Piezoelectric based Biosignal Transmission using Xbee

Mohammed Jalil, Mohamed Al Hamadi, Abdulla Saleh, Omar Al Zaabi, Soha Ahmed, Walid Shakhatreh and Mahmoud Al Ahmad
Electrical Engineering Department
United Arab Emirate University
AlAin, UAE
m.alahmad@uaeu.ac.ae

***Abstract*—This paper is showcasing the development of an innovative healthcare solution that will allow patient to be monitored remotely. The system utilizes a piezoelectric sheet sensor and XBee wireless communication protocol to collect and transmit heart beat pressure signal from human subject neck to a receiving node. Then, using signal processing techniques a set of important vital parameters such as heart rate, and blood pressure are extracted from the received signal. Those extracted parameters are needed to assess the human subject health continuously and timely. The architecture of our developed system, which enables wireless transmission of the raw acquired physiological signal, has three advantages over existing systems. First, it increases user's mobility because we employed XBee wireless communication protocol for signal transmission. Second, it increases the system usability since the user has to carry a single unit for signal acquisition while preprocessing is performed remotely. Third, it gives us more flexibility in acquiring various vital parameters with great accuracy since processing is done remotely with powerful computers.**

Keywords*—Piezoelectric; XBee; medical sensors; vital signs; remote health monitoring

I. Introduction

According to the World health organization (WHO) 2015 reports, the most common health complaint is cardiovascular disease for both Emiratis and expatriates [1]. Furthermore, the Health Authority Abu Dhabi (HAAD) latest statistics disclosed that the leading cause for expat women death is cancer, followed by cardiovascular disease while Emirati women leading cause for death is heart disease [1]. Thus, UAE health authorities are working hard to keep up with the growing number of population, the increasing burden of chronic diseases, the rising number of aging people and the expanding medical tourism in the region [1]. Reports showed that in 2013 alone, UAE healthcare expenses reached $16.8 billion [2]. A study performed by the Emirates Cardiac Society surveyed more than 4,000 people reported important findings. They found that nearly nine out of ten people in UAE are at risk of cardiovascular disease and one out of three of them are ignorant of this matter [1]. Cardiovascular disease are the leading cause for death worldwide — taking 17.3 million lives yearly — and UAE is not excluded [1]. Treatment for cardiovascular disease in UAE currently account for 36% of the total healthcare expenditure [3]. The above mentioned problems have been fueling the rapid and increased interest in wearable mobile sensors and wireless sensing networks for healthcare applications. It is expected that those two technologies could reduce healthcare expenditure and disease prevalence by facilitating continues health monitoring and early disease detection. In this paper, the design and development of wireless health monitoring system is presented. The system utilizes piezoelectric sheet sensor to acquire physiological signal and employs XBee wireless communication protocols to send the acquired raw signal to a receiving node for processing and vital parameter extraction.

The remainder of this paper is organized as follows: Section II gives an overview of existing wireless health monitoring systems; Section III describes the experimental setup and various wireless communication protocols considered; and Section IV describes the data processing, the parameters extraction algorithms and the results. We then present our conclusion in Sections V.

II. State of Art

The employment of wearable, cheap, unobtrusive, noninvasive, and wireless sensors in healthcare applications has attracted research and industries attention equally nowadays. The result of this devoted attention was huge number of applications and various technologies and products integration. In this section, a summary of the developments made in wearable, wireless, and medical monitoring systems will be presented. Wireless Health Monitoring System (WHMS) usually consists of three main parts: Physiological Signal Acquisition Module (PSAM), Signal Processing Module (SPM), and Remote Monitoring Module (RMM). Each and every part of these modules consists of submodules. Fig. 1 illustrates the main and submodules for wireless health monitoring systems (WHMS). The first part of any WHMS is usually the physiological signal acquisition module (PSAM). This module consists of two submodules which are biosensors and wire or wireless transmission unit. The second module is the signal processing module (SPM). This module compromises three submodules: signal wire/less receiving unit; memory, central processing unit (CPU) and wire/less transmission unit. The third module is the remote monitoring module (RMM). This module consists of wire/less receiving unit, database and a reports generating mechanism.

