SURVEY ON WIRELESS BODY AREA SENSOR NETWORKS FOR HEALTHCARE APPLICATIONS: SIGNAL PROCESSING, DATA ANALYSIS AND FEEDBACK

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ABSTRACT. Wireless sensor networks (WSNs) technologies are considered as one of the key of the research areas in computer science and healthcare application industries. The wireless body area sensor networks (WBASNs) is a wireless network used for communication among sensor nodes operating on or inside the human body in order to monitor vital body parameters and movements. The paper surveys the state-of-the-art on WBASNs discussing the major components of research in this area including physiological sensing, data preprocessing, detection and classification of human related phenomena. We provide comparative studies of the technologies and techniques used in such systems.

Keywords: Wireless Sensor Networks (WSNs), Wireless body area sensor networks (WBASNs)

INTRODUCTION

A wireless sensor network (WSN) is an infrastructure-less network that consists of a number of self-configuring wireless devices capable of sensing vital signs for characterizing contemporary phenomena. Such vital signs include, but not limited to, environmental e.g. air quality, ambient e.g. temperature and pressure, and human e.g. heart and brain signals. The sensor data readings are transmitted over a wireless communication channel to a base-station that will be gathering raw data from all sensors, then to a running application that analyzes and makes decisions based on these readings. In this paper, a number of widely applicable capabilities, such as sensing and preprocessing, communication (sending & receiving), feature extraction and detection & classifications are briefly discussed. Healthcare industry is one of the world's largest and fastest-growing industries. Consuming over 10 percent of gross national product of most developed countries, healthcare can form an enormous part of a country's economy. Several factors lead to the increasing demand for revolutionary solutions in the healthcare industry, including i) increasing number of chronic disease (CD) patients; currently more than 860 million (WHO, 2006), ii) CD accounts for less than 50% of the population in US and Europe, but more than 80% of the healthcare spending (Intel, n.d), iii) increasing of death caused by CDs, 76% in Qatar (WHO, 2006; Hatler, Gurganious, & Chi, 2008) and iv) percentage of people over 60 is on the rise (WHO, 2006).

Due to these factors, traditional healthcare cannot provide the scalability required to cope with the growing number of elderly and CD patients as it requires a physical one-to-one relationship between the caregiver and the patient (WHO, 2006). Therefore, the need for high performance, cost-effective healthcare solutions is one of the critical strengths for any developing country seeking sustainable future advancements (Hatler, Gurganious, & Chi, 2008). Remote monitoring using WSN have recently emerged to provide real-time patient surveillance and provide CD patients with more autonomy. The conditions most commonly treated by these remote monitoring services include diabetes, cardiac arrhythmia, sleep apnea, asthma and chronic obstructive pulmonary disease (Dolan, 2010). Using wireless sensors in the field of healthcare is one of the potential areas, which is expected to save $25 billion dollars worldwide by 2012 through leveraging cost-effective solutions and applications as highlighted in the healthcare market report from OnWorld (Hatler, Gurganious, & Chi, 2008).

WBASNs enable constant monitoring of the health conditions of people with chronicle diseases. WBASN consists of multiple on-body and ambient sensor nodes, capable of sampling, processing, and communicating one or more physiological signs (e.g., heart activity, brain activity, movements, blood pressure and oxygen saturation) over an extended period. Such physiological signs are measured using different types of sensed signals such as the ElectroCardioGram (ECG), ElectroEncephaloGram (EEG), and acceleration. Also, it is used for communication among sensor nodes operating on, or inside the human body in order to monitor vital body parameters and movements as well as to enable its user with quality of life, assisted living, sports, or entertainment purposes (Huang et al., 2009). Respiration is one of the most important applications for human to survive. The primary function of the respiratory application is to supply the blood with oxygen in order for the blood to deliver oxygen to all the body. So the rate of respiration plays a key role in intensive care and neonatal. The most common way to monitor the rate of respiratory has been the visual observation of the patient, but in recent times has involved modern technologies in this area.

