ICIC Express Letters ICIC International ©2017 ISSN 1881-803X
Volume **11**, Number **10**, October **2017** pp. 1547–1554

RESEARCH ON INTEGRATING PCB SOLDER JOINTS EXTRACTION METHOD BASED ON PIXELS INFORMATION FOR PCB INSULATION PACKAGING SYSTEM

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Received April 2017; accepted July 2017

Abstract. *With the development of electronic information technology, high density integrated circuits have appeared in large quantities. To prevent the electromagnetic influence of the integrated circuits installed in such devices, it is necessary to make insulation package for them. Aiming at the low efficiency and material waste in traditional packaging methods, a PCB insulation packaging system based on machine vision and 3D printing is proposed in this paper. Firstly, the structure of PCB insulation packaging system is designed. Then, for the existence of various problems like small welding area, large quantities of solder joints and dense position of the solder joints on the integrated circuit board, the solder joints extraction algorithm based on the pixels information is proposed in the paper in order to locate the PCB solder joint areas. Finally, the solder joints location tests are carried out to compare the method proposed in the paper with the solder joints detection method based on color space model. The results indicate that the proposed method is fast and suitable for different kinds of PCBs, and can greatly improve the filling rate of solder joint areas and filter out the false pixels, which provide support for an effective PCB insulation packaging system based on the accurate positioning method of PCB solder joint areas.*
Keywords: PCB, Solder joints location, Pixels information, PCB packaging system

1. **Introduction.** With the development of electronic information technology, people's lives are full of different kinds of electronic products, which are becoming smaller but more effective, so the printed circuit boards (PCBs) of most equipment are filled with high integrated and complex circuits. The circuits interfere with each other or the outside, so it is essential to implement the PCB insulation package [1]. At present, there are two methods for PCB insulation encapsulation [2]. The first is artificial spraying insulating materials; for large quantities of PCB, it requires a lot of manpower and wastes lots of materials. The second is spraying a whole coating of insulating materials through the packaging machine; in spite of the high degree of automation, it would waste a large quantity of materials and cost more molding time with the extra ultraviolet (UV) curing in the mass production.

UV light curing insulation resin is provided with low VOC (volatile organic compounds), good insulation, high efficiency and other characteristics [3]. It will not produce environmental pollution, not affect the PCBs size and achieve uniform insulation PCBs with UV light curing insulation resin. Digital micro-jet technology can produce micron droplets to spray accurately, which has the advantages of simple manufacturing process, high molding efficiency and high material utilization [4]. It will improve the packaging accuracy and curing time of insulating materials to achieve the PCB insulation package with the digital micro-jet technology. The digital image processing method is used to extract and locate the PCB solder joints, and then the target digital information is transmitted to the computer to control the three-dimensional printer so that the insulation material will be sprayed on the solder joint areas, which can effectively promote the degree of automation, save material loss and improve packaging accuracy.

At present, many scholars have studied PCB solder joint positioning methods using image processing technology, such as, histogram-based feature analysis methods [5,6], template matching methods [7-9], gray-based projection methods [10,11], and the solder joint detection methods based on color space [12,13]. The histogram-based feature analysis method is achieved by extracting and analyzing the histogram of solder joints image [5,6]. The template matching method is accurate but difficult to operate [7-9]. The gray-based projection method is accomplished by using the color threshold to binarize the solder joints image and extracting the X, Y axis projection of the binary image [10,11]. The gray scale histogram of the solder joints image is statistically analyzed and the segmentation threshold of the solder joint is corrected through the solder joint detection method based on color space [12,13]. These methods can achieve fast and effective location of solder joints, but only for welding one by one [14,15]. They cannot meet the requirements of locating the solder joints of the entire image at the same time. Combined with the characteristics of the small PCB size, the large number of solder joints, the small single spot area and the compressed welded, the traditional methods mentioned classify and locate the solder joints one by one so that they are not suitable for the positioning of various solder joints in a wide range. The PCB solder joints extraction method based on pixels information is studied in this paper, which can effectively complete the overall extraction and location of the multi-pattern solder joints and is suitable for different PCBs. In addition, the method proposed in this paper can reduce the extraction of false pixels which are not in the solder joints areas and improve the filling rate of the solder joints areas. The method can accomplish the solder joints location in one time and improve the positioning accuracy to provide reliable positioning information for insulation packaging for the solder areas on the PCBs. The insulation package system can promote the degree of automation to improve efficiency and reduce material loss effectively.

