

Development of a portable digital colour meter for lignocellulosic fibers

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The present study has intended to develop a battery powered portable digital colour meter works on the principle of photo reflectance to measure the whiteness value of lignocellulosic fibers. The developed instrument has comprised light-emitting diodes, photodiodes, capacitor, display, microcontroller, and battery with booster. Light-emitting diodes (LEDs) of 5 mm have been used to provide uniform illumination and BPW34 silicon PIN photodiode sensors provided to measure the reflected light from fibre which intern produces voltage, which has then calibrated for color values. The calibration has revealed that there is a high degree of correlation between output voltages for given whiteness value with R² value more than 0.97. The developed instrument has been tested for three fibers *i.e.*, jute, mesta and kenaf. The results have been compared with commercially available colour measuring instruments like colour and lustre meter and spectrophotometer. A comparative analysis has shown that the readings from the developed portable instrument are not significantly different ($P > 0.05$) from those of commercial instruments. Further, instrument measurements are repeatable and reproducible in nature. The device is battery-powered, with a charge lasting up to two days. The instrument can be used to measure the color of other fibers as well.

Keywords: Jute, Kenaf, Mesta, Repeatability, Whiteness value

1 Introduction

The demand for natural fibers is increasing worldwide due to environmental concerns. It is estimated that by 2030, the global market size of natural fibers will reach USD 74.99 billion¹. Natural fibers, including those of plant and animal origin, possess excellent flexibility, fineness, and a high ratio of length to thickness compared to synthetic fibers. These fibers are used in developing technical textiles, apparel and value added products². Among the various fiber parameters, color is one of the most important physical properties that first attract manufacturers and buyers. The visual appeal of the fiber can significantly influence the product's marketability, as consumers often choose products based on color. Additionally, understanding the color is essential in the dyeing process, making the measurement of fiber color imperative before processing. Fibers with a higher whiteness index are easier to bleach and dye, making the subsequent processing steps more efficient and cost-effective³.

Natural fibers, due to fluorescence, emit specific wavelengths of light when illuminated. Some commercial instruments measure the colour by measuring reflected light¹. To measure the colour of fibers, spectrophotometers are commonly used. These instruments are highly accurate but are also expensive, sophisticated, and have relatively low sensitivity. To address these issues, ⁴developed a portable spectrophotometer for measuring the colour of textile fabrics using the TCS 3200 colour sensor and Arduino Uno microcontroller. This system was tested on 10 samples and achieved 100% accuracy. However, it generates frequency values rather than direct colour values. Colour measurement using image RGB is widely adopted in computer vision⁵. Used RGB values from images to measure the colour of jute fiber in terms of whiteness index⁵. The main drawback of using image RGB is its dependence on the setup, environment, image pixels, illumination and type of camera. RGB sensors are available in the market which provides RGB values of products developed a handheld colour device using RGB sensor⁶. This device includes four LEDs to indicate

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qualitative fiber characteristics and battery level, powered by a rechargeable battery. Three of the LEDs indicate fiber characteristics such as very good, fairly good, and average categories. ICAR-NINFET, Kolkata, developed a digital colour and lustre meter based on the principle of the reflectance photometer⁷. In this instrument, light-emitting diodes are placed at a 45° angle, and the light falls on the fiber. The instrument displays the colour and lustre of fibers in digital form. However, it requires a continuous power supply and must be positioned perpendicular to the fibers, as placing it at any other angle can yield different results. Generally, fibers are purchased at the farm level and from remote locations. The lack of proper digital portable colour meters led to subjective assessments of the fibers. Additionally, according to BIS standard IS: 271 (2020), the whiteness value of jute, mesta, and kenafibers is used to grade them as good, average, and poor. As per the review study, there is no portable, digital instrument available for measuring colour of lignocellulosic fibers. Therefore, this study aimed to develop a portable, digital, and battery-operated colour meter for measuring the colour of lignocellulosic fibers. The newly developed instrument was calibrated and its performance was evaluated. Additionally, it was compared with commercially available instruments. It is anticipated that developed instrument will facilitate farmers, entrepreneurs and buyer to distinguish the test colour of fibre.

