CAPACITIVE SENSING FOR PULSE RATE MONITORING

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Abstract: This paper describes pulse rate monitoring using capacitive electrodes on finger or wrist. The technique uses a single frequency measurement suitable for low cost and low power applications. The system may enable convenient, comfortable, and continuous monitoring. Pulsatile flow resulted in approximately 5-10 fF of capacitance variation, a level easily measured using inexpensive capacitance measurement integrated circuits.

1 INTRODUCTION

Automated pulse and heart rate measurements have become commonplace with the development of personal training and health monitoring devices. These devices are accurate and easy to use. However ECG based systems require either a chest strap which may be uncomfortable or inconvenient, or require use of a finger touch sensor and therefore do not provide continuous monitoring. Pressure based systems require a finger, wrist, or arm cuff that periodically inflates, can be uncomfortable, and does not provide continuous monitoring. Optical systems (pulse oximeters) require an optical transmitter with adequate intensity output to penetrate tissue, and although many battery operated models are available, they are not compatible with very low power operation.

Bioimpedance measurement methods have found many applications, however they have seldom been applied to simple pulse rate monitoring. One reason may be that obtaining the wealth of information available from a complex impedance measurement requires at least four contact electrodes usually using gel on at least one limb, wired to precision bench top electrical instrumentation (Bayford 2006). However if capacitance is the only parameter to be measured, the situation is changed.

Capacitance sensing has become very common in recent years. Traditionally capacitance sensing suffered from a reputation of being susceptible to parasitic effects and requiring unstable high input impedance circuitry. Most measurements involved bridge circuits (Mohanty 2004) or network analyzers (Ferrier 2008). However those complexities have largely been overcome using microcontroller based capacitance measuring circuits. These sensors are now widely used in consumer electronics for non-contact switches, sliders, and track pads. In addition to the benefit that capacitance switches do not require direct electrical contact, they also draw no direct current in any state, and are therefore suitable for low power applications. With no direct current the devices are inherently low noise, although support circuitry may not share this benefit.

These now ubiquitous capacitance sensing IC's have been demonstrated in many applications including chromatography systems (Takeuchi 2008). They also have potential to be used in finger or wrist band pulse rate monitors, enabling low cost and very low power operation for ambulatory monitoring, or in combination with other sensors for more complete vital sign monitoring.

2 METHODS

2.1 Experimental

In order to test the feasibility of measuring pulse rate using finger capacitance measurement, the Analog Devices AD7746 capacitance to digital converter was used. This integrated circuit is specified to provide 4fF accuracy and 4 aF resolution at a 32kHz measurement frequency, and has a 2 wire I^2C compatible digital interface (Analog Devices, Inc. 2005). The IC is available as part of an evaluation board, using a Cypress Microsystems CY7C68013

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Ez-USB microcontroller for the I^2C to USB interface to a personal computer for programming and data acquisition (Cypress Semiconductor Corporation 2005).

A schematic of the measurement system is shown in Figure 1. A key factor enabling the measurement is close contact between the finger and electrode. This can be achieved by incorporating electrodes into a finger clip similar to a pulse oximeter, or incorporating them into a cuff using a fabric hook-and-loop closure. The cuff approach can be less bulky and more secure than the clip, although the cables may be inconvenient.

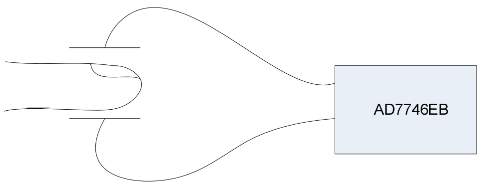

Figure 1: Schematic of finger pulse measurement.

Excitation and measurement electrodes were constructed from copper tape strips 6 mm wide and 14 mm long covered with dielectric tape. Electrodes were adhesive mounted on a fabric hook-and-loop cuff for attachment to the finger. Electrodes were connected to the AD7746 using coaxial cables approximately 400 mm long. Measurements were completed with the subject's arm resting on a table top approximately 20 cm below the level of the heart. The capacitance measurement circuit was set up using the evaluation board software (Analog Devices, Inc. 2005). The IC was set to a typical configuration with one excitation electrode driven by excitation channel B with an amplitude of $V_{DD}/2$, and one input electrode connected to the positive terminal of input channel 1. The capacitance measurement was then single-ended with continuous sampling at a rate of 16.1 Hz. No further signal processing was used.

For wrist measurements, electrodes with dimensions identical to those used in the finger monitor were located on either side of the radial artery. These were also fixed in place using a fabric hook-and-loop band. The measurement procedure was identical to the finger measurement.

This work was intended only as an initial feasibility study for this technique and no efforts were made to evaluate the effect of position and motion artifacts, or the variation in results for different subjects.

