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Biomedical applications of Bluetooth technology

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Abstract

In the paper the features of Bluetooth wireless mobile communication technology important in biomedical applications are discussed. Comparison with other wireless technologies in this field is presented. Several examples of prototype medical systems using Bluetooth devices are also shown as well as prospective applications of this technology in wireless, wearable Bluetooth-compatible biomedical sensors. Some of the author's own concepts concerning the Bluetooth technology usage models for wireless health care systems are described. Currently developed own prototype Bluetooth systems for wireless pulse rate measurement, respirometry and Holter Electrocardiography are described as well as some other projects for home care applications.

Keywords: Bluetooth technology, Bluetooth devices, biomedical equipment, medical wireless systems, telemedicine, biomedical sensors, HomeCare, pulse rate measurement, respirometry, Holter Electrocardiography.

Biomedyczne zastosowania technologii Bluetooth

Streszczenie

W artykule przeanalizowano właściwości bezprzewodowej, mobilnej technologii komunikacyjnej Bluetooth, istotne z punktu widzenia zastosowań biomedycznych. Zaprezentowano porównanie z innymi bezprzewodowymi technologiami stosowanymi w tej dziedzinie. Opisano przykłady prototypowych systemów medycznych z wykorzystaniem urządzeń Bluetooth, a także możliwe zastosowania tej technologii w rozwiązaniach bezprzewodowych, zdatnych do noszenia na ciele biosensorów. Przedstawiono własne koncepcje autora związane z modelami zastosowań technologii Bluetooth w systemach opieki zdrowotnej. Opisane zostały opracowane ostatnio własne prototypowe systemy Bluetooth do bezprzewodowych pomiarów częstości pulsu, respirometrii, elektrokardiografii holterowskiej, a także inne projekty związane z opieką w środowisku domowym.

Słowa kluczowe: technologia Bluetooth, urządzenia Bluetooth, sprzęt biomedyczny, medyczne systemy bezprzewodowe, telemedycyna, sensory biomedyczne, opieka domowa, pomiar częstości pulsu, respirometria, elektrokardiografia holterowska.

1. Introduction

Mobile, wireless medical technologies are developing very rapidly, offering increase in quality and safety of services in this area. One of the most recent and most promising wireless technologies in biomedicine is Bluetooth (BT) [3, 6, 7]. This global standard for wireless communications was developed and introduced some years ago as a low-cost replacement of simple point-to-point cabling. However, there are also many other advantages of the BT technology leading to a strong gain of interest among manufacturers of communications and computing equipment for business and home use [1, 2].

There have been already numerous interesting implementations in these fields, many other, prospective "usage models" or "scenarios" are still being developed. Most of them arise from an important feature of the Bluetooth technology – very simple, quick creation of small networks (piconets) connecting devices, practically without any intervention of their users. As far as the biomedical equipment market is concerned, Bluetooth technology still seems to be a "newcomer" – in the last years only a few examples of applications of the BT devices in prototype medical systems have been demonstrated [3, 6, 7, 10].

2. Bluetooth technology and requirements concerning biomedical wireless communications systems

Some features of the Bluetooth technology make this system an ideal solution in biomedical teleinformatics. Along with the Wi-Fi systems (IEEE 802.11x standard) it is easy to set up complementary wireless health care networks [7]. Comparing the BT properties with the demands typical of these applications, one can easily state what follows:

- range: from 10 m (Class 3) to 100 m (Class 1); this is appropriate for a huge number of applications covering patient monitoring in Intensive Care Units (ICU) and Emergency Medical Systems (EMS) as well as home health care systems;
- energy consumption: very low, including energy saving modes; ideal solution for battery operated mobile biomedical equipment;
- bandwidth, data transfer: 432,6 kb/s (symmetrical transmission channels), reaching 721 kb/s (asymmetrical, one-direction transmission); this bandwidth allows to transmit theoretically even 100 ECG channels [8]; thanks to the frequency hopping system (FHSS) transmission is reliable even in the presence of severe noise;
- networking: thanks to advanced protocols – very simple, automatic forming of small flexible networks ("piconets", consisting of up to 8 devices: 1 "master" and up to 7 "slaves" – fig. 1); piconets can communicate one with another forming "scatternets";

