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Colorimeter design for dry food-products inspection using TCS3200 sensor and Arduino Mega-2560

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KEYWORDS

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ABSTRACT

This report describes the successful construction of a Colorimeter CK20.1 prototype using a TCS3200 sensor based on the Arduino Mega-2560 microcontroller for solid foodstuffs inspection. The sample color exposed is presented in RGB form. In this experiment, a commercial colorimeter (ColorFlex EZ Spectrophotometer, with the output, is in *L*a*b** form) was applied as a validator of the prototype quality performance on color reading for green beans, wheat flour, palm sugar, ground coffee, and cocoa powder. Data were analyzed for mean comparison using t-test or Mann-Whitney for normally or not normally distributed data, respectively. Before data analysis, the RGB data provided by the prototype was transformed to L*a*b* by the template available from colormine.org and vice versa for the data provided by the ColorFlex EZ. The results showed that color component measurement data from the Colorimeter CK20.1 prototype and the Color FlexEZ were significantly different (p<0.05) for all the foodstuffs observed; however, the color produced by each color component is likely very similar visually. Further development of the CK2.1 prototype is being done to provide a cheap and practical color detector.

Introduction

The role of color in a food product is critical. Color is a sensory factor often used to evaluate a food product because food color relates to the nutritional value of fresh agricultural produce and the level of ingredients changing during processing (Kutlu et al., 2022; Zhou et al., 2022). Color become important for consumers to judge the quality of natural foods (Kennedy et al., 2005). Therefore, color can influence consumers in choosing a food product (Annette and Stafford, 2023)

Distinguishing colors by looking visually alone has not been able to produce accurate measurements for food quality due to some factors, such as lighting conditions and subjectivity (Ammann et al., 2020). Therefore, a food color evaluation might become a solution to determine the food quality (Lan et al., 2022). Nowadays, color-measuring instrument technology to assess the quality of a food product has primarily developed based on the color of the outer or inner parts of the food products and the juice/food extract (Dang et al., 2021; Lan et al., 2022; Thao et al., 2022). Some examples are colorimeters, color analyzers, tintometers, and spectrophotometers. However, the devices are mostly costly (HunterLab, 2023).

In addition, the Arduino microcontroller has become popular because it is an easy-to-use, open-source electronics hardware, and software platform. Arduino boards can read inputs - light on sensors, finger on buttons, turn on LEDs, and print something online. Arduino can also tell what to do by sending instructions to the microcontroller (Arduino, 2022, 2023). Using the TCS3200 color sensor, some color-measurement instruments have been developed by employing the Arduino microcontroller for standard white color (Li et al., 2014; Ratnawati and Vivianti, 2018; Zulkarnain et al., 2019), a television screen service (Chen and Zhu, 1996). In the food system, there is also developing an instrument to detect borax in food (Iwanto et al., 2018), determination of final titration in the titrimetric method (Li and Zhang, 2011), and identify the quality of liquid milk and fruit juice (Pratama et al., 2012).

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This research aimed to develop a simultaneous and automatic color-measuring instrument using a TCS3200 color sensor based on an Arduino Mega-2560 microcontroller, namely CK20.1. The output data plot on a 3.5" Nextion LCD. CK20.1 is expected to function as a chromameter that is easy, inexpensive, accurate, and efficient.

Research Methods

Materials

The materials used are Polylactic Acid (PLA) plastic plates to make colorimeter boxes/containers using a 3D printer. Arduino Mega-2560 made in Italy. The TCS3200 color sensor (made in Austria), HC-SR04 ultrasonic sensor (made in China), 3.5" Nextion LCD (made in China), and jumper cables were obtained from an online store. Screws and bolts were obtained from a material shop in Samarinda. Mung bean seeds were obtained from traditional markets in Samarinda. While palm sugar (Pino brand), wheat flour (*Segitiga Biru* brand), cocoa powder (Roman brand), and ground coffee (*Kopi Kapal Api* brand) were obtained from mini markets in Samarinda.

Experimental design

This research was conducted in three stages: constructing, testing, and validating the colorimeter prototype.

Colorimeter prototype construction

The colorimeter prototype 3D design was created using the Fusion 360 application and printed using a 3D printer. The prototype box material used is PLA plastic type. The prototype consists of two parts, each dimensioned according to the hardware dimensions and the adequacy of sample loading to be tested. The hardware, i.e., Arduino Mega 2560, TCS3200 color sensor, HC-SR04 ultrasonic Sensor, 3.5" Nextion LCD, and jumper cables, are assembled and attached to the container design made.

