Color Detection System Using an Open Path Reflection Method

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Abstract— Human eye is very capable of differentiating colours; however, people will describe the same tone differently. This weakness makes verbal description inadequate in applications that require precise colour detection and management. Colour measurements are a method of expressing the colours sensed by humans as values. Colour measurements are related to illumination, spectral characteristics of the object, and the spectral sensitivity characteristics of the human eye. As the spectral distribution of the light and the spectral sensitivity characteristics (colour-matching function) of the eye defined in the JIS standards, a colour value can be determined if the spectral reflection of the object is known. On the other hand, the spectral transmittance can be used for the calculation if the light passes through the object. Based on JIS standard, the spectral distribution of the illumination and colour matching function is calculated using multiple conditions. Thus, for each spectral illumination distribution, a different coefficient is set. Consequently, the JIS standard sets different colour matching functions according to the view field. 400 nm to 700 nm in a range of wavelength is required to conduct colour measurements test, which is similar to the wavelength that can be sensed by the human eye. A better solution is to describe colour in numeric terms using adequately calibrated UV spectrometer via open path reflection method. This experiment will be conducted using fibre optic reflection probe. This research will provide some insight into colour perception, measurement and specification, and how the data produced by colour sensors are applied.

Keywords—color measurement, open path reflection technique, JIS Standard, fiber optic

1. INTRODUCTION

Colour is a fundamental element of object appearance which supported by the existence of spectral light. In our daily life, everything around us emerges with colours, and our eyes react an observer to contemplate every image shaped by its tone. Brainard *et al*. [1] concluded that light plays a role in colour appearance since colour relies on its existence. Muthu *et al*. [2], has determined that white light itself is a combination or reaction of spectral colours including red, blue and green as the main ones to contribute the variety of colours. Each type of tone has a different emissive energy within electromagnetic radiation or spectrum. Figure 1 illustrates an electromagnetic spectrum where UV(Ultraviolet), Visible (VIS) and Infrared (IR) light is located explicitly within their wavelength range. UV wavelength is starting from 10nm till 400 nm. It consists of different types of UV light such as extreme UV(EUV), far UV (FUV) and near UV(NUV). Yokono *et al*. [3] has determined that VIS is only the small part of it which is located from 400nm till 700nm. The rest is IR light starting from 700 nm till 1200 nm. IR light source is beneficial for structure analysis purpose.

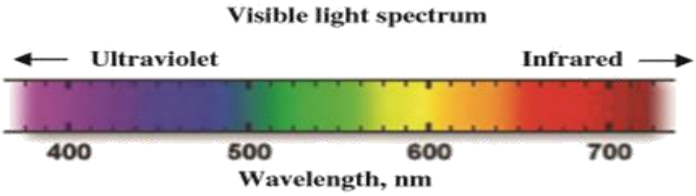

Figure 1: Electromagnetic Radiation.

Jha [4] stated that electromagnetic spectrum is formed by a vast range of frequencies at the speed of light which also well known as an oscillation constructed by frequency and spectral wavelength. The summation or integration of the three different types of the spectrum may form a white light as the primary light source. Object illumination also plays its specific role to indicate which colour it belongs to observable. Therefore, these two collaborative elements evaluate the object's size, shape and surface to model it as see able material. All these particular attributes cannot possibly get emerged without light. Transmittance and absorbance are two invertible values of light interaction when the light source is shining over material or object. The fewer transmittance values, the more amount of light is being absorbed by the material and vice-versa. The light transmittance occurs by a radiant energy which is also called emission. Okazaki *et al*. [5] found out that colour of the object is odd one of the transmittance because of its effect towards the absorption. Therefore, the appearance of the object with own specific colour that only absorbs the colour spectrum from the light source distribution. This method is the way on how the object gets coloured. At the same time, the unabsorbed light will only transmit as a proportional variable due to the light absorption by the object.

On the other hand, colour measurements are a method of expressing the colours sensed by humans as values. This paper mainly to investigate the optical spectrum of primary colours which are red, green and blue (RGB) and determine the wavelength for optimum absorption of primary colours red, green, and blue.

