Information Technologies based on Wavelet Transform for Soldered Joints Diagnostic of Printed Circuit Boards

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Abstract. In modern instrumentation, the number of soldered joints in printed circuit boards can reach several thousand. Diagnostics of the soldered joints defects within the optical wave length range is carried out using automated diagnostic systems. A number of stages of the existing information technologies for such systems are implemented on the basis of target functions extremum search using the gradient estimation. In the large batches of products production, the use of expensive automated diagnostic systems within lighting subsystems and high cost positioning are justified. These subsystems can provide improved noise immunity. However, in conditions when small batches of products are produced, and at some stages (for example, when positioning by comparison with a standard/prototype images) in general, such objective functions can be noisy and can be multi-extremes. For such cases, information technologies based on methods of enhanced noise immunity are required. Such an increase in noise immunity can be provided by methods using wavelet transformation. For this purpose, information technologies were proposed using wavelet transformation-based procedures that improve noise immunity and reduce the error of procedures in the diagnostic systems of printed circuit boards and their soldered joints.

Keywords: Automated Diagnostic Systems, Solder Joint, Printed Circuit Boards, Wavelet Transformation

1 Problem description

In modern instrument production, the number of solder joints (SJ) in the printed circuit boards (PCB) can reach several thousand [1-14]. Diagnostics of solder joint defects in the optical wavelength range is carried out in automated diagnostic systems (ADS) of the solder joints (Fig. 1) [15-26]. In the existing ADS, the detection of PCB

assembly defects is carried out by comparing their images with the images without the defects (standard/prototype images). Such a comparison in the ADS is carried out using systems of the precision mechanics and high cost optics.

Reducing the requirements for such systems in order to reduce the cost of small batches of products production leads to uneven illumination of objects and the appearance of multiplicative and additive interference in images. In conditions with interferences and signal-to-noise ratio (power) for additive interference ranging from 8 to 11 and from 7 to 10 for multiplicative interference, such automated diagnostic systems are not operational. In the existing automated diagnostic systems, the combination of images for comparison is carried out on the basis of gradient methods searching for the minimum of the multimodal function and this way to determine the error in combining with the standard/prototype image. Such methods are not functional within the signal / interference ratio being less than 15. Therefore, for such a combination of images, information positioning technologies are needed because it can provide necessary reliability in the conditions of interference and a priori uncertainty due to small sets of training data. To this end, it is proposed to implement these IT on the basis of the developed multi-start optimization methods of the wavelet transformation [27-32].

Often the reduction of the resource consumption in automated diagnostic systems and reduction the operational speed are increased by conducting diagnostics on the conveyor for PCB panels (not separate PCB's) (Fig. 2). In this case, several automated diagnostic systems are present at different stages of the PSB assembly. For example, when assembling a PCB during mounting components on a surface, these are the stages of pattern printing, resistors and integrated circuits (ICs) placement (with a small output range) (Table 1).

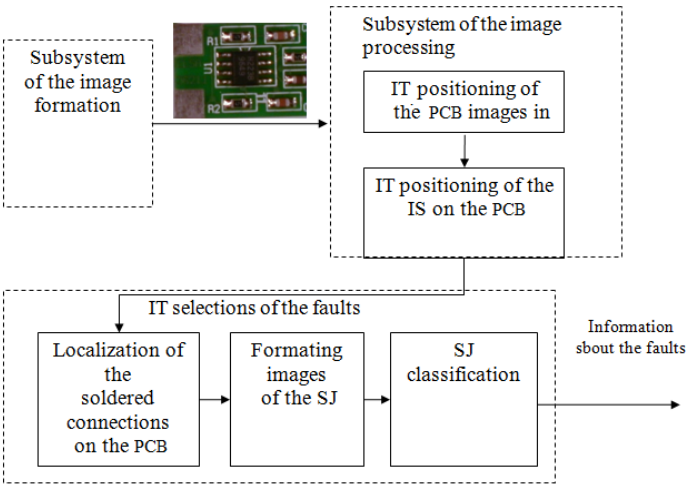


Fig. 1. Fragment of the automated diagnostic system (ADS) block diagram for soldered joints within the optical range

