A Distributed Infrastructure for Veterinary Telemedicine

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Abstract—**The livestock industry can benefit tremendously from systems that continuously monitor cattle state-of-health, allowing the industry to maintain high meat quality, react to the presence of disease, and predict its spread. Requirements for these monitoring systems are similar to requirements that drive human ambulatory monitoring systems based on wearable sensors and wireless data communication. This paper presents early results from an effort to develop a veterinary telemedicine infrastructure based upon wearable monitoring technology originally developed for home health care. The functional layout of the infrastructure is described, and initial hardware and physiological measurements are presented.**

Keywords— **Bluetooth, electronic medical records, pulse oximetry, telemedicine, veterinary medicine, wearable sensors, wireless communication**

I. Introduction

A. Motivation

The agricultural sector is the backbone of the American economy, employing millions of people directly while providing quality foodstuffs for a worldwide customer base. The livestock industry, in particular, has suffered through serious economic hardships, but has persevered to regain its preeminent position in the world market despite intense foreign and domestic pressures. To bolster the quality of livestock products and reduce the threat that bioterrorism poses to this industry, the United States must make a quantum improvement in its ability to monitor animal state of health, track animal transport, and prevent the spread of disease.

B. Research Goal

The overall goal of this project is to research and develop the 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, whether from natural or terrorist events. Information storage, trend analysis, and health prediction lessons learned from this effort will have immediate application to similar systems targeted at assessing and predicting state of health in human populations. Human and veterinary medicine share a common goal: to change a reactive, episodic care delivery model into a proactive, predictive model, where the health of individuals or populations can be predicted based on current state-of-health assessments and trend data.

We plan to place Bluetooth-compliant monitoring stations near cattle congregation points, such as feed bunks and watering tanks (see Fig. 1). These stations will upload data from nearby environmental sensors and Bluetooth-enabled cow bells/collars, where the animal-worn units will communicate with global positioning, environmental, and biomedical sensors that are either worn by the animals or come within close proximity to the cattle. Algorithms will perform preliminary analyses on local data prior to uploading feedlot/ranch summary data to regional databases, where these data can then be correlated with data provided by other producers. Significant findings can be broadcast to veterinary personnel, producers, and government authorities.

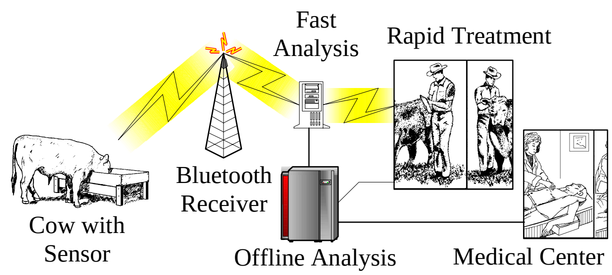

Fig. 1 Cattle state of health monitoring system.

C. 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 in its third year of task force meetings and demonstrations [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 are demanding accountability from people who grow and supply their beef, pork, and chicken.

Identification systems permit movement tracking, but they do little to provide early warning signals for potential disease outbreaks. 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 morbidity [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 experi-

This material is based upon work supported by the National Science Foundation under grants CCR/ITR–0205487, BES–0093916, and EPS–9874732 (with matching support from the State of Kansas). Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

ments 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].

Parameters like body temperature, heart rate, respiration, and activity can be monitored in cattle by noninvasive methods. Through the use of radio-telemetry, these variables can help to determine stress levels in free ranging animals. In most cases, transmitters are mounted externally in harnesses or collars worn by the animals. Body temperature, while commonly measured with a rectal thermometer, can be obtained remotely via an infrared imaging camera. For electrocardiogram and heart rate acquisition, electrodes on a belt can be placed in the sternal region and behind the shoulder. Respiration rate is often measured by chest expansion and contraction using plethysmographic techniques, but it can also be recorded via a thermistor placed next to the nose. Accelerometers and computerized pedometers are widely used to monitor daily activity, with applications ranging from heat stress detection to the identification of the onset of estrus. Cool thermal profiles can indicate the onset of sickness by noting vasoconstriction (retention of heat) or reduced metabolic activity before the effects become obvious to the naked eye [10].

