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An instantaneous approach for determining the infrared emissivity of swine surface and the influencing factors

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ABSTRACT

Infrared thermal imaging technology has been widely employed in temperature measurements of human and animals and its accuracy relies on the determination process of the emissivity of the target to a large extent. However, common used methods were unable to determine the emissivity of the surface of living animals and thus lower the accuracy. In this paper, we suggested a new approach to acquire the infrared emissivity of living swine in real time. In the approach, the surface temperature of swine and reference body were measured to compute the emissivity and the measurement process was completed in a non-contact and non-invasive manner. We changed the surface reflection energy of animals and reference body by changing the ambient radiant energy and obtain the surface emissivity in real time without confirming the actual temperature of animal surface. In this way, the infrared emissivity of the animal surface can be determined instantaneously and without knowing the real temperature. Both swine specimen and a living swine were used in this study. Using this method, we measured the emissivity of different body sites of the swine. The results showed that the emissivity values at different body sites show the significant differences. The emissivity values at trotter and eye were respectively 0.895 and 0.930 and the emissivity on swine surface varied from 0.945 to 0.978. More important, the distribution of the infrared emissivity on a living swine was explored and the detailed differences of the emissivity on a swine surface can be cleanly seen. Furthermore, we studied the influencing factors on the emissivity of animal surface, through measuring the emissivity distribution on swine surface when pig specimens were sprayed with water on the surface or heated using this method. This study is of great significance for the accurate measurement of swine surface temperature.

1. Introduction

Infrared temperature measuring technology, as a non-contact and non-invasive mean, has been adopted in the temperature measurement of livestock and wildlife animals (GürdiL et al., 2007; Mccafferty and Dominic, 2007), disease detection (Montanholi et al., 2008; Schaefer et al., 2012) and animal welfare (Nääs et al., 2014; Stewart et al., 2005). Pigs, as an abundant domestic animal, provide meat and by-products to human beings. The temperature of pig body directly determines its health state. The infrared thermal image technique has been studied in the pig surface temperature measurement (Malmkvist et al., 2012; Loughmiller et al., 2001), core temperature measurement (Zinn et al., 1985; Chung et al., 2010), pig disease study (Siewert et al., 2014; Cook et al., 2015), and the quality monitoring of pork (Costa et al., 2010; Schaefer et al., 1989).

Skin emissivity is one of the crucial factors to acquire the temperature of people and animals and it directly affects the precision of temperature measurement (Mccafferty and Dominic, 2007; Taylor et al., 2014). The emissivity of human is 0.975 based on the study Vargas et al. (Vargas et al., 2009), however, the emissivity of pig body surface ranged from 0.920 to 0.980 (Metternick-Jones and Skevington, 1992; Gariepy et al., 1989; Kelly and Heitman, 1954; Soerensen et al., 2014). (Chung et al., 2010) studied the relationship between surface temperature and core temperature of gnotobiotic piglets with the emissivity of 0.98. (Malmkvist et al., 2012) surveyed the thermal effect of floor on newborn pig body temperature with the emissivity of 0.98. Siewert determined the temperature on swine head with 0.97 (Siewert et al., 2014).

The skin tissue emissivity was also previously studied. The skin emissivity was calculated by measuring the physical temperature and infrared radiation temperature (Kelly and Heitman, 1954; Soerensen et al., 2014). However, in the method, it was required to directly contact pigs, even penetrate the thermometer into skin

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surface or kill animals and it took time to complete the heat transfer, thus resulting in the huge error and the slow measurement. (Togawa, 1989) proposed a method to measure the skin emissivity by changing the infrared reflection of the surface via utilizing additional thermal radiator (TR) and the method was applied and improved in later skin emissivity study (Huang and Togawa, 1995; Otsuka et al., 2002). The method could quick complete the measurement, but it could not used to determinate the emissivity of living animals. In addition, transmissivity, absorptivity, and reflectivity were measured based on Kirchhoff's laws to acquire the emissivity of the skin indirectly (Sanchez-Marin, 2010; Villase Or-Mora et al., 2009).

Therefore, in order to improve the surface temperature measurement precision of infrared thermal imaging technology, it is necessary to develop a fast and accurate approach to determine surface emissivity of living animals. In this paper, we changed the surface reflection energy of animals and reference body by changing the ambient radiant energy and obtain the surface emissivity in real time without confirming the actual temperature of animal surface. The paper aims to calculate the emissivity distribution differences of living porcine body surface and explore the influences of some environmental factors on porcine surface emissivity.

2. Materials and methods

2.1. Samples and instruments

One swine specimen and one growing swine were provided by the Beijing Academy of Agriculture and Forestry Sciences. The swine specimen was made by a real swine and was about 40 kg weight. The body surface was clean and could be heated by external heat source from the opening in abdomen. The living pig was robust with the weight of 80 kg. The swine specimen was used to study the influences of different environmental factors on the emissivity and the living swine was used to measure the distribution of surface emissivity,the living pig was narcotized by the veterinarian after feed 1 h in the moring, in order to keep it quiet in the experiment. Portable FLIR SC620 infrared camera (IRC) (FLIR Systems, Inc., Wilsonville, OR, USA) has the following parameters: the spectral band of 7.5–13 μm, the resolution of 640×480, thermal sensitivity < 40 mK, the camera lens of 24° and the instantaneous field of view (IFOV) is 0.65 mrad for one detector element. The reference body was a white hood paper. The emissivity of reference body (ε_r) was 0.93 (Flir Systems, 2011). The power of the TR source employed in this study was 400 W to alter the background radiation In the experimental period, a standard blackbody was used to calibrate the IRC; the ambient temperature was 25 ± 2 °C; RH was $45 \pm 5\%$; the wind speed was 0.03 ± 0.01 m/s. Testo 435-2 multi-function meter (Testo AG, Germany) was adopted in the experiment. The remaining objects in the lab were covered by black velvet to reduce the emitted reflection. Alcohol was used to clean the sample surface.

