VISUAL INSPECTION SYSTEM FOR AUTOMATIC CONNECTOR PRODUCING MACHINES

HỆ THỐNG KIỂM TRA THỨ TỰ MÀU CHO MÁY SẢN XUẤT CÁP KẾT NỐI TỰ ĐỘNG

Le Quoc Nhat, Le My Ha
Ho Chi Minh City University of Technology and Education

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ABSTRACT

Today's high speed complex manufacturing systems require the development of automation technologies that can be effectively integrated into the system and use in manufacturers process. This paper proposes a new method for inspecting the order of electrical colored wires in industrial connector cables manufacture. The system is able to check the difference in the color, number of wires, and color sequence cables connector with the self-designing model. The system learns the model cable and then it can automatically inspect each cable assembly by machine. The key ideas of the algorithm are threefold: first, the rectangle connector parts of sample image and test image of product are analyzed and detected by using shape and region properties. The region of connectors are then extracted and rectified to vertical direction. Second, a robust segmentation algorithm for extracting wires from images even if they are strongly bent and partially overlapped. Third, a color recognition algorithm is able to cope with highlights and shadows. To verify the efficiency and effectiveness of the proposed method for color wires inspection, the authors report the system evaluation by many different samples with a variety of conditions. The representation of a strong point of this system is reliable method for extracting wire regions and analyzing color wire.

Keywords: *Automatic visual inspection; wires color sequence; self-designing; connector part; color recognition algorithm.*

TÓM TẮT

Hệ thống sản xuất phức tạp với tốc độ cao ngày nay yêu cầu phát triển công nghệ tự động có khả năng tích hợp hiệu quả vào quá trình sản xuất. Bài báo này đề xuất một phương pháp mới để kiểm tra thứ tự dây cáp kết nối trong ngành công nghiệp sản xuất dây cáp. Hệ thống có khả năng kiểm tra sự khác nhau về màu dây, số lượng dây, và thứ tự dây cáp kết nối bằng mô hình tự thiết kế. Hệ thống phân tích và lưu mẫu chuẩn, sau đó tự động đánh giá, kiểm tra cáp so với mẫu đã được lưu. Ý tưởng của thuật toán được chia thành ba phần chính: đầu tiên, phần kết nối sẽ được phát hiện nhờ vào việc phân tích các đặc tính và thông số liên quan. Thứ hai, thuật toán phân đoạn ảnh và trích xuất vùng có dây từ ảnh gốc thậm chí cả trong trường hợp dây bị rối và chồng chéo. Thứ ba, hệ thống phân tích, nhận dạng màu dây và có thể thực hiện trong trường hợp chiếu sáng không đều, sợi dây bị chói sáng hoặc xuất hiện đốm mờ. Để thẩm định tính hiệu quả của phương pháp đề xuất, tác giả đánh giá hệ thống dựa trên nhiều mẫu kiểm tra với các điều kiện thử nghiệm khác nhau. Ưu điểm nổi bật của hệ thống này là có phương pháp trích xuất vùng dây và phân tích màu dây với độ tin cậy cao.

Từ khóa: *Hệ thống kiểm tra trực quan; trình tự màu dây; mô hình tự thiết kế;cáp kết nối; thuật toán phân đoạn màu.*

