Pass	1	946.8438
15	1	972.8513	Fail	0		Pass	1	903.3544	Pass	1	949.1458
16	1	973.5809	Fail	0		Pass	1	908.8469	Pass	1	953.5035
17	1	971.7795	Fail	0		Pass	1	910.4453	Pass	1	952.6641
18	1	969.5051	Fail	0		Pass	1	908.3644	Pass	1	954.8974
19	1	970.0001	Fail	0		Pass	1	913.1055	Pass	1	955.672
20	1	969.098	Fail	0		Pass	1	912.0386	Pass	1	956.6894
21	Power ON	Power ON	7805 Volta	7805 Volta	7805 Volta	8 LEDs:Ste	8 LEDs:# M	8 LEDs:Ma	Resisaters	Resisaters	Resisaters
22	1	968.079	Fail	0		Pass	1	914.7829	Pass	1	951.642
23	1	972.1387	Fail	0		Pass	1	921.2989	Pass	1	959.208
24	1	966.5333	Fail	0		Pass	1	924.6181	Pass	1	961.3659
25	1	972.996	Fail	0		Pass	1	925.4215	Pass	1	960.8088
26	1	975.0664	Fail	0		Pass	1	926.8937	Pass	1	961.7158
27	1	974.6293	Fail	0		Pass	1	927.667	Pass	1	962.029

	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT
5	12MHz Crystal Oscillator :Step Status - Inspect	12MHz Crystal Oscillator :# Matches - Inspect	12MHz Crystal Oscillator :Match [1].Score - Inspect	W04 Bridge Rectifier Diode:Step Status - Inspect	W04 Bridge Rectifier Diode:# Matches - Inspect	W04 Bridge Rectifier Diode:Match [1].Score - Inspect	1st Electrolytic Capacitor :Step Status - Inspect	1st Electrolytic Capacitor :# Matches - Inspect	1st Electrolytic Capacitor :Match [1].Score - Inspect	2nd Electrolytic Capacitor :Step Status - Inspect	2nd Electrolytic Capacitor :# Matches - Inspect	2nd Electrolytic Capacitor :Match [1].Score - Inspect
6	Pass	1	924.4115	Pass	1	915.5902	Pass	1	958.1279	Pass	1	933.8278
7	Pass	1	923.1522	Pass	1	920.6326	Pass	1	958.3074	Pass	1	932.8988
8	Pass	1	926.7558	Pass	1	918.6239	Pass	1	958.5346	Pass	1	935.3646
9	Pass	1	929.1177	Pass	1	921.6293	Pass	1	959.4592	Pass	1	934.2664
10	12MHz Cry	12MHz Cry	12MHz Cry	W04 Bridg	W04 Bridg	W04 Bridg	1st Electro	1st Electro	1st Electro	2nd Electr	2nd Electr	2nd Electr
11	Pass	1	926.6781	Pass	1	922.9444	Pass	1	960.1553	Pass	1	934.8644
12	Pass	1	951.8665	Pass	1	956.637	Pass	1	963.1869	Pass	1	930.8491
13	12MHz Cry	12MHz Cry	12MHz Cry	W04 Bridg	W04 Bridg	W04 Bridg	1st Electro	1st Electro	1st Electro	2nd Electr	2nd Electr	2nd Electr
14	Pass	1	926.3166	Pass	1	941.2844	Pass	1	960.5352	Pass	1	934.663
15	Pass	1	927.6809	Pass	1	925.4313	Pass	1	960.2322	Pass	1	934.016
16	Pass	1	923.6688	Pass	1	925.6939	Pass	1	958.0668	Pass	1	933.1019
17	Pass	1	927.5942	Pass	1	925.8373	Pass	1	958.7875	Pass	1	937.8098
18	Pass	1	928.858	Pass	1	928.829	Pass	1	959.0328	Pass	1	935.4584
19	Pass	1	928.3112	Pass	1	928.9463	Pass	1	961.2861	Pass	1	936.4318
20	Pass	1	924.7972	Pass	1	926.3233	Pass	1	960.6267	Pass	1	936.7753
21	12MHz Cry	12MHz Cry	12MHz Cry	W04 Bridg	W04 Bridg	W04 Bridg	1st Electro	1st Electro	1st Electro	2nd Electr	2nd Electr	2nd Electr
22	Pass	1	939.6588	Pass	1	920.1325	Pass	1	956.7437	Pass	1	926.3842
23	Pass	1	952.293	Pass	1	920.6613	Pass	1	958.5145	Pass	1	928.6404
24	Pass	1	952.6682	Pass	1	921.3381	Pass	1	959.5524	Pass	1	929.0596
25	Pass	1	956.4667	Pass	1	916.0019	Pass	1	957.0118	Pass	1	928.8588
26	Pass	1	957.0541	Pass	1	917.6923	Pass	1	963.4296	Pass	1	931.2166
27	Pass	1	957.9984	Pass	1	920.8959	Pass	1	961.5933	Pass	1	933.8403

