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READING RESISTOR BASED ON IMAGE PROCESSING

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Abstract:

Based on a set of image processing techniques, an automatic approach for reading resistance of a carbon film or metal film resistor through its color bands is presented. Light source is investigated and light condition under controlled is recommended to help the extraction and identification of color bands. Resistor can be put at any orientation for recognition. Given a resistor image, the proposed approach is mainly composed of segmentation and horizontal alignment of resistor's body, extraction of color bands, as well as classification and identification of color bands. Verification of flipping over sequence of extracted color bands is also involved in our approach. K-Nearest Neighbor (K-NN) classification is used to train and classify both main body color and extracted band's colors. The correctness of extracting and counting color bands is 96%. Correctness of reading resistor value is 92%. The results confirm the feasibility of the proposed approach.

Keywords:

Color classification and identification; Image Processing, Resistorimage; Segmentation; Thresholding.

1. Introduction

Resistors are used frequently in the commercial products of electrical, electronic, and computer related fields. Color bands printed with twelve possible colors on carbon film or metal film resistors are used to represent the resistance. For a color-blindness [1,2] or non-professional person, it is very hard to read the resistor's value. It is worthy of studying from the academic and real application viewpoints even researches on resistor recognition based on image processing are rather rare.

Previous methodsfor reading resistor by image processingcan be found in[3-5]. The successfulness of recognizing a resistor depends however strongly onthe light source since it may result in unavoidable refection on the resistor surface, which will influence thedepicted information of the color bands. Carbon filmand metal film resistor have highly specular reflectivesurface which is unfavorable to image processing andcolor recognition. Resistor images (called R-image) taken without lightcontrol usually have severe non-uniform luminous intensity on image and make it more difficult for processingand higher error rate in recognition. In [4], specularreflection example happens to be located on resistor lateral side that is not the area for color bands recognition. Problem arises and may fail to recognize color ifspecular reflection zone is located on the extracted colorband area. Specular reflection on resistor image will increase processing complexity and cause erroneous resultnot only for color recognition but also for color bands extraction. Hence, in this study the first step is to developa simple but helpful method for setting up the light source which willmake an image based approach effective to recognize a4-band or 5-band resistor.

TABLE1. Mapping of color code, multiplier, and tolerance for resistor color band.

Color	C_1	C_2	C_3	M	τ
Black		0	0	10^0	
Brown	1	1	1	10^1	1%
Red	2	2	2	10^2	2%
Orange	3	3	3	10^3	
Yellow	4	4	4	10^4	
Green	5	5	5	10^5	0.5%
Blue	6	6	6	10^6	0.25%
Violet	7	7	7	10^7	0.1%
Gray	8	8	8		0.05%
White	9	9	9		
Gold			10	10^{-1}	5%
Silver			11	10^{-2}	10%

Based on the general rules of reading resistor value, the resistance of R_4 (4-band) or R_5 (5-band) resistor may be obtained respectively by the following expressions, where C_i, M, and τ denote the i-th color code, multiplier, and tolerance, respectively. Consider a 4-band resistor is aligned horizontally on the table and the colored band of tolerance is at right, the sequence of four colored bands from left to right is C_1, C_2, M, and τ. The often used mapping table may

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belisted in Table 1.

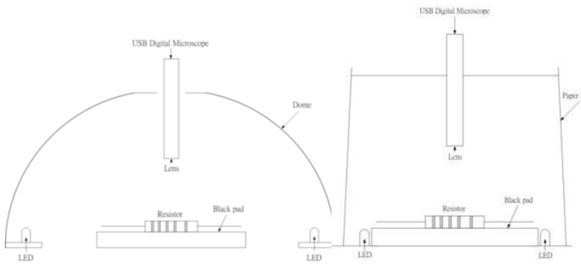
$$R_4 = (\sum_{i=1}^{2} C_i \times 10^{2-i}) \times M \pm \tau \quad (1)$$

$$R_5 = (\sum_{i=1}^{3} C_i \times 10^{3-i}) \times M \pm \tau \quad (2)$$

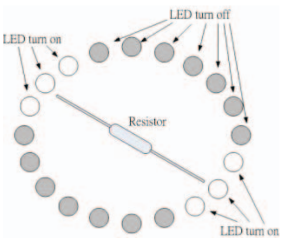
Except for the light source hardware setup to providea better environment for R-image acquisition, from the viewpoint of image processing thereare four main processing steps, namely resistor orientation adjustment, resistor segmentation, color bands thresholding and extraction, as well as recognition of color bands,to be developed for correctly converting the color bandsinto the color codes and then calculate the resistance using (1) or (2). To achieve this purpose,the main key is to have a good thresholding strategy inthe proposed approach since the processed R-image has been influenced more or less by the light sourceand the threshoding result will be further used on the segmentation of resistor's body, thedetection of resistor orientation, and the extraction of color bands. In accordance with the local variance property of illuminated image like the considered$R$-image, a thresholding method based on the localmean and the standard deviation like Niblacks method[6] is suitable for our application. Therefore a thresholding formula (called Yung-Jeng formula, or T_{YJ} in this paper) modified from Niblack [6, 7] and NICKalgorithms [8] will be presented and evaluated in this study.

