Development of a Portable Spectrometer for Ripeness Characterization in Oil Palm Fruit

(Rekabentuk Spektrometer Mudahalih untuk Pencirian Kematangan Buah Kelapa Sawit)

Ng Hui Xuan, Fazida Hanim Binti Hashim, Thinal Raj
Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia

ABSTRACT

Current detection of ripeness of oil palm fruit are using human eyes and sensors which are non-portable. Raman LiDAR is a good device to identify the ripeness of oil palm fruit in which it is a non-destructive method that produces a more accurate result. The main objective of this project is to create a portable spectrometer with the mission to identify the ripeness of oil palm fruit. This initiative is relevent to the plantation owner because it is important for them to harvest the oil palm fruit at the right time. If they are able to identify the ripeness with the help of a portable Raman instrument, it will significantly improve their harvest product. In this project, spectrometer is built as a receiver part to obtain the spectrum image from different light sources. Each optic components is stabilised by 3D printing customised holders and optical breadboard. Diffraction grating will separate the wavelength of light which is then focused by the mirrors. Next, webcam is used to capture the spectrum image to be processed in Matlab. Red, green and violet lasers are used as the light source because of its large penetrating power with high frequency. Along the project implementation process, it is found that Crossed-Czerny Turner is the most suitable technique to reduce stray light emission. The result obtained is in the form of graph of intensity vs pixel for the light sources tested. Resolution of spectrometer is identified at the end of the experiement. With the use of this portable Raman Spectrometer, weak Raman signal obtained from different fruit is possible to be captured for characterisation. With this, it is believed that the spectrometer will act as a receiver and processor for the Raman LiDAR.

Keywords: Raman Spectroscopy; Crossed-Czerny Turner; Light Spectrum; Laser; LED.

ABSTRAK

Teknologi semasa dalam usaha menentukan kematangan buah kelapa sawit adalah menggunakan mata ataupun penderia yang bukan mudahalih. Raman LiDAR adalah satu peranti yang penting dalam usaha menentukan kematangan buah kelapa sawit kerana ia memberi hasil keputusan yang lebih tepat tanpa merosakkan buah. Projek ini direka khas untuk mencipta spektrometer yang mudah alih bagi tujuan menentukan kematangan buah kelapa sawit. Usaha dalam menentukan kematangan bagi pihak peladang amatlah membantu kerana dapat menjimatkan masa mereka serta mengurangkan pembaziran dalam proses penuaian. Dalam projek ini, spektrometer dibina untuk menjadi bahan penerima bagi tujuan mendapatkan imej spektrum daripada sumber cahaya yang berlainan. Setiap komponen optik distabilkan dengan menggunakan pemegang cetakan 3D serta papan optik (optical breadboard). Diffraction grating digunakan untuk memisahkan gelombang cahaya yang kemudiannya difokuskan oleh cermin. Seterusnya, kamera web digunakan untuk menangkap imej spektrum tersebut bagi tujuan pemprosesanan dalam Matlab. Selaras dengan itu, laser digunakan sebagai sumber kuasa kepada sistem projek ini kerana tahap frekuensinya serta tenaga penembusan yang tinggi. Sepanjang masa perlaksanaan projek, didapati bahawa Crossed-Czerny Turner merupakan teknik yang paling sesuai kerana ia banyak mengurangkan pengeluaran cahaya sesat. Hasil keputusan adalah dalam bentuk graf intensiti vs nilai piksel. Resolusi spektrometer dikenalpasti pada fasa akhir penyelidikan ini. Dengan penggunaan Spektrometer mudah alih ini, isyarat Raman daripada buah berbeza akan dapat dicerap, maka dipercayai bahawa spektrometer ini dapat dijadikan bahan penerima dan pemproses kepada Raman LiDAR.

Kata kunci: Spektroskopi Raman; Crossed-Czerny Turner; Spektrum Cahaya; Laser; LED.

