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MEMSWear – Biomonitoring — Incorporating sensors into smart shirt for wireless sentinel medical detection and alarm

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This paper presents a method of using a body-distributed smart sensor platform for continuous detection of vital physiological signs in a body area network (BAN) system. An overview of the approach utilising predefined sentinel vital sign events is mentioned in order to optimise the platform in both hardware and software level. A BAN system consisting of smart sensor platform with short range ISM transmission will be used to communicate with a communication gateway. This communication gateway will encode and send the signals via Bluetooth to designated devices to inform caregivers, family members or transmit information to internet server.

Keywords: MEMSWear, BAN, microprocessors

1. Introduction

Singapore has an increasing rate of hospital admission across the board for all age groups [1]. This situation posts a problem of hospital beds not being able to meet the number of patients to be admitted. A remotely enabled biomonitoring system would enable patients that not as critical as ICU patients, yet requiring monitoring of their vital signs, to be monitored in the general wards. Once robust, the system can be used remotely in an elderly institution or home to enable biomonitoring detection.

Monitoring of physiological signals is not a new domain for research. Many groups are working on similar monitoring of signals. Chen *et al* [2] described monitoring of multiple vital signs based on mobile telephony and internet. NASA Ames Astrobionics team has developed Lifeguard that integrated commercially available vital signs detection onto a platform, and designed to be worn on the body of the wearer [3]. Amidst all these efforts on biomonitoring, we see the potential of detection of sentinel events instead of bench-like systems that are able to store huge data therefore reducing the analog requirements. Therefore, having low power consumption and light weight amidst other considerations are essential in the eventual platform. Our eventual aim is to enable wearer to have their bio vital signs detected and determined of a sentinel event on a 24/7 basis by simply having a low power system located on their shirts. This will enable the caregivers to respond to the wearer in the fastest possible time.

Here, this paper will describe a method to primer a move to meet the challenges mentioned above. This paper will discuss the architectural design of a wearable platform based on the existing MEMSWear platform to be developed for vital signs monitoring of human body condition; wirelessly, utilizing an array of sensors developed. Ambulatory methods of acquiring physiological data such as body temperature, blood pressure, blood pulse oximetry and ECG from a human body will be used and applied in the signal acquisition portion. Low power microprocessor embedded with other peripheral electronic circuitry is being built to enable remote data acquisition, processing and alert of sentinel events of a wearer. MEMSWear-biomonitoring will be able to detect wearer's blood pulse pressure, blood pulse oximetry, ECG and temperature. Upon detection of sentinel events, a wireless signal would be sent including the sentinel signal via Bluetooth™ (BT) method. Technical advances in miniaturization and wireless communications have enabled development of monitoring methods for short-range wireless communications not cumbersome by radio spectrum restrictions (e.g. ultra-wideband). These technical advances will, in future, enable applications of wireless monitoring without interference in ambulatory subjects, in home care, and in hospitals.

2. Overview of MEMSWear Biomonitoring

The four physiological sign, namely BP, ECG, SpO₂ and temperature detection, is integrated into a pre-designed wearable platform called MEMSWear. MEMSWear is a wearable device that can detect fall events through the use of gyroscopes and accelerometers [4]. MEMSWear Biomonitoring aims to build upon the fall detection capability of MEMSWear by detecting vital physiological signs on the same wearable system. The objectives are as follows:

- To enable vital signs detection of BP, ECG, SpO₂ and temperature through use of novel sensing methods
- To design smart sensors with BAN ISM transmission enabled
- To enable BT transmission of sentinel events from a communication gateway to external devices
- To eventually create a Smart Shirt capable of sending sentinel alarms to external devices

3. Development of wearable smart sensor platforms

The focal point of the biomonitoring system will be the wearable smart sensor platforms distributed as a Body Area Network (BAN) in a star formation. This is synchronised by a central communication platform, called a communication gateway, which also acts as a node to a wide area network (WAN) for remote monitoring. As a wearable system; size, weight and comfort is of utmost importance. The sensor platforms need to be compact, non obstructive and require minimal user intervention (e.g. minimal change of batteries). Optimising the circuit design, sampling rate and wireless communication rate, will in effect shape the designed platform. In the essence of optimising the system, a sentinel detection system will allow the wireless system to fall into sleep mode and activated periodically only to test for network connectivity and in the event of a patient alarm. Summarized in Table 1 is the distribution of vital signs acquisition, the electronics development phases and other system details for the Biomonitoring system.

