Research on design and implementation of high precision imaging colorimeter system

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Abstract. As an important parameter to characterize the apparent characteristics of objects, color plays an irreplaceable role in various fields. With the increasing demand for color quality, special color detection instruments are needed to measure color quickly and accurately. However, the current traditional color measuring instrument has some limitations, it is difficult to accurately measure the color of a certain part of the complex pattern, and it is very easy to miss the image information of the object surface.With the continuous development of machine vision technology and spectrum technology, hyperspectral imaging technology came into being. The advantage over traditional color detection instruments is that hyperspectral imaging technology obtains spectral and spatial information at the same time, so as to achieve accurate color detection.In this paper, machine vision technology and hyperspectral imaging technology are applied to the field of color measurement, and a high precision imaging colorimeter system is designed and developed. Compared with the traditional three-channel color detection instrument, the system has more spectral information carried by hyperspectrum, so it can more accurately restore the true color of the item, so as to achieve high-precision color detection.

Keywords: Machine Vision, Color Detection, Hyperspectral imaging technology, High precision imaging colorimeter.

1. Introduction

The traditional color measuring instrument is divided into photoelectric integrating measuring instrument and spectrometer measuring instrument. Compared with the photoelectric integrating color meter, the spectral color measuring instrument has higher measurement stability and accuracy [1]. Through computer processing of color data, spectral information obtained by spectral color measuring instrument can be extracted and analyzed more accurately, so as to realize color quantification. However, these two instruments have some limitations in the measurement process, that is, the measurement object must have a certain area and uniform color [2]. In some complex color scenes, it is difficult to accurately measure the color of a certain part of the pattern, and the image information of the object surface may be missing. Hyperspectral imaging technology has the characteristics of high spatial resolution and high spectral resolution, and it has been widely used in agriculture, geological detection, food detection and other fields [3-5], but its application in the field of color detection is relatively limited. The core of hyperspectral technology used in this research is to use imaging technology to conduct high-resolution spatial imaging of the target object, while using spectral technology to conduct dispersion imaging of each spatial pixel to generate hundreds of narrow bands to form continuous spectral coverage [6] to obtain spatial and spectral information at the same time, so as to achieve accurate color detection. Through computer processing and analysis of hyperspectral imaging data, the color values of high-resolution images can be accurately measured to meet the needs of high-precision color detection. Therefore, the application of computer technology and hyperspectral imaging technology in the field of color measurement is expected to overcome the limitations of traditional color measurement instruments, and provide more accurate and reliable color measurement solutions for various industries.

2. Design and implementation of system

2.1. Hardware system design

The high-precision imaging colorimeter system is composed of computer, optical camera, driving motor, mobile stage and light source. The overall structure of the system is shown in Figure1.

When the system is operational, the light source remains fixed in front of the moving platform, while the items to be measured are placed flat on the load displacement platform. The computer transmits instructions via serial communication to control the drive motor, which in turn regulates horizontal displacement of both the load displacement table and the items being measured. Simultaneously, instructions are sent to an optical camera by the computer to adjust its frequency for capturing a uniformly illuminated area ahead, ensuring even imaging of test objects. The acquired images are subsequently transmitted back to the computer through a data line for further analysis and calculation, resulting in obtaining an accurate representation of tested items; employing a color difference testing algorithm enables identification of any color defects.