2. Light Source and Resistor Acquisition

A CMOS digital microscope having200 million pixels with USB protocol is used to capture R-image, where 640×480 resolution is used. Controlling light illumination onto the resistor can reduce specular reflection from the surface of resistor body. Several types of diffuse light have been developed to solve specular reflection problem on glare, shining or specular surface object [9, 10]. We compared the effects of resistor illuminated by coaxial diffuse light, low angle ring diffuse light, dome diffuse light, paper cup (or box) diffuse light; and thus finally built an R-image acquisition device as depicted in Fig. 1(a) and 1(b). Coaxial diffuse light produces fewer halos but may produce uneven luminous intensity and reflection between two lateral sides as Fig. 1(d) shows. Low angle diffuse light will produce a strong halo ring as Fig. 1(e) shows. With smaller radius of dome diffuse light, halo also appears on the surface of R-image as Fig. 1(f) displays. Consider the cost effectiveness and better results, as depicted in Fig. 1(b) we developed a cheapest way by paper cup or paper box pasted inside with white paper to reduce the effects of specular reflection and halo asillustrated in Fig. 1(g) and 1(h). In addition, the controllable mechanism of LED lighting is also involved in this device as depicted in Fig. 1(c). The LED ring can be controlled to be a partial lighting with the paired LED on close to the longitudinal axis of resistor as exemplified in Fig. 1(i), which is determined by the detection of resistor orientation and will bepresented in next section.



(a) (b)



(c)

(d) (e) (f)

(g) (h) (i)

FIGURE 1. Schematic setup of R-imageacquisitionby (a) a commercialdome diffuse light source, and (b) self-made light source with paper cup.(c) Controllable LED lighting mechanism. (d-f) Halo phenomenon exists around the surface of resistor. (g,h) Halo effect has been suppressed by the proposed lighting source. (i) The resistor is illuminated by switchingon the paired LED.

3. Proposed Approach

3.1. Segmentation of resistor's body

Consider the inherent characteristics of R-image and based on the algorithms from Niblack [6, 7] and NICKalgorithms [8], a modifiedthresholding formula, calledT_{YJ}, is presented as follows to get better results for the segmentation of resistor's body and its color bands.

$$T_{YJ} = m + k\sqrt{j\sum_{\forall i}\left(\frac{p_i^2}{n}\right)} \tag{3}$$

Where m is the local sample mean, p_i denotes the i-th pixel intensity, n is the total number of pixels, $k$represents the Niblack deviation factor, and j is the newly defined factor.Usually k-factor is set heuristically in the range between 0.1 and 0.2, whereas j-factor is adjusted to get a better result not only for thresholding but also for noise suppression compared to the known methods.Based on our investigation presented in Section 4.1, j = 6 is selected in this study.Fig. 2(a) illustrates the result from the gray R-image ofFig. 1(i), in this processing stage all LED are switched on.

(a) (b) (c)

FIGURE 2.(a) Segmentation of resistor's body. (b) Convex hull result. (c) Horizontal alignment.

3.2. Horizontal alignment of resistor's body

After thresholding the gray R-image into a binary image (**B**), a median filter is used to remove noise and convexhull is used to maintain the main regions of resistor's body before finding itsorientationas Fig. 2(b) shows. If the resistor's body in **B** presents only one region, then its angle θcan be obtained by finding the line passing through the region center of mass about the lowest moment of inertia. Let A be theregion's area, the angleθmay be expressed as follows.

$$\theta = \frac{1}{2}\tan^{-1}\left(\frac{2M_{xy}}{M_{xx}-M_{yy}}\right) \tag{4}$$

$$\text{where } M_{xy} = \sum_{\forall i} x_i y_i - \frac{\sum_{\forall i} x_i \sum_{\forall i} y_i}{A},$$

$$M_{xx} = \sum_{\forall i} x_i^2 - \frac{(\sum_{\forall i} x_i)^2}{A} \text{and} M_{yy} = \sum_{\forall i} y_i^2 - \frac{(\sum_{\forall i} y_i)^2}{A}.$$

If the resistor's body in **B** consists of several regions, the union of all regions can be adopted and computed by (4) to obtain the orientation θ.The detected orientation of resistor can trigger the paired LEDon from both ends of resistor to fulfill the light projection as recommended in [3]. All the LED are switched oninitially,after the detection of resistor's orientation the paired LED at both ends of the resistor are kept lighting and others are switched off as illustrated in Fig. 1(c). Based on the detected orientation, Fig. 1(i) shows the result illuminated by switching on the paired LED, and its horizontal alignment result can be obtained as Fig. 2(c) displays.

