Ambulatory Instrumentation Suitable for Long-Term Monitoring of Cattle Health

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Abstract - **The benefits of real-time health diagnoses of cattle are potentially tremendous. Early detection of transmissible disease, whether from natural or terrorist events, could help to avoid huge financial losses in the agriculture industry while also improving meat quality. This paper discusses physiological and behavioral parameters relevant to cattle state-of-health assessment. These parameters, along with a potentially harsh monitoring environment, drive a set of design considerations that must be addressed when building systems to acquire long-term, real-time measurements in the field. A prototype system is presented that supports the measurement of suitable physiologic parameters and begins to address the design constraints for continuous state-of-health determination in free-roaming cattle.**

Keywords—**Ambulatory, cattle, health, instrumentation, physiologic parameters, telemetry, wearable sensors**

I. Introduction

Animal agriculture represents a large portion of the world economy. In the United States, the cattle industry is of particular importance; beef is a staple in the diet of most Americans. Whereas vast improvements have been made in animal care and meat quality, producers are still plagued by bovine respiratory disease complex as well as a variety of gastrointestinal and metabolic diseases, which affect up to 30% of animals in stock yards and large herds [1]. These illnesses cause numbers of cattle to be chronically poor performers, despite regular surveillance and treatment. As a result, U.S. producers lose millions of dollars in annual income. Agro-terrorism is an increasingly pertinent concern, given the devastation evidenced in recent outbreaks of (a) Foot and Mouth Disease (FMD) in England, (b) West Nile Virus and Newcastle's disease in the United States, and (c) Bovine Spongiform Encephalopathy (BSE) in the United States and Canada.

Long-term state-of-health monitoring in cattle may require the use of wearable sensors, implanted devices, environmental sensors, wireless data transmission, robust packaging, environmentally protected platforms, and on-board signal processing for noise reduction and parameter extraction. Vital parameters, behavioral indicators, and environmental conditions are all relevant to these state-of-health assessments. Challenges imposed by this endeavor include animal compliance and environmental factors such as weather. The economic feasibility of these systems and the durability of their packaging must also be considered. Other key issues include power delivery to the measurement system and the transfer/analysis of measured data.

A primary goal of the effort described in this paper is to develop a predictive model for disease detection in cattle patterned after state-of-health algorithms for the identification of human morbidity. The literature concerning cattle morbidity suggests that simultaneous collection of key vital signs (e.g., core body temperature, pulse rate, and respiration rate) would be a valuable starting point. Initial algorithms may be formulated by considering abnormal threshold values, adjusted for the influence of environmental factors, and weighted according to their apparent degree of importance. Any index of this nature should clearly discriminate between morbid and healthy animals [2]. Software analyses may include step-based logic (e.g., branching binary decision points and flow-charts for sequential decisions) and incorporate geographic impact [3]. Statistical methods may also be applied: multivariate and multidimensional analyses; analysis of variance and covariance; the principal components method; discriminate analysis; and linear/logistic regressions [3].

Risk factor assessment can allow identification of potentially problematic animals or populations [2]. Health status indicators, once selected and standardized, may permit health comparisons between animal populations in different geographic areas. Individual and herd health data can be stored in electronic medical records, used for trend analyses, and transferred through a secure information infrastructure to the cattle owners, area producers, veterinarians, medical researchers, and health officials.

This paper notes (1) physiological and behavioral parameters and (2) instrumentation design considerations that drive the development of an ambulatory instrumentation suite to monitor cattle state-of-health. The hardware and data for a prototype system are also presented.

II. Background: Acquisition Parameters

Livestock state-of-health determinations can be facilitated by the acquisition of a suite of physiological and behavioral parameters. Core body temperature, heart rate, respiratory rate, behavior (e.g., feed and water intake; activity), ambient temperature, humidity, wind patterns, and animal identification are all parameters that deserve consideration. This section addresses the types of parameters targeted for this effort and the methods by which these parameters can be ascertained.

