The implementation of automated optical inspection in printed circuit boards

Arash Aravand
.Department of Electronic, Faculty of Electronic & Computer Engineering, Tabriz University, Parlar Co, Tabriz, Iran.

Jafar Sobhi
Department of Electronic, Faculty of Engineering, Urmia University, Parlar Co,Tabriz, Iran.

Abstract
Different machines are used in the production of electronic boards to control the elements, the correct amounts and their directions. The automated optical inspection systems are used to solve the excessive complexity of printed circuit boards and increase the production with high accuracy as well as low errors. In cases where the quick inspection of the board is impossible, the inspection is done visually with eyes. Since, the eyes get tired of continuous work, automating this process increases the production and quality of products. Therefore, a lot of visual devices are presented in the industry. The automated optical inspection systems can be used at any stage of production. AOI is one of these systems. In this technique, AOI machine is able to get a picture of the board. The automated optical inspection system uses the registered image to compare the information of images with the information of the machines to detect errors and make decisions. Using this comparison, the AOI system can detect and identify any error or suspicious area. In the present article, we have attempted to build an AOI device to cover all the errors happening in the printed circuit boards at any stage of the production line. The traveling salesman problem is solved to control the direction of movement of the camera on the conveyor. To introduce any printed circuit board to the system, a software is designed that uses CAD file to obtain the type of elements on the printed circuit board and their conditions, finds the optimal route for the movement of X-Y table, detects the errors arising from lack of elements, elements' directions, the connection of two bases, the lack of soldering, cold soldering, added soldering, etc. in three stages of feature extraction, feature selection and decision-making. The results show that the device is efficient in the detection of the glue error before mounting of the element and the detection of SMD and DIP elements after bath.

Keywords:
Evolutionary algorithms, artificial intelligence, feature selection, feature extraction, error detection

1. Introduction

Automatic optical inspection, is a key technology used in the manufacturing of printed circuit boards. AOI provides a fast and accurate review of electronic collections and guarantees them in certain PCBs; in this case, the quality of products is high and the elements are correctly and flawlessly generated in the production line [1]. Despite the great progresses being made, current circuits are more complex than the boards being made a few years ago [2]. The introduction of SMT, and then the reduction of the size of elements mean that the boards are compacted, peace by peace. Even the relatively average-sized boards contain thousands of soldered nodes (points) and these are the points where most of the problems are caused [3] [4]. In addition, these increasing complexities in boards will mean that nowadays mechanical inspection is not appropriate. Today's market demands products with high volume and quality being brought to the market in a fast and reliable wat. Quick methods are needed to ensure that product quality remains high. AOI,[2] automatic optical inspection, is an essential tool in in-circuit test ensuring that costs are kept low as much as possible through the initial detection of errors. Automated optical inspection of printed circuit board is important because of the needs of modern manufacturing environment.[2][3] In the mass production of electronic equipment, it has been tried to increase the quality assurance factor in all the parts, components and finished products to 100%. This progress has caused the electronics industry to use the automated visual inspection in manufacturing printed circuit boards; board inspection may contain the identification of other false parts on the board, un installation of the pieces on the identified points, the false direction of pieces on the board, checking the correct connection of the soldering, checking the interruptions of copper on the board as well as the connection of two coppers to each other. In each case, suitable x-y tables, lighting equipment, and various cameras are required. The quality of each of these components depends on the piece and the measurement distance. With regard to the issues raised above, the objective of this project is to detect the errors of the printed circuit boards in production lines using image processing algorithms and artificial intelligence. Since, most of these errors are not simply detectable by eyes and the visual inspection is very time consuming, error probability is very high. That's why machine vision is used to increase the speed and reduce the errors.