2.2. Methods

Generally, IRC captures the infrared radiation emitted by the objects and then displays the radiation in the form of temperature on the screen through a series of transformation. In actual measurement, the infrared radiation entering an IRC includes the target radiation, environmental reflection, and the atmosphere radiation and can be expressed as:

$$I(T_R) = \tau_a[\varepsilon I(T_0) + (1-\alpha)I(T_U)] + \varepsilon_a I(T_a) \qquad (1)$$

where, $I(T_R), I(T_0), I(T_U)$, and $I(T_a)$ respectively represent the total radiation temperature, the target radiation temperature, and atmosphere radiation temperature. ε is the target emissivity; τ_a is atmospheric transmissivity; ε_a is atmospheric absorptivity; α is target absorptivity of the surroundings. In the short-distance measurement, $\tau_a = 1$; $\varepsilon_a = 0$. According to Kirchhoff's Law, α equals to ε in the temperature measurement for the opaque objects. Then, Eq. (1) is simplified as:

$$I(T_R) = \varepsilon[I(T_0) - I(T_U)] + I(T_U) \qquad (2)$$

When the ambient temperature is T_{U1}, the total radiation temperatures of target $I(T_{R1})$ and reference body $I(T_{R3})$ received by the IRC are respectively expressed as:

$$I(T_{R1}) = \varepsilon[I(T_0) - I(T_{U1})] + I(T_{U1}) \qquad (3)$$

$$I(T_{R3}) = \varepsilon_r[I(T_r) - I(T_{U1})] + I(T_{U1}) \qquad (4)$$

When the ambient temperature is T_{U2}, the total radiation temperatures of target $I(T_{R2})$ and reference body $I(T_{R4})$ received separately by the IRC are respectively expressed as:

$$I(T_{R2}) = \varepsilon[I(T_0) - I(T_{U2})] + I(T_{U2}) \qquad (5)$$

$$I(T_{R4}) = \varepsilon_r[I(T_0) - I(T_{U2})] + I(T_{U2}) \qquad (6)$$

According to Eqs. (3)–(6), the emissivity is calculated as:

$$\varepsilon(T_0) = 1 - (1-\varepsilon_r)\frac{I(T_{R2}) - I(T_{R1})}{I(T_{R4}) - I(T_{R3})}. \qquad (7)$$

According to Planck's law, we get:

$$I(T_R) = \int_{\Delta\lambda} R_\lambda L_{b\lambda}(T)d\lambda = \int_{\Delta\lambda} R_\lambda \frac{C_1}{\pi}\lambda^{-5}\left[\exp\left(\frac{C_2}{\lambda T}\right) - 1\right]^{-1} d\lambda \approx CT^n \qquad (8)$$

where R_λ is the spectral responsivity of the thermal imaging detector and it does not vary with the wavelength λ; C_1 and C_2 is the first and second radiation constant, respectively; C is a constant. Hence, Eq. (7) can be rewritten as:

$$\varepsilon(T_0) = 1 - (1-\varepsilon_r)\frac{{T_{R2}}^n - {T_{R1}}^n}{{T_{R4}}^n - {T_{R3}}^n}. \qquad (9)$$

The spectral band of SC620 IRC employed in the study is 7.5–13 μm and n=3.9889 (Okamoto, 1996). Eq. (9) is the final calculation equation adopted in the paper.

As shown in Fig. 1, the station of infrared data acquisition is composed of three parts. The infrared imaging part is consisted by IRC and laptop, which are connected by FireWare cable to record the infrared sequences at high speed. IRC was fixed by a tripod to ensure the stability and the dip angle between the IRC and the sample zone was 15°. For the opaque gray body, when the dip

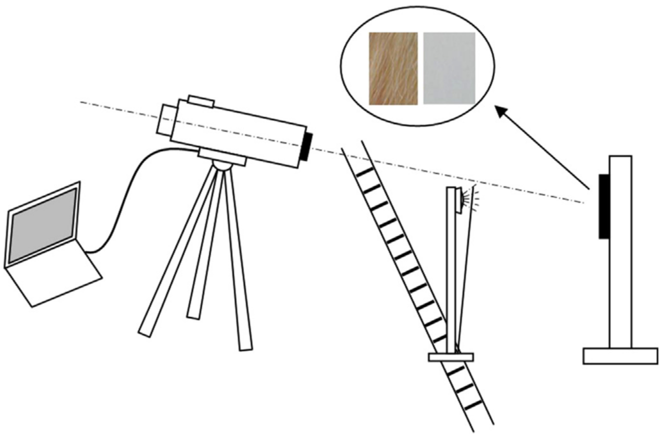

Fig.1. The experimental platform for emissivity measurement.