2.2 Electrical Model

An electrical model of the pulsatile flow is required in order to enable discussion of the measured results with respect to the physical system. At this stage a simple model of the finger tissue can be used, replacing it with a parallel capacitance and resistance. However it is important to include series capacitance between the finger and electrodes representing the dielectric and any small air gap. The model shown in Figure 2 can be easily evaluated using a circuit simulator, numerical calculation, or analytical methods.

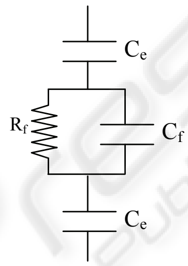

Figure 2: Electrical model for finger impedance.

Permittivity of the finger tissue is high, and depends on the exact composition of the tissue. However if the relative permittivity is approximately ε_r=3000 and the finger diameter is 13 mm, the finger capacitance using a parallel plate approximation should be about 170 pF.

The signal to be measured is associated with the pulsatile nature of the blood flow. The finger is not a rigid structure, so the increase in blood pressure during systole should correspond to an increase in volume of the finger. In addition, if the electrodes are attached to a rigid band, there will be a corresponding decrease in the gap between the finger and the electrodes.

A perceived drawback of a capacitive measurement is that the signal will be loaded by both the shunt resistance and the series capacitance components. The finger resistance will influence the measured value as it passes current, but provided the resistance is fairly high and the measurement frequency is high enough the effect is small. The dielectric coating on the electrodes and any air gap between electrodes and skin represent a low permittivity and small capacitance. However due to the series connection, these capacitances dominate the overall impedance of the system regardless of the measurement frequency. Fortunately, for a pulse measurement the exact amplitude of the measured impedance is much less important than the frequency provided the amplitude is adequate for measurement.

For a high resistance subject, the measured capacitance then is expected to be the series combination of the finger capacitance and the two electrode capacitances. Using the dimensions for electrode and finger mentioned above, and an air gap of 0.5 mm between electrode and skin surface produces a total capacitance of 0.74 pF. Further adding a sinusoidal variation of 1% in finger diameter (and corresponding reduction in gap) a capacitance fluctuation of about 8 fF is predicted.

3 RESULTS AND DISCUSSION

Initial experiments were completed using electrodes on the index finger. The capacitance variation with time is shown in Figure 3. It corresponds well with the pulse and shows features similar to a typical infrared absorption measurement. No attempt was made to shield electrodes in this measurement, and the capacitance values are sensitive to parasitic coupling to nearby objects and to movement of the subject. These effects require further study, but are commonly encountered and can be reduced through improved design and signal processing (Kim 2006).

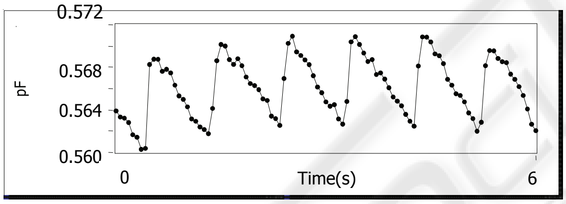

Figure 3: Capacitance measurement for electrodes mounted on the finger.

The mean capacitance shown in Figure 3 is 0.565 pF with a fluctuation around 8 fF, which is similar to the estimate from the electrical equivalent model. Detailed noise measurements were not completed, but the RMS noise level in stable operation and with no finger between the electrodes is less than 100 aF. The signal was not observed to show significant variation due to position on the finger or tension in the cuff. No quantitative measurements were made to investigate the effect of changing conductivity on the capacitance measurement.

A second measurement location was investigated using parallel electrodes held on either side of the radial artery using a wrist band. With this electrode arrangement the capacitance is between the facing edges of the electrodes, and the change is expected to be lower than with the finger measurement. In fact the amplitude variation in the capacitance was found to be similar to the finger measurement, however the total capacitance and noise level was higher as shown in Figure 4.

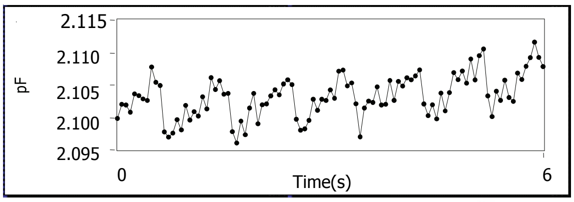

Figure 4: Capacitance measurement for electrodes mounted on the wrist.

While the pulse can be identified in this signal, an improvement in the signal amplitude or noise is required to make this a practical measurement. If this can be improved the implementation would be much more convenient for a subject using the sensor for continuous pulse monitoring as it could be incorporated in a wristwatch style instrument. However placement of the electrodes relative to the radial artery will be much more challenging than placement of the finger-cuff electrodes.

4 CONCLUSIONS

Capacitive measurement of pulse rate has been demonstrated to be an interesting technology for low cost and low power applications. The most promising results have been found using a finger cuff containing measurement electrodes which provided a pulsatile variation of approximately 8 fF.

ACKNOWLEDGEMENTS

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