Recording the Heart Beat of Cattle using Optically Pumped Magnetometers

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Abstract

Livestock farming occupies about 30% of the Earth's habitable surface area with a global value around £1 trillion. This important economic entity relies to a large extent on the health and welfare of the animals involved. Besides economic pressure there is also a growing interest from the consumer in the ethical keeping of livestock [Grandin 2014]. The animal's heart rate is a key indicator of stress and therefore an automated non-contact means of measuring heart beat could enable improved monitoring of animal welfare.

The electric signal of the heart muscle excitation and relaxation does also carries a magnetic field component. Reading the magnetic field to query heart beat information avoids the need for contact electrodes. We use an array of QuSpin Total Field Magnetometers (QTFM®). Using the background noise to time-shift the signals we optimize signal to noise ratio and record the magnetic heart signal down to 1 pT $Hz^{-1/2}$ in the 1–20 Hz frequency band. Using a mathematical algorithm we retrieve the heart rate and the shape of the magnetic heart excitation. Comparison to electro cardiograms shows good correlation.

1. Optically Pumped Magnetometry

Alkali vapour cell magnetometry offers extremely high precision measurements of magnetic fields. Total-field magnetometry allows for the design of compact and robust scalar magnetometers that can resolve small field changes

Figure 2: **QuSpin QTFM**
Total Field Magnetometers used in the sensor design.

2. Magnetocardiography (MCG)

New sensing technologies and data analysis platforms are enabling the development of smart solutions for livestock monitoring, providing farmers and vets with more objective and timely means of monitoring animal health and welfare. Heart beat parameters could offer a potential additional measure of animal condition if they could be captured by non-contact means. Recording electrocardiograms (ECG) on animals comes with challenges in sticking the electrodes to the animal's skin. Often shaving is required to obtain good contact. Furthermore, in large animals tissue between the electrode and the heart muscle leads to considerable animal to animal variations and to signal distortions [DeRoth 1980]. Recording an MCG circumvents these challenges.

3. Sensing Heart Beats

Optically pumped magnetometers have been successfully used in the recording of heart beats and MCGs have been shown to provide rich diagnostic information when using arrays of sensors.

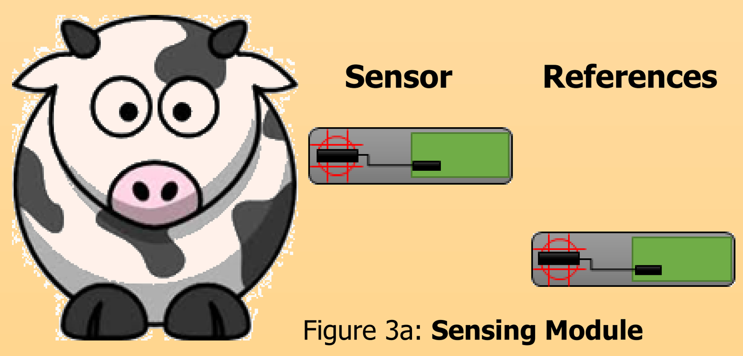
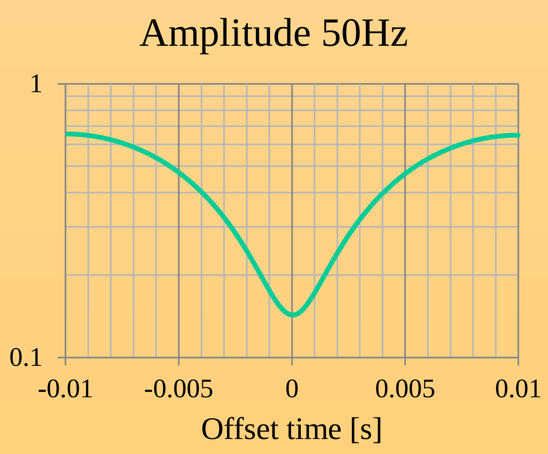


Figure 3a: **Sensing Module**

The sensor utilizes QuSpin QTFM® M_z scalar magnetometers with a transverse dead-zone measuring to a noise floor of 1 $pT.Hz^{-1/2}$. The set-up allows for compensation of the ambient field [Ingleby et al. 2017]. Precise timestamping enables noise suppression.