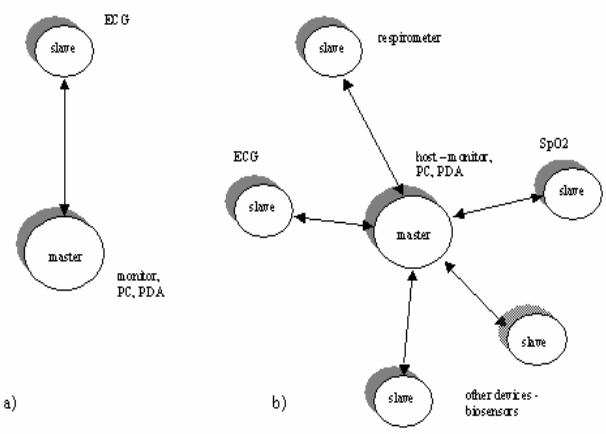

Fig. 1. Examples of the Bluetooth piconets: a) connection "point-to-point" and b) configuration "point-to-multipoint"; SpO2 states for a pulse oximeter
Rys. 1. Przykłady pikosieci Bluetooth: a) połączenie punkt-punkt i b) konfiguracja punkt-wielopunkt; SpO2 oznacza pulsoksymetr

- safety of using the BT systems in medical environment: interference with medical equipment, human body exposure – these factors are taken into account; the ISM (Industry, Science, Medicine – 2,4 GHz) band used by the BT technology and low RF power emission (1 mW for Class 3) cause that no significant problems arise in this area [6, 7, 9];
- data protection: this issue is also very important in medical teleinformatics; Bluetooth provides proper mechanisms (FHSS, error correction); optional encryption and authentication are also available;
- regulatory side, approvals: Bluetooth SIG (Special Interest Group) Qualification, Medical Devices Directive in the EU, FDA (Food and Drug Administration) and FCC (Federal Communications Commission) in the USA [6];
- small module dimensions: about 20x15x2,5 mm, including flash memory and antenna.

For comparison of the Bluetooth technology with other standards used in biomedical wireless systems, some chosen features were collected in tab. 1 [3, 7, 8].

Tab. 1. Comparison of features and capabilities of some most popular standards for wireless transmission from the point of view of biomedical systems requirements (marks: „2" very good, „1" acceptable, „0" poor); WMTS – wireless medical telemetry systems

Tab. 1. Porównanie właściwości i możliwości kilku najbardziej popularnych standardów transmisji bezprzewodowej z punktu widzenia wymagań systemów biomedycznych (oceny: „2" bardzo dobra, „1" zadowalająca, „0" słaba); WMTS – bezprzewodowe systemy telemetrii medycznej

Standard/ feature	IrDA	DECT	WLAN	WMTS	HomeRF	RFID	ZigBee	Bluetooth
Range	0	2	2	1	2	0	1	2
Bandwidth/Transfer rate	1	1	2	0	2	0	1	2
Energy consumption	2	0	0	2	1	2	2	2
Networking	0	1	2	0	2	0	2	2
Global usage/ operability	2	0	2	0	0	0	0	2
Module dimensions	2	2	0	2	2	2	2	2
Cost	2	1	1	1	2	2	2	1
Total (max: 14)	9	7	9	6	11	6	10	13

3. Prototype medical systems using the Bluetooth technology

So far, only a few examples of the BT devices in prototype wireless biomedical systems have been demonstrated, mostly in the USA; some are being developed in university research centers (in Europe: Germany, Italy, Spain) [3-8, 10]. At the MEDICA 2 Convention in November 2003 (USA) the following systems were presented:

- Stryker Endoscopy (Stryker Corp., USA) – Sidne™ (Stryker Integrated Device Network) for Operating Room, integrating the BT system with 802.11b network - first FDA certificate;
- 4100 Digital Pulse Oximeter/Medical Avant™ 4000 DPO System (Nonin Medical, Inc., USA) – first Bluetooth SIG approval, FCC certificate;
- 12-lead ECG transmission from M Series defibrillator/monitor via PDA, also ResQPOD and AED Plus (all from Zoll Medical Corp., USA) – wireless systems for EMS;
- LifeSync® Wireless ECG (LifeSync, USA) – ECG and respirometry system for EMS and ICU, shown on fig. 2 and 3;

Fig. 2. LifeSync® Wireless ECG – ECG and respirometry system; patient module [10]

Rys. 2. LifeSync® Wireless ECG – system EKG i respirometrii; moduł pacjenta [10]

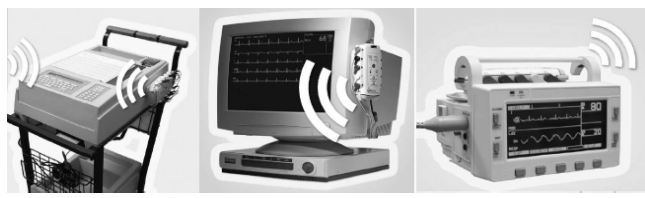

Fig. 3. LifeSync® Wireless ECG – ECG and respirometry system; receiving devices [10]

