A PROTOTYPE WIRELESS PERSONAL ECG MONITORING DEVICE CONNECTED VIA BLUETOOTH

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Abstract: Use of portable devices is daily growing (mobile phones, PDA, laptop); it is also offered the possibility to exchange data between them or with other devices, usually, via wireless connection. Besides, new tendencies in diagnosis are going towards the use of personal, portable or even wearable, biomedical instrumentation. In this scenario, different are the solutions adopted, depending on many factors: a brief overview about possible solution is reported. The specific aim of this work is to analyze the feasibility and the problems concerning the integration of the Bluetooth communication standard into existing or designed-on-purpose patient monitoring devices. In particular, a prototype of a personal wireless ECG monitoring device, operating in real time and connectable with generic Bluetooth (ver. 1.1) receiver was realised and tested with particular attention to efficacy, range, interference, data protection, cells consumption.

Introduction

Modern tendencies in diagnosis are going towards the use of personal (portable or even wearable) biomedical instrumentation; in general "cable free" equipments that result comfortable and appreciated by the patient because not limiting body mobility. In perspective, a personal monitoring, opportunely used in specific follow-up, may reduce the number of hospitalizations and improve patients' quality of life.

More and more frequently are available on the market wireless monitoring devices such as hospital patient monitors, ambulance or portable equipments, some homecare devices, etc. which uses RF telemetry systems, Wi-Fi connection, mobile GSM network or even satellite connection. Many of these systems may need to transmit the acquired data to a reference centre and/or to connect themselves to an existing communication network.

Different solutions have been implemented for patient wireless telemetry in the past (e.g. UHF or VHF3 radio, infrared links, etc.); nowadays more opportunities are available with digital communications. Due to its almost global availability, the 2.4 GHz Industry Scientific and Medical (ISM) unlicensed band constitutes a popular frequency band suitable to low cost radio transmission and it is not a case that it is also named "Medical". In addition, new modulation techniques (e.g. Frequency Hopping [10]) offer spread-spectrum, reduction of electromagnetic interferences, secure transfer protocols, encryption, and implementation of wireless networks [6].

On the other hand, specific problems are related to this kind of portable instrumentation e.g. the recoverability of the devices, the dimensions of the transmitter and the receiver, time of activity, power consumption and batteries, compatibility with the continued operation on patient body, interference with other telecommunications standards [3,4,9], and also problems of correctness and confidentiality of the transmitted data.

Among these alternatives, Bluetooth standard offers important advantages: operation in ISM band, low costs, relatively low power consumption, confidentiality of the data, dimensions of the transmitter, and, very important, this transmission protocol it is already embedded in most of portable, palm computers and mobile phones and already used in wearable devices (e.g. mobile phones wireless headsets) [5,7].

In conclusion, it is worth to explore the possibility offered by available technologies to realise a wireless medical devices connected to portable personal devices building a sort of personal medical network

Materials and Methods

In order to choose a communication solution, the requirements to fit for a wireless personal medical monitor were: use of a standard transmission protocol (preferably operating in the ISM band) for easy integration and usability, moderate consumption for battery powered device, suitable data rate exchange for real time functioning, rejection of interference for operation in any daily environment, secure protocols able to assure the confidentiality of the transmitted data.

Standard	Frequencies	Data Rate (max)	Distance (usual)
802.11b	2,4 GHz	11 Mbps	150m.
802.11a	5,8 GHz	54 Mbps	100m
IrDA	-	4 Mbps	2m.
Bluetooth	2,4 GHz	723 kbps	10m.

Figure 1: Wireless Technologies - General Standards

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At moment, possible wireless standards candidates are the 802.11x (Wi-Fi), IrDA and Bluetooth: their main characteristics are listed above in the figure 1.

We did not include the emerging ZigBee standard because of its limited integration, at the moment, in the existing electronic devices, and its relatively low data rate [8]; however, it offers extremely low power consumption.

For our purpose we firstly eliminated the IrDA option because it needs to have "line of sight" linking, it may suffer for uncertainness of connection in real-life environments and its power absorption.

Wi-Fi best fits as extension of existing cabled network but its usual range of about 100 meters (in open field) requires considerable power consumption, relevant for a personal device. However it is worth mentioning that many commercially available wireless patient monitors used in hospitals provide now a Wi-Fi connection and indeed it could be a suitable solution for hospitals, probably already served by a cabled or a wireless network.

Bluetooth it is used to connect a limited number (up to 8) of devices, in a limited range (1/10/100m depending on TX power) [1]. This standard also represents an interesting alternative for applications involving short distance and low power transmission: in terms of power consumption, interferences rejection (with the Frequency Hopping technique [10]), confidentiality of the data and the available integration in a great number of portable devices. Also in terms of transmitter/receiver dimensions, the Bluetooth standard fits size requirements (many mobile phones are equipped with a Bluetooth connectivity without any considerable rise in dimensions).