Arduino® Mega 2560 board accommodates the ATmega2560 microcontroller, which operates at a frequency of 16 MHz. The board contains 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a USB connection, a power jack, an ICSP header, and a reset button (Arduino, 2023).

TCS3200 parameters are supply voltage: 2.7-5.5 V, interface: frequency, Color sensor channels: RGBC, IR blocking filter, programmable color light-to-frequency converter, temperature range (ºC): -40 to 70, package: D pin count 8 (ams-OSRAM AG, 2022).

HC-SR04 ultrasonic parameters are operating voltage: 5V DC, operating current 15 mA, operating frequency 40kHz, min range: 2 cm (1 inc), max range: 400 cm / 13 feet, accuracy: 3 mm, measuring angle: <15ºC, dimension: 45×20×15 mm (Dejan, 2022).

A 3.5" Nextion LCD enhanced type NX4832K035_011N used in this prototype has parameters resistive, color 64K 65536 colors (16 bit 565, 5R-6G-5B), layout size 100.5 mm (L)×54.94 mm (W)×5.45 mm (H), active area 85.50 mm (L) × 54.94 mm (W), visual area 73.44 mm (L) × 48.96 mm (W), operating voltage 5V, operating current 145 mA and 15 mA in sleep mode, resolution 480×320 pixel, backlight LED, weight 38.2 g (ITEAD Studio, 2011).

The Arduino Mega 2560-based microcontroller works under the controller process by coding transferred via Arduino IDE software from a computer device to facilitate the colorimeter to read the sample's color.

Prototype calibration uses two color plates, namely black and white. The calibration plate is generated using the Corel Draw application to get a color that matches the specified value. The value reading on the white plate was adjusted to the RGB value of 255, and the black plate was adjusted to 0, then printed using photo paper for white and black using cover paper.

The power source used is an AC adapter. The colorimeter does not have a power button (on/off) to run the Arduino circuit and the TCS3200 Sensor. Instead, it lights up immediately when the power cable is connected to a power source, indicating that the colorimeter is in the standby position. The color sensor (TCS3200) measures the sample inserted in its place, then the sample color is displayed on the LCD.

Colorimeter prototype test

A serial test tested the colorimeter prototype's performance to adjust the color measurement's high sensitivity by determining the distance between the sample and the TSC3200 Sensor guided by an ultrasonic sensor.

Colorimeter prototype performance validation

A commercial calibrated colorimeter (ColorFlex EZ Spectrophotometer, Hunter Associates Laboratory USA) (HunterLab, 2023) validated the prototype performance by comparing the sample color measurement results.

Table 1. shows the ColorFlex EZ Spectrophotometer specifications. Measurement principle is port up or forward dual-beam

spectrophotometer with directional 45˚ annular illumination or 0˚ display. Sealed optics: 256-element diode array and a high-resolution concave holographic grating. Port/view diameter: 31.8 mm (1.25 in) illuminated/ 25.4 mm (1 in) measured. Spectral range: 400-700 nm. Spectral resolution: < 3 nm. Effective bandwidth: 10 nm equivalent triangular. Reporting interval: 10 nm. Photometric range: 0-150%. Light source: Pulsed Xenon lamp. Flashes per measurement: one flash. Minimum interval between measurements: 3 seconds. Standards conformance: CIE 15:2004, ISO 7724/1, ASTM E1164, DIN 5033, Teil 7 and JIS Z 8722 Condition C. Readable color scales include CIE *L*a*b**, Hunter Lab, CIE *L*C*h**, and CIE XYZ (HunterLab, 2012). The market price of the ColorFlex EZ Spectrophotometer reaches 11,615 USD (HunterLab, 2023).

The validation was carried out in the color component format of RGB and *L*a*b**. The ColorFlex EZ provides *L*a*b** color components, while the prototype provides RGB. Validation was performed using statistical analysis of mean comparison by t-test. Before data analysis, the RGB data provided by the prototype were transformed to *L*a*b** by the template available from Colorizer.org (Colorizer, 2020) and vice versa for the data provided by the ColorFlex EZ Spectrophotometer. The RGB data were input to the conversion template from the website of Colorizer.org to get the *L*a*b** result.

