Thermal Image Resolution on Angular Emissivity Measurements using Infrared Thermography

T. Nunak, K. Rakrueangdet, N. Nunak, and T. Suesut

Abstract—**This paper reports the effect of viewing angle and thermal image resolution (IFOV and FOV) of Thermal Imager (TI) on the emissivity, with a view to providing a potential temperature monitoring of equipment in the electrical power distribution system which the reliability of system is the most important concern. The results show that the emissivity, which is the most important parameter to obtain the accurate temperature, is approximately constant at the viewing angle less than 45^o. In case of the changing of the object to detector distance, this will not affect to the temperature measurement if MFOV at the object level is smaller than the targeted object. This can be concluded that TI is an effective tool to measure the temperature and monitor the failure of electrical equipment installed in the position at far away from the operator.**

Index Terms— **Emissivity measurements, thermal imager, viewing angle, thermal image resolution, electrical equipment**

I. Introduction

Emissivity (ε) of object and infrared detector-to-object distance are technical factors for an accurate infrared thermography measurement which are the source of uncertainty in temperature measurement with the infrared camera. Emissivity values play a significant role in the determination of correct temperature of an object surface. Emissivity depends on many factors such as temperature, surface roughness, wavelength, and viewing angle [1], [2], [3]. In general, emissivity of a real surface is interested in emission at a given wavelength or in a given direction, or in integrated averages over wavelength and direction [4].

Thermal imager (TI) or infrared thermography is a novel nondestructive technique that measures the temperature of an object remotely by measuring infrared radiation emitted by an object surface. It can be used as a tool for monitoring process and preventive maintenance since the faults generally presented with abnormal temperature distribution and easily detected by thermal image [2]. Electrical inspection is one of the monitoring applications that has successfully utilized from TI. The reliability is the most important topic that engineer who takes responsibility of the electrical power distribution system needs to concern in order to avoid the failure of equipment. This causes to the Condition Based Maintenance (CBM), based on using the real-time data, involves to the electrical system and need to be achieved maintaining the correct equipment before its failures actually occur. The contact measurement of temperature of the electrical power distribution system is usually impossible to achieve, whereas TI can be an effective tool to success [5], [6].

For accurate measurement of electrical equipment temperature by an infrared camera, emissivity and object to camera distance need to clearly understand. Since increasing of object to camera distance can decrease the spatial resolution of a thermal imaging system. This can affect to an accurate thermal image and can be achieved by choosing the right TI with the appropriate application. Spatial resolution is explained in many specifications of TI such as FOV, IFOV, and detector array [2].

There are several performance parameters of TI, which effected to a sharp and accurate thermal image, e.g. spectral range, temperature resolution, frame rate, and spatial resolution or thermal image resolution [2]. Some researchers have been studied about these parameters, e.g. Muniz *et al*. [7] have proposed the use of experimental models for error correction in temperature measurement by thermal imager due to the influence of the field of view of the imager's lens, combined with varying viewing angles between the measured object and the imager. However, they have not yet studied the accurate temperature measurement in the viewpoint of emissivity changes due to the thermal image resolution.

Also in general, the emission of a real surface differs from the Planck distribution. Emissivity of real surface obtained from TI with the specific infrared spectral band should be presented at a given direction. In 2011, Suesut *et al*. [8] have been studies the emissivity of electrical distribution equipment at a normal direction over wavelength band from 8 µm to 14 µm. Nevertheless, equipment in the electrical distribution system is installed at the approximately height of 10 meters above ground level, the operator who carry the TI for measuring the temperature of equipment usually is at an angle of elevation of 45^o with the targeted object.

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Therefore, the main objective of this paper was to study the effect of viewing angle and the thermal image resolution (IFOV and FOV) of TI as the influence of instrument on the emissivity, with a view to providing a potential method capable of actual implementation. Also, consideration about these parameters has the benefit to operator for choosing an appropriate thermal imager because they had an influence on an accurate temperature measurement.