2 Materials and Methods

2.1 Development of digital colour meter

The portable digital color meter was developed in the Quality Evaluation and Improvement division, ICAR-NINFET, Kolkata. According to IS: 271 (2020), the color characteristics of jute, mesta, and bimli are represented by the whiteness value of the

fiber, which is the ratio of reflected light to incident light.

The newly developed instrument operates based on the principle of photo reflectance (Fig. 1) and includes components such as a light-emitting diodes, photodiodes, capacitor, microcontroller, battery, and battery booster. The components used to develop portable colour meter is presented in Table 1. The circuit diagram of the color meter is illustrated in Fig. 2.

To ensure uniform sample illumination, four 5 mm light-emitting diodes (LEDs) were used, positioned at the centre of the circuit board vertically to focus light onto fibre. LEDs are preferred for their compact size, efficacy, energy efficient, fast switching and cost effective⁸. Since the developed instrument operates on the principle of measuring light reflectance, five BPW34 silicon PIN photodiode sensors were utilized and connected parallel. It offers high sensitivity to light, fast switching and response times, and a compact, lightweight design. The BPW34 is the most suitable photodiode sensor for lignocellulosic fibre as variation in light reflection caused by the fiber's moisture content, defects, trash, and the angle of incident light. When reflected light strikes the BPW34 photodiode, a voltage is generated as a result of the photovoltaic effect, allowing for precise quantification of the incident light intensity on the

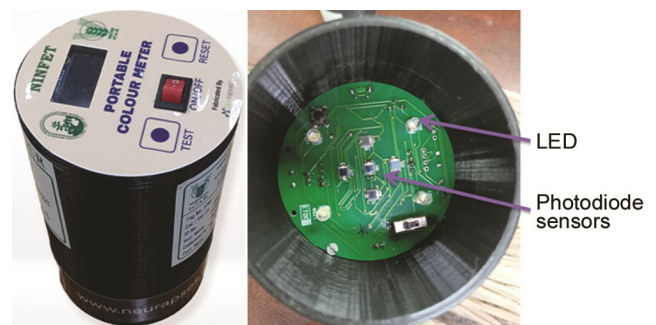


Fig. 1 — Developed portable colour meter.

Table 1 — Components used in the developed colour meter.

Sl. No	Components	Number	Specification
1	Light emitting diode	04	invento, operating voltage: 3-5 V, light colour: white, Head Size (Approx) : 5mm
2	Silicon PIN Photodiode	05	Vishay Semiconductors, operating temperatures: -40 to 100° C, reverse voltage: 60 V
3	Microcontroller	01	ATmega328-AU, maximum frequency: 20 MHZ, operating voltage: 1.8-5.5 V, Pin count: 32
4	Capacitor	01	SMD 103
5	Rechargeable Lithium-Ion Battery,	01	Power smart, capacity: 4800 mAh, power input AC: 3.7 V.
6	Push Button	02	Legrand, Switch type: Flush Push button, Voltage: 12V
7	Display	01	DWEII, Resolution: 128x64, Display: 16x2, Vcc: 3.3-5V
8	Battery Booster	01	XL6009 DC-DC Step-Up Converter, Input voltage: 3-32 V, Output voltage: 5-35 V, Switching frequency: 400 KHz

