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Measurements of Heart Motion using Accelerometers

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Abstract— **We have used acceleration sensors to monitor the heart motion during surgery. A three-axis accelerometer was made from two commercially available two-axis sensors, and was used to measure the heart motion in anesthetized pigs. The heart moves due to both respiration and heart beating. The heart beating was isolated from respiration by high-pass filtering at 1.0 Hz, and heart wall velocity and position were calculated by numerically integrating the filtered acceleration traces. The resulting curves reproduced the heart motion in great detail, noise was hardly visible. Events that occurred during the measurements, e.g. *arrhythmias* and *fibrillation*, were recognized in the curves, and confirmed by comparison with synchronously recorded ECG data. We conclude that acceleration sensors are able to measure heart motion with good resolution, and that such measurements can reveal patterns that may be an indication of heart circulation failure.**

Keywords— **Accelerometer, heart motion, cardiovascular**

I. Introduction

Single-axis accelerometers have previously been used to study the heart motion, e.g. to better understand the source of heart sounds [1], [2]. The aim of our work is to use a three-axis accelerometer to reproduce the full motion pattern of the heart, for application during open thorax surgery. In this paper we present results of the first animal studies. These studies were done with a sensor prototype made from commercially available accelerometers.

II. Medical Background

Cardiovascular diseases are the major cause of death in the western world. *Open thorax surgery* is today a part of standard clinical practice in the treatment of such diseases. Approximately one million such operations are performed every year, and the procedure is regarded safe. However, complications do occur.

An acceleration sensor attached to the heart surface during surgery will allow the doctor to follow the heart motion pattern in detail. In addition, an analysis system attached to the sensor can automatically monitor the motion and give a warning if deviations from the normal condition are detected. Hence, such a sensor can increase the patient safety during open heart surgery, and provide a useful supplement in the treatment of cardiovascular diseases.

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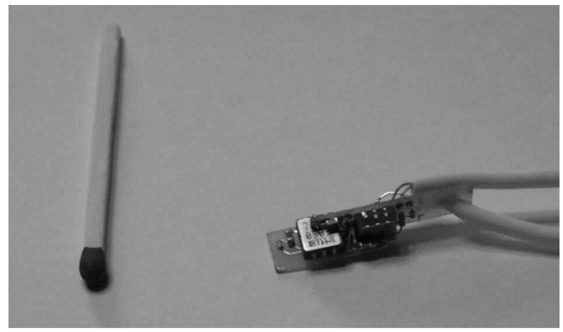

Fig. 1. The three-axis sensor, shown without plastic coating.

III. Experimental Method

A. Sensor Prototype

The experiments were done using sensor prototypes made by mounting two commercially available two-axis accelerometers at 90° angles (*ADXL311, Analog Devices Inc., Norwood, MA*). A picture of a prototype sensor is shown in Fig. 1. The bandwidth out from the sensors was reduced to 50 Hz, selected to preserve the finer structures in the heart motion, while minimizing noise. The frequency of a beating heart is typically between 1 and 3 Hz, for both humans and pigs.

B. Animal Model

The initial feasibility studies were done on anesthetized pigs. The chest wall, *thorax*, was opened, and one or two sensors were sutured to the outer heart wall. The first sensor was fastened near the *apex* of the heart. This part of the heart receives its blood supply from the *LAD* coronary artery [3]. If used, the second acceleration sensor was fastened higher, on a region supplied by the *CX* coronary artery. The pigs were ventilated by a respirator.

C. Data Acquisition and Analysis

The data acquisition setup is illustrated in Fig. 2. Analog data from each sensor were digitized at rate 250 samples/s using a 12-bit, 16-channel analog to digital converter (*DAQ-Pad 6020E, National Instruments, Austin, TX*). The ECG signal was sampled synchronously with the acceleration data, for reference. Several hours of heart beats were recorded for

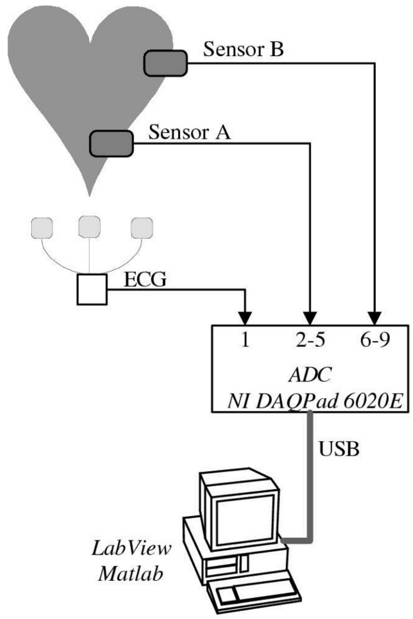

Fig. 2. Data acquisition setup used in the experiments. Data was collected from one or two sensors attached to a pig's heart.

