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INTELLECTUAL PROPERTY ACT NO. 36 OF 2003

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Title of Invention: A multi spectral imaging system to measure transmittance spectrum

Dear Sir/Madam,

<u>Acknowledgment of Application for the Grant of a Patent</u>

(1) It is here by acknowledged that your application for the grant of a patent under the above title has been received by this office. The application is being processed.

(2) The above mentioned number has been allocated to your application. Reference must be made to that number in all correspondence addressed to the Director General.

Yours faithfully,

Anoka Rodrigo

For Director General of Intellectual Property

DESCRIPTION

I. Title of the Invention

A Multispectral Imaging System to Measure Transmittance Spectrum of Translucent Liquids.

II. Technical field

A multispectral image is a collection of monochrome images corresponding to discrete wavelengths of the electromagnetic spectrum, namely in the infrared to ultraviolet. Since, a multispectral image has spectral information beyond the visible range, it can provide more information than an RGB image.

The absorption by and the transmission through a material depends on its physiochemical properties. Theoretically, when an electromagnetic wave (from an illumination unit) is incident on the interface of a translucent medium, the wave is either partially or totally reflected and the rest propagate in to the medium. A proportion of the propagated amount will be absorbed to the material whilst the remaining is transmitted through the material. These phenomena are referred to as optical properties and are useful for characterization as well as for identification of translucent materials. Aforementioned optical properties are analogous to energy transmission through and absorption by the cellular structure of the material.

This information can include physical and geometric observations of size, orientation, shape, color and texture, as well as chemical/molecular information such as water, fat, protein and other hydrogen-bonded constituents. However, the combination of two features (spectral and spatial) is not trivial, mainly because it requires creating a three-dimensional data set that contains many images of the same object, where each one of them is measured at a different wavelength.

III. Background art

A number of researches has been published on determining the quality of edible liquids. In the paper "Research on Edible Oil Quality and Safety System", by Lei Maochang, the quality of edible oil with respect to adulteration, illegal additives, lack of manufacturing standards and problems on raw materials has been presented. The authors of the paper "Physio-chemical parameters for testing of water – A review" Patil. P.N, Sawant. D.V, Deshmukh. R.N presented different parameters such as temperature, acidity, hardness, pH, sulphate, chloride, DO, BOD, COD, alkalinity that can be used to assess the quality of water. Most of the water quality testing procedures that were explained by the authors involve chemicals and the processes are tedious. To perform such analysis it requires human skills, therefore the analyses are not cost effective. The naked eye has color receptors for three wavelengths therefore the spectral information captured by the eye is either less or none. However, techniques for capturing information from bands such as infrared are developed and the most common technique is Fourier-transform infrared spectroscopy (FTIR) which is used to obtain the absorption or emission spectrum. In 2017, Abdul Rohman has presented a paper on "Infrared Spectroscopy for Quantitative Analysis and Oil Parameters of Olive and Virgin Coconut Oil: A Review". In this paper, a method to determine the changes of oil parameters through the changes in infrared spectra has been reviewed. In addition to this how infrared spectroscopy is combined with chemo metrics for quantitative analysis and determination of oil parameters of virgin coconut and extra virgin olive oil has been reviewed. Toshifumi Uchiyama introduced a new method to classify the water samples based on the purity with a UV-Vis spectrophotometer and a 30 cm pathlength cell utilizing the absorption spectrum of water samples. The authors of the paper 'Application of quality control methods for assessing wine authenticity: Use of multivariate analysis (chemometrics)' have summarized wine quality analysis methods such as chromatography, spectroscopy. The main drawback of these kinds of studies is the involvement of high initial investment due to the expensive equipment which is not a part of our invention.

The FTIR method is a time-consuming laboratory experiment and the need for a method that can be performed on site is necessary. Multispectral imaging systems used for this which are capable of acquiring information from discrete bands from a range of spectral bands. In the paper "Hypercam: Hyperspectral Imaging for Ubiquitous Computing Applications" by Mayank Goel et al a multispectral imaging system is presented to measure the reflectance from object's surface. The system consists of a camera and an LED array of selected bands. In the US patent No.10126242, a method for "Pure Spectrum Extraction from Biological Samples in Fluorescence Multispectral Imaging" has been introduced. In this method, image information for a sample that includes a fluorescent dye is obtained from the setup.