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A. Core Body Temperature and Thermographic Profiles

Core body temperature has been investigated as a method for detecting estrus, respiratory disease, and thermal stress in feedlot cattle (e.g., via a transmitter implanted in the peritoneal cavity [4]). Thermographic investigations (i.e. with an infrared camera) have shown that animals with a higher overall thermal profile (a warmer body surface) tend to be healthier and exhibit faster weight gain [5]. This technique has also been used to screen for respiratory disease, which in turn alters cattle metabolism and performance. Cool thermal profiles may indicate fever up to two days before the animal becomes sick or exhibits decreased metabolic activity [5].

B. Ambient Temperature, Humidity, and Wind

Environmental elements are important because livestock react to environmental stresses. Heat and cold stressors contribute to disease, decreased performance, and the readiness to mate and conceive [6]. Furthermore, airborne infectious particles make transfer of disease possible over great distances.

C. Heart Rate

Fluctuations in heart rate can indicate stress as well as state-of-health changes [7]. Obtaining heart rate from cattle via electrodes is especially difficult due to the thickness and large electrical resistance of bovine hide. With implantable electrodes, the potential for infections and biological reactions to the suture material present significant hurdles. Additionally, the electrode paste typically used for electrocardiogram measurements will not endure an outside environment for long durations. Dry electrodes offer hope, but electrode placement problems limit their long term usefulness.

D. Respiratory Rate

Respiratory rate can be used to detect illness and recognize stress. One common method to obtain respiration rate utilizes pressure transducers that measure changes in thoracic volume [8]. A more attractive option is to extract respiration rate from the variance in R-R intervals of the electrocardiogram [9, 10]. In this effort, we are also investigating the use of a thermistor, perhaps in a nose stud, to detect temperature fluctuations in inspired versus expired air.

E. Food and Water Consumption

Healthy steers spend more time at the feed bunk and return more often than morbid steers [1]. Healthy steers also drink more frequently, but not necessarily larger quantities. By monitoring feeding and watering behavior, sick steers can be identified three to four days earlier than with conventional methods [1]. We intend to track feeding behavior by correlating time spent near feed bunks with the position and movement of the head (measured using three-axis accelerometers).

F. Electronic Identification

Radio-frequency identification (RFID) tags appear ideal for identifying animals and maintaining animal/data associations. Reader placement at cattle congregation points such as feed bunks, watering troughs, or mineral feeders may provide information on various production parameters. Tracking of sick cattle to their farm of origin may also prove to be useful [11]. RFID components are available as eartags or implantable devices. The eartag versions can be read at a greater distance, whereas implantable versions are more likely to stay with the animal for its lifetime.

G. Movement

Global-Positioning-System (GPS) devices can provide early detection of morbidity in cattle by detecting decreased activity [12]. Further, GPS data can provide location histories of both individual animals and entire herds, identifying which animals may have been in contact with each other. GPS devices could also replace pedometers, which have been used to detect restlessness and increased activity as characteristics of estrus [4].

III. METHODS: PROTOTYPE MONITORING SYSTEM

Implementation of an ambulatory system for long-term health monitoring in cattle is a difficult engineering challenge. Core issues include determining which physiological and behavioral parameters provide the most relevant state-of-health information. However, an arguably more problematic set of issues involves sensor placement, sensor-module interactions, and the development of weather-proof equipment that is rugged enough to withstand the physical environment of large animals that are not particularly compliant. In an early attempt to provide a suite of relevant physiological parameters (both vital signs and behavioral elements), our team implemented a system that provided measurements including heart rate, core body temperature, activity (e.g., head position and movement for feeding behavior and posture), and location, as well as ambient temperature and humidity (see Figure 1) [13]. Heart rate was acquired with a horse heart rate monitor manufactured by Polar. Core body temperature was measured with a CorTemp® radio-telemetry bolus by HTI Technologies Inc. (acquisition of core body temperature in the reticulum has been verified as accurate by rectal temperature measurement. [14]). Activity measurements are made using ADXL150™ and ADXL250™ accelerometers manufactured by Analog Devices. These accelerometers are packaged inside a collar on the neck to monitor the movement and position of the head. The GPS device is a Trimble Lassen SQ™ unit. Ambient temperature and humidity are currently obtained with a Sensiron™ SHT11 ambient temperature and humidity sensor. All on-board processing is performed by a Microchip PIC18F8720™ microcontroller. Wireless telemetry is accomplished using a Brightcom Callisto II™ Bluetooth™ module. These parameters are processed (e.g., noisy analog data are smoothed; unneeded GPS information are discarded) and stored by the microcontroller. Once the microcontroller detects a nearby Bluetooth™ access point, it transmits these stored data in small packets over the wireless link. Wireless data integrity is protected using a checksum.

