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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

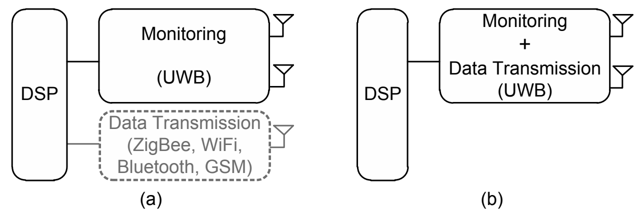

Fig. 1. Simplified block diagram of a) existing remote patient monitoring systems and b) the proposed system using only one hardware platform.

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, $Trig\_M$ and $Trig\_T$, 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, $Trig\_M$ 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

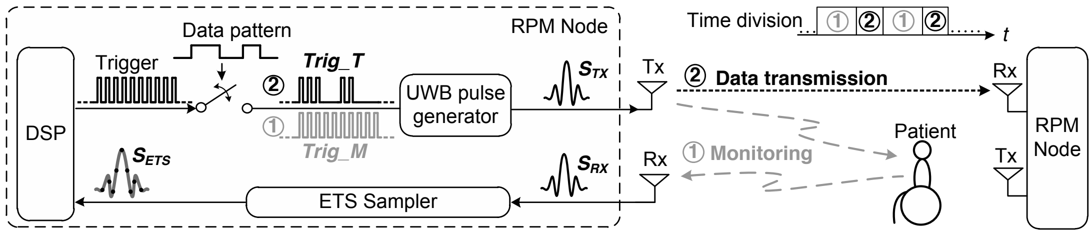

Fig. 2. Block diagram of the proposed dual-mode RPM platform.

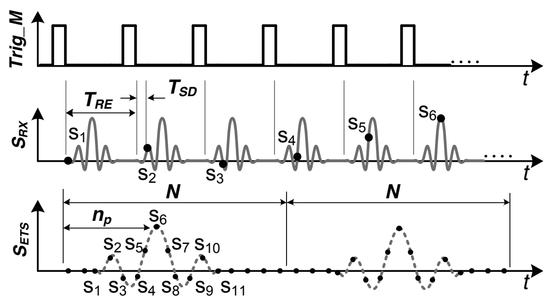

Fig. 3. Signal triggering and sampling using ETS.

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) index (n_p) varying with the respiration rate, which can be extracted from the samples by frequency estimation methods.

ETS is a low cost solution for high frequency signal sampling. However, it is challenging to use ETS for data transmission: ETS requires synchronization of the input signal for stable and fine resolution sampling. This is not an issue for the monitoring mode as both the pulse generator and ETS sampler are in the same RPM node and sharing the same clock. But for the data transmission, the transmitter and the receiver are in two different RPM nodes and unsynchronized (Fig. 2). Without synchronization, the ETS sampler takes samples randomly due to the random sampling clock phase shift and jitter, and hence the sampled waveform is randomly distorted (see S_{ETS} in Fig. 4). Therefore, conventional UWB modulation schemes requiring accurate waveform recovery are infeasible. Conventional on and off keying (OOK) requires fast real time data acquisition and hence is also infeasible. In the proposed RPLD approach, the pulse generator is triggered by $Trig\_T$, which has two different lengths of trigger pulses in one-bit time T_b (Fig. 4). For sending bit "0" a relatively short pulse burst length ($T_0 < 0.5T_b$) is used, while the pulse burst length ($T_1 > 0.5T_b$) for sending bit "1" is longer. In this way, both the data information (length of the pulse burst) and the clock (rising edge of the pulse burst) are merged in one signal. The ETS sampler in the receiving RPM node acquires

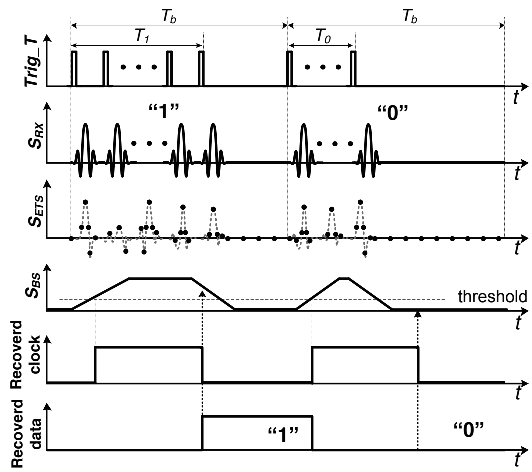

Fig. 4. Signal waveforms in the data transmission mode using RPLD.

randomly distorted pulses, but the lengths of the pulse bursts are kept. Further applying energy detection algorithms to the samples [8], E_{ETS} is converted to a baseband signal S_{BS}. The clock that has a period of T_b is recovered then by detecting the rising edges of S_{BS}. 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 $4.5-10$ dBi 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,

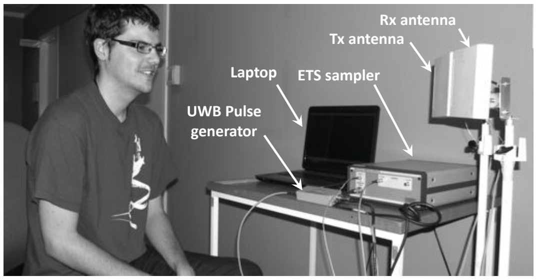

Fig. 5. The experiments setup for respiration rate monitoring.

