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Bluetooth–based approach to monitoring biomedical signals

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Abstract: This paper presents an approach to remote monitoring of basic physiological parameters using Bluetooth technology and the wired telecommunication infrastructure. As such, the system is convenient for use in continuous monitoring of patient health at homes, working areas and hospitals. The suggested architecture has been described at the levels of multi-point Bluetooth client, hospital-office-home Bluetooth server, and their integration in global telemedicine network. In paper, an emphasis is given on functional description of system components and the software data flow at the host side as well. The preliminary testing results of the realized prototype verified the advantages of Bluetooth based approach against classical one. The planned future work on this issue is presented as well.

Key-Words: physiological signals, monitoring, ECG, PPG, Bluetooth, microcontroller, home care

1 Introduction

The development of microelectronics, wireless communications and ICT has facilitated the new approaches in developing the medical measurements systems, especially in telemedicine. Continuous monitoring of physiological parameters (PP), like ECG, SPO_2, pulse rate, respiration rate, blood pressure, etc. can remarkably reduce the risk of serious complications in cases of chronic diseases. Classic systems for measurement of physiological parameters are based on fixed or ambulatory devices connected to the patient via cables. These systems often require the presence of medical stuff close to the monitored patient. Among others, the drawbacks of classic approach in monitoring the PP are: system immobility, high installation cost, classic AC/DC power supply, the risk of inadequate handling and of weak cable contacts, worn out equipment and so on. Modern telemedicine systems are focused in applying wireless systems offering the patient's mobility, reduced installation cost and much greater flexibility of realization. These systems are especially interesting when dealing with continuous monitoring of vital health parameters in hospital, home care or office care systems.

Monitoring of PP mostly include two types of wireless networks: short range communications – used for creating WPAN / WLAN networks (as Bluetooth, ZigBee, UWB) and long range WAN links (like GPS, GPRS, 3G, satellite links) [1]. Combinations of wireless and wired communication infrastructures are often used as well: when the acquisition is made wirelessly (more often) and the WAN links are realized using wired transmission systems or vice versa. Wireless telemedicine systems are expected to enable real-time acquisition of basic PPs and their transmission to other points of the system for remote monitoring and storage.

The system for monitoring of physiological parameters presented in this paper uses Bluetooth technology, which is primarily designed as a way of establishing simple ad-hoc connections among low power consumption devices. Compared to WLAN standard networks, the main disadvantages of Bluetooth are lower communication speed and transmission range. But, when dealing with small distance between devices and not highly speed-critical applications, Bluetooth technology seems to be more proper, because of its lower power consumption. Bluetooth uses high speed FHSS technique, which makes it robust. So, in the case where Bluetooth range overlaps with other wireless networks (WiFi, ZigBee, etc.), Bluetooth is expected to win the competition for the lower interference influence [2]. Comparing with typical WSN, Bluetooth means greater throughput and hence is convenient for using in real-time monitoring, when higher communications speeds are needed. Bluetooth transceivers are designed as low power consumption devices but there are technologies as ZigBee which are designed to be ultra low power consumption technology. However, great presence of embedded Bluetooth devices in modern mobile phones and other mobile computer platforms (Laptop, PDA, etc.), makes this technology more attractive in sense of scalability and compatibility for present and future applications.

In this paper we are trying to propose an optimal solution for monitoring PPs, based on fusion of

Bluetooth technology and general purposes microprocessors. Of course, the principle could be useful for others applications in case of migration from wire to wireless transmission or from traditional RF (AM and FM) links to modern wireless sensor networks.

The paper is organized as follows: Section 2 drafts the architecture of the proposed system solution. In section 3, the preliminary testing results are given followed by summary and the references.

2 System architecture

Present version of the system is mainly oriented to home care and hospital uses. Its architecture is given in Fig. 1. As seen, the physiological signals from remote patients are acquired and sent in reduced (vital signs) or raw data form to the server access point by using Bluetooth protocol. Besides multiplexing of Bluetooth packets, access point does the TCP/IP packing of payloads and enables remote monitoring from WLAN using standard connections such us PTSN, ISDN and ADSL.