This paper mainly focuses on surveying the state-of-the-art on WBASNs, discussing the major components of research in this area including physiological sensing and data preprocessing, feature extraction, detection and classification of human related phenomena. We provide a comprehensive studies and comparisons for sensor technologies used, wireless radio technologies, and different detection and classification techniques required to realize the end-to-end WBASNs framework for respiratory-related disorder detection and classification. Our survey framework consists of WBASN which captures medical phenomena that contains the raw data, communication environments, data fusion and major data processing at doctor side.

The rest of this paper is structured as follows: section 2, we talk about WBASN; it illustrates sensing and preprocessing operations like compression. Section 3 briefly discusses different communications technologies that can be used to transfer data to the gateway which gathers data and passes to the doctor side. Section 4 describes data analysis and feedback which includes feature extraction, detection and classification. Paper concluded presented at section 5.

WBASN SIGNAL PROCESSING AND COMMUNICATION FRAMEWORK

WBASN Signal Processing and Communication Framework (WSPC) framework consists of three major components for real-time applications, namely: sensing and preprocessing (SAP), application-specific WBASN communication (AWC), and data analysis and feedback (DAF) to the patient. SAP contains a number of sensors for capturing a raw data related to medical phenomena, e.g. blood pressure, respiratory rate, ECG, EEG, etc. AWC utilizes application-specific wireless protocols such as ZigBee (Cao et al., 2010) or Bluetooth (Krasteva et al., 2005) to transfer data from body sensors to the gateway, less commonly, in case of high data rates without compression, WiFi protocol may be utilized for intensive data transmission (fortypoundhead.com, 2008). Analysis of raw data including, possibly, detection and classification of medical anomalies will occur at the DAF component, providing strict and accurate criteria for the physician to make recommendations that maybe sometimes fed back to the patient to provide proactive treatment. Figure 1, shows the conceptual view of the WSPC framework.

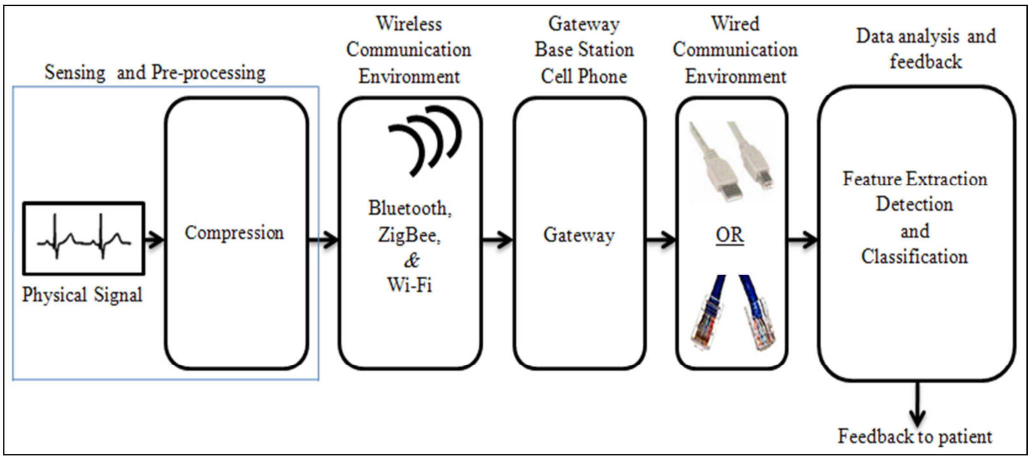

Figure 20. WSPC Conceptual Data Framework.

Sensing and Preprocessing

Sensor platform architecture typically consists of a sensing device, an operating system, and a communication and power management elements. Sensing is essential for all sensor networks, and its quality depends on largely progress in the manufacture of signal conditioning. Sensing is the detection of a physical presence of data and the transformation to a signal that can be read by an observer or instrument. To better observe a human's vital signals, a wide range of commercially sensors technologies are used to capture physical data such as, accelerometer, ECG, Electromyography (EMG), (EEG) electrodes, pulse oximetry, respiration rate, heart rate, blood pressure, blood sugar, and temperature sensors will be deployed. Table 1 illustrates some commonly sensors are employed in WBANs systems and their typical sampling rate (Huasong et al., 2009; Pantelopoulos, & Bourbakis, 2010).

Table 10. Description of Common Sensors in WBAN Systems.

