

Automated collection of heat stress data in livestock: new technologies and opportunities

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INTRODUCTION

Body temperature is among the most economically important phenotypes in livestock animals as it is tied to health, reproductive success, and productivity (St-Pierre et al., 2003; Duff and Galyean, 2007). Heat stress was estimated result in \$1.7 to 2.4 billion in losses in the livestock industry in 2003 (St-Pierre et al., 2003), which is likely an underestimate of today's losses. Animals may have elevated body temperature due to illness, injury, heat stress, toxin exposure, or other health-related issues. Unfortunately, it is only after we observe elevated body temperature that we can mitigate the effects of these stressors. Development of technologies to detect elevated temperature earlier or to predict and prevent the negative effects of a fever or heat stress would be extremely valuable.

Traditional measures of temperature and indicators of elevated body temperature have been used to identify sick and heat-stressed animals (Duff and Galyean, 2007; Burdick et al., 2012). Rectal

temperature is among the mostly commonly used measurement of body temperature. Additional indicators of heat stress include respiration rate (Collier et al., 2006), sweating rate (Dikmen et al., 2014), and blood flow measurement (Honig et al., 2016). These types of measurements are very labor intensive to collect. Automated phenotyping could provide temperature data in real time that would allow immediate intervention to prevent animal health-related losses.

The objective of this manuscript is to discuss automated body temperature monitoring technologies and to discuss their use to develop new strategies to overcome potential animal health problems. Herein, we compared and contrasted several different automated technologies for temperature monitoring. Rather than trying to discuss all devices that exist, the discussion below attempts to capture the majority of available technology types. Implications and potential uses for current technologies were discussed with particular emphasis in detection and prevention of heat stress.

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AUTOMATED TEMPERATURE DETECTION DEVICES

Temperature-Sensing Ear Tags (Tympanic Ear Canal Sensors)

A number of different, but related, ear temperature monitoring systems have been developed for use in cattle (Cow Manager BV, Gerverscop, NL; DoggTag, Herddogg systems, Longmont, CO; Fever Tags, Amarillo, TX; SenseTag, Quantified Ag, Lincoln, NE; TekVet Health Monitoring System, East Palmetto, FL). Among the most well-known ear temperature-sensing devices are the Fever Tag system (Fever Tags, Amarillo, TX). These devices are mounted on the ear and have a temperature sensor that is placed within the ear canal to measure body temperature (for application, see [Richeson et al. \(2011\)](#)). Examples of applications have been used primarily for detection of fever due to illness (i.e., bovine respiratory disease; [McCorkell et al., 2014](#)), but these tags could also be used to monitor heat stress. These devices flash a light out of the ear in a way that is meant to be visible from a distance when observing the head of an animal. To get an accurate reading, it is critical that these devices are properly inserted into the ear canal so that the temperature probe is retained in the correct position ([Davis et al., 2003](#)). In addition, environmental factors such as sun exposure could impact temperature readings, particularly if the sensor is not maintained in the correct position. Studies seeking to use these ear temperature-sensing devices to identify animals at the onset of fever have had mixed results ([Richeson et al., 2011](#); [McCorkell et al., 2014](#)). Most of these technologies transmit data wireless for remote use. In addition to collecting temperature data, many of the automated technologies record activity data using a 3-axis accelerometer to quantify animal movements. Accelerometer information can also be useful for predicting rumination in cattle, and could also be used to identify an animal hanging its head lower during an illness. For more information on similar ear temperature-sensing technologies, see [Davis et al., \(2003\)](#) and [Foulkes et al., \(2013\)](#).

Rumen-Reticular Boluses

Rumen boluses have the potential to provide many types of information about ruminants, including rumen pH, rumen temperature, and activity (Smaxtec animal care GmbH, Graz, Austria; [Alzahal et al., 2011](#)). These devices when placed in cattle are actually located in the reticulum or near

the junction between the rumen and reticulum. Among the advantages of this data type is that it can be transmitted wirelessly to data readers. In addition, while these devices are not reading data, they can act as a data logger to keep short-term amounts of data to then transmit in batches when near a receiving antenna. These devices are sensitive in reading body temperature but impacted by water volume, feed intake levels, and rumen microorganisms ([Davis et al., 2003](#); [Burdick et al., 2012](#)). In fact, rumen temperatures tend to run around 2 °C higher than rectal temperatures due to heat produced by microbes in the rumen. One downfall of data from rumen boluses is that it is limited to set time duration that the sensors will continue to transmit data before they stop recording and transmitting information (roughly 150 d or until the battery fails). The boluses can only be used one time and require additional equipment to capture the data.