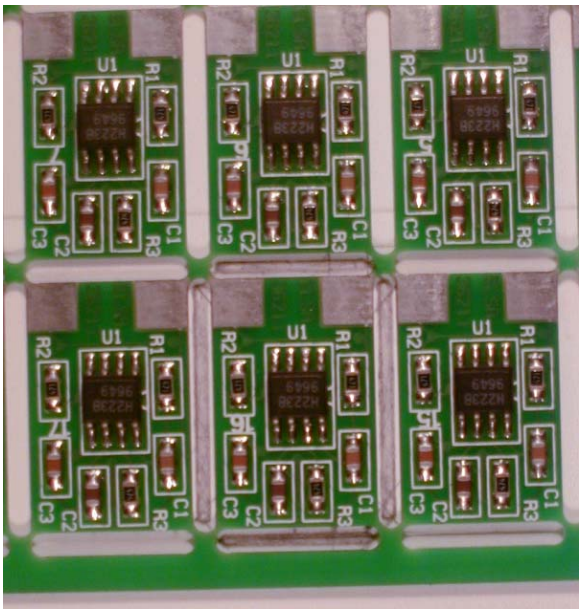


Fig. 2. PCB Panel

A generalized structure of the automated diagnostic system (ASD) in printed circuit board assemblies has been developed within the optical range (Fig. 3).

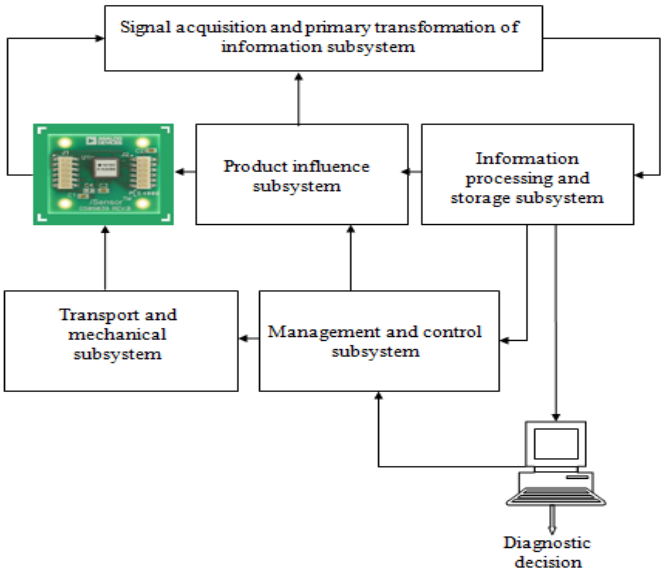


Fig. 3. Generalized structure of the automated diagnostic system for the printed circuit assemblies diagnostics within the optical range

Such an ASD may contain the following subsystems:

− subsystem influencing the object, which contains device impact on the object sources of illumination and / or penetrating fields (with fluoroscopy) and scanning devices;

− transportation mechanical subsystem, which contains the object delivery devices (loading and unloading elevators, conveyor), coordinate table, positioning devices;

− subsystems of signal acquisition and information conversion, which contain receiver-transducers of penetrating fields, devices for a signal pickup from receiver-transducers, devices for primary conversion and normalization of signals, image sensors, video processing devices (amplification, quantization and normalization of the video signal);

− subsystems of the computer-based processing and information storage, that are based on applied IT implemented signal and image processing.

Table 1. Types of defects at various PCB assembly stages

Stage	Type of defects detected during optical inspection
Screen printing soldering paste	Skip of the paste, improper application, lintels
Component positioning	The absence/presence of components, bevel, shear, wrong orientation and/or polarity. Printed circuit board (PCB) warping
Melting solder	Presence/absence, shear, bevel, polarity of components, correctness of soldered joints, defects in paste failure, solder bridges, raised connectors.

Practically, it is necessary to control the soldered joints for all PCB after the solder melting step. Such diagnostics in the existing integrated circuits are carried out by comparing the solder joints on the PCB with the reference images of the solder joints, so it is important to carry out the exact combination of such images.

