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Comparison of mean temperature taken between commercial and prototype thermal sensor in estimating mean temperature of oil palm fresh fruit bunches

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Abstract

Thermal imaging is widely utilized in agricultural applications such as examining plant physiology, yield prediction, irrigation scheduling, bruises and pathogen determination in fruits and vegetables. There is a need for a cost effective thermal device for this wide range of applications. In this study, a low-cost prototype thermal device was used to measure the temperature of FFBs at three maturity levels, that are under-ripe, ripe and over-ripe. The experiment was repeated using a commercial thermal camera. Then, the mean temperature obtained from both the prototype and commercial thermal sensors was compared. Our results showed the prototype thermal device is capable of estimating the mean temperature of oil palm FFBs with the values analogous to the mean temperature from commercial thermal camera with $R^2 = 0.71$.

Introduction

One of the important study features in agriculture is temperature measurement. In the past, instruments such as thermometers, thermocouples, thermistors, and resistance temperature detectors were used to measure temperature. Their demerits are that they can only give point information, are time-consuming, and contactable to the object. They cannot produce an overall reliable result. This problem can be overcome with the advent of remote sensing application in agriculture (Vadivambal and Jayas, 2010).

Remote sensing in agriculture is the art and science of examining and retrieving of crop and soil characteristic information utilizing sensors connected to satellite, aircraft and ground-based platforms (Tenkorang and Lowenberg-DoBoer, 2008). Prakash (2000) stated that thermal remote sensing is the division of remote sensing which obtains, processes and analyses data mainly in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum. Thermal remote sensing is differentiated with optical remote sensing where the radiation emitted from the surface of the object is measured instead of measuring the radiations reflected by the object. The temperature of the objects is estimated by measuring the radiations emitted by the objects. The spectral range of EM spectrum of terrestrial thermal remote sensing is normally in the region of 3 to 35μm and known as thermal-infrared.

Terrestrial thermal remote sensing has introduced thermal-infrared sensing technique of using thermal imaging. The radiation emitted from the target is converted to image with temperature data. There are many investigations utilizing thermal imaging in agricultural applications. For instance, Vadivambal *et al*. (2011) detected the sprout-damage barleys using thermal imaging and they found out the average surface temperature of healthy barley kernels is less than that of sprout damaged kernels. Another experiments carried out by Stajnko *et al*. (2004) using thermal imaging to predict apple yield in an orchard during the growing season. In this study, thermal imaging solved the problem of using colour imaging

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to estimate the number of apples as the colour of apples and the leaves is similar. Moreover, Varith *et al*. (2003) successfully determined bruises in apples under different treatments by thermal imaging which by detecting the temperature difference between bruised and sound tissues.

Besides, thermal imaging was performed in irrigation management and planning. The review done by Maes and Steppe (2012) indicated that thermal imaging is capable of computing the evapotranspiration and drought stress of crop in agriculture by measuring the canopy surface temperature. Meanwhile, Gonzalez-Dugo *et al*. (2005) also studied the determination of canopy temperature using thermal imaging to show the severity of crop water stress and subsequently assisting farm managers to better plan their irrigation scheduling.

In Malaysia, research has been done in classifying oil palm fresh fruit bunches (FFBs) into different maturity levels as this relates to the quantity and the quality of palm oil produced. Traditionally, the method used was to sort oil palm FFBs into different maturity levels by counting the number of loose fruits per bunch. This consumed much time and is labour intensive. Therefore, a more decisive, fast and accurate device is required to determine maturity of oil palm FFB (Saeed *et al*., 2012). Currently, investigations of involving various techniques such as digital images, near infrared images, fluorescence sensor, four bands optical sensors in detecting oil palm FFB's maturity had been performed (Razali, 2012; Hazir *et al*., 2012; Saeed *et al*., 2012; Kassim *et al*., 2014). There had been studies carried out in evaluating fruits' maturity using thermal imaging such as Japanese persimmons, Japanese pears, tomatoes, Ataulfo mangoes and apples (Danno *et al*., 1980; Hahn and Hernandez, 2005; Ishimwe *et al*., 2014).

Due to the wide agricultural applications of thermal imaging, a cost effective thermal device is needed. In this research, a low cost prototype thermal device was used to measure the temperature of oil palm FFBs at three maturity levels (under-ripe, ripe and over-ripe) followed by using a commercial thermal camera. The mean temperature obtained by the prototype and commercial thermal sensor was compared.

