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# Development of a low-cost wireless monitoring System supporting the Continuity of Medical Care of the Patient at home*

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*Abstract*— **The fusion of Biomedical Technology, Informatics and Medical Decision-making into the modern Clinical Decision Support Systems (CDSS), as well as the population ageing and the escalation of hospital costs are the driving forces for adopting decentralized systems of health care provision. One of the main problems arising with decentralized health care provision, such as Home Care, is the discontinuity of medical care. This discontinuity appears not only in medical data transfer, but also in the quality of medical supervision. In order to accommodate for the lack of sufficient medical supervision in Home-Care environment, we have developed low-cost prototype solution for monitoring basic physiological parameters. The implemented architecture is employing wearable biomedical signal acquisition modules, utilizing "off the shelf" technologies in order to minimize cost. These modules transmit the acquired vital signs through a wireless link to a laptop computer. A web application allows continuous quasi real-time supervision of patient's biosignals from any PC equipped with a web browser and appropriate authorization codes.**

## I. INTRODUCTION

Home-care and institutional Long Term Care (LTC), is commonly applied as a formal care for the elderly population. Data [1] from the Organization for Economic Co-operation and Development (OECD) show that in 21 developed countries 8.2% and 4.0% of the people over sixty five years are receiving home-care and institutional LTC respectively.

Providing LTC with equivalent medical equipment to hospitals was not an option until recent years, when miniaturization of medical equipment and fusion and informatics and communications occurred. LTC medical technology has different characteristics than the equivalent hospital technology. The majority of LTC patients are capable of performing basic tasks, maintaining a level of mobility. Thus, in order to ensure the quality of health supervision in a LTC setting, it is important to establish a continuous supervision system without compromising patient's mobility.

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Continuous supervision is important for patients suffering from chronic diseases such as cardiovascular and respiratory diseases, where acute life threatening complications are common. In U.S. over a million (77%) of nursing-home residents suffer from diseases of the circulatory system and approximately three hundred thousand suffer from respiratory disease (20.3%) [2].

Tele-monitoring applications have been classified by Korhonen et al. [3] in two groups. The first group is the wellness & disease management model where clinical personnel plays a supportive role in monitoring patient, and the independent living & remote monitoring model, where the medical personnel monitors health status. Remote monitoring devices fitting in the second model, allowing patient's mobility could be classified into three categories [4]. The data-loggers, which measure and store data between downloads, the data-forwarding systems, which measure and transmit data and the data-processing systems, which measure, analyze and transmit data analysis.

Data-loggers have the obvious disadvantage that they cannot communicate parameters and a change in health status between downloads. Data-forwarding devices are the obvious choice, when continuous monitoring is required. Forwarding devices are lacking processing power of data processing devices, but due to their simplicity it is relative easy to be designed and implemented with low cost; furthermore the processing algorithms could be upgraded or adapted to patient needs, without directly interfacing the device.

## II. THE AIM OF THE PROJECT

The present paper suggests and implements a wearable wireless remote-monitoring system of vital parameters for LTC patients. Recorded physiology parameters are transmitted through a digital wireless link to a portable computer. The portable computer's main tasks are: first to collect and present received data; second to provide an interface for clinicians for remote viewing of recorded data and analysis through the web; and third to submit the vital signs to a remote hospital server updating the patient's Electronic Health Record (EHR).

## III. SYSTEM'S OVERVIEW

The core of the system is a wearable data acquisition and digital wireless transmission module. The module was designed to acquire three parameters namely, the electrocardiogram (ECG), the Non-Invasive arterial Blood Pressure (NIBP) and the arterial Oxygen Saturation ($SpO_2$). Data communication was performed with an XBee 802.15.4 module by Digi International [5], which operates within Industrial, Scientific and Medical (ISM) radio bands [6].

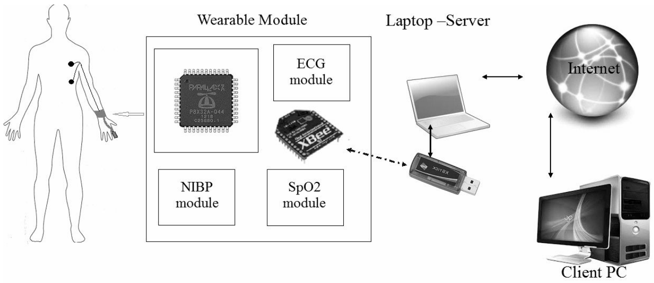


Figure 1. System's overview.