This paper is organized as follows. In Section 2, the insulation packaging system based on the three-dimensional printing is designed. The PCB solder joints extraction algorithm based on pixels information is also proposed. Additionally, test results and analyses are given in Section 3. Finally, conclusion and future work are drawn in Section 4.

2. Research on the Key Technology of PCB Insulation Packaging System.

2.1. **PCB insulation packaging system design.** The insulation packaging system based on the three-dimensional printing is designed to complete the goal of automatic insulation package of PCB, which controls the UV light-cured three-dimensional printing machine to spray insulating resin on the location of solder joints located by the extraction algorithm proposed in this paper. Considering various PCB types, the main technical requirements of the packaging system and the actual situation of the production site, the overall scheme of PCB insulation packaging system combined with 3D printing and machine vision technology is put forward in this paper.

According to the actual requirements of PCB insulation package, this system is mainly designed by the illumination, image acquisition system, computer control system, 3D printer and other components, as shown in Figure 1. The illumination includes a light source and a light source controller. The image acquisition system comprises a zoom lens,

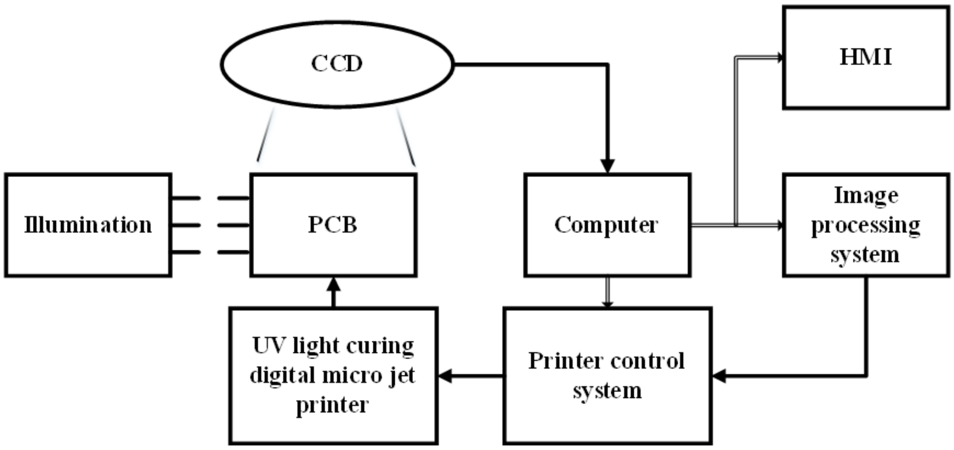


Figure 1. PCB insulation package system structure

a CCD industrial camera and an image acquisition card. The computer control system comprises an image processing system, a printer control system and a human-computer interaction interface.

2.2. **The PCB solder joints extraction algorithm.** Aiming at the characteristics of PCB small size, the large number of solder joints and small spot size, the solder joints extraction method based on pixels information is proposed. Firstly, the color of the image is analyzed and the RGB components of each pixel in the target region are modeled. Then, the maximum and minimum values of each component are found and the three-component interval of the target region is determined. Finally, the three-component value judgment is made for each pixel and the pixel points in the target interval are found.

2.2.1. *RGB model.* RGB is encoded as a color space by three variables to transform the color to a mathematical model. The RGB model can be represented by a Cartesian coordinate system, as shown in Figure 2, where R, G, and B are the three axes of the coordinate system respectively, and any point in the three-dimensional space is represented by the three variables in accordance with a certain proportion of the composition of the color. Most systems use RGB color models to display colors; for example, image acquisition devices usually use RGB color model.

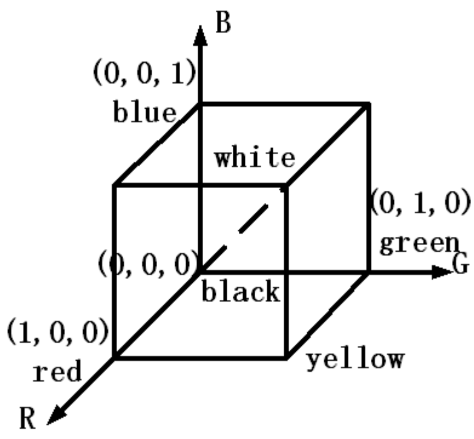


Figure 2. RGB color model

2.2.2. *Extraction algorithm based on pixels information.* The surface colors of PCBs can be simply divided into several areas of its image, including the main background area, silver solder areas, white or black lines and characters, etc. In order to find out the silver color, the pixels information extraction method is shown in Formula (1):