Material and Method

Samples

There were a total of 90 oil palm FFBs (30 oil palm FFBs from each category: under-ripe, ripe, and over-ripe) from Seri Ulu Langat Palm Oil Mill Sdn. Bhd. were tested in this experiment. The oil palm FFBs were from the species of Elaeisguineensis which its sub-species Nigrescens. The maturity of the oil palm FFBs was categorized by the mill officer who was also an oil palm FFB grader from the mill. The categorization of the FFBs was based on the oil palm FFB grading standards guideline from Malaysian Palm Oil Board (MPOB) as widely used by researches such as Hazir *et al*. (2012) and Saeed *et al*. (2012). One of the criteria used is the fruitlets detached from the bunch where under-ripe FFB had 1 to 9 fruitlets detached from the bunch while ripe FFB had 10% to 50% of fruitlets detached from bunch. On the other hand, over-ripe FFB had 50% to 90% of fruitlets detached from bunch.

Data collection

All the FFBs were placed on top of labelled sacks with one FFB for one sack on the ground at the mill. Then, each FFB's temperature was measured by the prototype thermal device. The temperature data was recorded in the format of 'text document' for further data analysis. Next, each FFB's thermal image was taken by using commercial thermal camera which is FLIR T440 thermal camera. The atmospheric temperature and relative humidity were determined by FLIR Extech Hygro-thermometer and recorded to be input in the parameter setting of the FLIR thermal camera when analyzing the temperature data.

Data analysis

The temperature data measured by the prototype thermal device was imported into 'Microsoft Excel' file type to be analyzed. The mean temperature of each FFB was computed. The thermal image of each FFB from commercial thermal camera was processed using 'FLIR Tools' and 'FLIR Reporter' software. The atmospheric temperature and relative humidity were input in 'FLIR Tools' for each FFB thermal image. After that, report in 'Microsoft Word' file of each thermal image was created by 'FLIR Reporter' with the template of 'IR and Photo' being selected. The mean temperature of each thermal image was determined by drawing polygon according to the shape of the FFB in the report created as indicated in Figure 1. The mean temperature of each FFB obtained from prototype thermal device and commercial thermal camera was tabulated and their difference was computed. Line charts and column charts were plotted to compare their mean temperatures. Furthermore, the correlation of mean temperature recorded by prototype thermal device and commercial thermal camera is identified using Pearson correlation of

SPSS software and regression analysis is performed by plotting scatter plots to determine the equations in relating their mean temperatures.

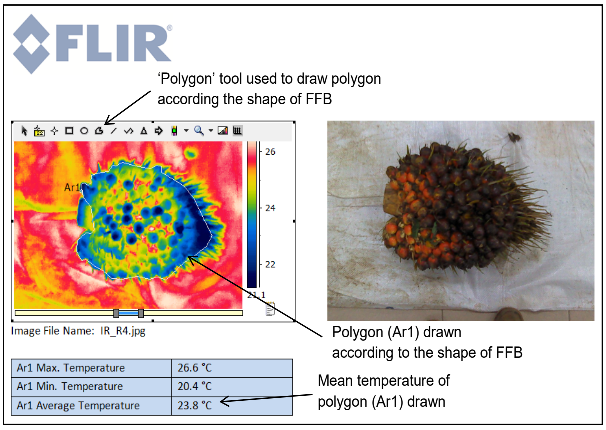


Figure 1. Mean temperature of FFB thermal image determined by polygon drawn in the report created by 'FLIR Reporter' with the thermal image on left and the corresponding digital image on right

Results and Discussion

Comparison of mean temperature between prototype thermal device and commercial thermal camera

The mean temperature taken by prototype thermal device is lower than that of commercial thermal camera for most of the FFB samples except for 4 samples of under-ripe and ripe FFBs and 12 samples of over-ripe FFBs as indicated in Figure 2. Figure 3 represents the average mean temperature difference of different category where 'Under-ripe', 'Ripe' and 'Over-ripe' are the different maturity levels and 'All' indicating all the samples involved in the computation. The average of mean temperature difference for each category in Figure 3 presenting that 'Ripe' category has the highest average mean temperature difference (1.8°C) followed by 'Under-ripe' category (1.39°C), 'All' category (1.08°C) and lastly 'Over-ripe' category (0.05°C).

From the results mentioned, prototype thermal device generally underestimates the mean temperature of commercial thermal camera for all the FFBs. It sometimes overestimates the mean temperature of commercial thermal camera for some of the FFBs. This inconsistency between underestimation and overestimation may due to the sensitivity of the low cost temperature sensor used in the prototype thermal device. All the categories show high standard deviation with 'Under-ripe', 1.64°C; 'Ripe', 1.54°C; 'Over-ripe', 1.50°C; and 'All', 1.72°C.

