

# An Integrated Cattle Health Monitoring System

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**Abstract**—Current clinical techniques for monitoring livestock health are insufficient, as they provide only sporadic information and require too much resource investment in terms of time and veterinary expertise. A sophisticated system capable of continuously assessing the health of individual animals, aggregating these data, and reporting the results to owners and regional authorities could provide tremendous benefit to the livestock industry. Such a system would not only improve individual animal health, but it would help to identify and prevent widespread disease, whether it originated from natural causes or from biological attacks. This paper presents results from a prototype telemonitoring system that utilizes wearable technology to provide continuous animal health data. The infrastructure, hardware, software, and representative physiological measurements are presented.

**Keywords**— Behavioral health, electronic medical records, Java, MySQL, telemedicine, telemonitoring, veterinary medicine, wearable sensors, wireless communication, ZigBee

## I. INTRODUCTION

### A. Motivation

The agricultural sector is an important part of the American economy, employing millions of people while providing products for a worldwide customer base. To improve meat quality as well as reduce the threat that bioterrorism poses to this industry, the United States must substantially improve its ability to monitor animal state of health, track animal transport, and prevent disease spread.

### B. Livestock Tracking & Animal State of Health Monitoring

The European Union, Canada, and other countries have started to monitor livestock herds [1,2]. The closest thing to a U.S. national tracking system is the National Farm Animal Identification and Records (FAIR) effort, a dairy-oriented pilot project [3]. Mandatory tracking of livestock will soon be a global requirement. Wary of anthrax, foot-and-mouth disease, mad cow disease, and other health concerns, consumers worldwide demand accountability from beef, pork, and chicken suppliers.

Identification systems permit animal transport tracking, but they do little to provide early warning signals for potential disease outbreaks and yield little data regarding animal behavior, forage, contact with other animals, or the environmental conditions experienced by the animals. Additional sensors are needed to monitor (a) cattle movement to feed and water and (b) physiological variables such as core

body temperature, heart rate, and respiratory rate. Previous research suggests that length of time spent feeding and feeding intervals are a positive indicator of animal health [4]. Various researchers have used GPS-enabled collars to track animal activity and derive state of health, with varying degrees of success [5-7]. Other experiments have used passive radio-frequency (RF) tags to monitor feeding intervals. These tags, which require no batteries, return only an identification number and are typically limited to ranges of one meter or less [8,9].

### C. Research Goal

The overall goal of this project is to research and develop an infrastructure to support monitoring systems that continuously assess cattle state of health in concentrated and distributed herds. These systems will improve the ability of the livestock industry to react to and predict disease onset and its epidemiological spread.

Traditionally, cattle health has been ascertained by visually assessing animal behavior or by manual inspections from a farmer or veterinarian. This is time-intensive and can realistically not be performed often. An on-board health monitor worn by each animal would provide a much less labor-intensive and more globally useful solution. Each time animal data are uploaded to a base station, the offline processor could analyze them to detect abnormalities. Animal status could then be easily summarized as discrete states of health, such as well, suspect, and abnormal. A cursory glance at the software output would yield a good overview of total herd health. Changes in behavior or vital signs could be detected in hours as opposed to days or weeks, allowing animals to be treated or quarantined much sooner.

In addition to providing an alternative to observations acquired by immediate caretakers, health data would also automatically become part of a larger information network. These data could be sent to regional and national collection centers that monitor the health of many herds, providing data to spot larger trends and support epidemiological research. This information, in concert with previous trend data, can then be used to generate a regional “health weather forecast” that can notify veterinarians, ranchers, and emergency responders that animal health concerns, possibly exacerbated by projected weather patterns, are imminent.



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## II. METHODOLOGY

### A. Overall Approach

The design of this system assumes that each animal receives a health-monitoring device and a unique identification number. This monitoring equipment periodically records the animal's heart rate, core body temperature, head motion, and absolute position (via GPS), as well as the temperature and humidity of the surrounding environment. The system can buffer these data for a period of several days. ZigBee-compatible download stations will be placed in areas of high animal traffic such as water troughs, feed bunks, and shelters. When an animal wanders within range of the wireless receiver, the buffered health data are uploaded to the base station for analysis and storage.