Fig 13. PCB Inspection Result



	AU	AV	AW	AX	AY	AZ	BA
5	2 * 5 Headers pin:Step Status - Inspect	2 * 5 Headers pin:# Matches - Inspect	2 * 5 Headers pin:Match [1].Score - Inspect	Transister :Step Status - Inspect	Transister :# Matches - Inspect	Transister :Match [1].Score - Inspect	Over all Result:Step Status - Inspect
6	Pass	1	905.0866	Pass	1	842.6108	Pass
7	Pass	1	907.4738	Pass	1	837.1105	Pass
8	Pass	1	910.2319	Pass	1	825.9537	Pass
9	Pass	1	909.7087	Pass	1	819.5709	Pass
10	2 * 5 Head	2 * 5 Head	2 * 5 Head	Transister:	Transister:	Transister:	Over all Result:Step Status - Inspect
11	Pass	1	910.9544	Pass	1	828.374	Pass
12	Pass	1	892.9683	Pass	1	856.7931	Pass
13	2 * 5 Head	2 * 5 Head	2 * 5 Head	Transister:	Transister:	Transister:	Over all Result:Step Status - Inspect
14	Pass	1	907.1802	Pass	1	847.6109	Pass
15	Pass	1	905.621	Pass	1	848.0436	Pass
16	Pass	1	898.5468	Pass	1	855.3009	Pass
17	Pass	1	901.6836	Pass	1	843.3683	Pass
18	Pass	1	901.4946	Pass	1	870.1308	Pass
19	Pass	1	902.7241	Pass	1	855.9509	Pass
20	Pass	1	905.778	Pass	1	867.8041	Pass
21	2 * 5 Head	2 * 5 Head	2 * 5 Head	Transister:	Transister:	Transister:	Over all Result:Step Status - Inspect
22	Pass	1	902.6679	Pass	1	841.0547	Pass
23	Pass	1	905.3516	Pass	1	839.4613	Pass
24	Pass	1	901.459	Pass	1	844.5236	Pass
25	Pass	1	911.3275	Pass	1	843.8953	Pass
26	Pass	1	911.3947	Pass	1	854.277	Pass
27	Pass	1	902.2225	Pass	1	855.2413	Pass

Fig 14. PCB Inspection Result

5. Application Window of Automated PCB

The NI LabVIEW has been used to develop the application of the Automated PCB Inspection System. By using Vision Builder AI Pallete, an API (Application Programming Interface) has been created to control Vision Builder AI programmatically through LabVIEW. There are two windows located in LabVIEW. The front panel window and the block diagram window. The front panel is the user interface of the VI. The user interface of the Automated PCB Inspection System is shown in the Figure 16. To design the user interface, we have used tools such as Image Display and Boolean buttons. The block diagram of the system is shown in the Figure 17. In the block diagram window, we have used tools such as Open Inspection.vi, Get Inspection info.vi, Get Inspection results.vi and Run Inspection Once.vi. The state machine architecture has been used to build the whole block diagram of the Automated PCB Inspection system. A state machine is an architecture that allows the dynamic flow of states depending on values from user inputs. The execution of the block diagram depends on the following four states Initialize, idle, Return and Stop. In the Initialization condition, the system launches a local vision builder AI engine to open and run the inspection. In the Idle condition, the system opens an inspection and then runs one iteration of the inspection currently loaded by the vision builder AI engine associated with the session and then returns results for all steps in the inspection. The results are updated after each iteration and are not updated asynchronously. The step results are given by the system in the form of an array. In the Return condition, the system closes a local Vision Builder AI engine and reverts back to the Initialization level. And in the stop condition, the user can stop the execution of VI by using the Stop button.