II. Theoretical Background

A. Basic Principle of Thermal imaging

An object emits infrared radiation at a temperature above 0 K. The amount of radiation emitted by an object depends on its temperature and emissivity. Emissivity is defined as the ratio of energy emitted from an object to that of a blackbody at the same temperature. In general, the spectral radiation emitted by a real surface differs from the Planck distribution (Fig. 1). Emissivity of real surface is interested in emission at a given wavelength or in a given direction, or in integrated averages over wavelength and direction [4].

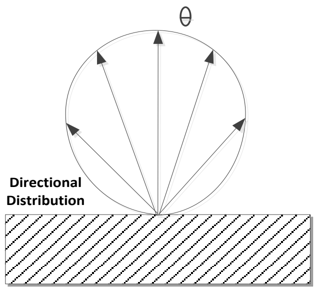

Fig. 1. Radiation emitted by a real surface at various directions or viewing angles (θ)
Source: Fundamentals of Heat and Mass Transfer [4]

For temperature measurement of an object with TI camera, the infrared radiation emitted from a measured object is converted into an electrical signal via IR detector in the camera and then processed into a thermal image which displayed a large number of point temperature over an area in form a thermal map of the measured object surface [2], [9].

B. Thermal Image Resolution

Thermal image resolution or spatial resolution is an important parameter, e.g. field of view (FOV), instantaneous field of view (IFOV), detector array, considered for choosing the infrared camera.

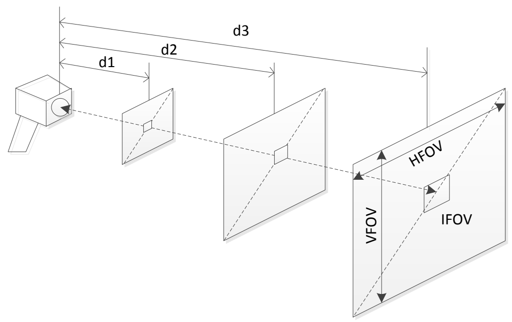

Fig.2. Spatial resolution at a different object to camera distances

This parameter can be used to indicate the ability of the camera to distinguish between two objects in the field of view. It primarily depends on object to camera distance, lens system and detector size. Thermal image resolution decreases with increasing object to camera distance as shown in Fig. 2. Lens system with small field of view has higher spatial resolution. Finally, detectors with larger number of array element will produce thermal images with better spatial resolution [2].

III. Experiments

A. Experimental Setup

The equipment required for the experiments consists of an infrared camera of a thermal imager, a tripod of camera stand, and a heating unit. Fig. 3 shows the schematic of a typical experimental setup, where the thermal imager camera is placed suitably in front of the sample placed on thermoelectric cooling device (TEC) constructed on the holder. TEC was used as a heat source. The temperature was controlled by a DC power supply (24 V 2.1 A) with a current regulator circuit. In order to measure the emissivity at various directions, a special sample holder was used to enable adjusting of the samples direction as shown in Fig 3.

The acquired thermal images are displayed on the TI screen and stored in the personal computer and real time temperature of the sample can be remotely measured. Typical thermal images of samples at normal direction and 45^{o} to the normal direction along with their original photograph are presented in Fig.4.

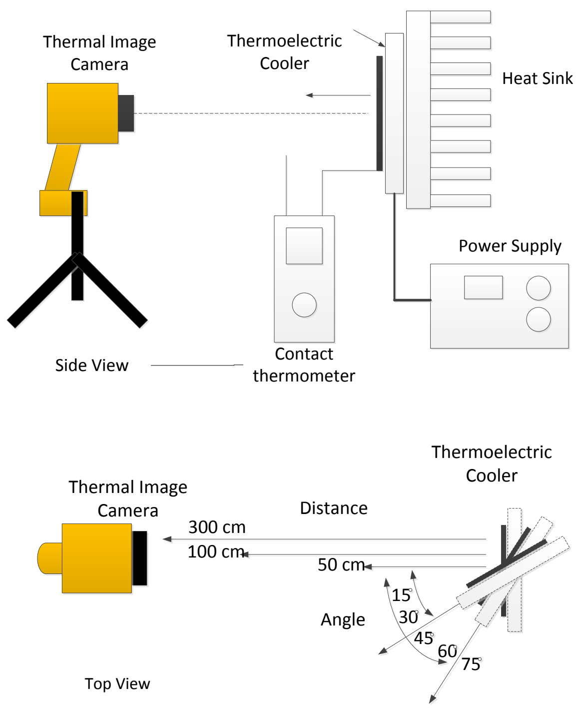

Fig. 3. Schematic of a typical experimental setup

B. Thermal Imager (TI)

Infrared detector with a band pass filter from 7.5 μm to 14 μm was used in experiments. A portable infrared camera or