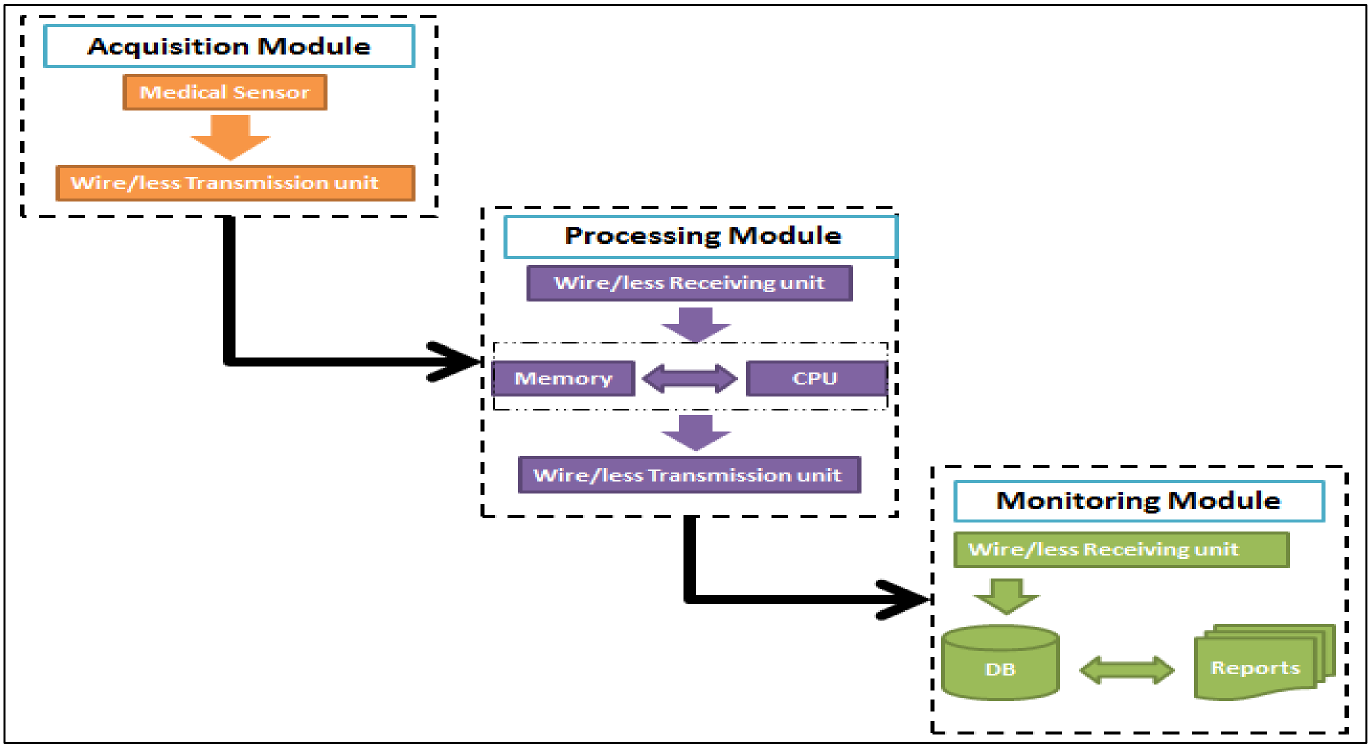

Fig. 1. Wireless Health Monitoring System (WHMS) general architecture.