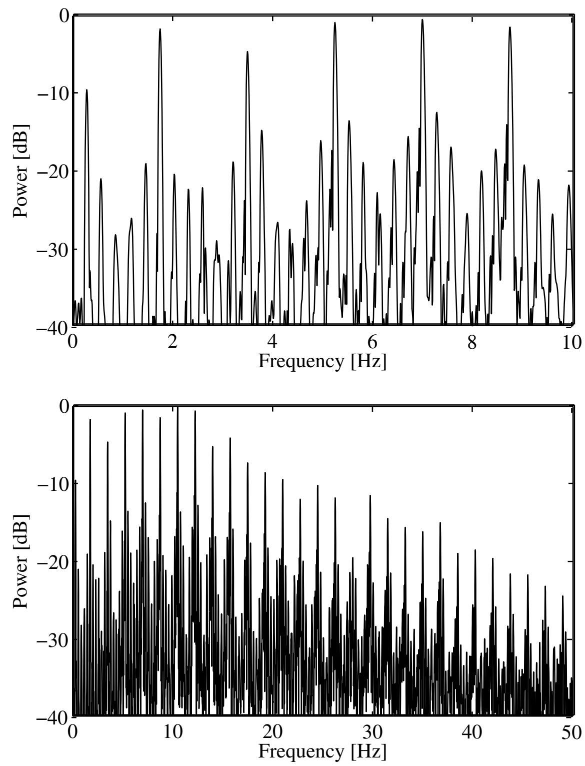

Fig. 3. Power spectrum of the heart acceleration. The upper graph shows the low frequency part. The lower graph shows the same data, with the frequency scale extended.

each experiment. Results were stored in the computer, and imported into MATLAB ((*The Math Works, Natick, MA*) for processing.

We are interested in the motion from the heart's own beating. The heart also moves due to respiration, and movements of the whole pig may further complicate the interpretation of the signals. The pig heart beats at a rate of about 1.5 Hz, or 90 beats per minute, while the respiration frequency is lower, typically less than 0.4 Hz [4]. Hence, the heart beating could be isolated by high pass filtering using the following procedure: DC components, caused by gravitation, were removed by subtracting the mean value. The resulting traces were run through a digital 4th order high-pass Butterworth filter with cut-off frequency 1.0 Hz. This filter was applied both forwards and backwards, to obtain zero phase.

IV. RESULTS

The power spectrum of a received acceleration trace is plotted in Fig. 3. The upper graph shows the low frequency part. Two series of harmonic peaks are recognized, corresponding to two distinct periodic motions: The respiration at 0.3 Hz and the heart beating at 1.7 Hz. The position spectrum is obtained by weighting this acceleration spectrum by $1/f^2$, where f is the frequency. This implies that the position spectrum is dominated by the peak at 0.3 Hz, hence, the heart's absolute position is mainly determined by the respiration.

The lower graph in Fig. 3 shows the same data with the frequency scale extended. This illustrates that the acceleration spectra contain information up to 50 Hz, or approximately 30 harmonics of the heart rate. All these harmonics should be included to resolve the finer details of the heart motion.

Fig. 4 shows the heart position calculated from the acceleration traces, using the procedure described in the previous section. For simplicity, only one of the axes is plotted. The ECG signal is shown in the lower part of each graph. These curves show that the heart motion can be nicely monitored with the accelerometer. Very little noise is seen in the curves.

The upper graph in Fig. 4 shows a normal heart beating pattern. The curve displays a periodic motion with amplitude slightly less than 1 cm, perfectly synchronized with the ECG. Arrhythmias are seen in the ECG signal, at 638 s and 643 s, and these are easily identified in the motion curve: The curve shows in detail how the arrhythmias briefly disturb the heart motion, and how the motion is restored to normal after approximately one heartbeat.

The lower graph shows a sick heart. No obvious deviation from normal pattern is seen in the first 7 heartbeats. At 769 s, the heart goes into fibrillation. This is seen both in the ECG and in the motion traces.

