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LOW COST AND LABORATORY SCALE NIR SPECTROSCOPY FOR QUALITY EVALUATION OF FRUITS AND VEGETABLES

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Abstract

NIR spectroscopy has proved to be one of the efficient and easy tools to monitor the quality of agricultural products. NIR spectrometers are versatile devices to monitor the ripeness or quality parameters of the fruits. We demonstrate a low-cost spectrometer design that is produced with off the shelf components. In this work, the development, characterization and validation of a prototype is discussed. The proposed device has a dedicated user interface on the PC to plot and analyze spectral data. The performance of the proposed spectrometer is comparable to existing laboratory scale spectrometers in terms of stability and resolution. The spectral resolution and response range of the proposed spectrometer are 20 nm and 640-1050nm, respectively. Proposed device consists of MEMS based Hamamatsu spectrometer sensor (C11708MA), microcontroller (Arduino) and IR light source. Roles of the Arduino are generating essential control signals and sampling output of the C11708MA. These spectral response data have a huge advantage in generating data sets that may be useful in building machine learning based models.

***Key words**: fruit and vegetable quality spectrometer, near infrared spectroscopy, non-destructive detection.*

INTRODUCTION

Spectroscopy is gaining importance for fruit firmness detection, pharmaceutical and environmental monitoring. Near infrared (NIR) is a fast and non-destructive method that can be applicable to any biological or non-biological materials. NIR technique has been widely used to measure internal qualities of various fruits such as tomato, apple, and kiwifruit (Huang, 2018; Ye et al., 2017; Li et al., 2017). Spectroscopy technique can be utilized in detecting plant diseases (Khaled et al., 2018). Besides, multiple spectrometer modules can be installed into packaging or processing lines for measuring quality characteristics of the goods. However, most spectrometer equipment which is utilized in the industry or laboratory is expensive and bulky. Although, there has been some work on portable and low cost spectroscopy devices, there is a need for several improvements in terms of quality and repeatability of data (Das et al., 2016). Also, excessive price of these devices makes them less accessible for many researchers. This work aims to demonstrate a low-cost spectrometer design that is produced with off the shelf components.

An NIR spectrometer consists of a light source (tungsten, halogen or LED), sample presentation accessory, detector, and optical components, such as lenses. NIR radiation covers the range of the electromagnetic spectrum between 780 and 2500 nm. NIR spectrometer is a device that irradiates the sample with NIR radiation and measures the reflected or transmitted radiation.

There are three different measurement setups for obtaining near infrared spectra. These are reflectance, transmittance and interactance modes. In reflectance mode light source and sensor are mounted under a specific angle. In transmittance mode the light source is positioned opposite to the sensor. In interactance mode the light source and detector are positioned parallel to each other.

Micro Electro Mechanical Systems (MEMS) offers inherently device miniaturization and wide applications in sensors and actuators Thanks to MEMS technology spectrometer components can be easily produced in one package. Proposed spectrometer utilized with

MEMS based Hamamatsu spectrometer sensor (C11708MA) (Hamamatsu, 2018). C11708MA spectrometer sensor allows designing low price and high-performance spectrometer design. Longitudinal section view of the C11708MA is given is Figure 1.

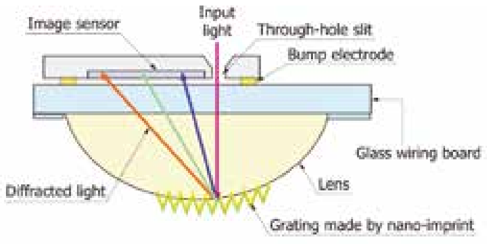

Figure 1. Longitudinal section view of the C11708MA (Hamamatsu, 2018)

C11708MA is equipped with 256-pixel CMOS linear image sensor, micro optical slit (75 x 750 µm), a grating that is formed on a convex lens. These features have made the C11708MA very compact and versatile.

In this work, we demonstrate a low-cost spectrometer design that is produced with off the shelf components.

The development, characterization and validation of a prototype are discussed. The proposed device has a dedicated user interface on the PC to plot and analyse spectral data.

The performance of the proposed spectrometer is comparable to existing laboratory scale spectrometers in terms of stability and resolution. Technical specifications of the C11708MA are given in Table 1.