In some systems, the data acquisition module sends the acquired data to the signal processing module (SPM) using wires like AMON System [4]. AMON combines the data acquisition module and the signal processing module in one component called wrist monitoring device. AMON uses wires to connect the two modules which is usually the case when the data acquisition module and the signal processing module are integrated in one component. Then, the raw signals and the extracted medical values can be sent to the remote monitoring module wirelessly using GSM technology. Another system that connect the PSAM and SPM via wires is the one developed by Sung-Nien and Jen-Chieh [5]. Their system employs two sensors to monitor patient health namely 1-lead ECG and respiration sensor. The acquired signals are sent to the SPM using wires and after processing the signal is sent to a local monitoring unit (placed at the patient room) via Bluetooth technology and from there to a remote monitoring unit via Wi-Fi network. Furthermore, Yuan-Hsiang et al developed a WHMS for patient monitoring during transportation [6]. The system connects PSAM and SPM via RS232 wire connection. The system can be used by ambulance staff to monitor the patient and to inform remote medical staff (in the hospital) about the patient current medical status which will ensure that correct medical measurement is taken timely. The advantage of this system is that it utilizes existing PDA devices technology to process the medical sensors data and to transmit the processed data wirelessly. Smart Vest system is a unique WHMS [7]. The system takes advantage of a washable shirt, which exploits an array of biosensors. The PSAM in Smart Vest utilizes ECG electrodes, temperature (Temp) sensor and photoplethysmography (PPG) sensor to acquire physiological signals. The SPM in Smart Vest is separated into two parts: the first part is connected to the PSAM via wires. This part performs several tasks for the raw physiological signal acquired such as filtering, amplification and digitization. The second part of the SPM is integrated with the RMM. The second part of SPM is responsible for deriving blood pressure (BP) by analyzing ECG and PPG waveform and extracting heart rate (HR) from ECG waveform. What is unique about this system is that it connects the two SPM parts wirelessly. A summary of the reviewed WHMS is presented in Table 1. From the table, it can be seen that several vital signs has been monitored using those systems such as: blood pressure (BP), heart rate (HR), arterial oxygen saturation (SpO2), temperature (Temp), respiration rate (RR) , Galvanic Skin Response (GSR)… etc. In addition, several wireless communication protocols were utilized such as the Global System for Mobile Communications (GSM), Bluetooth, WiFi, Wireless Local Area Network (WLAN), and Radio Frequency (RF).

TABLE I. SUMMARY OF WIRELESS HEALTH MONITORING SYSTEMS (WHMS)

The System	Sensors	Vital signs	Wireless transmission technology	PSAM and SPM
AMON System [4]	One-lead ECG, pulse oximeter, Blood Pressure, Acceleration Sensor, Temperature Sensor	BP, SpO2, HR, Temp (Optional: Glucose level and respiratory flow)	GSM	Combined in one unit and connected via wires
Wireless patient monitoring system [5]	one-lead ECG, respiration sensor	HR, RR	Bluetooth, WiFi network	Separate but connected via wires
Patient Transport system [6]	three-lead ECG, dual-wavelength photoplethysmographic (PPG) sensor	HR, SpO2	WLAN	Separate but connected via wires (RS232)
Smart Vest [7]	ECG electrodes, Photoplethysmogram (PPG) sensor, Thermistor	BP, Temp, HR, GSR	RF (Radio Frequency)	Separate connected via wires and wirelessly

Table 2 shows various research studies that were performed to measure heart rate or blood pressure or both. It summarizes the various methods used to measure important vital signs. As can be seen from the table, most research studies performed employed non-invasive methods because they are more convenient for use and require less drastic measures. Only one research study used invasive BP measurement [8]. Their argument is that this invasive method is very accurate and convenient for patients who require continues monitoring and have critical condition. Furthermore, most of the studies focus on fabricating new transducers to measure vital signs [9]-[11]. Only three studies considered the effect of sending vital signs parameters wirelessly [12]-[15]. Nevertheless, those three studies performed the processing of the acquired vital sign signal in the source point and sent the interrupted vital sign data wirelessly. In other words, the signal processing was performed at the source location. From one hand, this made the acquired signal less susceptible to motion artifacts and noise but on the other hand, signal analysis was performed using modest processor with limited processing power and small memory.

Compared to the above-mentioned systems, our system has several unique features. As far as we know we are the only WHMS which connects the PSAM and SPM wirelessly via XBee. In other words, unlike the existing systems patients don't have to carry SPM around since the signal processing is done remotely. Our PSAM acquires the raw physiological signals and sends it using XBee wireless communication technology to the SPM. There are three advantages of this design approach namely: mobility, usability and flexibility.

Our system frees the patient from wearing or carrying around the SPM along with PSAM which is the case with the existing WHMS. As a result, the patient mobility will increase because the PSAM usually is light and the acquired signal is sent wirelessly. Second, sending the raw signals wirelessly to a remote SPM will give us more flexibility in signal processing. In other words, the raw signal can be analyzed with powerful processing units which will ensure the extraction of various vital sign information with great accuracy. While in the above-mentioned systems, signal preprocessing was performed via a small-sized processing unit with modest memory and processing power. The processing unit had to be small since it is connected to the PSAM via wires otherwise the user will has to carry a big medical device. On the other hand, our system design architecture will increase its usability, since the patient has to carry a single unit which is the PSAM and hence he/she will be motivated to wear it continuously.