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In the field of error detection of SMD and DIP elements, the following researches have been accomplished: a method was provided by G. Acciani, G. Brunetti and G. Fornarelli in 2006. In this detection, first, the IC image and all bases of IC are removed from the board image, through Segmentation. Then, errors are detected by removing Geometric and Wavelet features as well as neural network training [6]. Fupei Wu and Zhang Xianmin proposed a method in 2011 that was used to detect IC errors through a lighting system with Red, Green and Blue lights. No Solder ،Surplos Solder ،Lacking Solder ،Lead Lift ،Lead Left ،Shift ،Bridge ،Pesoudo Joint errors were detected. The type of error is determined by feature extraction and segmentation of images and comparing them with a set threshold values [5]. A method is provided concerning the error detection in resistors and capacitors by Xie Hongwei et al. in 2011. The RGB lighting system was used for the detection; this method, as the previous method has used element segmentation. A set of features is extracted for each segment; due to the high number of features, the most effective feature as well as a method is proposed for each segment. Using the decision tree, the appropriateness or inappropriateness of the segments are determined. [7] To detect the basic soldering error of DIP elements, T.S. Yun and colleagues proposed a method in 1999. The method has used the removed features' image to detect errors and has provided a backup vector for each type of error through the use of X feature vector. [9] B. C. Jiang et al. in 2006 proposed a method for error detection with the removal of printed circuit boards' background and the discovery of basic parts through the feature extraction and comparing it with threshold values. Good Solder, Open Solder, Bridge, No Solder errors were detected. [8]
The aim of this project is to build a device to detect errors before and after installation of elements on the board. The device has the ability of error detection glued on the printed circuit board, before the element installation. Also, after mounting elements, the device is capable of error detection for SMD elements and DIP basic elements on the surface of printed circuit board. Therefore, a software is designed to receive the position of elements or segments of the printed circuit board that need to be inspected by the user or through CAD file. Then, the program being based on the position of defined elements extracts the centers of shooting points and solving the traveling salesman problem, it selects the best shooting path for the device. Finally, the device is ready for shooting and error detection. In the first part, the hardware of the device has been described. In the second part, the procedures of error detections of elements are mentioned along with their results. Finally, conclusions and comparisons with other works are expressed.

The first section: Image Acquisition system

a 5 Mpixel CDD camera with high resolution, a 12 mm lens and an RGB lighting system has been used- being shown in figure 1. The working distance of the lighting systems from the printed circuit board is 25 mm, the distance between the camera and the board surface is 100 mm. The amount of camera's FOV is 35 * 45 mm. To cover the surface of the printed circuit board for shooting an X_Y system was built with conveyor Figure 2.

Figure 1.RGB lighting system

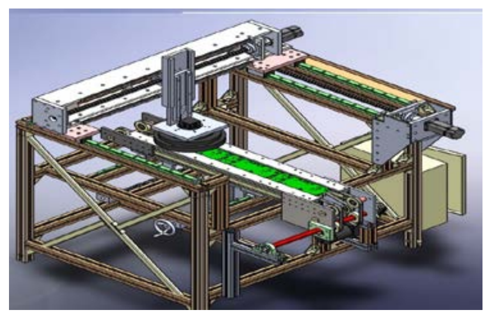

Figure 2. X-y table and conveyor

The second section: Inspection Algorithm

This section detects errors associated with 1) SMD resistance and capacitors, 2) IC SMDs, 3) basic elements in the DIP, 4) the detection of glue error on the board, 5) The best path to solve the traveling salesman problem. The following operations are conducted in order to detect errors in all sections of 1 to 4; image segmentation, feature extraction, feature selection and decision-making. These stages are explained in every segments.
The image of each element is divided into a series of segments after the removal of the original image of the board. These segments differ based on the type of elements and errors. In this study, the segments are combined according to the type of error being detected for the elements. In fact, by combining values of existing properties, we have created fewer features in a way that these features have all the basic information in the initial features. In this part of the segment which is an RGB image, first the desired color is removed from the desired ranges (red, blue, green and the color of elements) using the Color Segmentation. A series of removed colors are

used to obtain some information about the error detection, this information is called features. Since each image in RGB color space has 3 gray images and for each image 3 binary images can be calculated, the number of features for each segment -taking into account the extraction of 10 features- is 30 features (10*3 for each segment). Thus, the features in this sections are discussed. The issue of feature selection, is one of the issues being discussed in the context of machine learning and statistical identification of patterns. This issue is of great importance in many applications, because there is a large number of features in these applications, many of whom are either unused or of little information.[10] It does not create a problem in terms of information if the features are not removed, but the computational load for a given application increases.[10] In addition, it makes a lot of useless information to be stored along with useful data. Due to the increase in features, we have attempted to find the less features with the most effects in the resistance and capacitance part using genetic multi-objective algorithm NSGA-2.

A) Resistance and SMD capacitors

The elements of this group have two bases on the sides and the element is placed in the middle of the pad. Figure 3 shows the way of segmentation of SMD capacitor's pads, body of the element and sides of the element. To detect errors in the group first as shown in Figure 3. Each base is divided into a series of segments. The features mentioned in the section on feature extraction are extracted in the section feature extraction, are extracted for each of the segments of R1 to R5. Due to the large number of features and segments for detection, the best (most effective) features are selected using genetic multi-objective algorithm NSGA-2. In the following, we will explain and discuss the results. After the feature selection, the decisions are made about features by the cost faction of the evolutionary algorithm. Finally, to detect the type of errors, the outputs of each segment are combined and by the use of fuzzy logic the type of error has been determined. This is done intuitively by setting a Mamdani fuzzy logic. Further explanation of R6 and R7 segments are given below.