Intravaginal and Intrarectal Thermosensor Devices

Vaginal temperature measurements have been suggested to be extremely sensitive to picking up changes in body temperature, based on studies in humans ([Emmanuel et al., 2000](#)). In cattle, it appears that the ability to detect fever or other temperature changes was nearly identical when comparing automated rectal and vaginal temperature sensors ([Burdick et al., 2012](#)). Vaginal thermosensors appear to work well to detect increased body temperature in response to LPS treatment, which mimics inflammation and fever ([Burdick et al., 2012](#)). Multiple vaginal thermosensor technologies have been used in cattle, including iButtons (Maxim Integrated, San Jose, CA) and Hobo (Onset Co.) sensors. These devices can log considerable amounts of data but lack the ability to transmit the data wirelessly. Examples of side-by-side applications were conducted previously ([Dikmen et al., 2014](#)). One challenge with implantable sensors is that the size of the device may dictate its application in some species, making some technologies (i.e., iButtons) handy for use in animals of smaller size, such as heifers, pigs, sheep, and goats, compared with bulkier devices. [Burdick et al. \(2012\)](#) and [Davis et al. \(2003\)](#) also considered automated indwelling rectal temperature measurement probe and determined that these devices have similar sensitivity to the less invasive vaginal probes. Despite their more invasive nature, indwelling rectal temperature probes may be the most accurate and sensitive alternative for measuring body temperature in male animals for research purposes. However, stability of rectal probes, the influence of fecal temperature,

and keeping them stationary may be limitations in collecting accurate indwelling sensor temperature data (McCafferty et al., 2015). Additional information on indwelling rectal probes can be found in Reuter et al. (2010). Vaginal thermosensors can be used multiple times and require relatively little equipment for downloading data to a computer.

Additional Wearable and Implantable Devices

A variety of implantable devices are also available for temperature sensing, and new wearable technologies are constantly being developed. Devices have been developed for implantation around the rumen in cattle, which could be placed in other areas throughout the body (Alzahal et al., 2007). Microchip devices have been tested in pigs to sense body temperature, some of which can be read easily through radiotelemetry with a wand. Microchip technologies to measure body temperature in pigs have been found to generally correspond well to rectal temperature, typically ranging at 1 °C lower than the rectal measurement (Lohse et al., 2009; Jara et al., 2016). Many similar types of implantable devices have been developed, but all require invasive procedures to place the device within animals. Kou et al. (2017) recently described a method of measuring body surface temperature with a new wearable device worn on the leg of cattle. The method, which measures temperature at close contact to the muscle, was reported to be highly correlated to rectal temperature. Additional information on wearable devices can be found in the following review (Neethirajan, 2017).

Thermal Imaging

Thermal imaging holds great promise in detecting a combination of temperature and behavioral data that is likely related to heat and disease stress. To use thermal imaging on a large scale, software-based assignment of body temperature would be extremely helpful but requires considerable computation (Sellier et al., 2014). Development of this software is a rapidly evolving area. Determining where to mount cameras to get the best images and where to take the thermal images of the animal are important considerations. A large number of body areas have been used as references to get consistent and accurate body temperatures, with varying results in pigs (Soerensen and Pedersen, 2015). Measurements at the eye and base of the ear appear to work best in swine, though there is considerable variability. In cattle,

