Multi-channel Wireless ECG System

Yuliyan S. Velchev[1]

***Abstract* – In this paper a multi-channel wireless ECG system is present. According to the modern concept, the system is built as Wireless Personal Area Network (WPAN), formed by intelligent wireless ECG sensors and a coordinator – personal computer. The system is based on the Bluetooth™ standard for short range communication. This paper describes the overall system structure as well as the structure of the intelligent ECG sensor (signal conditioning and acquisition, signal processing and transmission over wireless link).**

***Keywords* – Telemedicine, E-health, ECG**

I. INTRODUCTION

The electrocardiogram (ECG) can be considered as simple but powerful non-invasive diagnostic tool in cardiology. The system shown in the paper introduces an improvement of classical ECG signal acquisition.

Nowadays the concept for transmitting medical data (particularly ECG) over short-range wireless link turns into forming a network from intelligent wireless sensors and personal computer. The main advantages of this concept are: increased patient mobility, simultaneously monitoring of more patient's ECG, possibility to make real-time analysis, possibility to store and forward the received ECG data using Internet, improved electrical safety of the patient. The described in this paper wireless ECG system utilizes the Bluetooth™ standard in order to form a wireless short-range personal network used to transmit the acquired ECG signal.

II. SYSTEM STRUCTURE

According to Figure 1, the system structure is based on intelligent sensors with wireless communication capabilities. The main part of each ECG sensor is Digital Signal Controller (DSC). The used signal controllers are dsPIC30f family, provided by Microchip Technology Inc. The built-in multi-channel ADC provides resolution of 12-bit. It samples the previously amplified and filtered ECG signal. The next stage is signal processing. In this project an adaptive filtering and decimation are used. DSC communicates with Bluetooth™ module via asynchronous serial interface. These modules along with PC (equipped with Bluetooth™ communication capability) form the so called Piconet, limited up to 7 devices. The PC application used to monitor the ECG signals is developed using LabView™ software.

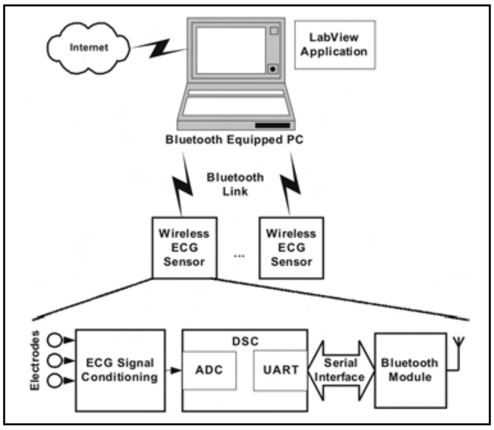

Fig. 1. System structure

One of the concepts in telemedicine known as "store and forward" is used in this project. So, this equipment is possible to be placed at patient's home and using Internet the ECG data can be forwarded to a hospital for further analysis and diagnosis by medical staff.

III. SIGNAL CONDITIONING AND ACQUISITION

Nowadays, the experts consider that ECG systems with 9, 12 or even 15 channels are suitable only for more complicated diagnosis, which is often a consequence from a relatively basic ECG diagnosis. The purpose of the described system is to help the doctor to track the patient's heart activity for a long period of time using only three ECG channels. As mentioned above, this can give enough information for medical staff.

The classic electrode placement is used (Figure 2), according to the well-known Enthoven's triangle.

