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# Electrocardiographic Pill for Cattle Heart Rate Determination

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*Abstract*—**Decreased agricultural profit margins and recent bioterrorism concerns have led to an increased interest in monitoring livestock health. Heart rate and core body temperature are traditional vital parameters for cattle health assessment, as they provide warnings for illness and disease. However, obtaining these data in the field is time and labor intensive, which speaks to the need for solutions that provide continuous and automatic acquisition of these parameters. This paper presents the design of a pill that can remain in an animal's reticulum and use electrocardiographic techniques to ascertain heart rate. The wired prototype has been tested with a fistulated steer. These tests demonstrate that consistent heart vector data can be acquired even in the presence of animal movement and rumination. After minor processing, these signals are suitable for use with peak detection circuitry that can automate heart rate determination.**

*Keywords*—**Cattle, electrocardiograph, heart rate sensor, pill, telemonitoring, veterinary telemedicine, wearable devices**

## I. Introduction

To reduce the threat that disease, whether from natural causes or bioterrorism, poses to the livestock industry, the United States must improve its ability to monitor individual animal health, track animal transport, and populate a national veterinary information repository useful for epidemiological studies [1-5]. Veterinarians and ranchers have traditionally relied on cattle appearance and behavior to assess state of health, primarily because episodic acquisition of cattle vital parameters in the field is time- and labor-intensive; even in the clinic it is only performed hourly. While multiple animal tracking efforts are underway that utilize emerging radio-frequency identification (RFID) technology [6-9], the global-positioning system (GPS) [10-16], and accelerometers for surrogate health assessment based on activity levels [17, 18], few tools exist to monitor cattle physiologic variables directly and continuously. Commercial ingestible pills are available that settle in an animal's reticulum and periodically transmit core body temperature to a handheld receiver unit [19, 20]. Injectible RFID chips have also incorporated solid-state sensors to acquire subdermal temperature [20].

The technique described in this paper provides heart rate by way of an electrocardiographic sensor that operates in the form factor of an ingestible pill such as those used to acquire core body temperature. While a microphone-based phonocardiographic technique was previously described in the context of this form factor [21], this paper focuses on the design of a pill that obtains an electrocardiogram (ECG) via electrodes placed on the pill's exterior, where the resulting signals are substantially improved relative to data obtained with phonocardiographic techniques [22].

This pill will be used with a wearable cattle health monitoring system under development at Kansas State University which seeks to record animal heart rate, core body temperature, head motion (three axes of acceleration), absolute position via GPS, and the ambient temperature and humidity of the surrounding environment [23-28]. The system can buffer data for several days. When an animal comes within range of a ZigBee-enabled base station at a water trough or feed bunk, its health data are uploaded for storage and analysis. These health data can then be sent to a larger veterinary information network which collects electronic health records from many herds and promotes the identification of health trends useful for epidemiological research.

## II. Methodology

### A. Electrocardiographic Hardware

The single-lead electrocardiographic hardware consists of a pair of electrodes that feed an AD620-based instrumentation amplifier circuit which incorporates a driven reference lead for removal of common-mode artifact. The circuitry also includes a highpass filter with a 0.16 Hz cutoff frequency for additional stabilization of the signal baseline. This hardware resides on a small board (see Fig. 1) as a companion to phonocardiographic and piezoelectric sensors and circuitry described in [21, 22]. This hardware is encased in a polyvinylchloride-pipe-based bolus that has been waterproofed, as shown in Fig. 2. In Fig. 2, the end of the pill closest to the viewer displays one copper electrode that surrounds the waterproof microphone. The other electrode exists on the far end of the pill, and the contact for the driven reference is the copper band around the middle of the pill. Signals acquired from this hardware pass through a long cable to the anti-aliasing board shown in Fig. 3. The

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board uses an 8th–order, lowpass Butterworth filter to block frequencies above 500 Hz. Filtered data are passed to a laptop computer through a 16–bit National Instruments data acquisition card (PCMCIA DAQCard–6036E). The cable facilitates placement and removal of the pill by means of a fistula surgically positioned on the side of the animal that allows direct access to the rumen and reticulum (see Fig. 4).