When choosing the number of automated diagnostic systems, the cost of repairs after performing this operation, the type of equipment for which these launchers are assembled for are taken into consideration. It is also taken into account that up to half of all defects of the PCB is concentrated in soldered joints of integrated circuits, as well as the fact that the cost of the repairs after soldering averages up to 60% of the repair cost of the PCB. Therefore, for medical equipment and security systems (for example, air bags in cars), it is recommended to perform diagnostics at the stage of placement of the integrated circuits. Such diagnostics is carried out by comparing with reference images of PCB, therefore the exact combination of images of such type is important. Therefore it is necessary to carry exact positioning of such images (in order to reduce costs of the automated diagnostic systems, the cost of PCB and to increase the performance).

2 Main stages of the developed information technologies of the automated system for printed circuit boards and soldered joints diagnostics

The developed information technology for PCB automated diagnostic systems includes the following steps.

Stage 1. Positioning of the PCB panel image along the contours of the reference marks (fig 4).

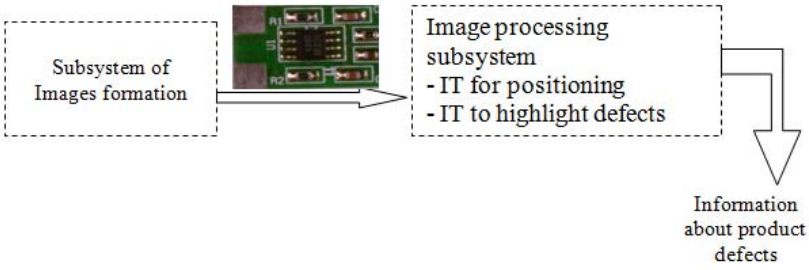


Fig.4. Processing sequence when information technology for positioning and defects selection on the print nodes are being used

This IT allows for automated positioning to use images of reference marks (RM) - marks of a familiar shape on the surface of printed circuit assemblies PCBs (Fig. 5) and has two modes: training mode and operating mode.

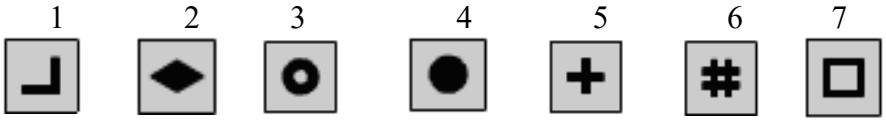


Fig. 5. Classes of reference marks

The training mode includes the following main stages (Fig. 6).

Stage 1. Pre-processing of the image of the product obtained with the help of a video camera in order to reduce the level of noise.

Stage 2. Binarization of the product image.

Stage 3. Localization of the reference marks. With the localization of reference marks, their coordinates on the image are determined, and their contours are selected and traced. The result of this stage is the coordinates of the contours of the reference signs.

Stage 4. Determination of the identification vector of the reference marks. As a result, a training sample is formed to classify reference marks.

Stage 5. Training of a multilayered neural network (MNN), as a result of which the surface is built, dividing the reference signs in the feature space. This dividing surface is used on the next stage in the operating mode during the classification.