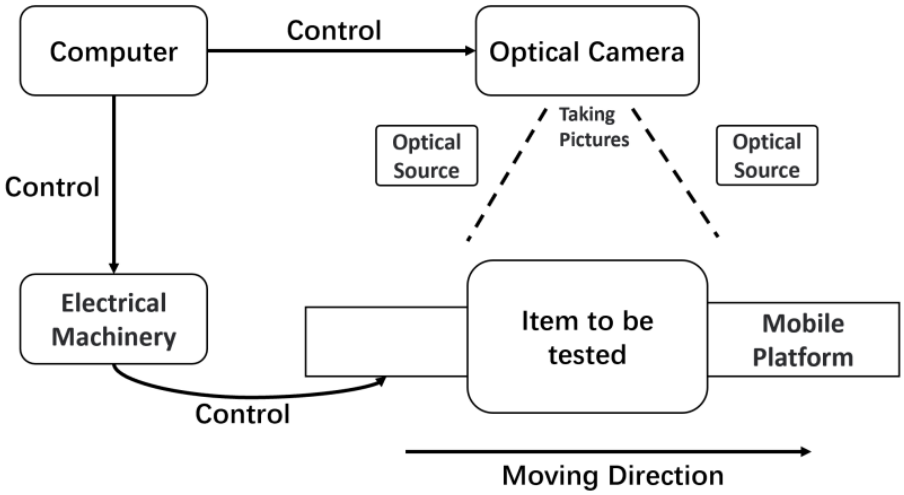


Figure 1. Hardware system overall structure diagram.

The construction of the hardware system entails the meticulous selection of various components. Following thorough comparison and investigation, the CCD detector with superior image resolution, dynamic sensitivity, reduced imaging noise, and enhanced image quality has been chosen for camera selection in this study. Regarding drive motor selection, a closed-loop control element known as the servo motor has been selected. Through its feedback mechanism, the servo motor can monitor and adjust the actual position and speed of the motor as required to achieve optimal speed response, smoothness, and control accuracy that perfectly aligns with the system's performance requirements. As for light source selection, after investigating commonly used light sources in current color measuring instruments such as LED lamps, fluorescent lamps, and halogen lamps; LED lamps have ultimately been chosen due to their high energy efficiency which ensures a stable and consistent optical environment while minimizing fraudulence and providing an extended service life.

2.2. Software system design

The software system consists of four components: the drive motor control module, the optical camera control module, the image shooting module, and the image processing module.

2.2.1. Drive motor control module

This module is utilized for controlling the drive motor to achieve various functions such as setting motion speed, acceleration, distance, and other parameters. As this system employs Googo GSHD-0062AEC-LTLM servo motor, communication is carried out using MODBUS protocol; hence corresponding functions are encapsulated in the serial package.

2.2.2. Optical camera control module

The purpose of this module is to regulate the optical camera by performing tasks like parameter configuration, image capture, and transmission. Allied Vision Prosilica GT 1920 camera is employed in this system. The company provides Vimba SDK development kit that supports multiple programming languages enabling users to easily and effectively manage camera controls. Image acquisition can be categorized into synchronous acquisition mode or asynchronous acquisition mode; however, this paper adopts asynchronous acquisition mode.

2.2.3. Image shooting module

The image shooting module serves as a unified control unit for both driving the motor and operating the optical camera. By considering push-sweep imaging principle [7], coordinated operations between the motor and camera are planned so that successful acquisition of item images for testing purposes can be achieved within the entire system.

2.2.4. Image processing module

The responsibility of this component lies in processing images obtained from the image shooting module. After conducting optical calibration on experimental environment and instruments, a series of image processing operations including denoising, synthesis, registration[8], color space conversion calculation of color differences etc.

In the step of image reflectance calculation, the reflectance data of the object is obtained by using whiteboard and blackboard calibration. The calculation formula is:

$$\mathrm{R} = \frac{\mathrm{R_0 - B}}{\mathrm{W - B}} \tag{1}$$

Where R0 is the measurement data of the item, B is the measurement data of the dark image (blackboard), and W is the measurement data of the white reference image (whiteboard).

In the image registration step, the synthesized image is registered with the standard template image to achieve spatial consistency and facilitate the subsequent series of calculations [9-10].