C. *Paper Focus*

The following sections focus on the basic information infrastructure required to promote ambulatory monitoring in cattle. Early sensor prototypes are described, and the accompanying physiological data are presented. Design considerations for this infrastructure are then compared to their counterparts in the human monitoring arena.

II. Methodology

A. *Information Infrastructure*

A functional layout for a distributed, Internet-based livestock information infrastructure is illustrated in Fig. 2. The entities depicted here include the following:

- **Producer:** The farm/ranch/feedlot where animal data are acquired and initially processed
- **Veterinarian:** Medical professional/group that provides regional animal health services
- **Regional Center:** A data processing and dissemination facility serving a geographic region
- **National Center:** A data processing and dissemination facility serving the nation
- **Knowledge Repository:** An electronic data warehouse that also provides access to specialized processing routines and diagnostic algorithms
- **National Weather Service:** Access point for weather information to correlate with animal health
- **Emergency Center:** First responders to disease outbreaks, including chemical and biological attacks

Each of these entities represents a distributed collection of

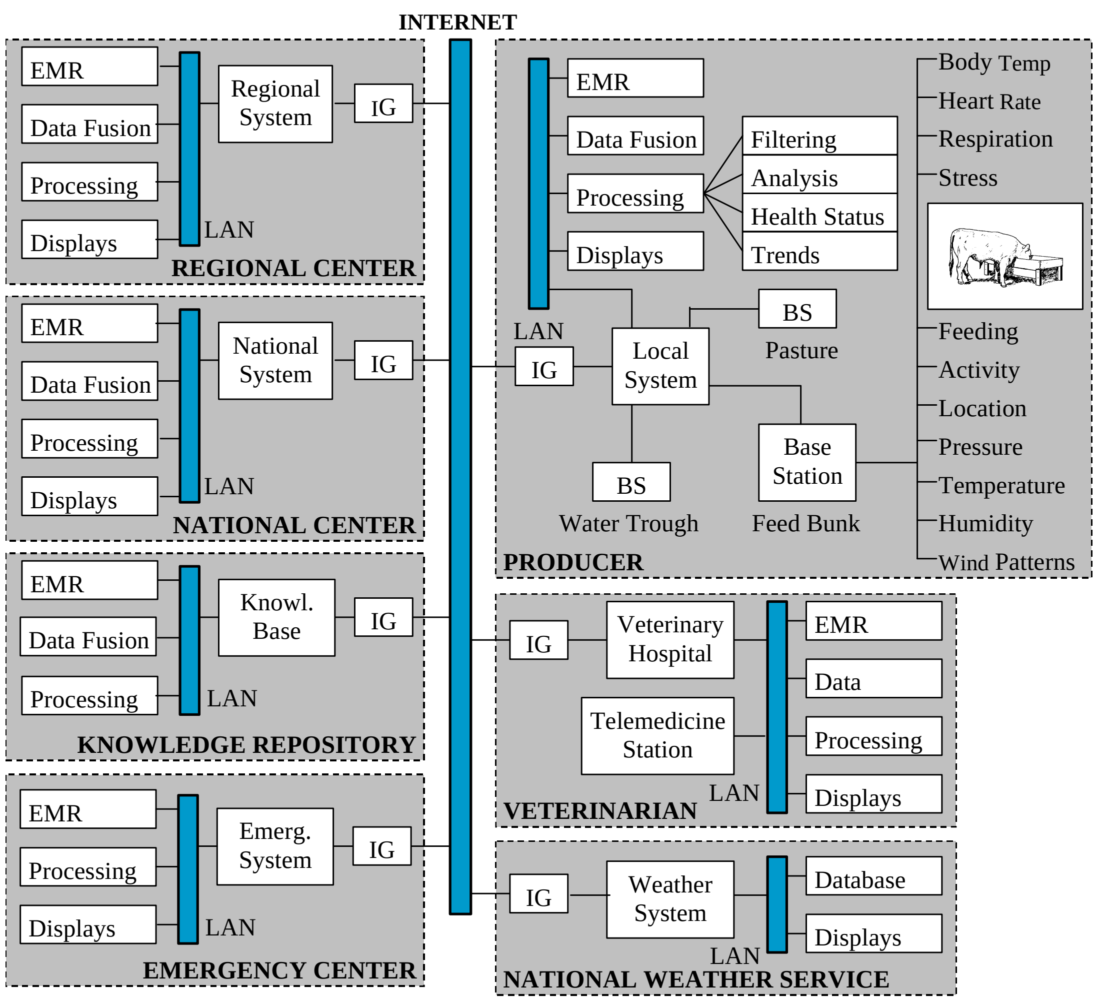

Fig. 2. Functional layout for a distributed, Internet-based livestock information infrastructure (BS = base station; EMR = Electronic Medical Record; IG = Internet Gateway; LAN = Local Area Network).

subentities and information resources.

In this scenario, animal data acquired by the producer (e.g., physiological, behavioral, environmental) are saved into a local electronic medical record (EMR) and then processed to assess state of health relative to previous trend data. These summary data are then uploaded via a secure Internet gateway to a regional center, which aggregates data provided by local farms and feedlots into a geographical health report. This report, 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.

B. *Prototype Monitoring System*

An important component of this overall effort is the merging of data from wearable sensors and the subsequent transfer of these data over a Bluetooth telemetry link. Our ongoing approach has been to use state-of-the-art, commercial technology to verify the accuracy of novel sensors designed in-house. As expected, commercial systems of this nature are rare. One product, manufactured by HQI Inc. (Palmetto, FL), utilizes a telemetric