Machine Vision for Quality Inspection of Cotton in the Textile Industry

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Abstract

Application of machine vision for quality inspection of cotton in the textile industry is proposed. This quality inspection, or automated visual inspection of cotton can be done by the analysis of a cotton image. The analysis involves color discrimination between cotton and impurities. Colors can be quantitatively described by color coordinates. Generally, human observers cannot discriminate between two colors if they can be described within an isodiscrimination contour. To inspect the quality of cotton, the image will be analyzed for impurities using this isodiscrimination contour. The issues of signal processing and illuminations will also be discussed. These factors can contribute to errors in the inspection system. Also, a method for significantly improving speed of image processing will be mentioned.

1. Introduction

Applications of automated visual inspection of color images have been limited by several factors for use in industry. Those factors are hardware complexity, high cost, large memory requirements and long processing time [1,2]. Automated visual inspection of a cotton quality can be done by analysis of cotton image. Impurities should be separated from cotton before being processed to the final product. The analysis involves color discrimination between cotton and impurities. Colors can be quantitatively described by color coordinates. Criterion for color discrimination or identifying impurities will be based on the Commission Internationale de l'Eclairage (CIE) standard. Then CIE-Luv color coordinates will be used.

2. Identifying Impurities

The automated visual inspection system of cotton quality consists of a color video camera and an image acquisition board working within a personal computer (PC). The color camera transfers the color video signals to the image acquisition board. This board provides conversion of images to an RGB format. We apply a CIE-Luv criterion, which is based on the perception that a human observer cannot discriminate between two colors if they can be described within the isodiscrimination contour. Firstly, the qualitative description of color in RGB and CIE-Luv coordinates will be discussed. Secondly, the fundamentals of CIE-Luv isodiscrimination contour will be calculated for the inspection of cotton quality. Finally, a lookup table of cotton color will create an isodiscrimination contour for cotton color identification.

2.1 Color representation

One of the popular color coordinates for computer applications is the RGB coordinate. However, an Euclidean distance in this coordinate cannot be used for color comparison, while the distance in the CIE-Luv coordinate can [3]. The RGB to Luv transformation can be expressed as [3-4]

$$L = \begin{cases} 116(\frac{Y}{Y_n})^{1/3} - 16 & (\frac{Y}{Y_n}) > 0.008856 \\ 903.3(\frac{Y}{Y_n}) & (\frac{Y}{Y_n}) > 0.008856 \end{cases} , \quad (1)$$

$$u = 13L(\frac{4X}{X + 15Y + 3Z} - \frac{4X_n}{X_n + 15Y_n + 3Z_n}), \quad (2)$$

$$v = 13L(\frac{9Y}{X + 15Y + 3Z} - \frac{9Y_n}{X_n + 15Y_n + 3Z_n}), \quad (3)$$

where X_n, Y_n, and Z_n are constants of values 0.9504, 1.0, and 1.09, respectively [3-4]. The definition of X, Y, and Z can be described by

$$X = 0.4306 * R + 0.3415 * G + 0.1784 * B, \quad (4)$$

$$Y = 0.2220 * R + 0.7067 * G + 0.0713 * B, \quad (5)$$

$$Z = 0.0202 * R + 0.1295 * G + 0.9394 * B, \quad (6)$$

where R, G, and B are values of red, green, and blue, respectively, in the RGB coordinate. Each prime color (R, G, or B) has 256 different values (ranging from 0 to 255) or 2^8 and can be represented by 8 bits of binary data in the computer. The 24-bit (three 8-bit representations of R, G, and B) RGB color coordinate will be used for our system. Color images of inspected cotton, consisting of piece (s) of cotton and background, are transferred to a PC. Then, color of each image pixel will be processed and identified whether it is cotton, impurities, or background color.

