# Integrated mobile electrocardiography

< Single space >

N. Vrček
Faculty of Organization and Informatics
University of Zagreb
Address: Pavlinska 2, 42000 Varaždin, Croatia
Phone: +385 42 390 867 Fax: +385 42 213 413 E-mail: neven.vrcek@foi.hr

M. Velić and Z. Stapić
Faculty of Organization and Informatics
University of Zagreb
Address: Pavlinska 2, 42000 Varaždin, Croatia
Phone: +385 42 390 867 Fax: +385 42 213 413 E-mail: zlatko.stapic@foi.hr

**Abstract - Modern mobile electrocardiographic equipment converges various technologies which contribute to the speed of reaction in critical situations and contributes to the quality of life of the patient. Such convergence is valuable, but solutions are still immature and there are certain problems which should be solved before full implementation. This article describes one solution of integrated mobile electrocardiograph which comprises mobile ECG, global positioning system, UMTS/GPRS transfer of data and Web services for connection of distributed components. The system records electrocardiogram, detects rhythm anomalies and immediately alerts doctor sending critical ECG segment and location of the patient. The doctor can contact the patient and send nearest ambulance by the optimal route. The fact that system works in real time and locates the patient might be crucial in certain situations. It has excellent potential, but requires technical and organizational infrastructure which will support its functioning.**

## I. INTRODUCTION

Modern technology enables better quality of life of sick and disabled persons. One of such areas is mobility of patients who do not require permanent professional care. Small dimensions, CPU power, memory and power efficiency of modern digital equipment is crucial for new approach to health care and telemedicine. The phenomenon which contributes to new paradigm of medicine care is strong convergence of various technologies located within single device. One such example is use of Personal Digital Assistants (PDAs). The number of applications of Personal Digital Assistants (PDAs) in different health care specialties has grown in recent years showing that real-time monitoring of vital signs is also feasible [1, 3, 4, 5, 6, 9]. Since PDA is able to display graphical information it can present certain vital biomedical signals in real time. The graphic capabilities of these devices are continuously improving and can not be regarded as limitation any more. Low-power mobile CPU's now have sufficient performance to process the signals in real-time, allowing prediction of possible medical emergencies and feedback about current patient's condition. Also these devices are capable to connect to various peripheral devices and can collect and transmit data in really seamless manner. Using such possibility to converge various technologies it is possible to make better and more mobile healthcare systems. These systems are important for efficiency of modern medicine in ageing society. They will bring necessary quality of life to sick or disabled persons and their development will continue because mobile platforms are becoming more efficient each day. This paper describes one application of PDA and converging technologies in mobile electrocardiography. This domain of medicine is very interesting and popular. There are also some regulatory documents which help development of related devices and solutions. The examples of such documents are guidelines for ambulatory electrocardiography published by The American College of Cardiology (ACC) and The American Heart Association (AHA) [2].

The system described by this paper was created from readily available commercial off-the-shelf (COTS) components and commercially available communication technology. System components were integrated by various links and appropriate software modules were developed. Modular architecture enables easy replacement of components without altering the global system architecture or requirements. Such systems are capable to help patients at risk for arrhythmias because they can be continuously monitored by healthcare professionals outside the hospital environment. In the case of emergency system is capable to raise an alarm and inform a doctor about patient's condition. Also, a patient can wear the device during normal daily activity, allowing cardiologists to obtain a deep insight in patient's condition, better than is available from short periods of monitoring in the hospital.

## II. SYSTEM ARCHITECTURE

An ECG represents the heart muscle's electrical activity as it is recorded from surface electrodes placed in standard locations on the body. Each ECG lead monitors the heart on a different plane and this information can be plotted as a series of deflections and waves that can be graphically represented, containing information about the heart's rhythm and condition. ECG monitors have been developed for many years and they are either stationary or mobile (Holter ECG). Holter ECGs have also been used for many years and has been proved as valuable resource. First they were realized on analog technologies (tape recorder) and eventually became fully digital. Today they are light ECG recording devices with considerable battery life and significant amount of memory capable of long lasting data acquisition [8]. However it is important to detect emergent situations and reduce the time between recording certain cardiac activity and medical analysis and treatment of potential pathological states. Therefore, in certain situations, recorded ECG should be transferred as soon as possible to electrocardiologist. Modern technology enables such alarming procedure without expensive equipment and infrastructure.

The system described in this article is capable to overcome these problems and consists of three integrated components.