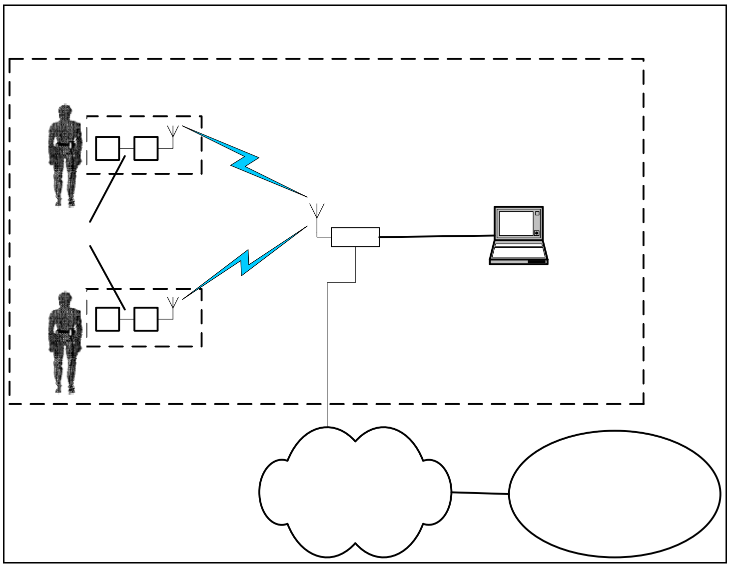


Fig. 1: System architecture for monitoring of physiological parameters

2.1 Bluetooth Client

Bluetooth Client continuously sends data to the server over Bluetooth links. The system architecture is designed to provide “Serial over Bluetooth” communication. The client part consists of sensor conditioner (A) and Bluetooth transceiver (B). The sensor conditioner functionally integrates the measurement circuit and microcontroller. The measurement circuit is based on standard analog and digital components. It performs detection, sampling, filtering, and amplifying and operates in chopper (PPG) and continuous mode (ECG) in order to reduce the consumption. The spanned analog signals are fed to microcontroller in order to be digitalised post-processed and forwarded to the transceiver module. As microcontroller the ATMega16, from Atmel’s 8bits RISC family has been chosen, because of its performances like low power, high speed and fully integration (timers, ROM, RAM, EEPROM, UART, etc). Fig 2.

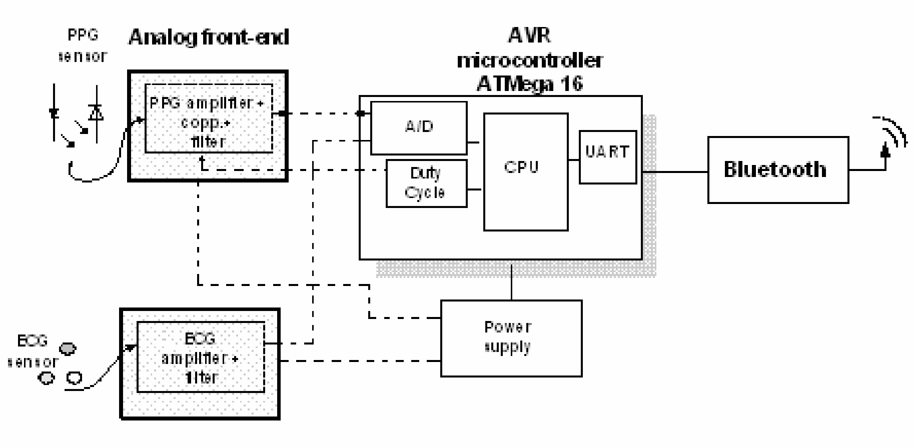


Fig. 2: Hardware architecture of Bluetooth client

It communicates, through UART interface, with Initium Promi ESD Bluetooth transceiver module. This module is of power class 1 with specified output power of 63 mW. Its sensitivity varies in range from -84 dBm up -20 dBm. The outdoor distance range, according to the manufacturer specifications (in case of using patch antenna), can achieve the maximum of 1200 m [3], while with antenna combination used in this project should assure the range up to 100 m. The communication speed microcontroller-transmitter could be between 19200 – 115200 bps. The both sensor conditioner and transmitter are single supply powered with 5V and 3.3V respectively.