A. Problems Statement

In our current world, we have so many selections of colour to choose. Toning colour is a shade of colour by having a different quality of illumination, deepness, or tone, or producing a particular effect within a picture or other image. The distinctive characteristics or visual outcome of a shade of colour. There are thousands of colours and this has make people confuse to identify colours correctly. Currently, there is no standard coding colour applied worldwide. Thus, by having this colour sensor can help people to identify colour easily especially in textile and painting industries.

B. Project Scope

For this research study, the research project of the colour detection is focusing on the spectroscopic study of the colour differentiation. The initial stage of experiments includes the absorption spectrum of three primary colours which are red, green, and blue. The absorption spectrum has to be thoroughly studied, and the optimum wavelength of the absorption for each intensity has to be determined. Then, it has to be verified and compared with the colour spectrum standard.

2. LITERATURE REVIEW

In this current world, there is various type of method to detect colour. Colour detecting or colour sensor has become vital because it has been applied in many industries such as medication, agriculture, marine, food technology, robotics, art and many more.

Frankie and Demob [6] have determined the development of a sensor which is long-range, sensitive and, ultimately, compact.

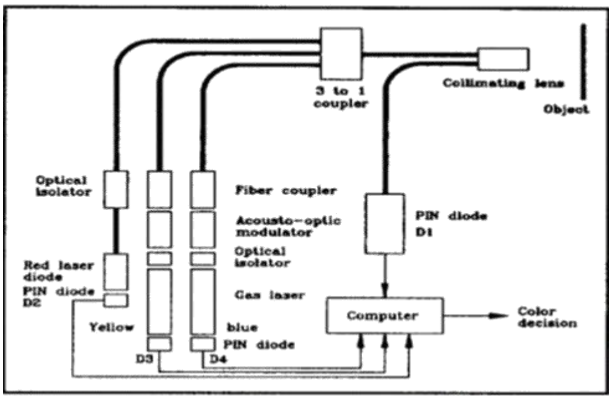

Figure 2: Experiment setup of fibre optic colour sensor.

Figure 2 shows the experimental setup of the fibre-optic colour sensor which was proposed [6]. As can be seen in Figure 2 three lasers were used to replace the white light source. Despite using more points to enhance the colour definition, a broad range of colours can be generated (and identified) by mixing only three beams of light with different visible wavelengths, was found to be a more effective and popular way. 670nm red light, 594nm yellow light and 488nm blue light was generated by an InGaAlP diode laser, HeNe laser and Argon ion laser respectively. This sensor is suitable for application in robots due to its superiority in remote sensing and high operation speed as compared to other colour detection schemes.

In recent years, research on colour detecting has been widespread. Wachowiak *et al*. [7] has found a new colour concept using tuneable photodiode which has an excellent spectral response, no external filters are required, and the independency of spectral response on the lateral geometries of the photodiode.

Omi *et al*. [8] has also came up a new method for developing colour sensor which is based on uniform Fibre Bragg Gratings. In the study, they developed a prototype of the tuneable photodiode in the standard of 130 nm CMOS technology. The tuneable spectral response was verified by electro-optical measurements and the spectral sensitivity of the whole sensor system can be adjusted by using a specific software functions. Since only one single photo diffusion region needs to be connected to function, the overall sensitivity is maximized, thus reducing the size of the sensor.

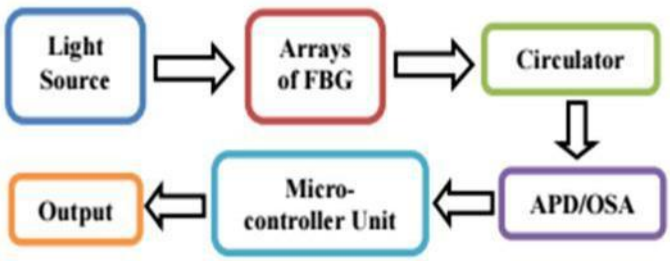

Figure 3: Block diagram of detection system.