INTRODUCTION

Current method for ripeness detection of oil palm fruits are using human eye and sensors which are non-portable. There is a need for a device that is able to detect the ripeness of fruit non-destructively. The ripeness of fruit is a process that involves the changing in colour of fruit until it achieves the texture and a desired quality. In general, fruits became softer and sweeter when it is ripe. Investigating the fruit ripeness is very important to minimize the loss and maximising the profit by harvesting good quality fruit. Currently technology using visible and infrared light in identification of product quality with non-destructive method has became a trend which can be proven by researches from (Magwaza et al. 2012) and (Makky & Soni 2014). Spectroscopy analysation using visible and near infrared has been used widely for fruit characterisation such as pomegranate (Khodabakhshian et al. 2016), maggo (Subedi et al. 2007) and plum (Louw & Theron 2013). Moreover, near infrared is specifically used in identifying ripeness of oil palm fruit and the research were carried out by (Basri et al. 2017; Kasemsumran et al. 2012; Silalahi et al. 2016).

Understanding the nature of fruit ripeness is useful before categorising them. This project aims to identify a suitable way to detect the fruit ripeness. There are 2 approaches to detect fruit ripeness which is 'destructive' and 'non-destructive' method. The destructive method identifies the fruit ripeness by crushing it to check the colour of inner fruit. However, destructive identify the ripeness without destroying the fruit. One of the non-destructive way is NMR (Nuclear Magnetic Resonance) to detect the sugar content in the fruit. High sugar content indicating that the fruit is ripe (Bellon et al. 1992).

In year 2017, Raman LiDAR started to be used as a new device to identify the ripeness of tomato and it has been proven to be working in tomato fruits by (Trebolazabala et al. 2017). Raman LiDAR is a heavy and big device which is not portable. Testing can only be made in the laboratory. Portable Raman LiDAR are increasingly used for analysing and component identification in plenty of studies. A search on web recorded 177 scientific words about "portable" and "Raman" in title published from 1992 onwards and remain concentrated until today (Nekvapil et al. 2018). In Raman LiDAR, it has two parts which is source and receiver. This project aims to produce the receiver part of the Raman LiDAR which is the spectrometer.

The development of portable spectrometer among college student has increased and it can be shown in the research (Albert et al. 2012; Bougot-robin et al. 2016; Yeh & Tseng 2006) in development of absorption spectrometer. Whereas for the development of light spectrometer, it can be seen in the research of (Mohr et al. 2010; Quagliano et al. 2013; Trindade et al. 2014). Absorption spectrometer will evaluate the absorption of radiation in the form of frequency and wavelength while light spectrometer is able to separate the wavelength of light spectrum. Spectrometer is a device used to obtain the wavelength of light over a wide range of electromagnetic spectrum. It is equipped with good quality diffraction grating. When a light source is projected on the diffraction grating in the spectrometer, it will separate the wavelength of light. For example, when a white light falls on the grating, it is dispersed into RGB colours. This RGB spectrum can be analysed in Matlab to obtain its intensity, its pixel and also its wavelength. The properties of different light sources could also be compared using the spectrometer.

There are two main types of spectrometer design based on different grating. Transmissive grating allows light spectrum to travel across it. The spectrometer is able to capture the light spectrum behind the grating. Whereas reflective grating requires mirrors to reflect the light emission before and after it is being diffracted. There are 2 different kinds of spectrum sources which are continuous and line sources, incandescent is an example of continuous spectrum source while fluorescence and LED are examples of line spectrum source.

The reason of creating portable spectrometer is to capture the Raman signal and convert it to spectrum format to be processed in Matlab. The reason of choosing green laser as the source is because it achieves the lowest wavelength requirement so that it has high frequency and intensity. Violet laser is not considered as it will cause the fluorescence effect as it interact with the oil palm fruit which would saturate the Raman signal.

3D printing and customizing the holders for each component including the optical breadboard provides high stability for the spectrometer. It works as a base to make sure that every component is fixed in a particular location to ensure good vibration control. The Crossed-Czerny Turner method also improves the transmissive spectrometer by reducing the stray light emission. Calibration of wavelength is done to make sure that the wavelength of the light sources is accurate. It involves the addition of components to align the light source including collimating mirror and focus mirror. The focal length of the collimating mirror is made short to reduce the distance among components so that the size of the spectrometer can be minimized. When the light has been diffracted and separated into its chromatic components, focus mirror will be used to make sure that the light is aligned into the web camera from the diffraction grating.

Matlab is used in the process of identification of ripeness in oil palm fruit so that it can present the information in the form of a spectrograph. For example, LED spectrum can be separated into RGB colour. Spectrograph is not only used to classify colour of light, it can also used to identify the intensity corresponding to the pixel value. The pixel value at its highest intensity can be used to plot the graph of wavelength vs pixel value. The resolution of the spectrometer can be obtained from the gradient of the graph.