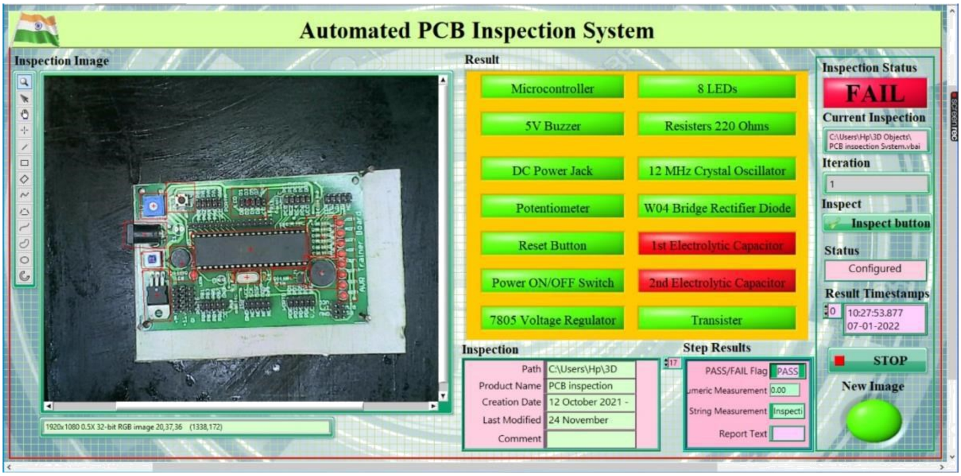


Fig 15. Application window of Automated inspection system

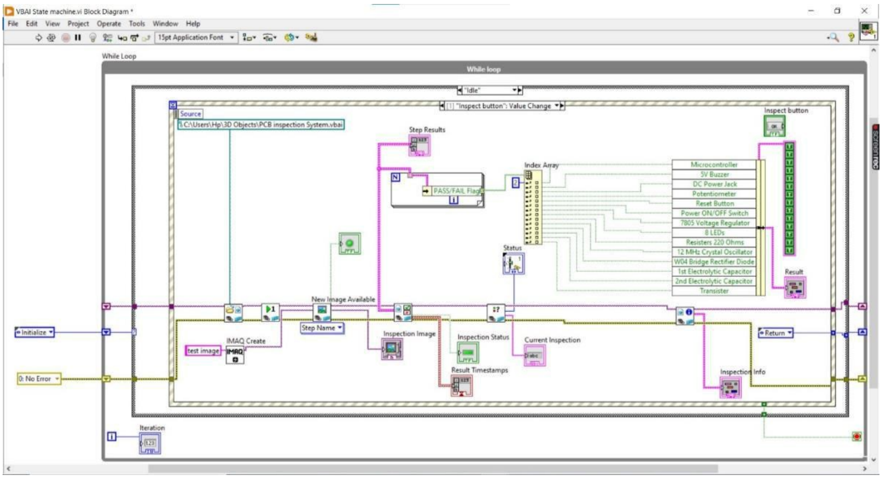


Fig 16. Block diagram of Automated PCB Inspection System

6. Result

The proposed automated PCB inspection system is used to inspect the AVR Trainer Board. Initially, it takes one minute to start the inspection and then it gives the result of each inspection within 10 seconds. In every inspection, it checks all the components of AVR Trainer Board one by one and displays the results on the Application window of the Automated inspection system shown in figure 16. If the component is present then it displays a green button. If the component is missing or improper positioned then it displays a red button. The final result of the inspection depends on the status of all the components. Also, to maintain the inspection data the system stores result of every step in the CSV file type.

7. Conclusion

The proposed Automated assembled PCB inspection system is useful at the final stage of the PCB manufacturing process in manufacturing industries. because it detects the defects such as missing components and improperly positioned components. It has been found that the proposed system is useful for small PCB manufacturing units. They can adopt this system to reduce the time of the inspection and minimize errors. It is a very low-cost inspection setup for small industries. It can be easily implemented with a simple camera and one computer.

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