The color space conversion converts the calculated reflectivity matrix into the Lab matrix according to the optical formula [11-12]. The optical formula is as follows:

$$\begin{cases} L = 116f(Y/Y_0) - 16 \\ a = 500[f(X/X_0) - f(Y/Y_0)] \\ b = 200[f(Y/Y_0) - f(Z/Z_0)] \end{cases} \tag{2}$$

Formula,

$$\mathrm{f}(\frac{\mathrm{X}}{\mathrm{X_0}}) = \begin{cases} (\frac{\mathrm{X}}{\mathrm{X_0}})^{\frac{1}{3}}, & \frac{\mathrm{X}}{\mathrm{X_0}} > (\frac{24}{116})^{\frac{1}{3}} \\ (\frac{841}{108})(\frac{\mathrm{X}}{\mathrm{X_0}}) + \frac{16}{116}, & \frac{\mathrm{X}}{\mathrm{X_0}} \le (\frac{24}{116})^{\frac{1}{3}} \end{cases} \tag{3}$$

$$\mathrm{f}(\frac{\mathrm{Y}}{\mathrm{Y_0}}) = \begin{cases} (\frac{\mathrm{Y}}{\mathrm{Y_0}})^{\frac{1}{3}}, & \frac{\mathrm{Y}}{\mathrm{Y_0}} > (\frac{24}{116})^{\frac{1}{3}} \\ (\frac{841}{108})(\frac{\mathrm{Y}}{\mathrm{Y_0}}) + \frac{16}{116}, & \frac{\mathrm{Y}}{\mathrm{Y_0}} \le (\frac{24}{116})^{\frac{1}{3}} \end{cases} \tag{4}$$

$$\mathrm{f}(\frac{\mathrm{Z}}{\mathrm{Z_0}}) = \begin{cases} (\frac{\mathrm{Z}}{\mathrm{Z_0}})^{\frac{1}{3}}, & \frac{\mathrm{Z}}{\mathrm{Z_0}} > (\frac{24}{116})^{\frac{1}{3}} \\ (\frac{841}{108})(\frac{\mathrm{Z}}{\mathrm{Z_0}}) + \frac{16}{116}, & \frac{\mathrm{Z}}{\mathrm{Z_0}} \le (\frac{24}{116})^{\frac{1}{3}} \end{cases} \tag{5}$$

For the calculation of X, Y, and Z, see Formula (2.1). The values of X0, Y0, and Z0 are 95.047, 100, and 108.883.

After the color space conversion, the color attribute of the item can be quantified using Lab value, so the color difference between the item to be tested and the standard item can be expressed as the

distance between the two in Lab space, that is, the calculation formula of color difference is shown in (2.6) :

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (6)$$

Where ΔL represents the brightness difference between the item to be tested and the standard template, Δa represents the red and green difference between the item to be tested and the standard template, Δb represents the yellow and blue difference between the item to be tested and the standard template, and ΔE represents the color difference between the two [13].

3. System function display

3.1. Hardware system implementation

The specific hardware equipment is shown in Figure 2. The imaging colorimeter system consists of servo motor, optical camera, light source and computer. The components of the entire hardware system are placed on a high-precision damping platform to ensure that the entire system is horizontal. During the shooting process, try to keep the surrounding environment dark except the LED light source to reduce the interference and influence of external light on the image acquisition, so as to ensure the quality of the captured image; by adjusting the direction of the stage and the camera lens, the two are perpendicular to each other; by adjusting the lift table, ensure that the lens is at the same height as the object to be measured to ensure that the complete image can be obtained. The computer is connected to the servo motor through the USB to RS-485 data line, and the servo motor controls the movement of the load displacement table. The items to be measured are discharged on the load table, and the LED light source is placed directly in front of it for lighting. The computer is connected to the optical camera via the GigE cable, and the camera is directly controlled to take pictures using the Vimba API.



Figure 2. Physical hardware system.

3.2. Image acquisition result

In this experiment, the designed motor drive module and the camera control module are used for image acquisition. Figure 3 shows the original image acquired by the image shooting module, which is the spectral data obtained by the dispersion, interference and diffraction of light through a series of optical systems. The system uses tiff format for storage.