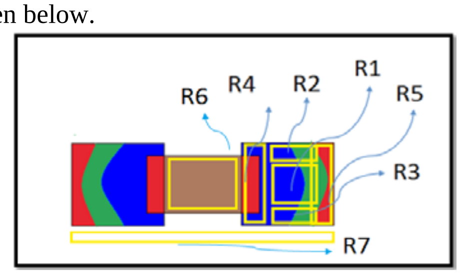

Figure 3. the elected segments of the SMD capacitors' pads for error detection

B) Feature Extraction:

Features extracted from R1 to R5 segments for the RGB image in each segment are:

1. The red, blue, green area in every segment
2. The conjunction of all three colors in the length and width of each segment
3. Calculation of the center of mass of every 3 colors in each segment
4. Calculation of the maximum amount of continuity
5. The difference between the largest and smallest gray value for all 3 dimensions in each segment
6. The average of gray features' design
7. Average gray images for each 3 dimension
8. Objects' being in the shape of squares and circles for each 3 dimensions in each binary segment

C) Feature selection for R1 to R5 segments:

The principles for solving this problem follow the same general principles stated in the multi-objective genetic algorithms [13] [14]. Here, we just refer to the methods used in the project and explain the steps involved in the project as well as the way of performing these steps. Encoding of feature selection is a binary encoding that aims at converting the answer to a series of binary numbers (in binary). Crossover in the feature selection: 1. Single Point Crossover method, 2. Double Point Crossover method and 3. Uniform Crossover method are selected. Production phase of the initial population: according to the type of encoding system, the chromosomes of the initial population are produced for the searching. The number of the population, the chromosomes or the population size depend on the number of demanded population by the user. The initialization phase: in this phase an initialized function is used calculate the cost of each chromosome; this phase is the most important phase in the genetic algorithms. Two factors are used in this project. One of these factors is caused by the number of features and the other factor is the cost function of the chromosome categorization. Since, the aim is to reduce the error rate as well as the features, this issue is solved as a multi NSGA-2 issue. As described in the multi-objective genetic algorithms above [14][15] one advantage of this algorithm is that it gives us a series of answers for decision-making as Pareto Front at the end of each phase. Evaluation phase: In this phase, the evaluation is on the classification of Pareto Fronts according to the priorities which are selected according to the number of the populations. Taking a ratio for the number of features in each stage, we can search for the best answer among the Pareto Fronts with priorities of one. The stopping criterion for the algorithm is that if an answer is repeated, first the Mutation factor in algorithm is increased so that in case of being trapped in the local minimum, it can get out of it, but if an answer is repeated more than a certain amount, the algorithm is stopped. The flowchart is shown in Figure 4. The cost function: two cost functions are used for feature selection; LVQ faction and the combination function being combined of some SVMs. Each categorizing function, categorizes each segment of the pad into three categories: 1. Good 2. Excessive 3. Bad. The procedure was performed for each segment of 400 training data; 40 percent of them were used for training of the categorization faction and 60 percent were used for the Test function. The best cost, error and effective features of the results of both cost functions are shown in Table 1. In the following, a fuzzy mamdani logic is intuitively set for the decision making to decide on the error by giving cost function's qualities in every 5 segment (good - bad - Excessive). Figure 5 shows a block diagram of fuzzy logic to determine the type of error. Finally, 5 types of error out of 5 segments are used in the soldering of Resistance elements and SMD capacitors. This 5 types of error can be named as follows: No soldering, Excessive soldering, No pad (tomb stone), cold soldering and safe soldering. For more explanation on the way of detecting errors by the fuzzy logic, a few rolls are mentioned in the following. Table 3. Shows the error detection results for 1000 capacitor and resistor elements used in 4 different boards. The same applies to error detection methods of other SMD elements such as diodes and LEDs of SMDs.

Coefficients used in the algorithm:

2. Roles:

1- If (R1) is (Excessive) and (R2) is (Excessive) and (R3) is (Excessive) and (R5) is (Excessive) Then Pad is (Excessive solder)
2- If (R1) is (Good) and (R2) is (Excessive) and (R3) is (Excessive) and (R5) is (Excessive) Then Pad is (Excessive solder)
3- If (R1) is (Bad) and (R2) is (Excessive) and (R3) is (Excessive) and (R5) is (Excessive) and (R4) is (Excessive) Then Pad is (Tumbstone)
4- If (R1) is (Bad) and (R2) is (Bad) and (R3) is (Good) and (R5) is (Bad) Then Pad is (Cold solder)
5- If (R1) is (Bad) and (R2) is (Bad) and (R3) is (Bad) and (R5) is (Bad) Then Pad is (NO solder)