To validate the measurement data provided by Colorimeter CK20.1, a linear regression analysis was performed to determine the correlation with measurement data provided by ColorFlex EZ. This method was performed according to Dang et al. (2021) comparing two types of colorimeters. The regression analysis was run using SigmaPlot v.12.

Results and Discussion

Colorimeter CK20.1 prototype specification

The resulting colorimeter prototype is named Colorimeter CK20.1, which consists of a sample container and a microcontroller housing. Table 2. shows the specifications of the Colorimeter CK20.1 prototype. The sample container has a dimension of 12.0×4.5×5.5 cm, and the microcontroller container has dimensions of 12.0×8.0×9.0×3.0 cm for length, width, front height, and rear height, respectively (Figure 1 and Figure 2). Figure 3 presents the colorimeter prototype hardware assembly.

The advantage of the Colorimeter CK20.1 prototype is that it is cheap and consumes relatively low electric current. For example, it operates under a 5V output cellphone charger, laptop, or power bank. In addition, the CK.20.1 prototype is portable and light. However, the weakness is the proximity sensor, which is still manually operated, and the TCS3200 Sensor, which still has limited capacity in color reading.

Table 1. Commercial color analyzer ColorFlex EZ specification*

Parameters	Specification
Weight	4.5 kg (9.9 lb.)
Dimension (height x weight x length)	16 cm x 13 cm x 36 cm (6.3-in x 5.1-in x 14.2-in)
Communications Interface	-USB OTG to computer
	-USB A to Keyboard, printer, barcode scanner
Standards Conformance	CIE 15:2004, ISO 7724/1, ASTM E1164, DIN
	5033, Teil 7 and JIS Z 8722 Condition C
Safety Compliance	UL, CSA, IEC, or equivalent
System Power	100-240 VAC/0.4A, 47-63 Hz

*) HunterLab (2023)

Table 2. Colorimeter CK20.1 specification

Parameters	Specification
Weight	450 g
Cover dimension of Arduino (h × w × l)	9.0 cm × 8.5 cm × 12.5 cm
Sample box dimension (h × w × l)	12.0 cm × 5.8 cm × 7.5 cm
Interface communication	USB printer to a computer
Touchscreen	Yes (Resistive type)
Memory capacity	256 kB
Reading distance	2-7 cm
System Power	Power cable/USB printer (current consumption 5V/0.6A)

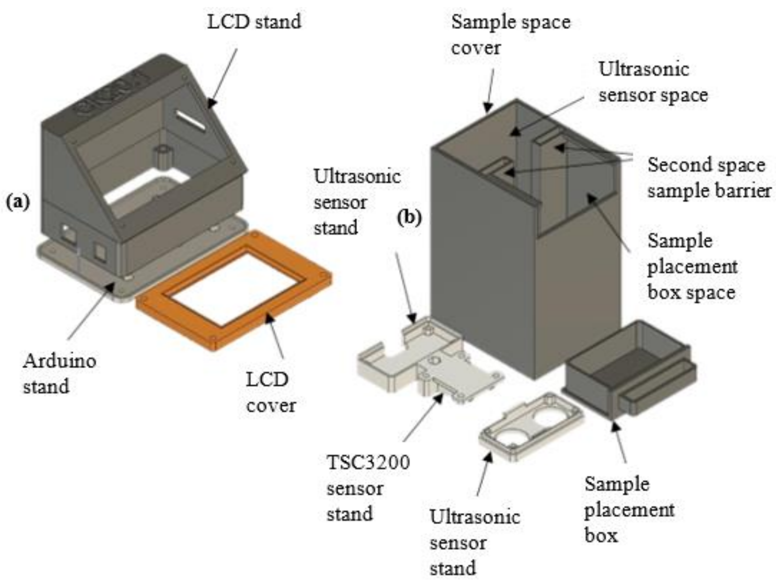

Figure 1. Colorimeter CK20.1 prototype design. Arduino box (a), Sample box for color identification (b).