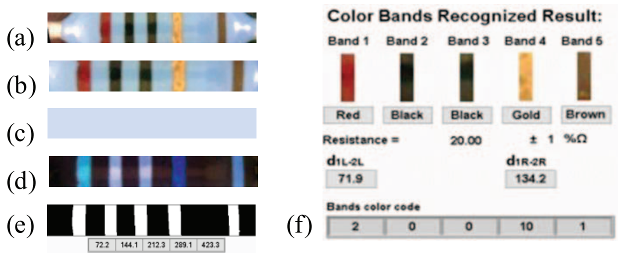


FIGURE 3. Resistor main bodyregion confined by (a)y-range, and further by (b)x-range. (c) Main body color. (d)The absolutely differencing image between (b) and (c).(e) The extracted five color bands. (f) The obtained resistance20 $\pm$ 1%Ω.

3.3. Extraction of color bands

Resistor main body can be furtherconfined to a limited range since only the color bands are necessary for recognition. The confining process includes two steps. First, based on the centroid horizontal line of the resistor its height can be confined within a limited y-range, e.g. ±35 pixels, as Fig. 3(a) shows.Then based on its gray image and after noise removal process, find the most-left and most-right x-coordinate of gray level changing at top border $[x_{tl}, x_{tr}]$ and bottom border $[x_{bl}, x_{br}]$. Then the confined x-range of left border and right border is defined by max (x_{tl}, x_{bl}) and $\min(x_{tr}, x_{br})$, respectivelyas Fig. 3(b) displays. The resistor main body color as shown in Fig. 3(c) can be obtained by averaging the four corner's colors in Fig. 3(b) as the schemeused in [4]. Fig. 3(d) shows the absolutely differencing image between Fig. 3(b) and 3(c). After gray conversion and image thresholding (T_{YJ}), all five color bands of the resistor can be extracted as Fig. 3(e) shows.

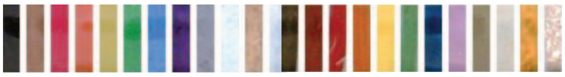


FIGURE 4. Color bands with 18×70 pixels extracted from (a) 4-band, and (b) 5-band resistors.

To recognize a resistor belonging to 4-band or 5-band, except for directly counting the color bands in thresholding result as given in Fig. 3(e) it may also be determined by the classified main body color as given in Fig. 3(c). In usual, the main body color of a resistor between 4-band and 5-band is rather different. Further, based on the thresholding result and the confined region, the color bands can be extracted with the size of 18×70 in this study. Figure 4 shows some color bands extracted from 4-band and 5-band resistors, which will be used as samples for color training and identifying.

3.4. Color classification and identification

There are 12 possible colors used for color bands on resistor to represent its resistance. In this study, they are sampled and trained with different illuminations under commercial dome and self-made diffuse light sources. Because some color bands with the same color name are more or less different in 4-band and 5-band, some colors in 5-band may be similar to the different colors in 4-band, e.g. silver color in 5-band resistor displayed in Fig. 5(a) is similar to gold color in 4-band resistor displayed in Fig. 5(b). To avoid color classifier being confused by similarity of different color between 4-band and 5-band, two training databases are built to reduce color misclassified.

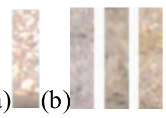


FIGURE 5. (a) Silver color in 5-band resistor is similar to (b) gold color in 4-band resistor.

In this study, color feature is obtained from HSL color space, and K-Nearest Neighbor (K-NN) classification is used to train and classify colors. K=1 is used in this work. When band's color is added to the color classifier during the training phase, the classifier calculates color feature and assigns the associated class label to the feature. Then it classifies regions in extracted band's image into their corresponding classes for color identification. Note here that the color of resistor image is usually influenced by illumination variation, thus luminous intensity component is ignored in our classification system to increase the robustness of color bands recognition. This process is also applied to the classification of main body color corresponding to the number of color bands.