Table 1: Overview of MEMSWear Biomonitoring

Vital Sign	Signal Acquisition	Initial Elec. Phase I	Final Elec. Phase II	Sentinel Event	BAN System	Wireless method to ext. devices
Temperature (°C)	Combine	TI MSP430	TI MSP430	> 38.3°C	Short range ISM transmission	Bluetooth
SpO ₂ (%O ₂)		TI MSP430		< 90%		
BP (sys/dias)	Combine	TI MSP430	TI DSP	> 140/90		
ECG (waveform)		TI MSP430		Life-threatening cardiac arrhythmias		

3.1. Temperature and SpO₂ sensors

Human body temperature is reflective of our internal physiological processes, with alternations being encountered in disease states, e.g. hyperthermia (fever) in times of sepsis, thyroid storm and hypothermia in Addisonian states. Adequate arterial oxygen saturation is essential for the maintenance of life a human being cannot survive more than five minutes without oxygen supply to the brain. As such, oxygen saturation is a vital sign that is commonly monitored in hospitalized patients with any of these conditions.

Temperature and pulse oximetry sensors will be situated on a single housing assembly unit to become a smart sensor capable of detecting signals and processing them. A novel idea to integrate temperature measurement and SpO₂ at the ear is being looked into. Thermopiles will be incorporated on a location of the device whilst the LEDs and a Light-to-frequency converter would be located at the ear lobe location. The design of a smart sensor that can acquire both temperature and SpO₂ signals from the ear location will be novel. In essence, the ear temperature and SpO₂ smart sensor will be worn like a clip over the ear. Together, this smart sensor will enable detection of both the temperature and SpO₂ raw signals, process the signals and to transmit the sentinel event signals through a short range band ISM transceiver to a communication gateway using a BAN system.

3.2. BP and ECG sensors

High blood pressure, or hypertension, is a serious problem. It is an important risk factor for cerebrovascular disease (strokes), coronary artery disease (heart attacks) and can also cause damage to vital organs like the kidney. The ability to monitor blood pressure continually and accurately is extremely useful. Incorporating pressure or force sensor located at the radial artery to detect pulse waveform and combining the pulse delay from either the ECG or SpO₂ would allow the blood pressure to be derived using the pulse wave transit time (PWTT) and pulse wave velocity (PWV) techniques.

On the other hand, patients especially elderly who have survived cardiac arrest, ventricular tachycardia or cardiac syncope, have an increased risk of sudden cardiac death. Since many of those patients (elderly) are normally living at home, it is imperative to develop a medical grade, low cost and unobtrusively worn smart ECG sensor for long term monitoring, continually logging heart rate data and providing detection of life threatening events. Therefore, in this project, a single channel wireless, wearable ECG smart sensor will be developed.

BP and ECG sensor signals were able to be processed using a microcontroller and sent to a PC using RF transmission [5]. We would be investigating novel ways of measuring BP that is non-invasive and safe utilizing the PWTT, PWV and designing the sensor probe assembly. The ECG sensor will incorporate electrode method using one lead configuration.

4. Body Area Network

The short range ISM transmitters will be integrated onto each of the smart sensors. Forming a Body Area Network (BAN), each smart sensor with the ISM capability will be able to communicate with a communication gateway consisting of an ISM transceiver interfaced with a BT transmitter. This communication gateway will be centrally located and will function like a communication link between the human and the external device as shown in Figure 2. The working mechanism is as such. The smart sensor will acquire, process the raw signals and transmit to the communication gateway. Only upon the detection of sentinel events as shown in Table 1 would the sensor circuit boards send the sentinel signals to the communication gateway. The RF transceiver will then send a request for the rest of the smart sensors to send the latest reading to be sent to the body station. The communication gateway will then send the sentinel alarm reading along with the rest of the received signals and alarm timing immediately to the nearby BT enabled devices as an alarm.