$$\begin{cases} f_{1r} = f(x_1, y_1, r) \\ f_{2r} = f(x_1, y_2, r) \\ \vdots \\ f_{nr} = f(x_1, y_n, r) \\ \vdots \\ f_{n^2r} = f(x_n, y_n, r) \end{cases} \quad \begin{cases} f_{1g} = f(x_1, y_1, g) \\ f_{2g} = f(x_1, y_2, g) \\ \vdots \\ f_{ng} = f(x_1, y_n, g) \\ \vdots \\ f_{n^2g} = f(x_n, y_n, g) \end{cases} \quad \begin{cases} f_{1b} = f(x_1, y_1, b) \\ f_{2b} = f(x_1, y_2, b) \\ \vdots \\ f_{nb} = f(x_1, y_n, b) \\ \vdots \\ f_{n^2b} = f(x_n, y_n, b) \end{cases} \tag{1}$$

where, f is the color image, $1 \sim n^2$ is the pixel points of solder joint areas chosen from the color image, $x_1 \sim x_n$, $y_1 \sim y_n$ are the rows and columns of the solder joint pixel points chosen from the color image respectively, r, g, b are the three-color components of a color image, $f_{1r} \sim f_{n^2r}$, $f_{1g} \sim f_{n^2g}$, $f_{1b} \sim f_{n^2b}$ are RGB components of overall pixel points respectively.

The RGB components of each pixel points in solder joints area are extracted by Formula (1), the maximums and minimums from $f_{1r} \sim f_{n^2r}$, $f_{1g} \sim f_{n^2g}$, $f_{1b} \sim f_{n^2b}$ are found respectively to get the RGB region of solder joint areas, as shown in Formula (2):

$$\begin{aligned} f_r &\subseteq \left[\ f_{r\min} \quad f_{r\max}\ \right] \\ f_g &\subseteq \left[\ f_{g\min} \quad f_{g\max}\ \right] \\ f_b &\subseteq \left[\ f_{b\min} \quad f_{b\max}\ \right] \end{aligned} \tag{2}$$

where, f_r, f_g, f_b are RGB components of pixel points in solder joint areas respectively, $f_{r\min}$, $f_{r\max}$, $f_{g\min}$, $f_{g\max}$, $f_{b\min}$, $f_{b\max}$ are the maximums and minimums of RGB components in solder joint areas respectively.

The proposed solder joints extraction method based on pixels information in this paper can locate all the solder joints in the whole PCB image at one time, and generate the solder joints digital image which can provide effective image visual information for the subsequent printing. The algorithm is simple and fast, and can adapt to different kinds of PCBs.

Due to the uneven lighting conditions and the electronic interference of camera, there is some noise pollution in the collected PCB color image. This will reduce the image signal-to-noise ratio and obscure PCB image detail information, which will interfere with the subsequent solder spot location. Therefore, to meet the quality of a certain location of the solder joints, PCB images must be pretreated before positioning, including image denoising, image contrast enhancement in several aspects. In this section, the main process of the solder joints location algorithm is as follows:

(1) Collect the color image of the PCB, filter out the image of high-frequency noise with the 3*3 median filtering, filter low-frequency image noise with the 3*3 mean filtering, and take linear changes to enhance the contrast and highlight the image details;

(2) Analyze the color type and feature of the color image, select solder joint areas to calculate the coordinate range and pixel numbers of the selected area, namely $x_1 \sim x_n$, $y_1 \sim y_n$ and n^2;

(3) All the pixels in the rectangular area are sorted from the first to the n^2, and extract the pixels information, which is the RGB component of each pixel;

(4) Sort the RGB components of each pixel according to the number respectively to find the maximum and minimum values of each component to obtain the RGB component

range as shown in Formula (3):

$$\begin{aligned} a &= f(i,j,r) \subseteq \left[\begin{array}{cc} f_{r\min} & f_{r\max} \end{array}\right] \\ b &= f(i,j,g) \subseteq \left[\begin{array}{cc} f_{g\min} & f_{g\max} \end{array}\right] \\ c &= f(i,j,b) \subseteq \left[\begin{array}{cc} f_{b\min} & f_{b\max} \end{array}\right] \end{aligned} \tag{3}$$

where f is the image to be processed, i, j are rows and columns of image respectively, r, g, b are three-color components. The solder joint area in the color image is the set of target J, where the target J is the pixel point satisfying the above characteristics, as shown in Formula (4):

