Detection of Foreign Bodies in Roasted Coffee by using Active Thermography

A. Ngoensod, N. Nunak, and T. Suesut

Abstract—**This paper presents the detection of foreign bodies in roasted coffee by using active thermography with real-time thermal image processing. Foreign bodies, including stone, wood, etc., are found in roasted coffee beans contaminated during drying process and transportation. The principle of radiation from objects with different emissivity and heat capacity is applied. The heat radiation from the roasted coffee and the foreign body are different; therefore, the thermal image can be used to identify the foreign objects. The active thermography system consists of a thermal image camera and computer image processing, heat source and conveyor system controlled by programmable logic controller. The testing and experimental results of the proposed system show that the foreign bodies in roasted coffee beans can be found in all batches, however, the number counting of foreign objects are inaccurate.**

Index Terms—**thermal image processing, Active Thermography, emissivity**

I. Introduction

In northern Thailand, the hill-tribe farmers grow Arabica coffee, while Robusta coffee is grown in South of Thailand [1]. Thailand is the third grown coffee in Southeast Asia [2]. Normally, the coffee production starts from growing coffee, harvesting the cherries, processing of cherries, drying the beans, milling process and finally roasting process. The quality of the coffee is not only depending on the odor and taste, but also the quality of production is very important. Consumers always have high expectations about food purity [3]. Generally, roasted coffee beans contain a small percentage of foreign bodies such as stone and wood. Therefore, it is important to find the way to get coffee 100% pure [4]. In coffee industrial production, many of coffee producers need a pure coffee without any foreign bodies matter because foreign bodies will reduce the quality of coffee. The traditional detection of foreign bodies in coffee by using a person or sorting apparatus, it is not as good as it should be.

The color sorters are the machines replacing hand sorting that consists of the functions of the human hand, brain and eye by separating the color. The color sorter can reduce the amount of foreign bodies, but it cannot be done effectively for 100% [5]. There are many possible reasons for the limitation, for example, the difference material with the same physical size and same color.

The destoner or specific gravity separator is widely used in coffee industry based on the principles of different specific gravity. This machine can be used to produce roasted coffee for the finest quality and it is suitable for the large coffee industry [4].

To overcome this problem, in recent years, many new applications of infrared thermography have been developed [3][6][7]. Infrared thermography is a nondestructive evaluation method with an increasing span of applications. This technique is able to detect contaminants or inhomogeneities. Many industries use thermal image to detect foreign bodies.

Infrared nondestructive testing is particularly suitable to evaluate the quality of fruit, vegetables, seeds, flour, etc. This method includes passive and active infrared nondestructive testing. In active infrared nondestructive testing, the sample under test is stimulated by appropriate thermal activation and thermal images are collected in a determined interval time in order to reconstruct the time–temperature curves of the sample. By analyzing the behavior of the curves for any image pixel, inhomogeneities, flaws and foreign objects can be individuated even in the case of internal defects [7].

In this work, the problem has been solved by using active thermography to find foreign bodies in roasted coffee products. The principle of active thermography was applied to the foreign body detection system for roasted coffee beans.

II. Principle

A. Emissivity

Emissivity is the coefficient of thermal radiation which ranges from 0 to 1, can be defined as a ratio of the thermal radiation from the surface of any object to the thermal radiation from a black body at the same temperature. The maximum thermal radiation that surfaces can radiate (Ideal surface or black body) is $\varepsilon = 1$.
Emissivity of a surface, denoted ε, is defined as

$$\varepsilon = \frac{E(T)}{E_b(T)} \quad (1)$$

Manuscript received December 22, 2016; revised January 9, 2017. This work was supported in part by Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, 10520

A. Ngoensod is with department of Instrumentation and Control Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand 10520

N. Nunak is with department of Food Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand 10520 (e-mail: Navaphattra@gmail.com).

T. Suesut is with department of Instrumentation and Control Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand 10520 (corresponding author e-mail: taweepol.su@kmitl.ac.th).

where

E(T) is the thermal radiation energy of any object (equation 2);

$E_b(T)$ is The thermal radiation energy of a black body at the same temperature as that surface (equation 3 and 4);

$$E(T) = \varepsilon\sigma T^4 \quad (2)$$

$$E_b(T) = \int_0^{\lambda} \frac{C_1}{\left[\lambda^5 \exp\left(\frac{C_2}{\lambda T}\right) - 1\right]} d \quad (3)$$

$$E_b(T) = \sigma T^4 \quad (4)$$

where σ is the constant of Stefan–Boltzmann is equal to 5.67 x 10^{-8} W / m^2 • K^4.