### B. Measurement Parameters

Body temperature and heart rate may be compared to known trends in circadian rhythm over the course of a day. Deviation from the norm is a good initial indicator of aberrant behavior and possibly illness. Patterns could even be established for each individual animal, allowing more subtle changes to be detected. By factoring in the environmental conditions, both from sensors placed on the animal and from recorded weather observations in the area, environmentally stimulated behavioral changes can be distinguished from those stimulated by disease.

We also plan to use animal head motion to assess behavior, a method that has several advantages. A head motion sensor is a simple device that can be packaged inside a small enclosure and placed on an ear tag or halter. It does not need to be ingested and is easy to retrieve and replace, in case of malfunction. As motion must be sampled at rates of 50 Hz or greater per channel, this type of sensor places a considerable load on both the power and storage systems. To ameliorate this, we plan to sample motion for several seconds, with time intervals between sample sets. On-board algorithms will then classify motion into different types of behavior, which can be stored as a few bytes per minute rather than many bytes per second.

Behavior is known to be an early indicator of animal health. A sick animal will tend to eat and move less than other members of the herd. It will also tend to lag behind the herd. While eating trends at known feeding locations can be approximated based on time spent in those locations, actual observations of behavior and position can provide much more quantitative data, including the approximate amount that an animal has eaten. When coupled with GPS location, head motion can provide a complete behavioral profile. If used in tandem with physiological observations, behavior can also account for observed fluctuations in heart rate and temperature, allowing a comprehensive activity and health record to be compiled.

### C. Prototype Monitoring System

The current prototype consists of custom hardware designed to integrate a collection of sensors and commercial products into one system. The core of the system is an AMD 186 processor on a Tern microcontroller board. Custom real-time code runs directly on the hardware to efficiently coordinate sensor sampling and save power. Compact flash memory buffers the data samples during trials and provides a backup in case of database failure or fatal wireless errors.

Core body temperature is monitored by a commercial CorTemp bolus placed in the reticulum of the animal through a cannula. The bolus wirelessly transmits data through the animal to an HQI reader unit, which communicates with the main data logger board via a serial link. Once the bolus warms to the body temperature of the animal, accurate readings of core body temperature can be obtained.

To monitor heart rate, we use a Polar heart rate belt designed for race horse training. The belt acquires an animal's heart vector using a standard set of electrodes. This system is unsuitable for long-term deployment since the sensors require a conductive gel to maintain good electrical contact with the skin; the gel can dry up or the electrodes can move out of position within a matter of hours. Electrode placement is important and can easily be disrupted by the animal rubbing itself on trees or other objects. However, this belt-based device performs well for short-term comparative analyses. The Polar belt and the CorTemp bolus can both communicate with the HQI reader unit.

A custom bolus under development will monitor both core body temperature and heart rate [10]. A small microphone embedded in the bolus is used to acoustically detect heart sounds, which are then converted to heart rate. The collected data are transmitted through the animal to the storage system using a 315 MHz wireless link. Heart rate data acquired with the Polar belt are used to corroborate the measurements from this experimental implementation.

The head motion sensor is a three-axis accelerometer enclosed in a waterproof casing, which is attached to a halter placed on the animal. Currently, raw accelerometer data are collected from the animal and sent directly to the base stations for later analysis. When an efficient algorithm for on-board processing of accelerometer data has been developed, it will be implemented on the core processor or a processor dedicated to the task. This will vastly reduce the memory required for data storage as well as the power required for wireless data transmission.

Location is detected using a Trimble GPS receiver. Our system periodically records animal location and uses time data received from the GPS satellites to accurately timestamp sampled data.

### D. Information System Support

To better indicate the behavior and health status of a given animal, we created a database and application to assist with data analysis. The MySQL database consists of several

tables that store animal data. When an animal arrives within the range of a ZigBee wireless receiver (i.e., base station), the wearable system detects the network and establishes a connection. The database server running on the base station hosts a program that interprets the packets it receives and then uploads these data to the database. The database contains several tables into which animal information, health data, and environmental parameters are inserted. The animal ID is the primary key which associates an animal with its dataset. To assist with analysis, each data element is given two time stamps; one for when it was recorded by the device and another for when it was uploaded to the database. This allows a post-processing application to provide time-dependent analyses of parameter trends. For example, assume the core body temperature of an animal is abnormally high, possibly indicating the animal is ill. A database query can then retrieve previously recorded data to identify a specific date when this trend began, the location of the animal at the time, and other cattle with which this animal has been in contact. Tools like these can aid in the early identification of disease and help stop subsequent disease spread.