METHODOLOGY

This project includes 3 parts. The first part is calibration of wavelength, the second part is the setup of 3D printing spectrometer, the third part is the assembling and acquiring of spectrum. Figure 1 shows the steps to complete the flow of project.

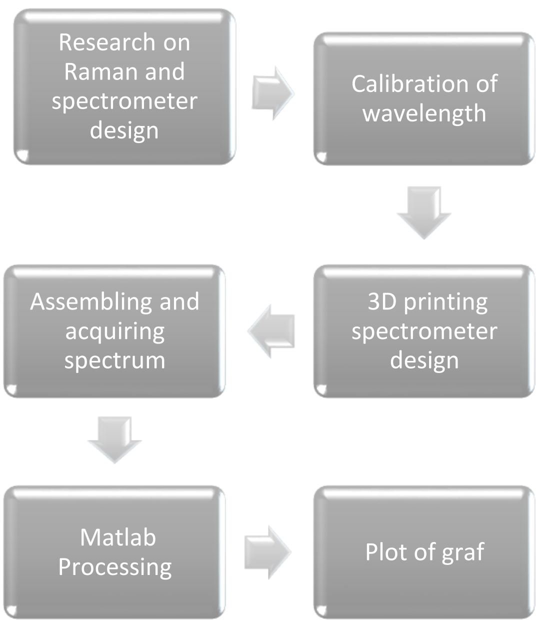

Figure 1 : Flow of project

Calibration of laser pointer wavelength can be done by using student spectrometer and the formula as shown in Equation 1. When the measured wavelength is obtained, it can be used to plot the pixel vs wavelength graph. The components holder are designed by using autodesk Fusion 360. Figure 2 shows the student spectrometer used in this project

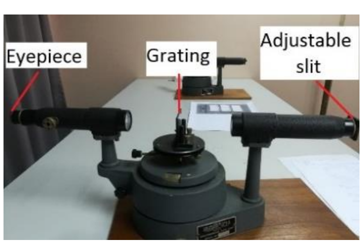

Figure 2 : Student Spectrometer

This spectrometer is consists of a collimating mirror to make sure that the light source is parallel before it reaches the grating. The light source will be entering from the adjustable slit, while the grating is placed at the center to separate the light into different wavelengths. Light spectrum can be observed through the eyepiece. For LED light spectrum consisting of RGB colours, the eyepiece can be rotated until the first spectrum color is observed. Vernier scale shows the degree of turning in the eyepiece which can then be put into the formula as shown in Equation 1 to calculate the wavelength. Figure 3 shows the plan of projection that is obtainable when the student spectrometer is tested with a light source. For laser that has high penetrating power, a projection platform is used instead to avoid eye damage.

$$d \sin\theta = k\lambda$$

d = jarak antara *grooves* dalam *diffraction grating*

θ = sudut cahaya *diffracted* daripada paksi 0

K = Nombor perintah

λ = jarak gelombang sumber cahaya

Equation 1

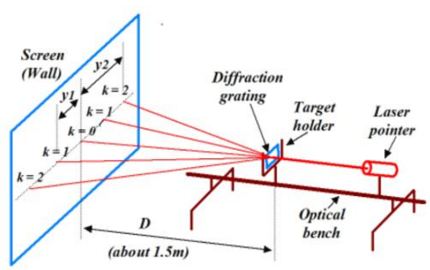

Figure 3: Plan of projection

The second part is the setup of 3D printing spectrometer. Optical components require high stability where a tiny movement in the experiment process could impact the accuracy of the results. Every component has its unique size and it is important to customize the individual holder for every component. Autodesk Fusion 360 is a good platform to achieve this target. In this chapter, every component holder will be built with Autodesk Fusion 360 including the optical breadboard, components' holder, and components' base.

Optical breadboard is a vibration control platform. It can be used for optic experiment to maintain component's stability. It is heavy so as to minimize the possibility of vibration during experiment. This optical breadboard is 18x18cm consisting of 49 holes. The holes are used to fix the component with specific screw. In this project, this breadboard is built by using Autodesk Fusion 360 as shown in Figure 4.