Therefore we choose to explore the possibility and the features offered by the Bluetooth standard to realise a wireless connection with medical devices.

Our first attempt was to build a general Bluetooth wireless connection to get rid of cables connecting commercial medical devices to PC via serial communication.

The main task was to design and to realise a prototype of a general purpose personal Bluetooth monitoring device, with the following HW/SW requirements: ECG "real-time" monitoring, simple patient interface (just an on-off switch and two thumbs electrodes), programmable sampling frequency (100-1000Hz), minimum ECG resolution 1μV, wireless Bluetooth 10m range of transmission, reduced dimension and light weight, battery powered, data security and encryption, operation in ISM band, user-independent connection with receiving devices (e.g. palm PC, mobile phones, etc.), simple acquisition and storage software, possibility of simple signal processing on-site and eventual data transmission to reference centres.

The prototype was designed as a general-purpose patient monitoring device, thinking about the possibility to integrate other patient's signals (depending on specific monitoring purposes).

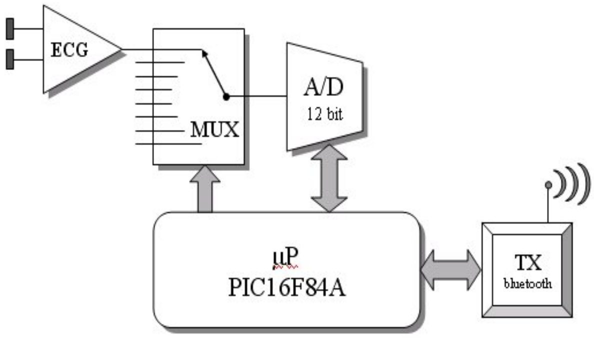

Figure 2: Block diagram of the device, showing its different main sections.

The ECG module mainly consists of two-thumbs electrodes, a low supply voltage instrumentation amplifier (INA128p - CMMR > 100 dB) followed by active filters. A multiplexer offers the possibility to select up to 8 analog channels and up to 4 digital inputs (at moment only a single analog channel is used for the ECG signal). Analog signals are sampled using a 12-bits A/D converter.

A widely available PIC microcontroller (16F84A) was programmed to interface the MUX and the ADC and then to produce serial data stream, which are provided to a Bluetooth (ver. 1.1 compliant) transmitter module, visible in figure 3, already equipped with a small antenna (OEMSPA13i - ConnectBlue).

A battery pack provides a +/- 5V dual power supply and all the circuitries were enclosed in a plastic case of 15x9x6 cm in dimensions, on which only an on-off switch and two electrodes are presented to the user. The device weight is about of 300 grams [3].

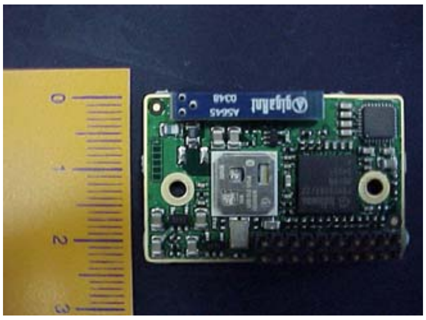

Figure 3: The Bluetooth module

The Bluetooth module needed a first configuration session to assure the link with the receiving Tablet PC, creating the so-called "piconet" in witch the laptop was programmed to play the role of master.

Piconet is the name given to a Bluetooth network that, as mentioned before, distinguish itself from other networks.

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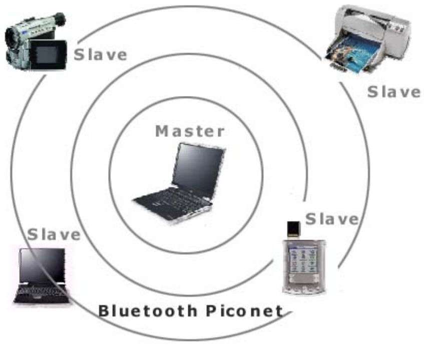

Figure 4: Example of a piconet network

As switched-on, the Bluetooth module is automatically initialised for "pairing" the receiver: it starts a paging session (discovering devices), and when find the its specific (the only one authorized to communicate with) receiver (in our case the tablet PC) it automatically begins the real time transmission of ECG data and implementing also the data security protocols (encryption).

A Simple software was developed to receive and to store ECG data; it has also simple signal processing capability. The software graphical interface was made user-friendly and give the possibility to see the ECG signal and other simple information in real-time during patient's monitoring [2].

