# THE WIRELESS MONITORING OF VITAL PARAMETERS: A DESIGN STUDY

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***Abstract***– *This project shows the way vital parameters can be transmitted and visualized with no connecting cables necessary to the PDA. This was realized using a sensor developed with an integrated Bluetooth interface and a PDA, also equipped with Bluetooth. This radio connection can span up to 10 m, and parameters, such as pulse frequency, oxygen saturation in blood, ECG measurements and plethysmograms, can be transmitted. Using the software introduced in this work, the transmitted measurements can be displayed numerically or graphically on the PDA. The software simultaneously checks for any limits and sends a warning message if these limits are exceeded. All received data are additionally documented.*

***Keywords***– *monitoring of vital parameters, ECG, Bluetooth, medical sensor, PDA*

## Introduction

The monitoring of vital parameters is an every-day thing in medicine. Despite the increased improvement in measurement and display methods, the devices haven't been able to keep up with the development of technical possibilities. Especially in the areas of intensive care and emergency services, the connecting cables from the sensors to the corresponding instruments often hinder the medical care or cause a time delay. Other weak points of wired sensors include the frequent separation of the cables from the sensors, the limited cable length, and the time that's lost in attaching all the cables to the sensors and instruments. This problem should not be underestimated, as it's been conformed over and over in medical emergency situations.
The most important innovation in this project is logically the monitoring of vital parameters without connecting cables, but also the possibility of visualizing the vital parameters on a commercial PDA.

## Goals

One of the goals of the project is to install a permanent transmitter on the patient at the beginning of the treatment, which multiplexes and amplifies the measurements of the sensors on his body. These amplified measurements are digitalized by the transmitter and are sent to the receiver, which could be any of a wide variety of devices (Fig. 1).
The goal of this work was to optimally realize the wireless transmission of vital parameters in realtime to a commercial PDA.

The most important criteria in transmitting medical measurements by radio is the robustness of the radio connection and the data security. The radio connection must be guaranteed in a specified framework and false measurements must never occur in the transmission. It is also to be observed that medical measurements are personal data of the patient, and the privacy of the patient should be protected from unauthorized third parties.
Despite these requirements, there shouldn't be any limits in the general function of the visualization device. Time delays should be especially avoided.

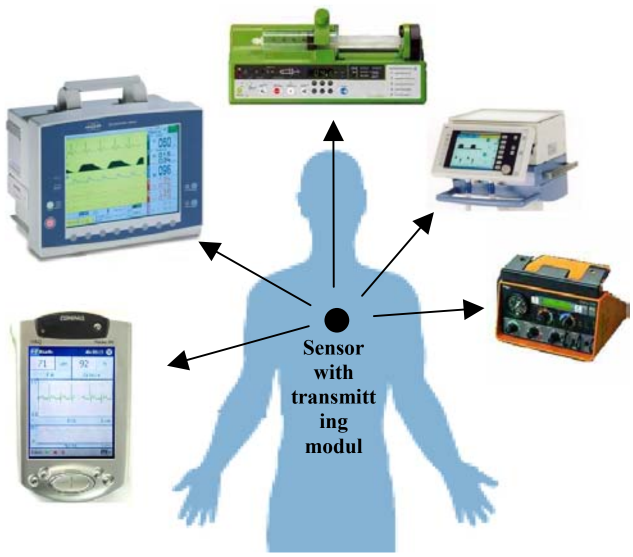


Figure 1: Overall concept

## Materials

### Bluetooth

Bluetooth was selected as the transmission standard, since it fulfills our requirements for the transmission of medical measurements the best [1, 2]. Using a frequency hopping and error correcting procedures, the connection is robust against disturbances and secures the transmitted data from being falsified. Bluetooth also has state-of-the-art encryption, which protects the transmitted measurements from unauthorized access, thereby guaranteeing data protection.

### Hardware

To realize this project, all connecting cables should be replaced by alternatives. It was decided to use radio as the

transmission medium for transmitting the measurements of the various sensors. The IEEE 802.15 WPAN (Wireless Private Area Network) standard was chosen, also known as the Bluetooth Standard.
The sensor's hardware is based on an embedded module developed under this project with Bluetooth functionality.
The receiver consists of either a PDA or a handheld PC with an integrated or added-on Bluetooth interface. At the moment, however, it is still difficult to find suitable system platforms for this application, since the development of Bluetooth products is at its beginning.
The software for the PDA was developed on a commercial PC. The compiled programs were transferred to the PDA via the docking station. Debugging was usually done on the PDA itself.
A laptop with a Bluetooth PCMCIA card was used for the virtual sensor and for demonstration purposes.

## Methods

**Software Architecture**
The software called "BlueOx" which runs on the PDA was implemented object-orientedly. All sub-modules were derived from one module class (Fig. 2).