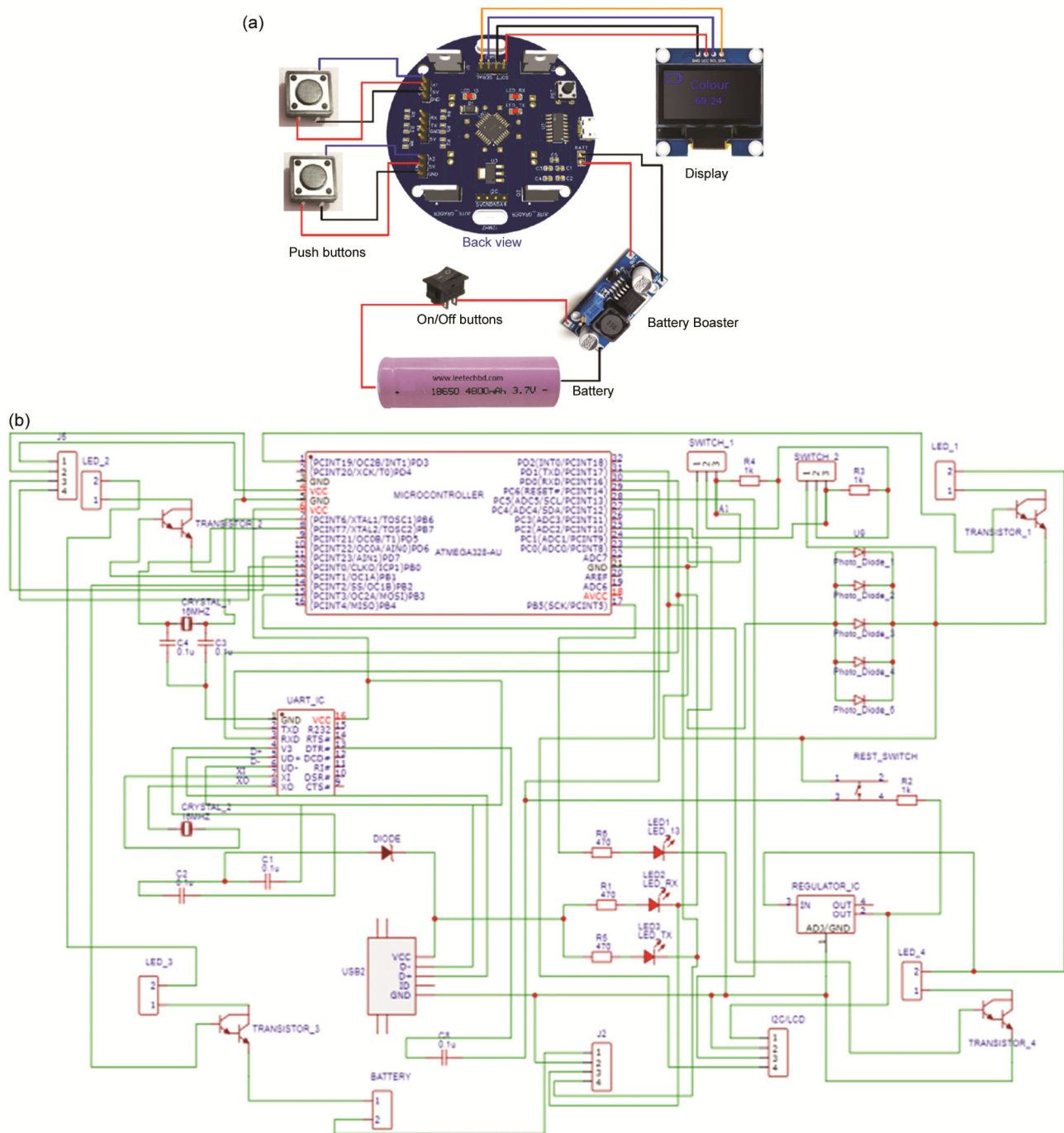


Fig. 2 — (a) Schematic and (b) Line circuit diagram of the developed portable colour meter.

sensor. To remove unwanted frequencies generated by the BPW34 sensors, the SMD 103, a type of surface-mount device (SMD) filter, is used to filter signals. A 4800 mAh battery was used to power various components of the developed instrument, including the light-emitting diode, photodiode, microcontroller, and other circuitry. To provide a stable 5V supply for the light-emitting diode, an XL6009 boost converter

integrated circuit (IC) was utilized. To display the color value and battery level, a 0.96-inch organic light-emitting diode (OLED) liquid crystal display with a resolution of 128x64 pixels was provided. The LCD features a black backlight and blue text, which facilitates clear and accurate result presentation. Two push buttons are used: one for "Reset" and the other for "Test".

The microcontroller, ATmega328-AU consists of 32 pins, was used to receive voltage data from the BPW34 sensor through the SMD103 capacitor and calculate the whiteness index of the fibers. After finalizing and assembling the circuits, the Arduino code was uploaded to the microcontroller. This code contains instructions that guide the board on the specific functions it needs to perform. Circular housing made of PLA (3D printed) with 1200 mm × 750 mm (L × D) encased the PCB, switches and sensors.