In the paper, "Multispectral Imaging Using LED Illumination and an RGB camera" by Raju Shrestha et al, has proposed a method to acquire multispectral images through combinations of selected bands. The method involves the responsivity of the camera to different wavelengths and the illumination of each LED for each combination. In 2018 Yang Chen et al has presented a method to establish an identification model for edible oil types in the paper "Identification of Edible Vegetable Oil Types Based on Multi-kernel Learning and Multi-spectral Fusion" This method has used serial and wavelet fusion approaches to fuse Raman and near infrared spectral data.

In the paper “Oil Adulteration Identification by Hyperspectral Imaging Using QHM and ICA” by Zhongzhi Han et al has presented a method to identify adulteration level using hyperspectral images acquired under ultraviolet and halogen excitations. In the US patent No. 9759704, “Device and Process for Oil Quality Monitoring Based on Light Waves”, a system and a process for detecting oil quality using a light source and a sensor. The inventor has proposed different arrangements to monitor the quality standards of translucent samples. In this method as light is traversed through the oil in the oil container and sensor is used to capture the return signal. This signal is used for quality determination. The invention proposed in the above patent can only be used to capture the local variation of the liquid sample so that the sensor reading may be not able to correctly recognize the quality parameters. In our invention we eliminate that drawback by designing the system such a way that it captures the global variation of the sample so the effect of the heterogeneity can easily be addressed.

IV. Technical problems

Assessment of food quality is a major concern in today’s food and beverage industry because of public health concerns and customer satisfaction. Consumers are more and more concerned about the safety of the food they purchase in the modern society. In the context of multispectral imagery most researches are done based on reflective properties of the opaque material. However, this method is loosely applicable for liquids since most of them are translucent, therefore light penetrates the liquid. The conventional food quality assessment methods include wet chemical methods and FTIR spectrograph, though these methods are highly laborious, time consuming, invasive and manually operated.

Although multispectral cameras with high spectral and spatial resolutions are available, they are quite expensive. Therefore, implementing such a multispectral imaging system for the use of a small or a medium scale industry is not commercially viable. At the same time, depending on the application it may not require a multispectral camera with higher spectral and spatial resolution that eventually leads to a higher cost and computational complexity.

V. Technical solutions

Here a low-cost multispectral imaging system to measure the transmittance spectrum of food samples was developed. This imaging system has the capability of capturing multispectral images from ultraviolet (UV) to near infrared (NIR) having a resolution of several spectral bands and number of bands and wave length of the bands can be adjusted according to the application. This multispectral imaging system was developed based on 9 wavelengths selected from ultraviolet (UV) to near infrared (NIR) region of the electromagnetic spectrum. As shown in figure i, the system comprises of several components. The detailed description of the invention is given in the section VIII.

VI. Brief description of drawings

Figure i shows the multispectral imaging system which is used to capture the transmittance spectrum of a sample.

Figure ii shows the power spectral density distribution curves of the LEDs used in the LED switching circuit.

Figure iii describes the procedure of capturing the 9-dimensional spectral images.

VII. Advantageous effect

The conventional methods to evaluate the quality of liquid-based food quality are time consuming, invasive, destructive and manually operated. Therefore, a need to perform this evaluation in an accurate, faster and a cost-effective manner has arisen. In this product, we present a way to assess the quality of a liquid based food in real time with high accuracy using a low-cost multispectral imaging system utilizing transmittance spectra.

VIII. Mode for invention

We have developed a multispectral imaging system which measures the transmittance spectrum of edible oils (liquids). This device can be used determine the edible oil quality in a non-invasive and non-destructive manner.

In the following sub sections A-G ; the comprehensive description of the components of the invention is given.

