The performance of the C12880MA MEMS sensor for classification of the roasting level of coffee bean

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Abstract. The cupping test has been widely used to assess the roasting level of coffee to produce high-quality coffee beans. However, the method requires a longer process and sophisticated sensory analysis. The procedure could only be assessed by the certified panellist. Lately, commercial microelectromechanical system (MEMS) technology has been developed, which could be used for building a small spectrometer sensor. This gives the opportunity to adopt bench-top spectrometer sensing into the low-cost portable sensor. This research aims to study the performance test on the C12880MA MEMS sensor to determine the level of roasted coffee. A total of 90 samples from each 30 medium roasting level (Light to Medium, Medium, and Medium to Dark) was prepared. Spectrum data of samples were measured using a C12880MA sensor ranging from 312.162nm to 868.503nm. Linear Discriminant Analysis (LDA) was performed to classify the roasting level. The result showed that both LDA using full-spectrum and interval spectrum gave 100% accuracy with no falsely classified.

1. Introduction
A cupping test is an essential stage to determine the quality of the roasted coffee bean. The procedure relies on identifying sensory parameters comprising aroma, flavor, after test, acidity, viscosity, balance, uniformity, sweetness, clean up, and overall test [1]. Using the certain protocol, Specialty Coffee Association protocol, for instance, professional panelists will assess all the sensory parameters of the sample to understand the quality of roasted coffee beans [1]. However, the process is lengthy, high-cost and requires professional panelist [2] who is limited in Indonesia. Besides, the increase of demand for high-quality coffee beans is unequal to its production [3]. Not rare, low experienced panelists get involved in the cupping test process to cut short coffee bean production [4], which could lower the quality of coffee beans. Even further, in some cases during cupping tests, psychology and gender contribute to different sensorial analyses [4], which would lower the uniformity of high-quality coffee. Therefore, it is important to develop technology as an option to assess the quality of roasted coffee that is rapid, low-cost, and resulting in uniform quality.

Research confirms that the use of bench-top UV/Vis spectroscopy has positive interaction on important chemical components in coffee beans such as caffeine (CF), chlorogenic acid (CGA), and caffeic acid (CFA) [5, 6]. Tandem with chemometrics analysis, UV/Vis spectroscopy can be used as a method to predict chemical compounds of agricultural products [7,8,9]. Other than that, the presence of Micro Electro Mechanical Systems (MEMS) UV/Vis sensor (compact-sized sensor operating in...
ultraviolet to visible spectrum) attracts many researchers to utilize the technology to build a low-cost customized instrument to replace the use of bench-top UV/Vis spectrometer [10,11]. So, it opens the possibility to develop a low-cost instrument that could predict the quality of roasted coffee beans rapidly. This paper will emphasize the use of MEMS UV/Vis sensor (Hamamatsu, C12880MA) as a basic component to classify several levels of roasted coffee beans.

2. Material and methods

2.1. Sample preparation
Green bean of Arabica coffee was collected from Arjuna Mountain, Malang, Indonesia. 1.5 kg of the bean was cleaned and transported to the Morning Roast roasting workshop for further roasting then, cupping test process was conducted in Amsterdam Coffee, Malang. 3 different Medium Roasting Levels, Light to Medium (LM), Medium (M), and Medium to Dark (MD), were prepared. To get the Medium Roasting level, the roasting drum was firstly heated until 160°C. The green coffee bean was then put on it, so the temperature of the bean would decrease to 150°C to reach the first crack. 3 levels under Medium Roasting level were obtained by continuing heating process until the bean reached 162°C roasted for 12 minutes, 165°C roasted for 14 minutes, and 168°C roasted 18 minutes for Light to Medium, Medium and Medium to Dark respectively. During roasting, the bean would experience a development process to attain the same roasting level between the outer part and its flesh bean.

