Personal Electronic Nurse – medical monitoring system

András Tóth*, Lóránt Vajda**, Ferenc Vajda*

*Budapest University of Technology and Economics,
Department of Control Engineering and Information Technology
{totha, vajda}@iit.bme.hu

**Bay Zoltán Foundation for Applied Research, Institute for Applied Telecommunication Technologies
vajda@ikti.hu

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A common problem in Telecare systems is that the physician and nurses are unable to be with a patient with sufficient frequency. This paper introduces a wireless telecare system for patients in and out of the hospital. The primary goal of this study is to establish real time monitoring of the patient's vital signs in a system called the Personal Electronic Nurse (PEN). The biomedical data for each patient, such as, ECG, blood pressure and body temperature are pre-processed on the PEN Mobile Device and transmitted to a Data Collection System using wireless communication and embedded technologies. The system is able to monitor patients' vital data and to display their personal information in a continuous fashion. The main features of the system have been implemented and tested. The results are promising and show the system can the various modules to collect sensor data and send it to the collector system successfully.

1. Introduction

In the past, the medical care monitoring for a patient was managed only by measuring of vital signs manually, documenting the measured values on paper, and communicating over phone lines or handheld devices. Nowadays, sensor network solutions are becoming an important part of medical administration systems. Important features of these systems are low energy consumption, small size and reliability. Patients that use such solutions are accepting the monitoring systems as long as they do not feel that they are watched all the time by an intelligence system ("Big Brother" effect). Therefore, it is not enough to create small and low weight devices, but it is getting important to use wireless technologies.

We have developed a system called Personal Electronic Nurse (PEN) that facilitates collaborative and time-critical patient care in the telecare community. First, automated vital data collection is accomplished and can be processed locally and accessed remotely by the care personnel (nurse, doctor, etc.). One of the most important features of the system is its scalability so it can serve from one patient to hundreds and could expand from one room to a national service.

The modularity of the system is highly defined in terms of software and hardware. At the design phase we decided to use currently available, stable and trusted platforms and technologies. This enabled us to create a reliable and cost effective system which is very compatible and easily made in comparison with other similar systems in the market.

The main contributions of this paper are the following:

- A review of similar systems is presented with a list of pros and cons.
- Based on the conclusions a system plan and realization method is given.
- Finally, the functioning system and future plans are presented.

2. Overview of wireless telecare solutions

A rapidly increasing number of healthcare professionals believe that wireless technology will provide improved data accuracy, reduce errors, costs and improve the overall patient care service quality. In our vision the problems raised in such systems can be solved on three levels:

(i) Collect and preprocess the sensor data locally by defining intelligent data filters and saving data streams on local storage;
(ii) Prepare a dynamic data collector system;
(iii) Develop of easy-to-use display devices.

A good example of a telecare system developed especially for out-of-hospital situations is the MobiHealth [1] project, which uses 3G technology for patient monitoring. The system is able to analyze all the collected vital data continuously, getting the disease characteristics and analyzing the causes. MobiHealth can be successfully used for large distances, however, it is too complex and expensive. On the other hand, the system uses continuous streaming of all of the patients vital data on the wireless link, which is not desirable at all in such systems, since this solution leads to a large overhead.

An other solution dealing with sensor systems for telecare solutions was developed by the Shimmer mote community [9]. This mobile mote uses two wireless channels for communication, Bluetooth and Zigbee, which