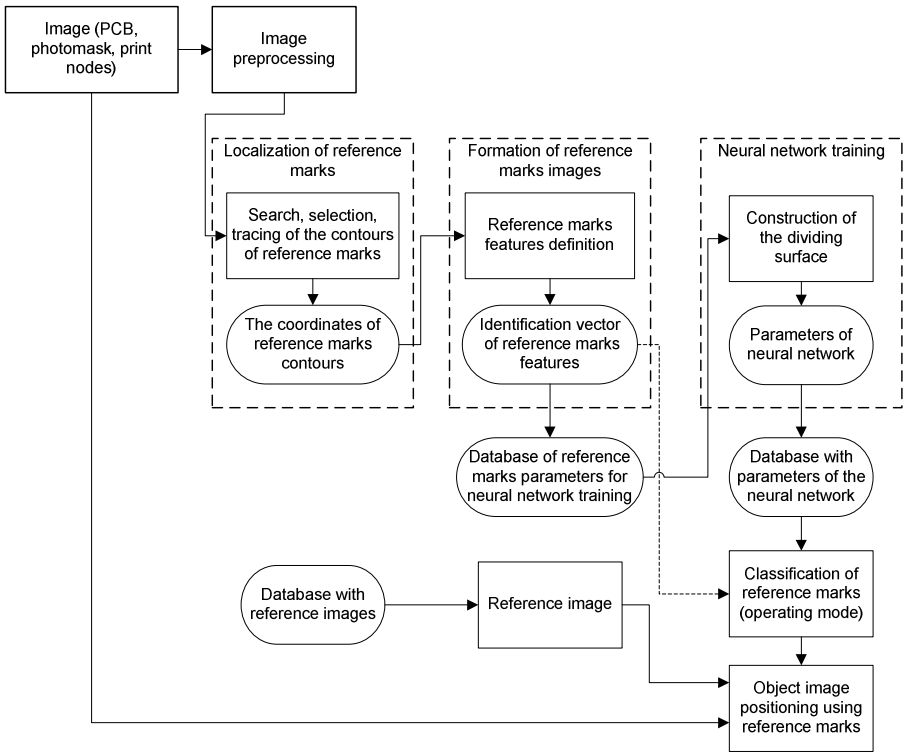


Fig. 6. Basic IT of the reference marks positioning procedures

In operating mode, the following steps are implemented.

Stage 1. Classification of reference marks. The operator of the ASD receives information about the belonging of the reference marks to a certain class - that is, the result of recognition - a classification decision.

Stage 2. Positioning of the object image on the reference marks is relative to the standard, coming from the database (Fig. 7).

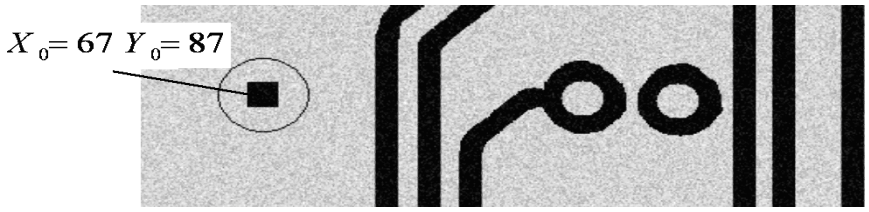


Fig. 7. Fragment of the PCB image and the result of localization of reference marks

The implementation specifics of the IT procedures for the positioning of printed circuit assemblies of control stations by the reference marks are described below:

a) image pre-processing. In order to reduce the level of additive interference arising in a television sensor at the stage of forming a digital image of an object, is proposed to be conducted with the application of the median filtering. It implements a non-linear noise removal procedure. When the procedure is implemented, a window is created that moves through the image, covering an odd number of its pixels. The value of the current pixel is replaced by the median of the pixel values in the window. The intensity drops with such processing in contrast to the smoothing filters. In order to reduce the level of multiplicative noise caused by uneven illumination, homomorphic filtering was applied.

b) binarization. To highlight the defects of the printed circuit assemblies of the PCB in the ASD, binarization of their images and references is performed. This procedure should ensure invariance to intensity transformations and reduce the amount of information processed by the system. In this case, the error of binarization should not exceed the 50% of the track width of printed circuit assemblies of the PCB. During binarization, the following decision is made: is there a track (useful signal) or substrate (background) among the pixels of the image? Depending on this, the pixel is assigned the value "0" or "1".

c) localization. For the localization of reference marks, a method of localization of small-sized objects in the image using the wavelet transform was chosen. As a result of the localization procedure, a traced contour of the reference marks of PCB and the coordinates of their position (centers of gravity) are obtained (Fig. E). This reduces the amount of information for the identification procedure.

d) identification. Based on the calculation of geometric moment features using information about the characteristic points - the most informative part of the contour of the reference marks. The first and second coefficients of the discrete cosine transform of the moment-signs, the geometric sign of compactness, and the Euler number are included in the feature set. The selected features provide: scale, shift, and rotation invariances sufficient for the requirements of the practice.

e) reference marks classification. It is carried out with the help of MNN (perceptron). The result of MNN learning is stored in the database with the parameters of the MNN (see Fig. 6). Then, at the recognition stage, a set of reference marks obtained under the noisy conditions is supplied to the input of the perceptron. As a result of the calculations, the class of the relay is determined in the network output.