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thermal imager TIi400 (Fluke Corporation, USA), with a temperature measurement range of -20 to 1,200°C and an accuracy of ±2°C at 25°C or 2%, whichever is greater, was used in experiments. The thermal detector was a Focal Plane Array, uncooled microbolometer of 320 x 240 pixels with the field of view 24° (horizontal) x 17° (vertical), spatial resolution (IFOV) 1.31 mRad and minimum focus distance of 15 cm. An addition lens type (telephoto IR) with the field of view 12° (horizontal) x 9° (vertical), IFOV 0.65 mRad and minimum focus distance of 45 cm was also used. The thermal sensitivity was 0.05°C at 30°C. Thermal images were analyzed by thermal imager software Fluke SmartView® 3.5. The thermal image resolution of Ti400 at different distances is presented in table 1.

TABLE I
THERMAL IMAGE RESOLUTION OF THERMAL IMAGER (TI400) AT VARIOUS OBJECT TO DETECTOR DISTANCE

Distance (cm)	FOV[a] (cm)	IFOV[b] (cm)
50	21x16[c]	0.07x0.07[c]
100	42x31	0.13x0.13
300	126x94	0.39x0.39
300[e]	63x47	0.2x0.2

[a]Field of View; [b]Instantaneous Field of View;
[c]Horizontal size x vertical size; [d]IR tele lens type