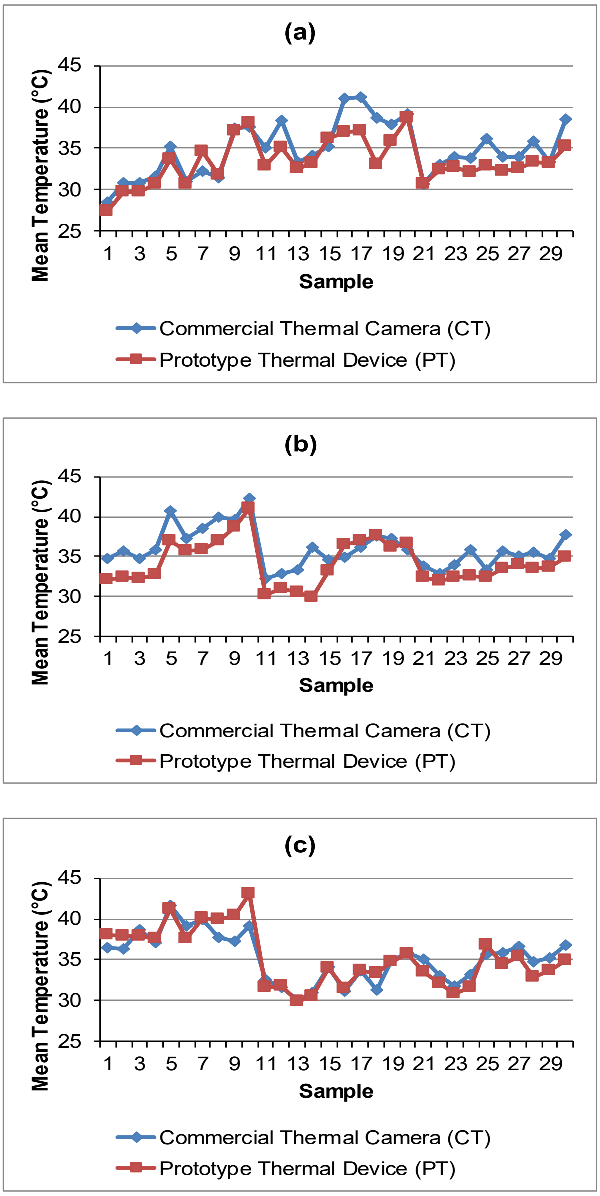
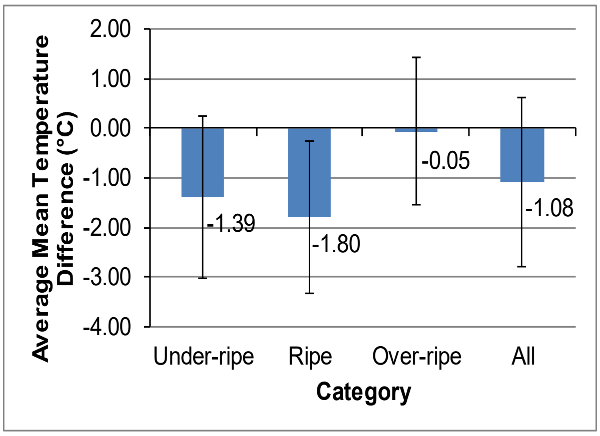


Figure 2. Line chart of mean temperature from prototype thermal device and commercial thermal camera for (a) Under-ripe FFB, (b) Ripe FFB and (c) Over-ripe FFB



*Mean Temperature Difference = PT – CT

Figure 3. Column chart of average mean temperature difference of FFB in different category

Correlation of mean temperature from prototype thermal device and commercial thermal camera

The mean temperature obtained from prototype thermal device is significantly correlated to commercial thermal camera (P<0.01) as illustrated in Table 1 with Pearson correlation values of 0.865, 0.826, 0.906, and 0.834 for 'Under-ripe', 'Ripe', 'Over-ripe' and 'All' category, respectively. As a result, 'Over-ripe' category gives the best estimation of mean temperature recorded by prototype thermal device to mean temperature measured by commercial thermal camera.

Table 1. Pearson correlation of mean temperature measured by prototype thermal device and commercial thermal camera in different category

Category			Prototype
		Pearson Correlation	.865**
Under-ripe	Commercial	Sig. (2-tailed)	.000
		N	30
		Pearson Correlation	.826**
Ripe	Commercial	Sig. (2-tailed)	.000
		N	30
		Pearson Correlation	.906**
Over-ripe	Commercial	Sig. (2-tailed)	.000
		N	30
		Pearson Correlation	.834**
All	Commercial	Sig. (2-tailed)	.000
		N	90