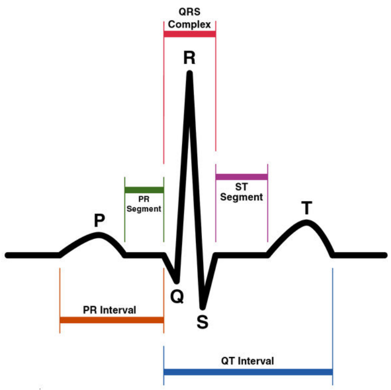

Fig 1. Characteristic shape of ECG signal

First is a Bluetooth enabled digital Holter ECG which records ECG signal. Recorded data is stored on local memory and transferred to PDA via Bluetooth link. Second is GPS enabled PDA which runs software for ECG data acquisition, analysis, patient positioning and transfer through GPRS/UMTS network. Third is doctor's application which collects data transferred from PDA, makes further analysis and presents collected ECG for further interpretation. These three components are integrated in complete system based on service oriented architecture (SOA).

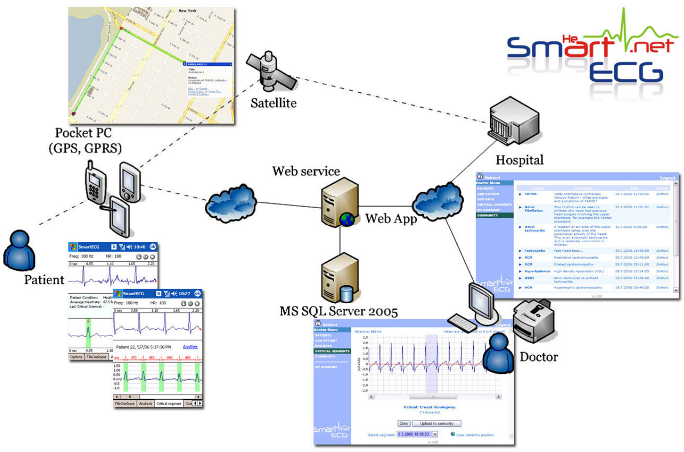

Fig 2. System architecture

Holter ECG monitor is the core module of the system. It is designed specially for detecting, sampling, preprocessing, storing, analyzing and transmitting real time ECG signals. ECG data is transferred over a Bluetooth link to the PDA. Bluetooth is low power and relatively robust wireless communication standard and gives patient freedom to move within limited distance without PDA [12, 13]. It uses license-free industrial, scientific, and medical (ISM) frequency band between 2.4 and 2.4835 GHz. Frequency hopping reduces signal fading and interference from other nearby devices transmitting in the ISM band. There are other class radios which provide increased transmission range and data rates but at greater cost and power consumption. Also Bluetooth is widely accepted standard and becomes more used by many technical devices.

PDA collects transferred ECG samples, performs simple digital signal processing and stores them in internal memory. In this system Windows based PDA is used running SQL Server Mobile relational database. The C# software developed for PDA performs communication with Holter ECG and stores data to PDA database. Beside that PDA software performs basic rhythm analysis of collected ECG data due to limited computing and power resources. Complex computing needs more resources that can't be offered by the hand-held instrument such as the PDA described here. Therefore on PDA analysis of heart rhythm is performed. It is based on Pan-Tompkins algorithm [10] for QRS detection preceded by optional FIR filter for smoothing noisy signals. This algorithm was chosen because of its simplicity and relative efficiency. It works in time domain and is capable of working in real time without significant CPU power available.

The Pan-Tompkins algorithm (PT) is a filter combined with threshold (θ) based method for R-peak (QRS complex) detection. It comprises of a bandpass filter, differentiator, a squaring operation and a moving window integrator. The bandpass filter filters out excess noise and smoothes signal. The differentiator and squaring operation accentuates steep features, and the integrator carries out a smoothing operation. Integrator window length might be adjusted such that features with a particular width are accentuated. R-peaks are detected in regions where the filtered signal rises above the threshold θ. If no R-peak is detected within a predefined time interval, R-peaks are looked for where the filtered signal rises above a second, lower threshold θ2. After R-peak detection is completed in the time window, θ (and θ2) are updated according to filtered signal amplitudes in the window. Detection of R-peak is crucial for QRS detection and also for ECG rhythm analysis. PT algorithm allows reliable R wave detection which enables raising alarms in case of rhythm anomalies. More precise QRS and rhythm detection can be performed on stationary platform and thus verify PT algorithm accuracy.