III. EXPERIMENTAL SETUP

In this section, the experiment design and setup will be described thoroughly. Fig. 2 illustrates the experimental setup for the proposed remote health monitoring system. Fig. 2(a) depicts a human subject placing piezoelectric sheet sensor on top of his carotid artery to sense the pressure pulse in this major artery. In Fig. 2 (b) the transmitter module, the receiver module and a simple RC-filter are illustrated. The two modules are responsible of making a wireless connection using XBee protocol between the PSAM and the SPM.

The signal at the receiver node (XBee module) are filtered by a simple RC-filter to extract the analogue signals from the received Pulse Width Modulated (PWM) signal and with some digital signal processing, a set of vital parameters are extracted. The transmission module and the receiver module we used were XBee pro S1. Also, in the lab during the experiment we utilized the oscilloscope to display the acquired raw signal in the receiving point. In this setup, the stress signal sensed by the piezoelectric sheet was sampled at a sampling rate of 100Hz and converted into binary data and then assembled in frames and transmitted to the receiver module where they are filtered, processed and displayed on the oscilloscope. For our setup, we employed XBee communication protocol for many reasons. First, XBee protocol is a wireless communication standard for low data transmission rate and long distance. Thus, it is suitable for sensors and devices that do not require high data rate but needs long battery life, minimal user intervention and long distance. Second, XBee is convenient for different kind of applications such as medical, home/office automation and military applications. In addition, XBee networks may be implemented with several different and flexible network structures [18]-[21].

TABLE II. SUMMARY OF WIRELESS HEALTH MONITORING SYSTEMS (WHMS)

Paper	Procedure		Focus	Vital sign	Transducer		Transmission	Location
	Invasive	*Non-invasive*			*Type*	*Material*		
[9]		x	fabrication	BP	piezoelectric		NA	wrist
[10]		x	fabrication	BP	piezoelectric	EMF plastic	NA	upper arm
[11]		x	fabrication	BP	piezoelectric	ceramic bimorph beam	NA	wrist
[15]		x	fabrication	HR, RR	piezoelectric	aluminum nitride	NA	in bed
[12]		x	fabrication and Transmission	BP	piezoresistive		transmitting module employing a surface acoustic wave	upper arm
[8]	x		fabrication	SPO, BP	piezoelectric	cellular polypropylene	NA	directly at an arterial vessel
[16]		x	fabrication	HR	piezoelectric	PVDF polymer	NA	wrist
[17]		x	fabrication	Arterial Pulse Analyzers	piezoelectric	ceramic plate sensors	wired to a tablet	wrist
[18]		x	fabrication	BP	piezoelectric	zirconate titanate	NA	
[13]		x	Transmission	HR and BP	Commercial		XBee	upper arm
[14]		x	Transmission	BP	photoelectric plesthysmography (PPG)		XBee	finger tip
[19]		x	Exploration	HR and BP	piezoelectric	sheet	NA	chest
[20]		x	fabrication	HR	piezoelectric	sheet	RF	ear

Table 3 depicts four wireless communication standards that are frequently used in WHMS. As can been seen in the table, XBee has low data rate in comparison to the other three wireless communication standards but it has a very long battery life, considerably long range and huge network structure can be built using XBee because the maximum number of nods that can be accommodated in one network equal 65000. Thus, XBee is one of the most used wireless communication standards in ehealth applications [22]. For all the above-mentioned reasons, we chose XBee wireless communication for our WHMS.

IV. RESULTS AND DISCUSSION

There are always tradeoffs between usability and reliability. The system architecture we exploited although improved patient mobility and increased system usability but it introduced noise to the acquired signal. The employment of XBee wireless communication protocol introduced a DC offset to the acquired signal.