The block diagram as shown in Figure 3 is the detection system that was proposed [8]. When a light beam propagates through the FBG arrays of different grating periods, there will be a gradual shifting of Bragg wavelengths for various colours, where the arrays are inscribed in a single-mode fibre (SMF) to facilitate the single mode propagation. Now the pulse containing Bragg wavelength will be reflected back via circulators, and afterwards, it can be detected by Optical Spectrum Analyzer (OSA) or any suitable photodiodes like avalanche photodiodes (APD) or PIN photodiodes. In general, photodiodes will work as a translator of an optical signal into an electric signal. Thus, for each wavelength, a specific amount of current will be produced and these values of current are then compared to a calibrated micro-controller unit which performs as a decision circuit. So based on the actual value of current, the particular colour can be detected. An LCD or LED display can be connected to the microprocessor unit to show the desired colour as the output. In this detection system, there are quite a number of advantages was offered with the use of SMF such as having the same core-diameter, cladding-diameter, core refractive index and cladding refractive index for the variations of grating periods. There are also some other choices available instead of Light Source Arrays of FBG Circulator APD/OSA Micro Output Controller Unit. Nevertheless, every systems has its own weaknesses, and for this system, the maximum weighting factor was limited to 30 during the curve fitting in order to limit the sensitivity to measurement noise

The testing object is decided by the type of applications chosen to sense the colour. In this work, the testing object is a cloth material as it is focused on textile applications for colour identification and colour shade matching. The necessary experimental arrangement is shown in Figure 4. However, the model is found to have low efficiency and accuracy to detect toning colours of diversity texture of cloth materials in textile industry. Gudkov *et al*. [9] has described in his study an extremely fast, highly sensitive and accurate detection using a novel instrument single photon spectrometer which also allows the analysis of feeble fluorescent signals obtained from mixtures of multiple fluorescent dyes.

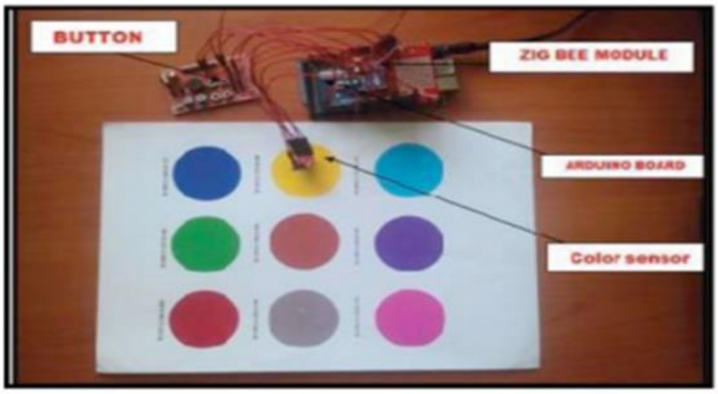

Figure 4: Experimental setup of transmission block.

A detailed description of single photon spectrometer is given in Figure 5which presents a block diagram of the spectrometer. Polychromatic fluorescence collected by the input fibre passes through the spectral separation module, and the decomposed fluorescent signal illuminates photosensitive pixels of the 32-channel photo-sensor. The obtained photocount is transferred to a computer for recording and data processing.

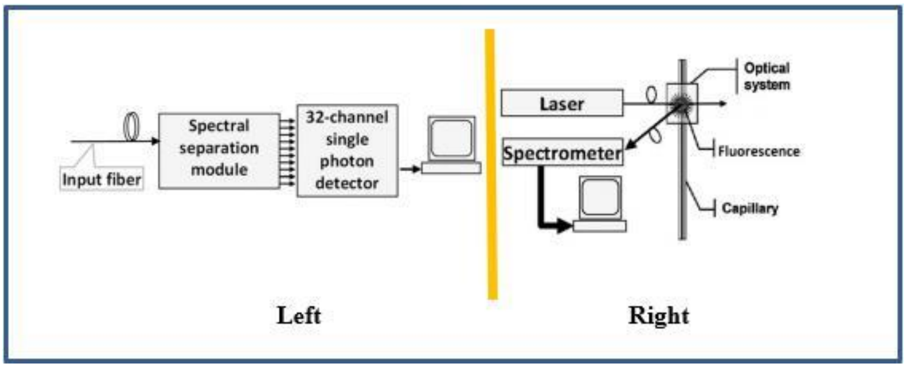

Figure 5: Block diagram of the spectrometer (left) and schematic of the measurement setup (right).

The measurements of fluorescence spectra have been set up as in the block diagram is shown in Figure 5 (right). A substance that needs to be analysed has been placed in a capillary which is injected into a fiberized optical system. Fluorescence in the analyte is excited by Ar-ion laser, collected by the fibre (200 mm core diameter) and delivered to the spectral separation module of the spectrometer. Detection of the capillary content is done by pumping the analyte through the capillary using a programmable micro-pump. However, this system is only suitable for which require highly accurate identification of biological samples labelled with multiple fluorophores.