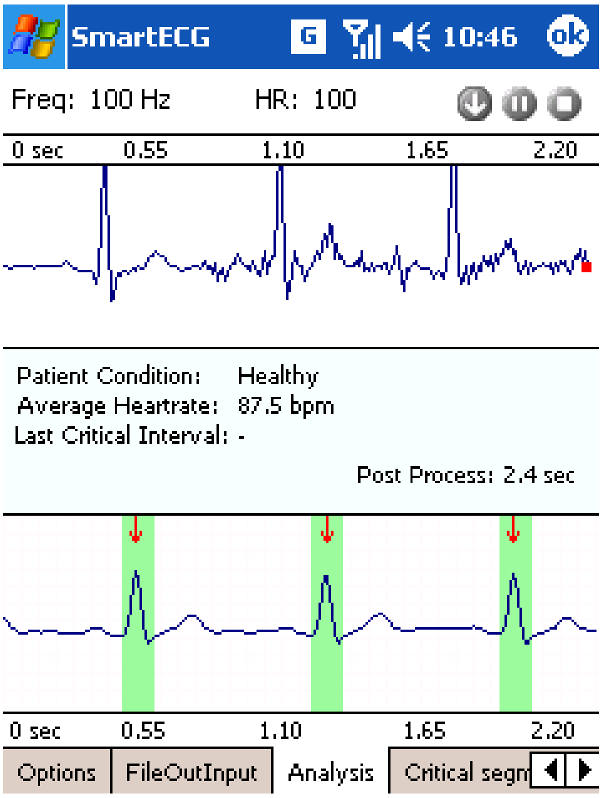

Fig 3. PDA application

The program on PDA also visualizes collected data and shows proper messages to express abnormal conditions of the monitored patient. The PDA is equipped with GPS system which utilizes GPS satellites to precisely locate coordinates. The GPS system consists of three prime components: GPS satellites, earth control, and user receiver. In this integrated mobile ECG system it is used to transfer patient's position to central system. However, environmental factors affect location accuracy and the ability to acquire patient position. A signal can be blocked when a patient is inside a building. Therefore the system stores the last good position (LGP) and time stamp which enables approximate positioning of patients. GPS is most accurate but not the only possible positioning system which can be used on presented integrated mobile ECG. Instead of GPS location based services (LBS) of mobile operators might be used. These services are usually presented in context of mobile marketing [7] but they have quite accurate positioning capabilities which can be used in telemedicine. The Cell ID is the simplest LBS and has accuracy of 500 m. More sophisticated methods such as Angle of Arrival (AOA), Time of Arrival (TOA), Observed Time Difference (OTD) can achieve accuracy of 100 m which comparable with GPS [14].

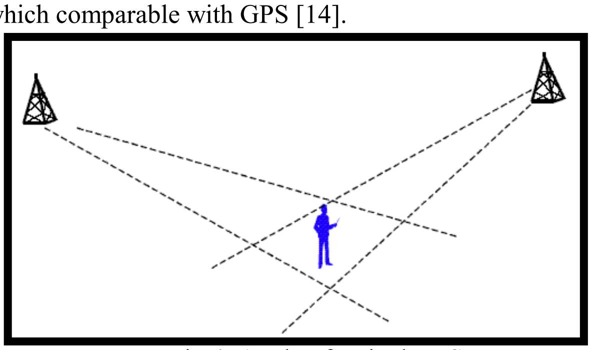
Fig 4. Angle of arrival LBS

Data from PDA is transferred to central system via public wireless link (WiFi, GPRS, UMTS). The speed of transfer was sufficient in presented project. Maximum speeds usually stated for common wireless standards are: Global System for Mobile Communication (GSM) - 9kbps, General Packet Radio Service (GPRS) - 171,2 kbps, Wireless LAN (WLAN) - 11 Mbps. However certain caution must be taken while using shared public frequency resources in telemedicine. These standards have become so pervasive that we rarely think of them in terms of sharing a regulated medium [6]. The problem arises if wireless link is overloaded with different signals which coexist within same bandwidth. As yet, no definitive study has been accepted that fully characterizes these effects in telemedicine. There are some dedicated networks which are usually used by services with special authorization such as *TErrestrial Trunked RAdio* (TETRA) developed by European Telecommunications Standards Institute (ETSI). Such specialized network is extremely useful in case of emergency when commercial network is nonfunctional or overloaded. Important aspect of presented project is that it can adapt to various wireless links and standards to make it useful in various situations. To avoid possible problems due to the speed of wireless communication channel, in this project critical ECG segments were marked and system is capable of transferring only them instead of complete recording. Critical ECG segment is part of ECG signal in which PDA application detected rhythm anomalies and if link is too slow only the segment is sent which should be sufficient for preliminary diagnosis by the doctor.