Table 1 Results of feature selection for individual segments

Regions	R1	R2	R3	R4	R5
LVQ	2.0907	4.7801	3.1127	0.5702	**0.4883**
	7	5	5	3	**5**
SVM	2.5281	4.3944	3.3708	0.987	**0.8424**
	7	6	5	4	**9**

Table 2 coefficients used in feature selection algorithm

The number of repetitions	The initial population	Pressure coefficient	Recombination rate	Mutation rate
100	100	0.8	0.5	0.7

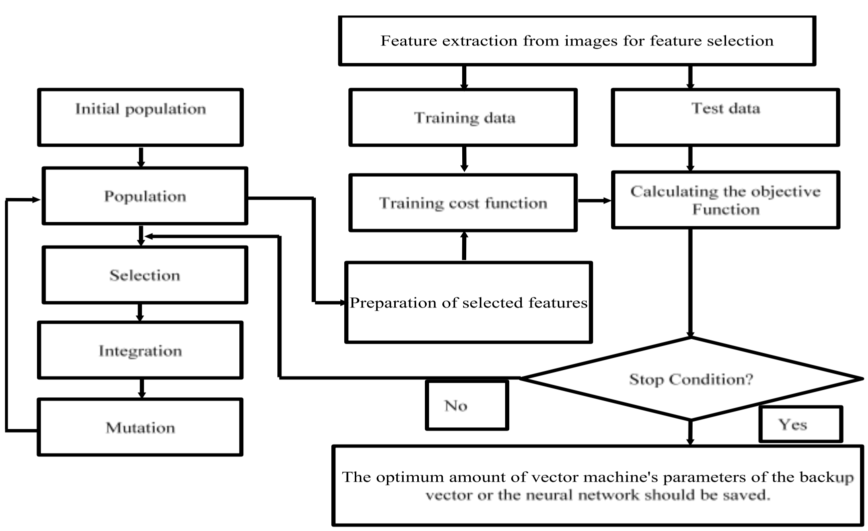

Figure 4. Flowchart of the feature selection

The sixth segment R6:

The sixth segment is taken into account for the detection of 'no element' error. Removing the color of the element's body and comparing it with a threshold value, we can decide on the detection of the 'No element' error. The threshold varies for the removal of the desired color by the user.

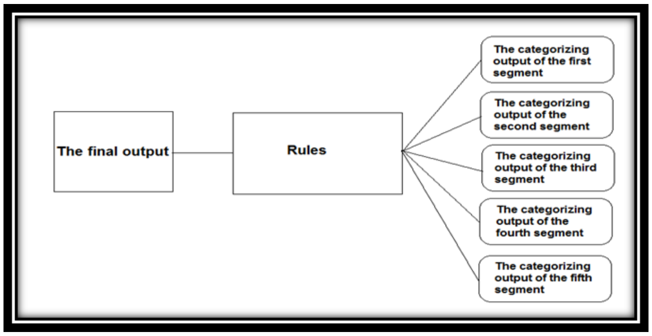

Figure 5. a block diagram of Mamdani fuzzy logic

3. The seventh segment R7:

The seventh segment is considered for the detection of bridge error between two pads. Removing the total area of the solders' color (Red, Green, Blue) and comparing it with a threshold value, we decided on the detection of the bridge error between two pads.

Table 3. Results of the error detection of SMD resistance and capacitors

The type of categorizer	The type of error	The number and percent of respondents error		
LVQ & mamdani Fis	No solder	97	91	93.81
	Excessive solder	377	365	96.81
	Tombstone （No pad）	5	5	100
	Cold solder	21	19	90.47
	Safe solder	478	473	98.95
SVM & mamdani Fis	No solder	97	95	97.93
	Excessive solder	377	365	96.81
	Tombstone（No pad）	5	4	80
	Cold solder	21	18	85.71
	Safe solder	478	452	94.56
R6	No element	18	17	94.44
R7	Bridge between two gaps	4	4	100

The type of categorizer	percent
LVQ & mamdani Fis + R6 & R7	96.354
SVM & mamdani Fis + R6 & R7	92.77

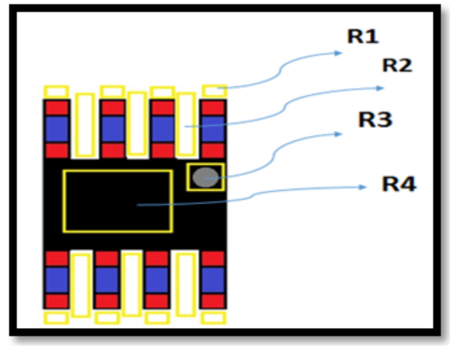

Figure 5. The way of dividing segments of IC

1) SMD ICs:

This group, like the first group is divided into a series of segments. For each segments, some features are extracted and finally the error is detected for each segment. The segmentation of ICs for error detection is shown in Figure 5. The bridge, Pseudo joint, no element and element direction are detected for ICs.
For the error detection of ICs, first R4 segment is investigated, if there is no error in this segment, other errors will be investigated. If an error is detected in the R4 segment, it is considered as No element error and there no need to investigate the other segments. 4 segments are taken into account for ICs and since these segments are adequate for the type of error detections, and each segment is determinant of one type of error, also the segments are not dependent on each other like the first group, less features were involved in the error detection. Therefore, the feature selection stage has been removed from this detection. In the following, we will describe the segments and selected features for each segment. The first R4 segment indicates pseudo joint error. First, the area occupied by Red, Green, Blue colors is extracted. If the red color is more than the sum of the two other colors, the segment has a pseudo joint error. The second segment R2 indicates the Bridge error. First the area occupied by Red, Green, Blue colors is extracted. Calculating the largest association of colors for Red ‹Green ‹Blue and comparing both features of the segment, it is realized that the error can be detected if the features are larger than the threshold value of R2. Usually ICs have a series of symbols to detect their direction such as small circle on ICs or semicircle at the top of the body of IC or a line on the body. These signs are used in the R3 third segment to detect the direction of IC. Segment 3 specifies the right direction of ICs; extracting the colors from this segment and comparing it with the threshold value, we can detect the right direction of ICs. If the resulting number is less than the threshold value, the error is detected for the segment. The R4

segment identifies the No element error. By removing the color of IC's body – which is black- or the green color of the printed board and comparing it with the threshold value, the No element error is detected. Table 4 shows the results of the 800 different ICs in 4 different types of boards:

Table (4) the results of error detection for ICs of SMD

Type of errors	The number of errors and the percentage of error detection		
Bridge	200	199	99.5
Pseudo joint	200	194	97
No element	40	40	100
Direction of the element	40	38	95
Total percentage		98.875	

2) DIP elements:

Some features are extracted from the image of the pad for the third group or DIP elements. Considering 3 main segments for the pads – being shown in figure 6- the errors of ‹No Solder ‹Less Solder ‹Bridge‹ ‹Holes in Solder, Excessive Solder, and no lead, safe solder are detected.

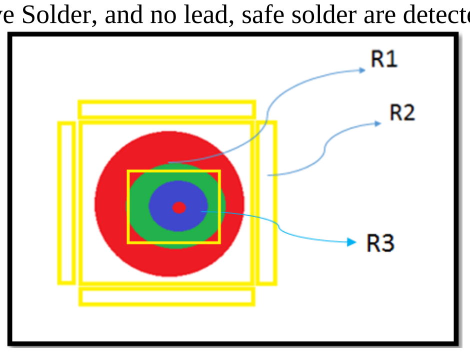

Figure 6. Segmentation of DIP elements

The first segment which detects the Bridge error is like R2 segment in ICs. The three other errors occur in the second segment R2and as in resistance, the capacitors need high precision for the detection. This precision is because of the presence of large number of errors in a segment. As with all segments, we extract the features from the segment and detect errors of less solder, excessive solder, No pad, and No solder. The following feature are extracted; the area of Red, Green, Blue colors in the segment, the largest object for the three colors of Red, Green, Blue of the segment, the largest association of extracted color in length and width of the segment, the circularity amount of the closest red color to the center of the base and the center of the mass of object in segment. Threshold value for the error detection in each segment or blocks can be changed by the user. The third R3 region is located right in the middle of the second segment containing the 50% of the second segment; it is used to detect the error of Holes in the solder.

The features related to the area of the Red color as well as the dark color of the holes in bases are extracted. Calculating the area and comparing it with the threshold value, the error is detected. If the condition is not met, the Hole error will be determined. The threshold value is changeable by the user. As seen in Figure 7, several features are combined to make decisions. Table 4 shows the results of the detection for 990 DIP pads from 4 boards.
Dis: shows the distance of the desired color from the center of the image.
Cir: shows the circularity of the desired color
Area: shows the area of the desired color in the image
BigArea: shows the largest area of the object in terms of the desired color.