2.2. Bluetooth server

The Initium Promi MSP (C) access point acts as wireless multi-serial server, which receives “serial over Bluetooth” data from wireless links and packs them to the TCP/IP frames. Each Bluetooth transceiver (associated for one patient) is identified by unique 48-bit hardware address joined to the appropriate TCP/IP port of the server. Host PC accesses the ports of the server through TCP/IP protocol and the frames are converted to the serial data through the Virtual Comm port emulator. Promi MSP together with host PC makes the server subsystem.

The software of whole system consists of microcontroller code and server application, designed in CodeVision AVR and Visual Basic respectively. The host application enables configuration of TCP/IP server its interconnection to PC via Virtual COMM ports as well as multifunctional GUI. Current version provides several functions such as logging mechanism, pausing, signal flow, software filtering, grid adjustment, zooming, printing, saving and so on.

Algorithm of the serial data reception, frame format and their visualisation using VB developed software is showed in Fig 3. As can be seen, the developed communication is based on original algorithm and frame format. The fields as: Number of samples, Sampling frequency and Number of channels, make the application applicable for different frequencies and frame lengths. The data screening function is called when the frame termination appears and if the frame passes the CRC check procedure. The initialisation of the serial data reception starts with opening of COMM ports which correspond to the appropriate TCP port of the server, using VB COMM control and the Virtual COMM port software.