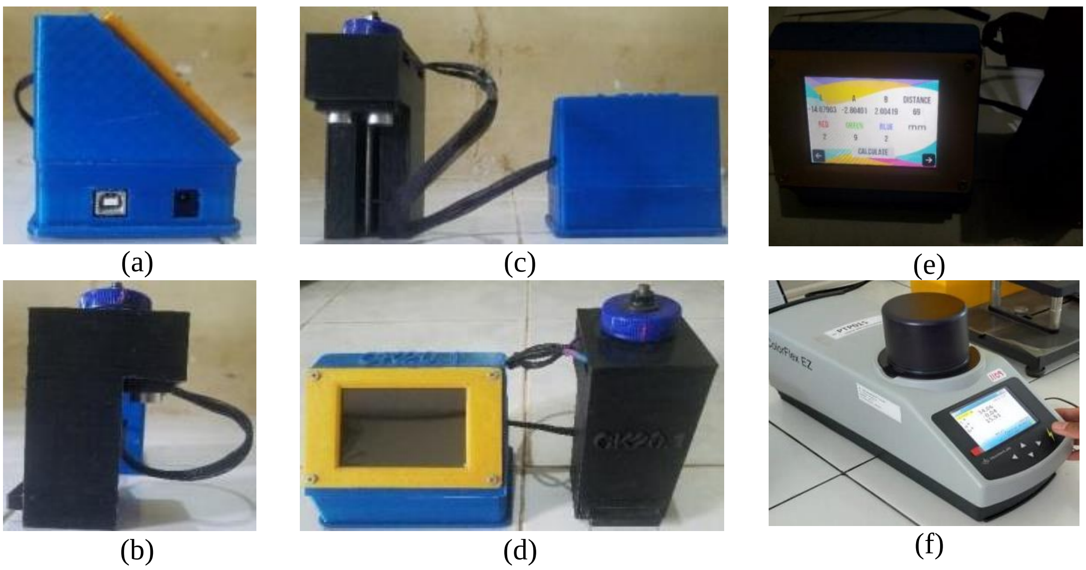

Figure 2. Colorimeter CK20.1. prototype design performance: left side (a), right side (b), rear side (c), front side (d), color identification (e). ColorFlex EZ design performance during operation (f).

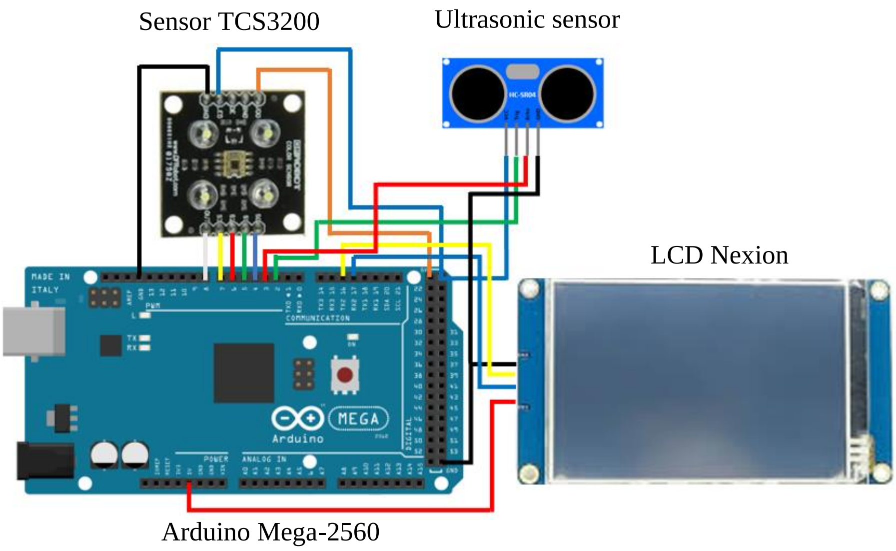

Figure 3. Colorimeter CK20.1 prototype hardware circuit

Color reading performance of colorimeter CK20.1 prototype

The construction of the Colorimeter CK20.1 prototype is based on the RGB provided by the Corel Draw application, as described in the design experiment. The color reading performance of Colorimeter CK20.1 started following the pre-conditioning of the prototype by warming up for at least one minute to ensure that the prototype was running normally and well. The color sensor of the CK20.1 prototype works well, indicated by a large and small R-value of the TCS3200 Sensor in response to light and dark colors, respectively.

The distance between the sample and the color sensor strongly influences the color measurement results of the CK20.1 prototype. In this study, the CK20.1 prototype has an ultrasonic sensor as a sample distance meter, with a reading range of 20-70 mm, to obtain the optimal distance between the color sensor and the sample. A space that is too close reduces the sensitivity of the TCS3200 Sensor in measuring the color components (RGB values) (Table 3.).