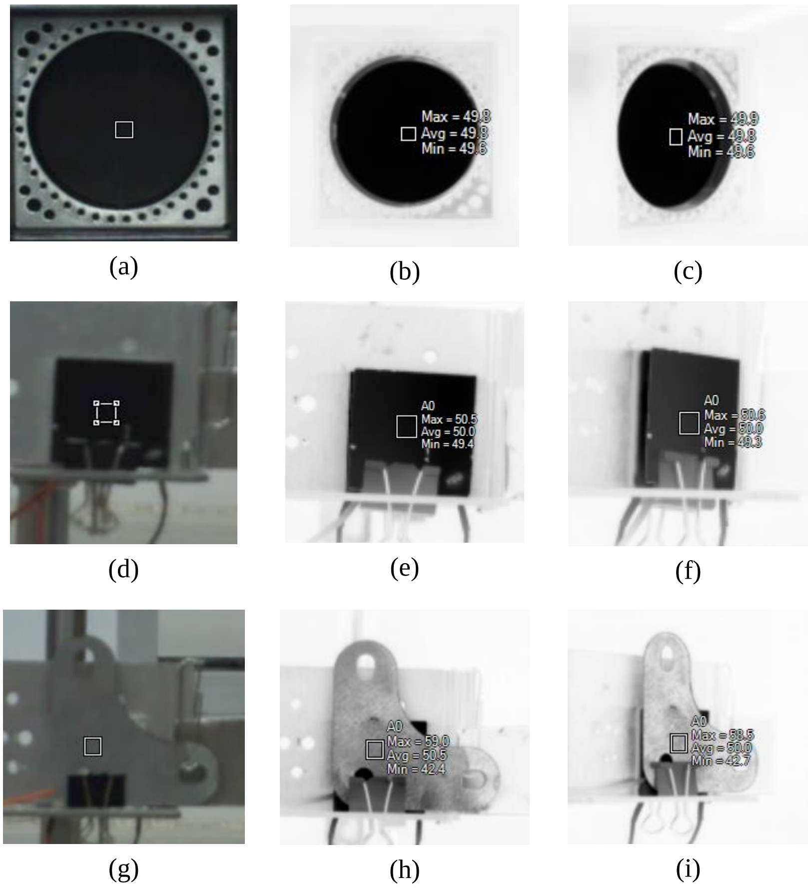


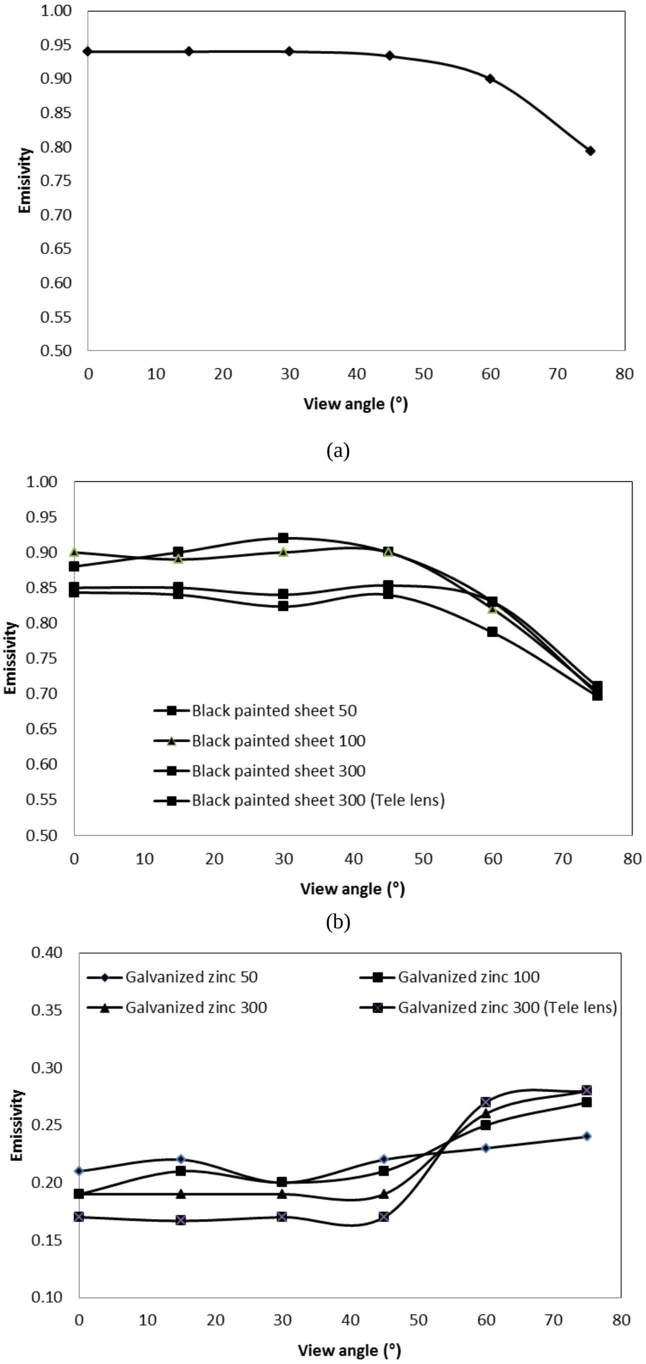
Fig. 4. Typical (a, d, g) original photograph and thermal images (b, e, h) at normal direction and (c, f, i) at 45° to the normal direction of blackbody, black painted sheet, and galvanized zinc sheet, respectively

C. Measurement Method

Three types of experiments were carried out. The change of emissivity of targeted object due to variations in viewing angle was studied. Then, the effect of IFOV and FOV changes on emissivity was investigated by changing the object to detector distance and lens type. The radiation emitted from the sample is measured using an infrared radiation detector, which has been calibrated at a blackbody model 9132 (HART Scientific, USA) during separate measurement in order to ensure that the obtained results from each experiment had no effect of the instrument.

Temperature of sample surface measured by TI was simultaneously measured with a J-type contact thermocouple, in order to record the actual temperature, which are placed on the sample surface, close to the area viewed by the infrared detector. Emissivity of the object at each condition as displayed in TI was adjusted until the temperature measured with TI equal to that of a thermocouple, then the adjusted emissivity is the actual value of the object. The reflection temperature or sometimes call the background temperature (T_{BG}) is a parameter that affects the emissivity measurement; therefore, it was monitored during experiments for determining the reflection of radiation of the surrounding. In this study, T_{BG} was between 25.1°C to 26.4°C.