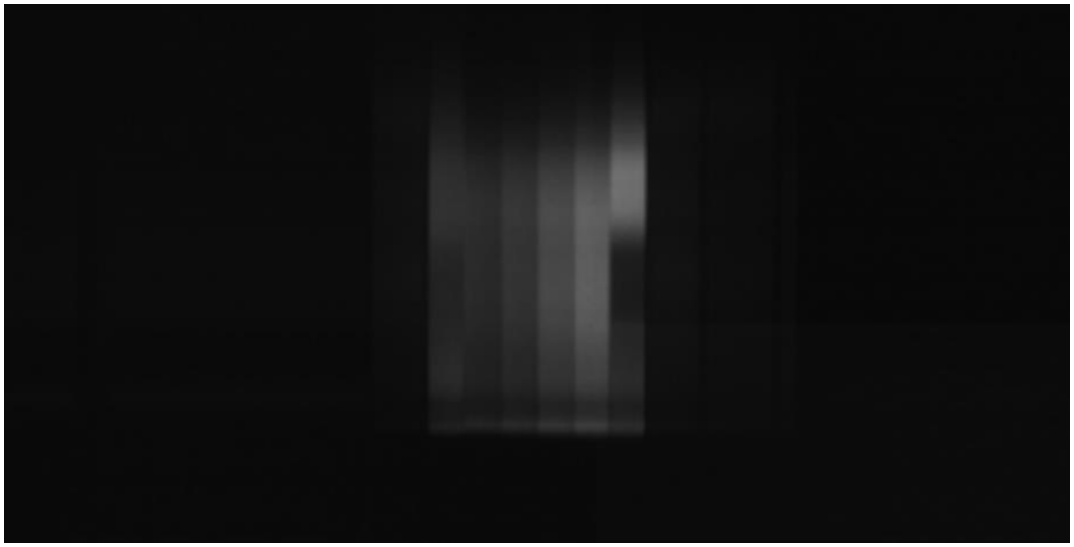


Figure 3. Original image.

Figure 4 and Figure 5 shows many images obtained by shooting the items to be tested once. The shooting sequence of the images contains the spatial information of the images, so the name of the images is defined as "project name shooting serial number.TIFF" to facilitate the subsequent synthesis of images.



Figure 4. A set of pictures.

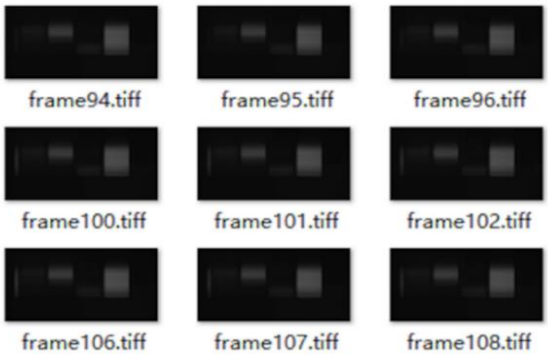


Figure 5. Another set of pictures.

3.3. Spectral curve acquisition

Based on this system, spectral images of corresponding pixel points can be obtained by clicking any point in the collected images, and the results are shown as follows Figure 6 and Figure 7:

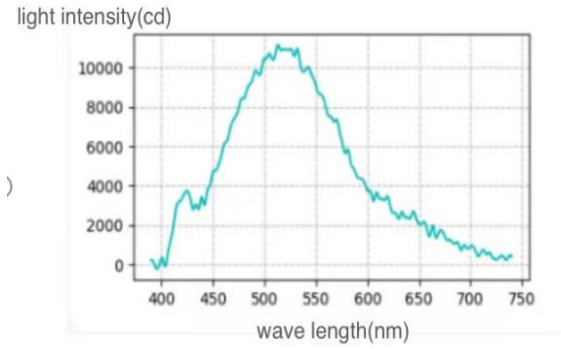


Figure 6. Spectral images of pixel points.