1. INTRODUCTION

For many years, visual inspection and quality control are performed by humans. In many cases, humans can do the job better than machines but it is impossible to maintain the productivity in the long time, they get tired quickly. Moreover, they are slower than the machines that the production process speed is affected. There are also cases, the products are so small size that human vision can observe and visualize. Also, in some environments (e.g, nuclear industry, chemical industry, under- water inspection, etc) inspection may be diffi- cult and dangerous for human interaction directly. Automatic visual inspection machines provide innovative solution in the direction of manufactures in industrial systems. An industrial system integrated automatic visual inspection can rapidly get result not only high accuracy, but also lower cost production in production. The widely application of computer vision systems include semicon- ductor production [1-2]. The other applications are delicate electronics component manufacturing [3], granite quality inspection [4], quality textile production [5], glass manufacturing[6], integrated circuits manufacturing [7] and many others. According to the advantages of using vision system for automatic product inspection machine, a method for automatic color cable inspection is proposed. There exist some papers were discussed to this topic, the closest paper is proposed in [8]. From the result of this research, it's really promsising in the real application. However, there exist some limitations need to improve such as the connector parts in this research are fixed. Hence, when carry out to the real application, it's limited to the automatic system, which the connector cables may appear with arbitrary geometric shapes and random position in the workspace. Moreover, the electrical wires in these samples are assembled pretty sparsely. In case the density of wires is dense or the size of wire is decreasing, the wire-overlapping problem will occur. In those cases, the separate wire regions are difficult to be segmented and extracted. Almost those disadvantages are solved in our research. A strong points of this system are able to automatically adjust tolerances in color measurement depending on the colors of wires to be check. Besides, a color recognition algorithm able to cope with highlights and different finishing of the wire insulation. Overall, the structure of the sample consists of the plastic connector part which have the rectangle shape in general cases with 15-color wires, as shown in Fig. 1. The order of color of wires depends on the type of product. The machine learns and saves the parameter of sample image as reference, then waits for a human operator to insert the test image and the actual inspection process takes place. From the structure of product, the authors can see that there have several difficult points in inspection problem need to be solved. The key ideas in this paper are how to align the images and extract exactly each wire regions and then extract the wire patches. The overall proposed scheme is illustrated in Fig. 2.

This paper is organized as following: In section 2, the proposed system is described, such as system requirements, design principles, user interface, and hardware introduction. In section 3, the image alignment and wire region extraction method are described. Also, the method for center of wires determination, color analysis, and connector sequence is presented. In section 4, evaluating performance to demonstrate the accuracy, effectiveness of the proposed method, true positive rate and their outcomes are reported. Finally, section 5 presents the conclusions for the proposed method, a summary of the work done as well as the future works.

2. SYSTEM DESCRIPTION

The cable inspection system described in this paper is designed to be checking the difference in the color and number of wires cables connector in industrial environment. Thus, the authors need to design the workspace system like industrial environment with artificial light in order to minimize noise factors from natural environment.

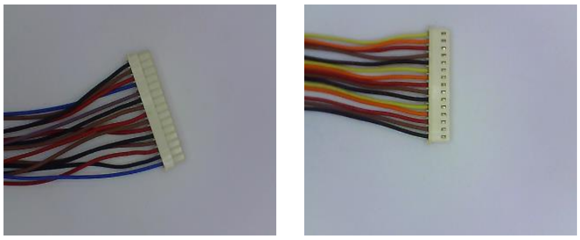
2.1 Design requirements

- The system must be compact and simple, suitable for study and research.
- Easy to replace, upgrade and maintain regularly.
- The workspace must be isolated in order to minimize the noise sources.
- The user interface must be simple, easy to understand and fully functional.

2.2 System requirements

The inspection system must be able to check whether test object is correct with sample object or not. Also, the system must have capability of operating in real time, they are able to check the production without affecting the production process speed. Besides, they must be of high reliability and should be able to handle a number of different situation:

- The wires are bent and overlapped.
- The connector parts can be different in size and color. It depends on the specific product.
- Wires can appear at any position on the working plane.
- The connector parts can appear both obverse and reverse randomly.