2.2 Criterion for the Same Color: Isodiscrimination Contour

The Euclidean distance of two colors (between reference and measured color) in CIE-Luv coordinate is given by

$$\Delta E_{Luv} = \sqrt{(\Delta L)^2 + (\Delta u)^2 + (\Delta v)^2}, \quad (7)$$

where Δ quantities on the right hand side of the equation represent differences between the corresponding coordinates of the two colors. For color comparison, if the value of the Euclidean distance in the CIE-Luv coordinate, which was shown experimentally for color discrimination of human perception, is 3, two colors can be reliably discerned by a human observer. We can generate CIE-Luv values, within the threshold distance of 3, into a lookup table (LUT). It is also known as an isodiscrimination contour. The identifying impurities can be done by comparing the color of each pixel (in RGB coordinate) to all possible colors of cotton in the lookup table. If the color of the pixel is not in the lookup table, it is determined as impurities. Therefore, the greater the number of RGB values in the lookup table, the more accurate the identifying; but the longer the processing time.

For example, calculation of the lookup table can be done as follows:

I A color with RGB coordinates of R=255,G=249, and B=255 or (255,249,255) is chosen as cotton color because its the most frequently occurring cotton color.

II. Transformation of RGB to CIE-Luv coordinate. Substitute R=255, G=249, and B=255 in equations (4), (5), and (6) to obtain the value of X, Y, and Z. Then, applying the values of X, Y, and Z in equations (1), (2), and (3) results in L=99.35, u=1.42, v=-1.71, respectively.

III. The Euclidean distance (ΔE_{Luv} < 3) results in the isodiscrimination contour shown below
Ranges of L, u, and v are as follows:
L is between 96.35 and 102.35, u is between −1.58 and 4.44, and v is between −4.71 and -1.29, respectively.

IV. Values of the CIE-Luv coordinate satisfying III and equation (7) will be converted to values of corresponding RGB coordinates. These values will be in the lookup table used for recognition of color of cotton of the automated inspection system. Calculate the valid Euclidean distance among the range of L, u, and v by varying the increment of 0.5.

V. After the isodiscrimination contour in the CIE-Luv lookup table is prepared, conversion to RGB (the format used in color comparison of the system) lookup table.

VI. Transformation from the CIE-Luv to the RGB coordinate, the format obtained form the image acquisition board, can be done as follows:

First, CIE-Luv can be converted to XYZ coordinate by equations (1), (2), and (3). Then, XYZ can be transformed to the RGB coordinate by following relations:

$$R = 3.0633 * X - 1.3933 * Y - 0.4758 * Z, \quad (8)$$

$$G = -0.9692 * X + 1.8760 * Y - 0.0416 * Z, \quad (9)$$

$$B = 0.0679 * X - 0.2288 * Y - 1.0693 * Z. \quad (10)$$

VII. There are 450 different values in the final RGB lookup table. These numbers affect signal processing speed and accuracy of identifying impurities.

3. Implementation and Results

Automated visual inspection shown in Fig. 1 consists of a color video camera, an image acquisition board working within a PC, and a lighting system. The cotton is illuminated by daylight (D65- one of standard light sources used by CIE) lamps inside controlled environment because illumination or color of the light source affects apparent cotton color. Image acquisition board converts color signals from the video camera to the RGB format and then the computer identifies impurities in cotton by color discrimination between cotton and impurities using the isodiscrimination contour mentioned earlier. Cotton with high impurities will be rejected and put in a collecting bin by a rejection mechanism such as a separation flap shown in Fig. 1.

Images captured from cotton in motion (under illumination controlled environment) as shown in Fig. 1 are in 24-bit RGB format. Each image contains 180 by 126 pixels and occupies 16 by 11.25 centimeters in length and width, respectively. The resolution of each pixel is 0.089 cm (16 cms/180 pixels). Image analysis includes edge detection and finding the area of cotton and identifying impurities. Fig. 2-a shows image of cotton at the center surrounded by background (dark color). We use purple as our background color to be easily distinguishable from color of cotton and impurities such as loose threads, plastics, cottonseeds, leaves, *etc.* Impurities are to the right of the center of the image.