After color bands for a resistor are identified, the corresponding color codes can be obtained based on the mapping in Table 1, and its resistance can be obtained by (1) or (2) for R_4 and R_5, respectively. However because the reading sequence of color codes is usually from left to right, the color bands should be examined previously based on the obtained horizontal alignment. From Table 1, some characteristics can be observed as follows. For 4-band resistors, the *tolerance* band is only represented by gold or silver color. For 5-band resistors, the *tolerance* band may be represented by other colors, e.g. brown, red, green, blue, violet, and gray colors; and the *multiplier* may also be represented by gold or silver color. If one of the following criteria satisfies, the sequence of color codes should be flipped over.

(1) The color band on the most-left end or the second left is recognized as gold or silver colors.
(2) For 5-band resistor, we found that the distance between multiplier band and tolerance band is usually greater than that between any two adjacent color bands. Therefore, we define d_l and d_r to be the distance between the most-left two-neighboring color bands and that between the most-right two-neighboring color bands, respectively. In normal case, $d_l < d_r$. In 5-band resistor, the criterion (1) is checked first. If it is not flipped over, we need further check the criterion (2). If $d_l > d_r$, then the sequence of color codes should be flipped over.

Fig. 3(f) illustrates the final resistance is correctly obtained as $20 \pm 1\%\Omega$.

TABLE 2. Data analysis of *j*-factor used in our thresholding method by the investigation of a brown-blue-black-gold resistor.

j	S	N	S/N
0.5	11143	3155	3.53
0.7	11124	2667	4.17
0.9	11103	2330	4.77
1.2	11088	1984	5.59
1.5	11074	1914	5.79
2.0	11015	1695	6.50
3.0	10943	1560	7.02
4.0	10903	1409	7.74
5.0	10882	1156	9.41
6.0	10847	935	11.60
7.0	9811	841	11.67
8.0	9642	779	12.38
9.0	9448	765	12.35

4. Analyses and Experimental Results

4.1. Analysis of *j*-factor

The modified thresholding formula (3) is used in segmentation of not only resistor's body for detecting orientation (phase 1) but also color bands for color classification and identification (phase 2). At phase 1, *j*-factor can be set at a wide range [0.1, 6] or even more due to the adoption of median filtering and convex hull processing. At phase 2, the *j*-factor is determined by the investigation of signal-to-noise (S/N) ratio since the correctness of color band extraction is of great importance to the color code conversion. Let S and N denote the number of pixels in color bands, and that of noisy pixels in non-color-band region, respectively. Consider a resistor having brown, blue, black, gold color bands for evaluation, some data of the *j*-factor with respect to S/N relationship are listed in Table 2. It suggests that j=6, where S/N starts at a stable high mark. This value supports a good thresholding result in our current system.

4.2. Analysis of thresholding methods

Since the presented thresholding method is modified from the methods of Niblack [6, 7] and NICK [8] and a key component in our system, it is worthy of providing an evaluation to confirm it. The resistor having brown, blue, black, gold color bands used in the *j*-factor evaluation of Table 2 is also taken here for the comparison as listed in Table 3. The result shows that the modified method can get more enough information and reduce the noise than other methods for thresholding color bands.

TABLE3. Comparison of thresholding methods with the brown-blue-black-gold resistor.

Methods	S	N	S/N
Niblack [6, 7]	11152	3213	3.47
NICK [8]	11092	2098	5.29
Proposed	10847	935	11.60

4.3. Results and discussions

In our experiments, we took individually 859 4-band and 854 5-band resistors for training as mentioned in Section 3.4, and 146 main body colors for identifying number of color bands from dome diffuse lightas well as paper cup (box) diffuse light. In addition, 50 resistor images captured lively from our microscope are used to evaluate the performance of reading their resistances. The experimental images cover all the possible twelve colors used in resistors. The automatically horizontal adjustment of *R*-image and the segmentation of resistor main body can achieve 100% correctness. The correctness of extracting and counting color bands is 96%, whereas the correctness of reading resistance is 92%. Compared to the other methods, the good performance by the proposed approach is achieved due to the improved controllable light source and thresholding scheme. In our examination,we observed that errors usually happened at the color misclassification of main body and/or extracted bands. This provides us a definite direction to improve the current system and evenfurther realize a useful system for practical application in the near future.

5. Conclusions

An automatic approach based on image processing techniques is presented in this paper for reading resistor value. To solve the problems of specular reflection and halo on resistor surface when resistor image is being captured, an inexpensively controllable light source is developed. A modified thresholding method is adopted for segmentation of resistor body and its color bands, which is further helpful for the color band classification and identification.The proposed approach can read effectively not only 4-band but also 5-band resistors with any orientation. Experimental resultshaveconfirmed the feasibility of the proposed approach.

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