(a) (b)

Figure 1. *Electric cable. (a) is obverse and (b) is reverse of cable*

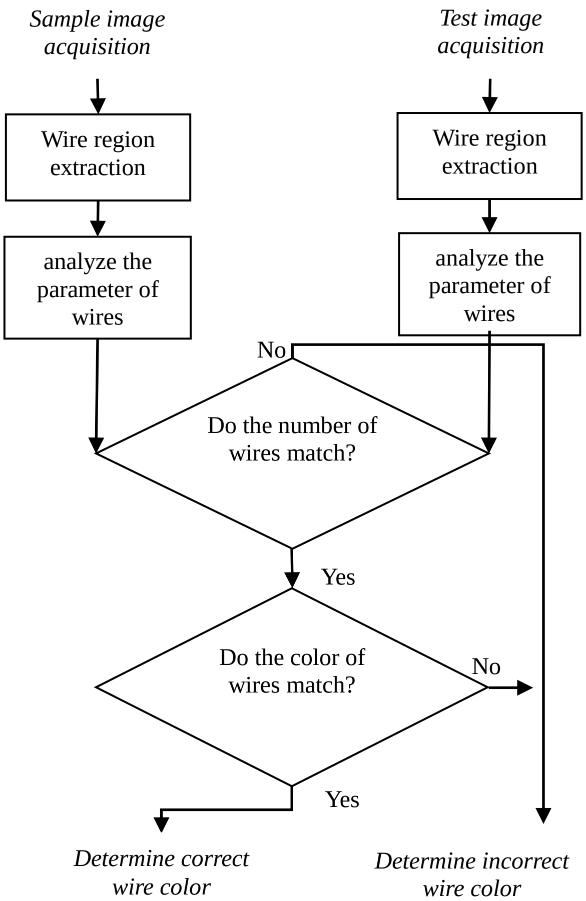


Figure 2. *The overall proposed scheme for colored wires inspection.*

2.3 Introduce the system

2.3.1 Box

The half-closed box are made by cardboard, as shown in Fig. 3. White color shade tape is placed inside the box in order to increase the amount of reflection. Besides, white color rarely presents in the electric wire color.

2.3.2 Camera

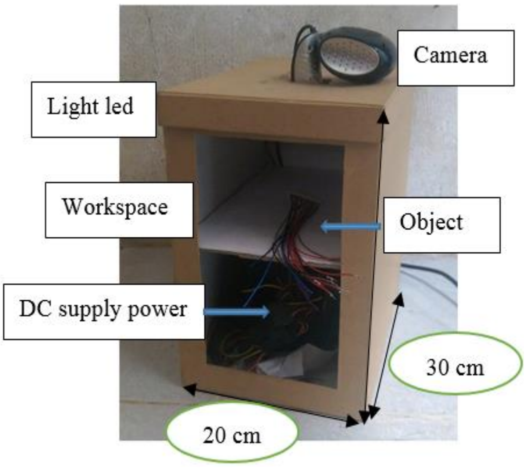


Figure 3. *Hardware system*

As usual, original image is acquired by camera. But this model is just used for study, research. So, The authors replaced camera by webcam Bluelover S11.The webcam is fixed on top of the box, at a height of 120 mm to the working plane.

2.3.3 Led bar

In industrial visual inspection, light control is very common, and lighting is therefore part of the system itself. Choices at this stage strongly influence the image quality and the system performance and should be made in order to minimize the noise sources. The products are lighted by 12 white lighting sources (1W LuxeonLeds). The light system is fixed on the top of the box, at a height of 120mm to the working plane andemits white light.

2.4 Graphic user interface

Graphic of this system is carefully designed to provide a functional controller fully, as shown in Fig.4. At the beginning of a new production, the GUI starts in the learning mode. At this phase, the GUI requests inserting the sample and test objec, then the system will automatically analyze parameter of sample and test object. After that, the GUI switches to the inspection mode. First, the system carefully checks the number of wires and checks whether there are absence of empty slots in the connector, then checks color sequence.

3. ALGORITHM

All the solfware for this visual inspection is developed in C++ and is based on the OpenCV and OpenNI2 library [9] for data structures and classes, color conversion, and image processing algorithms.