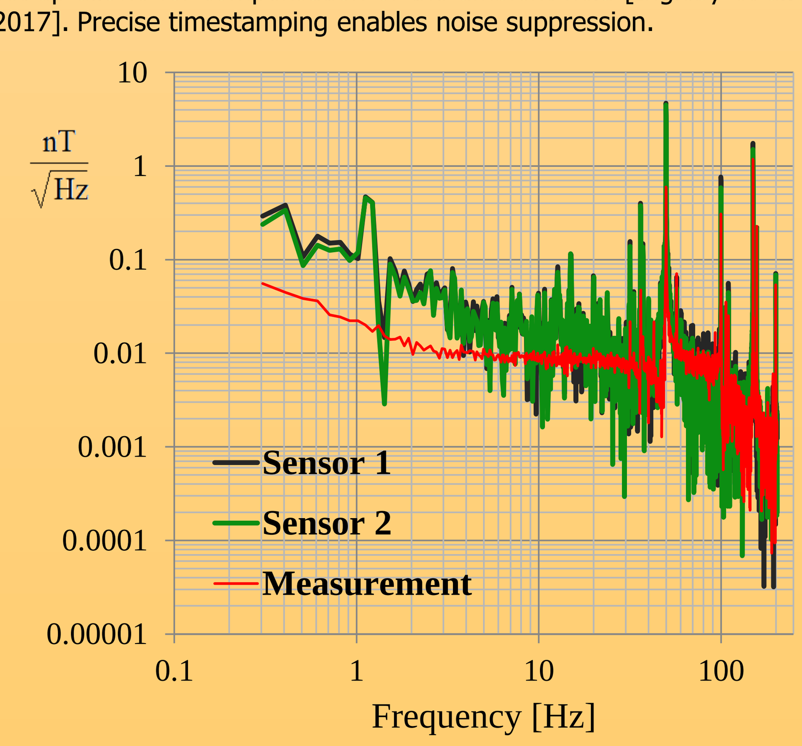


Figure 3b: **Noise Suppression**

The timestamped recordings of the sensors in the array are shifted to minimize the power of the 50 Hz background thus allowing for optimum alignment of the data traces (green, black) to minimize the noise on the measurement trace (red).

4. Monitoring a Heart Rate

Heart rate is a physiological indicator of animal stress and therefore a potential measure of welfare. It is also an indicator of some diseases, such as milk fever. To be able to track short term variations in the heart rate it is necessary to record the heart rate from short measurement intervals.

Verifying the measured rates against conventional measurements: taking the tail pulse, listening using a stethoscope or taking an ECG, found good correlation between the magnetically recorded and the true heart rate.

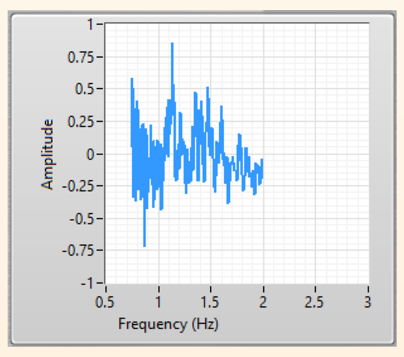


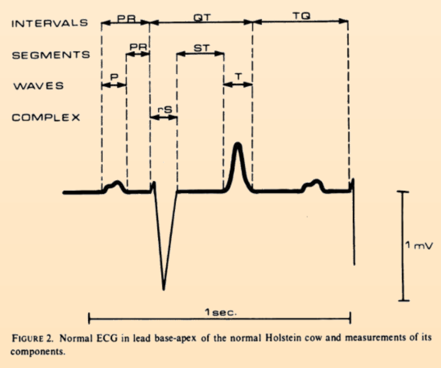
Figure 4: **Frequency Tracking**
The heart rate is identified by a distinctive peak in the frequency.

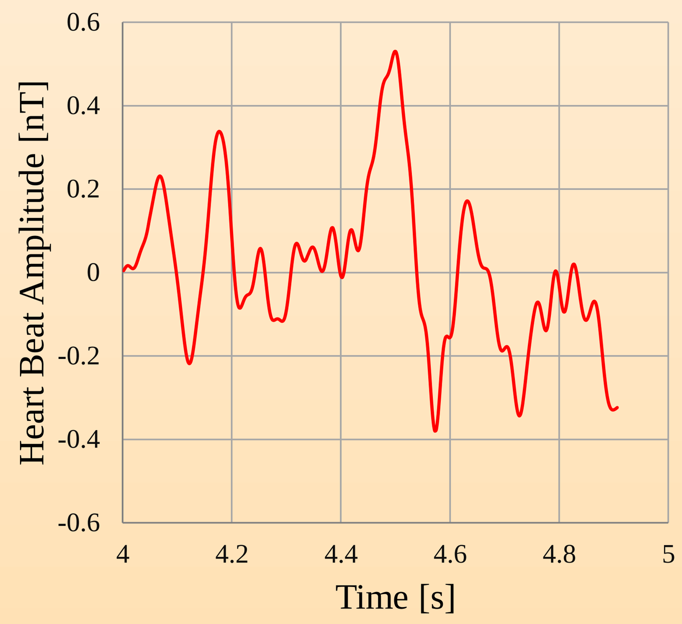
5. Recording the Timing of the Heart Beat

The action of the heart muscle is determined by electrical conduction along specialized tissue thus generating a characteristic sequence of heart actions. Magnetic recordings of a cow's heart beat reproduce the characteristic time intervals as shown in ECG references [DeRoth 1980].