The Body Area Network is a system of miniature, wearable sensors and short range, ultra low power wireless data links. The system is optimized to track vital signs, personal performance data, and

other sensor information in the near-body environment. In terms of power consumption, BAN is 10 to 1,000 times more power efficient and 1/3 the cost of Bluetooth applications.

Therefore, BAN sensors are inexpensive, unobtrusive, disposable or replaceable and have low power consumption can last for months or years depending on the application. A short range ISM band transceiver will be integrated in the smart sensor for communicating via Body Area Network to a patient worn, communication gateway, which can relay information to a BT enabled device that acts as an interface to the internet world. It communicates over a short-range body area network to a communication gateway that relays the data over WLAN or WAN to a server for distribution to a respondent device i.e. hospital, caregivers, medical servers or doctors.

In essence, the vital signs signal data flows pass a chain of BAN modules from each sensor to a communication gateway, which consolidates the data streams of all sensor modules attached. It transmits the data to a home base station, from where they can be forwarded via telephone line or internet.

Considerable attention should be spent on a high level of security for the new BAN transmission protocol. Appropriate encryption mechanisms should be integrated in BAN Communication. Finally, it must be guaranteed that patient data are only derived from each patient's dedicated BAN system and cannot be mixed up with data from other patients or BAN systems at the same location.

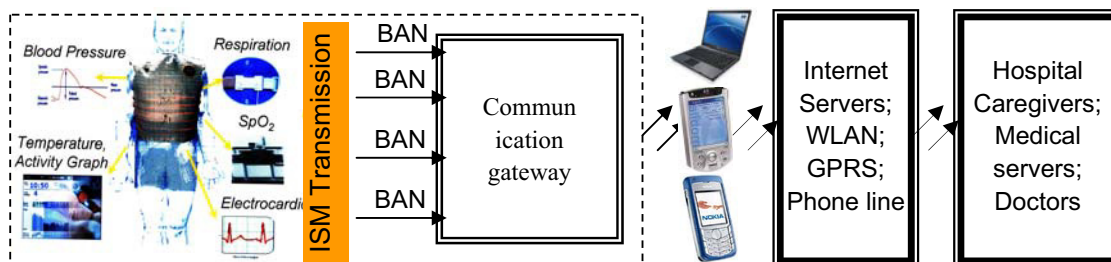


Figure 2: Schematic of BAN and external components' interface

5. Preliminary Results

We have developed the prototypes of the sensor platform, using Texas Instrument's MSP 430 family of 16-bit RISC microcontrollers and one of them shown in Figure 3. The primary design, consisting of amplifiers, signal conditioners and analog to digital converters are the common components incorporated across the entire smart sensor platforms. Acquired data can be relayed to a computer for offline analysis via a serial port. Optimal novel signal processing algorithms, designed using the offline analysis will be converted to C language and ported into the boards. Vigorous research and decision of the optimal spectral transformations including advanced signal processing techniques will be done.

The short range ISM module will be incorporated into a future board, designed to optimise the size for packaging purposes. The design of a communication gateway will be looked into, with attention given to future wireless networks, which are designed for wider range and lower power consumption.

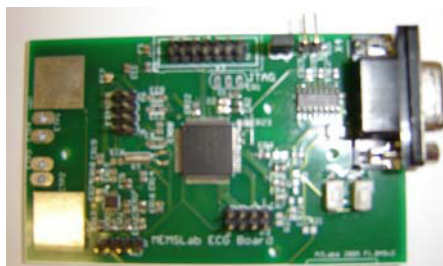


Figure 3: Picture of an ECG sensor processing circuit board

6. Conclusion

This paper has presented a research direction—to allow a wearable platform where different physiological sensors can communicate with the processing unit and thereafter to send a sentinel alarm to a nearby BT enabled device. We have also plans in future to incorporate this system with MEMSWear's fall and daily activities detection.

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