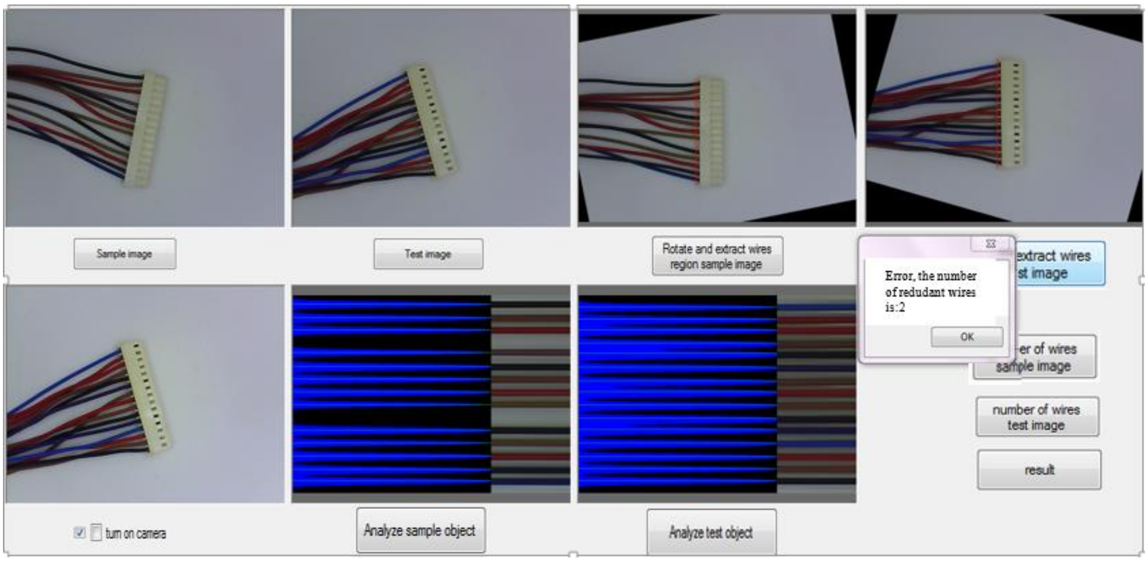


Figure 4. *Graphic user interface.*

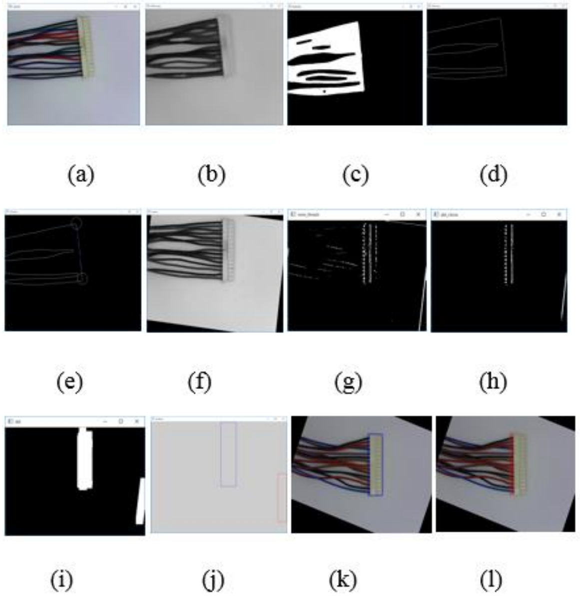


Figure 5. *Wire identification at various steps: (a) is original image. (b) is converted to gray image. (c) is converted to B&W image from RGB. (d) is canny image. (e) is Hough Transform image. (f) is rotated image. (g) is converted to B&W image. (h) is regions of interest. (i) is holes filling. (j) is calculate and eliminate incorrect zone. (k) is result of detection and rectification. (l) isExtracted the wires region (Region of Interest).*

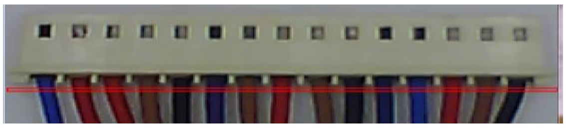


Figure 6. *The RoI exploited for wire segmentation.*

(a) (b)