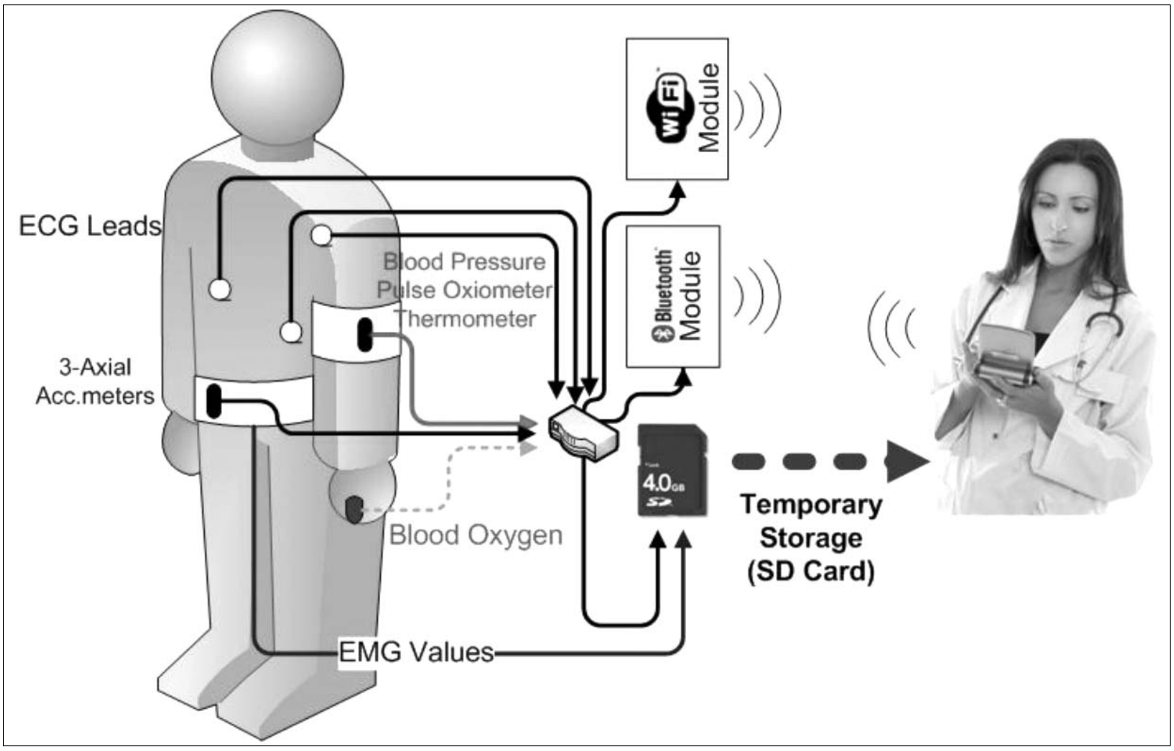


Figure 1. Data storage solution

are available in the mobile device. Having two wireless radios switched on all the time on increases energy consumption. Another drawback of this system is that from the development point of view Shimmer mote is very expensive.

There are several solutions available that can solve data processing and data display problems. One of the satisfying approaches is the Code Blue project's [7] platform independent VitalDust application. Unfortunately, it has a proprietary protocol, which cannot be integrated with other third party systems, and is undesirable from the present medical care point-of-view.

3. System design and implementation

Using existing standards and recommendations in an overall system makes it easy expandable and compatible with other systems and helps solving the problem of scalability.

