Wireless Health Monitoring System
The Vital Transmitter

Shaima T. Abdelmageed, Reino Virrankoski, Prof. Mohamed El-Musrati.

Communication and Systems (ComSys) Engineering Group
Faculty of Technology, University of Vaasa
Vaasa, Finland
eng.shaima.eng@hotmail.com

***Abstract*— This document demonstrates a few modifications to the wireless health monitoring systems currently available, to target senior people and children around the world. It explains the structure of the conducted system while discussing the required details to achieve continuous, instantaneous monitoring, and a definite reliable system. The system currently exist as my Master thesis project and it forms the foundation for plenty of future work as will be indicated at the end of this document.**

***Keywords*— BLE, wireless monitoring, SMS, ECG-sensor, correlation, Emergency room ER.**

I. INTRODUCTION

The idea is about monitoring patients' vital signs (blood sugar, blood pressure, heart pulses, body temperature) wirelessly and maintain a personal record (user's mobile) and official medical record (in the hospital) of these vital signs; by establishing a WPAN (Wireless Personal Area Network) based on low energy Bluetooth (BLE) to transfer the vital sign from the measuring device into the user's mobile phone and send it from there as a Short Message Service (SMS) through cellular network to hospitals and/or emergency centres.

II. SYSTEM MODEL

As indicated, the system "The Vital Transmitter" consists of vital sign measuring device that is featured with a built-in Bluetooth 4.0 (Bluetooth Low Energy - BLE), this device is paired with the user's mobile phone through Bluetooth connection to be able to send the measured results to the mobile phone, which runs the Vital Transmitter's software program; its main role is to analyse these results by comparing each received measurement to a pre-set thresholds in order to decide whether to send an alerting SMS to the Emergency centre/ relative member/family doctor. The program is also capable of displaying these results to the user in a user-friendly personal record. Among the settings, it gives the option of inserting the contact numbers of ER/ family member and/or family doctor, and more importantly the option of selecting the age zone of the user, which affects the thresholds dramatically. These thresholds were set after a cooperative discussion with a specialized doctor, to assure the accuracy of the system and to avoid unnecessary alerting SMS's.

The software program was based on Android to be compatible with wider verity of mobile phones, at the time being. [1.]

III. THE VITAL TRANSMITTER

The chosen case study was to monitor the Heart Rate, since the heart condition is considered as the most essential vital sign, and hence, the following details were conducted.

A. The Main Algorithm

The entire system was built on this algorithm, which was maintained under the supervision of a cardiologist to set the thresholds and consider the age zones and activeness level of the user, putting in mind the targeted group of people.

For instance, setting the age zone for non-athletics, is straight forward for cardiologists (e.g. 1 – 10 years has the range 70 – 100 beats per minute, where 70 bpm is the lower limit and 100 is the upper limit), and for athletics, it is necessary to get the exact age of the user in order to apply it into one of the following equations to set the upper limit, while the lower limit is 60 bpm:
If the user's age > 30 ➔ 190 – (age – 30) /2;
If the user's age < 30 ➔ 220 – 30; [2]

After setting the user's age zone and activeness level, the thresholds will be automatically set to the according values. The algorithm compares the received heart rate to the pre-set thresholds (Upper boundary limit & lower boundary limit). As long as the read value is in the range of these thresholds, the user is in good condition (called normal range) and the system will only keep the record (in the mobile phone and the hospital record). Otherwise, if the heart rate jumps higher than the upper limit or drops below the lower limit, then the alerting system will go on by sending SMS to the emergency centre to report the medical situation along with the geographical location of the user as a supported service by the mobile phone.
It is important to declare that setting the age zone is very sensitive; it could also be referred to the doctor in case of serious conditions. Among the options there is the sleep mode, which relaxes the alerting system in terms of the lower limit, while keeping the upper limit value as it is.

B. Why SMS?

The current similar systems depend on the cellular network to provide Internet connection, which require one of these services: General Packet Radio Service/ Enhanced Date Rate for GSM Evolution/ High Speed Data Packet Access (GPRS/EDGE/HSDPA) [3, 4, 5, 6, 7, 8, &9], and a supportive Smart phone. Looking at the target group of users (senior people and children) it rarely happens that those people use such services neither such mobile phones.