Table 1. Technical specifications of the C11708MA

Dimensions	27.6 x 16.8 x 13 mm
Weight	9g
Spectral range	640-1050 nm
Supply Voltage	5 V
Power Consumption	30 mW
Number of pixels	256

The digital resolution and response range of the proposed spectrometer are 2 nm/pixel and 640-1050 nm, respectively. The designed device and supplied software is user friendly so that anybody with basic knowledge of spectroscopy can easily use it. Spectrometer device communicate with computer via USB cable.

MATERIALS AND METHODS

In this section, the essential components of the proposed spectrometer are described in detail. The block diagram of the spectrometer system designed in this study is given in Figure 2.

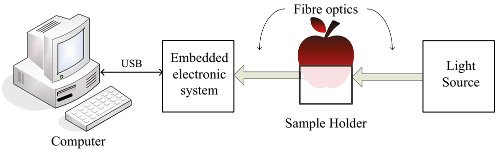

Figure 2. System containing computer, embedded system and light source

Proposed device consists of three parts: computer, embedded electronic system and light source. Light source holds the NIR lamp and fibre optic cable in an appropriate geometry. In our work, we prefer tungsten lamp as the source of the NIR light. Higher light intensity levels can be obtained by using tungsten lamp. Power consumption of tungsten lamp is somewhat high respect to the LED and laser sources. In future works for the mobile and battery-based operation system can easily utilize with LED light source.

Embedded electronic system is responsible for the generating control signal of the MEMS spectrometer chip.

The block diagram of the embedded electronic system is given in Figure 3.

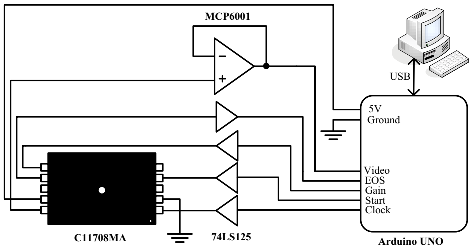

Figure 3. Block diagram of the embedded electronic system

Arduino UNO generates clock pulse for C11708MA which was set to 1 kHz in the proposed design. Arduino sends a start pulse to C11708MA to trigger the pixel read-out process and the interval between two start pulses is accepted as the integration time of the sensor. When Arduino receives a capture command from MATLAB, a start pulse was triggered which initiated the charge integration of each pixel. The C11708MA provided an End of Scan (EOS) pin which was used to terminate the read out process. As declared above, main purpose of the embedded electronic system is sampling and sending the spectrum data to the computer. Embedded electronic system is controlled by the computer software for coherent detection of spectrum. Embedded electronic system utilized with low cost Arduino microcontroller board. Roles of the Arduino are generating essential control signals and sampling output of the C11708MA. Arduino UNO contains built in 10-bit precision Analog to Digital converter (ADC). Resolution of this ADC is suitable for NIR spectrometer application. C11708MA contains 5 digital I/O interface pins for logical control and one analog output for spectral response data. To avoid excessive current sink from analog output port buffered with OPAMP (MCP6001) buffer amplifier.

The embedded software based upon the open-source Arduino IDE platform. The Arduino firmware was developed with the Arduino IDE and provides an easy to navigate hierarchical menu system for selection of device functions. The computer software was developed in the MATLAB environment. The computer software stores and displays received spectrum information.

As decelerated above, C11708MA contains 256 pixels to detect specific wavelengths. These pixels are numbered and these numbers have to be transformed into the corresponding wavelength. This can be done by a multiorder polynomial as given in Eq. (1).

$$\lambda(nm) = A_0 + B_1x + B_2x^2 + B_3x^3 + B_4x^4 + B_5x^5 \quad (1)$$

where, x is the pixel number and A_0, B_1, B_2, B_3, B_4 and B_5 are calibration coefficients whose values are supplied by the sensor producer. This approximation polynomial gives a precision wavelength vector. Computer software generates a wavelength vector by using Eq. (1). Computer software also detects the peak and Full Width at Half Maximum (FWHM) values of the spectrum. Peak and FWHM values are important for evaluating the properties of the sample.

Off the shelf fibre optic cable has been used for the assessment of light levels inside the fruit sample which has been illuminated with NIR light source. The probe has minimal effect on the light being measured and enables the direct measurement of light levels at any location in the fruit.