Figure 5: **Heart Beat Time**

The time intervals between a published reference heart beat (black trace & numbers) and the MCG recording (red trace & numbers) match well with key elements in the heart beat sequence.





Period	P Wave	PR Interval	PR Segment	QRS Complex	ST Segment	QT Interval (Systole)	T Wave	Diastole
Duration ECG [ms]	100	200	100	90	200	400	100	400
+/- sd	11	22	18	8	34	34	18	59
Duration MCG [ms]	125	250	125	200	100	450	150	350

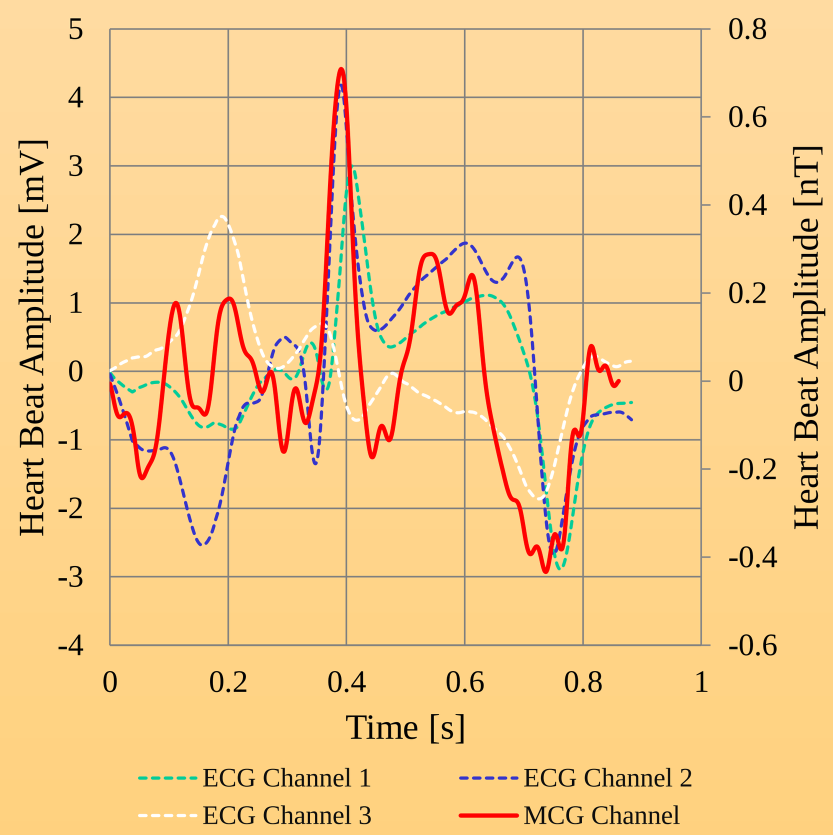
6. Matching a MCG with an ECG:

The current standard in monitoring the heart beat is the electro cardiogram (ECG). We are recording an ECG in the Einthoven configuration and match the signal to the magneto cardiogram (MCG). Aligning the signals from three different ECG configurations with the MCG signal shows matching features in the P-wave, the QRS complex and the T-wave. The amplitudes of the ECGs and the MCG agree with theoretical calculations [Alday et al. 2016]

Figure 6: **ECG & MCG Recording and Traces**

Holding pen as used in the measurements at Langhill Farm, The Royal (Dick) School of Veterinary Sciences.

Three different ECG configurations and a MCG are recorded in parallel from a test animal. Timestamping allows for synchronisation of the two signals.



Conclusions & Outlook

Non-contact sensing of physiological parameters opens opportunities for the monitoring of animal wellbeing in farming and provides an early-warning system for the health of the animal. While a potential strength of an ECG lies in its versatility in picking up different electrical aspects of the heart action it is also prone to interference from other tissue leading to considerable animal to animal variation [DeRoth 1980]. A MCG offers potentially better reproducibility and standardisation of measurements.

References:

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