2.2. Instrument development
Instrument development was conducted in Power and Agricultural Machinery Laboratory, Department of Agricultural Engineering, Universitas Brawijaya. A main functional part of the instrument consists of a MEMS UV/Vis sensor (Hamamatsu, C12880MA) to obtain spectral data, 1 W blue LED as a light source, a Bluetooth module to transfer spectral data, and a microcontroller to activate all components. All electrical parts were then assembled into Polyactic acid (PLA) cup-like electrical enclosure, which fabricates using a 3D printer Original ANET A8. The diagram of the instrument is shown in Figure 1.

![Figure 1. Block diagram of instrumentation system.](image)

2.3. Spectral acquisition algorithm
In order to activate all electrical components, the acquisition algorithm (Figure 2) was designed using Sketch software using C++ based programming language before it was then uploaded into the microcontroller. When the trigger button was activated, the light source would emit light, and the C12880MA sensor was activated to obtain spectral data in the form of light transmittance. The spectral
data were wirelessly transferred to a personal computer using Bluetooth. To study the optimum light source, 5 different LEDs (Red, Green, Blue, Yellow, and White) were omitted.

![Figure 2. Acquisition algorithm of system.](image)

2.4. Sampling procedure

This study was initiated for further sensory analysis (cupping test), which was influenced by the brewing condition. Therefore the C12880MA sensor would obtain spectral data of brewed coffee in the cuvette (Figure 3). Ninety total samples were prepared for spectral acquisition using the instrument. Each sample was ground and brewed to obtain 1 cup of coffee liquid for testing. 1 cup of coffee liquid was brewed with 10 grams of ground coffee bean and 180 ml of hot water with a temperature of 95°C. The sample was stirred and kept for 4 minutes. Then it was filtered using filter paper and placed into a cuvette on the instrument. Then, the spectral data were obtained and sent to a personal computer in a CSV format file for chemometrics analysis.

![Figure 3. Sampling setup.](image)

2.5. Linear Discriminant Analysis (LDA)

Linear Discriminant Analysis (LDA) was performed using The Unscrambler 10.3 Trial version. LDA was used to classify the samples by maximizing the distance between means of category then minimizing the variation (scatter) within each category. LDA will reduce the dimension of the dataset into a new linear projection to classify categories [12,13]. Here, spectral data was set as classification input while 3 roasting levels (Light to Medium, Medium, and Medium to Dark) were set as a category. To understand the performance of the LDA model, accuracy and confusion matrix will be examined [8].

3. Results and discussion

3.1. The design of the instrument

The prototype of the instrument is packed into a cup-like enclosure, as seen in Figure 4. The instrument consists of (a) cup lid as a barrier to incoming light, (b) top case which contains (c) a UV/Vis sensor to capture the transmittance of the sample, (d) cuvette as a sample container for placing liquid samples, and (e) LED as a light source. And on the handle (f) is equipped with an on/off switch and push-button to run the instrument. (g) The bottom case separated from the top case to put electronic components. (h) LED indicators to indicate the instrument is active.
3.2. Wavelength resolution and spectral response

The commercial C12880MA sensor had a spectral response from 350nm to 780nm. However, it might vary depending on its serial number, which should be calculated using the calibration coefficient on the datasheet. C12880MA sensor captured light intensity from 288 points (pix) ranging from UV to Visible spectrum [14]. The 1st to 288th pix measurement was converted into wavelength using Equation 1, so it would generate 312.162nm to 868.503nm. Even though the sensor could capture light intensity in UV to visible spectrum, sensor characteristics showed the most sensitive region around 400nm to 500nm [14]. Therefore blue LED was used as a light source for spectral acquisition data. In every wavelength measurement, the sensor would capture light transmittance (obtained transmittance) as 10-bit digital data varied from 0 to 1023. Equation 2 was used to change 10-bit data into 0-1 absorbance response.

\[
Wavelength (nm) = A_0 + B_1 \times pix + B_2 \times pix^2 + B_3 \times pix^3 + B_4 \times pix^4 + B_5 \times pix^5
\]  

(1)