IT for defect allocation involves the following steps.

Stage 1. Binarization of the reference images and controlled products.

Stage 2. Median filtering of the product image. In order to exclude false defects from consideration (relative shift results by 1 pixel on images, for example, current PCB and standard one), median filtering is used to ensure the noise immunity of the decision on the presence of a defect. By varying the length of the median filter, you can identify defects with a given accuracy.

Stage 3. Determination of the resistors and capacitors solder joints defect locations on the image of the PCB.

Selection of such defects is performed by combining the binarized images of the PCB relative to the standard ones based on their pixel-by-pixel comparison. In Fig. 8 a fragment of the PCB image is presented with identified defects.

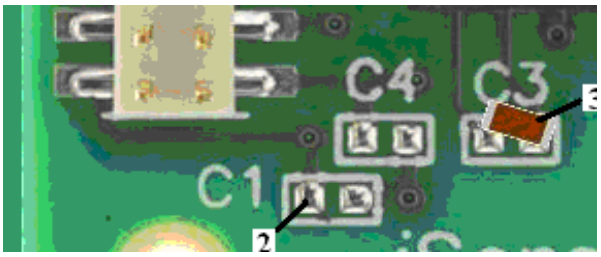


Fig.8. Fragment of the PCB assembly with defects in the capacitors soldered joints

To assess the recognition accuracy, a database was used which consisted of 100 photographs of printed circuit assemblies of various sizes, rotation and tilt angles, and various levels of illumination. As a result of testing such an ASD, the recognition accuracy was 0.85. The noise immunity of the system was increased on average by up to 20% compared to the existing systems through the use of developed information technology that meets the requirements of practice. The reliability of diagnostics in terms of interference on the signal-to-noise ratio range 10 ... .20 (in power) increased up to 1.2 times in comparison with the existing ASD.

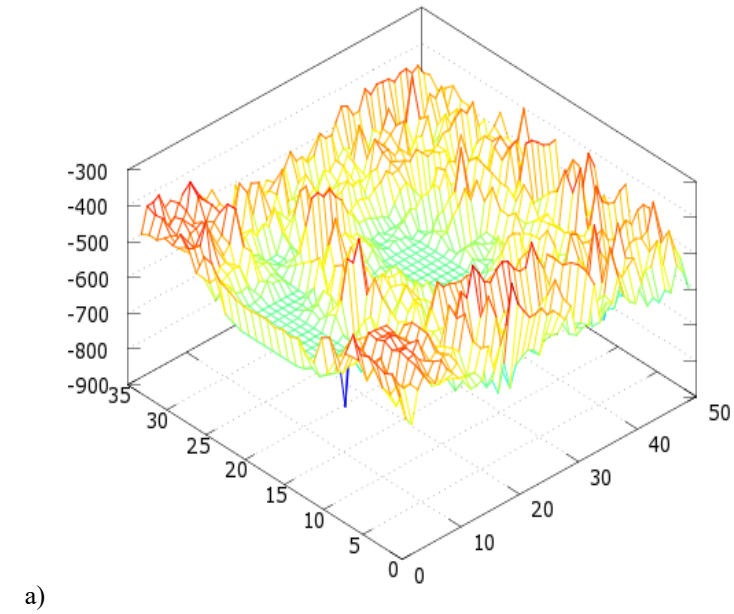
The next step is to determine the defects of components with a small lead pitch (Fig. 9). Information technology for components positioning in automated diagnostic systems for soldered joints with a small range of component conclusions involves the implementation of two main stages.

The first stage is the positioning of the PCB by the reference marks, the second stage is the positioning of the resistors, capacitors and integrated circuits on the PCB image (see Fig. 1).