Besides, the battery life that could be extended in case of using Global System for Mobile communication (GSM) only. Not to mention the economical cost of Internet service compared to SMS that is mainly part of mobile phone packages, and who knows The Vital Transmitter might become part of the health insurance plan one day!

C. Bluetooth 4.0 (BLE)

Bluetooth low energy (Bluetooth 4.0) is a new, open standard developed by the Bluetooth Special Interest Group (SIG). It's targeted to address the needs of new modern wireless applications such as ultra-low power consumption, fast connection times, reliability and security. Bluetooth low energy consumes 10-20 times less power and is able to transmit data 50 times quicker than classical Bluetooth solutions. It is designed for new emerging applications and markets, but it still embraces the very same benefits we already know from the classical, well-established Bluetooth technology. [10.]

The Bluetooth feature was introduced officially to the wireless medical sensors recently in June 2011 [11], but before that communication was possible through Infrared (IR) and USB (Universal Serial Bus), which are both not practical, with IR the two devices should be physically close to each other and with USB the cable is the problem! The communication technology changed with the market need for more practical, reliable, and quick products for wireless health monitoring systems. In this project, we are taking Bluetooth contribution into the second level, where BLE can help in achieving practical and continuous monitoring, since it consumes less battery compared to normal Bluetooth. This issue is very fatal when it comes to small devices with continuous transmission like in medical monitoring.

D. Obstacles during the experiments

The main obstacle was finding a cell phone that supports Bluetooth 4.0 to be compatible with the ECG-sensor with the built-in BLE. As of now, there is no mobile phone featured with Bluetooth 4.0 (BLE) except for iPhone 4S, which is not open for file transfer through Bluetooth with any non-apple device. [12.] yet it is promised by many mobile manufacturers to support this technology soon.

To solve this problem, the measuring device was replaced by a simulating code based on Java programming language for Windows and also tried doing it with Linux, since the scope of the project is not the characteristics of the transmitted figure neither the device itself, the Ideal Vital Transmitter addresses BLE, but for testing purposes Standard Bluetooth was accepted as the first medium but the second medium (cellular network – SMS) was kept as it is, since using SMS as the alerting mechanism makes the Vital Transmitter unique and fits perfectly for the targeted group of people, putting in mind that mobile phones with built-in BLE will not be an obstacle in the near future.

The continuity of the Bluetooth connection could have been a problem if it wasn't for the pairing connectivity method; where most of devices tend to terminate the connection after the completion of transferring the intended file, which is not desired in our scope of work. In addition to the fact that in many cases, the Bluetooth connection is also terminated whenever the application goes to the background running mode, which is controlled by the mobile phone software. Assuring the continuity of the connection, regardless the mode of running foreground or background mitigated this problem. Other problems were the usual suspects to any wireless communication system, the network congestion of the cellular network, which might drop the SMS or even cause the whole connection to fail, but such consideration is rather drastic than realistic, yet it is reserved as a threat.

E. Discussion of Future work

Thinking globally was the concept behind taking the Vital Transmitter from reporting vital sign values and reasoning upon them to deeper level, to be more informative and more beneficial for health decision-makers.

According to the chosen case study, the Vital Transmitter is capable of alerting emergency section when the heart rate (number of beats per minute) drops below a lower limit or exceeds an upper limit; the SMS contains mainly the heart rate value, which is not always informative for the doctor. The user might forget to set his sport activity level, forget to set the sleeping mode, or even do sort of heavy lifting or climb upstairs after a long working day, which will trigger the alerting SMS, though it is not needed at this time (which is considered as worst case scenario). As well from the doctor's viewpoint, the patient needs to be examined for further investigation and these results will assure whether a danger was found or not, so the doctor's time was still consumed for non critical case, though currently the system is serving the proposed aspects perfectly, each threat of the worst scenarios was addressed for better service, yet the second phase of The Vital Transmitter will provide much more reliable service by all means.