The spectrometer, light source and sample holder design was wholly completed in Sketchup (Sketchup, 2018), a solid modelling software designed by Google. The design of the case body is shown schematically in Figure 4. The case was printed with polylactic acid (PLA) media.

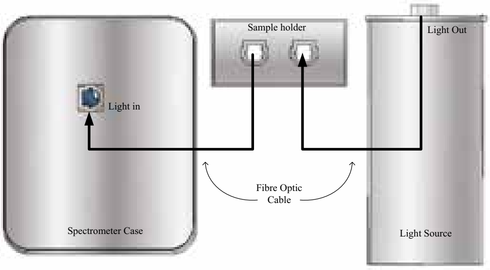

Figure 4. 3D design of the spectrometer

RESULTS AND DISCUSSIONS

The spectra of apple and carrot fruit samples are shown in Figures 5, 6, respectively. The similar spectral pattern was also observed in the spectra of apple fruit measured in the interactance mode.

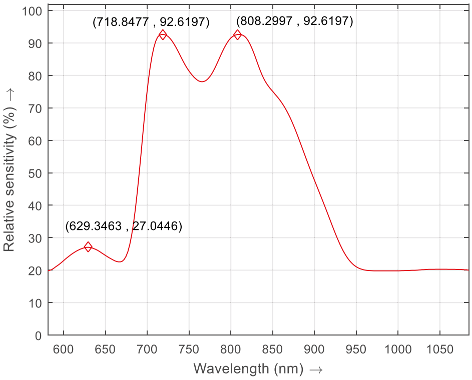

Figure 5. Transmittance spectrum of apple

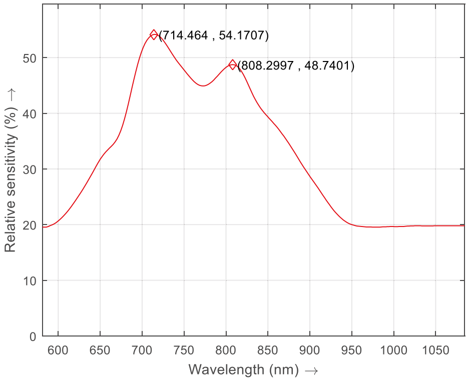

Figure 6. Transmittance spectrum of carrot

CONCLUSIONS

In conclusion, the designed MEMS based NIR spectrometer is a portable and low-cost device. In the Results and Discussions section it was shown that proposed device works with sensitivity and resolution acceptable for many tasks both in education and research. Future work is necessary for this design to realize the full potential of the tool for fruit internal properties detection applications. As discussed above main role of this device is obtaining set of spectral response data for various types of fruits. These spectral response data may be useful in building machine learning based models. In addition, work is needed to make the NIR spectrometer portable, such as the incorporating batteries.

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REFERENCES

Das A.J., Wahi A., Kothari I., Raskar R., 2016. Ultra-portable, wireless smartphone spectrometer for rapid, non-destructive testing of fruit ripeness. Scientific reports, 6, 32504.

Hamamatsu web site accessed: 23.02.2018 https://www.hamamatsu.com/jp/en/C11708MA.html

Huang Y., Lu R., Chen K., 2018. Prediction of firmness parameters of tomatoes by portable visible and near-infrared spectroscopy. Journal of Food Engineering, 222, 185-198.

Khaled A.Y., Abd Aziz S., Bejo S.K., Nawi N.M., Seman I.A., Onwude D.I., 2018. Early detection of diseases in plant tissue using spectroscopy-applications and limitations. Applied Spectroscopy Reviews, 53 (1), 36-64.

Li M., Pullanagari R.R., Pranamornkith T., Yule I.J., East A.R., 2017. Quantitative prediction of post storage 'Hayward' kiwifruit attributes using at harvest Vis-NIR spectroscopy. Journal of Food Engineering, 202, 46-55.

Sketchup web site accessed: 23.02.2018 https://www.sketchup.com/

Ye X., Ishioka S., Zhang S., 2017. Estimation of the degree of red coloration in flesh of a red-fleshed apple cultivar 'Kurenai no Yume' with a UV-vis-NIR interactance device. Post-harvest Biology and Technology, 124, 128-136.