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Remote detection of human electrophysiological signals using electric potential sensors

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We describe the measurement of human electrophysiological and movement signals remotely from a seated subject. An ultrahigh impedance electric potential sensor, designed specifically to reject external noise, is used to measure the electric field at distances of up to 40 cm from the surface of the body. The sensor is able to provide continuous data acquisition, at full sensitivity, without saturation by external noise sources. Respiration and heart signals are seen simultaneously and are separated using digital filtering techniques. All of the results reported were obtained in an open unshielded environment in close proximity to line operated computer equipment. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2964185]

There is much current interest in technologies which enable the remote measurement of physiological parameters. The applications span the fields of security, biometrics, ambulatory monitoring of patients, home healthcare, and vital sign monitoring of people in safety critical situations such as drivers or pilots. The ability to identify uniquely an individual from biometric information alone is the holy grail of current security research.[1] A peculiar and useful property of such biometric information is that it cannot be revoked.[2] Such a system may be used for either verification or identification[3] of an individual for access control or security monitoring. The current focus is on technologies for fingerprint recognition,[4] iris scanning, facial imaging, or voice recognition[5] with a number of other techniques such as keystroke pressure and time patterns,[6] the topic of research projects. By contrast, we show how a biometric measurement may become accessible by using an electric field sensor to acquire electrophysiological signals remotely (in particular, a cardiac signal) without the necessity for physical contact with the body.

In this paper we describe remote measurements of the electric field due to respiration and heart activity. We demonstrate that we are able to monitor passively both electrical and movement signals with this technique by comparing measurements made from the front with those from the back of a subject. To put this in perspective, alternative techniques such as optical vibrocardiography[7] and microwave Doppler radar[8] are active and require irradiation of the subject with either laser or microwave sources. In addition, these two techniques detect the signal resulting from chest wall movement, not the electrophysiological signal due to the heart, and are therefore restricted to operating from the front of the subject only. The data presented were acquired using a modified ultrahigh input impedance electric potential sensor (EPS), invented at Sussex and previously described in the literature,[9] which has been adapted so that it may be programed to reject external noise at particular frequencies. The EPS technology is a generic measurement technology which may be configured to measure either electric field or spatial potential and has many applications including nuclear magnetic resonance,[10] dry electrode electrophysiology,[11] nondestructive testing of composite materials,[12] and array imaging.[13] Work previously reported by the authors on the remote measurement of heart signals could only be performed within an electrically screened enclosure.[14] However, this development allows us to measure electrophysiological signals in an open unshielded environment even in close proximity to sources of line noise such as computer equipment.

We present preliminary results using this electric field sensor which enables the acquisition of electrophysiological signals remotely without the necessity for physical or electrical contact with the body. In particular, the cardiac signal is used as an example, since there are alternative remote techniques available for comparison and a pulse oximeter signal may be used as a reference. We believe that these results make accessible a class of biometric measurement which contains both physiological (cardiac) and behavioral (movement) components.

The EPS is capable of operating in a free field environment and monitoring the spatial potential due to voltage sources in the vicinity of the measurement electrode. It is able to do this due to the prodigious input impedance of the sensor. Input capacitance has been measured to be as low as 10 fF (associated input resistance of 10^{15} Ω) with an operating bandwidth from <1 mHz to >100 MHz. The design incorporates an integrated electrode/active sensor with internal input bias current circuitry and guarding. It became apparent during the development of this technology that the sensors were eminently suitable for electrophysiological measurements. Conventional electrophysiology sensors use Ag–AgCl gel electrodes which make low resistance electrical contact to the skin. The extremely high input impedance of EPS means that they are not affected by variations in contact resistance in the same way as conventional electrodes and may therefore be used dry. Indeed, high quality electrocardiograms (ECGs) may be measured from either the fingertips or the chest, including through clothing. We have also demonstrated the ability to acquire ECG data from two EPSs positioned on the wrists[15] with the subject moving their limbs, or truly ambulatory while walking around using a radio data link. In the measurements described above the sensors are in

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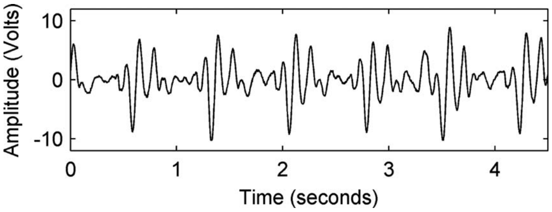

FIG. 1. Data collected from the back of the subject with a 10 cm air gap between the sensing electrode and the surface of the body. These data were collected in an open unshielded environment with the subject holding their breath for the duration of the measurement.

physical contact but not resistive electrical contact with the surface of the body. This mode of operation provides a degree of self-shielding from environmental noise and also enables the full range of electrophysiological signals to be monitored.