A. Monochrome Camera

The sensing device used for the MSI system was the ‘FLIR Blackfly S Mono, 1.3 Megapixel, USB 3 Vision monochrome camera’ (part number BFS-U3-04S2C-CS). The device is relatively inexpensive, and consumes low power which is around 3W. The camera was made up with an ON-semi python 1300 CMOS sensor which is able to capture the images at a resolution of 1280×1024 pixels. A 10-bit analog to digital converter was used to digitize the sensor readings. For the camera a Fujinon YV3.3x15SA-SA2 lens was used which has a variable focal length of 15mm to 50mm.

B. LED Switching Circuit and Controller Board

The stimulation method used for the imaging system was LED illumination. For this, a selected number of wavelengths were chosen as suggested in literature to optimize the information extracted and the cost of the unit. The LED switching circuit has nine light emitting diodes for each spectral band as described in Table i. A locally developed AC regulated 12V DC power supply unit is used to provide the required power to the LED driver ICs (MAX16839ASA+). Power spectral densities of the nine bands LED system are shown in Fig. ii.

Table i - Details of the led array system

LED Number	Part Number	Manufacturer	Dominant wavelength (nm)	Emitting spectral band(nm)	Half power bandwidth(nm)
1	VLMU3100	Vishay	405	375 – 425	10
2	SM0603BWC	Bivar	430	385 - 525	50
3	SM1204PGC	Bivar	505	450 – 550	20
4	5973209202F-ND	Dialight	590	520 – 620	10
5	5975112402F	Dialight	660	630 – 685	20
6	QBHP684-IR4BU	QT Brightek	740	690 – 760	20
7	VSMY2850G	Vishay	850	825 – 875	10
8	VSMF4710-GS08	Vishay	890	865 – 915	10
9	VSMS3700-GS08	Vishay	950	915 - 1000	20

C. Integrating Hemisphere and Dark Chamber

In spectroscopy it is necessary to have a uniform intensity distributed on the incident surface. This was achieved with an integrating hemisphere which is made up of aluminum with an inner diameter of 130mm. In addition, the hemisphere was used to focus the most of the light waves from the illumination unit onto the sample. The monochrome has different spectral responses for various wavelengths. Hence, it is important to inhibit any leakages onto the sample from the external environment which could corrupt measurements. In order to mitigate these interferences a dark chamber was designed to confine exposures and to take spectral images in a controlled environment and a sequence. With this hardware setup no further corrections were required for physical interferences.

D. Computerized Controller System

A computerized controller system was needed to automate the process of capturing the images, powering up the camera and maintaining the synchronization between the LEDs and the camera shutter time. The controller required 2 USB type A ports, one port connected to the camera and the other connected to the LED controller board.

E. Discovery Board and USB to UART Converter

A discovery board (STM32F0) was added to the design which acts as an intermediate controller in between the LED controller circuit and the computerized controller system. Once a computerized controller sends a signal, initially it reaches to the converter (FT232R) where it gets converted to an UART signal. Thereafter, the discovery board sends LED drive signals based on received signal through the converter.

F. Calibration

A specific procedure was followed for the calibration which is known as the reflectance calibration, of the proposed MSI system. Two reflection standards were used as the references; a high reflective white ceramic plate as the white reference and plate covered with lamp soot as the black reference plate. Non uniformity of the images due to the spatial irregularities was taken care by capturing 6 sets of images of each of the black and white references while they were rotated. Then the averaged value of the two image sets was taken as the white (W) and the black (B) references. Finally, the normalized intensity (I) of each pixel was calculated from the raw image pixel (R) using equation (1). The exposure of the camera lens was adjusted appropriately to avoid saturation.

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

G. Operation

When the camera is turned on, a command is sent through an UART communicator to the LED controller board (discovery STM32F0) to turn on the first LED. Next the controller board sends a signal to the corresponding LED driver IC and the driver IC changes its state and lights up the corresponding LED. Finally, the camera is instructed to capture the image and store it in the computer. This procedure is repeated until the all 9 multispectral images are captured as shown in the flowchart Fig. iii.