Emissivity depends on the type of object, the surface of the object and the surface temperature of the object.

B. *Active thermography*

Active thermography is a method that enabled nondestructive testing assessment of properties of materials. This method needs external heat source to stimulate the thermal energy to the sample. The difference of thermal radiation between the sample and the defects can be classified by the thermal image. There are 3 methods for active thermography: pulse methods, lock-in methods and pulse phase methods.

Meinlschmidt [13] was developed thermographic detection of defects in wood-based materials. When wood sample under detection was heated with heat source, the temperature of the surface will increase suddenly. The speed of heat at surface diffused into the sample based on the thermal properties such as emissivity, density and heat capacity. The defects in the sample made an obstacle for the heat spreading process. Thereby, the surface temperature over the defect would drop slower than the temperature in other areas and the surface over the defect expressed the hot spots for a long time.

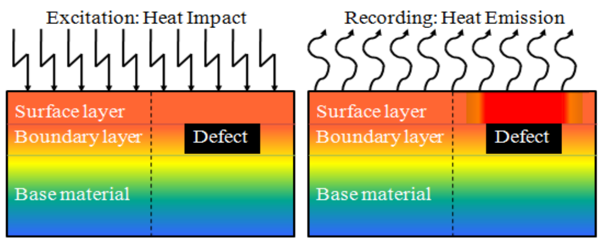


Fig. 1. Principle of active thermography (adapted from P. Meinlschmidt)

III. EXPERIMENTAL SETUP

The experiment setup consisted of infrared thermography camera FLIR series A315 (see Table I), Halogen light bulb 50-60 Hz 100W, Conveyor 15x160 cm^2 7.27 cm/sec, Programmable Logic Controller Omron C200HX, photo sensors, and computer for thermal image processing as shown in Fig. 2.

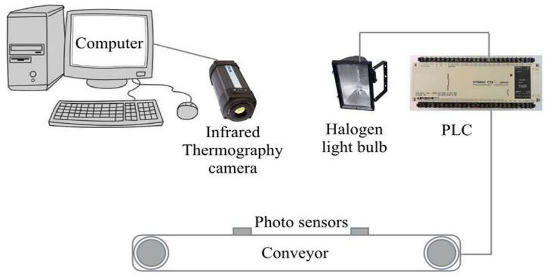


Fig. 2. The detection system for foreign bodies in roasted coffee by using Active thermography.

TABLE I
TECHNICAL CHARACTERISTIC OF IR CAMERA [15]

Measuring range	–20 to +120°C (-4 to 248°F) 0 to +350°C (32 to 662°F)
Accuracy	±2°C or ±2% of reading
Resolution	320 × 240 pixels
Spectral range	7.5–13 µm
Thermal resolution	320 × 240 pixels
Image frequency	60Hz
Field of view	25° × 18.8° / 0.4 m (1.31 ft.)
IFOV	1.36 mrad
Sensor	Uncooled microbolometer
Camera Interface	Gigabit Ethernet

A. *Foreign bodies detection procedure*

The detection procedure started from preparing the sample by mixing the roasted coffee and foreign bodies (i.e. stones, wood), and placed the sample on the tray. The conveyor system controlled by PLC was turned on. Then the sample tray placed on the conveyor belt. When the sample tray was passed to the first photo sensor, the belt would be stopped in order to heat for 50 seconds by stimulating light source. Afterward, the conveyor belt would move the tray to the second photo sensor which was the position for acquiring thermal image by infrared thermography. This step spent time for 4 seconds, including cooling time of sample and thermal image processing. The thermal images were analyzed to detect foreign bodies in roasted coffee using Vision Builder Software AI 2013 (National Instruments) by using functions stimulate acquisition, extract RGB, filter image, threshold image and detect objects, respectively according to the flowchart as shown in Fig. 3. The analysis was divided into 2 parts. There was detecting of foreign bodies and counting the number of foreign bodies. Stimulate acquisition is used for exporting images into the program, extract RGB is used for converting images to 8 bits, filter the image is used for suppressing the high frequencies, threshold image is segmented color into 2 colors (black and white), and detect object is used for counting the number of foreign bodies.