A new sensor system of low-cost reflective colour sensor based on RGB LED and frequency modulated has been implemented. Bajić [10], identified a colour sensor, based on neural networks using an artificial intelligent technique, and the sensor was able to determine the colour of an object after 3 seconds. The new developed sensor has a better performance in the context of artificial smart sensor due to its higher speed of colour determination. It determines colour instantaneously and has simpler hardware and software design.

In practice, there are two most common implementations of the reflective colour sensor. The first one uses a broadband white-light source, and three photodetectors with different spectral characteristics usually accomplished using optical filters. The second one uses three light sources at different wavelengths (typically RGB LED) and one photodetector with a broad spectral response. The sensor described in this section belongs to the second group, and its general structure is given in Figure 6. There are several methods for multiplexing RGB LEDs. The most common types of multiplexing are a time-division and frequency multiplexing technique. The main drawback of time-division in this application is low speed, in comparison to frequency modulated. In this paper, the frequency modulated red, green and blue component of RGB LED is used. However, this application is only suitable for certain like chemistry and environment protection because it detects through the liquid.

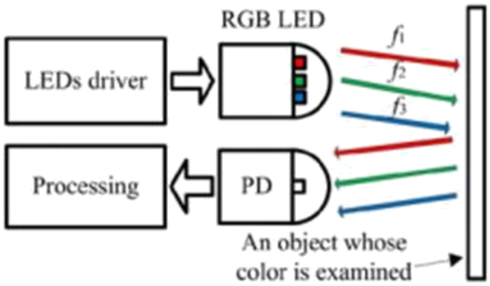

Figure 6: A principle scheme of reflective colour sensor using three light emitting.

In Oct 2017, an automated colour sensor system has been developed using LED and LDR which controlled by Arduino. Amhani and Iqbal [11] stated that this sensor system importantly been developed with low cost sensor and to be applied in simple application like robotics industry. The outcome of the test conducted was a success with a very small error. However, this system is only limited to 10 colours detection in time.

Colour is an important measure of quality in the agricultural and food industries because it is considered by consumers to be related to product freshness, ripeness, desirability and food safety. Colour analysis and, in particular, computer vision analysis has recently been reported as a viable method to monitor various food processes, e.g. cheese ripening process. Orlowska *et al*. [12], stated that colour measurement instruments, by the standards developed by the CIE (Commission Internationale del'Éclairage) will transform or filter reflected spectra to produce reproducible colour values. CIE Lab and Whiteness values initially defined by the CIE in 1976 constitute the most widely used numerical colour-space system. The objective of the present study was to monitor syneresis in a cheese vat using colour parameters derived from a fibre-optic sensor, to achieve higher levels of process control, thus improving the cheese quality.

Another color sensor application in agricultural industry was developed to investigate the suitability of true color sensor for the detection and differentiation of crop and weed plants which experiment on toned green color included. Oliver and Peter [13] stated that true-color sensors manage to detect small differences in luminance and the coloration of objects. The experiment used single sensor controller that built-in, actuators can be addressed and activated in real time. The result was a success but it has its own limitation which it is in ideal environment. A test in real environment should be carried out .

Colour parameters derived from the sensor were used to predict known syneresis and whey indices. In this study, cheese curd was made under a randomised factorial design with two experimental factors, i.e. milk fat level and cutting firmness, and three replicates were used to investigate colour changes over syneresis. The levels of milk fat and cutting firmness examined were 0 %, 2.5% and 5%, and 5 Pa, 35Pa and 65 Pa, respectively, giving a total of 27 trials [13]. Coagulation temperature, milk pH, rennet, calcium chloride concentrations, cutting procedure and stirring speeds were kept constant throughout the study. However, for further developments, possibly involving new spectral analysis techniques, would be required to reduce the error of prediction to a level that is beneficial for industrial application.