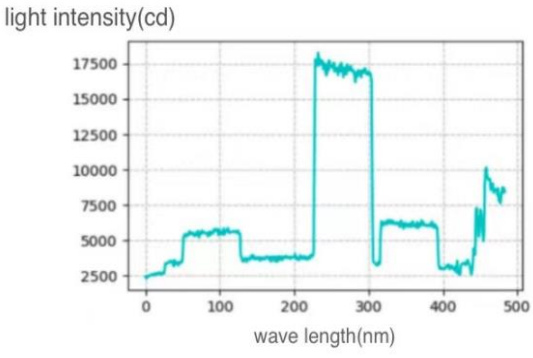


Figure 7. Spectral images of pixel points (2).

3.4. Image processing and sample inspection

After the image is taken, the image processing module is called to calculate the reflectivity of the image and convert the color space in the background process. Finally, the item is judged to be

qualified according to whether the color difference between the image and the standard template exceeds the set threshold. The resulting image and the corresponding reflectivity curve are as follows Figure 8 and Figure 9:

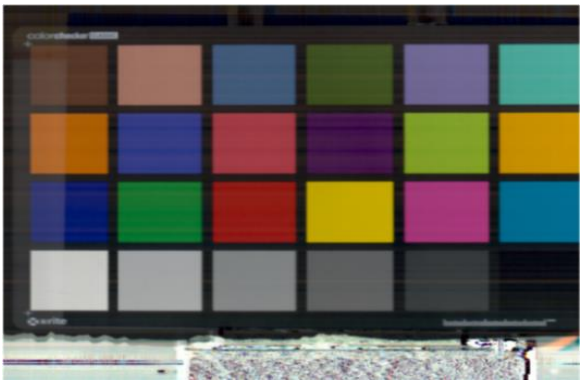


Figure 8. Converted color image

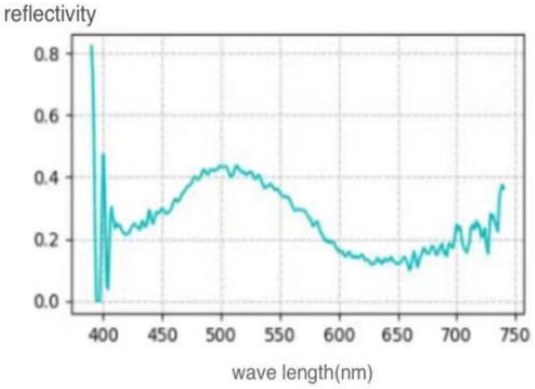


Figure 9. Reflectance image

A total of 256 printed items were randomly selected in this study, and 244 qualified items and 12 unqualified items were judged through the above series of steps to detect the samples. And it can give the judgment result whether the current project is qualified.

4. Conclusions

In this paper, the current color detection technology and hyperspectral imaging technology are studied. Based on the working principle of imaging colorimeter and the basic theory of optics, based on the color detection standards, the functional requirements and performance requirements of high-precision imaging colorimeter system are proposed, and the functional structure diagram of the system is given. The design scheme of high-precision imaging colorimeter system is written and the system is developed. The hardware system is built and the software function module is written.

In view of the limitations of the current color inspection instruments on the market, this paper uses hyperspectral imaging technology to design and develop a high-precision imaging colorimeter system, which can basically meet the needs of high-precision color inspection, but there are still some shortcomings that need to be improved:

(1) The time complexity of the algorithm in the image processing module is too high. Although it can achieve high-precision imaging, it consumes too much time, cannot achieve real-time detection, and cannot meet the requirements of industrial production. In the later work, the image algorithm should be optimized to reduce the time complexity of the algorithm, so as to meet the real-time needs of actual production.

(2) At present, the system is very sensitive to the external light environment and is easily affected by the interference of the external environment, which has a negative impact on the images collected by the system, resulting in the failure to truly restore the chromaticity of the item, making it impossible to achieve high-precision color detection. In the follow-up work, it is necessary to modify the hardware system to reduce the impact of the external environment as much as possible at the physical level. In addition, the software can also be upgraded to optimize the image acquisition algorithm and image processing algorithm with the help of machine learning or neural network, so as to correct the impact of the external environment on the image and improve the imaging accuracy, so as to further improve the performance of the entire system.

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