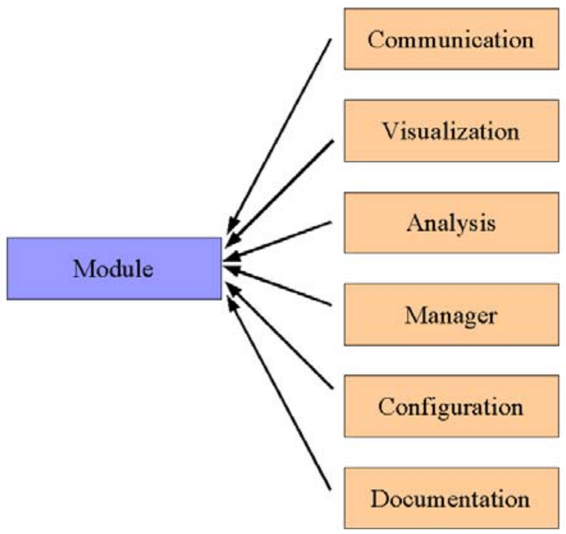


Figure 2: Class diagram of the BlueOx software

Also, thread-based development was chosen in order to be able to guarantee the realtime capability of the system and to keep the most important functions available at all times. The main thread runs in the manager class. Each module, such as the communication and visualization modules, have their own threads.

**Manager**
The manager module is the heart of the system, which controls each of the other modules. It organizes the data flow and data processing, depending on priority, in order to guarantee the reception and realtime visualization of the data. When there is sufficient computation time, other modules are dynamically included, which expands the system's functionality.

**Visualization**
The visualization module is responsible for data preparation and measurement display. It is implemented such that is can be easily adapted to other display formats and sizes by configuration, so that the software can also be used, for example, on a handheld PC. It is also possible to display the data graphically, as well as numerically. The visualization module gets its data from the manager.

**Communication**
For communicating via Bluetooth, the software makes use of the Bluetooth driver function of emulating a serial port, which represents the interface between the software and the Bluetooth module. The communication module receives the data via a protocol similar to the European Data Format (EDF Format) [3]. As in EDF format, first, information concerning the type and capacity of the receiving channels are transmitted in a header. Then comes the data with time stamp, in order to guarantee the realtime data capability. All received packets are confirmed to the sensor by the PDA. The communication module generates program-internal measurement objects from these data and prepares them for "pick-up" by the manager. If the connection is lost, there is an automatic reconnect.

**Analysis**
The analysis module checks the data. Limits of the various measurements are checked, and are highlighted visually if they exceed the limits. Acoustical alarms are also possible.

**Configuration**
The configuration contains all settable program parameters and can also be changed at runtime. The threads are configured with the data of this module at the time they are created.

**Documentation**
The documentation saves all received data in EDF format. This allows the transmitted data to be called at any later time.

**Sensors**
The distant end of the BlueOx software on the PDA consists of a pulse oximeter or ECG sensor, which are equipped with Bluetooth functionality and are controlled by a microcontroller.
In addition to the hardware sensor, software is written with the virtual sensor which simulates the hardware sensor on a normal PC which has a Bluetooth interface. This software was developed mainly for test purposes and error correction. Precise error scenarios were simulated in order to test the reaction of the BlueOx software, and if necessary, to add to it.
The software is also used for demonstration purposes. It sends the stored data cyclically to the BlueOx software and simulates a real person with sensors attached to his body.

## Results

The BlueOx software was implemented and tested as described above (Fig. 3). The ECG and plethysmogram are graphically displayed, and the pulse and oxygen saturation are displayed numerically in realtime. This allows all measured vital parameters to be seen at once.


Figure 3: BlueOx software on a PDA

The BlueOx software is configured and controlled over a menu. If the PDA goes out of range of the Bluetooth connection, data are no longer displayed until it returns, at which point transmission and visualization are automatically continued. The maximum distance for data transmission within buildings is about 10 m. The computational performance of an average, modern PDA is sufficient for the tasks described here. The transmission bandwidth used for the data is very small compared with the potential defined in the Bluetooth standard [1].

## Discussion and Outlook

The developed demonstration system obviously fulfills the set requirements. The wireless monitoring of vital parameters works and the 10 m range is longer than any cable being used now. The fears that the computational performance wouldn't be enough for the PDA could not be confirmed, thanks to the thread-based software architecture and the selected implementation.

Since the development of Bluetooth-compatible hardware is clearly progressing, more advanced software functions, such as selecting among several patients within range, switching channels, or automatic searches, will be realizable soon.

Emergency service applications include the planned integration of a mobile phone in the PDA, with both the transmission of temporarily saved data, and data streaming in a clinic. Patient monitoring during transport in the rescue vehicle can also be continued, despite potentially hazardous local conditions, since no cables are there to complicate things.

Another application field of this technology would be the continuous monitoring of long-term, stable patients at home. Data is saved on the PDA., which can be transferred to the appropriate doctor's PC for analysis. This data could also be stored in an internet-supported patient record [4-6].

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