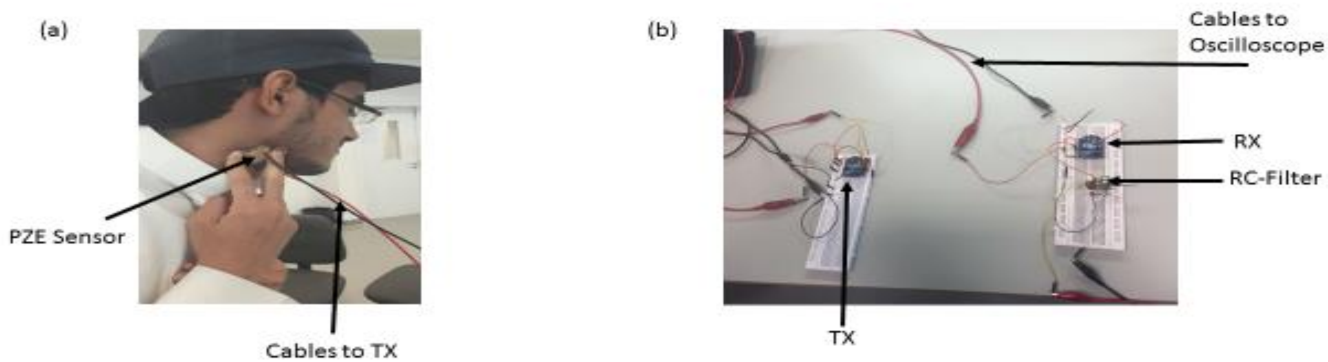

Fig. 2. Experiment setup (a) Piezoelectric sensor anchoring at the neck; (b) TX and RX XBee Modules.

TABLE III. WIRELESS COMMUNICATION STANDARDS

	IEEE Standard	Range (meter)	Maximum data rate (kbps)	Battery life (days)	Maximum Number of nods
XBee	802.15.4	1-75+	20-250	100-1000+	65000
Bluetooth	802.15.1	1-10+	720	1-7	8
Wi-Fi	802.11b	1-100	11000+	1-5	32
GPRS/GSM	1XRTT/CDMA	1000+	64-128	1-7	1

At the SPM, a number of steps were taken to preprocess the acquired signal. First, a moving average filter with cutoff frequency of 20Hz was used to remove the white noise. Second, the signal was analyzed to detect the type of the DC offset that was introduced because of transmission using XBee wireless communication protocol. The detected DC offset trend was found to be nonlinear. Third, a low order polynomial fitting technique was used to remove the nonlinear trend from the signal.

After preprocessing, the data was analyzed and important parameters were extracted. The parameters extracted were the maximum and minimum absolute values and the time interval between peaks.

To calculate real-time heartbeat rate, we needed to find the average period of a measured cycle which was found to equal 0.824 second. This means using the resulting piezoelectric voltage signal the estimated heart rate per minute equal 72 beat per minute. To calculate the blood pressure and heart rate values we used the method explained in Saadat et al. work [19]. The method state that the piezoelectric sensor output voltage is directly proportional to the exerted pressure on the piezoelectric material. To calculate the pressure one must know the equivalent turn ratio for the piezoelectric sensor [23]. The equivalent turn ratio for the piezoelectric material can easily be calculated from the information listed in the sensor data sheet [24]. Fig. 3 shows the resulting pressure signal extracted from the piezoelectric voltage signal.

The extraction of blood pressure using piezoelectric sensor will facilitate the continuous monitoring of heart rate and blood pressure.

V. Conclusion

This study is an attempt to develop an innovative healthcare solution that will allow patient to be monitored remotely. In particular two vital signs will be monitored namely heart rate and blood pressure. To this end, a piezoelectric sensor film was used to measure the pressure variance resulting from a heartbeat at the neck. This location has two advantages: good physiological signal to noise ratio (SNR) because carotid arteries are the major blood vessels that deliver blood to the brain, they are big and thus the pressure pulse waveform obtained from them will be very clear. Furthermore, a sensor placed in the neck is less prone to motion artifact.