The viewing application is a Java Web Start based program that runs on an Apache Web Server. The main goal of the application is to provide a means to access the database via the Internet so that state-of-health analyses can be performed from different locations. This application provides a graphical user interface to interpret the data received from the health monitoring system. Application features will facilitate Internet-based animal monitoring. For example, a GPS feature will display movements of selected cattle in a herd, and a temperature graph will display the core body temperature of selected animals over various time periods. The application is designed with a plug-and-play architecture so that analysis modules may be easily added.

### III. RESULTS AND DISCUSSION

The performance of the prototype system has been promising. Body temperature measurements are accurate and provide a reliable indicator of illness. Fig. 1 displays a representative 48-hour data set from a healthy steer. An unforeseen benefit of detecting the temperature in the reticulum is that water causes a sudden cooling of the bolus when the animal drinks. These events are depicted as sudden temperature drops in Fig. 1. After each event, the bolus then experiences a slow return to the animal's core temperature. This provides information about the frequency of drinking, which is affected by health and environmental conditions.

Heart rate data have also provided useful results. The heart rate trend over the course of a day follows a predictable circadian rhythm: lower at night and slowly rising to a more active level during the day. Intermittent activity periodically increases heart rate. We anticipate that accurate behavioral data will correlate with observed heart rate data to explain intermittent deviations from the norm. Typical heart rate data for a healthy steer are depicted in Fig. 2. Both data sets acquired during this 20-minute interval were

obtained from the electrode-based Polar belt, which provides a wireless signal that can be interpreted by both a Polar wrist watch and the HQI reader unit. The Polar wrist watch, typically employed by horse trainers, was used to corroborate the measurements acquired with the HQI reader unit. The deviation between the respective signals is a result of a difference in post-processing algorithms. The data from the HQI reader are unprocessed: the reader reports every value as it is received from the belt, then powers itself down every few seconds to save battery power. The wrist watch, however, does not power down and uses a proprietary moving average technique to report the current value based upon its sensibility relative to the previous values.

As noted in the previous section, a custom bolus design is underway that will replace this belt-based approach. A typical acoustic signal received from the prototype temperature/heart rate bolus is depicted in Fig. 3. The acoustic signal from the microphone is fed into a peak detector circuit, which generates a trigger pulse that represents the beginning of a heart rate interval every time the acoustic signal exceeds the threshold denoted by a capacitive discharge voltage. The time between successive trigger pulses yields a heart rate measurement only in the case where the elapsed time is sensible. Rumination and animal movements can create acoustic artifacts, as illustrated in the right panel of Fig. 3. False triggers from these noise sources and the reliability of the wireless link are being addressed in follow-on design implementations [10].

Motion data (see Fig. 4) have proved less immediately useful. While these accelerometer signals provide potentially rich information regarding different kinds of animal activity, the frequency-dependent character of these data does not map cleanly to different behaviors. We are investigating more sophisticated methods of processing these data, including time-frequency spectral assessments (see Fig. 5) and neural network approaches.

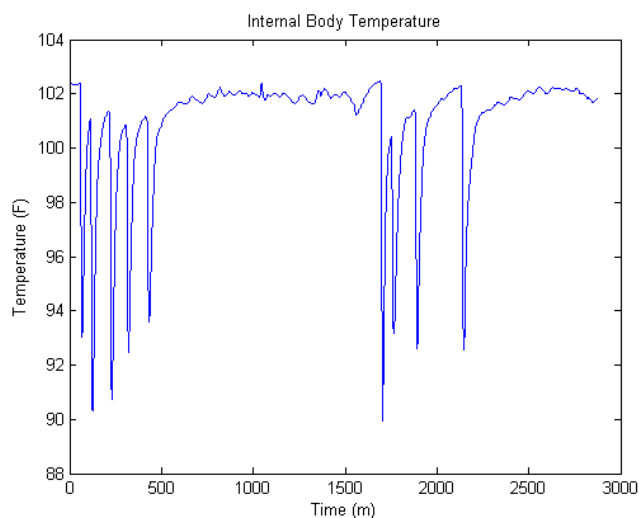


Fig. 1. Internal temperature of a healthy steer over a 48-hour period.