B. *Estimation of cooling time for detecting foreign bodies*

This process for estimating a suitable cooling time after the roasted coffee beans was heated. The estimation was started by preparing the sample. After that the samples were heated for 50 seconds in order to increase the temperature of the samples around 40°C by stimulating light source. Then the samples were cooled down for 24 seconds in the ambient temperature and infrared thermography camera will be used to record thermal image into video files. Finally, the roasted coffee beans and stones were analyzed the temperature by

ISBN: 978-988-14047-3-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

using FLIR IR Camera Player software. The experiment was repeated for five times.

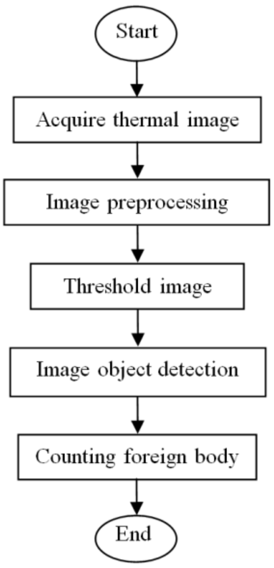


Fig. 3. Image processing for detecting foreign bodies

C. *Emissivity measurement*

From the previous work [14], we applied this method for measuring the emissivity of roasted coffee bean and stone. In this emissivity measurement, the sample tray and the black tape were placed on an aluminum plate which was heated by water in a hot water bath for 85°C. The emissivity value shown on the thermal camera was adjusted the temperature to the temperature on the thermal camera was equal to the temperature at the thermocouple.

IV. Results and Discussion

The experiment results were divided into 3 parts: foreign bodies detection procedure, estimation of cooling time for detecting foreign bodies and emissivity measurement, respectively.

The foreign body detection procedure included detecting of the foreign object and counting the number of foreign bodies. Thermal images have clearly shown the difference between roasted coffee beans and foreign bodies, even though the eyes could not distinguish at some parts. FLIR IR Camera Player software was acquired thermal images and analyzed the temperature. The optimal setting temperature for the level and the span of this experiment was 27°C - 47°C.

For the detection of foreign bodies, the experiment was done randomly for 200 times with the sample containing the foreign body and the roasted coffee. The testing result found that the proposed system could correctly detect the foreign bodies for 100%. The detection result from Vision Builder AI shows pass for pure roasted coffee and shows fail for detecting the foreign bodies as shown in Fig. 4.

However, counting the number of foreign bodies was found some errors. The samples in this experiment were added 1, 2, 3, 4, and 5 pieces of the foreign bodies, respectively and the experiment was done 10 times repeatedly. The result found error 2 times of the total 50 times. The examples of counting the number of foreign bodies have shown in Fig. 6.

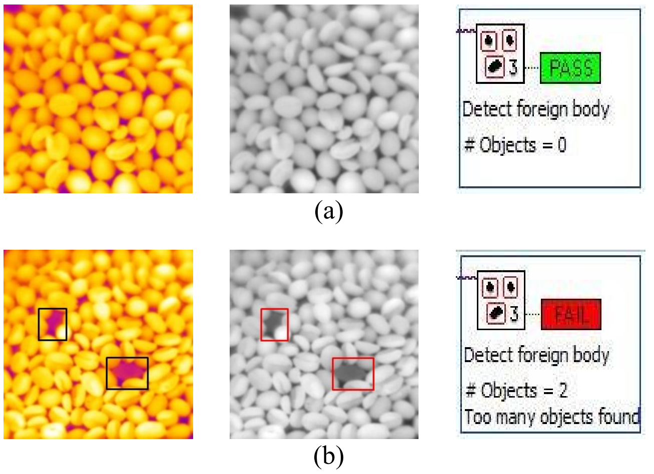


Fig. 4. The examples for detecting foreign bodies. There are thermal images from infrared thermography camera, gray images converted by FLIR IR Camera Player software and the result from the program. (a) The detection of stones in roasted coffee, there is no any foreign body, the program cannot detect foreign bodies. (b) The detection of stones in roasted coffee, the program can detect foreign bodies.

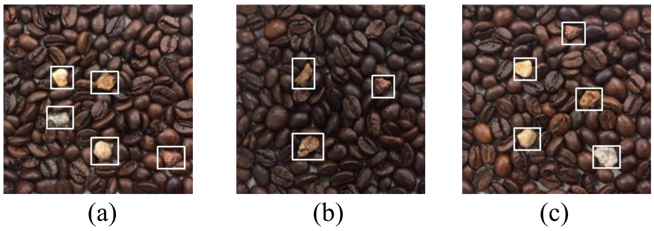


Fig. 5. Examples of roasted coffee beans and stones are mixed together. (a) 5 pieces of stones in roasted coffee, (b) 3 pieces of stones in roasted coffee and (c) 5 pieces of stones in roasted coffee