The following case studies show, how the aforementioned imaging system can be used to assure the quality standards of translucent consumables namely coconut oil and water.

Case study 01 – Coconut oil quality assessment

Within the present food industry, the demand for coconut oil is immense. The difference in market share and costs are often exploited by producers and distributors. To reduce the cost of production, the most common fraudulent activity which can be seen is adulteration with palm oil. Detection of the palm adulterant becomes quite difficult because palm oil has similar physical and chemical characteristics to coconut oil. For this case study authors have considered adulteration of coconut oil with palm oil as the adulterant. Since oil is transparent, the transmittance spectrums of the oil samples were measured by the MSI system using the configuration as per figure i.

Authentic coconut oil was obtained from a reputed producer and nine sample sets were prepared by mixing coconut oil with palm oil in different adulteration ratios $0\%,\ 5\%,\ 10\%,\ 15\%,\ 20\%,\ 25\%,\ 30\%,\ 35\%,\ 40\%$ For each sample, three sets of multispectral images were captured using the imaging system. For this study, a window size of 30×30 was captured from each multispectral image to compute the data matrix. Then FDA was performed on the data matrix to increase the separability in each class. the nine-dimensional original data set was projected to the low dimensional space of five dimensions using the eigenvectors computed in the FDA step. Then, the Bhattacharya distance was calculated with respect to the 0% adulterated sample. The functional relationship between the statistical metric (Bhattacharya distance) and the adulteration was modeled using a 2-degree polynomial given by $b = 0.01094p^2 + 2.202p$ with $R^2 = 0.9876$ where b represents the Bhattacharyya distance and p represents the adulteration level.

Case study 02 – Water quality assessment

As a result of the increased urban population, industrial and agricultural activities, and climate changes, lakes, and reservoirs experience an increase in nutrients and sediment concentration. To combat this problem, it is imperative to engineer rapid water quality screening techniques for various parameters such as pH, conductivity, turbidity, etc. this study proposes a method to assess the pH of water with multispectral imaging which utilizes the transmittance spectrum.

Initially, the acidic and alkaline solutions with different pH values were prepared using nitric HNO_3, Sodium Hydroxide $NaOH$ pellets and distilled water were used. The distilled water sample was considered as the $pH = 7$ sample. After applying the dark current reduction preprocessing step, a window size of 30×30 pixel was cropped from each monochrome image and each cropped image was denoised by smoothing the images using a median filter. The dataset was randomly separated into two groups for the training and testing of the classifier. First, the dimensionality of the training samples was reduced to three using Principal Component Analysis (PCA). Then, Fisher’s Discriminant Analysis (FDA) was performed to improve the classification accuracy of the algorithm by increasing the separation between different pH classes. Next, the k-Nearest Neighbor (k-NN) algorithm was used to construct the classifier.

IX. Industrial applicability

This product is used to assess the quality of liquid-based food products in real time. The adulteration level of commercial coconut oil adulterated with low-cost adulterants such as palm oil are measured from the device. The device can be altered to measure the quality of wine, pollutant level of water and can be extended to assess the quality of other beverages and oil into the bargain.

The developed algorithms in the section VIII can be easily deployed in food industries; thereby establishing a universal quality standard. The manufacturers/distributors/consumers can easily verify the quality of the liquid-based consumables as they only need to deposit a sample inside the chamber and the result can be obtained within seconds. Similar to the studies in VIII, the standards can be developed for other consumables and it requires a collection of controlled samples to build an appropriate algorithm. Therefore, the said system is quite useful for all the stakeholders of the food industry.

X. Abstract

This invention discloses a multispectral imaging system that measures the transmittance intensity of predefined discrete spectral bands through the samples to classify them according to predefined quality standards. A multispectral image is rich in information compared to an RGB image; hence the samples can be classified more accurately with the former imaging system. Here presents a design of multispectral imaging system that can be used to assess the edible oil quality. The system comprises an array of nine LED bulbs with nominal wavelengths between 405 nm and 950 nm. The light emitted from the LED array penetrates the oil sample placed inside a dark chamber and transmits through the medium to reach the monochrome camera. One LED bulb from the array is lit at a time and the images of the sample under the influence of that bulb are acquired and this procedure is repeated for every LED bulb. After the data acquisition, every pixel is represented as data point in a Euclidean space following standard image processing principles. This high dimensional representation is then reduced to lower dimensional representation by applying standard dimensionality techniques. The experiments were performed to identify the adulteration level of coconut oil with palm oil and to identify the pH values of water samples. The imaging system was built using off the shelf electronic components making it a cost-effective solution.