In robotic industry, colour sensor has also been actively implemented. For example, a research in developing a robotic arm control in the 3D space using marker detection has been done by Szabo and Gontean [14]. The markers have different colours and are placed at the joints of the robotic arm. The coloured markers are distinguished with image recognition algorithm using stereo cameras. The control platform used in this experiment is an FPGA development board running Ubuntu Linux 12.04 LTS graphical operating system. The system becomes fascinating because the robotic arm control system is only an FPGA circuit that does not require a desktop computer to control the robotic arm. This idea produces a compact but massive system. Thus, making it unsuitable for today's industrial automation. Furthermore, the system developed does not produce a real-time image.

The colour sensor has also become vital in the marine industry. The sensor application is to provide a potent tool for assessing the health of the marine ecosystem and also create an understanding to the changes in the global climate system. According to Rakesh and Palanisamy [15] a proposal of sustaining the global ocean colour observations including 250-m spatial resolution, multispectral resolution, broad spectral coverage including UV, VIS, NIR, and SWIR bands, high SNR and dynamic range, capability of measuring clouds, aerosols, and sun glints, and other critical design characteristics was done. This advanced ocean colour sensors can provide a diversity of bio geophysical products to support a rising variety of applications thus, serving the expanding needs of the scientific community. In the meantime, it will also help to maintain the continuity of Type 2 sensors and sustain the current remote sensing capability (global observations). However, in order to fully exploit the usefulness of these spectral and radiometric characteristics of the sensor as well as achieving those ambitious goals by many, an improved retrieval algorithm will need to be developed.

Chen *et al*. [16] has determined a CFAST technology whereby it is more stable and faster than FAST. It used grey value images and the first methods on colour images. To identify a point as a critical point, in FAST 16 pixels' circle around each pixel were under-examined, cf. Figure 7. In a grey value image, one can now decide whether a point is brighter or darker than the centre of the circle. In a case where a certain number of related points in FAST is continuously brighter or darker, this can be identified as a critical point. For the implementation to be fully functional, these 9 points have to be connected, and the remaining seven can be chosen arbitrarily. Therefore, a method was developed to obtain more stable and vital points. By doing so, it can be seen that this technique is a sort of an extension of the constancy condition of FAST in the form that we demand for a particular kind of uniformity. To achieve this, the requirement that has been imposed here was, that a certain number of points must be similar to the centre to get more stable vital points. However, to enable a better comparison with the standard algorithms on grey value images, the application of a descriptor is the next significant step. At this moment, one must note that this descriptor also has to allow a fast execution since otherwise the speed advantage of the detector will be lost.

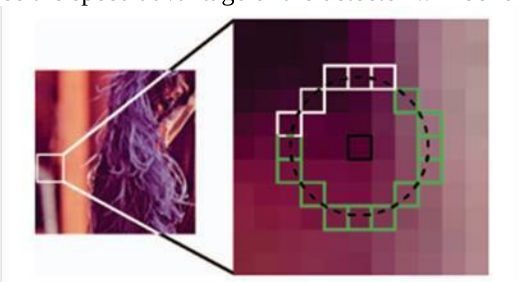

Figure 7: Illustration of cFAST in an extract of the Lena image, whereby the 11 connected dissimilar pixels are shown with green and the 5 similar points with white.

3. METHODOLOGY

In this research study, an open-path reflection technique which also called as a spectroscopic principle is proposed to carry out a particular research on the colour sample using reflection probe. The advantage of the open-path method is that a significant proportion of the light sensed by the detector will have interacted with the test sample. Paper colour sample is placed in a black box. It should be appropriately sealed to avoid any light interruption. A broadband light source is used to transmit the light into the sample before getting detected by the miniature UV spectrometer. A set of optical fibres are proposed and used to stream the light to the test cell and the detector after reacting with the sample. The proposed generic design of the experimental setup is shown in Figure 8.

This figure shows how the equipment been set up to experiment. The list of equipment needed as follows:

Laboratory Equipment

1) Halogen Light source
2) Reflection Fiber optic cables
3) Paper color test sample
4) Spectrometer
5) Black box

