A Data Collection and Communication Module for Telemedicine and mHealth Systems

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ABSTRACT

Wearable body sensors have become an important basis for today's medical and fitness applications. To assist athletes or to take care of elderly people in everyday life situations, sensor data can be collected and processed to give helpful feedback. However, the data collection process of multiple or different sensor systems still had to be done manually by the user or an expert, which usually takes a lot of time and can lead to errors.

This paper presents an embedded data collection and communication module based on an AT90USB microcontroller, which can automatically acquire data from various wired and wireless sensors (e.g. via USB or Bluetooth®). The obtained data can be cached, preprocessed and transmitted to a specified central server using LAN, Wi-Fi or GMS/GPRS. Through unified expansion slots, additional communication devices and a BeagleBone™ embedded can be extended to handle many different sensor systems. Moreover, wired sensors can be charged through appropriate circuits. This data collection and communication module operates without any input settings and special knowledge by the user.

Five prototypes with different configurations and extension units concerning communication interfaces and computation power have been built up. The evaluation of the transfer reliability with 100%, whereupon 98% of data could be transmitted at once and the remaining 2% with the next attempt, confirms the stability of data transmission.

Categories and Subject Descriptors

B.4.1 [**Input/Output and Data Communications**]: Data Communications Devices

General Terms

Design, Management

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Keywords

Telemedicine, mHealth, wearable sensors, USB, GSM/GPRS, BeagleBone, microcontroller, data acquisition and transmission, autonomous, embedded computing

1. INTRODUCTION

In modern society the domains of healthcare, medicine and sports are gaining greater influence in recent research [1]. One focus of research is to assist treatments of patients [2] or to take care of elderly people in different situations of life [3], [4]. An optimal mentoring of athletes during training sessions and competitions is another important aspect. Among other possibilities to fulfill this tasks, wearable body sensors are used [5]. Discrete sensors or sensor nodes, which are directly attached to the body, can capture different quantities. Sensors can also be integrated into shoes or clothes. By this integration the sensors are not perceived by the user and there is no misbehaviour interfering with the data measurement process.

Many sensors support measuring physical quantities like acceleration, rotational speed, inclination or angle, which are mainly used for motion detection. Other quantities like temperature, pressure, humidity or medical parameters such as EEG or EMG signals, blood pressure and pulse are also of interest. But measuring data obtained by the sensors is not sufficient. It is only possible to give useful feedback for patients' therapy or meaningful training support for athletes after processing and evaluating all sensor data. From the beginning of the measurement to full data evaluation diffe-

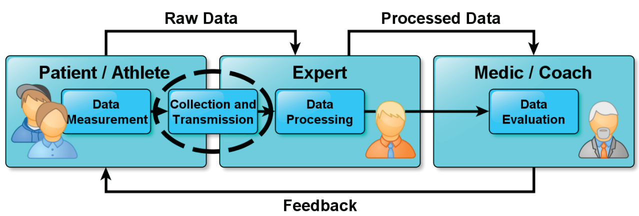

Figure 1: There are four steps from measuring biomedical sensor data by the user to its evaluation through the medic or the coach. The dashed circle marks the data collection and transmission step.

rent steps have to be carried out. These steps are illustrated in figure 1. The first step includes the measurement of data. This could be done by a single sensor or a sensor node, which can measure a plurality of quantities. In most cases, a single sensor is not sufficient for the required task. In this case it is required to attach multiple sensors to different places of the body. Afterwards, all sensor data is acquired, collected and transmitted to a central place. Following this, the sensor data can be surveyed and processed by experts. In the last step, calculated information is evaluated by medics or coaches to give helpful feedback concerning therapy or successful training.

The contribution in this paper deals with the second step, the acquisition, collection and transmission of sensor data (marked by the dashed circle in figure 1). Although this step is the interface between data measurement by the user and data processing by the expert, the collected data still have to be manually preprocessed and classified. This procedure is time-consuming and can lead to errors.

One example of this gap can be found in the mobile gait analysis for diagnosis and therapy in Parkinson's disease (PD) [6]. For this purpose, patients carry commonly used Shimmer™ [7] sensors at each shoe to measure gait patterns. To further improve this patient's monitoring, data needs to be recorded at home for a long time. Due to limited battery power and storage capacity, measured data has to be collected and transmitted for additional processing after some time. Furthermore, the battery needs to be charged. Considering the PD patients of this example as the intended users, it becomes clear that they can hardly have the expertise to read out data from sensors or provide it to medics or coaches. To solve those problems, the aim of this work is to develop a data collection and transmission module, which acquires data from various sensors (e.g. Shimmer sensors), collects it and transfers it to a central server. This data acquisition system has to work as an autonomous device without any interaction by the user.