Rys. 3. LifeSync® Wireless ECG – system EKG i respirometrii; urządzenia odbiorcze [10]

- MobiMed (Ortivus AB, USA) – ECG, SpO2 (pulse oximetry), respiratory rate, blood pressure for EMS;
- wireless ECG monitoring (Stollmann, Germany) – for ICU;
- 4-lead ECG recorder, battery operated (GSI/Lumonics, USA);
- FreeStyle Tracker Blood Glucose Monitoring (TheraSense, USA), piconet with a digital BT-enabled glucometer, PDA and a printer;
- Achilles DexterQUS (GE Medical Systems, USA), a piconet built of a bone ultrasonometer Achilles InSight, PDA and a printer – for osteoporosis risk assessment;
- Wireless Telehealth for Home (RTX Healthcare, USA), a piconet with a blood pressure/pulse rate monitor, personal weight scale and PSTN&GPRS/GSM Telehealth Gateways – for Home Care.

As examples of university research projects one may consider:

- a wireless, Bluetooth-based medical communication platform (Karlsruhe, Germany) – a piconet connecting wearable BT-biosensors and therapeutic units with a central display [8];
- @Home (Darmstadt, Germany) – a modular Bluetooth-based telemedicine system for remote patient monitoring [4, 5].

4. Developing own prototype BT-medical systems

The author's projects on biomedical applications of the Bluetooth technology are realized at the Department of Cybernetics and Electronics of the Institute of Electronics, Telecommunications and Information Technology, Faculty of Electrical Engineering. Our team worked some years ago on wireless transmission of vital signals of mining rescue screws and we gathered a lot of experience in this field. Also students have been involved in designing the prototype systems. First goal was the BT-Holter – a system for long-term ECG data recording and wireless transmission to a PC or PDA. In our first design, in 2003, the ATmega103L microcontroller (Atmel) and OEMSPA13i BT

module (Code Blue Communications) were used. The next study, realized within the student M.S. thesis, was based on an ATmega8L microcontroller (Atmel) and a Bluetooth RS-232 Adapter (CC&C). The ECG amplifier was developed as well as software for recording and simple analysis of the ECG signals on a PC. As a result, a fully working prototype system was elaborated (fig. 4 and 5).

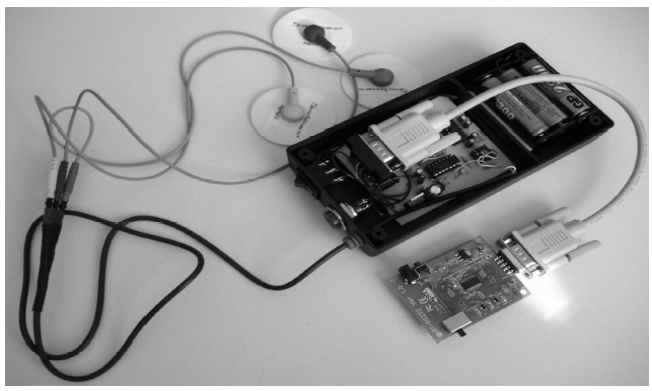

Fig. 4. Prototype of a BT-Holter ECG; patient module
Rys. 4. Prototyp elektrokardiografu holterowskiego; moduł pacjenta

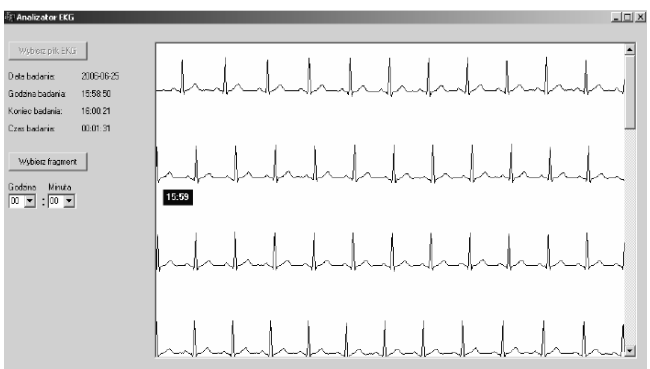

Fig. 5. Prototype of a BT-Holter ECG; printout of the PC screen with remote ECG recordings
Rys. 5. Prototyp elektrokardiografu holterowskiego; ekran komputera ze zdalnymi zapisami EKG

Other biomedical parameters and signals were the subject of our research as well. In the work on wireless respirometry (at the first step we focused on the rate of respiratory action), the thermistor sensor placed close to the nose and a Development Kit (Ezurio) with the blu2i Bluetooth module was used (fig. 6). The prototype, also developed as a M.S. thesis, is shown on fig. 7. The same Development Kit was also used in a preliminary study on wireless pulse oximetry.