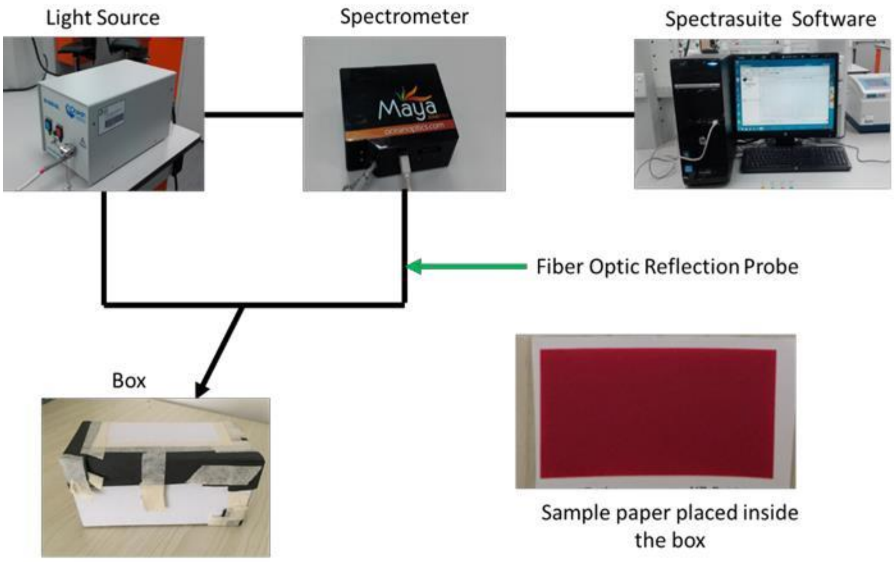

Figure 8: The Experimental Setup.

Based on Figure 8, the light source, the spectrometer and the black box were connected using optical fibres complete with standard SMA fibre coupling. SMA is a fibre optic connector, and it stands for Sub-Miniature version A. SMA connector uses a threaded connection to keep the plug intact in the socket. It is also compact and has mechanical durability.

The light is transmitted through the optical fibre as seen in Figure 9, coupled into the spectrometer, and is collimated by a spherical mirror. The collimated light is diffracted by a plane grating, and the resulting diffracted light is focused by a second spherical mirror. An image of the spectrum is projected onto the linear detector array. In this setup, an elongated charged-coupled device (CCD) array spectrometer was used. In this investigation, a CCD spectrometer was selected as a detector as it offers many advantages.

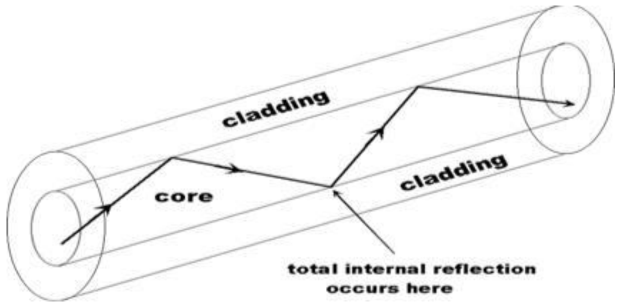

Figure 9: Lights Transmission in Fibre Optic.

The advantages of CCD over Photodiode Array (PDA) include a more straightforward design since no series of electronic switches, and an associated driving circuit is required. CCD also has a smaller output capacitance which is equivalent to one pixel while the PDA readout line is equivalent to hundreds of pixels. Consequently, the readout noise of a typical PDA is about two orders of magnitude higher compared to a CCD detector.

Another advantage of using CCD spectrometers is that they are arranged in a two-dimensional array. The advantage of using a two-dimensional array is the ability to perform side-by-side readings, suited to multiple optical inputs so that various spectra are obtained simultaneously. Hence, a reference signal can be captured on simultaneous measurement to trace any multiple changes such as lamp fluctuations. Therefore, the spectrometer with CCD installed is more suitable for use in applications where the light source intensity is not linear. Another reason that the CCD spectrometer was selected in this investigation was that it has better UV sensitivity compared to a PDA spectrometer.

Spectra Suite software was used in conjunction to acquire and analyse the data from the spectrometer. This software was the software package provided by the vendor of the spectrometer (Ocean Optics). It was used in throughout this investigation as described above purely for data capture from the instrument. The step by step of the experiment conducted was summarised in Figure 10 below.