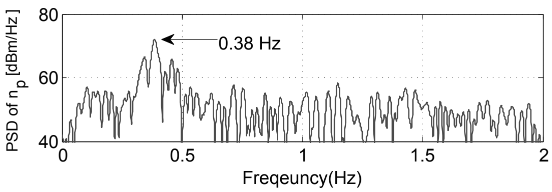

Fig. 6. Evaluated respiration frequency based on the measured signal.

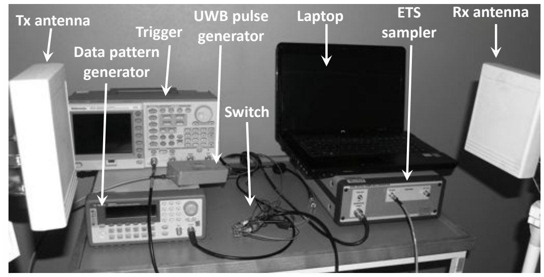

Fig. 7. Experimental setup for data transmission.

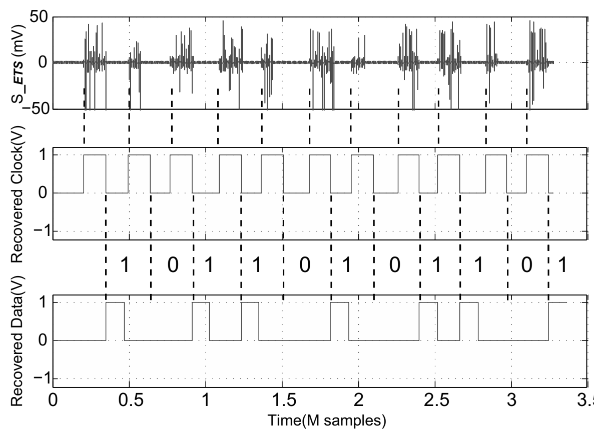

Fig. 8. Measured pulse signal samples, recovered clock and data.

Rx antenna and laptop were used as the receiver. A Tektronix® arbitrary/function generator AFG 3252 was used as the trigger source and an Agilent® arbitrary waveform generator 33250A was used as the data pattern source to modulate the trigger signal using a Dow-Key® 401-420832A microwave switch. The distance between the Tx antenna and Rx antenna was about 1 m. The measured results are shown in Fig. 8. In the test, the trigger frequency was 500 kHz, and T_b was 3 s. T_1 and T_0 were 2 s and 1 s, respectively. The sampled signal at the receiver side (S_{ETS}) is shown in the top figure in Fig. 8, while the sent data was "10110101101". It is clear that the 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

[1] E. Bayliss, J. Steiner, D. Fernald, L. Crane, and D. Main, "Descriptions of Barriers to Self-Care by Persons with Comorbid Chronic Diseases," *The Annals of Family Medicine*, vol. 1, no. 1, pp. 15–21, May 2003.

[2] C. Bachmann, M. Ashouei, V. Pop, M. Vidojkovic, H. Groot, and B. Gyselinckx, "Low-Power Wireless Sensor Nodes for Ubiquitous Long-Term Biomedical Signal Monitoring," *IEEE Commun. Mag.*, vol. 50, no. 1, pp. 20–27, Jan. 2012.

[3] H. Hjortland and T. Lande, "CTBV Integrated Impulse Radio Design for Biomedical Applications," *IEEE Trans. Biomed. Circuits Syst.*, vol. 3, no. 2, pp. 79–88, Apr. 2009.

[4] Y. Wang, A. Fathy, and M. Mahfouz, "UWB Microwave Imaging System with A Novel Calibration Approach for Breast Cancer Detection," in *2011 IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS)*, Jan. 2011, pp. 63–66.

[5] Y.-C. Jenq, "Digital Spectra of Nonuniformly Sampled Signals: Fundamentals and High-Speed Waveform Digitizers," *IEEE Trans. Instrum. Meas.*, vol. 37, no. 2, pp. 245–251, Jun. 1988.

[6] Sensiotec. (2012) The Virtual Medical Assistant. [Online]. Available: http://sensiotec.com/technology-platform

[7] IEEE, "IEEE Standard for Information Technology- Information Exchange Between Systems- Local and Metropolitan Area Networks Specific Requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)," *IEEE Std. 802.15.4*, pp. 1–670, 2003.

[8] L. Xia, K. Shao, H. Chen, Y. Huang, Z. Hong, and P. Chiang, "0.15-nJ/b 35-GHz IR-UWB System With Spectrum Tunable Transmitter and Merged-Correlator Noncoherent Receiver," *IEEE Trans. Microw. Theory Tech.*, vol. 59, no. 4, pp. 1147–1156, Apr. 2011.