Table 3. RGB measurement data from some solid foodstuff at various sample distances using Colorimeter CK20.1 prototype

Distance (mm)	**Mung beans**			**Wheat flour**			**Palm sugar**			**Ground coffee**			**Cocoa powder**		
	R	**G**	**B**	*R*	*G*	*B*	**R**	**G**	**B**	*R*	*G*	*B*	**R**	**G**	**B**
20															
Mean	226	202	179	255	255	255	233	140	102	153	77	55	249	176	156
SD	3	2	1	0	0	0	3	2	3	2	3	4	2	4	1
25															
Mean	169	149	125	255	255	255	176	95	66	127	62	47	215	145	128
SD	3	2	3	0	0	0	2	2	2	2	2	2	1	2	2
30															
Mean	123	111	87	255	255	255	164	81	51	92	38	23	184	119	101
SD	2	2	2	0	0	0	2	3	3	5	7	5	3	1	4
35															
Mean	86	83	61	255	255	255	121	55	32	82	38	24	152	92	76
SD	2	4	3	0	0	0	3	2	2	1	3	4	2	1	3
40															
Mean	69	59	38	248	237	254	104	54	40				119	79	62
SD	1	1	2	1	1	1	4	1	3				3	1	3
45															
Mean				213	210	223							123	76	71
SD				2	2	2							3	3	4
50															
Mean				157	153	162									
SD				3	2	3									

Note: Data obtained from 6 measurements

The TCS3200 Sensor consists of four photodiode groups. Each group has a different sensitivity in the photodiode response to reading the wavelength of the light. For example, the photodiode that detects red and clear has a high sensitivity value when it detects light intensity with a wavelength of 715 nm.

In comparison, at a wavelength of 1,100 nm, the photodiode has the lowest sensitivity value, which explains that the TCS3200 Sensor is not linear and has a sensitivity that changes with the measured wavelength of light (Styandi et al., 2019). Therefore, it is necessary to determine the ideal conditions for measuring the right sample color, which could be resolved through data validation using the results of sample color measurements using a commercial colorimeter.

A test of the CK20.1 prototype in an external environment with different light intensities (bright and dark) provided a good performance, indicated by an insignificant difference in RGB values. This result suggests that the design of the container for the sample color measurement is light-tight, which is vital because the TCS3200 color sensor has weak performance in light environments (Usman, 2005).

Table 4. Measuring food color using a commercial Color Analyzer ColorFlex EZ and Colorimeter CK20.1 prototype

***Foodstuff* / colorimeter type**	**Component color type**					
	R	G	B	*L**	*a**	*b**
Mung beans						
ColorFlex EZ (y)	89.11±0.03b	79.31±0.01a	54.85±0.05a	34.07±0.01a	-0.07±0.02b	15.94±0.03b
CK20.1 (x)	85.50±1.90a	83.30±2.58b	61.10±2.51b	35.06±0.82b	-3.23±1.85a	13.47±1.96a
Linear regression	y=88.835-0.00323x	y=79.653-0.00409x	y=55.376-0.00861x	y=34.230-0.00466x	y=-0.0744-0.00136x	y=16.006-0.00480x
R^2	0.0576	0.572	0.159	0.320	0.0258	0.123
Wheat flour						
ColorFlex EZ (y)	213.64±0.04a	204.75±0.03a	189.51±0.03a	82.64±0.01b	0.49±0.01a	8.67±0.01b
CK20.1 (x)	212.80±1.23b	210.60±1.51b	222.60±1.71b	84.91±0.33a	2.99±1.17b	-5.70±0.96a
Linear regression	y=211.419-0.0104x	y=204.153-0.00284x	y=189.075-0.00197x	y=82.304+0.00391x	y=0.483+0.00217x	y=8.666-0.00135x
R^2	0.119	0.0237	0.0165	0.0177	0.145	0.0239
Palm sugar						
ColorFlex EZ (y)	102.92±0.03b	62.44±0.03b	29.09±0.08a	30.54±0.01b	14.33±0.02a	27.33±0.04b
CK20.1 (x)	101.00±1.70a	54.70±2.11a	33.90±2.51b	28.35±0.60a	18.50±1.51b	23.00±3.64a
Linear regression	y=103.267-0.00346x	y=62.987-0.00993x	y=29.447-0.0106x	y=31.022-0.0168x	y=14.275+0.00317x	y=27.329+0.000234x
R^2	0.0486	0.386	0.115	0.760	0.0724	0.000407
Ground coffee						
ColorFlex EZ (y)	67.85±0.03b	41.86±0.03b	26.10±0.12b	19.82±0.01b	10.09±0.03a	15.19±0.07a
CK20.1 (x)	62.70±2.00a	31.70±4.83a	14.10±7.28a	16.14±1.61a	13.00±2.11b	17.67±2.57b
Linear regression	y=67.828-0.000305x	y=41.889-0.000980x	y=26.115-0.00121x	y=19.848-0.00177x	y=10.137-0.00339x	y=15.306-0.00640x
R^2	0.000316	0.0184	0.00544	0.0821	0.0534	0.0504
Cocoa powder						
ColorFlex EZ (y)	114.75±0.02a	79.00±0.02	54.92±0.05a	36.92±0.01a	11.97±0.02a	20.19±0.03b
CK20.1 (x)	118.40±2.68b	78.40±1.35	61.10±2.60b	37.35±0.26b	14.64±1.71b	17.13±1.64a
Linear regression	y=114.713-0.000311x	y=78.940-0.000732x	y=55.223-0.00494x	y=37.190-0.00729x	y=11.909-0.00428x	y=20.280-0.00571x
R^2	0.00129	0.00257	0.0661	0.0924	0.188	0.120