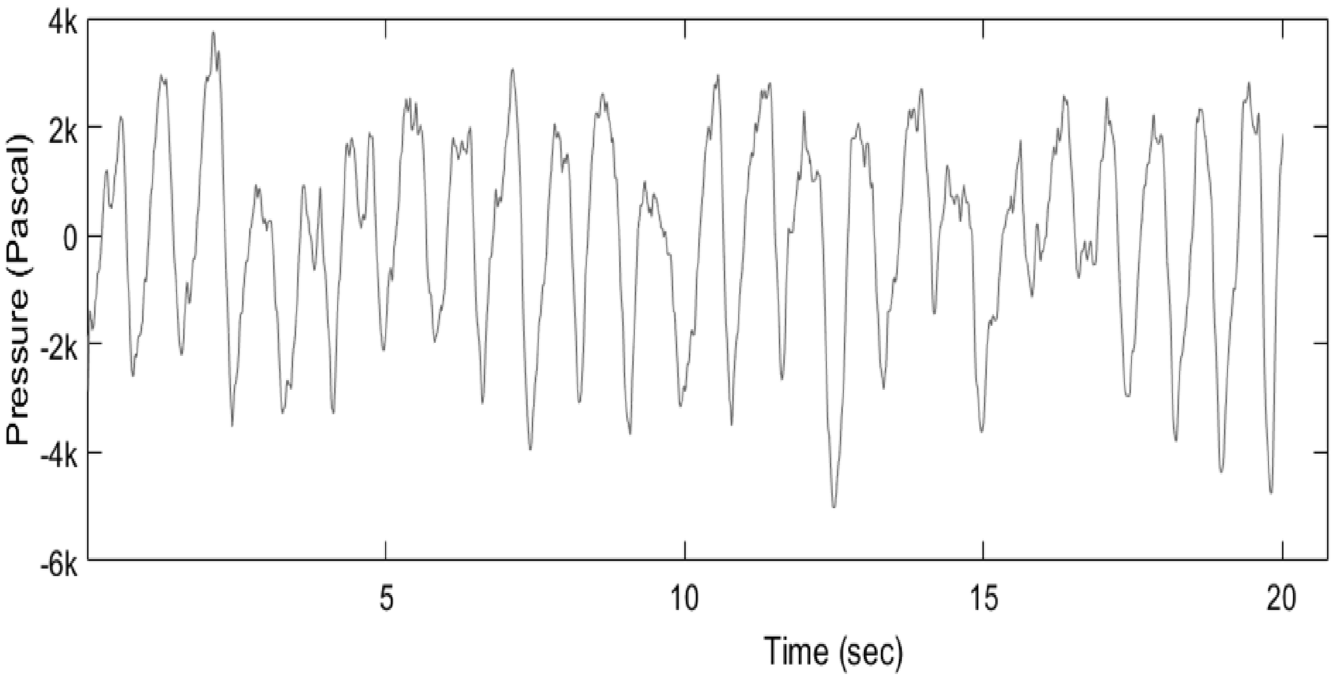

Fig. 3. Pressure signal extracted from the piezoelectric sensor voltage signal.

Acknowledgment

The authors wish to acknowledge the support received from Research Office at the UAE University under SURE 2016 projects grant.

References

[1] J. Bell, “The state of the UAE’s health: 2016 | GulfNews.com,” 2016. [Online]. Available: http://gulfnews.com/gn-focus/special-reports/health/the-state-of-the-uae-s-health-2016-1.1658937.

[2] “The U.A.E. Healthcare Sector.”

[3] “Prospects ahead for UAE’s healthcare sector – Emirates Business.” [Online]. Available: http://emirates-business.ae/prospects-ahead-for-uaes-healthcare-sector/.

[4] U. Anliker, J. A. Ward, P. Lukowicz, G. Tröster, F. Dolveck, M. Baer, F. Keita, E. B. Schenker, F. Catarsi, L. Coluccini, A. Belardinelli, D. Shklarski, M. Alon, E. Hirt, R. Schmid, and M. Vuskovic, “AMON: A wearable multiparameter medical monitoring and alert system,” IEEE Trans. Inf. Technol. Biomed., vol. 8, no. 4, pp. 415–427, 2004.

[5] J.-C. Yu,Sung-Nien and Cheng, “A Wireless Physiological Signal Monitoring System with Integrated Bluetooth and WiFi Technologies,” in Engineering in Medicine and Biology 27th Annual Conference, 2005, pp. 2203–2206.

[6] Y. H. Lin, I. C. Jan, P. C. I. Ko, Y. Y. Chen, J. M. Wong, and G. J. Jan, “A wireless PDA-based physiological monitoring system for patient transport,” IEEE Trans. Inf. Technol. Biomed., vol. 8, no. 4, pp. 439–447, 2004.

[7] P. S. Pandian, K. Mohanavelu, K. P. Safeer, T. M. Kotresh, D. T. Shakunthala, P. Gopal, and V. C. Padaki, “Smart Vest: Wearable multi-parameter remote physiological monitoring system,” Med. Eng. Phys., vol. 30, no. 4, pp. 466–477, May 2008.