Calibration coefficient C12880MA sensor, serial no 17F00046:

\[
\begin{align*}
A_0 &= 3.094635399E+02; & B_1 &= 2.699236630E+00; & B_2 &= -1.245721966E-03 \\
B_3 &= -6.022781484E-06; & B_4 &= 1.337962431E-09; & B_5 &= 9.917921897E-12
\end{align*}
\]

Absorbance = 

\[- \log_{10} \left( \frac{OT \times \frac{1}{1023}}{\text{1023}} \right)\]

(2)

Where:

\[OT = \text{obtained transmittance}\]
3.4. Spectral analysis and classification using LDA

During roasting, the physicochemical compound, including colour of the coffee bean, would change due to the Maillard reaction. High roasting temperature can cause Maillard, which allows reaction between certain amino acids such as chlorogenic and reducing sugar creating brown color [15,16]. As the MD level of the coffee bean was processed by the highest temperature, the intensity of the brown color of MD was also the highest, allowing more light to absorb than in the case of M and LM. As seen in Figure 5, there was spectral shifting on MD. This was because there was retention sampling time for MD that caused changes in a certain chemical compound on the coffee bean. However, chemometrics analysis relies on spectral shape (fingerprint) in order to classify three roasting levels. Thus, it did not create changes in the classification of three roasting levels. Two configurations of the spectrum (317.55nm-859.29nm for full-spectrum and 450.64-561 nm for interval spectrum) were compared to identify the best classification.

![Figure 5](image.png)

**Figure 5.** The spectrum of coffee in using blue LED at 3 roasting levels.

From total datasets, 2/3 of data was used for developing calibration model while 1/3 of data was set as a prediction. Thus, in 90 total samples, 60 samples were used as a calibration and 30 samples as a prediction. LDA was performed to classify three different roasting levels. As seen in Figure 6A, using full-spectrum, the three roasting levels were well separated based on each class. Also, LDA using partial spectrum (Figure 6B) could classify the roasting level. Two spectrum configurations provide 100% accuracy when classifying the sample, but LDA using interval spectrum had wider boundary between M and LM than using full spectrum. This indicated that LDA model using interval spectrum had better performance to correctly classify roasting level of future samples. This finding was in-line with some studies stating that interval spectrum will eliminate uncorrelated spectrum, only the most effective spectrum was utilized to build a model and as a result interval spectrum gave better performance of chemometrics model than full spectrum [9,17]. Therefore, for practical use, LDA using interval spectrum could be better for classification.
Figure 6. LDA Plotting Result for (A) Full Spectrum and (B) Interval Spectrum.

Other 30 samples comprising 10 sample of each roasting level were used to validate the LDA model. As shown in Table 1, both LDA using full-spectrum and partial spectrum could classify the roasting levels well by the model with 100% of accuracy. This finding indicated that the C12880MA sensor tandem with LDA provided a highly correlated model to classify roasted coffee beans, and this opened the opportunity to do further study in quantifying sensory analysis using the sensor.

| Spectrum Configuration | Actual Category | Predicted Category, Calibration sets (n=60) | Predicted Category, Prediction sets (n=30) |
|------------------------|-----------------|---------------------------------------------|--------------------------------------------|
| full Spectrum          | Light to Medium | 20 0 0                                      | 10 0 0                                     |
|                        | Medium          | 0 20 0                                     | 0 10 0                                     |
|                        | Medium to Dark  | 0 0 20                                     | 0 0 10                                     |
| Interval Spectrum      | Light to Medium | 20 0 0                                     | 10 0 0                                     |
|                        | Medium          | 0 20 0                                     | 0 10 0                                     |
|                        | Medium to Dark  | 0 0 20                                     | 0 0 10                                     |

Table 1. Confusion matrix of three roasting levels using LDA.

4. Conclusions
Testing the performance of the C12880MA MEMS UV/Vis sensor has been conducted. The result showed that spectral response from the sensor with Blue LED tandem with LDA resulting promising results to classify 3 different levels of roasted coffee bean. For future works, a quantification experiment would be conducted.
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