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Influence of environmental factors on infrared eye temperature measurements in cattle

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ABSTRACT

Environmental factors were evaluated to determine potential limitations in using cattle eye temperatures obtained through infrared thermography (IRT) for early disease detection systems or in animal welfare research studies. The effects of the following factors on IRT eye temperatures in cattle and a fabricated surrogate "eye" were evaluated: camera to object distance, wind speed, camera settings (distance, emissivity, and humidity), and solar loading. Wind speed in both live animals and using a surrogate "eye" was found to decrease the IRT temperature. In the presence of ~7 km/h wind, the mean IRT eye temperature decreased by 0.43 ± 0.13 °C and; at higher wind speeds (~12 km/h), the temperature decreased by 0.78 ± 0.33 °C. Direct sunlight was found to increase the IRT eye temperature by 0.56 ± 0.36 °C. It was determined that environmental factors impact IRT temperature measurements significantly and therefore must be managed to ensure reproducible and accurate readings.

1. Introduction

Infrared thermography (IRT) is a non-invasive, remote, and passive method of measuring the infrared radiation emitted from the surface of a subject in order to determine radiated temperature. IRT has been used in veterinary and animal sciences mainly to detect surface temperature fluctuations correlating to various surface and/or core temperatures (Stewart et al., 2005; McCafferty, 2007). It has been suggested that IRT temperatures of the lacrimal caruncle region of the eye may correlate with core body temperature, in essence serving as a proxy for core body temperature (Ng and Kaw, 2006). The use of IRT to measure eye temperature is rapid, relatively easy, and less invasive compared to alternative methods of body temperature measurement such as rectal thermometers, tympanic infrared thermometers, thermal microchips, and rumen boluses (Johnson et al., 2011; Timsit et al., 2011). Researchers have attempted to demonstrate the diagnostic potential of IRT as an early disease detection technology. Many of these studies have shown that IRT is successful in detecting elevated IRT eye temperatures in a feedlot setting (Schaefer et al., 2007, 2012). In addition, research into the development of automated IRT systems for obtaining cattle eye temperatures under field conditions is ongoing (Schaefer et al., 2004, 2007, 2012; Gloster et al., 2011). Further, IRT has been used in the cattle industry as an assessment tool aiding in the detection of animal fear- and pain-related physiological responses associated with handling procedures (Stewart et al., 2008; Schwartzkopf-Genswein et al., 2012), branding (Schwartzkopf-Genswein and Stookey, 1997), castration (Stewart et al., 2010; Coetzee, 2011), and dehorning (Stewart et al., 2009).

Early detection of a febrile state based on eye temperature with IRT would be highly desirable in determining the incidence of bovine respiratory disease complex (BRDc), one of the most common and financially important diseases in the cattle industry. Substantial numbers of animals in feed yards fail to exhibit traditional clinical signs of BRDc and often go undetected (Reeve-Johnson, 2001; Thompson et al., 2006; Duff and Galyean, 2007; Weary et al., 2009). Furthermore, the use of IRT to detect and measure stress levels in cattle has been a focus of many recent studies due to increasing consumer awareness and demand for improved animal welfare and humanely produced products (Stewart et al., 2005; Schwartzkopf-Genswein et al., 2012).

The majority of researchers assessing IRT recognize that external environmental and physical factors may influence IRT measurements collected in the field (Stewart et al., 2005; Johnson et al., 2011). The need for the use of standardized methods to reduce measurement error such as maintaining a fixed focal length and angle has also been emphasized (Schaefer et al., 2012).

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However, few studies have evaluated environmental factors beyond the recording of ambient air temperature and relative humidity that may influence the accuracy and validity of temperatures determined by IRT (Gloster et al., 2011). Important factors such as wind speed and solar radiation/loading are sometimes but generally not recorded and may have significant influence on IRT readings (McCafferty, 2007). In addition, the total radiation energy emitted or absorbed by an animal's body is contingent on the emissivity of its skin (Poikalainen et al., 2012). Emissivity is the measure of an object's ability to emit and absorb radiation, expressed as the ratio of the radiation emitted by a surface to the radiation emitted by an ideal blackbody at the same temperature. Infrared cameras measure this emitted energy or thermal radiation to visualize and measure the surface temperature of an object. Emissivity of different objects can have a value anywhere from 0 (shiny mirror) to 1.0 (blackbody) and generally emissivity will depend on wavelength. The visible spectrum emissivity will be dependent on color (wavelength). In the Infrared (IR) spectrum, however, it is surface structure and composition which are important, not color. The emissivity factor of unshaven cattle skin is approximately 0.93–0.98 depending on coat quantity and length (Stelletta et al., 2012). The IR emissivity of human skin has been widely reported in the literature as 0.97, while most researchers using IRT in cattle studies use 0.95 as the emissivity setting for their IRT camera (Stelletta et al., 2012; Gloster et al., 2011).

