An Impulse Radio Ultra Wideband System for Contactless Non-invasive Respiratory Monitoring

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Background

The use of ultra-wideband (UWB) technologies in medicine is an emerging research trend in recent years. Compared with X-ray imaging, UWB radar uses non-ionizing electromagnetic waves that are harmless to the human body. UWB signals offer high precision ranging on a sub-millimeter level, and are resistant to multi-path fading. This makes UWB a potentially cost-effective solution in medical diagnostics and monitoring applications like real-time localization and tracking.

After the US Federal Communication Commission (FCC) approved the limited use of UWB technology in 2002, UWB systems have drawn considerable attention for non-contact medical applications [1]. One important application is in sleep monitoring, where measuring the respiratory amplitude and breathing rate is crucial for sleep apnea diagnosis [2, 3]. Various UWB technologies have been studied, including frequency modulated UWB [4, 5], and impulse radio (IR) UWB [6-8].

In our recent research, we have used UWB to track the respiratory effort of human subjects in order to detect medical conditions like sleep apnea and other breathing disorders. Obstructive sleep apnea is the most common form of sleep breathing disorder, and occurs when there is partial or complete cessation of airflow due to upper airway obstruction, while ventilatory effort by the patient persists. Sleep apnea affects sleep duration and quality, leading to chronic partial sleep deprivation with consequent well-recognized impaired neuro-cognitive function and daytime performance, increased risk for metabolic and cardiovascular diseases (e.g., hypertension, coronary heart disease, life-threatening arrhythmias and stroke) and motor vehicular accidents [9-12], and a diminished quality of life. Large prospective cohort community-based studies have also added to the growing evidence that sleep apnea increases risk of death [13, 14].

In order to diagnose sleep apnea and other respiratory and sleep disorders, an overnight polysomnography (PSG) is performed in hospitals. Respiratory inductive plethysmography (RIP) is utilized for measuring the respiratory effort of the patient as shown in [15]. In RIP, elastic belts are worn around the chest or abdomen, and respiratory movements are measured by detecting the change in inductance of the belt due to the respiratory effort. This is an invasive technique for respiratory monitoring. Over tightening of the belts can
impede the patient’s respiratory efforts, and shifting of body position during sleep often leads to loss of signals due to loosening of the belts. The belts also add to physical discomfort and may result in sleep disruption for the patient. The lack of adequate sleep time and loss of data signal may mean that the patient is required to repeat the PSG. Recently there have been new developments such as fabricating capacitive sensors in clothes, which can be worn by the patient in order to facilitate respiratory monitoring [16, 17]. However these methods may produce inaccurate results due to patient movements during sleep or other factors like ambient room conditions. Physical wear and tear of the capacitive sensors embedded in the fabric is also a challenge. Other methods involve the use of unobtrusive sensors and on-body wearable devices in order to measure the respiratory effort [18, 19].

A wireless, contactless and non-invasive respiratory monitoring system using IR UWB that can be used in PSG studies, home respiratory monitoring applications or other applications like physiotherapies has many advantages. The IR UWB signal has very large bandwidth, which facilitates high time resolution, and allows precise ranging estimation. Since human respiratory motion is on the order of millimeters, IR UWB is well suited for respiratory monitoring. In addition, the low power and non-ionizing properties of the IR UWB radar make it an ideal candidate for long time use. The use of IR UWB for estimating the breathing rate has been proposed by Lazaro et al. and Lai et al. [7, 8]. Their systems consist of two UWB antennas, one for transmission and the other for reception, and are pointed directly at the chest of the human subject. However, the performance of such systems is sensitive to the movement of the subject. Since one fixed antenna is used, if the human subject is not facing the antenna at a sufficiently small angle, the signal backscattering comes mostly from the side of the body instead of from the chest area, resulting in poor estimation accuracy.

### Current Research on UWB Respiratory Monitoring

To solve the problem of the human subject not facing the UWB antenna at a sufficiently small angle, we propose a setup comprising of multiple UWB transceivers. Multiple transmit and receive antennas are placed at different locations to ensure that the backscattered signal can be detected by

![Estimated chest wall motion from our IR UWB system superimposed on the output from a RIP belt.](image)

**Figure 2:** Estimated chest wall motion from our IR UWB system superimposed on the output from a RIP belt. Different colors for the IR UWB curve correspond to different state estimates for the subject facing direction $\rho(t)$. 
at least one receiver antenna no matter which direction the human subject faces. The system setup has been shown in Figure 1. One of the main challenges in such a setup is how to intelligently make use of measurements from all of the receiver antennas to estimate the respiratory motion. This process of “fusing” the information from multiple receiver antennas is done by a hidden Markov model (HMM) based method. The HMM is a stochastic model in which the actual chest wall position of the subject is “hidden” from the system as the IR UWB system only indirectly measures the position by capturing the backscattered signal. By analyzing the backscattered signals from all antennas, we can not only estimate the chest movement, but also the direction that the human subject is facing. In addition, to help in automatic diagnosis of sleep disordered breathing, we have developed a method to segment the time series of chest wall motions into normal and abnormal breathing periods, based on their statistical characteristics.

We have verified the performance of our system and algorithms on 15 human volunteers. In our experiments, we compare the performance of our IR UWB system with the medical gold standard using RIP belts. It is found that on average, our estimation is over 81% correlated with the measurements of the RIP belt system. An example of the output from our algorithms is shown in Figure 2. The state $p(t)$ at time $t$ indicates the direction the subject is facing. In our experiments with two UWB transceivers, we discretize this direction into three possible states. In state $p(t) = 1$, the subject is facing antenna 1 directly, in state $p(t) = 2$, the subject is facing both antennas, and in the last state $p(t) = 3$, the subject is facing antenna 2 directly. The different colors in Figure 2 correspond to the different directions the subject is facing. It can be seen that our IR UWB system tracks the subject’s wall motion and facing direction very closely.

**Conclusion**

UWB is a promising technology for use in medical monitoring and diagnostics. We have developed an IR UWB respiratory system that can track the chest wall motion of a human subject and her facing direction. This system improves on the current RIP belt method of measuring respiratory motion as it is contactless and non-invasive. The experimental results in this research have shown that the performance of our system is comparable to the performance of the RIP belt.

**References**


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