The threshold size of impurities is set to 0.1 cm^2 or 13 square pixels, calculated from $0.1cm^2/[(0.089\ cm)^2$ for 1 square pixel]. A spot of impurity is defined as at least 13 pixels connected together (one pixel can be connected to eight possible adjacent pixels). If it is less than 13 pixels and the color is not background, the spot is regarded as noise (too small a size for a spot of impurity). Cotton is identified and assigned black color in Fig. 2-b. Background and impurities are assigned different colors (purple and white, respectively) but are shown in white color in Fig. 2-b. To identify cotton color a 24-bit RGB lookup table is used. A better method for color identification is using a 3-dimensional lookup table (3D-LUT) array to identify cotton color. The LUT is a block of random access memory (RAM) whose address inputs are corresponding to three independent coordinates of red (R), green (G), and blue (B) [1]. In the memory array, a three dimensional area of 450 values (in isodiscrimination contour) can be defined by setting the contents to logic 1. The remaining locations within the 'color cube' are set to 0. Using RGB coordinates in LUT would result in a very large 'color cube' (256*256*256 bytes or 16 Megabytes of memory).

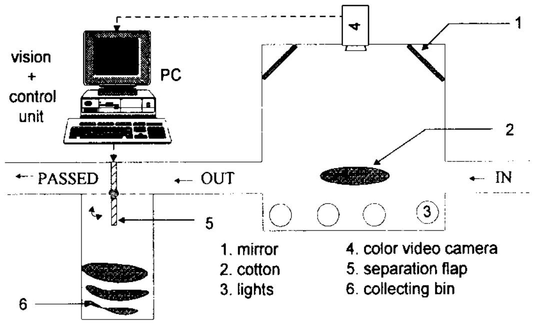
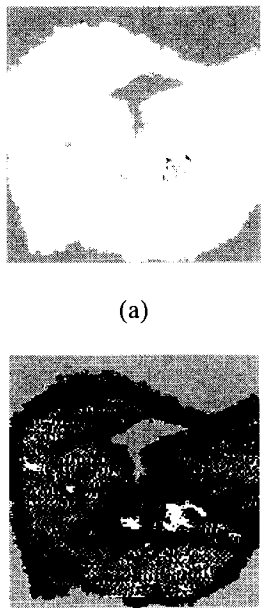


Fig.1 Experimental setup



(b)

Fig. 2 Cotton image (a) before and (b) after identifying impurities using color isodiscrimination contour.

We observe the range of values in the original lookup table and come up with the minimum threshold of each color coordinate. From these values, we design an equally accurate but smaller lookup table which results in a smaller memory array of 15,625 bytes (25*25*25 bytes). The speed of image processing is greatly improved and memory requirement is greatly reduced.

4. Discussions

Fig. 2-b shows a satisfactory result. Because the image in Fig. 2 (a) was captured from the controlled environment (see Fig. 1) with a constant white (D65) light source, the image is sharp, good quality and noise is assumed to be negligible. Thus, no noise removal schemes are required [5].

However, some scattered white points [see Fig. 2 (b)] in cotton indicate that some of the cotton values are not in the lookup table, which may result from a relatively large increment size of 0.5 of the isodiscrimination contour and some shadows because the cotton surface is not flat. Some factors contributing to errors in the inspection system are:

I. lighting system includes illumination, brightness, and color spectrum of light source.

II. number of elements in 3D-LUT involves Euclidean distance and Luv step increment for generating isodiscrimination contour. There is trade-off between accuracy and processing time. The optimum number of elements is 450, a Euclidean distance of 3 and Luv step increment of 0.5.

III. resolution or size of each pixel in the image

IV. types of impurities such as color, surface reflectance, and size.

V. video camera setting such as exposure control, f-stop, and frame rate.

Processing time for the 3D-LUT method is less than 100 ms with a Pentium 200 MHz and can be improved by using a faster CPU (now Pentium IV 1.4 GHz is available) or using an LUT of less than 450 values, which can affect accuracy of analysis. The optimum number of values in LUT versus the accuracy of analysis should be further investigated.

5. Conclusions

The automated visual inspection of cotton quality makes use of color isodiscrimination contour criterion. The important factors for color image processing are the lighting system (under controlled environment), the video camera setting, and image processing algorithms such as edge detection and reduced 3D-LUT technique.

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