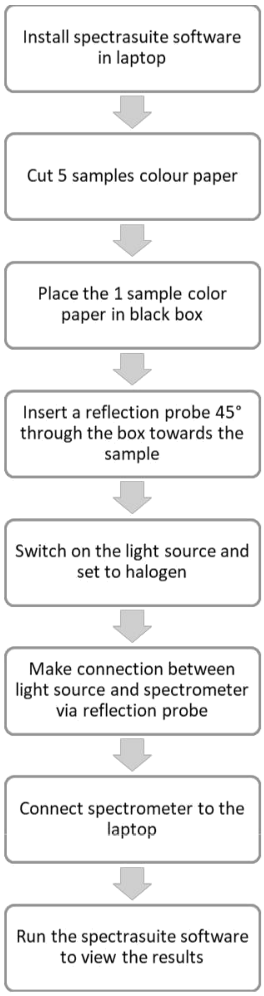

Figure 10: Experimental Flowchart.

1. Sample Colour Paper

In the experiment, the colour paper that will be used is the sample colour taken from chart paint catalogue. In the directory, there are hundreds of colours listed complete with their code. Therefore, five colours from the catalogue will be chosen as a sample in the experiment. The sample colour paper will be placed in the black box one sample at a time.

2. Light Source

The DH-2000 light source offers stable, continuous output from 215-2500 nm. Halogen light source will be used in this research. Before the experiment started, the light source needed to be warmed up to 25 minutes. The combination of the halogen gas and the tungsten filament produces a halogen cycle chemical reaction which redeposits evaporated tungsten to the filament, increasing its life and maintaining the clarity of the envelope. Because of this, a halogen lamp can be operated at a higher temperature than a standard gas-filled lamp of similar power and working life, producing light of a higher luminous efficacy and colour temperature. The small size of halogen lamps permits their use in compact optical systems for projectors and illumination.

3. Spectrometer

Recent advances in miniature spectrometer technology and enhanced UV response provided by enhanced optical components have allowed these devices to be used as viable UV detectors. The UV improved CCD detector means that they can detect a large number of discrete intensity values across a wide range of wavelengths with spectral resolution down to 0.02 nm depending on the geometry (grating and entrance slit choices). The spectrometer used in this project was a miniature spectrometer, HR2000 from Ocean Optics. It uses Sony ILX511 CCD detector, which can provide spectral resolution down to 0.035 nm (FWHM).

4. Reflection Probe

The method used in this project is based on an open-path reflection optical technique. The purpose of using the reflection probe is to diffuse or specular reflectance from solids fluorescence and color. Through reflectance measurements, the intensity of a sample, or examine differences between objects for sorting or quality control can be measured. The samples may be automotive parts, paint, coffee beans, dyed human hair or lizards, making it challenging to choose the right system. A reflection probe collects light at the same angle as it illuminates, and can be used for either specular or diffuse reflection measurements. It is made of 6 illumination fibers around a single read fiber, which results in a 25° full angle field of view. It seems intuitive to connect the 6-fiber leg to the spectrometer, but it is actually more efficient to use the single fiber leg for detection. That's because each illumination fiber projects a cone of light from the source. All of them overlap at the sample in the center, exactly where the read fiber is looking. The path length of the traveled light will influence the interaction between amount of the tested sample and the light. This step is very important to analyze the sensitivity of the detection system

5. Detector Software

The detection of color system uses a miniature UV spectrometer as the detector and interfaced with a PC or laptop using Spectrasuite and LabVIEW software application as an experimental display. Spectrasuite software is used for the initial stage as only reflection spectrum can be viewed. Meanwhile, LabVIEW software is used as the primary software to be a real-time measurement system which may directly display the color concentration over the intended wavelength region.

6. Real-time Measurement

SpectraSuite Software will be used during the testing. However, this software cannot display the color concentration with optimum wavelength absorption in real time which is a disadvantage for any system that requires continuous monitoring. Thus, an additional acquisition and analysis program will be developed via Labview (Laboratory Virtual Instrument Engineering Workbench) software. This will be used in order to achieve the last objective in this research. Popp et. al (1997) stated that through this software data from the spectrometer can be analyzed, as well as to develop a program that can display color concentration with optimum wavelength absorption in real time. Therefore, the real-time measurement system can help to quickly calculated and computed integration time, response time and wavelength saturation to display the outcome of the experiment conducted.

7. Analysis of the spectroscopic measured data

The reflection spectrum of colors is measured. Its reflection cross-section in the selected wavelength region is calculated and analyzed. The optimum reflection wavelength is identified to increase the sensitivity of the detection system. The reflection spectrum of basic color was also analyzed.