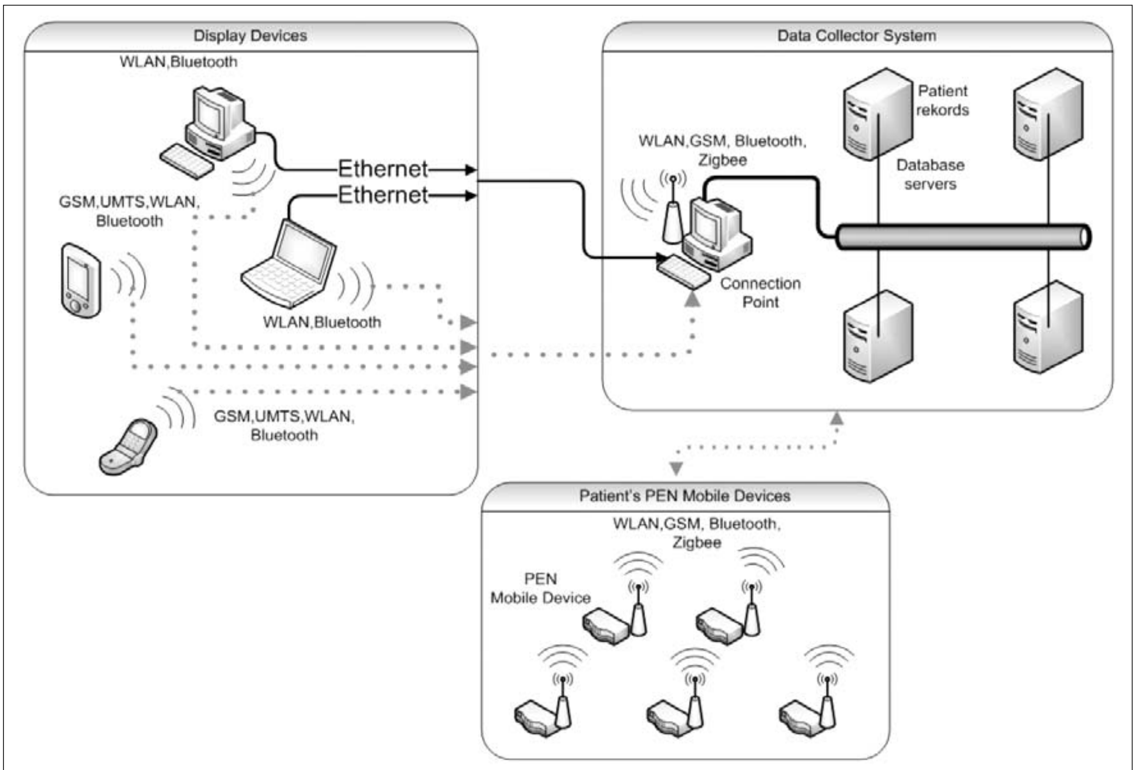


Figure 2. Planned system modules

The system has three main components *(Figure 2)*.

(1) The *PEN component*,

which contains mobile devices. These devices can use several wireless communication channels depending on the user demands. Our main goal is to develop a mobile element, which can measure and deliver the patients vital data. To accomplish this, an effective data collecting and processing network is needed too, which can securely gather and display all of the patient' data. Measured data in the PEN component is pre-processed based on pre-defined filters and rules. If the available bandwidth of the communication channel cannot deliver the continuous streaming, temporary data storage must be included in the PEN. It is also important that the data be represented in a standardized format. An internal storage solution is also helpful to move the collected vital data, for example, to a PDA used by a doctor or nurse by simply changing the storage memory *(Figure 1)*. In this way, only high priority data has to be sent through the (wireless) communication channel. A remote configuration and management scheme has to be done in the PEN, which allows for a remote update of the PEN units software, driver upload and management.

(2) *Data Collector System* –

Used for data storage of patient records. There is also a higher intelligence requirement for data processing and representation than in the PEN unit.

(3) *Display Devices* –

These can be a PDA, PC or other mobile phone device which is capable to run a lightweight application software for visualization of the measured and processed data.

3.1 Wireless technologies

As stated, currently available solutions involve only fixed communication technologies in the system. We have developed a solution which can handle various types of communication connections (Bluetooth, Zigbee, GSM, WLAN) switching transparently between them as needed.

Figure 3 represents a multi-communication setup. In this way, if a user uses the PEN in a Bluetooth area, then Bluetooth technology is used for communication. Moving the user in a WLAN environment, the communication is changed transparently to WLAN. If a new communication module is purchased, that can also be used with this system by changing the communication module (of course, providing a driver for it is necessary). Therefore, the communication module can be changed on the fly and the needed driver parameters are stored on the unit itself or can be downloaded from the storage memory.

3.2 Modularity and open devices

Developing any new device always raises the question of how to reuse the existing modules which would otherwise have to be redesigned from the ground up. In our vision, at the design phase, we use as much as we could from existing industrial standard modules. In this way, stability is increased, and less expensive system can be produced.