2. STATE OF THE ART

There are several approaches in the field of sensor data collection and distribution, which will be presented next. Each particular problem has a different background. All of these approaches share a long distance data transmission over the internet using different methods.

An example is the design of a data collecting module based on RTL8019AS [8]. It measures individual sensor data and transmits the data by a special LAN network chip. This module has the advantage of being very simple in construction and cheaply producible. To evaluate this device simple analog signals were used as sensor replacement. Another article describes a wireless data collection system using PIC16F877 and GPRS [9]. In this case a data collection system is built with a low power microcontroller (µC) as dedicated logic and a GPRS module that can send sensor data over the mobile network. Only information such as analog and digital signals can be transmitted. The system should be applied for practical industrial fields and monitoring of real-time live data. In [10] a high power µC based on ARM9 is used for the design of a wireless sensor network data collection terminal. Unlike [9], the sensor data transmission is solved not via GPRS but through a sub 1 GHz RF transponder. The disadvantage of this solution, however, is that only one single type of sensor can be integrated into existing systems. Again, only low-level analog and digital signals can be transmitted.

The previous approaches do not describe the transfer of biomedical data, because these data are usually more complex in their structure than simple analog and digital signals. The transmission of biomedical data from medical devices and sensors is achieved by the HEARTFAID [11] platform. The scope of this acquisition and transmission system is to use devices measuring relevant data to support patients with a chronic heart failure. In this case, however, no dedicated hardware is currently developed. The authors implemented software that can be integrated into existing devices, for example smartphones that can transmit all relevant data to the Internet. An embedded personal area network to local area network gateway is presented in [12]. This module is able to automatically collect data from wearable sensors wirelessly and to provide these data to a local area network. Sensors can be connected through a 2,4 GHz ISM band transceiver and the local back-end server is connected through a wired LAN connection. Another approach is the novel healthcare IT platform LOBIN [13]. This platform allows monitoring physiological and vital parameters and can track the location of a patient's group in a hospital environment.

The problem of most approaches mentioned above is that these systems have only been developed for specific purposes. Many more of these "island solutions" exist, suitable for customized applications and therefore supporting only single and specialized sensors or devices. It is obvious that most solutions can only transmit simple signals. This reinforces the need for development of a system that firstly provides support for many different purposes and secondly acquires data from a variety of sensors and devices. It should also be possible to expand such a module with different extension modules without difficulties and limitations. Since the module is mainly used for medical applications, it must work without any flaw and the handling by the user must be as simple as possible.

3. SYSTEM DESCRIPTION

This section gives an overview over the designed system and explains in detail the hardware and software components

3.1 Design Criteria

Right from the start, two main design rules of the hardware development and construction were defined:

Modularization: Power supply and main electronics are separated and developed individually to realize a modular design. This makes it easier to exchange both components for subsequent revisions. All communication systems like the server communication over internet and the sensor device communication are accommodated through pluggable and unified modules. Therefore, unified slots and connectors are installed to replace or extend present functionality.

Extensibility: The module provides a variety of different adapters and connectors to integrate already conceived but not yet implemented extensions. Even the basic version is designed with structural elements to support possible extensions. Various modules can be applied to these elements, such as an embedded computer to increase computing power and storage capacity, larger display devices for a better user interaction, or a battery supply for outdoor use. The main use of the extension slots is to add wired and wireless communication interfaces to support lots of different sensors.

3.2 System Overview

A schematic overview of the hardware design is given in figure 2. The solid boxes constitute a fully functional ba- sic version. The basic module consists of a power supply and a main board in a common enclosure. The core of the main board is the *Atmel*® USB host µC AT90USB1287, which operates as a central unit to communicate with dif- ferent connected USB devices (e.g. sensor systems, extensi-

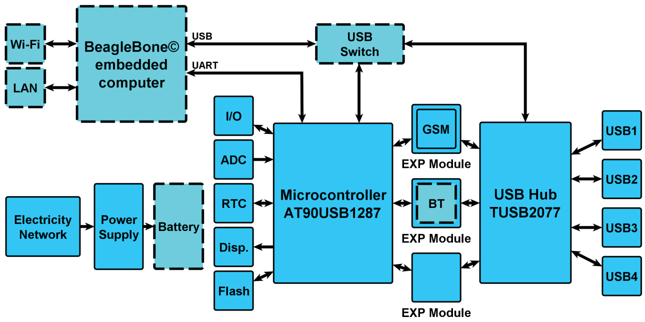

Figure 2: Schematic hardware overview. Dark boxes represent the basic configuration of the module, light dashed boxes show extendable functionality.

on modules or GSM/GPRS modem). Besides the USB host functionality, the controller provides a variety of interfaces such as UART, SPI and I^2C, as well as digital and analog inputs and outputs. All interfaces are available on any of three unified extension slots to expand the functionality. This is important to connect sensor systems with different interfaces than USB. The board includes peripherals comprising the real time clock DS1307 for keeping time, the data flash storage chip AT25DF041 to store configurations or to cache sensor data and the seven port USB hub TUSB2077 to input multiple USB sensors. The basic server side communication is done by a GSM/GPRS extension module including the SIM900 modem. The advantage of using the mobile phone network is that connection to the server can be established at any time.