Reception of recorded data and waveforms was performed from a laptop computer equipped with an Xbee USB Stick (XStick by Digi International) [5]. Data were acquired and displayed through a client-server web application, utilizing Microsoft.NET technology [7].

### A. Wearable module

The heart of the wearable module is the Propeller microcontroller from Parallax [8]. The controller is designed with 8 cores running at a clock speed of 80MHz. The advantage of utilizing a multi-core microcontroller is that it can run parallel tasks simultaneously in deterministic times. Our application required several tasks to be performed in parallel: data acquisition, signal processing, wireless data transmission and display. The module incorporates a 4 channel 10-bit analog to digital converter (ADC), sampled at 1.2 kHz (300 Hz per channel), and a 2 channel Digital to Analog converter (DAC). We designed a custom version of the open hardware architecture of Propeller Board of Education (BOE) [9] for the purpose of the project, minimizing design time. The Propeller BOE architecture embedded the XBee module in the design.

The XBee module characteristics allow operation within the ISM band (2.4 GHz), 30 m indoor range, bi-directional communication, data encryption and more important 802.15.4 network topology [5, 6]. The 802.15.4 network topology accommodates star networking topology, allowing multiple devices (wearable monitoring systems) to "talk" to a central node (laptop). This feature could be beneficial when multiple patients are present in the vicinity, or when we intend to monitor multiple parameters.

The system also features a 128x128 display (uOLED-128 4D Systems), for displaying monitored data.

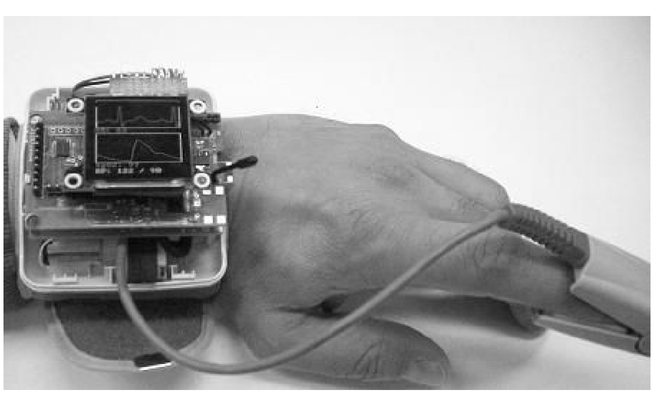

Figure 2. Wrist wearable module.

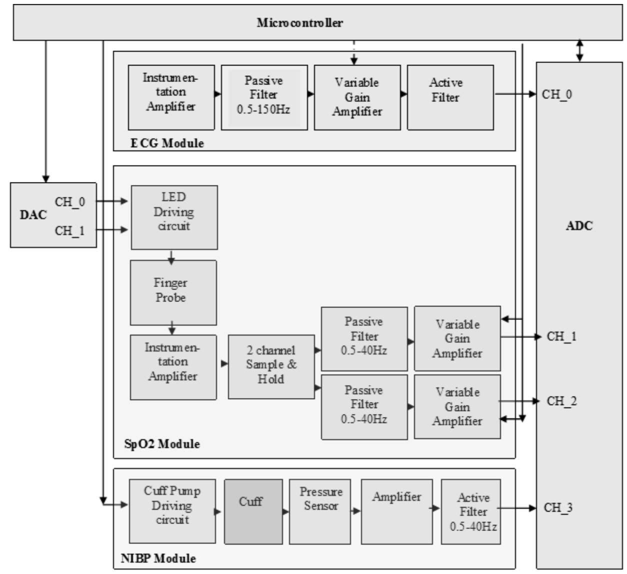


Figure 3. Modules' signal acquisition block diagram.

Since XBee communication is bi-directional the remote client can perform simple remote tasks, such as resetting the wearable module, pausing acquisition, requesting and scheduling NIBP measurements, adjusting algorithms' coefficients and enabling or disabling the wearable display.