2.2 Calibration of portable colour meter

After developing the color meter, it's crucial to calibrate the setup to ensure it functions correctly and provides accurate readings. Standard color papers are placed beneath the meter, and the voltage generated in relation to the standard whiteness value, as well as the whiteness values obtained from the standard papers, are recorded. This data is then used to generate the calibration curves.

2.3 Performance evaluation of the developed instrument

To evaluate the performance of the developed portable color meter, the instrument was tested with fifty samples each of jute, mesta, and bimli. The sample fibers were free from defects, root content, and other impurities, and the testing area was marked to ensure that other instruments could be tested in the same location. For spectrophotometer testing, fibers from the tested area are cut and used for the analysis. The laboratory conditions used for the colour measurement are $27 \pm 2^\circ\text{C}$ and $65 \pm 2\%$, temperature and RH, respectively. A comparative study of the developed instrument versus existing instruments was also conducted.

2.4 Statistical analysis

To analyze the difference between developed instrument and existing instruments, an Dunnett multiple comparison test has been conducted in SPSS software (IBM, SPSS statistics, version 25) at 95 % confidence level. To examine repeatability and reproducibility, the process suggested by⁹ and one way ANOVA was employed.

3 Results and Discussion

A portable color meter was designed to measure the whiteness value of fibers using photodiode sensors and LED lights. During preliminary tests, it was observed that increasing the LED height resulted in a lower voltage output, which undetectable. Hence, LED was positioned at a height of 50 mm, with a

60 mm distance between the photodiode sensors and the fiber. After the instrument was developed, it was calibrated using standard reference papers. The calibration curves indicates that there is a high degree of correlation between output voltage for given whiteness value with R^2 value more than 0.97 (Fig. 3). For calibrating the instrument readings, the MAP approach was used which enhances accuracy by incorporating both observed data and true values, ensuring precise estimation of the whiteness value.

After calibration, the instrument was tested using three lignocellulosic fibers: jute, kenaf, and mesta. It was observed that once the test button was pressed, the instrument displayed the reading within 0.7 seconds.

3.1 Comparative evaluation

The newly developed instrument underwent extensive testing to assess its accuracy in measuring the color of fibers (Fig. 4). The results were compared with those obtained from existing instruments, such as the color and lustre meter and the spectrophotometer (Fig. 5). A Dunnett multiple comparison test revealed that the readings from the developed instrument showed no significant

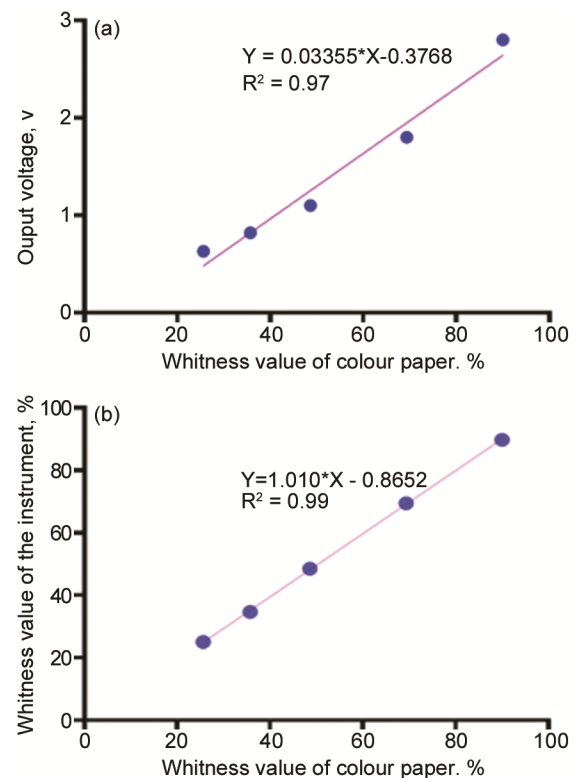


Fig. 3 — Calibration curves for (a) photodiode sensor and (b) colour meter .

difference ($P>0.05$) ($F=0.06, 0.04, 0.02, P=0.994, 0.92, 0.87$) when compared to the other instruments. From the figure, it can be observe that the measured results from the developed colour meter are quite similar to other instruments, indicating that the



Fig. 4 — Testing of colour meter.