The suggested system combines the heart rate measurement to the ECG resulting signal (Electrocardiogram signal) it works as follow:

The user's ECG resulting signal is sent from the ECG device, received by the mobile phone, which will check the behaviour of the signal, to decide whether it is a temporal change (short period of decrement/short period of increment) or a permanent change, which is known as a disease; this is done by comparing the resultant ECG signal behaviour to a typical

ECG signal of the addressed diseases, the comparison is based on the correlation concept, where the user's signal will be cross-correlated against several known diseases' signals, and the closest one (the closest correlation result to zero) will be estimated as the user's medical case, this estimated disease name will be sent along with the heart rate measurement to the emergency centre, so that the doctor can make more sophisticated decision, the patient might need certain medical equipment or medication in the sent ambulance. Not to mention that it will enhance the reliability of the Vital Transmitter, since short changes won't be encountered as a danger, unless they are periodical.

The idea sounds simple, yet it needs to be studied very carefully from medical point of view to wisely choose suitable heart conditions to be addressed by this system, and from the technical aspects as well; since the mobile phone application is suppose to handle analogue signals (ECG signal) and perform correlation and reach reliable decision according to the corresponding selection.

Currently, I've studies the heart condition named "Arrhythmia" which is a problem with the rate or rhythm of the heartbeat. During an arrhythmia, the heart can beat too fast, too slow, or with an irregular rhythm. A heartbeat that is too fast is called tachycardia and a heartbeat that is too slow is called bradycardia. [13.]

Many types of Arrhythmia could be addressed, but for the time being, I've chosen to study: Atrial Fibrillation, and Ventricular Fibrillation. Each of which is explained here briefly, as we – engineers – look at it:

Atrial Fibrillation (AF): is the most common type of serious arrhythmia. It involves a very fast and irregular contraction of the atria. [13.]

Ventricular Fibrillation (V-fib): occurs if disorganized electrical signals make the ventricles quiver instead of pump normally, without the ventricles pumping blood to the body, sudden cardiac arrest and death can occur within a few minutes. [13.]

Those two heart conditions are fatal, specially the second one, but they are both very special cases; that might differ from one person to another in the heart rhythm, and hence, might be hard for the correlation-based comparator to diagnose them specifically, so to be more general, in case the user/patient has irregularity in his heart rhythm yet the suggested system cannot decide what type it is, I've included the Tachycardia and Bradycardia in this system.

This addition, which is called "Combining the Vital Transmitter with ECG Signal", will be finalized during the next 2 years as part of my PhD. dissertation. For now, the conceptual view of the system is addressed within the thesis literature of my MSc. the next figure gives a hint about the system.

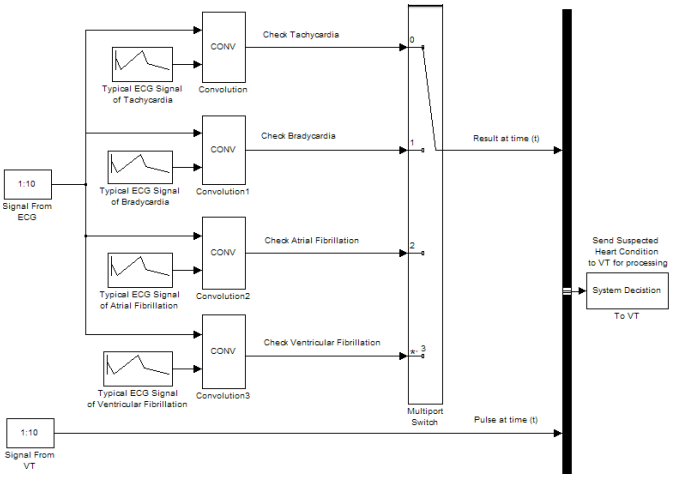

Fig. 1 SIMULINK Model of the conception to the future Vital Transmitter

F. Conclusions

When you think of the Vital Transmitter as a whole project, it simply addresses wireless medical monitoring; by considering all the possibilities for longer battery life for both involved devices (measuring party and alerting mechanism); by the BLE and the SMS deployment, it also succeeded as an instantaneous system; by programming the automatic transmission of the alerting SMS, and by using of the pairing concept for the Bluetooth connection along with the avoidance of back-grounding the application on the mobile phone, in addition to being a practical monitoring system in the same time; where no surgical fixation neither many devices are involved. The combination of the Vital Transmitter and the ECG-Correlation method, which will be a great step towards Wireless Health Care Systems that is based on the Vital Transmitter once more as a foundation and essential part. Using this project as a base for future work is fundamental and was considered during the process of work.