link between a small transceiver box and a temperature sensitive bolus (a 1 by 4 inch ingestible pill). When swallowed, the pill lodges in the reticulum of the cow and sends continuous core body temperature and heart rate measurements to a transceiver box attached to the back of the animal. The box is also compatible with electrode-based Polar belts used to measure horse heart rates during training, where each belt is positioned around the thorax behind the animal's front legs. Fig. 3 illustrates (A) the electrode belt (lengthened to fit a cow), (B) the CorTemp bolus and transceiver box, and (C) the process of inserting the CorTemp bolus directly into the reticulum of the animal via a rumen fistula, a portal on the flank of a cow that gives researchers direct access to the animal's digestive system.

This technology is new and used in a limited number of research environments, so it is relatively expensive. Additionally, the system does not provide the suite of data necessary for a distributed cattle monitoring environment. Light-based sensors, accelerometers, GPS devices, and other wearable/remote sensors will supplement, or even replace, systems like the one depicted in Fig. 3.

During these sessions, we utilized a light reflectance sensor connected to a pulse oximeter circuit to acquire red and infrared photo-plethysmographic data from the ear of the cow. These data are presented in the next section.

III. Results

A. *Physiological Data Acquired to Date*

For the experiments depicted in Fig. 3, the sensors acquired heart rate and core body temperature values of approximately 70 beats per minute and 102 °F, respectively. As stated earlier, we attempted to replicate these data with a reflectance sensor originally designed for human use. Fig. 4 illustrates the sensor placement that yielded optimal results (A), and the gray scale inset (B) shows the extended network of arteries and veins present in the bovine ear [11]. Heart rate was calculated from the plethysmograph (C) by noting the fundamental peak in its Fast Fourier Transform (D). This rate (72 bpm) was consistent with the result acquired by the electrode belt. Blood oxygen saturation calculations based on these data (as performed in traditional pulse oximeters) are currently underway. While design work remains to address sensor stability, signal-to-noise ratio, packaging, etc., these data clearly show that this unique approach to vital sign monitoring in cattle holds promise.

Fig. 3. Electrode belt (A) and temperature bolus (B) used to acquire heart rate and core body temperature, respectively.