IV. RESULTS

The prototype system developed by our team can collect physiological and behavioral data for a few hours at a time. The system and some sample data are shown in Figure 1. Early tests were performed in a 20m by 50m corral. The GPS data (A) in Figure 1 indicates the movement of the animal as it was led in circles around the pen (time is the vertical axis). The ambient humidity data and ambient temperature data (B) indicate the respective environmental factors on the day of the experiment. The accelerometer data (C) represents thirty seconds of data where the animal moved its head. Core body temperature (D) shows where the bolus was inserted into the animal's reticulum. The communications link between the bolus and the reader was not established for approximately 30 minutes due to the readers power being off for system adjustments. Heart rate (E) is shown for approximately one hour. Finally we have a picture of the measurement system (F) with the visible parts of the system labeled.

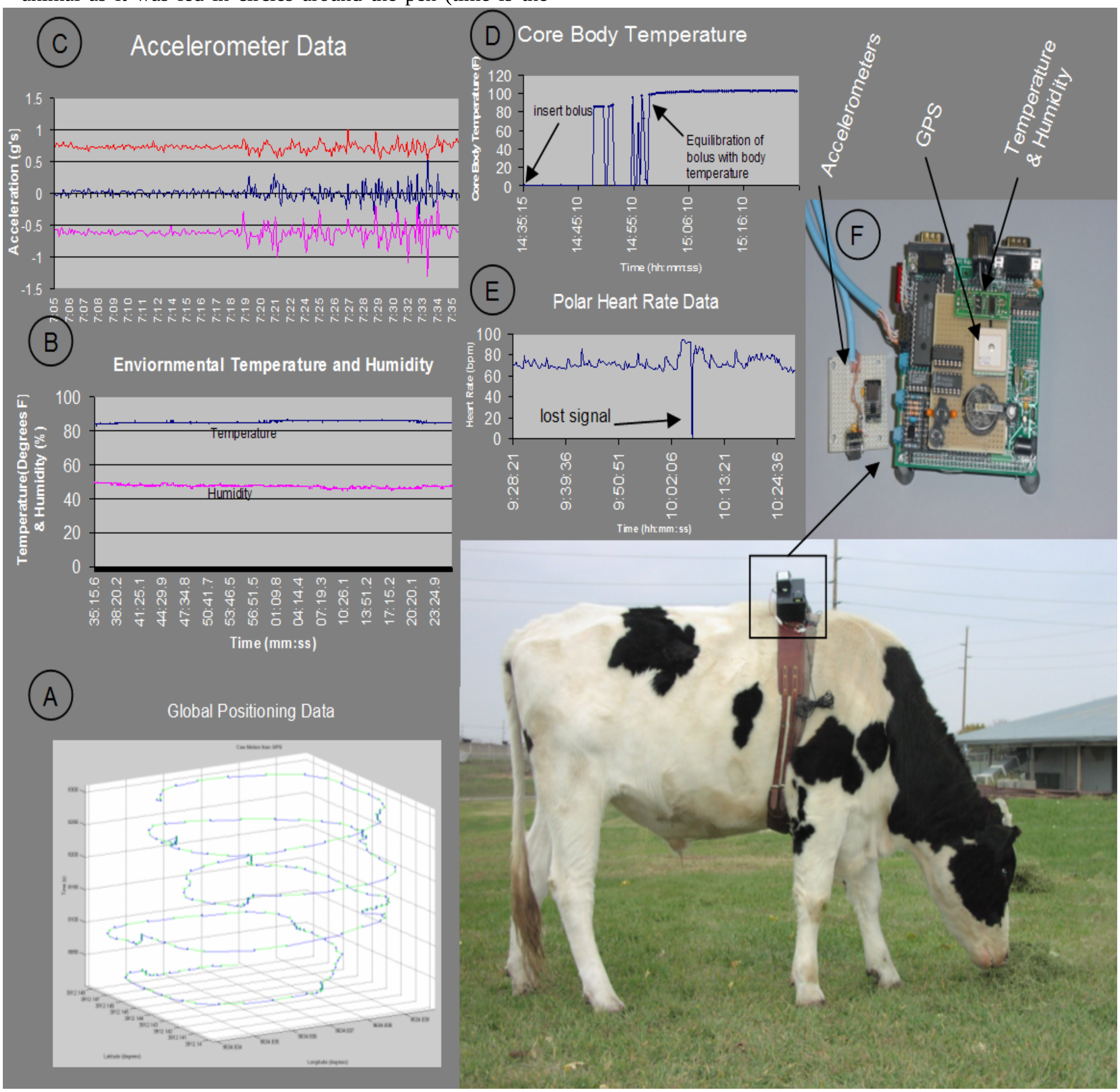

Figure 1: Prototype Measurement System and Preliminary Data

V. DISCUSSION

A. Future Directions

Work is underway to replace the CorTemp® bolus with a less expensive, small, injectable temperature and RFID transponder developed by Destron Technologies, a division of Digital Angel Corporation. Other efforts include replacing the system microcontroller with a more powerful unit that can improve data processing capabilities and thereby reduce the need to store all sensor data on board. We are also assessing the use of acoustic sensors (e.g., in a bolus placed in the reticulum) to obtain heart rate, respiration rate and digestive activity. This approach has the advantage of moving sensors into a more predictable, internal environment.

B. Design Considerations

Environment. Most cattle spend their lives outdoors in temperatures ranging from sub-freezing to 100+° F. This large ambient temperature variability requires special electronic components. Further, the measurement system must tolerate extreme humidity ranges, including full submersion in water and mud. These considerations also apply to the sensors themselves, which are normally applied in controlled clinical environments.