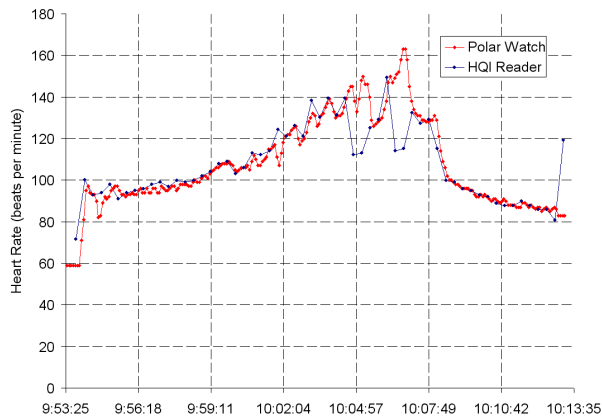


Fig. 2. Heart rate data for a healthy steer over a 20-minute interval.

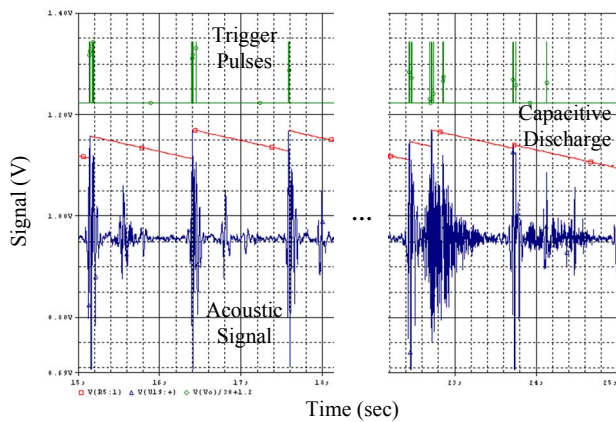


Fig. 3. Typical acoustic signal from the microphone in the custom bolus.

## V. CONCLUSION

Advanced monitoring tools, a distributed software infrastructure, and processing algorithms will allow the livestock industry to react to and predict disease onset in cattle and its subsequent spread. This paper presented early results from a cattle-worn system capable of acquiring multiple physiological and environmental parameters: core body temperature, heart rate, GPS location, ambient temperature & humidity, and motion (via a 3-axis accelerometer). While early data have yielded previously unobtainable information about ambulatory animal activity, more work remains in the areas of heart rate detection, accelerometer data analysis, multi-parameter health assessment algorithms, and information aggregation in a collection of local/regional databases.

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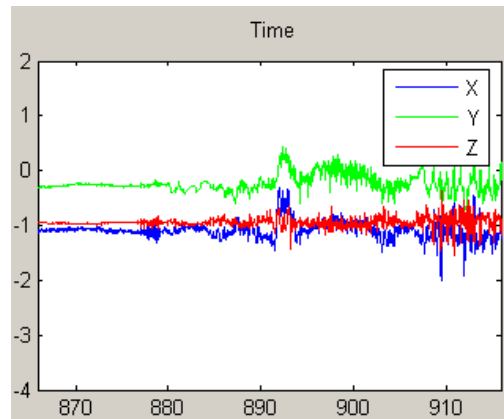


Fig. 4. Signal versus time for each axis of a 3-axis accelerometer worn on the head of a steer. These signals have a static DC offset due to gravity.

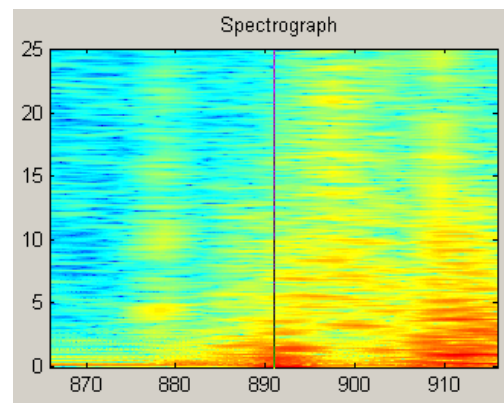


Fig. 5. Time-frequency spectrogram (y units = frequency; x units = time) for an aggregation of the three accelerometer axes during walking.

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