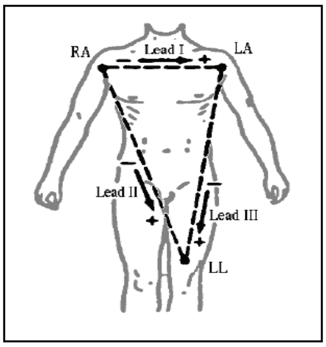

Fig. 2. ECG electrode placement

[1]Yuliyan S. Velchev is with the Faculty of Communications and Communications Technologies, Technical University of Sofia, Address: 8, Kliment Ohridski St. Sofia-1000, BULGARIA, E-mail: julian_velchev@abv.bg

The spectrum of the ECG signal is concentrated from DC to about 120Hz. Peak to peak voltage can be considered of no more than 3mV. The ECG amplifier must be with high input impedance and very high CMRR (over 100dB). In order to met these strong requirements an instrumentation amplifier INA2126 or INA2128 (made by Texas Instruments) is used as first stage high CMRR amplifier. Figure 3 shows the simplified diagram for ECG signal conditioning. The gain of instrumentation amplifier is limited to 10mV/mV, because of possible amplifier saturation, which can be caused by electrodes polarization or power line noise. Power supply is ±9V (made by DC-DC conversion from the battery power). To achieve better CMRR, a "right leg driven" circuit is implemented. The common mode signal is fed back to the patient's body (right leg) to minimize the power line interference. Also this signal is used as reference input for adaptive filter, discussed in the next chapter, The DC component is removed by high-pass first-order passive filter. The overall gain is set to 1V/mV, so the next stage gain is 100mV/mV. In addition, this stage provides level shifting in order to match the voltage level requirements for ADC. The spectrum is limited to about 100Hz by low-pass active filter. The analog ECG signal is sampled by 12-bit ADC which is a peripheral part of the DSC. Sampling rate is chosen to be 1000Hz, thus the requirements for analogue low-pass filter is reduced. Also the setting time of adaptive filter is minimized significantly.

In future work the amplification will be made by Programmable Gain Amplifier (PGA), adjusted dynamically by DSC. In this case the gain can be increased when the power line noise is weak, so achieving better ADC resolution.

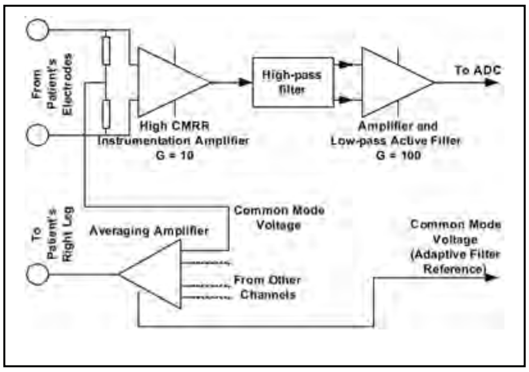

Fig. 3. ECG signal conditioning

IV. Signal processing

Despite of high CMRR amplification and "right leg driven" circuit implementation, the power line interference is still significant. To remove this component without corrupting the ECG signal, an adaptive filter with 32 taps is used. According to Figure 4 a referent signal which is derived from common mode voltage is used as input signal in Normalized Least Mean Squares (nLMS) adaptive filter. Thus, the error signal is actually the ECG signal with removed uncorrelated power line interference.

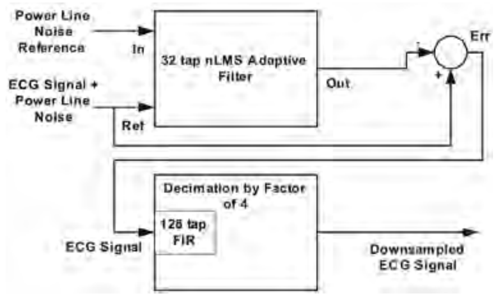

Fig. 4. ECG signal processing

The nLMS algorithm can be expressed as:

$$y[n] = \sum_{m=0}^{M-1} h[m] * x[n-m] \tag{1}$$

$$h(n+1)[m] = h(n)[m] + nu * e[n] * x[n-m] \tag{2}$$

$$e[n] = r[n] - y[n] \tag{3}$$

$$nu = \frac{mu}{mu * E[n]} \tag{4}$$

$$E[n] = E[n-1] + x^2[n] - x^2[n-M+1] \tag{5}$$

Where: *y[n]* is the output signal ("Out" in this case), *x[n]* is the input signal ("Ref" in this case), *r[n]* is referent signal ("In" in this case), *mu* is adapting factor, *E[n]* is estimated input signal energy, and *h(n)[m]* are the filter coefficients in time "*n*".