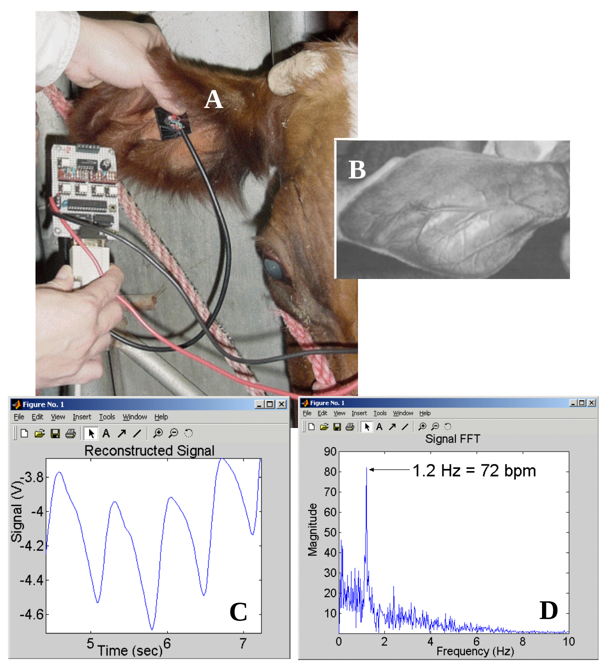

Fig. 4. Light-based sensor measurements from the ear of a cow that yield plethysmographic and heart rate data.

Fig. 5 illustrates the progress our team has made to date on a wireless platform that integrates a suite of sensors. The sensor module, controlled by a PIC 18F8720 microcontroller (A), collates GPS serial data from a Trimble Lassen SQ GPS unit with serial I/O (B), red/infrared reflectance data from an in-house pulse oximeter (C), and core body temperature from an HQI CorTemp unit (D). Activity (accelerometer), ambient environmental temperature, and humidity sensors are planned additions that will add substantive information regarding state of health and the living environment of the animal. The data stream that incorporates these sensor data is transferred over a wireless link, using a BrightCom Callisto 2 module (E), to a Compaq iPaq Model 3870 handheld computer utilizing an Anycom Bluetooth CF-2001 CompactFlash Card. These devices communicate with one another using the Serial Port Profile in the Bluetooth standard.

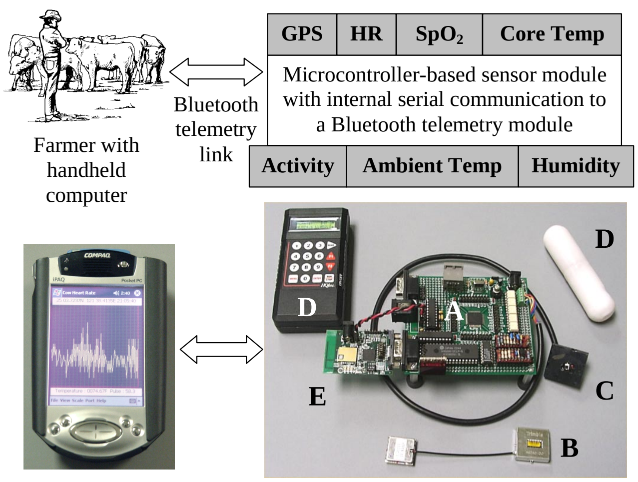

Fig. 5. Hardware for the current prototype monitoring system.

IV. Discussion

Large-scale telemedicine systems, whether designed for human or animal monitoring environments, share implementation barriers such as cost-effectiveness, interstate licensure, biocompatibility, status quo, market momentum, diagnostic feasibility, confidentiality, and usability. These monitoring systems also share design requirements:

- Low-cost wearable or nearby monitoring components.
- Distributed information systems comprised of intelligent components that interact directly with electronic medical records: information security is paramount.
- Health prediction based on current assessments and trend data, which requires the merging of medical, environmental, and even market/weather data.
- Systems designed for subjects that may not have the wherewithal to interact with them intelligently.
- Interoperability standards for ad-hoc system assembly.

Technology that is properly introduced into an animal monitoring environment can be effectively integrated into human monitoring environments, and vice versa.

V. Conclusion

This effort addresses a critical need: applied research that will allow the veterinary profession to react to and predict disease onset in cattle and its subsequent spread. Through development of a physiologic monitoring toolset, a distributed software infrastructure, and new processing algorithms, we can improve the financial stability of the livestock industry while becoming better prepared for epidemiological disasters, whether from natural or terrorist events. As demonstrated by the devastating impact of foot-and-mouth and mad-cow disease on the European farming industry, disease epidemiology needs much greater support at the local level. Economic benefits to producers will be significant: these systems will enable them to assess and treat animals sooner, optimizing meat quality while preventing the spread of disease.

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