A more challenging measurement is one where the sensor is remote from the surface of the body. Previously we have reported results for a cardiac signal measured in an electrically screened room[14] with detection up to a spacing of 1 m between the surface of the body and the sensor. In this paper we demonstrate the capability to reproduce some of these results in a normal open unshielded laboratory environment. For these measurements the sensor was located approximately 1.5 m from a wall and was surrounded by 50 Hz line operated equipment and trunking, as is common in these situations. The sensitivity of the EPS is such that under normal circumstances the device would saturate with 50 Hz and related harmonics preventing the acquisition of a signal. In order to solve this problem we have designed a sensor with the ability to reject the four principal components of line related noise, with 50 dB of rejection measured at 50 Hz. The frequency and width of these notches are digitally tunable via control of an external clock frequency. The result is a sensor with a barely perceptible level of line noise which is capable of operating at full sensitivity with an effective dynamic range which has been increased by up to 50 dB by the attenuation of the noise components. It has the sensitivity required to detect a cardiac signal remotely using a 5 cm diameter sense electrode.

The result shown in Fig. 1 is an example of a cardiac signal acquired with the subject seated and the sensor positioned 10 cm behind the chair. These are raw data collected in an operating bandwidth of 1–30 Hz and is real time with no digital signal processing or signal averaging techniques applied. By comparison, Fig. 2 shows data collected in the same way at a distance of 40 cm from the chest in front of the subject. The similarity between these results is indicative of the mainly electrical nature of the signal. In both cases the subject has held their breath for the duration of the data collection. In Fig. 3 the combined result for the movement signal due to respiration and the cardiac signal may be seen. Given the different timescales for these two physiological processes it is a relatively simple matter to separate these out using digital signal processing techniques. This has been achieved using a finite impulse response (FIR) filter with an equivalent corner frequency of 1 Hz and the result is shown in Fig. 4.

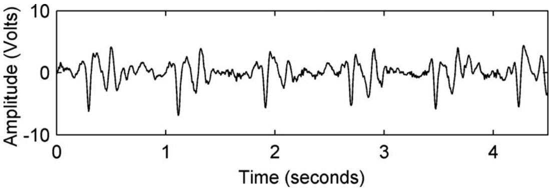

FIG. 2. Data collected from the front of the subject with a 40 cm air gap between the sensing electrode and the surface of the body. These data were also collected in an open unshielded environment with the subject holding their breath for the duration of the measurement.

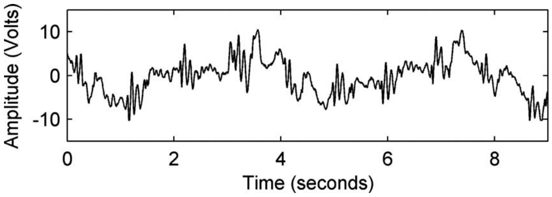

FIG. 3. Raw data showing both respiration and heart signal collected from the front sensor positioned 40 cm away from the surface of the body. No analog or digital signal processing or averaging has been applied to these data.

The data presented are consistent with previously published results obtained within a screened room environment,[14] although significantly different from contact ECG traces. The temporal relationship between the data presented and conventional surface ECG signals is clear. The main peak in the remote data is coincident with the arterial pulse, as determined using a pulse oximeter. The most likely explanation for the spread of the signal into the interval region is that we are at present observing a combined movement and electrical response from the surface of the body. This is supported by the data showing the modulation of the cardiac signal by respiration. Future work will include a study of the relative sensitivity of the sensor to these two signals and techniques for separating them, which will include modeling the effect of movement in order to allow deconvolution of the two signals. Potential applications for this method include driver drowsiness and remote vital sign monitoring, for example, in a search and rescue environment. We believe that these results open up the possibility for a class of biometric measurement which contains both physiological (cardiac) and behavioral (movement) components which may find applications in the fields of healthcare and security.

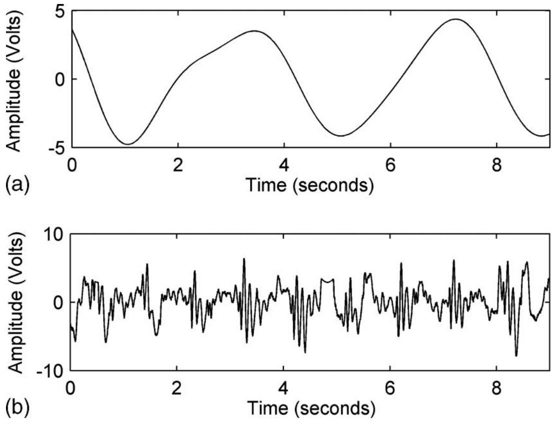

FIG. 4. The result of applying a simple digital FIR filter technique to separate the low frequency respiration signal from the higher frequency cardiac signal. (a) 1 Hz low pass filter applied to the data of Fig. 3 showing the signal due to breathing and (b) 1 Hz high pass filter applied to the data of Fig. 3 revealing the cardiac component.

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