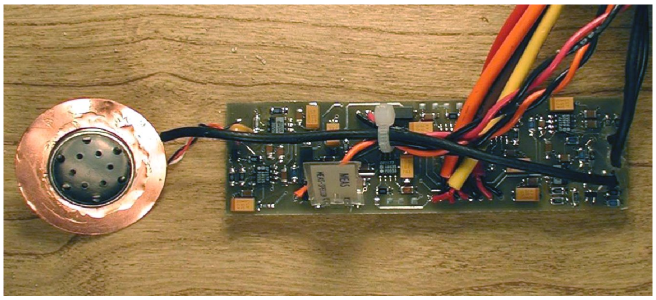

Fig. 1. Circuit board containing the microphone and ECG circuitry.

Fig. 2. Encapsulated data acquisition hardware and cable.

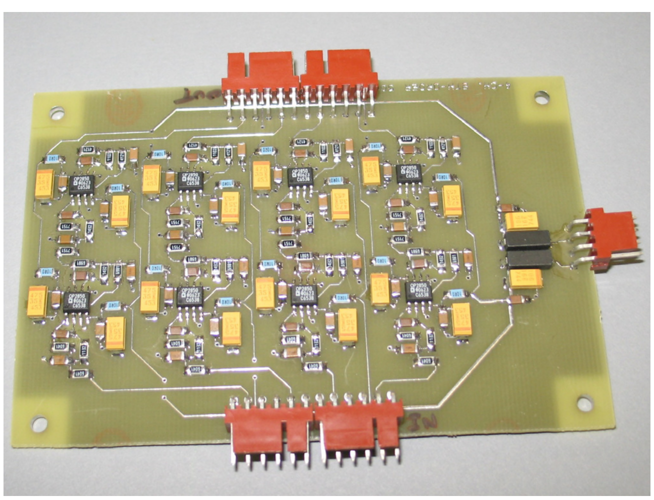

Fig. 3. Anti-aliasing board: 8th-order Butterworth lowpass filter with a cutoff frequency of 500 Hz.

Fig. 4. Placement of the wired pill into the reticulum of a fistulated steer.

## III. Results and Discussion

With this prototype system, the length of the pill cable and the presence of nearby power lines and transformers combine to generate substantial 60 Hz artifact. The ECG data are therefore filtered with a 55 Hz lowpass filter, yielding signals such as the one depicted in Fig. 5. Note that the individual QRS complexes (see the arrows in the figure) are visible in the signal even in light of the dramatically varying baseline. To minimize the baseline drift and to retain the signal components useful for heart rate determination, the data are further filtered with a bandpass filter with low and high cutoff frequencies of 4 Hz and 30 Hz, respectively. A typical ECG that exists after each of these two processing stages is illustrated in Fig. 6. Note that while the original ECG was noisy and contained significant baseline drift, the processed ECG is almost ready for circuitry that can calculate heart rate based on thresholding techniques. For this experiment, the steer has a heart rate of approximately 85 beats per minute, or one beat every 0.714 seconds.

One early concern was whether the copper plates would be too close together to detect a meaningful heart vector, but these figures illustrate that the data are high quality. While these data are promising, they exhibit characteristics that must be further addressed. First, the amplitudes of the spikes vary greatly over time even though they are nearly always prevalent. Second, the orientation of each QRS complex depends on the alignment of the pill axis relative to the heart vector. These complexes can point up or down or seem to disappear depending on that relative orientation, which potentially affects the robustness of the approach, especially if peak detection circuitry is employed. Third, point-to-point noise affects the quality of the time-domain signals and their frequency-domain spectra.

In response to these issues, the ECG data are first differentiated using a point-to-point derivative (i.e., a highpass filter), which accentuates the upswing and downswing in each QRS complex and removes some of the variation in peak-to-peak signal levels. The data are then rectified to compensate for pill orientation. Finally, a four-pass, 25-wide sliding average window (i.e., lowpass filter) is applied to smooth the signal and enhance the fundamental frequencies in the signal spectra. Fig. 7 illustrates a portion of the data from Fig. 6 that have been processed in this way. These data are well-suited for peak detector circuitry.