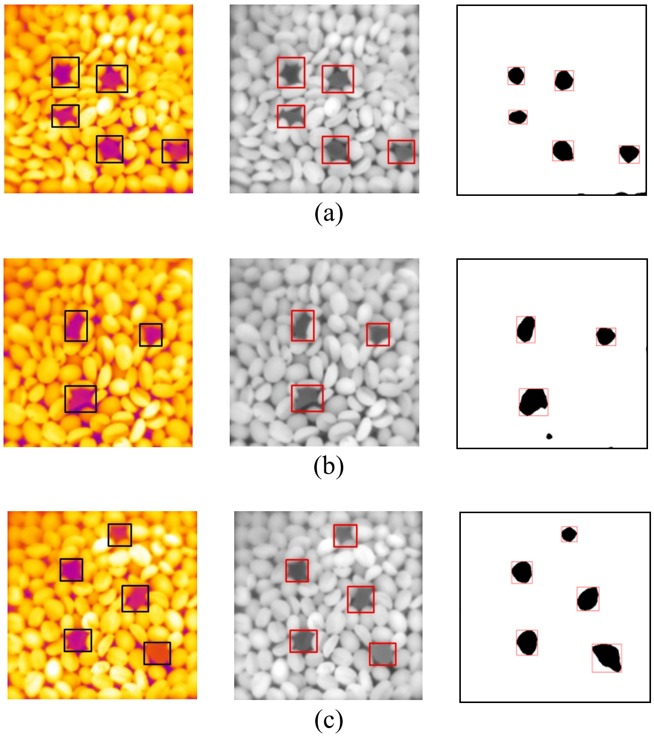


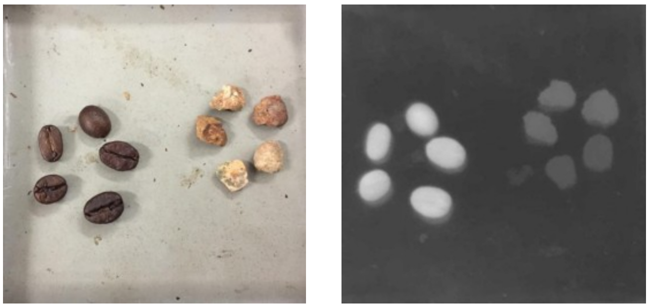
Fig. 6. The examples of counting the number of foreign bodies from Fig. 5. There are thermal images from infrared thermography camera, gray image converted from FLIR IR Camera Player software and the result from the program. (a) The detection of stone in roasted coffee, the program can count 5 from 5 pieces of foreign bodies. (b) The detection of stone in roasted coffee, the program can count 3 from 3 pieces of foreign bodies. (c) The detection of stone in roasted coffee, the program can count 5 from 5 pieces of foreign bodies.

ISBN: 978-988-14047-3-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The problem may be caused by the segmentation of the thermal image. The image processing algorithm cannot classify the difference between the roasted foreign bodies and sample tray, therefore, the function of counting object is mistaken the operation.

Fig. 7 shows gray images recorded from the infrared thermography. The intensity level relating to the temperature, low temperature was dark gray and high temperature was bright gray.

The estimation result of cooling time for detecting foreign bodies has shown in Fig. 8. In x-axis represents the time (seconds) and the y-axis represents the temperature (°C). After stimulating with same heating time, the temperature of the stones was constant, but the temperature of the roasted coffee beans was gradually declined because both materials had different emissivity. The suitable time for detection was the first second which the tray was moved to the position of the infrared camera due to the temperature between roasted coffee beans and stones was the most difference.



(a) (b)

Fig. 7. The image and gray image of sample tray is placed with 5 pieces of roasted coffee beans and 5 pieces of stones.

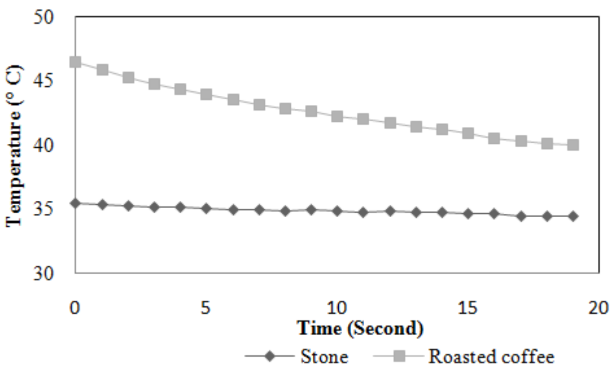


Fig. 8. Temperature curves of the sample in cooling times after the coffee beans and stones are heated about 4 seconds. In x-axis represents the time (seconds) and the y-axis represents the temperature (° C).