Power. Ambulatory systems require batteries, which introduces several design considerations. Among these are current-draw limitations, a minimum operating voltage, a desired battery lifetime, and easy accessibility for replacement. Another consideration is power distribution. Routing power from one device to another must be accomplished through wires or, over a very short range, using induction. Although the inductive method is inefficient, it provides the option of extremely low-power, implantable devices. Wires are problematic, providing potential mechanical failures via snagging and rubbing.

Intermittent rather than continuous measurements can reduce the amount of power required. This also reduces the amount of data that must be processed and transmitted; further alleviating power needs and telemetry bandwidth limitations. These frequency and duration tradeoffs are currently under investigation.

Telemetry. Data communication modalities for ambulatory systems are limited. The options are to store data for direct download or to transmit the information wirelessly. If real-time diagnoses of health status are desired, wireless communication is the clear preference. On-demand wireless data transmission also allows the offloading of data processing from the power-constrained ambulatory system.

VI. CONCLUSION

Long-term health monitoring of free-range cattle imposes design constraints that are very different from those required for ambulatory human monitoring systems. However, as in human point-of-care systems, the aggregation of physiologic, behavioral, and environmental data is the ideal starting point for automated algorithms that assess state of health. This paper summarized the acquisition parameters relevant to ambulatory cattle monitoring and presented initial results from a wearable system designed for cattle health assessment. Future efforts will focus on the transition from current bulky apparatuses to wireless systems that incorporate both implantable sensors and low-profile, external devices appropriate for cow-bell and collar form factors.

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