To simplify user interface, the patient need only to operate only an on/off switch. Once the system is on, acquisition and transmission of data is automatic.

The wearable system is powered by a 9V Li-Ion rechargeable battery (500mAh). The system consumes approximately 60 mA with display unit turned off and a single NIBP measurement per hour. Consumption is affected by the frequency of NIBP measurements and display unit utilization; consumption climbs to 140mA with continuous use of the display. The unit under low power consumption setup is capable of continuous measurements and transmission for 8 hours.

### B. Physiology parameters acquisition modules

The ECG module (Figure 3) is capable of acquiring a single Einthoven lead (I, II or III), depending on electrodes placement. The ECG signal is acquired from two chest electrodes (Figure 2) connected with a shielded cable to the module (cables are not identifiable in figure 3).

The ECG signal is acquired, amplified and filtered with the use of passive and 2$^{nd}$-order active filter in the frequency range of 0.5 to 150 Hz. The filtered signal is sampled at 300 Hz, satisfying Niquist theorem and providing an ECG signal of sufficient quality for diagnostic purposes [10, 11]. The patient's Heart Rate (HR) is calculated based on a derivative R wave detection algorithm [12]. R wave is detected when signal's amplitude exceeds a threshold $\Theta$ (frequently adapted by software as a percentage of the recorded peak amplitude) and when there is a fast change in signal's slope (signal's derivatives); according to (1).

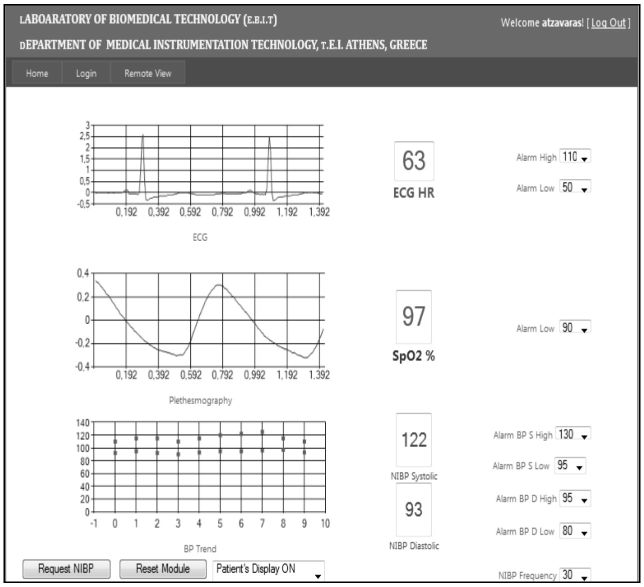


Figure 4. Web application screenshot.

$$R(n) = \begin{cases} 0, & x(n) < \Theta \\ 1, & \begin{array}{l} x(n) \geq \Theta \& \\ \Delta x(n)/\Delta n > \theta 1 \& \\ \Delta x(n+1)/\Delta(n+1) < \theta 1 \end{array} \end{cases} \quad (1)$$

*Where:*
*x (n) : measured signal (sample n)*
*Θ : Amplitude threshold*
*θ1,2 : Derivative thresholds (1 positive slope, 2 negative slope)*

The arterial pulse Oximetry signal is acquired with a Nellcor finger sensor. DAC interfaces to LED driving circuit adapting Red and Infrared (IR) LEDs current for sufficient light absorption signal. The finger's photodiode sensor signal is amplified (employing a differential current sensing trans-impedance configuration), filtered and sampled at 300 Hz utilizing two ADC channels; one for each wavelength. $SpO_2$ is calculated from the averaged natural logarithm ratio of RED and IR amplitudes (Peak and valley method [13]).NIBP measurement is performed according to an oscillometric technique [14]. A wrist-cuff is inflated to a clinician's predefined pressure. During deflation the cuff pressure and pressure oscillations are monitored. Initiation of oscillations marks systolic blood pressure (BP), while termination marks diastolic blood pressure. During NIBP measurements, $SpO_2$ measurement is suspended; both NIBP and $SpO_2$ sensors are located on the same hand resulting in false $SpO_2$ alarms during NIBP blood flow occlusion.