XI. Claims

1. A multispectral imaging system to capture the transmittance information of a sample for determination of edible liquid quality parameters comprising:
    i. A light source array of LEDs with a LED driver circuit configured to transmit light through the liquid container
    ii. A mechanism to concentrate the light beam to the sample
    iii. A sensing device configured to sense the intensity of the residual light from the light source array after it has transmitted through the specimen and to produce a signal in commensurate with the measured intensity
    iv. A circuit configured to synchronize the operations between the sensing device and the light source array
    v. A containment to preclude interferences from outside light sources
2. The multispectral imaging system as claimed in claim 1 wherein the said system is composed of an array of LED bulbs with nominal wavelengths in infrared to ultraviolet region.
3. The multispectral imaging system as claimed in claim 1 and 2 wherein the said system is composed of nine LED bulbs with nominal wavelength in range of 395 nm – 960 nm.
4. The multispectral imaging system as claimed in claim 1 wherein the said system is composed of a sensing device to capture the multispectral images.
5. The multispectral imaging system as claimed in claim 4 wherein the said system is composed of a monochrome camera as the sensing device.
6. The multispectral imaging system as claimed in claim 1 wherein the said system is used to measure the quality parameters in translucent liquids.
7. The multispectral imaging system as claimed in claim 1 and 6 wherein the translucent liquid is a consumable liquid.
8. The multispectral imaging system as claimed in claim 1 and 7 wherein the consumable liquids is coconut oil.
9. The multispectral imaging system as claimed in claim 1 and 7 wherein the consumable liquids is water.