4. CONCLUSION

In conclusion, the research work is carried out to develop a colour detection system or sensor color using a miniature spectrometer through an open-path technique. It may be able to diagnose the wavelength of the maximum absorption spectrum for primary colour and colour toning through the analysis of the experimental sample of colour paper. Also, to develop a real-time measurement system to display the result. In the future, this technique can help to detect and efficiently differentiate colours. This research study should be beneficial in the medical, textile and paint fields.

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REFERENCES

[1] D.H. Brainard, J.M. Kraft, and Longere, "Color constancy: Developing empirical tests of computational models. Colour perception: From light to object," pp.307-334. 2003.
[2] S. Muthu, F.J. Schuurmans, and M.D. Pashley, "Red, green, and blue LEDs for white light illumination. Selected Topics in Quantum Electronics," IEEE Journal of, 8(2), pp.333-338.
[3] J. C. Maxwell, " A Treatise on Electricity and Magnetism," 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73, 2002.
[4] T. Yokono, S. Shimokawa, M. Yokono, and H. Hattori, "Infra-red spectroscopic study of structural change of liquid water induced by sunlight irradiation," Water, 1, 29-34, 2009.
[5] S. N. Jha, "Colour measurements and modeling. In Nondestructive Evaluation of Food Quality". Springer Berlin Heidelberg. K. Elissa, "Title of paper if known," unpublished. pp. 17-40, 2010.
[6] T. Okazaki, T. Orii, A. Ueda, A. Ozawa, and H. Kuramitz, (2017). "Fiber Optic Sensor for Real-Time Sensing of Silica Scale Formation in Geothermal Water," Scientific Reports, 7(1), 3387.
[7] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, 1987.
[6] Y. C. Frankie and M.S. Demob, "Fiber Optic Color Sensor for Color Detection," Dept of Electrical Engineering.Hong Kong, pp.124-126, 2016.
[7] A.Wachowiak, S. Slesazeck, P. Jordan, J. Holz and T. Mikolajick, "New Color Sensor Concept Based on Single Spectral Tunable Photodiode," IEEE.
[8] A. I. Omi, N. M. Faiyaz, and M. Faisal "A Novel Color Sensor Based on Uniform Fiber Bragg Gratings by International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT)." 2014.

[9] D. Gudkov et al., "Detection of multi-color fluorescent objects with single photonspectrometer, Biiosensor and Bioelectronics," 39,152-155, 2013.
[10] J. S. Bajić, B. Dakić, D. Z. Stupar, M. P. Slankamenac, and M. B. Živanov, "The frequency-modulated reflective color sensor." MIPRO, Microelectronics, Electronics and Electronic Technology, 168–172, 2012.
[11] A. Amhani and Z. Iqbal, "Automated Color Sensor System Using Ldr And Rgb Leds Controlled By Arduino," ARPN Journal of Engineering and Applied Sciences, vol. 12, no. 19, 2017.
[12] K. Orłowska, P. Słupski, M. Świątkowski, P. Kunicki, A. Sankowska, and T. Gotszalk, "Light Intensity Fibre Optic Sensor for MEMS displacement and vibration metrology." Optics and Laser Technology, 65, 159–163, 2015.
[13] O. Schmittmann, and P. S. Lammers, "A True-Color Sensor and Suitable EvaluationAlgorithm for Plant Recognition." Institute of Agricultural Engineering, University Bonn. 2017.
[14] R. Szabo and A. G. Lynxmotion, " AL5 Type Robotic Arm Control with Color Detection on FPGA Running Linux OS" in: 24th Telecommunications forum TELFOR,Serbia 2016.
[15] R. K. Singh and P. Shanmugam, "A Multidisciplinary Remote Sensing Ocean Color Sensor: Analysis of User Needs and Recommendations for Future Developments," IEEE Journal of Selected Topics in Applied Earth Observations And Remote Sensing, Vol. 9, No. 11, 2016.
[16] R. Chen, F. Formenti, H. McPeak, A. N. Obeid, C. Hahn, and A. Farmery, "Experimental investigation of the effect of polymer matrices on polymer fibre optic oxygen sensors and their time response characteristics using a vacuum testing chamber and a liquid flow apparatus." Sensors and Actuators, B: Chemical, 222, 531–535, 2016.