Figure 7. *RoI rectification result: (a) is wire region image and (b) is wire region image was resized.*

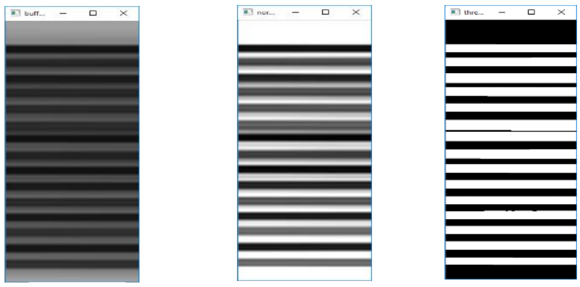
The algirithm of this system can be summarized into four main steps: first, connectors are detected and located, then wire regions can be extracted. Second, the method for center of wires determination is proposed. Third, color analysis of wires is also described. Fourth, color comparison and connector sequence are presented. All the steps will be described in detail in the following.

3.1 Connector detection and wire region extraction

In this kind of system, the connector parts can be appeared in the arbitrary positions. In order of dealing with bent and overlapped wires, the authors need to detect the connector part, then extract the wires region where locate closely the connector parts.

Firstly, rotating the input image processing: The color image of sample is converted to gray scale image by using the weight factors for each channel as:

$$Gray=0.2989*R+0.5870*G+0.1140*B \quad (1)$$



(a) (b) (c)

Figure 8. *ROI rectification result: (a) is gray scale image, (b) is normalize filter image, (c) is black and white image.*

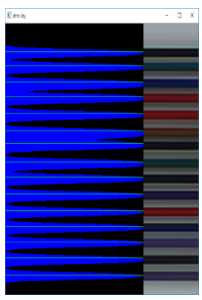


Figure 9. *Gray-level histogram of each wire.*

Where *R*, *G,* and *B* are the intensity value of Red, Green and Blue channel of original image respectively. The result is shown in Fig.5(b). The black and white image are obtained from the gray scale by using the global adaptive threshold (Otsu method) [10]. As shown in Fig.5(c). Using canny algorithm to detect edge of object. As shown in Fig.5(d). Then, using Hough Transform method [11] to detect the longer edges of connector part and utilize as the features of connector part to detect two peaks of longer edges. Then the tilt angle is calculated and then rotate original image to vertical direction. The result is shown in Fig.5(f).

Secondly, connector parts detection processing: The color image is converted to gray scale images. Then, the gray image is converted to black and white images using Threshold (Otsu method). The result is shown in Fig.5(g). The criterion for connector part detection is the number of connectivity pixel. The large region of the connected pixel is selected as the regions of cable connector part. The result is shown in Fig.5(h). Then the hole filling result is shown in Fig.5(i). According to the feature of height and width of connector parts, the authors can detect connector part exactly. The result is shown in Fig.5(j) and Fig.5(k).

Thirdly, extracting the wires region processing that is region very close to the connectors. Thus, effects due to bending or overlapping are reduced. As shown in Fig 5(l). And Fig 6.The similar processing are also applied for the test image.

3.2 Wires identification

Wires are distinguished from background based on their gray value. Due to the effects of uneven illumination, the noise and reflections in the other area are different. Therefore, the equalization processing is implemented. As it can be seen in that analysis, The authors use GaussianBlur and MedianBlur filter to smooth an original image. To be easy to observe and visualize by human vision, the image (3x290) pixel is resized to (200x500) pixel, as shown in Fig.7.The color image is then converted to grayscale image. The result is shown in Fig.8a. Then the gray image is converted to black and while image using Otsu method after using Normalize filter to improve the contrast of image. The results are shown in Fig 8(b) and Fig 8(c).The gray-level histogram of vertical scan lines of ROI image is shown in Fig. 9.As you can see, there is a wire at each peak of the gray-level histogram. By this way, the authors can correctly determine the single wire.