4. Processing system plans

As mentioned before, the essence of PEN is to incorporate existing standards and solutions. To do this it was

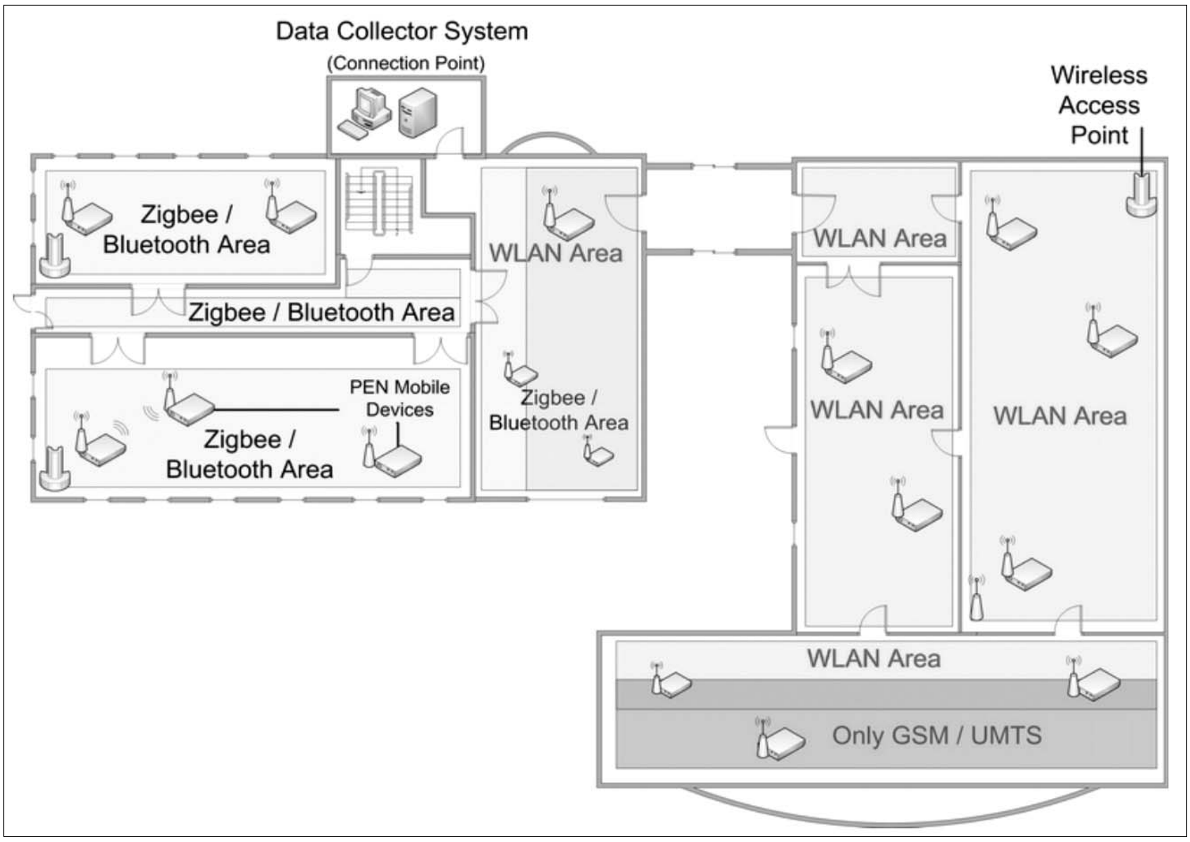


Figure 3. Multi-communication setup

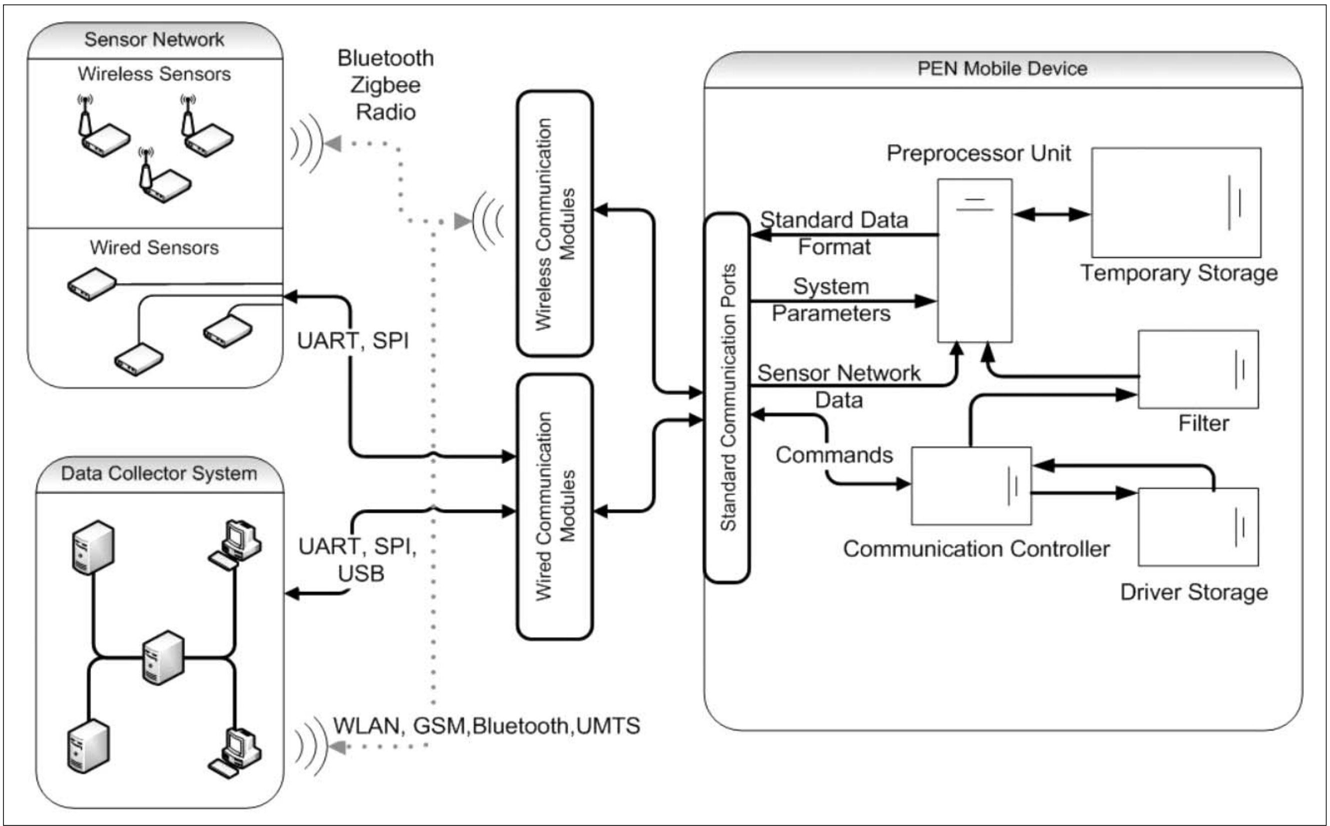


Figure 4. Modular architecture of the system

necessary to create a complex driver architecture for the communication and sensor modules. The main problem we solved was how to find the right driver system for the connected elements, and make the system ready to use it.

4.1 PEN Mobile device

During system design we understood that the resources in the mobile device were limited. Therefore creating complex services on the PEN itself is not possible. Moreover, the energy consumption of these nodes has to be kept on a low level. In a mobile device the wireless communication modules are the main energy consumers. The less these modules are used, the lower the power consumption. In this way, within the PEN, the measured data has to be preprocessed (by filtering methods), compressed, stored on an internal storage and sent only at communication times of the wireless modules. Data compression is also useful to avoid communication overhead.

The above mentioned filtering methods can be divided into two main parts:

(1) Development of a uniform standardized sensor data format, which allows the system to understand and analyze the measured information without reference to the sender sensor type.

(2) Design of algorithms which can fit the measured parameter of a user into a general User Profile. Therefore, the application has to learn about the user specific parameters and edit the measured values in the mobile device. If a measurement shows an emergency scenario, then the communication channels are immediately used to send out alerts. Additional measurements are stored on the internal storage of PEN and sent out only if needed by the Data Collection System.

Depending on the wireless communication technology used, the system can perform stable, multi-hop communication [2] and if needed, extends the range of the radio communication and decreases energy consumption.

The modular architecture of the PEN mobile device can be seen in *Figure 4*. Different internal units of the PEN can be seen as well with the internal interfaces between the units represented. The possible connection types between sensor networks, PEN and Data collector modules are shown as well.