thermal imaging has been used to attempt to predict heat stress (Salles et al., 2016; Unruh et al., 2017). In beef cattle, infrared thermography was successful at identifying heat-stressed animals but could not identify animals at risk of heat stress early in the day (Unruh et al., 2017). Information about the best location to measure temperature has been defined in dairy cattle. Thermal images taken from the forehead were most closely related to rectal temperature in Jersey cattle, while right and left flank were mostly closely related to the calculated thermal humidity index (THI; Salles et al., 2016). Recently, hand-held thermal imaging devices have been tested as an alternative approach to capture thermal images (Vogel et al., 2016). The best areas to achieve accurate and consistent measurements may vary slightly from species to species. At this time, it is uncertain how factors like UV light might impact thermal images. Ambient temperature can impact the observed animal temperatures (Soerensen and Pedersen, 2015). Thermal cameras can cost a few thousand to tens of thousands of dollars and require considerable time to review the images unless software is available to filter and review the data. For additional information on thermal imaging technologies, see Soerensen and Pedersen (2015) and Neethirajan (2017).

Critical Factors in Comparing and Utilizing Automated Thermosensing Technologies

In order to be able to use thermosensing data in real time to make management decisions, a number of important factors should be considered. Data collection needs to be truly automated. Data transmission through radio telemetry (wirelessly) is critical for getting up-to-date information on individual animals. Sensitivity and variability of temperature measurements are important considerations. The frequency of measurement in which these devices collect data is also an important consideration. In some cases, having data more often is advantageous to observe acute variation, but in other cases, more frequent temperature observations may be uninformative because temperatures may not deviate or factors like water consumption may impact temperature readings. Furthermore, in the case of image and video data, data reduction may be more important because of the huge data storage requirements that can exceed 2 Tb of hard drive space per week, per camera. Environmental factors and measurement location on the animal can also impact the accuracy, sensitivity, and variability of temperature measurements. Thus, monitoring local ambient temperature,

humidity, and airspeed are important factors in evaluating automated data collection. The ability to prevent stress due to animal handling, which can elevate temperature, and reduced invasiveness of the technology are additional important considerations (Curley et al., 2006; Burdick et al., 2012). Technologies that reduce the need for human intervention may therefore provide more accurate assessment of body temperature. Ease of configuring these technologies in facilities or on animal (i.e., in a stable, easy to identify anatomical location) is also important. All of these technologies will likely have challenges with animal-to-animal variation in stable body temperature, making it difficult to declare a common activation threshold to declare a fever or heat stress in all animals. Use of individual animal temperature data over time is likely needed to set individual specific body temperature thresholds. Costs of these technologies and tradeoffs in their measurement accuracy in comparison with rectal temperature (i.e., the current gold standard) will also guide which technologies will provide the most helpful information to prevent heat stress and disease-related losses.

FUTURE APPLICATIONS IN LIVESTOCK

Automated temperature detection devices have a wide array of potential applications within industry. Beyond the applications described herein to monitor animal health and potential heat stress, these data could be associated with trait phenotypes to determine whether they have been used as indicator traits for selection of more disease resistant or heat tolerant cattle. Various temperature measurements may be related to other quantitative production traits of interest (e.g., growth rate, feed intake). In addition, it has been suggested that maternal heat stress may have profound life-long effects on offspring health, growth, and survival, making these data useful in managing gestational environment (Monteiro et al., 2014; Tao et al., 2014; Johnson et al., 2015; Dahl et al., 2016; Guo et al., 2016; Monteiro et al., 2016; Laporta et al., 2017). Development of software to collect, manage, run predictive models (using machine learning methods), integrate, and serve data to cattle producers using meaningful and easy to interpret analytics is important. At this time, these aspects of automated temperature phenotyping need considerable development. The development of portable device applications such as phone apps will also be critical to facilitate data collection, annotation, and interpretation on-farm.

SUMMARY AND CONCLUSIONS

Automated phenotyping technologies to measure body temperature provide new opportunities to manage livestock. Due to large animal-to-animal variation, measurement at the animal level would be useful to manage heat stress and disease. Current costs of some technologies may make them prohibitive for use on commercial farms but allow research that can inform producers on how best to manage or select for animals with improved heat tolerance and potentially disease resistance. Wireless data transmission, availability of suitable internet network speed, and capacity to transfer data may provide challenges in capturing this data in some locations. Future development of these technologies will require real-time data collection, data management, and development of predictive models to determine the risk of heat and disease stress to allow for early intervention to prevent or limit losses in current and future generations of animals.

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