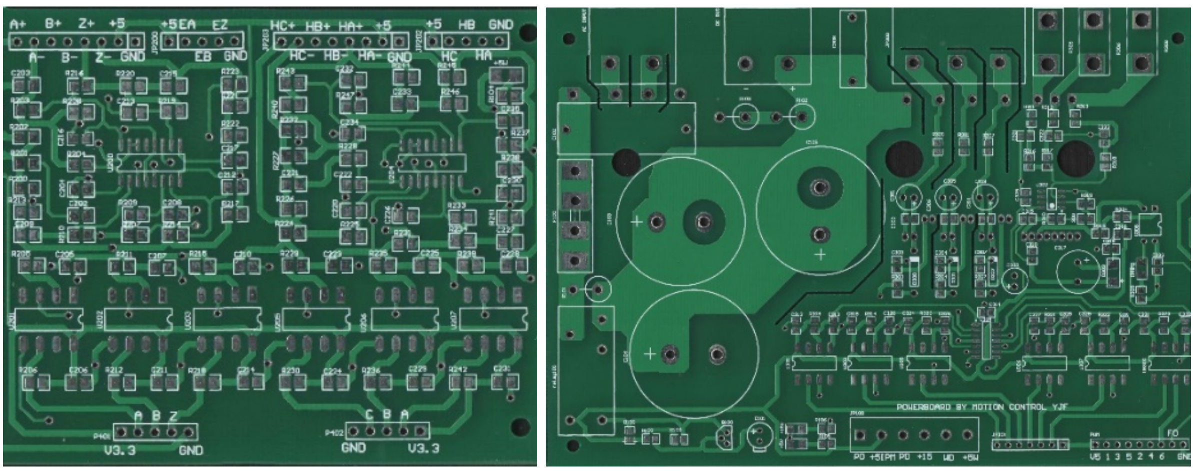
$$J \subseteq a \cap b \cap c \tag{4}$$

(5) After segmenting the solder joints from the color image, the redundant information is still present in the segmentation image. Starting from the first pixel point in the upper left corner of the image, search the pixel points of pixel value 255 row by row and mark the target pixel points to find the connected domain in the segmentation image, keep the connected areas with the areas greater than 3000;

(6) After removing the redundant information, the image retains the segmentation of the solder joints. The image is expanded with a 3*3 rectangular structure to fill the internal areas of the solder joints.

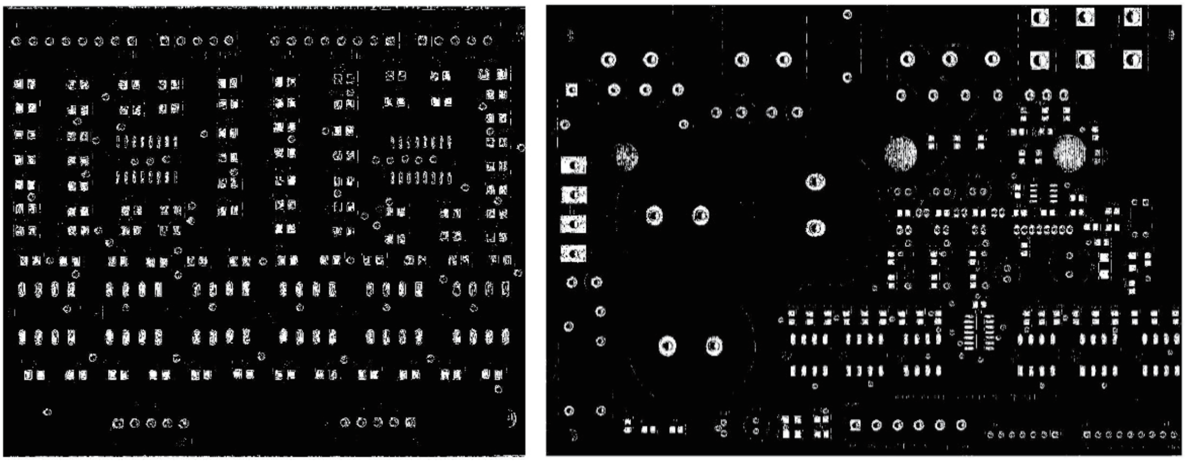
3. **Test Results and Analysis.** In this section, the tests of actual PCB are carried out to verify the effectiveness of the proposed algorithm. Furthermore, the solder joints detection method based on the color space is used to compare with the proposed method in this paper. The PCB used in the test is Arduino's 2 kinds of development hardware board for wearable equipment. The color original figure collected by camera is shown in Figure 3. From Figure 3, it can be seen that the PCB solder joint areas are diverse and most of them are small and difficult to position. As a result, the accuracy of positioning is hard to improve.