ACKNOWLEDGMENT

The Vital Transmitter is an idea that was induced by my father, it had been evolved as a dream during the years of Engineering studies, and today it has became a reality thanks to the support from my instructor and supervisor who believed in me, they have encouraged the pursuit of my goal and made me aim higher.

REFERENCES

[1] *BEGINNING ANDROID ™ APPLICATION DEVELOPMENT*, Wei-Meng Lee, 2011 by Wiley Publishing, Inc., Indianapolis, Indiana.

[2] Verbal Communication with Dr. Mohamed El-Sheikh, Registrar Adult Cardiology at Prince Sultan Cardiac centre, Riyadh, KSA.

[3] E. Jovanov, D. Raskovic, J. Price, A. Moore, J. Chapman, A. Krishnamurthy. (2001). Patient Monitoring Using Personal Area Networks of Wireless Intelligent Sensors. *Biomedical Sciences Instrumentation*, Vol. 37, pp. 373-378. Copyright ISA.

[4] E. Jovanov, D. Raskovic, R. Hormig. (2001). Thermistor-Based Breathing Sensor for Circadian Rhythm Evaluation. *Biomedical Sciences Instrumentation*, Vol. 37, pp. 493-497. Copyright ISA.

[5] Emil Jovanov, Aleksandar Milenkovic, Chris Otto, Piet C. de Groen. (2005). A wireless body area network of intelligent motion sensors for

computer assisted physical rehabilitation. *Journal of Neuro-Engineering and Rehabilitation*, 2:6, Available from Internet <URL: http://www.jneuroengrehab.com/content/2/1/6>

[6] Jovanov, E., A. Lords, D. Raskovic, P. Cox, R. Adhami, F. Andrasik. (2003). Stress Monitoring Using a Distributed Wireless Intelligent Sensor System. *IEEE Engineering in Medicine and Biology Magazine*, pp. 49-55. Copyright IEEE.

[7] Jovanov, E., A. Milenkovic, S. Basham, D. Clark & D. Kelley. (2004). Reconfigurable Intelligent Sensors for Health Monitoring: A Case Study of Pulse Oximeter Sensor. *Proceedings of the 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, San Francisco, pp. 4759-4762.

[8] Jovanov, Emil and Milenkovic, Aleksandar, WHMS - Wearable Health Monitoring Systems, http://www.ece.uah.edu/~jovanov/whrms, accessed: Wednesday, February 1, 2012, 04:24 PM.

[9] Otto, Chris, Aleksandar Milenkovic, Corey Sanders & Emil Jovanov. (2006). System Architecture of a Wireless Body Area Sensor Network for Ubiquitous Health Monitoring. *Journal of Mobile Multimedia*. Vol. 1, pp. 307-326.

[10] Bluetooth low energy technology – how it works, Bluetooth™ Special Interest Group, published on 18-May-11, Available from Internet <URL: http://www.bluegiga.com/BLED112?downloads>

[11] Bluetooth (Medical & Health), <URL: http://www.bluetooth.com/pages/medical.aspx>, accessed: Wednesday, February 1, 2012, 10:59 PM, Vaasa, Finland.

[12] Pachal, Peter. October, 2011, "The iPhone 4S Is the First Bluetooth 4.0 Phone", available from Internet <URL: http://www.pcmag.com/article2/0,2817,2395178,00.asp, accessed: Saturday, March 11, 2012, 12:59 AM>

[13] National Heart Lung and Blood Institute, http://www.nhlbi.nih.gov/health/health-topics/topics/arr/, accessed: Saturday, March 3, 2012, 08:36 PM, Vaasa, Finland.