Note: Data (mean±SD) were obtained from 10 measurements. Data were converted from the value "RGB" to "*L*a*b**" or vice versa using a color converter from colorizer.org (Colorizer, 2020). The color component of each commodity followed by different letter indicates a significantly different (p<0.01, Mann-Whitney Rank Sum Test) between measurements by CK20.1 and Color Flex EZ.

Colorimeter prototype validation

Compared to the CK20.1 prototype, the ColorFlex EZ Spectrophotometer has a Xenon lamp as the light source. The xenon lamp shoots the sample surface, which is then reflected toward the spectral Sensor. In addition, the light measurement uses six high-sensitivity silicon photocells with a double-back beam system reflected by the sample (Ririn and Usman, 2011). According to Hunter Lab (HunterLab, 2012), an *L* value with a range between (0-50) indicates color darkness, then an *L** value with a range between (51-100) indicates color brightness. Therefore, the three attributes of the Hunter Lab color system are *L*a*b**. The *L* value indicates the brightness of the sample with *a* value from 0 to 100. The *a** value indicates the degree of red (*a*+) or green (*a*-) green with a value scale from -80 to 100. Finally, the value of *b** indicates the degree of yellow (*b*+) or blue (*b*-) with a value scale from -70 to 70. The ColorFlex EZ Spectrophotometer was calibrated using a white plate before use (Meutia et al., 2019).

The difference of color type result between the prototype and the validator (ColorFlex EZ), a vice versa validation were conducted using the color characteristics transformation from RGB to *L*a*b** and vice versa provided Colorizer.org as described in the experiment design. Validation the sample color readings results from the Colorimeter CK20.1 prototype with ColorFlex EZ Spectrophotometer shows that color readings for samples that have 35-45 mm from the TCS3200 Sensor produce the closest data. For green beans, ground coffee, cocoa powder, brown sugar, and wheat flour, the data from CK20.1 is the closest to the ColorFlex EZ data, respectively, which are 35, 36, 40, 41, and 45 mm. However, the results for measuring the color of the samples produced by CK20.1 and ColorFlex EZ were significantly different (p<0.01) (Table 4.). The correlation between the data provided by Colorimeter CK20.1 and ColorFlex EZ is also very poor, which is proved by the low R^2 value of each color component (Table 4.). These results suggest that the color reading quality of the CK20.1 prototype is lower than the performance of a commercial colorimeter (ColorFlex EZ spectrophotometer). Dang et al. (2021) demonstrated the validation between the self-design Colorimeter and the commercial one using the correlation of each color component by linear regression with a correlation power (R^2) value of 0.77-0.99.

Conclusion

A prototype design of a Colorimeter CK20.1 using the TCS3200 color sensor and Arduino Mega-2560 is potentially developed into a commercial colorimeter. Although the color components resulting from a control commercial ColorFlex EZ Spectrophotometer were significantly different, the color visualization is likely very similar. Developing coding might increase the accuracy of the Colorimeter CK20.1 prototype in color detection.

Declarations

Conflict of interests The authors declare no competing interests.

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