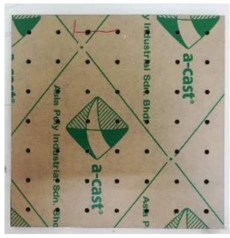

Figure 4: 3D printed breadboard

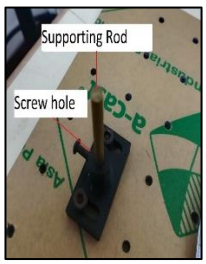

Figure 5: 3D printed base

The supporting base consists of two parts. The upper part is a gold rod which is used to slot into the component holder. It has a diameter of 4 mm which is compatible to the diameter of the hole in the component base. The bottom part is a component base having two identical 1 cm holes allocated for the screw to stabilize the component on the optical breadboard. Figure 6 shows one of the component holder design. The hole at the center with diameter 4 cm enables the gold rod to be fixed inside.

Figure 6: LED holder

Diffraction grating of rotational platform with protractor is important to rotate the diffraction grating to its specific incident and diffraction angle. The incident and diffracted angle can be calculated from the formula in Equation 2.

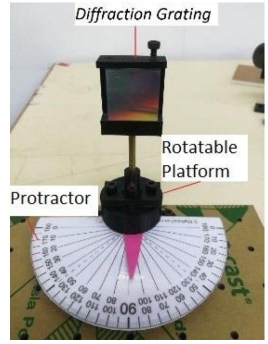

Figure 7 Rotational platform of diffraction grating

Choose a geometry = Ø

$$\alpha = \sin^{-1}\left(\frac{\lambda c G}{2\cos\frac{\emptyset}{2}}\right) - \frac{\emptyset}{2}$$

Where $\beta = \emptyset - \alpha$

α = incidence angle $\quad \beta$ = diffracted angle

Equation 2

Crossed Czerny Turner technique is used as it can reduce stray light emission. The arrangement is in zig-zag pattern as shown in Figure 8. This design is flexible as various focal lengths can be applied to obtain various linear dispersion values which would result in the changes in the resolution of spectrometer too.

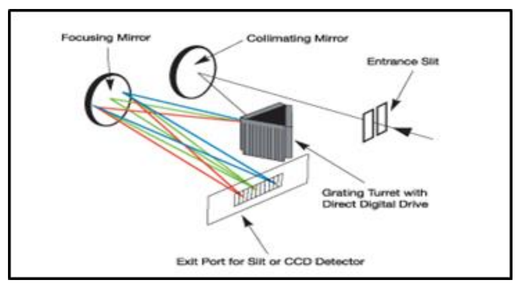

Figure 8: Arrangement in Crossed-Czerny Turner.

The next part is the arrangement of component following the Crossed-Czerny Turner technique as shown in Figure 9.

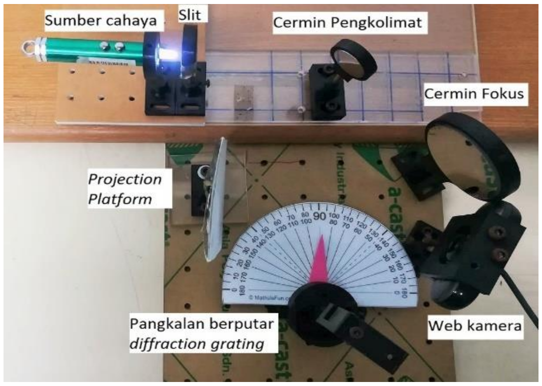

Figure 9: 3D printed spectrometer

RESULTS AND DISCUSSION

The first part of this project is calibration of laser wavelength. The result in Table 1 shows the comparison between the stated wavelength and the measured wavelength. It recorded the highest deviation in green laser which is 19nm.

TABLE 1. Calibration of laser wavelength

Laser source	Stated wavelength (nm)	Measured wavelength (nm)
Red	650	638
Green	532	503
Violet	405	407

Next, the 3D printed spectrometer is tested with a LED light source. The best spectrum produced will be processed in Matlab to produce the graph as shown in Figure 10. The same setup will be used to test for red, green and violet laser which will produce the graph as shown in Figure 11, 12 and 13.

