Biomedical Applications of UWB

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Abstract— **This summary presents an overview of the application of Ultra Wideband (UWB) signals to biomedical applications and describes the contents of the full paper to come. Specifically, the full paper examines UWB applied to remote vital signs monitoring and gait analysis. We provide an overview of the potential for using UWB in these applications along with a summary of recent results. Results from previous studies are summarized and new results will be presented for both applications in the full paper.**

I. Introduction

In February 2002, the FCC legalized the use of Ultra-Wideband (UWB) by releasing a set of spectral masks that stipulated the emission level and frequency of operation for imaging, radar, and communication purposes, sparking a huge amount of interest in UWB technology. Although the initial hype may have been slightly overblown, UWB has found its way into two current standards. To date UWB has formed the basis of the WiMedia Wireless Personal Area Network standard as well as played a role in the latest 802.15 standard (802.15.4a). The former standard represents the communications aspect of UWB (high rate, short range) whereas the latter standard represents the radar/ranging capabilities (fine temporal/spatial resolution). In this work we are primarily concerned with the latter capabilities.

Impulse Radio (IR) is a form of UWB signaling which uses streams of baseband pulses of very short duration, typically on the order of a nanosecond, thereby spreading the power spectral density of the radio signal over a few gigahertz. IR-UWB has several applications due to its robustness in harsh environments, its ability to fuse accurate position location with low-data rate communication and its covertness for tactical applications. IR-UWB also has the potential for strong material penetration capabilities (specifically in the lower bands approved by the FCC for radar applications) as well as robustness to multipath fading. Multipath resolution down to a fraction of a nanosecond in differential path delay provides excellent spatial resolution for short range radar applications in addition to an elimination of significant multipath fading. Additionally, UWB provides other potential advantages such as jamming resistance and low probability of detection.

For all of these reasons, the use of IR-UWB signals has been suggested [1] for several medical applications. In this paper we focus on two applications in particular: vital signs monitoring [2], [3], [4] and gait analysis [5], [6]. In section II we briefly outline the application of UWB to Vital Signs Monitoring and mention some of the important results to date. In the full paper we will provide a comprehensive overview of existing results and provide new results which demonstrate improved robustness. In section III we describe the application of UWB to gait analysis. Additionally, we briefly discuss the main results. Again, in the full paper we will summarize previous results we have obtained and provide the latest findings.

II. Vital Signs Monitoring

The coefficient of reflectivity of the air-to-dry-skin interface for electromagnetic waves in the 300-900MHz range is approximately 72% [1]. This respresents the fraction of the energy of electromagnetic waves incident on dry skin that is reflected. Therefore, in an IR-UWB radar setup, the motion of a human body can cause significant changes to the observed multipath profile. As shown in [2], [3], the expansion of the chest cavity creates an observable change in the multipath profile, which can be exploited to estimate the respiration rate. Further, it can be shown that accurate respiration rate estimation can be performed even when the direct path between the transmitter, the subject and the receiver is obstructed. The estimation of heart rate based on the above method has also been investigated based on a mathematical framework provided in [2].

A few potential emergency response scenarios where this technology could be applied include: (1) As a solution to the problem of triage when people are trapped under debris; (2) Through-the-wall health monitoring of victims in hostage rescue scenarios; (3) Detection of skiers trapped under snow after an avalanche; (4) Continuous assessment of a patient's respiration and heart rates in a non-invasive manner and (5) vital-signs monitoring for lie-detector tests and athletic performance monitoring [7].

The main advantages of UWB signals over the microwave Doppler radars used in previous studies are the good material penetration (thereby providing better coverage and the ability to perform through wall measurement or monitoring) and strong multipath resistance. The large bandwidth of UWB signals and the extremely low power-spectral density may produce lower electro-magnetic interference (EMI) as well as lower Specific Absorption Rates (SAR) and the adverse effects of microwave radiation on the human body may be alleviated.

The basic concept and mathematical framework for vital signs estimation using UWB was presented in [2]. Further, measurement results in [2] provided proof-of-concept and demonstrated the potential for very high accuracy (particularly for breathing rate). The idea was furthered in [4] where the multi-target problem was analyzed. Specifically it was shown that when multiple subjects are present, the same system as presented in [2] could accurately measure multiple breathing rates (and to a lesser degree heart rates), albeit with additional signal processing. In the full paper we will summarize these results and also present new results. The new results relate to an improved estimation algorithm that provides enhanced performance in poor SNR scenarios.

III. Gait Analysis

Gait analysis is the quantification and interpretation of human locomotion or motion [8]. Motion analysis [9] has found successful application in several areas. In orthopedic medicine and rehabilitation, an injury's healing progress can be monitored; in a manufacturing or business setting, methods to enhance efficiency of certain job tasks can be found; in sports medicine, motion analysis has been used to improve athletic performance in a variety of sports, including golf, track and field, baseball, and tennis. Motion analysis has even aided in the development of a space suit for NASA (National Aeronautics and Space Administration) and is constantly used by film and game industries to realistically reproduce the human gait.

Motivated by the results in [6] and by the well–recognized properties that IR–UWB radio technology shows in many biomedical applications [1], [2], [4], in [5] we proposed a UWB–based full–body motion capture system and analyzed its performance in terms of ranging accuracy when diffraction phenomena due to propagation around the human body are explicitly taken into account. In particular, the specific contribution of [5] was twofold: a) it provided an accurate analysis of the interaction between UWB pulses and the human body when different limbs of the body may obstruct the Line–of–Sight (LOS) between transmit and receive sensors and b) it compared various ranging algorithms by taking into account pulse distortion phenomena due to the human body.

In the full paper we will summarize the above results and provide additional results on system-level requirements (e.g., link budget, number of sensors, etc.) for a UWB-based gait analysis system. Although our previous work showed that accurate ranging is difficult when the line-of-sight is obstructed in a body area network, by using well-placed sensors, a sufficient number of accurate ranges are available for proper gait analysis.

References

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