4.2 Data Collector System

The main parts of this module are the *data collector, processor* and *storage* units. It is important to have all components operate in a fast but safe mode. At this time, several groups have developed solutions for such purposes. Unfortunately, these solutions are too specific and unique to include them in our system.

To have a scalable and compatible system, we have decided to use the recommendations of the NESSI [3] community. NESSI is founded to specify recommendations for standardized software and service interfaces. Moreover, the system is designed to handle a multi-connection architecture.

4.3 Display Devices

In such a system, a module is needed, which allow users to login into the system safely, check the measured vital data, check the processed and analyzed results and perform modifications on the system, if necessary. Of course authentication mechanisms and user rights have to be set carefully. For this component, NESSI recommendations are also used to access the database and data handlers.

5. System Realization

In this project, a model-level plan of the PEN system is completed.

Based on the results, a prototype of the PEN Mobile Device has been created and tested. The main part of the PEN is the highly spread Atmel microcontroller, the ATMega128, used in many embedded systems. The Atmel controller is the heart of the mobile device, having high performance, low power consumption and a low costs. Moreover, this platform has several available software solutions to manage file systems on external storage or control the standard communication channels simultaneously.

The software components for ATMega128 are written in programming language ANSI C. The controller has an 8 channel 10-bit Analog to Digital converter for measuring the signs of analog medical sensors. Moreover, it has various standard communication channels such as two TTL serial ports, which can use UART and SPI communication standards. The ATMega128 can raise his calculation abilities up to 16 MIPS. Important point at the system development phase was that the ATMega128 had a free downloadable development platform, called AVRStudio [4].

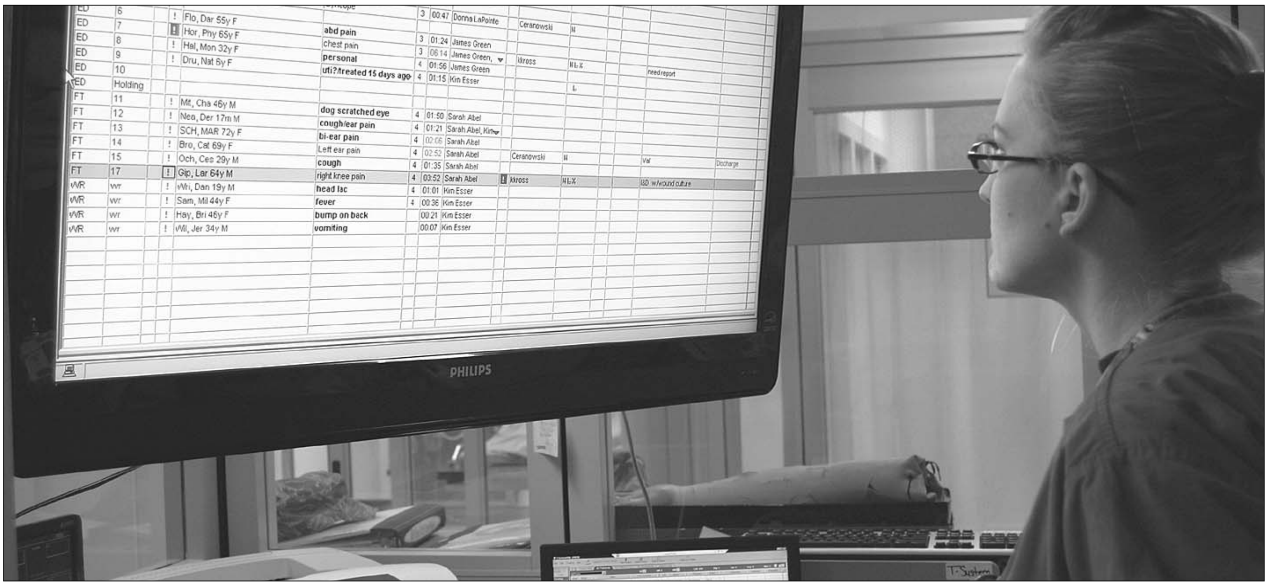
For the wireless communication channels in the prototype we have used Bluetooth (Rainsun BT20) and Zigbee (Telegesis ETRX2) technologies. The module of Rainsun [5] is a high quality Bluetooth solution with low power consumption in idle mode (about 20uA). It has also 8 input-output channels, which can be programmed by the user. An 8 MB flash memory can be found to store the Bluetooth stack and the user applications. This module supports the full Bluetooth protocol Stack up to HCI, with full speed and full piconet support. It makes driver system and easier to control the unit. UART communication port is also available with programmable baud rate up to 1.5 M to connect to the main controller.