3.3 Color inspection

The most important thing the authors need to notice when extracting color is to minimize noise factor. In theory, noise factor usually appears while storing and transfering process. But in this case, source of the noise factor consists of two main reasons: first, the model is self-designing with half-closed box. Thus, the effect of natural environment is really strong.

Second, the limitations of this system are camera and lighting system. Because of the shortage of capital. The authors install a basic webcam which is cheaper than dedicated camera. Thus, the original image affected by noise is very strong. They can affect a high number of the pixels composing a wire. To cope with such high noise levels, it is necessary to develop an algorithm that is specific to the problem of wire color detection. All the steps will be described in detail in the following.

Firstly, the Gaussian filter with dimensions 9x9 pixels is applied as the pre-process in both images to smooth the intensity cause by the glare phenomenon. The result of gray conversion and filtered images is shown in Fig. 8a.

Secondly, the filtered image is then transformed into the Hue Saturation Value (HSV) color space. As explained before, the noise factor effects in random wires region, this often occurs because of the uneven illumination. Our solution is that each wire is not analyzed as a whole, but it is divided into horizontal bins. The size of bin is 1x1 pixel. So, the total number of bin is 200 on the wire region dimensions 200x500 pixels. This restricts the effect of noise to a small portion of the analyzed region. Each bin is analyzed into the H, S and V channels and the mean value of H, S and V channels of each wire is calculated and saved. The parameter of each wire will be saved into separated row. So the sample has 15 wires and the authors have 15 rows equivalently. The system uses this result to compare between sample image and test image.The similar processing are also applied for the test image.

3.4 Wire comparison

First, the system will compare the number of wires of test object with the reference. If thenumber of wires of test object is different from the reference, the system will show the result and the position of wires where is non-connected. Color wire inspection is triggered when the number of wires of the test image is equal to the number of wires of a sample image. Each wire in sample image and test image is compared in turn. The authors use the static threshold sets (L_Th_H, H_Th_H; L_Th_S, H_Th_S; L_Th_V, H_Th_V). Three Thresholds are defined:

$$\Delta H = |H_{sample} - H_{test}| \quad (2)$$

$$\Delta S = |S_{sample} - S_{test}| \quad (3)$$

$$\Delta V = |V_{sample} - V_{test}| \quad (4)$$

Two colors A and B, are assumed to be equivalent if their components satisfy at leasttwo out of three following criterion:

$$L\_Th_H \le \Delta H \le H\_Th_H \quad (5)$$

$$L\_Th_S \le \Delta S \le H\_Th_S \quad (6)$$

$$L\_Th_V \le \Delta V \le H\_Th_V \quad (7)$$

Wherein values of L_Th_H, H_Th_H; L_Th_S, H_Th_S; L_Th_V, H_Th_V are determined based on the experiment.

In theory, the authors need to compare only the value of H channel to evaluate whether the test wires are correct with the sample wires or not. Because each color in HSV color space has a different value of H channel, so the authors can use this feature to inspect. However, in our system, the disadvantage of hardware has much affected to the inspection process. So, the accuracy when using only value of H channel to determine whether two colors are equivalent is not reliable. That’s the reason why the authors use both value of S and V channel to compare.

3.5 Connector sequencing

In the production phase, the obverse and reverse of the connectors are appeared arbitrarily, i.e., the model A has four wires, labeled as: A={a,b,c,d}. If A appears in obverse, the label is A={a,b,c,d}. But if A appears in reverse, the label is A={d,c,b,a}. To cope with this problem, a connector sequencing algorithm was developed. Sequencing is performed by considering the wires of the model, and matching them in the sequence observed in the analyzed image. For example, the test object B have four wires, labeled as: B = {1,2,3,4}. The sequence will set “a” as a reference to the first wire of the image; the first wire of the test model is then compared with the reference, “a”. The comparison continues considering the following wires, that is: 1

will be compared to a, {2-b}, {3-c}, {4-d},..; Then, the reference is reversed, that is: 1 will be compared to d, {2-c}, {3-b}, {4-a},.. There are two cases are able to occur now: if A and B are the same, one of the two comparative cases is quite right, the GUI notifies the user with a clear message "No Data Error". If A and B are different, both of comparative cases are incorrect, the system will consider which one is less incorrect than the other, then show the result and the position of the incorrect wires.

