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Development and evaluation of a fuzzy logic classifier for assessing beef cattle thermal stress using weather and physiological variables

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ABSTRACT

This research was carried out to develop a fuzzy logic classifier that integrates both weather and animal factors to assess individually the level of thermal stress in feedlot finishing cattle. An experiment was performed with two groups of Nellore feedlot finishing cattle for the acquisition of weather and physiological data including the average of surface temperature in different parts of the animal body using infrared thermography. A statistical analysis of the data was applied to seek the best correlation between the weather and physiological measurements and the infrared thermography (IRT) measurements in different parts of the animal body surface and to orient the construction of membership functions. A knowledge-based system was constructed from rules that associate the memberships of the input variables dry bulb temperature, wet bulb temperature and front surface infrared temperature which were found to be suitable for predicting the rectal temperature. Predicted rectal temperature was rated for the level of thermal stress and compared with the real rectal temperature and a traditional temperature–humidity index. The results indicated little correspondence between the fuzzy classifier and temperature–humidity index (29.3%), but the average rectal temperature value during the day showed great consistency (83.2%) between the fuzzy classifier and animal's response. In addition, the IRT measurements allowed an accurate assessment and classification of the individual thermal stress of animals in the same day. The proposed fuzzy classifier resulted in better estimates of the thermal stress level when compared to the traditional temperature–humidity index and fuzzy-based systems previously developed.

1. Introduction

One of the focuses of scientific and technological developments in animal production systems is currently related to improving the decision making process for increasing productivity and efficiency in resource utilization. It has long been known that climatic and environmental conditions especially have a significant impact on the performance of feedlot cattle because high ambient temperature, humidity and solar radiations reduce the performance, decrease animal comfort and, in extreme situations, can lead to the death of the animal (Collier et al., 2006; Scharf et al., 2011; Gaughan and Mader, 2013). The performance is adversely affected because conditions of increased temperature reduce the dry matter intake, increase the body temperature and decrease weight gain (Mader and Griffin, 2015).

Many indices of thermal stress considering environmental variables have been proposed (Dikmen and Hansen, 2009), and the one that is mostly used in research is the temperature–humidity index (THI) (Thom, 1959). Adjustment of the THI has been studied to better fit the prediction of thermal stress for animals, but the use of THI is limited and it does not consider the individual response of each animal and species (Brown-Brandl et al., 2005a; Eigenberg et al., 2005; Silva et al., 2007; Dikmen and Hansen, 2009). Furthermore, the thermal stress is a result of thermal energy exchange between the animals and the environment, and depends on both physiological and environmental factors (Taylor et al., 1969; Collier et al., 2006; Mader and Griffin, 2015).

Physiological responses such as respiration rate and body temperature are good indicators of animal welfare (Burfeind et al., 2012; Gaughan and Mader, 2013; Scharf et al., 2011). However, the approach to animal status assessment traditionally includes manual and visual scoring that is laborious, invasive and stressful for the animal (Wathes et al., 2008). Thus, the development of models for predicting the thermal stress that considers, in addition

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to environmental factors, the physiological response of the animal can contribute more adequately to infer the animal health and welfare (Mader, 2006; Silva et al., 2007; Dikmen and Hansen, 2009; Scharf et al., 2011).

Among the non-invasive tools, infrared thermography was studied for use in instrumentation systems, for continuous monitoring of the temperature of the body surface profiles and correlation with other animal welfare factors (Wathes et al., 2008). Montanholi et al. (2008) examined the relationship between the infrared thermography temperature of different body locations and heat and methane production in dairy cows. Schaefer et al. (2012) investigated the use of infrared thermography to non-invasively identify animals with bovine respiratory disease and examined the feasibility of automating the collection of infrared thermography data. Metzner et al. (2014) compared different algorithms for the evaluation of udder skin infrared thermography pictures for automated computer-supported processing and detection of acute mastitis and fever. Martello et al. (2015) evaluated the use of infrared thermography images as a tool for monitoring the body surface temperature of beef cattle, and its relationship with residual feed intake.

As a complement, it is important to investigate and develop a system based on non-invasive sensors integrated with soft computing techniques to allow continuous assessment of animal welfare for climate management in livestock production systems (Huang et al., 2010; Wathes et al., 2008). Brown-Brandl et al. (2005b) constructed and evaluated five different models to predict thermal stress for cattle: two statistical models, two fuzzy inference systems and one neural network. The weather data and the respiration rate collected during the experiments were applied to construct the models that use the weather data to estimate the respiration rate. The models based on soft computing tools, neural network and fuzzy logic, presented better results, but the authors noted the need for improvements to refine the prediction. Shao and Xin (2008) applied a real-time image processing system to detect movement and classify thermal stress state of group-housed pigs based on their resting behavioral patterns. Mirzaee-Ghaleh et al. (2015) observed the better performance of a fuzzy controller for monitoring and management indoor variables of a poultry house (temperature, relative humidity, and concentration of CO_2 and NH_3) when compared to a conventional on/off controller. The fuzzy system presented better performance for assessing and controlling the indoor variables with high accuracy and lower energy consumption.