Illumination of the surface of an object does not change its emissivity, although for high accuracy IRT, ambient illumination must be taken into account. Solar radiation reaching the earth includes mainly visible radiation. When cattle are exposed to solar radiation some portion of the visible radiation may be absorbed and re-emitted as heat, or IR radiation. Since the visible radiation is color dependent, blacker cattle should absorb more solar radiation, and solar loading effects will be greater, when measuring IR temperatures.

The influence of environmental factors needs to be understood because even a small effect on IRT temperature may introduce sufficient error to alter research results when used as an alternative assessment tool or it may result in the false interpretation of an animal's state of health, and may lead diagnostically to either false positive or false negative errors. For example, Schaefer et al. (2012) reported only a 0.8 °C difference between true positive and true negative BRDc in cattle using automated IRT as an early disease detection prognostic tool. Thus, before IRT is extended into field use, such as in feedlots, as a diagnostic tool requiring critical temperature differences of <1 °C, it is critical to first evaluate key environmental factors which may influence the accuracy of IRT measurements.

The objective of the present study was to determine how some common environmental factors affect IRT eye temperatures and to document the relationship between IRT and rectal temperature in cattle. The paper first looks at the relative distributions of IRT eye temperature and rectal temperature in cattle and evaluates the requirement of precision of the IRT eye temperature in order to detect elevated body temperatures. Environmental parameters such as camera to object distance, wind speed, and solar loading were then examined to assess their effects on IRT measurements.

2. Materials and methods

The study consisted of three experiments: one laboratory and two field studies. The protocol for the field trials using Holstein cows and Angus feedlot cattle were conducted according to Anon (2009). Two commercially available infrared cameras, FLIR I40 and E60 infrared cameras (FLIR Systems Inc., Wilsonville, USA), were used for all IRT measurements. Both of these cameras have stated manufacturer accuracies of ±2 °C of the true temperature, and a thermal sensitivity of less than 0.05 °C. The main difference between the two cameras is in pixel resolution. The FLIR I40 resolution is 120 × 120, while the E60 is 320 × 240. Ambient temperature and humidity are important required camera inputs in order to take accurate measurements according to the camera manufacturer, and were recorded with a Brunton ADC Pro portable weather meter prior to their input into the respective cameras (Brunton Outdoor Group, Riverton, USA). IRT images were analyzed using ThermaCAM Research 2.10 Pro (FLIR Systems, Danderyd, Sweden).

2.1. Establishing the relationship between IRT eye and rectal temperature

A total of 73 Angus cross steers (body weight 309 ± 5 kg) were used to determine the relationship between body temperatures collected via a rectal thermometer and IRT of the average temperature in the lacrimal region of the eye. The handling facility was within a barn to reduce the environmental effects of wind or solar radiation. Rectal temperature was obtained immediately following the IRT measurements. The portable weather meter was used to verify a lack of wind/draft within the barn. Rectal temperature was obtained using a digital thermometer (GLA-M500 Agricultural Electronics, San Luis Obispo, CA) and eye temperature was obtained using a FLIR I40 infrared camera (FLIR Systems Inc. Wilsonville, USA). All IRT and thermometer measurements were obtained over a three hour span on the same day and both measures were taken on each steer. The IRT measurements were taken from a standard distance of one metre while the animals were restrained in a squeeze chute.

2.2. Effect of solar loading and wind speed

The effects of solar loading and wind speed in the field were examined using a total of 79 Holstein dairy cows from a local dairy farm (Blackwell Dairy Farm, Kamloops, Canada). IRT measurements were taken with the cattle situated in a headlock feeding system with a FLIR E60 infrared camera (FLIR Systems Inc., Wilsonville, USA). The headlock feeding system was aligned along a northwest–southeast axis. The cattle were evaluated as they voluntarily approached the feed bunk where their heads were automatically locked in upon entry. The facility was equipped with a perforated awning which was used to shade the cattle. Two sets of IRT measurements were taken within a 30 min time frame, with and then without the awning in order to block the effect of solar loading on the dairy cattle.

To observe the effect of solar loading, IRT eye temperatures were taken from the left eye of 15 of the dairy cows and the right eye of 12 of the same cows. Three cows were released early as they had finished feeding and had become agitated as a result of the restraint, which resulted in a modest missing of data points. Because of the northwest-southeast arrangement of the feeding system, the left eye was directly exposed to sunlight, while the right eye was blocked (shaded) from direct sunlight by the head of the cow. The first IRT measurements (of both left and right eyes) were taken while the cattle were exposed to sunlight. The second IRT measurements were taken with the perforated awning extended all the way down to provide shade. The measurements were taken at midday, so the sun was situated in the southern part of the sky such that the left eye of all animals was oriented towards the sun and the right eye was oriented away from the sun. Therefore, there were three conditions: direct sunlight (left eye with no awning), indirect sunlight (right eye with no awning), and shaded with awning (both eyes).

To observe the effect of wind speed, IRT eye temperatures were obtained from the eyes of 52 dairy cows with and without the