4. EXPERIMENTAL RESULTS

The system takes about 4 months to design and finish, it has been tested in real connector. Tests involved several different connectors types and the number of wires ranging from 2 to 20, Cables used for this experiments were very popular in Vietnamese market.This system takes approximately 4 seconds to check and report the result.The system is evaluated by accuracy (ACC) and true positive rate (TPR) standard. This proposed method are described as follows:

$$ACC = \frac{TP + TN}{TP + TN + FP + FN} \quad (8)$$

$$TPR = \frac{TP}{TP + FN} \quad (9)$$

where *TP* is true positive, which is defined as the order of wires on products are correct compare with the reference and the system detected correctly. *TN* is true negative i.e., the products exist defect, and the failure is correctly classified by the system. *FP* is false positives and *FN* is false negatives, i.e., The order of colors on the product is correct but the system detects as the failure and the last case happens when the inspection system does not recognize a defect and classifies the part as good, while a defect is actually present. The algorithm was tested on 150 positive samples and 150 negative samples of every 5-wire connector type, 15-wire connector type, and 20-connector type. Results obtained during the testing phase in terms of TP and TN are summarized in Table I, while in Table II the values of accuracy and and true positive rate are reported. The accuracy is sensitive to lighting condition because the half-closed box is used in these experiments. The background color and the glare of image strongly affected to the final results.

Table 1. *True positive(TP) and True Negatives(TN) over the total number of analyzed connectors.*

	TP	TN
5-wire connector	146	144
15-wire connector	141	137
20-wire connector	138	132
Total	150	150

Table 2. *System performance evaluation using ACC and TPR.*

	ACC	TPR
5-wire connector	96.66%	97.33%
15-wire connector	92.66%	94%
20-wireconnector	90%	92%

5. CONCLUSION

A system for automatic visual inspection for colored wires connector cables was presented in this paper. Cardinal factors affecting the productivity of automated inspection system are discussed and related to the literature in the field. The proposed method and experiments showed that even the connector parts are appeared arbitrarily in the working plane but the detection of connector parts, rectification and image alignment can transform the images to standard form correctly for the further processes. The system can deal with the typical situations of a real-world scenario: wires that overlap and wires made of different materials. Illumination issues like highlights and shadows are also handled. The other advantage of this proposed method is the robustness of wire position detection and wire patches extraction even that the cable wires are displacement and deformable in the real experiments. The accuracy of the proposed method is high even the experiments were carried out on the different type of connector cables under different lighting condition affected to product in the half-closed box.

The main sources of error come from two main factors: strong noise on the observed wires, which make it almost impossible to determine the wire color precisely, and uneven illumination conditions. These problems could be solved if the hardware were more professional,i.e., installing filtering lenses into camera can acquired the image which can avoid the glare of wires. Moreover, the resolution of acquired image is also better.

In order to carry out to the real application, the system should be decreased time consuming for processing. The sources of time consuming come from two main factors: the processing time for detect connector part and color analysis. The authors proposed two methods to solve this problem. First, hardware should be designed more professional with saturated lighting system, dedicated camera,...The acquired imagewould bemore resolution and minimize noise factors from natural environment. Thus, the authors can rapidly get the result without preprocessing steps. Second, designing an automatic system toinsert cables into a workspace. By this way, the connector parts is appeared at the same position in the working plane. So the authors don't need to detect connector parts before analyzing the color.

The limitations in the current system are that it can't work with electric wires have a color very similar to the background. The proposed method is replacing the background color by the other bright color which is different from products color.

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Corresponding author:
Le Quoc Nhat
Ho Chi Minh City University of Technology and Education
Email: quocnhatute@gmail.com