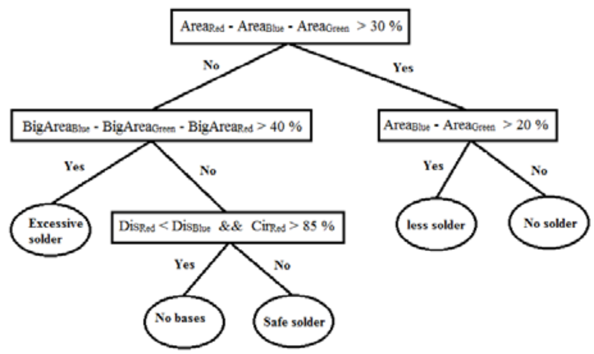

Figure 7. The flowchart of error detection for the second segment of Dip

Table 4. Results for the basic elements of DIP error detection

Type of errors	Number of errors	Number of correct detections	Output
Bridge	212	212	100
Excessive solder	50	55	100
Less solder	85	81	95.29
Hole in the solder	178	162	91.01
No solder	8	7	87.5
No solder	43	47	100
Safe solder	414	411	99.27
Total percentage			96.152

3) Glue detect errors in printed circuit boards:

SMD elements are assembled on printed circuit boards either through Paste or tin bath. In the second method, Fig. 8 and 9 Red Glue is used for the fixation of the elements on the printed circuit board and avoidance of falling into tin bath. In order to avoid errors such as dropping of the elements, the elements' shift on the board and the dislocation of glue under the element, we have discussed Glue errors before Mount operation. In this section we have tried to detect errors of glue's wrong location, rubbing of the glue, the inadequateness of the volume of the glue, the lack of glue and safe glue.

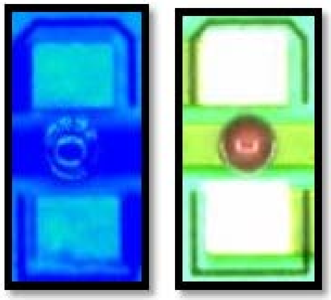

Figure (8) Image of the glue with two lighting systems

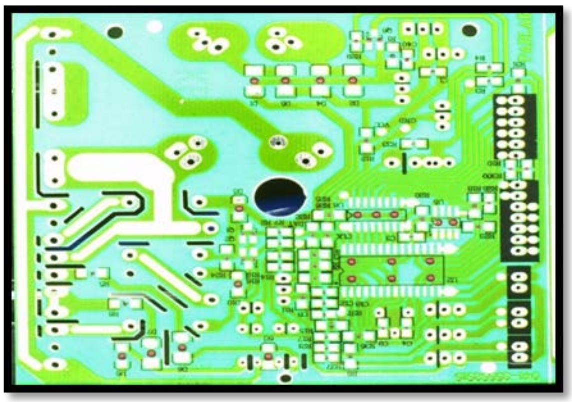

Figure 9. the image of the board before Mounting

After shooting and extracting the check points as previous methods, some features are removed from the image for error detection; also fuzzy logic is used to classify the type of errors. Extracted properties are: 1. Area of the glue in the image (the color of the glue), 2. Perimeter of the glue in the image, 3. The circularity of the glue, 4. The Max and Min extraction of the object continuity in the image as glue, 5. Extracted object number as glue, 6. Calculation of the center of extracted mass area as glue, 7. The area of the blue part of the glue in the picture is shown with the blue color. In this survey, the volume of the solder in not expressed numerically. The error is only detected if the glue does not have the right amount to keep the element; the error is shown to the user on the image. Mamdani fuzzy logic is used to detect. For example, some samples of rolls are given below regarding the fuzzy logic:

Table (9) Results of the glue error for 3500 different boards

No glue	100
Inadequate volume of the glue	91
The rubbing of the glue	97.61
Inappropriate location of the glue	98.7
Less glue	93
The total percentage of the glue	96.062

1- If GlueAreaLess and GluePeremeterLess Then LessGlue
2- If GlueCircularityLess and GlueCountinuslyWidthLess and My_Bad Then RubbingGlue
3- If GlueCircularityLess and GlueCountinuslyLengthLess and Mx_Bad Then RubbingGlue
4- If Number_of_GlueObject_MoreThanOne and GlueCountinuslyWidthMach Then RubbingGlue
5- If Number_of_GlueObject_MoreThanOne and GlueCountinuslyLengthMach Then RubbingGlue

The improvement of the moving path of the camera to reduce the time processing of shooting:

The whole time of the process is started from the shooting time on the printed circuit board and continues till the detection of all errors of the board. To reduce the travelling time of the device and the suitable route for shooting, we need to select an optimal rout with the shortest length.[11][12] This problem can be solved by connecting the rout of the camera to the Traveling Salesman Problem and solving it.