[8] P. Bingger, J. Fiala, A. Seifert, N. Weber, A. Moser, F. Goldschmidtboeing, K. Foerster, C. Heilmann, F. Beyersdorf, P. Woias, and H. Zappe, “IMPLANTABLE MULTI SENSOR SYSTEM FOR IN VIVO MONITORING OF CARDIOVASCULAR PARAMETERS Department of Microsystems Engineering – IMTEK , Freiburg , GERMANY Department of Cardiovascular Surgery , University Hospital Freiburg , GERMANY ABSTRACT | I R = = f (ps,” no. Fig. 1, pp. 1469–1472, 2009.

[9] J. Im and C. Lessard, “A study for the development of a noninvasive continuous blood pressure measuring system by analyzing radial artery pulse from a wrist,” … Med. Biol. Soc. 1995., …, pp. 1033–1034, 1995.

[10] J. Kerola, V. Kontra, and R. Sepponen, “Non-invasive blood pressure data acquisition employing pulse transit time detection,” Proc. 18th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc., vol. 3, pp. 1308–1309, 1996.

[11] S. K. Kahng, “Blood-Pressure Transducer,” vol. I, no. 2, pp. 54–56, 1972.

[12] A. Giorgio, R. Diana, a. Convertino, R. Marani, and a. G. Perri, “Design of a wireless digital measurement system for the blood arterial pressure control,” 2007 Asia-Pacific Microw. Conf., pp. 375–378, 2007.

[13] M. C. Huang, J. C. Huang, J. C. You, and G. J. Jong, “The wireless sensor network for home-care system using XBee,” Proc. - 3rd Int. Conf. Intell. Inf. Hiding Multimed. Signal Process. IIHMSP 2007., vol. 1, pp. 643–646,

[14] B. A. Zneid, M. Al-zidi, and T. Al-kharazi, “Non-invasive Blood Pressure Remote Monitoring Instrument Based Microcontroller,” vol. 4, no. 2, pp. 252–257, 2014.

[15] N. Bu, N. Ueno, and O. Fukuda, “Monitoring of respiration and heartbeat during sleep using a flexible piezoelectric film sensor and empirical mode decomposition,” Annu. Int. Conf. IEEE Eng. Med. Biol. - Proc., pp. 1362–1366, 2007.

[16] D. Buxi, J. Penders, and C. van Hoof, “Early results on wrist based heart rate monitoring using mechanical transducers.,” Annu. Int. Conf. IEEE Eng. Med. Biol. Soc., vol. 2010, pp. 4407–10, 2010.

[17] P. Gatkine, S. Gatkine, S. Poojary, S. Chaudhary, and S. Noronha, “Development of Piezo-electric Sensor Based Non- invasive Low Cost Arterial Pulse Analyzer,” BMEiCON, pp. 2–5, 2013.

[18] R. Liang and Q. M. Wang, “Pulse pressure sensor based on flexible PZT thick-film composite device,” IEEE Int. Ultrason. Symp. IUS, pp. 1559–1562, 2014.

[19] I. Saadat, N. Al Taradeh, M. Al Ahmad, and N. Bastaki, “Non-invasive piezoelectric detection of heartbeat rate and blood pressure,” Electron. Lett., vol. 51, no. 6, pp. 452–454, 2015.

[20] J. H. Park, D. G. Jang, J. W. Park, and S. K. Youm, “Wearable sensing of in-ear pressure for heart rate monitoring with a piezoelectric sensor,” Sensors (Switzerland), vol. 15, no. 9, pp. 23402–23417, 2015.

[21] “Network Specifications | The XBee Alliance.” [Online]. Available: http://www.XBee.org/XBee-for-developers/network-specifications/.

[22] A. Pantelopoulos and N. G. Bourbakis, “A Survey onWearable Sensor-Based Systems for Health Monitoring and Prognosis,” IEEE Trans. Syst. Man, Cybern. Appl. Rev., vol. 40, no. 1, pp. 1–12, 2010.

[23] S. Roundy and P. K. Wright, “A piezoelectric vibration based generator for wireless electronics,” Smart Mater. Struct., vol. 13, no. 5, pp. 1131–1142, 2004.

[24] Johnson Matthey, “Datasheet Piezoceramic Masses.” [Online]. Available: http://www.piezoproducts.com/fileadmin/user_upload/pdf/jm_piezoproducts_data_sheet_piezoceramic_masses_en_15_01_2015.pdf. [Accessed: 26-Sep-2016].