### *C. Laptop server and remote client*

The laptop server hosts the USB XBee stick, which provides the wireless communication to the wearable module and a web application developed with Microsoft.NET technology (Figure 4). The Web application receives quasi-real time data, transmitted by the wearable module **and** presents data's waveforms (single lead ECG and Plethysmography), numerical values (HR, $SpO_2$ and BP) and as physiological parameters numerical trends. The basic signal processing, such as signal filtering, HR and $SpO_2$ calculation is performed on the wearable device. The processing power of the server is reserved for the future employment of more demanding clinical decision support algorithms, still under development and implementation. Access to remote viewing is provided by user authentication. Authenticated users are allowed to change alarm limits for the monitored parameters and apply remote operations on the wearable module, such as resetting the device, enabling and disabling wearable display, initiating a NIBP measurement and changing NIBP measuring intervals.

## IV. PRELIMINARY EVALUATION

The functionality of the wearable module has been tested mainly with the use of patient's simulators. The ECG acquisition as well as HR detection algorithm was tested with a BIO-TEK Instruments Inc patient simulator (model: Lionheart multi-parameter simulator). The developed HR detection algorithm was found to accurately detecting HR at 30, 60 and 120 bpm. HR was calculated by an averaged R to R interval of five pulses. Similarly the $SpO_2$ accuracy was tested with a Fluke Biomedical finger $SpO_2$ simulator (model: Metron daeg $SpO_2$ simulator). Oxygen saturation measurement was tested in the range of 80 to 99%, with an accuracy of +/- 2%; at a HR of 60 bpm and a motion free setup. Due to lack of a NIBP simulator, the NIBP measuring module was tested on the authors. The NIBP measurement was performed successively by the wearable device and a blood-pressure measuring equipment based on Kortkoff's sounds method. Although there was no significant difference (<+/- 5mmHg) between the two methods, there are several limitations concerning this test: the detection of Korotkoff's sounds is subjective; the measurements were not tested against hypertension and hypotension clinical scenarios.

XBee communication was tested with a walk test. A subject wearing the acquisition module walked outside the laboratory at small distances. Signals were transmitted through brick walls for distances over 30m.

## V. DISCUSSION

The implemented architecture is employing wearable biomedical signal acquisition modules, utilizing "off the shelf" technologies, such as commercially available modules and open hardware architectures, in order to minimize cost and design time (Table I). These modules transmit the acquired vital signs through a wireless link to a laptop computer. A web application allows continuous quasi real-time supervision of patient's biosignals from any PC equipped with a web browser and appropriate authorization codes.

TABLE I. THE EMPLOYED MODULES

| **Modules Description** | |
|---|---|
| ***Module description*** | ***Module*** |
| Wireless communications | XBee 2.4GHz 802.15.4 module by Digi International |
| Display | uOLED 128, 4D Systems |
| Main board | Custom version of Parallax's Propeller BOE open hardware platform |
| ECG, $SpO_2$ & NIBP | Custom module |
| Wireless PC communications | XStick® module by Digi International |

The adoption of remotely controlled Home-care information systems that create paperless EHR seems to be inevitable in contemporary healthcare environment, and the developed system is our contribution, towards this direction. However, there is always the risk of "information pollution" by the data-overload that all monitoring systems and their eventually associated electronic records can generate, concerning both, their data archiving and safeguarding process. On the other hand, increased technical and administrative regulations, aiming to improve quality, could also create an obstacle to achieving the primary goal that any EHR has, i.e. to improve the quality of care and patient's safety. The reason for this risk is related with the "consumption" of the rather limited in the field of Home-care human and material resources, towards gaining compliance relevant technical-administrative mandates. Presently, we are still in the phase to re-implement in the presented above new software and hardware configuration, ECG-waveform detection and evaluation algorithms, already published elsewhere [15-18], supporting clinical decision making.

Finally, we are working on: the server to server communication with an EHR-system, including also quasi-real time vital signs update, based on the presented platform, as well as a new design utilizing reflectance pulse oximetry measuring method.

## Acknowledgment

This research project has been co-funded by the European Union (European Social Fund) and Greek National resources under the framework of the "Archimedes III: Funding of Research Groups in TEI of Athens" project of the "Education & Lifelong Learning Operational Programme".

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