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Non-contact measurement of angle of view between the inspected surface and the thermal imager

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HIGHLIGHTS

- A method of measuring the angle of view was proposed.
- The proposed method does not need contact with the inspected object.
- The proposed method employs laser distance meters, commonly available in the market.
- The experimental evaluation led to estimations with acceptable errors.

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ABSTRACT

The angle of view between inspected object and thermal imager influences the values of temperature measured by infrared thermography. This happens because the emissivity depends on the angle of radiation, and because the apparent temperature measured is influenced by that angle of view combined to thermal imager's field of view. Therefore, it is necessary to know the angle of view during thermographic inspection, which is generally not feasible due to safety reasons. This paper develops a method of measuring the angle of view with no contact with the inspected object, by employing laser distance meters, commonly available in the market.

1. Introduction

Infrared thermography is a technique widely used in predictive maintenance of electrical equipments because it is non-invasive, non-destructive and safe [1–4]. Also because many defects have temperature rise as a primary symptom of failure [1,4,5].

Many factors can affect temperature measurement through infrared thermography: skill of the thermographer performing the inspection; imager characteristics; environmental conditions such as air temperature, relative humidity and wind speed; electrical current load of the inspected device and its surface emissivity [3,6–12]. There are mathematical models that estimate the influences and satisfactorily correct the introduced errors of these factors [2,3,7]. For instance, Fig. 1 shows the variation of surface emissivity of electrical conductors, non-conductive objects, and a black body. Thus, if the emissivity is not properly informed by the thermographer to the thermal imager software, there may be a measurement error due to this parameter.

Recently, researches have been developed to evaluate the influence of the angle of view between the imager and the inspected object into the measured temperature by thermal imagers. In addition to this, there is evidence that the thermal imager's characteristics combined with the angle of view also introduce measurement errors. The survey results published in [13] indicate that thermal imagers with different fields of view (FOV), inspecting the same object, present diverse errors of measurement when varying the angle of view. By considering only the emissivity dependence to angle of view, it would not be expected a difference in measurement errors with thermal imagers of different FOVs.

More recently, another research [14] found out that the angle of view causes temperature measurement errors as a function of FOV. These errors can lead the thermographer to misdiagnose. For example, a thermographic inspection with an angle of view equal to 60° leads to temperature measurement errors in the range

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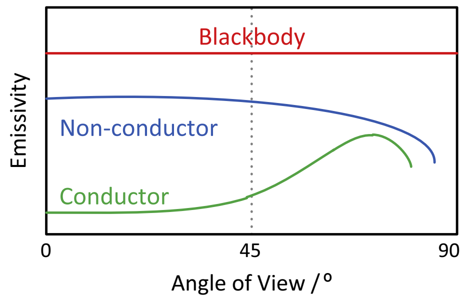

Fig. 1. Typical directional characteristic of the emissivity of conductive and non-conductive surfaces, compared to black bodies. Adapted from [1].

−4/−5% [13,14]. For normal operation of electrical equipments, operating temperatures rise over ambient 50/60 °C [1,3]. In these cases, the errors introduced in the temperature measurements can reach 5 °C. On the other hand, a temperature difference higher than 4 °C between similar electrical equipments indicates a possible failure [3]. Empirical models were developed to correct this measurement error as a function of the involved variables: measured temperature, angle of view and FOV.

Fig. 2 illustrates a hypothetical situation where the thermographer is not able to be positioned frontally to the inspected surface, zero angle of view. It is a typical situation of electrical substations where the equipment to be inspected is at a considerable height from the ground where the inspector is. In this situation, the temperature measurement would be subject to measurement errors due to the steep angle of view.

This paper develops a method to estimate the angle of view between the thermal imager and the inspected surface without physical contact. The method can be used in installations where, for any reason, especially safety, it is necessary to maintain a safe distance from the inspected object. This situation is typical of electrical installations.