Table I shows emissivity of roasted coffee and stone from the experiment. The results of the emissivity were the difference between roasted coffee bean and stone. After the samples were stimulated, the surface temperature of the samples was different because of the thermal properties.

TABLE I
EMISSIVITY OF THE MATERIAL

Material	Emissivity
Roasted coffee	0.75–0.78
Stone	0.80–0.85

V. CONCLUSION

In this work, the detection of foreign bodies in roasted coffee was done by the principle of radiation from objects with different material properties such as emissivity and heat capacity. Consequently, the heat radiation from the sample surface and a foreign object surface is different. Therefore, the thermal image can be identified the contaminated objects from the roasted coffee beans by using active thermography. The testing and results of the system show that it can detect foreign bodies in roasted coffee beans accurately. However, it still has some problems caused by the thermal image processing. The result of experiment presents a clear comparison between roasted coffee and foreign bodies. This system can be improved to an automatic real-time system and this principle can apply to detect foreign bodies in other products as well.

REFERENCES

[1] A. Pongsak, "Coffee Production Status and Potential of Organic Arabica Coffee in Thailand", in *Assumption University : AU Journal of Technology*, June 7, 2015.

[2] S. Chintongprasert, A. Saekoe, “Potentiality to export coffee in Thailand to Asean”, *journal of marketing and management of Rajamangala University of Technology Thanyaburi*, 2015.

[3] G.Ginesu, D.D. Giusto, V.Margner and P. Meinlshmidi, “Dection of Foreign Bodies in Food by Thermal Image Processing”. *IEEE Transactions on Industrial Electronics*, vol. 51, pp. 480-490, 2004.

[4] D. Giesen. (2013, March 17). Coffee destoner [Online]. Avalable: http://www.giesencoffeeroasters.eu/roaster-equipment/coffee-destoner

[5] J. M. Low, W. S. Maughan, S. C. Bee and M. J. Honeywood, “Sorting by colour in the food industry”, *Woodhead Publishing Limited and CRC Press LLC*, London, 2011.

[6] L. Senni, M. Ricci, A. Palazzi, P. Burrascano, P. Pennisi and F. Ghirelli, “On-line automatic detection of foreign bodies in biscuits by infrared thermography and image processing, *Journal of Food Engineering 2014,* vol. 128, pp. 146–156, Dec. 2013.

[7] S. Bagavathiappan, B.B. Lahiri, T. Saravanan, John Philip and T. Jayakumar, “Infrared thermography for condition monitoring – A review”, *Infrared Physics & Technology*, vol. 60, pp. 35–55, September 2013.

[8] J. Trefil, “The Nature of Science: An A-Z Guide to the Laws and Principles Governing Our Universe”. *Houghton Mifflin Harcourt.*, 2003, pp. 377.

[9] M. Quinn, “Thermal Radiative Transfer and Properties (Book style)”, *John Wiley & Sons.,* 1992, pp.56.

[10] Chelladurai, V., Jayas, D. S. and White, N. D. G. 2010. “Thermal imaging for detecting fungal infection in stored wheat*”. Journal of Stored Products*, vol. 46, pp. 174-179, 2010.

[11] S. Benzerrouk, “Active and Passive Thermography for the detection of defects in green-state poedermetallic compacts”, Degree of Doctor of Philosophy, Worcester Polytechnic Institute, August 2011.

[12] F.P. Incropera, D.P. DeWitt, T.L. Bergman, and A.S. Lavine, Fundamentals of Heat and Mass Transfer, 6th ed., John Wiley & Sons, 2007, pp. 746–747.

[13] P. Meinlschmidt, “Thermographic detection of defects in wood and wood-based materials”, *14th international Symposium of nondestructive testing of wood*, Hannover, Germany, May 2nd -4th, 2005.

[14] K. Rakrueangdet, N. Nunak,T. Suesut, and E. Sritham, “Emissivity Measurements of Reflective Materials using Infrared Thermography”, *the International MultiConference of Engineers and Computer Scientists 2016*, vol. 1 , March 16 - 18, 2016.

[15] FLIR A315 [Online]. Avalable: http://www.flir.co.uk/automation/display/?id=41955

ISBN: 978-988-14047-3-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)