V. DISCUSSION

The results show that accelerometers can measure the heart motion in great detail, and that abnormalities in the

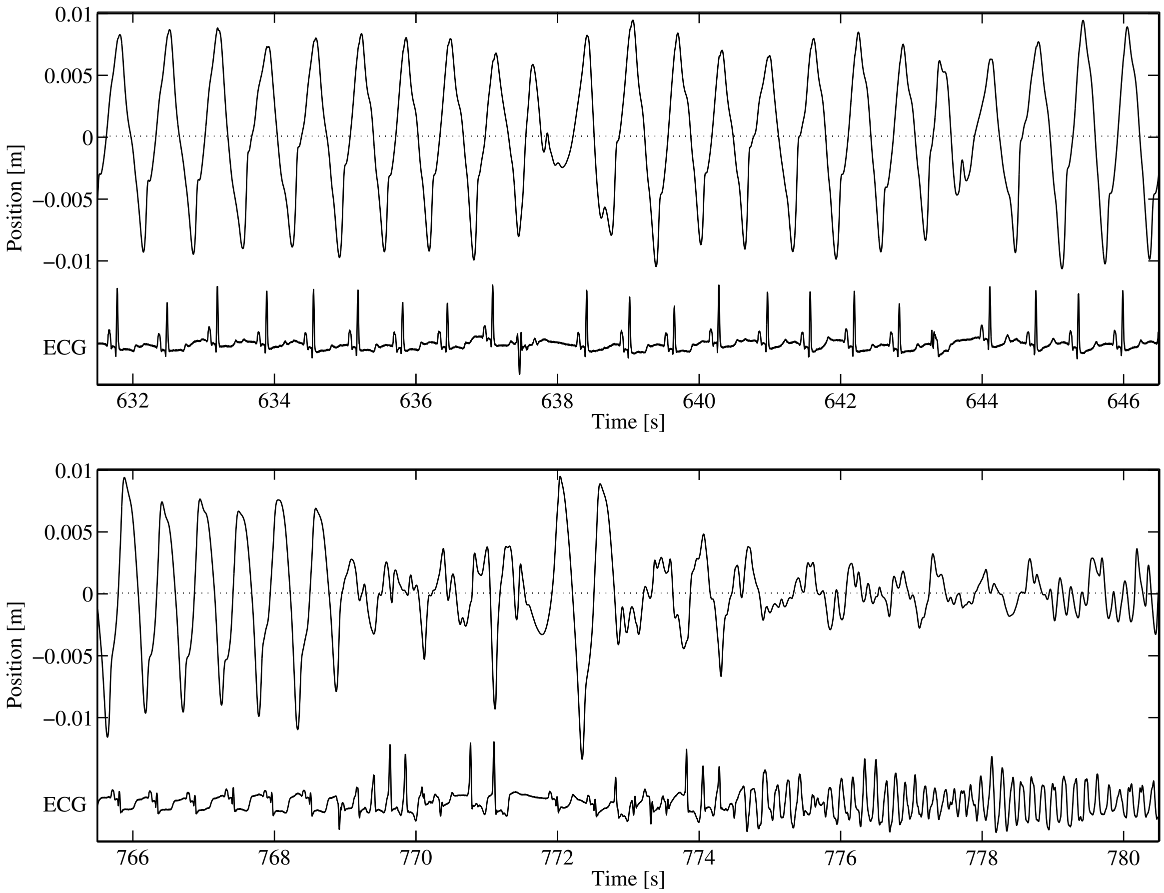

Fig. 4. Heart position as function of time. Only one of the three axes is plotted, and the ECG signal is shown for reference. The upper graph shows a normal heart motion pattern with arrhythmias at 638 s and 643 s. The lower graph shows a sick heart that goes into fibrillation at 769 s.

motion pattern can be recognized. The results have also shown that it is critical to remove motion due to respiration when interpreting heart motion data.

The heart motion involves some rotation. Hence, the sensor will rotate in the gravitational field, with frequency equal to that of the beating heart. This rotation cannot be distinguished from an acceleration, and may disturb the interpretation of the motion data. This disturbance does not seem critical, but it must be kept in mind when interpreting the signals.

VI. Conclusion

Three-axis accelerometers are able to measure the motion of the heart with good resolution. The measured motion traces can reveal patterns that may be an indication of heart circulation failure.

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