For the color images of the PCBs above, test results of the solder joints detection method based on the color space is shown in Figure 4. The method can locate the solder joints in the PCBs, but the welding areas are not complete, locations are blurred, and even there are more misjudgment points in the background area. All the above will probably lead to many problems, for example, less spraying of the target areas and mistaken spraying of the background area when spraying the insulating material with the UV light curing printer. The solder joints extraction method based on pixels information is proposed and



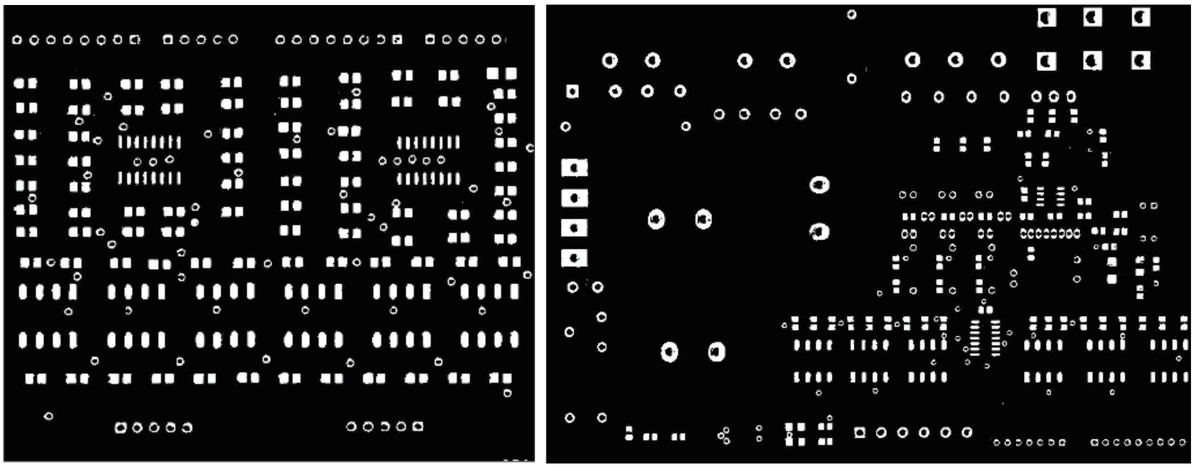
(a) (b)

Figure 3. The physical picture of PCBs using in experiment



(a) (b)

FIGURE 4. Experiment results of the detection method based on color space



(a) (b)

FIGURE 5. Experiment results of the method proposed in this paper

used to experiment. The results are shown in Figure 5. From Figure 5, it can be seen that the whole area of the solder joints in the color image can be extracted, and the extracted image is clear and complete. There are few misjudgment points in background area, and the solder joints positioning is accurate. Finally, the positioning image is shown in binary format and put into the computer as a digital image. The computer controls the printer to spray the insulating material at the corresponding position. The white part is where the insulating material is sprayed. The black part is not required to spray the insulating material section. So there is no identification of color problems, which will not have an impact on the experimental results.

Besides, the filling rate of the solder joints and the false positive rate of the background region are calculated by programming and the statistical results of the two kinds PCBs are shown in Table 1.

Table 1 shows that the filling rate of the rectangular and circular solder joints is more than 80% and the false positive rate in the background area is also lower than 1.1% in the positioning image, which is processed by the method proposed in this paper. The results show that the proposed algorithm can effectively improve the location accuracy of the solder joint areas, and provide reliable visual location information for the spraying target.