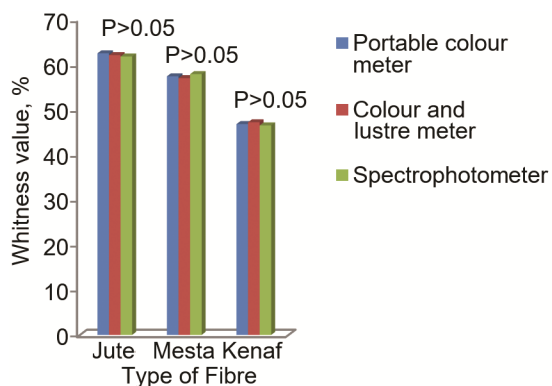


Fig. 5 — Comparison between average values obtained from developed portable colour meter and existing colour meters ($p>0.05$ indicates significant difference).

developed testing instrument is suitable for obtaining reliable color values.

The developed instrument is battery operated with charge lasting up to two days. With a total weight of 800 grams, the instrument is ideal for conducting experiments in the field, remote locations, and laboratories (Table 2). Other two instruments *i.e.*, colour and lustre meter and spectrophotometer needs continuous supply of power as well as controlled environment to get accurate results. The developed instrument is capable of testing the colour of fibres up to 99 %. The total cost incurred for fabrication was Rs. 15,000=00 which was less than commercially available instruments. Since majority of the components are locally available, making it less expensive than the existing methods. The time required to test the 15 samples using the developed instrument and existing colour and lustre meter was 5 min while testing with spectrophotometer took 15 min. Overall, the developed instrument is a low cost, accurate and portable unit for testing the colour of lignocellulosic fibers.

3.2 Repeatability and reproducibility

Two critical performance indicators of the instrument are repeatability and reproducibility, as they are crucial for ensuring the accuracy, reliability, and consistency of results. Repeatability test of the developed instrument was conducted for jute fiber testing. One way ANOVA for measured value was performed in SPSS software (Table 3). To calculate repeatability and reproducibility of the instrument, mean square value of the within group was considered as suggested by⁹. The mean square value of colour meter is 0.42 and its square root value was 0.64. Considering the 95% confidence intervals of Sr, the repeatability limit (r) is $r=0.96 \times \sqrt{2} \times s_w$ which

Table 2 — Performance characteristics portable colour meter with other instruments.

Sl. No	Particulars	Portable Digital colour meter	Colour and lustre meter	Spectrophotometer
1	Size of opening, mm	70	30	25.4
2	Power required	4800 mAh (Battery)	220 V AC 50Hz	220 V AC 50Hz
3	Colour measurement range	0-99 %	0-99 %	0-99 %
4	Time required for testing 15 Samples	5 min	5 min	15 min
5	Machine cost, Rs	15,000	1,20,000	4,00,000
6	Weight, Kg	0.8	2.8	25

Table 3 — ANOVA of repeatability and reproducibility of colour meter.

Particulars	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1936.41	9	215.15	505.06	0.00
Within Groups	4.26	10	0.42		
Total	1940.67	19			

provides an estimate of the limits within which 95% of measurements should be. The repeatability value of the instrument was 0.86 %. Instrument values are repeatable since the difference between two readings is less than the repeatability value of the instrument. Reproducibility (Srp) was calculated in the same way as repeatability. Thus, instrument values are repeatable and reproducible.

4 Conclusion

This article describes the method of development, evaluation and comparative assessment of portable colour meter for measuring colour of the lignocellulosic fibers. Instrument operates based on the principle of photo reflectance and includes components such as a light-emitting diode, photodiode, capacitor, microcontroller, battery, and battery booster. Array of silicon PIN photodiode sensors (BPW34) are placed exactly at the center to sense reflected light and converts it to voltage, which is calibrated for colour value. The readings from the developed instrument were compared with those from commercially available color measuring instruments and showed good agreement with the values obtained from the commercial instruments. Further, instrument measurements are repeatable and reproducible. The instrument developed adheres to BIS standards and can therefore be used to measure the color of jute,

mesta, and kenaf. The developed instrument is battery operated with charge lasting upto two days. With a total weight of 800 grams, the instrument is ideal for conducting experiments in the field, remote locations, and laboratories. The total cost incurred for fabrication was Rs. 15,000. This instrument can be used to measure the colour of other lignocellulosic fibres.

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