Sensor Type	Signal Type	Description of measured data	Sample Rate
Accelerometer	Body Move	Measure the acceleration relative to freefall in 3D.	100 KHz
ECG/EEG/ EMG	Skin/ scalp electrodes	Measure Electrical activity of the heart, skeletal muscles, and brain activity respect.	250/250 2khz
Pulse Oximetry	Oxygen saturation	Measure the oxygenation or the amount of oxygen that is being "carried" in a patient's blood	<1 Hz
Respiration	Piezoelectric/ Piezoresistive	Number of movements indicative of inspiration and expiration per unit time (breathing rate).	150 Hz
Heart rate	Pulse oximeter/	Frequency the cardiac cycle	60 khz
Blood pressure	Arm cuff-based monitor	Measures the systolic pressure and diastolic pressure.	<1 Hz
Blood glucose	Strip-base glucose meters	Measurement of the amount of glucose (main type/source of sugar/energy) in blood.	<1 Hz

Temperature probe	Body and/or skin temperature	A measure of the body's ability to generate and get rid of heat	< 1 Hz

The wireless sensor node operating system (OS) plays a fundamental role in the overall capabilities and performance of the platform. Early research into OS for sensor networks lead to the development of TinyOS by UC Berkeley's researchers (http://www.tinyos.net/). OS is used in the processing of signals captured. A transceiver communication unit allows the transmission and reception of data to other devices that connects a wireless sensor node to a network. Details about the communication environment will be discussed in section 3. Power management provided by the operating system is to enforce an optimal way of utilizing energy. Conserving power involves accessing/controlling components on the sensor node. The components which expose power management interfaces are processor, radio and battery. The components that can be controlled to conserve power are processor and radio.

Data Compression

Data compression means that reduce the amount of physical data traffic that the sensor send in a small size to improve utilize bandwidth communication, power consumption, speed the processing, and memory space as well as save time. Data compression can be categorized into two methods: lossless method which will get the original signal exactly after compression with no lost any part of it; this method will not achieve the low data rates. In contrast, lossy method will not get the original signal accurately after compression but can obtain a higher data rates. Lossy is preferred for ECG signals. Lossy method used two major criterions: i) compression ratio that is representing the ratio between the original signal and compressed signal and ii) percentage root-mean-square difference (PRD) which defined as the error criterion in estimating of signal rebuilt for lossy compression (Hua et al., 2010). The error criterion for lossy compression techniques to estimating the distortion of signal rebuilt with respect to the original one is very important, especially for ECG signal, where a slight loss or change of information can lead to wrong diagnostics. The controlled transmission quality measure PRD for ECG compression is described in Eq. 1:

$$PRD = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{\sum_{i=1}^{N}(x_i - \mu)^2}} \times 100\% \tag{3}$$

where x_i and $\hat{x}_i$ are the i^{th} samples of original and rebuilt ECG signals of length, N and μ is the signal mean value.

Kim et al. (2010) proposed quad level vector for ECG signal processing to achieve a better performance for both compression flow and classification flow with low-computation complexity. The classification algorithm was employed for the heartbeat segmentation and the R-peak detection methods. The overall energy consumption cost is reduced by 45.3% with the proposed compression techniques.

WBASN COMMUNICATION TECHNOLOGIES

Communication technologies in WBASN are a radio-frequency wireless networking technology-based that interconnects tiny nodes through sensor or actuator capabilities in, or inside a human body. WBASN healthcare applications use different types of wireless protocols like Bluetooth (IEEE 802.15.1) and Zigbee (IEEE 802.1.5.4 Standard) as well as WiFi (based on 802.11b) with different change of each technology for low power and long range. Each BASN consists of multiple of interconnected nodes on, or within a human body, which together provide a sensing, processing, and communication efficiencies. A WBASN system has its own characteristics, as listed in Table 2:

Table 11. WBASN System Characteristic.