The parameters of power line noise can vary in time, so the adaptive filter is very suitable choice to track the eventually changes of these parameters. Some other types of adaptive filters are experimented such as Least Mean Squares (LMS) and adapting by error signal sign. Achieved results (in terms of setting time) are worse than nLMS algorithm. The setting time and Signal to Noise Ratio (SNR) are in conflict for adaptive filters. The adaptation factor "*mu*" is determined experimentally (in this case the best results are when it is equal to 8). Experimental results show that in order to simplify the circuit, a formed square wave signal from common mode voltage can be used as reference for adaptive filter. So, instead of additional analogue channel for reference an external interrupt input in DSC can be used. By this way the performance of the adaptive filter is reduced insignificantly. The sampling rate is 1000Hz, which is above the required minimum. So, decimation by factor of 4 is implemented to change the sampling rate down to 250Hz. A FIR type low-pass digital filter with 128 taps is used along with decimation. The cut-off frequency for this filter is 120Hz. All described above signal processing is in format 1.15 (fixed point data). The software is developed with MPLAB C30 compiler.

V. WIRELESS COMMUNICATION

In this project the Bluetooth™ v1.1 communication standard is met by using Class A modules, type F2M03C1 with chip antennas. Figure 5 shows the protocol layer model for these modules. As can be seen the upper layer is so called Wireless UART (WU, SPP), which means that the user is free to build complicated communication software. The communication is simple as organizing the link over rs-232 standard. In PC each module is associated as two virtual COMM ports (incoming and outgoing). The data encryption capabilities of Bluetooth™ standard are enabled in this project also.

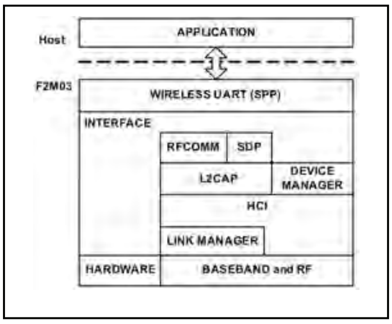

Fig. 5. F2M03C1 protocol layer model

Serial communication is organized with hardware handshaking (RTS/CTS) and two additional digital lines (first of them to initiate the connection and the second to inform the DSC whether the connection is available). The Bluetooth™ module connected to PC is standard USB dongle with Serial Port Profile (SPP) support.

VI. EXPERIMENTAL RESULTS

LabView™ based software is developed to communicate with ECG sensors and to display the received data. Figure 6 shows the process of ECG signal acquisition during the adaptation of nLMS filter.

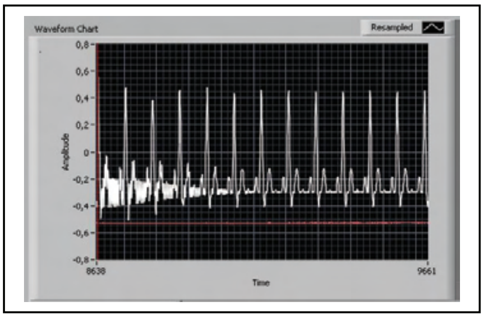

Fig. 6. ECG waveform during the nLMS filter adaptation

Figure 7 shows the same ECG signal after nLMS algorithm has been fully adapted to the power line interference.

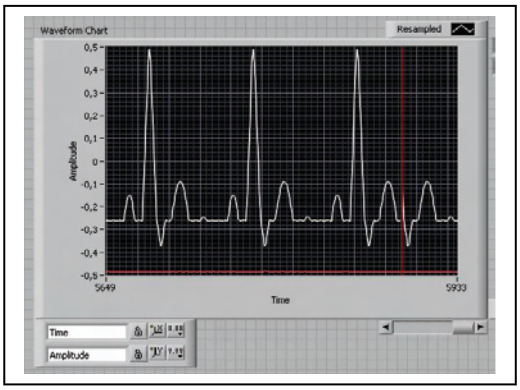

Fig. 7. Acquired ECG waveform after nLMS filter has been fully adapted

The experiments have confirmed that the Bluetooth™ wireless communication is reliable in the range up to 30m indoor and up to 100m in outdoor conditions.