Drawings

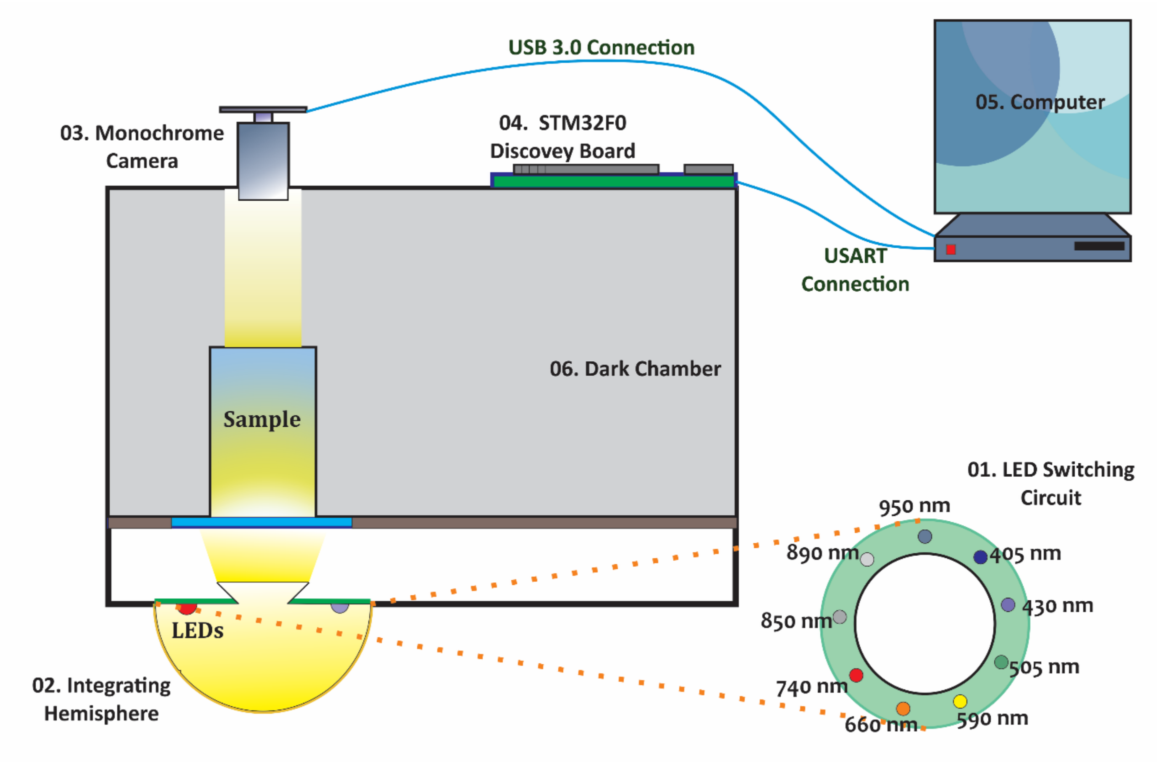

Figure i - Multispectral imaging device

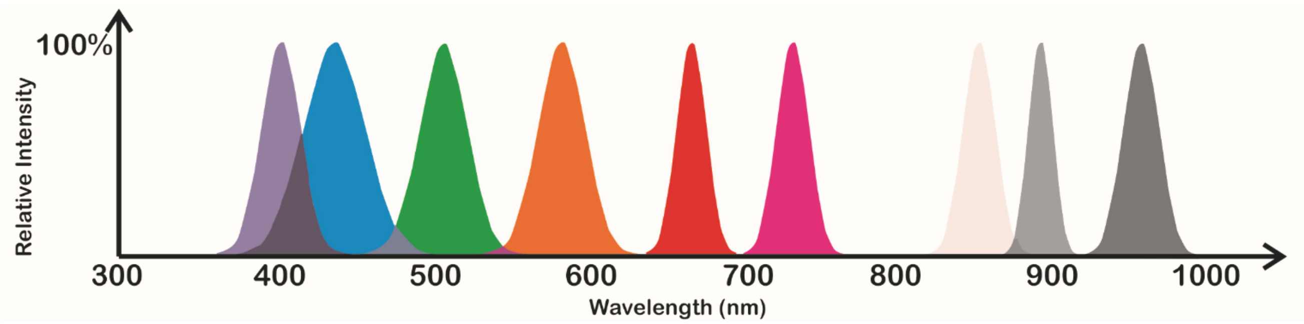

Figure ii – Power spectral density curves of the LEDs

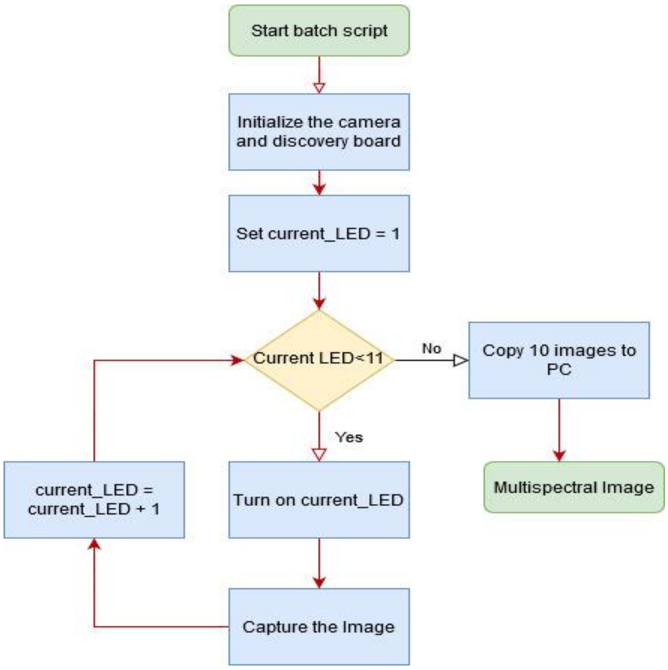

Figure iii– The procedure of acquiring the multispectral images