Characteristic	*Description*
Architecture	WBASNs have certain sensor nodes on or inside a human body; but in Wireless Personal Area Network (WPAN) includes router nodes around human body as an infrastructure for sending data away from WBASNs. Every node is a sensor node as well as a router node
Density	The number of sensor nodes deployed on/in body depends on the application; sensor nodes grouped into different groups, but routers is widely distributed
Data rate	Most WSNs are applied for remote monitoring, where events can occur irregularly. In comparison, human's physiological activities are mostly periodic, and as a result, the generated packet streams have steady data rates
Latency	For certain medical applications, latency caused by underlying communications network of a WBASN-WPAN system is critical. Power saving is definitely useful in WBASN-WPAN, but certain nodes could be always on rather than go to sleep often, and whenever necessary to change the battery
Mobility	Humans move. Even those people with particular medical treatment are likely to move sometimes. Compared to equipments wired bedside which limit patients' mobility, WBASN takes benefit of wireless connections. However, this also contributes to the complexity of the network (Cao et al., 2010)

In the following subsection a brief description on Bluetooth technology based on IEEE 802.15.1 protocol and ZigBee technology that is based on IEEE 802.1.5.4 standard protocol as a sensor communication environment. WiFi based on 802.11b protocol, in case if there is a high data rate and no compression, is discussed as well.

Bluetooth

Bluetooth is a wireless technology designed to connect different wireless devices such as telephones, notebooks, PDAs, printers, computers and so on (fortypoundhead.com, 2008). It is also low power and low processing with an overhead the protocol, which is means, the applications with Bluetooth are virtually endless. Bluetooth isn't line of sight and it provides short-range (30 feet) of 10 meters, which can be increased up to 100 meters, Bluetooth operates in the 2.4 GHz band with moderately fast transmission speeds (data rate) of 800 Kb/s (Krasteva et al., 2005). Eventually, Bluetooth as short-range wireless technology is very suitable for many medical applications. The Bluetooth Health Device Profile (Latuske, n.d) was released by the Bluetooth special interest group in June 2008, which contributed to the propagation of Bluetooth in many healthcare applications. Bluetooth and WiFi use the same frequency range, but employ different modulation techniques. The main application of Bluetooth is to replace cables in a variety of small-scale applications, whereas WiFi is used to provide wireless high speed connectivity for general local area network access (Akiba, 2009).

ZigBee

ZigBee is a standard targeting low-data-transfer-rate, low-power-consumption and low-cost wireless applications. ZigBee is used for wireless control and sensing inside a home or hospital if the application does not talking to a phone (fortypoundhead.com, 2008). Its lower physical data rate is traded for lower power consumption, and together with a simpler protocol stack, ZigBee devices enjoy relatively longer lifetime. It uses a wide range of frequencies: sixteen channels in the 2.4 GHz. It can accommodate up to 2^{64} nodes in the network (Ken, & Xiaoying, 2010). It is corresponding to Bluetooth technology in terms of infrastructure-oriented mesh networking support (Krasteva et al., 2005). Its applications are different from home and industrial automation to remote control and medical monitoring. Authors in (InterBluetooth, n.d) used Zigbee in design and implement an intelligent system for remote monitoring ECG, analysis and diagnosis. ZigBee is designed if a number of different radios were deployed in a particular area, the network will figure our automatically without user intervention taking care of retries, in addition to, the network self-recovery, acknowledgements, and routing data message. The technology found in ZigBee is intended to be simpler and expensive than Bluetooth.

Wireless Fidelity (WiFi)

WiFi refers to certain types of wireless network protocol 802.11b standards to communicate devices to each other without cords or cables. WiFi is more convenient for running full-scale networks; it enables better range from the base station, a faster connection, and better security than Bluetooth (InterBluetooth, n.d). Therefore WiFi can be also used for online communication method to notify and alerts doctor if both the doctor and patient are in one building (Zhao et al., 2001). Despite the high power consumptions of WiFi-based devices this technology will become essential for intensive health signals with high data rates and lightweight or no compression. WiFi differs from Bluetooth in that it covers greater distances and provides higher throughput, but requires more expensive hardware and may present higher power consumption (Akiba, 2009). Table 3 shows the comparison between ZigBee, Bluetooth and WiFi (Krasteva et al., 2005; Khan, Hussain, & Kwak, 2009):

Table 12. Comparison between ZigBee, Bluetooth and WiFi.

