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Review on the Use of Infrared Thermography to Monitor the Health of Intensively Housed Livestock

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Abstract

Present and emerging diseases of livestock are a major threat to food security and human health. Radiated temperature measurement by infrared thermography can be automated to remotely record the surface temperature of animals, both individually and in groups, and forms the basis of a disease detection system. Radiated temperature is a measure of energy loss and is determined by the physiological state of the animal and the prevailing environmental conditions. The most effective use of infrared thermography mitigates confounding effects such as ambient temperature, time of day, human handling. Residual temperature is a variable that better reflects thermal responses to physiological conditions independent of thermoregulation to ambient conditions.

Keywords: Infrared thermography; Ambient temperature; Residual temperature; Disease detection; Welfare

Introduction

At the time of writing (1st April 2021) the world is gripped in a corona virus pandemic that has infected 129, 865,850 people worldwide and caused 2,833,193 deaths: a mortality rate of 2.18%. This is only the latest example of a zoonotic disease having the potential to end millions of lives. More than half of all human infectious diseases are of zoonotic origin and about 75% of all emerging infectious diseases are zoonotic [1]. The vast majority of which occurs in poorer regions of the world, particularly Africa, India and South America, where humans are in daily close contact with their livestock. Many of the zoonotic diseases in these regions are parasitic due to the high prevalence of parasites in the livestock population.

In more affluent regions, livestock production has become increasingly concentrated into ever larger housing operations. Perhaps the best-known examples of which are in China comprising of 11-story barns housing many tens of thousands of pigs and producing up to 2 million pigs per year. The scale of such operations massively reduces contact between humans and animals, and reduces the prevalence of zoonotic, particularly parasitic, diseases within the livestock population. However, the downside of intensive housing conditions is that once an infectious agent enters the system it can very quickly infect vast numbers of animals. A case in point is the divesting affects African Swine Fever (ASF) had on the Chinese population of pigs [2]. Within a year of the appearance of ASF in 2018 more than 50% of the Chinese herd had been wiped out, and a resurgence of the disease in 2021 in northern China has destroyed and estimated 20% of the northern herd. Another downside to intensive farming is that a fast-spreading infection can spread from the farm to the food chain very rapidly, potentially affecting large numbers of people.

Diseases of livestock adversely affect the food supply, as is the case with ASF, and zoonotic diseases have a devastating impact on human health. In intensive-housing operations the sheer number of animals and the very few numbers of stockpersons required to run such operations obviate the need for automated systems to non-invasively monitor aspects of the animal's physiology and behavior that can be interpreted in terms of health and welfare. The close monitoring of the health and welfare of our livestock is in humanity's best interests, and one technology with enormous potential for such close monitoring is infrared thermography.

Literature Review

Infrared thermography is a technique to measure the surface temperature of objects, including animals. Thermal imaging cameras detect radiation in the long-infrared range (approx. 9,000-14,000 nm) of the electromagnetic spectrum and map the temperature of each of the camera's pixels to produce a thermo gram, i.e. a temperature map of the surface of an object. There are many parameters and other factors that need defining to obtain thermal images from which tractable data can be obtained. Typical examples are emissivity, camera-to-object distance and angle, exposure time, full or partial frame images, background infrared radiation, ambient temperature and humidity, solar loading, amongst others. The exact parameters will depend on the species and housing environment. Other factors that affect IRT measurements, or the efficacy of the measurements for decision-making, are the performance characteristics of the camera such as accuracy, sensitivity, resolution, and sampling frequency. The more expensive IR cameras have greater image resolution but how much this influences decision making based on temperature measurements is yet unknown. Similarly, the latest multispectral cameras are capable of imaging in 3D and it is feasible to express surface temperature as a function of surface area. Since radiated temperature is at least partly a function of animal size, expressing radiated temperature as a function of surface area may prove to be a significant advance in the interpretation of thermal responses to febrile disease.