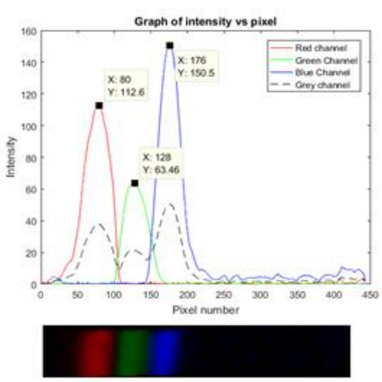

Figure 10: LED

The best arrangement for the spectrometer can be identified by experimenting it with the LED. The position whereby the LED spectrum is the brightest without saturation will be the final setup of the experiment. This spectrometer is possible of capturing Raman signal.

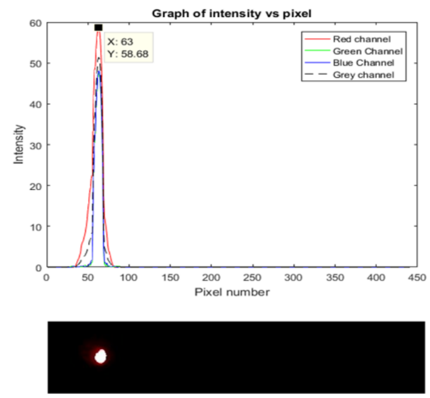

Figure 11: Red Laser

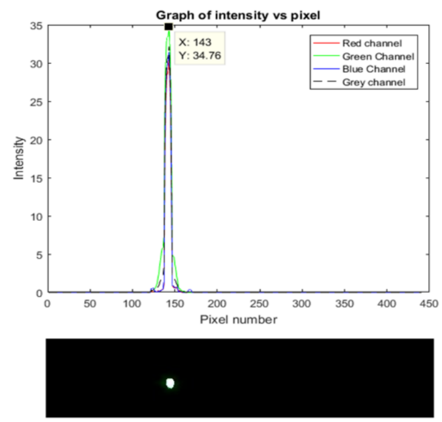

Figure 12: Green Laser

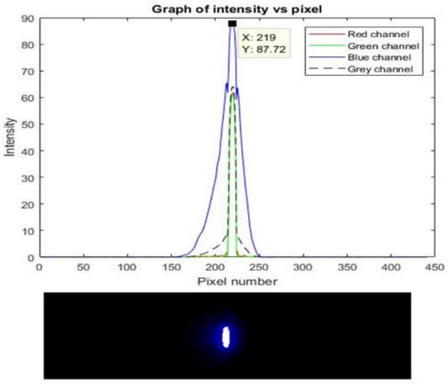

Figure 13: Violet Laser

Next, the pixel value recorded with the highest intensity will be matched with the measured wavelength recorded in Table 1. The final graph will record the value of measured wavelength vs pixel value of 3 lasers.

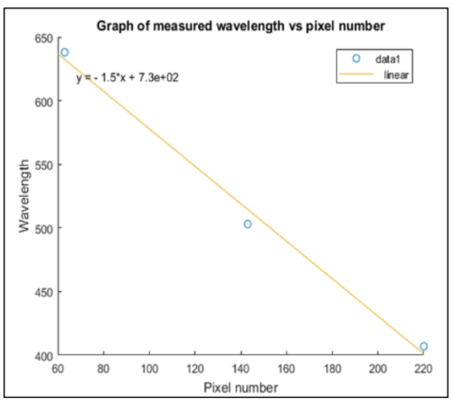

Figure 14: Graph of measured wavelength vs pixel value.

This graph also recorded the resolution on spectrometer with 1.5nm/pixel. It is able to capture any Raman signal that has the value larger than 1.5nm/pixel. Laser has a high frequency and strong penetrating power hence it produces a narrow spectrum band. This makes it a good source to identify the peak value in the graph. Laser calibration is important to ensure accuracy. It recorded the highest deviation in green laser which is 19 nm. 3D printed spectrometer customizes holders for each component to ensure that they are stable in the experimental process. Crossed-Czerny spectrometer is able to enhance the quality of the transmissive spectrometer by reducing the stray light emission. RGB laser correlates the pixel value with the wavelength producing a resolution of 1.5 nm/pixel.

CONCLUSION

For the operation wavelength of 407 nm to 638 nm, the spectrometer is able to provide a resolution of 1.5 nm/pixel. 3D printed spectrometer is possible to capture Raman signal. Future work would be using the green laser as the source and oil palm fruit as target to complete the function of a ripeness detector.

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