Category	ZigBee	Bluetooth	WiFi
Cost	Cheap	Cheap	Inexpensive
Ease of use	Not Easy	Easy	Acceptable
Range	20-25 feet	30 feet	100 feet
Reliability	Reliable	Not very reliable	Not very reliable
Flexibility	Good	Poor	Fair
Scalability	Excellent	Poor	Fair
Power Consumption	Low	Average	High
Interoperability	Good	Excellent	Excellent

DATA ANALYSIS TECHNIQUE AND FEEDBACK

ECG Feature Extraction plays a vital role in diagnosing most of the cardiac diseases. Recently, numerous research and techniques have been developed for analyzing the ECG signal. The proposed schemes were mostly based on fuzzy logic, artificial neural networks, support vector machines, and other signal analysis techniques. Zhao & Zhang (2005) proposed a feature extraction method using wavelet transform and support vector machines. The paper presented a new approach to the feature extraction for reliable heart rhythm recognition. The results of computer simulations provided to determine the performance of the proposed approach reached the overall accuracy of 99.68%. The features extracted will then be used to detect an adverse patient event using a function of all the features measured, without classifying the severity of this event. On the other hand, classification is used to provide grade levels for the severity of the patient's adverse event. The research work in (Noh et al., 2007) tries to find out significant heart rate variability signal through comparison between power spectrums of ECG-Derived Respiration (EDR) and R-R interval variability ratio. The result shows that classification of set of significant data is confirmed as worthy data because cross correlation results are mostly bigger than 0.7.

Data analysis will lead to useful feedback to the patient; we can summarize them in three categories; namely: Information, recommendation, and diagnostic. The information feedback (Durham et al., 2009) focuses on sending transparently, to the patient, the information output from the detection and classification phase, without any data inference that can lead to diagnosing the patient symptom. The physician will then look at the analyzed data to provide the appropriate treatment to the patient and send the appropriate feedback to do so. The recommendation feedback focuses on automatic extraction of possible treatments for the patient, and presents this to the physician merely as a recommendation. The physician will look at the recommendations and decide what treatment will be provided to the patient as a feedback (WellDoc, 2010). Lastly, diagnostic feedback is in a way a futuristic concept, where the physician can be removed from the loop for certain illnesses. In this scenario, the information outcome from the data analysis phase can be used to search in a medical treatment database using some intelligent techniques to provide the appropriate treatment for the patient without the physician intervention.

CONCLUSION

In this paper we have provided a survey of this promising field through a survey of pioneer WBASNs research projects and enabling technologies, including, sensing and preprocessing, communication environments of WBANs, data analysis and feedback that have feature extraction, detections and classifications. In particular, for life-saving applications, thorough studies and tests should be conducted before WBANs can be widely applied to humans. Compression is used to reduce the amount of physical data traffic that the sensor send in a small size to improve utilize bandwidth communication, power consumption, and memory space. Bluetooth is low power and low processing with an overhead the protocol. ZigBee is low-data-transfer-rate, low-power-consumption and low-cost wireless applications. WiFi is more convenient for running full-scale networks; a faster connection, and better security than Bluetooth. On other hand the feature extraction plays a vital role in diagnosing most of the cardiac diseases and it is a good tool for detecting certain illness.

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REFERENCES

Akiba. (2009, 2 November). Bluetooth/zigbee healthcare wars? Retrieved from http://blogs.gartner.com/nick_jones/2009/06/09/bluetooth-zigbee-healthcare-wars/

Cao, H., Liang, X., Balasingham, I., & Leung, V. C. M. (2010). Performance Analysis of ZigBee Technology for Wireless Body Area Sensor Networks. In J. Zheng, S. Mao, S. F. Midkiff & H. Zhu (Eds.), Ad Hoc Networks (Vol. 28, pp. 747-761): Springer Berlin Heidelberg.

Dolan, B. (2010). Home health monitoring was $10B market in 2010. Retrieved 1 February, 2011, from http://mobihealthnews.com/9793/home-health-monitoring-was-10b-market-in-2010/

Durham, K., Van Vliet, P. M., Badger, F., & Sackley, C. (2009). Use of information feedback and attentional focus of feedback in treating the person with a hemiplegic arm. Physiotherapy Research International, 14(2), 77-90. doi: 10.1002/pri.431

fortypoundhead.com. (2008). Bluetooth Pros and Cons. Retrieved 2 November, 2010, from http://www.fortypoundhead.com/showcontent.asp?artid=2480

Intel Corporation. Reconceiving disease management Steps toward achieving the promise. Retrieved 7 November, 2009, from http://www.intel.com/healthcare/pdf/7INCO001_WhitePaper_LO6.pdf

Hatler, M., Gurganious, D., & Chi, C. (2008). WSN for Healthcare: A Market Dynamics Report. ONWorld's Research.