Remote PC and database server are located in medical institution where data are finally collected and thoroughly analyzed. This software has more functions than PDA application and can visualize signal to the high level of detail. This enables specialists to diagnose patients' condition and decide the course of action if necessary. It also uses Web services and relates GPS position of the patient with the map of the area. This feature enables exact positioning of the patient and navigation of ambulance in the case of emergency. The fact that the map is obtained through Web service enables use of public maps without complicated in house solutions. However public maps have variable accuracy depending on the part of world that is being presented and system depends on high speed Internet connection.

Presented system was tested on limited number of patients and selected segments from MIT-BIH Arrhythmia database [11]. The MIT-BIH Arrhythmia database contains 48 half-hour excerpts of two-channel ambulatory ECG recordings, obtained from 47 subjects studied by the BIH Arrhythmia Laboratory between 1975 and 1979. The recordings were digitized at 360 samples per second per channel with 11-bit resolution over a 10 mV range. For the purpose of this project one channel of database was used. Over the years MIT-BIH database became de facto standard for testing various ECG related algorithms.

Obtained results can be regarded as satisfactory within limits of testing scope and required features.

## III. CONCLUSION

Convergent mobile technologies enable new approach to healthcare and telemedicine with significant improvement of patient's life. By using these technologies it is possible to develop efficient low cost solutions without deteriorating quality of medical service. This paper presents one such solution built from standard COTS components. Developed system is fully functional mobile electrocardiograph which utilizes software components integrated by service oriented paradigm. The system was tested in laboratory environment on real patients and MITH-BIH database signals. Obtained results show that presented solution is capable to work in actual environment. It might be expected that such systems will eventually enter full scale use and that telemetry of biomedical signals will become widely accepted way of patients' monitoring.

## REFERENCES


[1] Cheng, P., Tsai, L., Lu, L., Yang, D.: The Design of PDA-based Biomedical Data Processing and Analysis for Intelligent Wearable Health Monitoring Systems. Proceedings of the Fourth International Conference on Computer and Information Technology, pp. 879 – 884, IEEE 2004.

[2] Crawford, M. H.: ACC/AHA Guidelines for ambulatory electrocardiography. Journal of the American College of Cardiology, vol. 34, pp. 912-48, 1999.

[3] Dong, J., Zhu, H.: Mobile ECG detector through GPRS/Internet, Proceedings of the 17th IEEE Symposium on Computer-Based Medical Systems. pp. 485 – 489, IEEE, 2004.

[4] Dong, J. et. al. Wearable ECG Recognition and Monitor, Proceedings of the 18th IEEE Symposium on Computer-Based Medical Systems, pp. 413-418, IEEE, 2005.

[5] Fensli, R., Gunnarson, E., Gundersen T.: A Wearable ECG-Recording System for Continuous Arrhythmia Monitoring in a Wireless Tele-Home-Care Situation. Proceedings of the 18th IEEE Symposium on Computer-Based Medical Systems, pp. 407-412, 2005.

[6] Liszka, K., et. al. Keeping a Beat on the Heart. Pervasive Computing, pp. 42-49. IEEE, October-December 2004.

[7] Malloy, A. D., Varshney, U., Snow, A. P.: Supporting Mobile Commerce Applications Using Dependable Wireless Networks, Mobile Networds and Applications 7, 2002, pp. 225 - 234.

[8] Martin, T., Siewiorek, D.: Non-ideal Battery Properties and Low Power Operation in Wearable Computing. Proceedings of the Third International Symposium on Wearable Computers, San Francisco, CA, October, 1999, pp. 101-106.

[9] Nelwan, S., Van Dam, T., Klootwijk, P., Meij, S.: Ubiquitous mobile access to real-time patient monitoring data. In IEEE in Computers in Cardiology, pp. 557– 560, Sept. 2002.

[10] Pan J, Tompkins, WJ. A Real-Time QRS Detection Algorithm. IEEE Transactions on Biomedical Engineering. pp. 32:230-236, 1985.

[11] Physiobank—Physiologic Signal Archives for Biomedical Research. http://www.physionet.org/physiobank/, 2006.

[12] Sturman, J.B.: Bluetooth 1.1: connect without cables. Pearson Education, 2001.

[13] Specifications of the Bluetooth System www.bluetooth.com, 2006.

[14] Warrior, J., McHenry, E., McGee, K.: They know where you are. IEEE Spectrum 40(7) (2003) pp. 20-25.