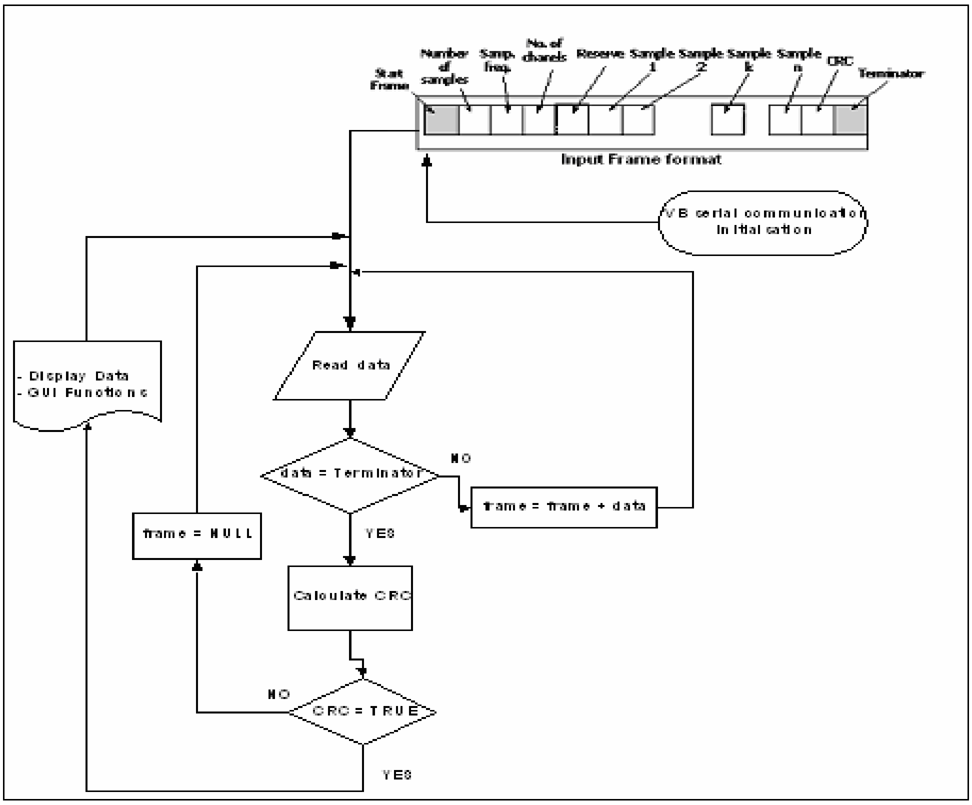


Fig. 3 The algorithm of Visual Basic based Virtual instrument data flow

3 Preliminary testing results and future work

The experimental part of the project has been performed through two phases. After the development of hardware prototypes and necessary software support the system functionality has been verified in APEG Laboratory of University of Montenegro. The experimental setup was included two sensor nodes (patient 1 and patient 2) and one server (Bluetooth access point and networked PC). The PPG and ECG signals are obtained under following conditions: sampling frequency = 100 Hz, 10 bit A/D resolution and variable UART communication speed between microcontroller and the Bluetooth module (19200-115200 bps). Developed Visual Basic “user friendly” software receives the Bluetooth transmitted samples and screens them. One example of on-line monitoring of ECG signal (from patient 1) and PPG signal (from patient 2) is illustrated in Fig 4. As seen the data are sent in original amplitude-time form. During this phase of experiment, system has shown satisfying and stabile results.

The second testing phase comprised the evaluation of quality of Bluetooth link in both indoor and outdoor conditions. As indoor area one reinforced concrete building (Telecomm Montenegro building) has been selected. This building presents very noisy conditions, because of installed telecomm and IT transmission equipments and networks.

Removable nodes sent the 2000 frames of 512 pseudo random 10bits samples from different distances and attitudes. Both sensor nodes at different speeds transmitted the data simultaneously. At the end of frame a 16bit CRC-CCITT was incorporated. Each receive frame that contains more than one false sample was considered as corrupted. The probabilities of corrupted frames are given in Fig. 5 (a) and (b) for indoor and outdoor cases for different transmission speeds and distances.

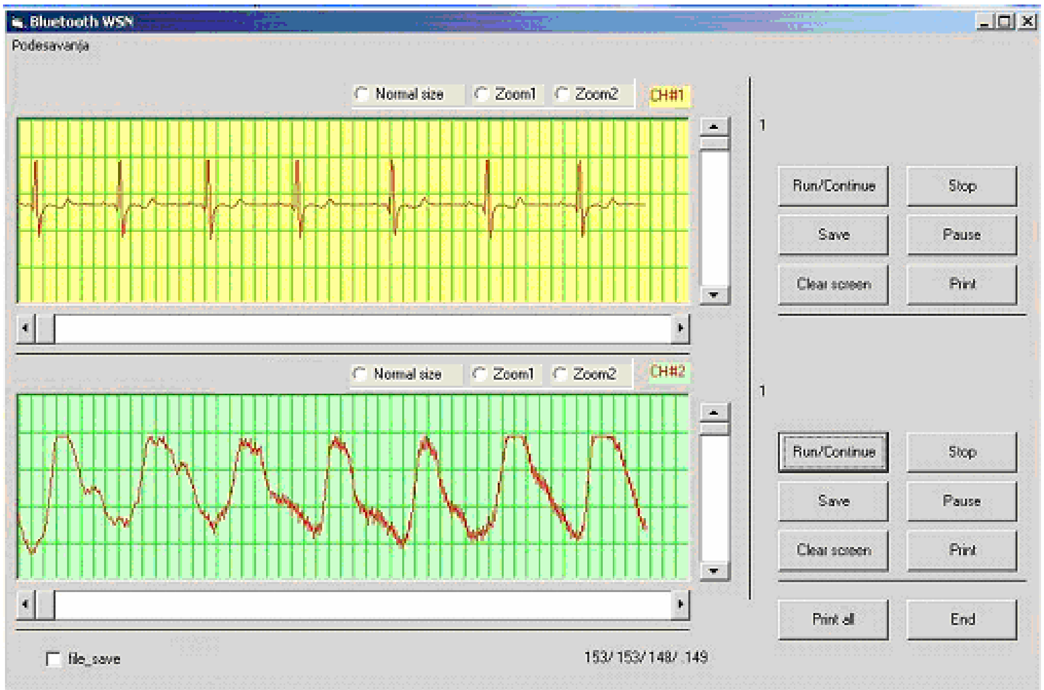
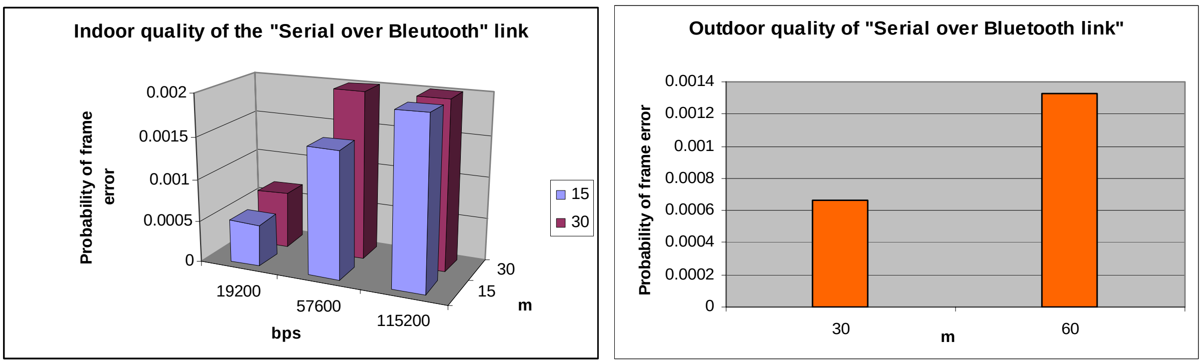