Hua, K., Wang, H., Wang, W., & Wu, S. (2010). Adaptive Data Compression in Wireless Body Sensor Networks. Paper presented at the IEEE International Conference on Computational Science and Engineering (CSE-2010).

Huang, L., Ashouei, M., Yazicioglu, F., Penders, J., Vullers, R., Dolmans, G., et al. (2009). Ultra-Low Power Sensor Design for Wireless Body Area Networks: Challenges, Potential Solutions, and Applications. JDCTA: International Journal of Digital Content Technology and its Applications, 3(3), 136-148.

Huasong, C., Leung, V., Chow, C., & Chan, H. (2009). Enabling technologies for wireless body area networks: A survey and outlook. IEEE Communications Magazine, 47(12), 84-93.

InterBluetooth. Bluetooth vs WiFi. Retrieved 2 November, 2010, from http://www.interbluetooth.co.uk/bluetooth-vs-wifi.html

Ken, C., & Xiaoying, L. (2010). A Zigbee Based Mesh Network for ECG Monitoring System. Paper presented at the 4th International Conference on Bioinformatics and Biomedical Engineering (iCBBE), Chengdu, China.

Khan, P., Hussain, M. A., & Kwak, K. S. (Sept. 2009). Medical Applications of Wireless Body Area Networks. International Journal of Digital Content Technology and its Applications, 3(3), 185-193.

Kim, H., Yazicioglu, R. F., Merken, P., Hoof, C. V., & Yoo, H.-J. (2010). ECG signal compression and classification algorithm with quad level vector for ECG holter system. IEEE Transactions on Information Technology in Biomedicine, 14(1), 93-100. doi: 10.1109/titb.2009.2031638

Krasteva, R., Boneva, A., Georchev, V., & Stoianov, I. (2005). Application of Wireless Protocols Bluetooth and ZigBee in Telemetry System Development. Problems of Engineering Cybernetics and Robotics, 55, 30-38.

Latuske, R. Bluetooth Health Device Profile (HDP). Munich: ARS Software GmbH.

Noh, Y., Park, S., Hong, K., Yoon, Y., & Yoon, H. (2007). A Study of Significant data Classification between EDR extracted and frequency analysis of Heart Rate Variability from ECG using Conductive textile. In R. Magjarevic & J. H. Nagel (Eds.), World Congress on Medical Physics and Biomedical Engineering 2006 (Vol. 14, pp. 4100-4103-4103): Springer Berlin Heidelberg.

Pantelopoulos, A., & Bourbakis, N. G. (2010). A survey on wearable sensor-based systems for health monitoring and prognosis. IEEE Transactions on Systems, Man and Cybernetics - Part C, 40(1), 1-12. doi: 10.1109/tsmcc.2009.2032660

Stankovic, J. A., Cao, Q., Doan, T., Fang, L., He, Z., Kiran, R., et al. (2005). Wireless sensor networks for in-home healthcare: potential and challenges. Paper presented at the High Confidence Medical Device Software and Systems (HCMDSS) Workshop, Philadelphia, PA.

WellDoc. (2010). WellDoc. Retrieved 7 February, 2011, from http://www.welldocinc.com

WHO. (2006). Country Cooperation Strategy for WHO and Qatar 2005–2009. Retrieved 1 November, 2010

Zhao, Y., Yagi, Y., Juzoji, H., & Nakajima, I. (2001). A study of wireless IP for telemedicine. Paper presented at the Fourth International Symposium on Multimediam Communications (WPWC'01), Alborg, Denmark.

Zhao, Q., & Zhang, L. (2005, 13-15 Oct. 2005). ECG Feature Extraction and Classification Using Wavelet Transform and Support Vector Machines. Paper presented at the Neural Networks and Brain, 2005. ICNN&B '05. International Conference on.