**. Correlation is significant at the 0.01 level (2-tailed).

From the scatter plots plotted as demonstrated in Figure 4, the mean temperature of prototype thermal device of 'Over-ripe' category fits well to mean temperature of commercial thermal camera with highest r-squared value of $R^2 = 0.8329$ using logarithmic equation (3). The equation for each category to determine mean temperature of commercial thermal camera by using mean temperature obtained from prototype thermal device is as below:

Under-ripe category:
$y = 0.09702x^{1.02}$
$R^2 = 0.7654$ (1)
Ripe category:
$y = 0.745x + 10.51$
$R^2 = 0.682$ (2)
Over-ripe category:
$y = 27.251\ln(x) – 61.659$
$R^2 = 0.8329$ (3)
All category:
$y = 2.1708x^{0.7894}$
$R^2 = 07071$ (4)

where
x = mean temperature recorded by prototype thermal device
y = mean temperature estimated

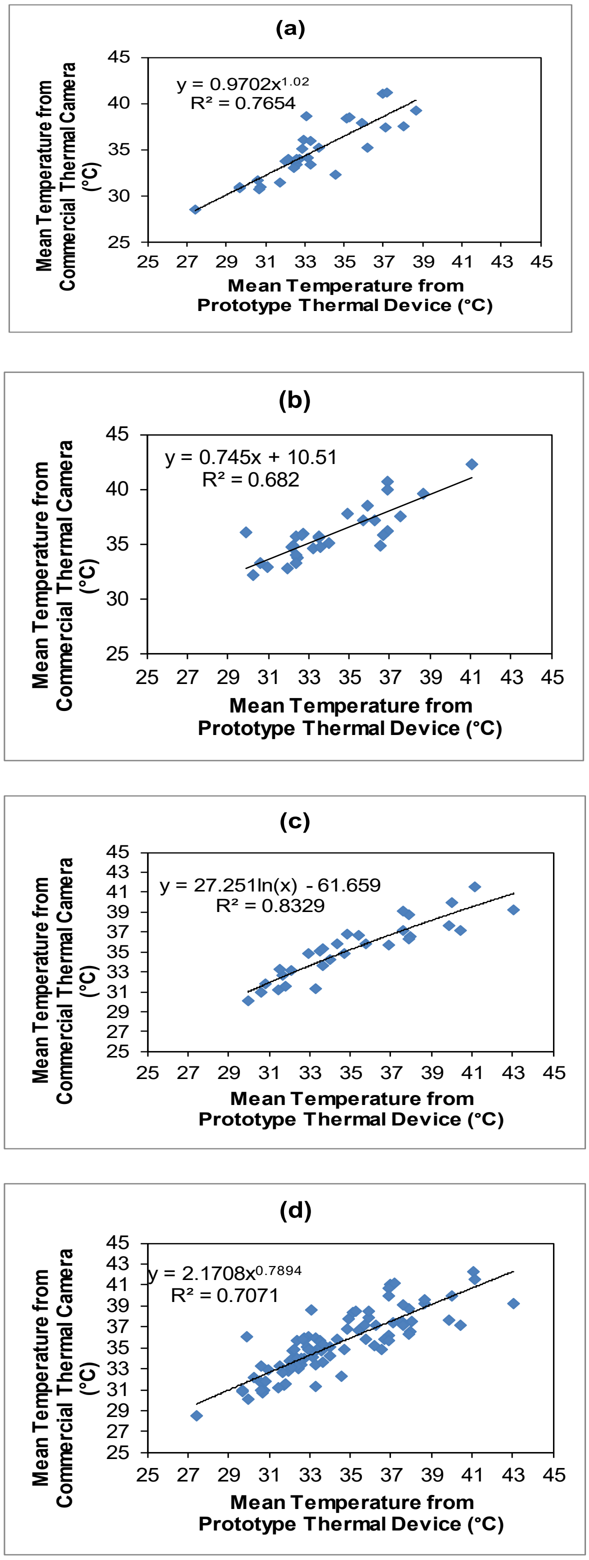


Figure 4. Scatter plot of mean temperature from commercial thermal camera versus mean temperature from prototype thermal device of (a) Under-ripe FFB, (b) Ripe FFB, (c) Over-ripe FFB and (d) All FFB

Conclusion

The prototype thermal device in this study underestimates the mean temperature of commercial thermal camera for most of the FFBs with an average of 1.39°C for under-ripe, 1.80°C for ripe, and 0.05°C for over-ripe FFBs. All the categories give high standard deviation from the range of 1.50 to 1.72°C. The correlation of mean temperature recorded by prototype thermal device and commercial thermal camera is significantly correlated ($P<0.01$) for each category. Hence, the prototype thermal device is capable of estimating the mean temperature of oil palm FFBs with the values analogous to the mean temperature from commercial thermal camera using the Equation (1), (2), and (3) for each maturity level.

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