Experiments were performed on two types of samples: square piece of black painted sheet, as a representative of the high emissivity sample, and galvanized steel sheet, as a representative of the low emissivity sample, as a part of the electrical distribution equipment such as PG clamp, connector or bolt. The sample coated with a black-paint for



(a) (b) (c)

Fig. 5. Emissivity of (a) blackbody device, (b) black painted sheet, and (c) galvanized zinc steel sheet as a function of the emission angle at distance of 50 cm, 100 cm, 300 cm, and 300 cm with addition tele infrared lens

enhancing surface emissivity. The emissivity of each sample was measured at the temperature of 50°C normal to the surface and at the viewing angles 15°, 30°, 45°, 60°, and 75° to the normal direction at object to detector distance of 50 cm, 100 cm, and 300 cm. For each viewing angle the same sample was used for emissivity measurement. Each experiment was repeated three times and the average value was taken from the recorded data.

IV. Results and discussions

A. Effect of Viewing Angle on Emissivity

The first experiment was carried out to understand how the angle of view was influenced to the emissivity. Changing in the emissivity was recorded in each direction, and results for all samples are shown in Fig. 5 (a, b, and c). It can be seen that the emissivity of all three types of samples is approximately constant over a range of viewing angle and dramatic changes to increasing or decreasing with increasing of viewing angle depends on sample types. Emissivity of blackbody device and black painted sheet starts to decrease at the angle beyond 45°, whereas that of galvanized zinc steel sheet increases at this viewing angle. These results are in agreement with reported in the textbook of Fundamentals of Heat and Mass Transfer [4], which explained about the influence of viewing angle on emissivity of a surface. For emissivity of conductors, it is approximately constant over the range of angle less than or equal to 40 ($\theta \leq 40^{o}$), after which it increases with increasing of angle. In contrast, for the emissivity of nonconductors, it is approximately constant for angle less than or equal to 70 ($\theta \leq 70^{o}$), beyond which it decreases sharply with increasing of angle.

B. Effect of distance between object and detector on Emissivity

The increasing of object to detector distance causes the increasing of the size of a single pixel (IFOV) and the horizontal and vertical enlargement of the total measuring field (FOV) at the object level as explained in Fig. 2. FOV and IFOV of TI at various distances is shown in Table 1. It can be seen from the results in Fig. 5 (b and c), the emissivity for all distances at the same viewing angle are quite similar. This is thought to be due to the measured size or measurement field of view (MFOV) at the object level is smaller than the targeted object, as a highlighted rectangular frame on the picture in Fig. 4, for all objects to detector distances and all viewing angles even IFOV and FOV are changed.

C. Effect of Lens type on Emissivity

Changing IR lens from standard type to tele type can also changes the thermal image resolution as IFOV and FOV changed. It can be seen from the Fig. 5 (b and c) that the emissivity of both standard lens and tele lens at the same distance (300 cm) has almost the same values. This can be explained with the similar reasons of changing in object to detector distance. However, it was found that there is a slight variation in the results of the galvanized zinc steel sheet at a distance of 300 cm. This is probably due to the emissivity of this sample is quite low, causing to the sample meets the large effect of the surrounding radiation.

V. Conclusion

From the importance of accurate temperature measurement using TI, especially when used for monitoring the operation of the electrical power distribution system that the reliability of system is the most important thing, this paper reports the effect of viewing angle and thermal image resolution (IFOV and FOV) of TI on the emissivity, with a view to providing a potential method capable of actual implementation. The results show that the emissivity, which is the most important parameter to obtain the accurate

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temperature, is approximately constant at the viewing angle less than 45°. Although changing of the object to detector distance causes to change the thermal image resolution, this will not affect to the temperature measurement if MFOV at the object level is smaller than the targeted object. This can be concluded that TI is an effective tool to measure the temperature and monitor the failure of electrical equipment installed in the position at far away from the operator. Nevertheless, most of electrical equipment has the low emissivity that will be affected from the surrounding radiation. Their exact values of emissivity at each angle should be reconsidered with concern the reflection, and also the results should be brought to determine the emissivity correction methodology at different angles in further research.

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