A Dual-Mode UWB Wireless Platform with Random Pulse Length Detection for Remote Patient Monitoring

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Abstract—This paper presents a dual-mode ultra-wideband platform for wireless Remote Patient Monitoring (RPM). Existing RPM solutions are typically based on two different hardware platforms; one responsible for medical-data monitoring and one to handle data transmission. The proposed RPM topology is based on a single hardware platform, but it is capable of both monitoring and data transmission. This is achieved by employing a new random pulse length detection method that allows data transmission by using a modulated monitoring signal. To prove the proposed concept a test system has been built, using commercial equipment, and satisfactory results are obtained.

Index Terms—Equivalent time sampling, IR-UWB, Random pulse length detection, Remote patient monitoring.

I. INTRODUCTION

Remote Patient Monitoring (RPM) is one of the solutions desired to cope with future low-cost and efficient healthcare demands [1]. The demand for RPMs is mainly due to the increasing population of the elderly, which is the majority suffering from chronic diseases. These diseases require periodic monitoring which results in high cost and inconvenience to patients. Incorporating RPM in health care systems could significantly reduce the cost, while improving patients’ quality of life [1].

The two main functions of RPM systems are medical data monitoring and wireless transmission of the acquired data. Depending on how data is acquired, RPM systems can be categorized as contact or contact-less. Contact RPM systems require patients to wear sensors which may be both inconvenient and uncomfortable [2]. Due to the features of non-ionizing radiation, portability and low cost, ultra-wideband (UWB) technology has been increasingly used for contact-less bio-data monitoring in RPM systems [3], [4]. Combined with low cost equivalent time sampling (ETS) techniques, UWB can be used to develop low cost systems for monitoring a wide range of bio-data including respiration rate, urine accumulation, breast cancer etc. [3], [5].

While suitable for bio-data monitoring, ETS requires input signal synchronization and can therefore not be used directly for data transmission. Existing RPM solutions therefore add an extra platform, based on ZigBee, Bluetooth or WiFi, to carry out data transmission [6] (Fig. 1(a)). However, these technologies are originally aiming at medium or high data rate applications (250 kbps for ZigBee [7]), and thus they are power-inefficient for bio-data transmissions where the needed data rate usually is low. Furthermore, these technologies use communication schemes different from UWB, and thus an additional transceiver and antenna are needed, which increases the device size and cost. For practical RPM deployments, where usually many RPM nodes are needed to cover a target area, high cost and big form factor are unacceptable.

This paper proposes a dual-mode RPM wireless system topology that allows the use of conventional monitoring hardware for both bio-data monitoring and transmission (Fig. 1(b)). A random pulse length detection (RPLD) technique is proposed and adopted to enable data transmission using modulated monitoring pulse signal, eliminating the need for extra data transmission hardware.

II. THE PROPOSED RPLD TECHNIQUE

Fig. 2 illustrates how RPLD enables a conventional UWB monitoring hardware for dual-mode operation on a time division basis. The platform consists of a UWB pulse generator, an ETS sampler, and a DSP. The switching between the two modes is done by configuring the trigger signal into one of the two different forms, \textit{Trig\_M} and \textit{Trig\_T}, which are periodic and modulated, respectively. The configuration can be done by the DSP or by a switch driven by a data pattern signal (Fig. 2).

For easier understanding of the monitoring hardware the monitoring mechanism is briefly explained first. In the monitoring mode, \textit{Trig\_M} triggers the UWB pulse generator to send repetitive pulse signals (Fig. 3). The signal reflected from the patient is sampled by the ETS sampler. The ETS sampler takes one sample from each reflected pulse at every rearm time \( T_{RE} \) with a sequential delay \( T_{SD} \). \( T_{RE} \) is significantly longer than Nyquist sampling time required in real time sampling and hence ETS is power efficient and low cost as no expensive
fast sampling analog to digital converter (ADC) is required [5]. The samples taken from $N$ signal periods are combined to reconstruct one period of the signal (See $S_{ETS}$). When $N$ samples are taken, a new sampling period starts. The DSP then processes these samples to extract bio-data. Take respiration rate monitoring as an example. While breathing, the patient’s chest heaves and it changes the distance between the RPM node and the patient. This results in a time of arriving (TOA) shift and jitter, and hence the sampled waveform is randomly distorted (see Fig. 2). Without synchronization, the ETS sampler takes samples from the input signal with a period of $T_b$, which has a period of $T_b$ and a deviation of $\Delta T_b$. The sent data is recovered by sampling $S_{BS}$ at the falling edge of the recovered clock (Fig. 4).

**III. EXPERIMENTAL VALIDATION**

Equipments from GEOZONDAS® were used to build a test system to validate the proposed concept. The UWB pulse generator was GZ1120ME-50EV that has a 4–6 GHz bandwidth. The ETS sampler was GZ6E that has a sequential delay resolution of 12.5 ps. The ETS sampler provides only a USB port for data acquisition, thus a laptop with MATLAB® was used for digital signal processing including respiration frequency evaluation in the monitoring mode and for clock/data recovery in the data transmission mode. The antennas have a gain of 4.5–10 dB in the 3.1–10.6 GHz UWB band. Fig. 5 shows the setup for respiration rate monitoring. Both the Tx and Rx antennas were facing the subject with a distance of about 1 m. The extracted respiration rate based on Fourier Transform of the measured $n_p$ is shown in Fig. 6. In this measurement the respiration rate was 0.38 Hz, corresponding to 23 breath periods per minute. For data transmission, a transmitting node and a receiving node are needed (Fig. 2). In this validation, the UWB pulse generator and Tx antenna used in the monitoring experiments were used as the transmitter, and the ETS sampler,
equivalent time sampling. The proposed hardware platform to enable data transmission using UWB pulse signals and (random pulse length detection) technique has been proposed for applications where the antenna size is critical, other small bow-tie phased-array antennas and the size are relatively big. It should be noted that the antennas used in this study were using energy harvesting for large scale healthcare networks. Development of long lifetime or self-sustaining RPM nodes at a data rate of requires the transmitter to send many pulses (here is averagely requires the transmitter to send many pulses (here is averagely reducing the sampling rate, while the power consumption of needs to obtain the samples from the sampler (fixed sampling speed (sent data had been recovered correctly.

In this test, the data rate was limited by the ETS sampler’s fixed sampling speed (500 kHz) and the time that MATLAB® needs to obtain the samples from the sampler (>0.8 s). This can be improved by using higher speed sampler and DSP devices to sample and process the data. In addition, using RPLD requires the transmitter to send many pulses (here is averagely 0.25 M pulses per second) so that the receiver can detect the signal with a low sampling rate. This is acceptable since the power consumption in the ETS is significantly reduced by reducing the sampling rate, while the power consumption of the UWB pulse generator can be easily kept below a few mW at a data rate of 100 Mbps [8]. This is very promising for development of long lifetime or self-sustaining RPM nodes using energy harvesting for large scale healthcare networks. It should be noted that the antennas used in this study were bow-tie phased-array antennas and the size are relatively big. For applications where the antenna size is critical, other small size UWB antennas can be used.

IV. CONCLUSION

A dual-mode ultra-wideband platform based on an RPLD (random pulse length detection) technique has been proposed to enable data transmission using UWB pulse signals and equivalent time sampling. The proposed hardware platform eliminates the need for extra communication hardware in existing RPM systems, which reduces both cost and size of RPM nodes. Based on the proposed concept, a test system capable of both respiration rate monitoring and data transmission has been built and satisfactory results were obtained.

REFERENCES