To expand the functionality, e.g. LAN, Wi-Fi and Bluetooth interfaces or more computing power, different devices (shown in dashed boxes) can easily be attached using the predefined extension slots. The BeagleBone embedded computer is an appropriate extension device for more memory space and computational power. It allows the use of more complex communication interfaces like LAN and Wi-Fi instead of GSM/GPRS to transmit sensor data. Moreover, the embedded computer enables memory and power consuming processing tasks and algorithms for further sensor handling.

The entire module is powered through a switching power supply by the electricity network, but also carries support for a battery power supply with different battery chemistries.

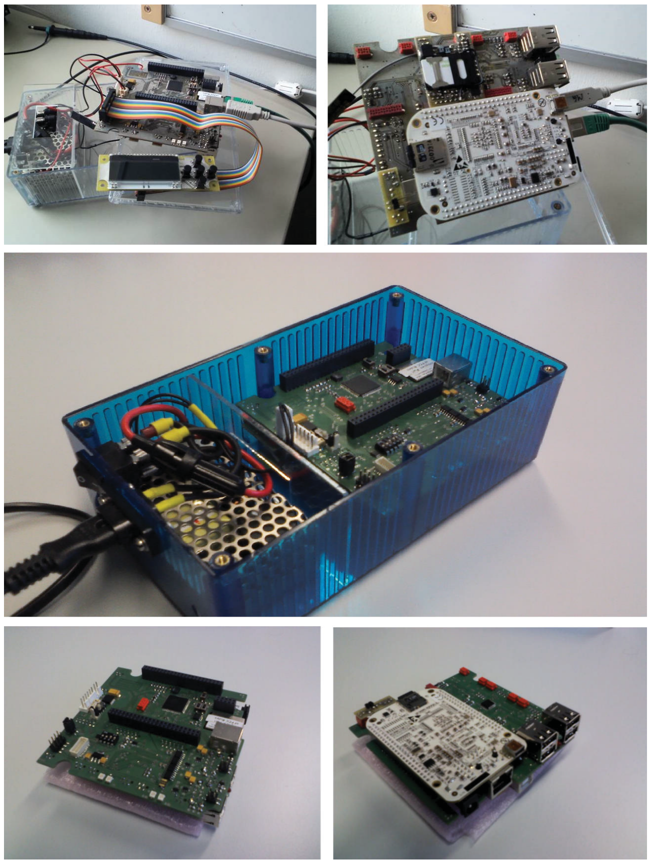

Figure 3: The top row of the figure shows on the left side the power supply, the main board and small text display of the module. The extension slots with the plugged GSM/GPRS modem (SIM card and antenna) are on the right side. The bottom row shows the main board from its top side (left) and from its bottom side (right) with a connected BeagleBone (white device). A fully assembled module inside an enclosure can be seen in the middle. The size of the complete data collection module is about 190 x 110 x 60 mm.

3.3 Software Implementation

The software implementation is split into two subsystems. One is the firmware running on the µC, the other the application software running under the embedded operating system *Angstrøm Linux* of the BeagleBone. The firmware of the µC is completely written in C using the *Atmel Studio 6* for fast and easy project development. Additionally there are two external open source libraries linked to the project. One is the LUFA [14] library, which implements the basic register functions to use the USB host interface of the AT90USB1287. Another external library represents all functions to incorporate a FAT (file allocation table) file system into the µC. It is called FatFs [15] and is especially suited for small microcontrollers with limited resources. Unlike the programming of the µC, the application program running under Angstrøm Linux is written in *Python*. It allows file manipulations and fully file system access as well as an object-oriented programming [16]. To get access to the external device detection system or to the boot options several shell scripts are required. These short scripts allow to combine processes running near the operation system to the higher level Python application program. More precisely, these scripts control the USB system, by inserting and ejecting sensors and the automatic start of the main application system after booting Angstrøm Linux.

The basic functionality has to be guaranteed in both subsystems. As shown in figure 2, the USB system is either connected to the BeagleBone or to the µC via a USB switch. Consequently, it makes no difference for sensor handling if the embedded computer is connected or not. The procedure is identical in both cases. Both software systems have the initialization of their essential peripherals, their communication systems and the iterative triggering of a device connection in common.