Table 1. Positioning accuracy of 2 PCBs using the method in the paper

	Filling rate (%)				False positive rate (‰)	
	Rectangular solder joints		Round solder joints			
	Method proposed in the paper	Color space based method	Method proposed in the paper	Color space based method	Method proposed in the paper	Color space based method
PCB A	88.25	62.34	85.85	78.39	10.53	21.83
PCB B	87.5	68.52	82.21	75.46	8.01	16.37

4. **Conclusion.** Aiming at the problems of PCB circuit board like large board area, small spot size, the large number of welding spots and various shapes, the PCB solder joints extraction method based on pixels information is proposed in this paper. The test results show that the developed method can effectively complete the whole PCB solder joints extraction simultaneously, the intact segmented solder joint areas and fewer misjudgments in background, which provides reliable location information of the solder joints for the PCB insulation packaging system. In the future work, the embedded PCB insulation packaging system will be further developed for more practical applications.

Acknowledgment. This work is partially supported by the National Natural Science Foundation of China (Grant Nos. 61601228, 61403210, 61273243), and the Natural Science Foundation of Jiangsu Higher Education Institution (15KJB510016), Natural Science Foundation of Jiangsu (BK20161021, BK20151548), and sponsored by NUPTSF (NY214173). The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers.

REFERENCES

[1] A. Schmidt, T. Döring and A. Sylester, Changing how we make and deliver smart devices: When can I print out my new phone? *IEEE Pervasive Computing*, vol.10, no.4, pp.6-9, 2011.

[2] U. Rathinavelu, M. S. Jellesen, P. Moller and R. Ambat, Effect of no-clean flux residues on the performance of acrylic conformal coating in aggressive environments, *IEEE Trans. Components, Packaging and Manufacturing Technology*, vol.2, no.4, pp.719-728, 2012.

[3] M. Kurimoto, H. Ozaki and Y. Yamashita, Dielectric properties and 3d printing of uv-cured acrylic composite with alumina microfiller, *IEEE Trans. Dielectrics and Electrical Insulation*, vol.23, no.5, pp.2985-2992, 2016.

[4] H. M. Dong, W. W. Carr and J. F. Morris, Visualization of drop-on-demand inkjet: Drop formation and deposition, *Review of Scientific Instruments*, vol.77, no.8, pp.085101-1-085101-8, 2006.

[5] F. Steiner and P. Harant, Solderability of the lead free surface finishes, *Proc. of Electronics System Integration Technology Conference*, Dresden, Germany, pp.365-369, 2006.

[6] H. Xie, X. Zhang and Y. Kuang, Solder joint inspection method based on image feature statistical analysis, *Chinese Journal of Scientific Instrument*, vol.32, no.2, pp.402-407, 2011.

[7] C. H. Wu, D. Z. Wang et al., A particle swarm optimization approach for components placement inspection on printed circuit boards, *Journal of Intelligent Manufacturing*, vol.20, no.5, pp.535-549, 2009.

[8] E. P. Leng, M. Ding, I. Ahmad et al., Lead-free effect in lead-free solder joint improvement, *Proc. of the 31st International Conference on Electronics Manufacturing and Technology*, Petaling Jaya, Malaysia, pp.541-548, 2006.

[9] H. Wu, X. Zhang, H. Xie et al., Classification of solder joint using feature selection based on bayes and support vector machine, *IEEE Trans. Components, Packaging and Manufacturing Technology*, vol.3, no.3, pp.516-522, 2013.

[10] T. Liang, D. Zhou and Z. Liu, A highlight processing technology for SMT solder joint gray image, *The 13th International Conference on Electronic Packaging Technology & High Density Packaging*, pp.899-902, 2012.

[11] K. Han, X. Wang and C. Yu, An efficient visual tracking method based on single CCD camera, *2012 International Conference on Machine Learning and Cybernetics*, Xi'an, China, 2012.

[12] J. Jiang, J. Cheng and D. Tao, Color biological features-based solder paste defects detection and classification on printed circuit boards, *IEEE Trans. Components, Packaging and Manufacturing Technology*, vol.2, no.9, pp.1536-1544, 2012.
[13] J. F. Khan, S. M. A. Bhuiyan and R. R. Adhami, Image segmentation and shape analysis for road-sign detection, *IEEE Trans. Intelligent Transportation Systems*, vol.12, no.1, pp.83-96, 2011.
[14] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, Pearson, UK, 2014.
[15] A. Gopalakrishnan, A. Almazroa, K. Raahemifar and V. Lakshminarayanan, Optic disc segmentation using circular hough transform and curve fitting, *The 2nd International Conference on Opto-Electronics and Applied Optics (IEM OPTRONIX)*, pp.15-17, 2015.