It is relatively easy to account for the constraints on IRT such as emissivity, reflected infrared radiation or camera performance. These factors can be measured with known accuracy and algorithms account for these effects in imaging analysis software. Much more difficult to control are the physiological processes and environmental influences that confound interpretation of surface temperature of living animals. Homoeothermic animals attempt through physiological and behavioral processes to maintain a relatively constant core body temperature in the face of often widely ranging ambient temperatures. Homoeothermic animals regulate body temperature via several physiological processes that are specific to different livestock species but perhaps the most important is by regulating blood flow to the periphery, or to specific anatomical sites such as ears or legs. In addition, factors that affect metabolism have an impact on an animal's surface temperature. Consumption of food, in terms of amount and composition, is associated with the heat increment of feeding, body temperature follows a circadian rhythm, anatomical locations differ in their sensitivity to blood flow, and responses to one physiological variable can confound interpretation of the reaction to a different physiological reaction. For example, it is sometimes necessary to restrain an animal to obtain an infrared image, but the act of restraint is likely to be a stressful experience that initiates a stress response, including an increase in radiated temperature. Thus, the act of obtaining the image confounds the interpretation of the temperature data obtained from the image. Indeed, physical restraint to capture IR images probably accounts for much of the contention surrounding the relationship between radiated temperature to feed and growth efficiencies reported in the scientific literature [3]. In addition, many studies rely on hand-held cameras, and often too few temperature measurements are taken to adequately define the physiological state in question. Clearly, the way forward in the development of infrared thermography as a diagnostic tool lies in the automation of the technology, from image-capture to image analysis to data analysis and reporting. We have developed automated image-capture systems for individual animals coupled to an automated feeding system, and for group housing [3-5]. These systems are totally non-invasive, they do not require handling of animals or even the presence of humans in the barn and thereby completely avoid a confounding stress response. They also permit large numbers of measurements to be made that more accurately define the animal's physiological states such as stress, pain, estrus, pregnancy, parturition, lactation, growth and feeding activity. Measurement of radiated temperature has been used to detect, diagnose, and monitor each of these biological states. Notwithstanding, the main application of infrared thermography is in disease detection, although from a cost/benefit perspective perhaps the most profitable application of IRT is in selecting the most feed and/or growth efficient animals [3].

Measurement of core body temperature is a standard procedure for diagnosis of febrile disease. Unfortunately, measurement of radiated surface temperature is often conflated with the measurement of core temperature. This is a mistake because surface temperature is partly a function of thermoregulatory processes to control core temperature and is affected by environmental variables such as ambient temperature. Radiated temperature often exhibits a characteristic biphasic response to infection. The initial reaction is a decrease in surface temperature as blood flow to the periphery is restricted to increase the core temperature. The observed decline in radiated temperature potentially provides an early warning of infection prior to the diagnostic limitations imposed by measuring of core body temperature.

There are essentially two methods of obtaining radiated temperature of animals, either as individuals or as a group of animals in a pen. It is technically easier but less diagnostically relevant to obtain radiated temperature measurements on a pen of animals. This type of image provides temperature information on the group yet can detect the presence of a febrile disease when only a few of the animals exhibits a febrile response [4]. Unfortunately, group imaging is not yet able to inform the producer which of those animals is exhibiting a febrile response, only that there is a potential problem in the pen or barn. At least this is the current situation but advances in imaging technology, particularly 3D imaging, may be able to identify individual animals from their body size and shape. However, until we arrive at that future our best diagnostics rely on identifying a significant change in surface temperature relative to previous temperatures measurements [4,5]. For group images this is best achieved using the maximum animal temperature as the diagnostic variable because it only requires one animal in a group to develop a febrile response for maximum temperature of the group to be raised. This hypothesis was tested using vaccination to elicit a febrile response, with differing numbers of animals vaccinated in each replication of the experiment to represent a range in prevalence [4]. In this model, an increase in the maximum temperature was noted when <10% of the animals were vaccinated. The average temperature of a group is much less diagnostically relevant because the febrile reaction of one animal is subsumed by the average temperature of the group. Of course, the more animals within the group that exhibit a febrile response the more diagnostically relevant the average group temperature becomes.

A problem to overcome with group imaging is that much of the temperature information from the image is obtained from everything in the image that is not the animals, i.e., walls, floor etc. and these have a major effect on the average image temperature. To obtain the average temperature of the animals it is necessary to separate the animals from the rest of the image using a segmentation algorithm. There are several published image segmentation algorithms that decompose the IR images based on various temperature parameters. The choice of algorithm determines the temperature range, and this can include the entire temperature range of the animal or a narrower range. In our studies we have employed an algorithm that identified the peaks in temperature distribution within the image and from these selects the lowest temperature between the two warmest peaks [3-5]. Applying the lowest temperature between the warmest peaks as a threshold isolates the animals from the background. Note that isolating the pigs from the background can be used to count clustering activity [4,5]. This is an important observation because group temperature depends to some extent on clustering activity. Indeed, clustering activity is a behavioral component of the febrile response. Note that the more clustering activity the higher the radiated temperature. There are two consequences to this observation. Firstly, it would be relatively easy to reject images in which there was more than one cluster, thereby focusing only on images in which all pigs are in a single cluster and consequently reducing the variation between images for group temperature measurements. Secondly, clustering behavior is an adaptive response to infection and thus quantifying clustering behavior from infrared images may be indicative of disease. Another aspect of group imaging is that it is relatively easy to observe the growth of the group in terms of the area of the image occupied by the animals, and growth rate may be indicative of chronic health problems. Thus, infrared imaging can be used to obtain thermal (radiated temperature), behavioral (clustering activity) and physiological (growth rate) data simultaneously on the same animals in the same images, all of which have diagnostic relevance.