Results

Features of the realised prototype device were tested using a tablet PC with an integrated Bluetooth module (figure 5). Experiments were carried out at the Dept. of Electronics and Telecommunications Engineering of the University "Federico II" of Naples.

It has to be mentioned that Dept. building is supplied with a Wi-Fi network. In the worse case Wi-Fi antenna was just 5 meters away from the laptop-ECG device area and even if possible problems in the recovering of the paired devices and a throughput of the signal were feared, they were not experienced.

In this environment the Bluetooth link has been analyzed in terms of range, interference rejection, integrity and security of the transmitted data.

The manufacturer of the Bluetooth module embedded in the ECG monitor declares 10-metres "Open Field" range of transmission and despite the presence of walls and many other kind of metallic surfaces, was never experienced a radio signal loss or linking problems within the 10 meters range.

Power-line frequency noise on ECG signal (lead I) resulted very reduced also because the device was completely floating. Some noise arise by insecure thumbs contacts with electrodes.

The use of prototype device resulted easy and intuitive, important characteristic for elderly or impaired people (potential users of personal monitors).

Dimensions of the device can be easily reduced if needed (circuitries only occupy a small space of case interior).

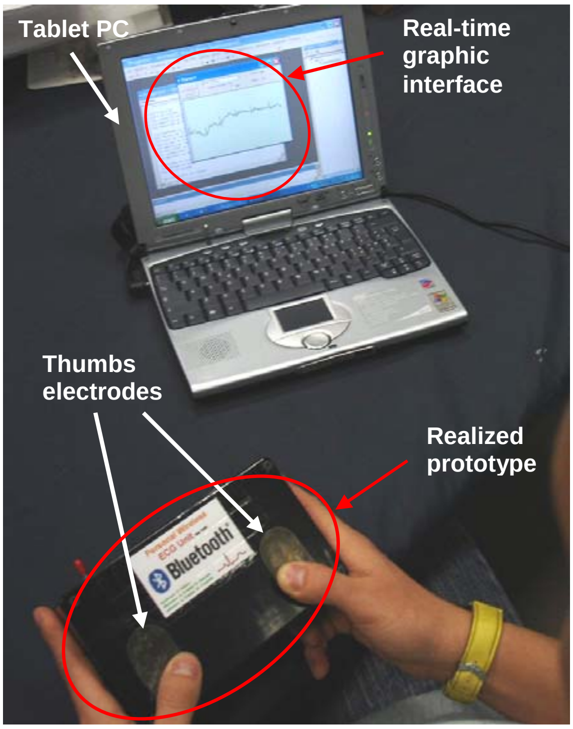

Figure 5: An example of the ECG wireless transmission realised

Power consumption of the device was also measured (in terms of the current absorption) in order to evaluate the battery autonomy. Three main circuitries were separately tested: the ECG front-end, the MUX, ADC and the PIC microcontroller (mounted on the same PCB) and the Bluetooth module.

For the ECG circuit we measured an absorption of 2 mA; the absorption of the PIC section was of about 10 mA. The current absorption of the Bluetooth module is conditioned obviously by its working conditions: during the data transmission the measured current was about 50 mA while it drops to about 40mA when not in transmission.

The current absorption of the whole personal ECG device) was therefore of about 60 mA: mainly conditioned by the supply current absorbed by the Bluetooth module. Hence, for example, using a standard battery pack (like those for mobile phones) the time of continuous operation is limited up to some hours.

Conclusions

At present, personal patient monitoring has a growing interest for healthcare services and opens new sceneries. Such devices become more are more sophisticated, providing enhanced capabilities, and also designed for specific patients' monitoring needs. They are always smaller, light weighting, need minimal intervention by medical doctors, nurses or patients (just place the electrodes and push a button) and generally able to store and eventually transmit data.

In this framework, the adoption of the Bluetooth communication technology can be considered even for a simple connection cable-replacement [5] of existing medical equipment. As mentioned, a wireless connection with a commercial ICU patient monitor (provided of a digital serial output) and a desktop PC was also successfully realised [2] using commercially available Bluetooth adapters.

Moreover, considering the expansion of Bluetooth technology, that promises to commercialise very low-costs devices, capable to be easily embedded in most diffused electrical and electronic device, Bluetooth deserve to be seriously considered for medical applications, mostly for personal monitoring devices.

A great advantage it is offered by the possibility to utilise widely used personal devices like mobile phones or PDA (more and more provided with Bluetooth) to connect with personal medical devices and also to connect with reference centres.

A concern remains about battery autonomy, at moment Bluetooth results not very suitable for wearable device performing a continuous monitoring all day long. For this requirement the ZigBee standard is much more promising but suffers for a much more limited diffusion.

Further work on this topic is oriented to develop specific software for PDA and mobile phones and to enhance the possibility of connection with reference centres.

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