This work aims to propose a novel method for predicting the thermal stress of animals by taking into account previous research efforts (Brown-Brandl et al., 2005b; Hernandez-Julio et al., 2014) which were made to develop non-invasive techniques based on their physiological responses and soft computing modeling. More specifically, a classifier of thermal stress for beef cattle based on a fuzzy logic inference system is developed. This system determines the physiological factor which predicts the thermal stress level by means of collected weather data, physiological measurements and non-invasive infrared thermography pictures of different body parts.

2. Materials and methods

A method for designing the classifier of thermal stress based on fuzzy logic was developed and applied. It consists of three main steps as shown in the flowchart in Fig. 1.

The first step corresponds to feeding cattle for a specific period for the acquisition of weather data, invasive physiological data and the average of surface temperature in different parts of the animal body using thermography.

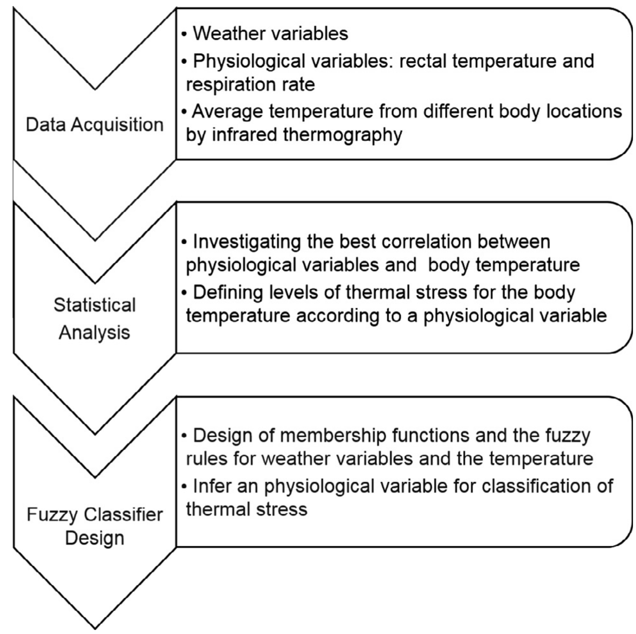

Fig. 1. Main steps proposed to design the heat stress classifier based on infrared thermography.

The second step corresponds to the statistical analysis of these data to determine which physiological variables, rectal temperature (RT) or respiration rate (RR) have the best correlation with the average infrared temperature of each body parts studied. In addition, it was sought to determine which parts of the body had a good correlation between their infrared temperature (IRT) and physiological variables (RR or RT). Thus, at this step it was possible to determine the physiological variable that would be applied while predicting output in the classifier, the part of the body whose temperature was used as a classifier input variable and the rating scale of heat stress from this input variable.

The third step corresponded to actual construction of classifier based on Fuzzy Logic (FC). A Fuzzy inference system is a soft computing tool of mapping from the given inputs to one or more outputs using Fuzzy Logic. The mapping created a basis on which decisions can be made, or patterns discerned. The process of fuzzy inference involves four main stages: (1) the membership functions associated to fuzzification; (2) the knowledge based on heuristic rules; (3) the fuzzy logic operators to aggregate the membership functions and the knowledge base; and (4) the defuzzification method (Zimmermann, 2001). The results of the second step were used for the construction of both membership functions of linguistic variables associated with the IRT as well as the linguistic output variable associated with the classifier's prediction.

2.1. Feedlot and data acquisition

The study was carried out at the facilities of Faculdade de Zootecnia e Engenharia de Alimentos (FZEA) of the Universidade São Paulo (USP) in Pirassununga, SP, Brazil, located at 21°57′02″S, 47°27′50″W at a mean elevation of 630 m above sea level. The average annual temperature is 22 °C, with approximately 1360 mm of rain per year. The study was conducted according to the Institutional Animal Care and Use Committee Guidelines of FZEA/USP (NRC, 2003).

The data acquisition consisted of two phases (two feedlots). The first phase was conducted to guide the development of the FC using weather and physiological measurements. The second phase was carried out to validate and enforce the FC developed. In the