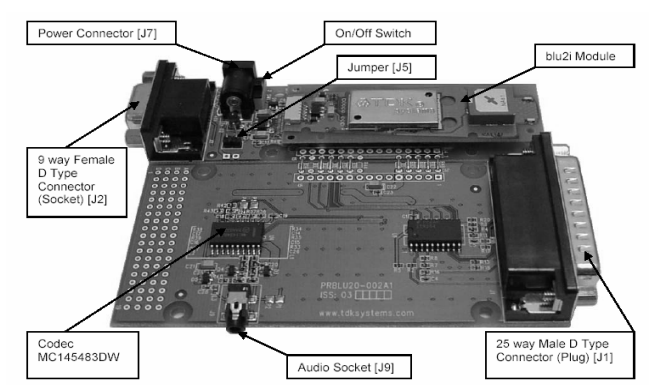

Fig. 6. Development Kit (Ezurio) with the blu2i Bluetooth module
Rys. 6. Zestaw rozwojowy (Ezurio) z modułem Bluetooth blu2i

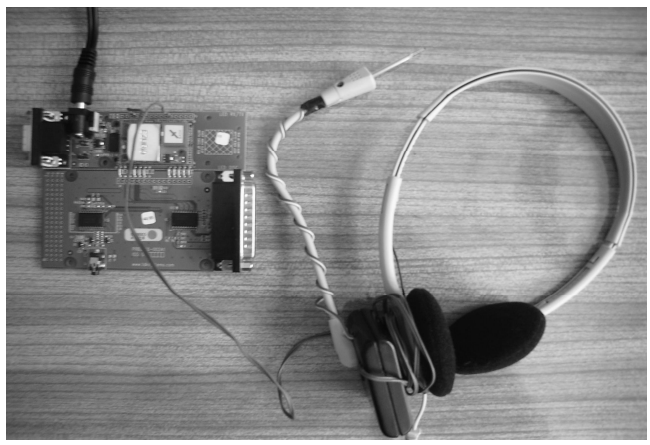

Fig. 7. Prototype of a BT-respirometry system with the thermistor and blu2i module
Rys. 7. Prototyp systemu respirometrii w technologii BT z modułem blu2i

Remote pulse rate measurements in mobile persons have seen a high level of interest from researchers in the field of bioengineering. In our first study on a BT - pulse rate meter we used an optoelectronic IR pulse sensor developed within the research work for mining rescue teams. The patient unit was based on a PIC16F876 microcontroller (Microchip) and a ROK101008 Bluetooth module (Ericsson). Also the software for visualization of the remote pulse recordings was elaborated (fig. 8).

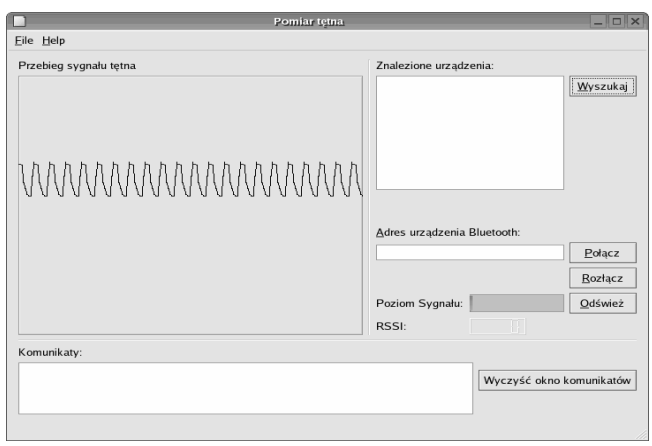

Fig. 8. Screen with the example of remote pulse recordings
Rys. 8. Ekran z przykładowym zdalnym zapisem pulsu

Other author's studies are focused on the BT usage models (scenarios) for Home Care applications, mainly for elderly and disabled people as well as patients during rehabilitation. Preliminary design work has been also undertaken for "Special Care" – e.g. BT-enabled hearing aids for people with hearing loss, BT-Braille keyboards and displays for visually handicapped people etc. Recently we have been working on the RFID and ZigBee technologies in similar fields of applications (a part of work is performed within the Consortium established currently for a European research project).

5. Conclusions

The Bluetooth standard seems to be one of the most promising mobile wireless technologies in biomedical applications. It has seen a high level of interest from medical equipment manufacturers for use in this market, as well as from researchers working on new solutions in health care. Together with other emerging communications technologies like RFID and ZigBee, Bluetooth can form a platform for wireless, mobile E-health services.

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