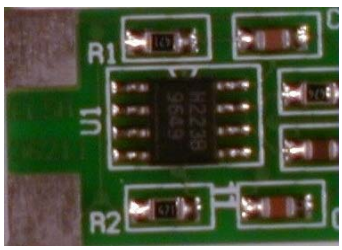
At the second stage, in order to determine the defects of the PCB of the integrated circuit, it is necessary to identify the region of these integrated circuits location on the image of the PCB. To solve this problem, the following methods are used, the ones that use information about the entire halftone image, and methods that use information about specific areas of the image - characteristic features.

For the methods of the first group, the computational costs are high, since the parameters of the soldered joints positioning are calculated from the information about the entire half-tone image of the PCB. The characteristic features method is easy to implement and has higher speed. Therefore, this method was chosen as the baseline for the positioning on the second stage (fig. 3). When searching for the position of the integrated circuits on the PCB, the minimum of the multimodal function should be found, which determines the error of combining the integrated circuit component and a sample (fig 3.a), with a signal-to-noise ratio below 6. Gradient methods of the minimum search that are traditionally used at this stage are not functional Signal / interference ratio is less than 15. To search for a minimum in such conditions, a multi-start optimization method in the wavelet transformation space has been developed [27]. This method was used in the work to search for the location of the integrated circuits and to align the reference image and controlled integrated circuits components in the ADS with the processing of information on soldered joints obtained in the optical range [27-29].

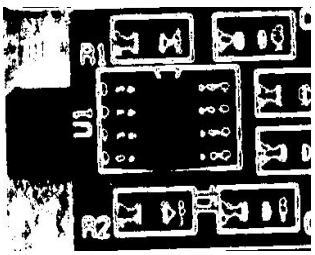
Within this the binarization of the PCB image by converting a halftone image (with a pixel intensity ranging from 1 to 256) into a binary one according to the intensity threshold is carried out. For this, two thresholds of binarization were accepted in the paper T1 and T2. Pixel of the binarized image B (x, y) takes the value of 1 $if\ \ A(x, y) < T_1\ or\ A(x, y) > T_2$ and the value of 0 $if\ \ T_1 < A(x, y) < T_2$. Here A (x, y) is a halftone image $T_1 = 77$ and $T_2 = 156$ - binarization thresholds. The result of binarization is shown in Fig. 9, c.



a)



b)



c)

d)

e)

Fig. 9. Error of PCB combining function and a standard (a); a fragment of the PCB (b); binarized image (c); masks with the designation PCB (U1) (d) and with soldered joints (e).

Than the image of the PCB is scanned using a mask with the marking of U1 (the label of this IS on the PCB) (see Fig. 9, d). The minimum of the combining image error (see Fig. 9, a) during such a scanning is found with the help of the multi-start optimization method with WT. The carrier length of the wavelet function (WF) in the search for a minimum in the coordinate x is 17, in y it is 8, the discretization step of the WF is 1, and in the implementation of the iterative search with the Haar's WF $\gamma_1 = 0{,}1$.

The minimum of the image alignment error was found in 3 iterations (at the start of the search in [1; 1], the coordinates of the minimum (25; 14), (19; 13), (17,13) were found). At the second stage of the search in the region of this minimum, scanning of the image PCB is performed with an image mask of the SJ of this IS (see Fig. 9, e). The minimum of this error function is also determined by using the optimization method with the WT for three iterations.

Than the positioning of the integrated circuit on the image PCB is made.

The developed information technology allows a fast search of soldered joints while the components are being mounted to the surface with a signal-to-noise ratio in amplitude starting from 5.

3 Conclusions

Thus, it can be concluded that during testing of the developed information technologies for soldered joints and automated diagnostic systems of the PCB based on procedures using wavelet transformation, the recognition accuracy was 0.85. In terms of interference in the signal-to-noise ratio range 10 to 20 (in power) the reliability of diagnostics increased up to 1.2 times compared to the existing automated diagnostic systems. The noise immunity was increased on average by up to 20% compared to the existing systems due to the use of developed information technologies that meet the requirements of practice.

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