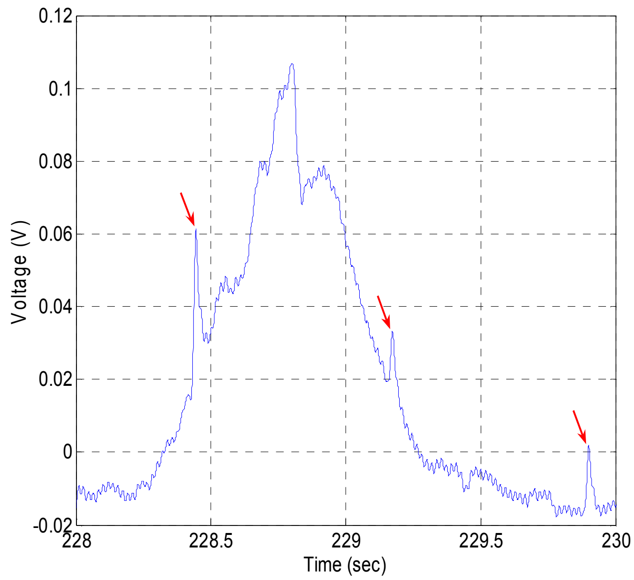


Fig. 5. Typical ECG received with the pill hardware. Arrows denote QRS complexes.

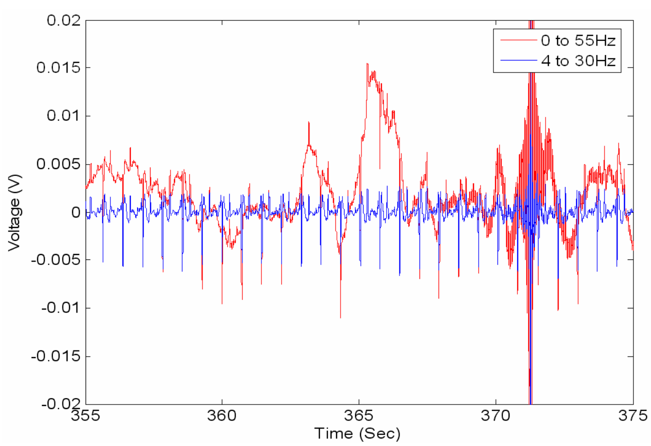


Fig. 6. ECG after the lowpass (red) and bandpass (blue) filter stages.

## V. Conclusion

Technologies to acquire continuous physiologic data from cattle can help to reduce the threat that disease poses to the livestock industry. This paper presented prototype hardware and early data for an electrocardiographic pill that will allow continuous acquisition of cattle heart rate and other cardiopulmonary parameters. Data acquired from this unit are robust in the presence of animal movement and rumination, especially when compared with previous approaches [21, 22], and a straightforward signal processing method can make these data suitable for peak detection circuitry used to calculate heart rate. Coupled with core body temperature (e.g., as in commercial pills), heart rate data should provide veterinarians with data to assess cattle state of health without the need to physically restrain these animals.

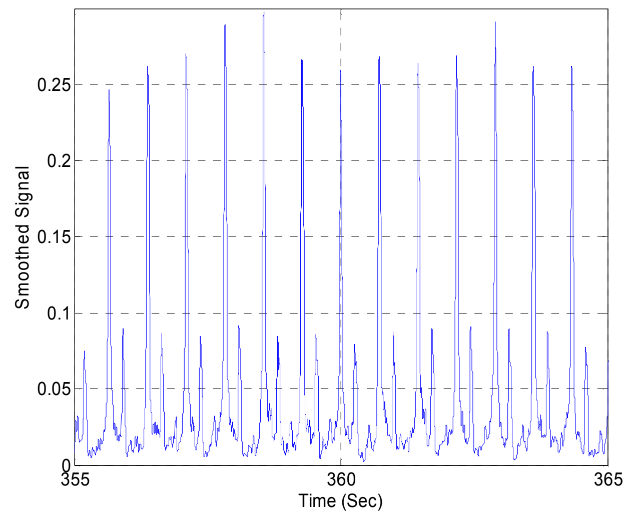


Fig. 7. ECG after differentiation, rectification, and smoothing.

To this end, further enhancements are needed. First, a wireless means must be developed to transmit these data from the inside to the outside of the animal. Since typical radio-frequency links fail in this environment due to signal attenuation by the tissue [22], the authors are working on the design of a magnetically coupled link similar to links implemented in existing core temperature pills [19, 20, 29-32]. Second, physical changes can be made to the pill to make the signal data less susceptible to pill orientation relative to the animal's heart vector. Also, signal processing methods employed with these signals need to be implemented at the chip level so that few data must be transmitted over the wireless link, which promises to be the primary battery draw in the entire pill-based system.

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