The Virginia Tech – Wake Forest University
School of Biomedical Engineering and Sciences
4th Student Research Symposium: May 12, 2005

Non-Contact Vital Signs Detection and Monitoring via Impulse Ultra Wideband Signals

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INTRODUCTION

Impulse-based Ultra-Wideband (UWB) radar systems are known to provide extremely high spatial resolution due to the use of extremely short, in the order of nanoseconds to picoseconds electromagnetic pulses. Experiments conducted in the past have shown that UWB systems can be used for remote vital signs monitoring. Thus, one of the major applications of these systems is in health monitoring and rescue mission scenarios. In this paper, we demonstrate the use of impulse-based UWB signals in the robust detection of chest-cavity motion and the accurate estimation of respiration and heart-beat rates, even in the presence of physical obstructions between the subject and the UWB antennas.

A UWB signals is broadly classified as any signal whose bandwidth is many times greater than the minimum required to deliver the desired data rate. Impulse UWB signals, in particular, are baseband pulses that have a time duration of 100-1000 picoseconds, (as shown in Figure 1), corresponding to wavelengths of 3-30 cm in air. The extremely short time duration of these pulses makes them ideal for situations requiring very precise ranging or positioning information.

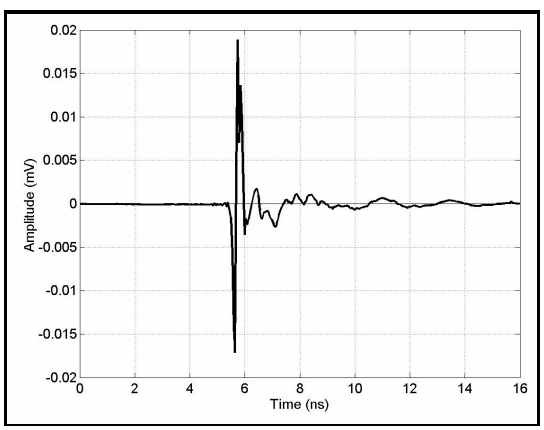

Figure 1: Example of an Ultra Wideband Pulse.

UWB signals have previously been suggested for vital signs monitoring by a variety of researchers [1-3], but the results found in the literature on the subject are solely of an experimental nature and to the best of our knowledge, an analytical approach to the estimation problem has not yet been developed.

METHODOLOGY

A typical setup for vital signs monitoring uses a standard bi-static radar configuration [4], with highly directional antennas, as shown in Figure 2. In this scenario, the subject must be facing the transmit (Tx) and receive (Rx) antennas, but may be located behind an obstruction such as a wall. A pulse generator will create UWB pulses separated by at least one pulse width, which are then radiated by the transmit antenna. Each pulse will pass through the wall and then reflect off the chest cavity of the subject (as well as other objects in the environment) and arrive at the receive antenna. As a result, the received pulse energy is smaller than the transmitted pulse energy. Furthermore, motion of the chest cavity due to respiration will result in small time differences in the arrival of the reflected pulse at the receiver antenna, as shown in Figure 3.

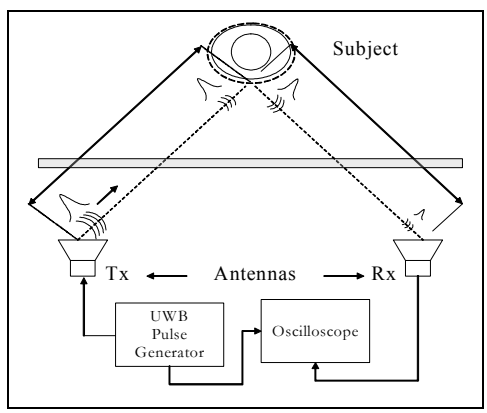

Figure 2: Typical Respiration Rate Measurement Setup

As breathing occurs, a change in lung volume and the displacement of the chest cavity take place. This effect can be modeled as a sinusoidal function of time, where the location of the skin-air interface relative to the transmitter's (and receiver's) location can be expressed as

$$d(t) = d_0 + \Delta d \sin\left(2\pi f_b t\right) \quad (1)$$

where d_0 is the mean distance between the test setup and the subject and f_b is the rate of respiration. The extremely short duration of UWB pulses means that, as the chest cavity expands and contracts, the distance a UWB pulse travels from Transmitter to the Receiver (and hence, the time of flight of the pulse) will vary, as illustrated in Figure 3.