Solving the Traveling Salesman Problem with genetic algorithm

In this section we will discuss the way of solving the Traveling Salesman Problem in this project. The encoding system used in this project is of permutation kind of encoding known as an encoding. According to the type of encoding system, the initial population of chromosomes are produced for searching. The population number or the number of chromosomes to search or the Population Size depend on the requests of the user. The initialization phase in which an initialization function is used to calculate the fitness of each chromosome is one of the most important phases in any genetic algorithm. Two factors are used in the project. One of these factors is caused by the number of edges in the permutation of chromosomes and the other factor is the length of the rout for the edges of chromosome. Since we want to join less features with more weights for each chromosome, we realize that the chromosome joining less features with more weights has a greater fitness and the likelihood of their selection in genetic operators becomes more. The population production phase includes Mutation and Crossover. In this project, like the feature selection method, we can use random selection or RouletteWheel selection. The RouletteWheel selection system, first locates all the fitness chromosomes on the RouletteWheel and then one of them is selected through random selection. The advantage of this method is that the chromosome having more fitness occupies more sectors than RouletteWheel and is likely to be selected. The Crossovers such as PXM and OX are used. A possibility is considered for each of them being randomly selected by RouletteWheel, Crossover. The crossover which has a greater probability is more likely to be selected. Mutatios such as: Insert Mutation, Swap Mutation, Inversion Mutation, are used in this process. A possibility is considered for each of them being randomly selected by RouletteWheel, Mutation. Mutation that has a greater possibility algorithm has a better chance of selection. In this project, we have considered the evaluation phase on the ground that at any moment an optimal tour is found, the optimized weight of the tour is given to the user so that the user can stop the search algorithm at any time. The stopping condition for the algorithm is that if an answer is repeated, first the Mutation factor in algorithm is increased so that in case of being trapped in the local minimum, it can get out of it, but if an answer is repeated more than a certain amount, the algorithm is stopped. The process is implemented for further comparison in two different directions by changing the initial population and the number of repetitions. The results are shown Figure 10 shows a flowchart of Genetic Algorithm.

According to the earlier sections we can say the power of genetic algorithms on the processors is parallel. This power on one processor does not show a good performance. In addition, the number of searching genetic algorithms affect the speed to achieve the optimal answer. The higher the number of the population is, the greater is the speed of reaching an optimal solution. Since the genetic algorithms are suitable for the searches with large ranges, the large number of chromosomes in question lead to the gradual reduction of the convergence rate. So with regard to the raised issues it is suggested to use the molecular coding to improve the movement of the camera; because it implements genetic structure.

Table (6) coefficient of genetic algorithm for solving TSP

Mutation rate	**Recombination rate**	**Pressure coefficient**
0.7	0.8	10

A) Sample:

Table (7) Results for solving TSP for the second sample

It = 500	It = 300	It = 100	population
NFE = 75100 156.1930	NFE =45100 168.5805	NFE =15100 263.7227	100
NFE = 66900 156,7200	NFE 135300 = 165.669	NFE =45300 266.737	300
NFE = 135.500 154.4557	NFE9.2750 = 162.287	NFE =75500 282.935	500

Optimal rout:

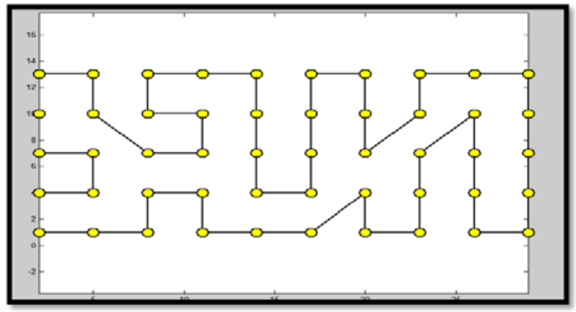

Figure (11) the optimal route for the second sample

The improvement of the fitness function over iteration:

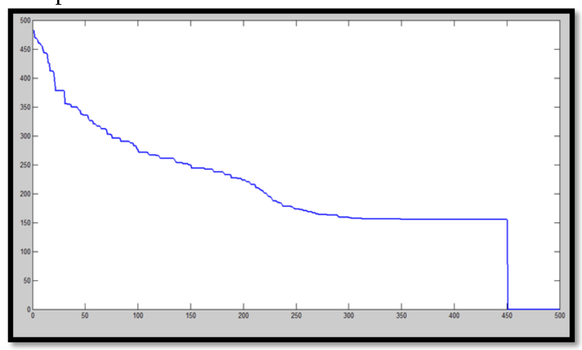

Figure (12) the improvement of the fitness function over iteration for the second sample

B) sample:

Table (8) Results of the TSP problem for the third sample

It = 500	It = 300	It = 100	Population
NFE =75100 55.6810	NFE =45100 57.3902	NFE =15100 84.08	100
NFE =66900 55.3250	NFE =135300 55.9601	NFE =45300 68.1815	300
NFE =135500 56.3284	NFE =92750 56.7408	NFE =75500 77.5184	500

The optimal route:

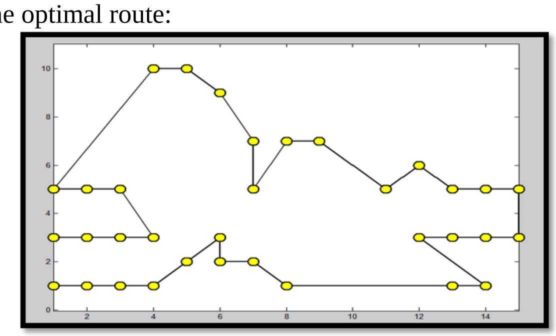

Figure (13) the optimal route for the third sample

The improvement of the fitness function over iteration:

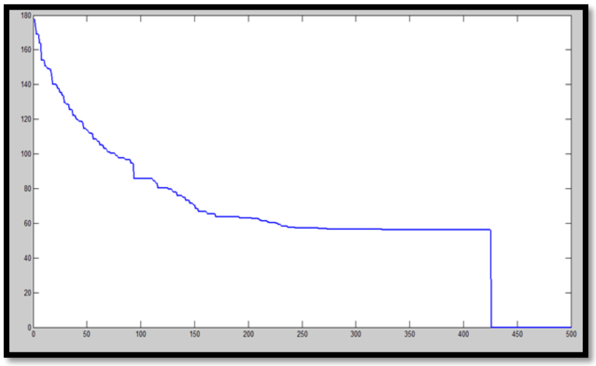

Figure (14) the improvement of the fitness function over iteration for the third sample

4. Conclusion:

Our goal in this project was to construct AOI system Fig. 15 and 16, and create algorithms for detecting various errors on various elements, being used in all sectors of production line. As mentioned the built device and its software can be used in two production lines, before mounting the elements and after the solder bath. In addition, with minor changes the mentioned methods can be used to detect errors of other elements such as: regulators, diodes, LED, SMD, and transistor. Tables (10 and 11) indicate a comparison between our method and earlier works. It is realized from the above tables that GS ‹ NS ‹SS ‹LS ‹PJ ‹CS ‹ES ‹TS ‹MS ‹Br ‹SF ‹Dir ‹LL ‹Sh ‹ LB ‹NP ‹HS and ES have the errors of Good solder ‹No Solder ‹Surplos Solder ‹Less Solder ‹Pseudo Joint ‹Cold Solder ‹Excessive Solder ‹Tomb Stone ‹Missing ‹Bridge ‹ Shift ‹Direction ‹Lead Left ‹Shift ‹Lead Bend ‹No Pad ‹ Holes in Solder and Excessive Solder, respectively. As it can be seen, the number of errors detected in this work are more than the previous works. The comparison is indicated in the following tables. The identification of the glue error is not considered in the tables, because it had not been regarded in the previous works.

Table 10. Comparison of the basic elements of DIP

Type Defec	Our Methoc	SVM [9	CHF [8
GS	Y	Y	Y
ES	Y	Y	N
LS	Y	Y	N
HS	Y	N	Y
NP	Y	N	N
NS	Y	Y	Y
Br	Y	N	Y
Total	96.152	98.01	97.3

Table 11 comparison of the resistance and IC methods

Type	Our Method		Decisior	SDL
Defect			[7]	[5]
GS	Y		Y	Y
NS	Y		Y	Y
SS	N		Y	Y
LS	N		Y	Y
PJ	Y		Y	Y
CS	Y		N	N
ES	Y		N	N
TS	Y		Y	N
MS	Y		N	N
Br	Y		N	Y
SF	N		Y	N
Dir	Y		N	N
LL	N		N	Y
Sh	N		N	Y
LB	N		N	Y
Total	SVM & Mamdani & IC	LVQ & Mamdani & IC	97.3	98.6
	95.32	97.12		

Figure (15) Inside of the built machine

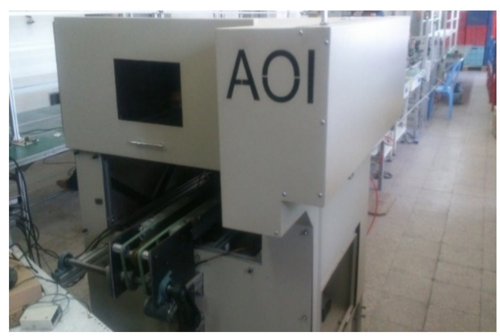

Figure (16). The built AOI machine

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