VII. CONCLUSION

In this paper a multi-channel wireless ECG system is described. As can be seen from above, the achieved experimental results are satisfying. The future work will be concentrated in terms to increase the number of nodes, which are now limited up to 7. By using next generation of DSC from Microchip (dsPIC33F, PIC24F) it will be possible to increase the number of channels and overall system performance, because of Direct Memory Access (DMA) capability. Also, it is obviously that the system needs to be developed by adding computer-based ECG analysis (QRS complex detection at next stage of development and more sophisticated methods in the future).

REFERENCES

[1] D. Dimitrov, “Communication system in medicine”, handbook, Sofia, 2005.

[2] D. Dimitrov, Y. Velchev, "Communication Protocol for Medical Mobile Network", Proceedings of 48-th IWK, TU – Ilmenau, Germany, pp. 55-56, Ilmenau, Germany, 2003.

[3] D. Dimitrov, D. Vasileva, "One Channel ECG System", Proceedings of 48-th International Scientific Conference of Information, Communication and Energy Systems and Technologies, ICEST ’03, pp. 510-512, Sofia, Bulgaria, October 16-18, 2003.

[4] D. Dimitrov, M. Nikolova, "Reconstruction of Periodical Impulse Sequence", Proceedings of Regular International Conference of Association of Computer Technique of USA on Computer Application – ACMBUL’92, p. 34-1, 34-5, 4-8 October, 1992, Varna, Bulgaria.

[5] D. Dimitrov, Y. Velchev, “Distance Analysis of ECG”, Proceedings of the Technical University-Sofia, Volume 52, p. 69-75, Sofia, Bulgaria, 2003.

[6] D. Dimitrov, M. Nikolova, “Parameters Estimation in Computing Restoration Signals with Noise Spectrum”, BAND 1, VORTRAGSREIHEN, 43 Internationales Wissenschaftliches Kolloquium, Technische Universitat, Ilmenau, Germany, p. 607-612, 21-24.09.1998, Ilmenau, Germany.

[7] R. Paradiso, “Wearable Health Care System for Vital Signs Monitoring”, Proceedings IEEE Int. Conf. Information Technology Applications in Biomedicine, pp. 283-286, 2003.
[8] E. Jovanov, P. Gelabert, R. Adhami, B. Wheelock, R. Adams, “Real Time Holter Monitoring of Biomedical Signals”, DSP Technology and Education Conference DSPS’99, August 4-6, 1999, Houston, Texas, 1999.
[9] E. Jovanov, D. Raskovic, J. Price, A. Moore, J. Chappman, A. Krishnamurthy “Patient Monitoring Using Personal Area Networks of Wireless Intelligent Sensors”, Biomedical Sciences Instrumentation, Vol. 37, pp. 373-378, 2001.
[10] R. Ruiz, J. Perez, J. Sierra, S. Maguillo, “SCP-ECG Transmission by a Tele-medicine Home Care Device: an Implementation Approach”, The 2nd Open ECG Workshop 1-3 April, 2004, Berlin, Germany, pp. 16-18, Berlin, Germany, 2004
[11] Y. Jasemain, E. Toft, L. Arendt-Nielsen, “Real Time Remote Monitoring of Cardiac Patients at Distance, Integration of the ECG into the EHR & Interoperability of ECG Device Systems”, The 2nd Open ECG Workshop 1-3 April, 2004, Berlin, Germany, pp. 48-50, Berlin, Germany, 2004.
[12] T. Desel, T. Reichel, S. Rudischhauser, H. Hauer, “A CMOS Nine Channel ECG Measurement IC”, ASIC, 1996. 2nd International Conference, October, 1996.