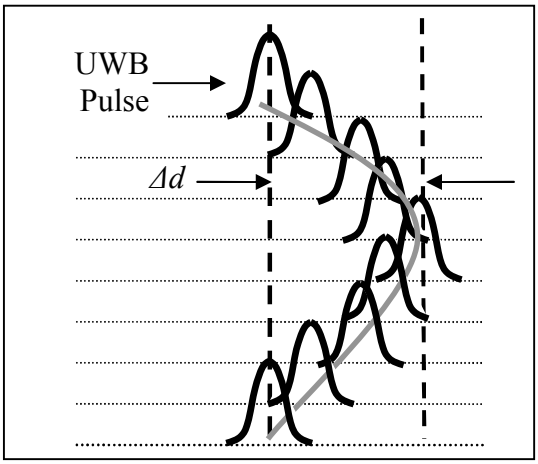

Fig. 3: Illustration of the Time-Varying Distance Traveled by a UWB Pulse Reflecting off the Chest Wall.

Thus, the instantaneous range R of the subject at an average distance d_0 can be determined from the arrival of the received pulses by the following equation:

$$R = c \cdot (\tau - \tau_0) \tag{2}$$

Where $\tau = \frac{d_0 + \Delta d \sin(2\pi f_b t)}{c}$ and $\tau_0 = \frac{d_0}{c}$. In reality, the received signal will consist of not only the pulse reflected by the subject, but also pulses reflected by other objects in the environment, known as clutter. Fortunately, a RADAR filtering technique known as Moving Target Indicator (MTI) can be used to significantly reduce or eliminate the effects of clutter on the received signal, so that the only signal left is the one due to the motion of the subject [4]. The above analysis also holds true for the detection of heartbeats, although the change in distance and time (Δd_0 and τ) are obviously smaller.

EXPERIMENTAL SETUP

To evaluate the accuracy of the UWB-based vital signs monitoring, a simple experiment was setup as shown in Figure 2. The antennas used were TEM horn antennas and were directed toward the subject. The transmit antenna is connected to a pulse generator which produced UWB pulses with a width of 300 picoseconds. The received waveforms were stored on a computer connected to the oscilloscope. Pulses were transmitted at a rate of 200 Hz, to ensure Nyquist criteria were met for breathing rate (20-30 Hz) as well as heart rate (60-90 Hz). Measurements were recorded over a 60-second time duration, and the number of times the subject breathes during the measurement, as well as the average heart rate was recorded.

RESULTS

Measurement results are shown below in Table 1. As seen from the table, there is only a small difference between the estimated and measured values for respiration rates. There is a larger variance for the measured values of heart rate. The variance is likely due to the small change in distance as the heart, combined with the relatively wide pulse and 200 Hz pulse repetition frequency. These results do, however, indicate our beliefs that UWB technology can be applied for health monitoring and rescue missions.

Table 1: Summary of Vital Signs Measurement Results

Test	Actual Breathing Rate	Estimated Breathing Rate	Actual Heart Rate	Estimated Heart Rate
1	6.3	6.2	80	85
2	14	13.7	80	70
3	34.5	33.6	64	62
4	16.5	17.1	–	–
5	31	31.1	–	–

CONCLUSIONS

We have proposed a new impulse-based UWB approach to the non-invasive monitoring of respiration rates. This technology has potential applications in health monitoring, hostage rescue, triage and athletic performance monitoring. Further, we have shown that monitoring can be performed through walls and therefore can be achieved in a completely covert and non-invasive fashion. Further studies need to be conducted to refine the extraction of heart rate and other vital signs using UWB signals.

REFERENCES

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