If a valid sensor can be verified, predefined procedures are executed to process the appropriate sensor and to store its data as files. To connect different sensors, simple configuration data or setup files are used. These configurations contain all necessary information to handle the corresponding sensor and its data. Another time-triggered event manages the upload of sensor data and the download of new software updates or sensor firmware modifications. In addition to this basic functionality, the software of the BeagleBone logs important incidents and stores information about connected sensors and appendant sensor data into SQLite databases.

If no connection to the server is available, the sensor data is temporarily stored either in a file system established on the flash memory chip controlled by the µC or on the hard drive of the BeagleBone. Collected data will be uploaded as soon as there is a connection (LAN, Wi-Fi or GMS/GPRS) to the internet and to the server. The server is implemented as a FTP server, which provides the same file and folder structure for both clients.

4. EVALUATION

A first evaluation analyses the transfer reliability of the GSM/GPRS modem SIM900 and its driver implementation, as the transfer reliability is one of the module's essential functionalities. Therefore different files of different sizes, recorded by Shimmer sensors, are uploaded to a test FTP server, downloaded and verified by a test software.

Three sensor data files with a size of 1 kB, 10 kB and 50 kB are transmitted by the modem. The 1 kB files and the 10 kB files were uploaded and downloaded ten times, whereas the 50 kB files were transmitted five times. The transfer reliability experiment results are summarized in table 1. One can see, that only one upload failed, although 49 other transmissions finished successfully.

Table 1: Successful transfers by transmission of different file sizes.

file size	successful uploads	successful downloads
1 kB	10 / 10	10 / 10
10 kB	9 / 10	10 / 10
50 kB	5 / 5	5 / 5

Further evaluations on transit times from obtaining various sensor data to the final data storage on the FTP server are currently in progress. One focus is the investigation of possible sources of interferences on the communication from different wired and wireless sensors to the data collection device and on the data transmission process from the device to the server. Additionally, usability and suitability of the complete system is evaluated in current research studies about gait analysis of patients with Parkinson's Disease.

5. DISCUSSION

Regarding the evaluation of the transfer reliability, the module can be confidently used to transmit sensor data to a common FTP server. The one failed upload was presumably caused by a poor connection quality. However, this does not affect the functionality at all. During the next upload activation phase in normal operation the upload will be restarted and the transmission repeated. The results show that the transmission of data is stable during uploads and downloads and furthermore independent of the transferred data volume.

But there are still some workaround solutions to be addressed. One is the USB implementation of the µC. To communicate with new USB sensor types, customized drivers have to be developed. Due to the fact that the resources of the µC are limited, this task is difficult to solve. The consequent use of the BeagleBone and the proportionately big overhead is therefore necessary even for less complex tasks. Although the user needs no special knowledge about the module and input settings, the use of other internet connections like LAN or Wi-Fi have to be intricately set by experts.

Nevertheless, the modularization and the extensibility have some drawbacks. One the one hand they allow the exchange and expansion of components, but on the other hand, they complicate the development effort. Interfaces and extension slots must be unified, which leads to restrictions in the design flexibility. For future extensions, electric components and space inside the module have to be considered, which are actually not needed in the basic version.

Further development should implement more sensor interfaces and sensor handling configurations to support a variety of commonly used sensor systems. Even the implementation of the application software of the BeagleBone has to be improved by a better interaction of until now single operating software components. Another disadvantage is to some extent the code duplication of software and firmware running on both subsystems. To ensure the same behavior between the BeagleBone and the µC, identical software has to be developed twice. This double expense should be reduced in future developments and identical software components should be consolidated as far as possible.

6. SUMMARY

This paper presents a data collection and communication module. The module can automatically acquire data from various wired and wireless sensors (e.g. via USB or Bluetooth). The obtained data can be cached, preprocessed and transmitted to a specified central FTP server using LAN, Wi-Fi or GSM/GPRS. Additional communication devices and a BeagleBone embedded computer can be extended to handle lots of different sensor systems. This module operates without any input settings or special knowledge by the user.

This work presents an important new step towards other data acquisition and transmission projects in medical and fitness applications. It can obtain data from a wide variety of sensor systems (e.g. Shimmer) and provide it at any time to a central server for further processing. This accelerates the data transmission pipeline from data measurement to data evaluation with less errors. Therefore, it can help to give faster and better feedback, which can support athletes during training sessions, assist patients in everyday life situations or monitor the elderly in home environments.

In future, this system will be used for long-term measurements of athletes and patients (e.g. PD patients), where a minimum of user interaction during data recording and processing is required, as well as an automatic data collection and transmission is needed.

7. ACKNOWLEDGEMENTS

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