The knowledge of the angle of view allows the thermographer to assess the emissivity of the inspected surface more accurately, and correct the measurement error due to their parameter. Thus, the uncertainty of measured temperatures would be smaller, leading to more assertive diagnostics.

2. Angle of view's non-contact measurement method

The developed method employs laser distance meters, with tilt measurement incorporated. Such instruments are fairly accurate and commonly have an uncertainty measurement range for distance from (1 to 2) mm, and uncertainty measurement for tilting close to 0.2° [15–17].

First, the simplest case it is studied where, even without direct sight, it is known that the inspected surface is perpendicular to the ground. The general case where the inspected surface has a generic angle with the ground is shown in sequence. In both cases, it will be considered the angle of view as the angle between the normal line to the inspected surface and the line connecting the thermal imager to the inspected surface. The less common case where the angle of view has a component in the horizontal plane can also be solved with the methods presented here by translating or rotating the Cartesian plane used in the study. However, a horizontal angle meter is required. The meters here considered [15–17] only estimate vertical angles of inclination.

2.1. Inspected surface perpendicular to the ground

If is known that the inspected surface is perpendicular to the ground (ground is considered the thermal imager position), the angle of view can be obtained directly by employing a tilt angle meter incorporated into a laser distance meter. For instance, the laser distance meter Leica DISTO D8 [18] and the BOSCH GLM-80 [19] are instruments able to this task.

In Fig. 3, the segment *AB* is the surface to be inspected and the point *C* corresponds to the location of the imager. The inclination angle of the imager (α) is obtained by direct measurement using the proposed instrument. By checking the *CDE* triangle, Fig. 3, it is noted that the angle γ is complementary to the tilt angle α, as

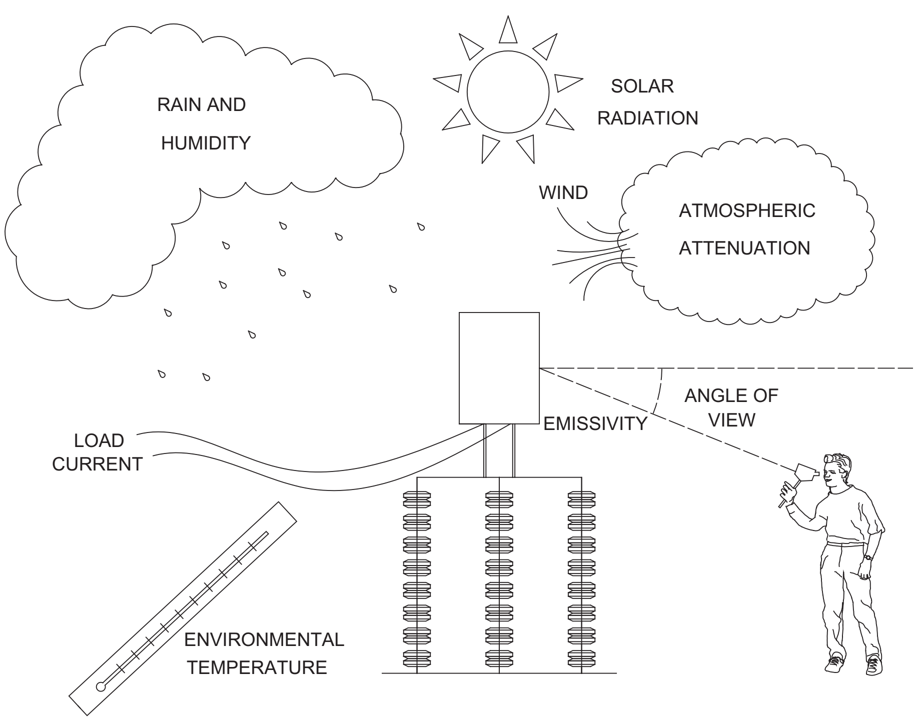

Fig. 2. Representation of angle of view between imager and inspected object. Adapted from [7].