The more common approach to disease detection is to obtain radiometric images on individual animals. In most studies this is done with a hand-held camera, much like the screening of human subjects during the current Covid-19 pandemic. However, it should be noted that single time point measurements are of very low diagnostic efficacy, if at all useful. Automating the imaging of individual animals is technically more difficult than group imaging because an animal ID must accompany the image. The most common automated method is to install a camera at water or feed station and capture images when the animal visits the station. Such a system requires a means of automatically capturing the animal's identification. This is usually achieved using Radio Frequency Identification Tags (RFID), or transponder. In a typical example in a swine unit, the pigs carry half-duplex RFID tags in their ear; often these tags are associated with a commercial feeding system. Thus, when a pig enters the feeding system a unique 15-digit identifier is detected by a transceiver and transmits the ID number to a computer. Ideally, manufacturers of automated feeder or watered systems would permit access of the infrared camera system to the unique identifiers of the RFID system. However, in our experience, this has not been the case and we install a separate antenna to detect the ID of an animal in the feeding system and to signal the image capture software to start recording images.

Often feeding systems are linked to a weigh scale and the weight of the animal is recorded each time it enters the feeding system. Thus, several variables are measured each time the animal enters the feeding system, inclusive of feed consumption, feeding duration, feeding frequency, animal weight, and radiant temperature. The positioning of the camera dictates the anatomic location of the imaging. For pigs, the easiest location is to set the camera above the feeder and obtain images of the dorsal surface. Unfortunately, spurious images of anatomical locations that only capture a part of the animal are often recorded, particularly as the animal enters or leaves the system. Spurious images must be automatically identified and eliminated from further analysis. In the special case of young animals newly introduced to an automating feeding system it is possible to get two animals in the system at the same time. Methods of automatically eliminating spurious images are generally based on the size and distribution of the animal's temperature. Thus, if only the head is captured in the image, this will represent a relatively small number of pixels compared to a full dorsal image and can be automatically excluded from further analysis based on size. It is more difficult to automatically identify images in which there are two animals. One approach is to look at the distribution of temperature within the image, and if there is a bi-phasic distribution in temperature above the threshold there is likely to be two pigs in the image and it can be rejected.

Discussion

Whatever system is installed controlling for environmental effects will significantly improve the diagnostic performance of IRT. As previously stated, livestock are homoeothermic animals that thermoregulate to their environment, and if we are to use thermal measurements to identify physiological conditions other than thermo regulation it is necessary to mitigate environmental effects. In our latest paper, we report on a simple method of mitigating thermoregulatory effects. Essentially, this involves recording ambient temperature with every IR image recorded and comparing ambient temperature with time-match animal temperature. Provided the ambient temperature range is within the thermal neutral zone for the animal the relationship is a straight line fit. Thus, given the ambient air temperature it is easy to calculate the predicted animal temperature from the equation. The difference between the observed and predicted animal temperature is the residual temperature. Thus, if an animal exhibits a positive residual temperature it is producing heat beyond that required for thermoregulation, such as a febrile response to disease. If the residual temperature is significantly lower than expected this may be an even earlier indicator of disease because it suggests that the animal is conserving heat to raise core temperature, i.e., the first phase of the febrile response.

In our laboratory we could not infect animals to test this hypothesis, but we could induce an increase in metabolic activity by vaccination or by feeding piglets growth-promoting antibiotics [4,5]. In these studies, we have shown that the residual temperature is more closely associated with the detection of increased temperature to vaccination and growth than the observed radiated temperatures. In addition, it is possible to obtain background radiated temperature from the same images used to obtain the animal's temperature. This is because the segmentation algorithm separates the animals from the background and the average background radiated temperature closely reflects the ambient air temperature. Thus, the background radiated temperature can be used as a proxy for ambient temperature. This reduces the complexity of the system by eliminating the requirement to record ambient conditions independently and simultaneously. Similarly, in a system recording individual animal temperature it is possible to target an area within the image to obtain the background radiated temperature.

Conclusion

Whatever system is installed in barns producers are very unlikely to be able to interpret raw temperature data and thus the system must provide the end-user with information upon which they can act. The goal is the continuous monitoring of the animals, housing infrastructure and environment, and the integration of these data into a model capable of decision making in near real-time. Advances in camera design, software development, automated animal ID, cloud computing, machine learning and artificial intelligence are presently converging to promote the incorporation of thermal cameras into farming practice.

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