Fig. 4: The signal view during the laboratory testing



(a) (b)

Fig. 5: a) The probability of frame corruption at indoor transmission
b) The probability of frame corruption at outdoor transmission

The proposed system is primarily dedicated for indoor use. As it can be seen from fig. 5, the probability of frame corruption at the radius distance of 30 m or 60 m in diameter, especially at 19200 bps speed of microcontroller's UART interface, is very small. The number of corrupted frames grows with speed and distances but it can be considered as satisfying even at these values. Since the experiment was performed under the worst case (high noise environment), we expect better quality of link in hospital and home.

3.1 Power budget

A very important aspect that we tried to optimize was the power consumption of the movable clients. Major part of the consumed energy went to Bluetooth transmitter. For that purpose, it was set to operate in low power mode, by specific AT commands. Table 1 gives the measured consumption for different operating modes. As seen, the most economic way is the mode of sending vital signs, where the transmitter is employed during discreet time intervals. Continuous mode is unsuitable concerning consumption, since the transmition takes more than 80% of total power amount.

Table 1: Power budget for different modes

Idle	Active + Acquisition	Active+ Sending 9600bps	Active+ Sending 115000bps
1mA	3.5mA	28.5mA	31.5mA

The future work on this issue is planned to be concentrated on: (i) improving hardware characteristics of system (by minimizing physical dimensions, (ii) raising the number of nodes, (iii) monitoring of more other physiological signals (EEG, temperature, breathing), (iv) improving software performance (by including some new software routines, optimizing the GUI, etc), (v) extending the local network to WAN and global telemedicine network, (vi) and on further quality measurements.

4 Conclusion

This paper tends to present an approach of system design for the monitoring of physiological parameters using Bluetooth technology. Since the system uses wireless data transmission from mobile patient to server, it turns out to be a very convenient system for patient monitoring in home and hospital care. The suggested architecture is described at the levels of multi-point Bluetooth client, hospital-office-home Bluetooth server, and their integration in global telemedicine system. Transmission system, on the whole, is realized as "Serial over Bluetooth." Preliminary testing results have shown the efficiency of system against the classical ones

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