The Zigbee Telegesis [6] module is also a good solution implement the Zigbee communication channel. It uses a very reliable core, which is based on Ember EM 250 Zigbee chip, having AT-style command set. The size of the chip is small and easy to integrate in the PEN mobile device. A 128 kB flash memory is integrated containing the full Zigbee stack support and the user's firmware or application.

It can act as an End device, Router or Coordinator and it makes easy to build complex ad-hoc network from the PEN mobile devices. In this module, the security is also guaranteed by using the AES-128 hardware supported encryption. These modules communicate with the Atmel controller on UART. Drivers and parameters to handle the wireless modules are stored in a temporary storage space on the internal storage memory.

For internal storage memory the system is using a Secure Digital memory card handled by the controller on a standard SPI channel. This memory is used for the measurement data storage as well as for driver space too. This module is made by Panasonic. The main controller can communicate with the storage card through SPI communication channel. With this connection mode the communication data rate can be up to 2 Mbps.

The device transfers the collected and filtered data to the database server on the computer. In this database, we can assign one record to each patient. These records can be assigned to doctors or nurse. To visualize collected and processed values a Java based patient record indicator is used which is developed at the Bay Zoltán Foundation for Applied Research. To store and forward data, the system uses an XML based scheme, which is built on the basic structure of with the Sensor ML [8] technology.



6. Conclusions and future work

During our work a prototype of a PEN Mobile Device was developed and implemented. Several standards and requirements are designed to be compatible with other system. We have developed also modules and interfaces based on industry accepted and highly standardized technologies. Remote firmware upgrades and remote device management are accomplished too. Therefore, the final developed system has a highly dynamic and scalable modular design with low power consumption and development costs.

Several performance and capacity tests of the system were done. At this time, we collaborate with a medical university and are designing pre-processing and post-processing algorithms for PEN devices and Data Collector Module for ECG and EMG sensors. The full technical performance testing results of the PEN will be published in an internal Technical Report and will be made available after validation.

As future plans, new sensor attachment to the system and testing are included. Also, GSM and UMTS communication channels are to be developed. If all the tests are successful, a network of a higher number of devices is to be tested in a real-life scenario with ECG and EMG devices included.

In the AAL (Ambient Assisted Living) Laboratory of Zoltán Bay Foundation for Applied Research, where the system was developed, our goal is that the PEN system will become an industry standard for safe, reliable and high speed patient monitoring and care.

Authors

ANDRÁS TÓTH received his M.Sc. in 2008 at Budapest University of Technology and Economics, Hungary and doing his PhD studies at Budapest University of Technology and Economics, Department of Control Engineering and Information Technology. He is currently working as a researcher in Bay Zoltán Foundation for Applied Research on projects connected to the sensor network and sensor data fusion in medical systems topics.

LÓRÁNT VAJDA received his M.Sc. in 2000 at Technical University of Timisoara, Romania and did his PhD studies at Budapest University of Technology and Economics. He is currently working as a researcher in Bay Zoltán Foundation for Applied Research on international and national projects connected to the AAL topic. He is also working with Wireless Personal Area Network and sensor networking technologies. He has authored/coauthored several refereed international papers, journals and conference contributions.

FERENC VAJDA received his Ph.D. in Electrical Engineering in 2006 from Budapest University of Technology and Economics, and is currently working as an assistant professor at the department of Control Engineering and Information Technology. His main research activities focus on processing 2D/3D images and on various areas of health information technologies.

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