# Implementation of Vital Signs Monitoring System Using Wireless Networks

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## ABSTRACT

This paper presents a vital signs monitoring system using wireless networks in Thailand. The system consists of vital signs measurements including electrocardiogram and heart rate. In addition to the health information of patients that is monitored, the location of patients specified using the global positioning system (GPS) is employed in the system. A prototype of the system has been developed and implemented. It was tested by a physician at Maharaj hospital, Chiang Mai. From the experiment, the developed monitoring system provides a promising result. The patients' vital signs and health conditions can be monitored in real-time while the patients are off the hospital. The health information of the patients can also be recorded in the system. Moreover, the location of the patients can be specified. The system can however be further developed for a more complete health monitoring system. Accordingly, the system may then be developed for industrial manufacture and real utilization of the system with a low cost.


**Keywords**: Vital signs; Heart rate; Blood pressure; Body temperature; Chronic patient; Health monitoring

## 1. INTRODUCTION

Several biomedical devices, e.g. portable medical devices, were designed during the past decade. Combined to the recent proliferation of wireless communication solutions, this presents exciting opportunity for the development of personal electronic health monitoring. For example, in western European countries and the United States of America, chronic patients are currently using personal digital assistants to collect and send critical medical data to a follow-up center or to their attending physicians who also have a similar handheld device connected to internet by means of a wireless general packet radio services (GPRS) enabled cellular mobile phone [1].

The European EPI-MEDICS project [2-4] has developed an easy-to-use, low-cost personal electrocardiogram (ECG) monitor (PEM) having the capabilities of recording anywhere and anytime a simplified one but of professional quality ECGs. Such PEM system can analyze the successive ECGs of a given patient with reference to a baseline ECG stored in a memory card embedded in the personal ECG monitor, detect the onset of an infarction or arrhythmias that are risky for the patient's health in almost real-time, and automatically transmit an alarm message together with the ECGs and the patient's personal electronic health record (PHR) to the nearest emergency center, 24-hour call center, or an alarm server that in turn will send a short message service (SMS) to the attending physician. The structure of the EPI-MEDICS project is shown in Fig. 1.

The PEM may be used on demand at different occasions such as at home, at work, or during a trip. Depending on the alarm level or on the scenario of use, the alarm message and the vital signs such as ECGs may be automatically sent together with the embedded PHR via a standard transmitter-enabled, GSM-compatible cellular mobile phone to an emergency call monitoring center or to the attending cardiologist. Major alarms are automatically transmitted to the nearest hospital's emergency call center.

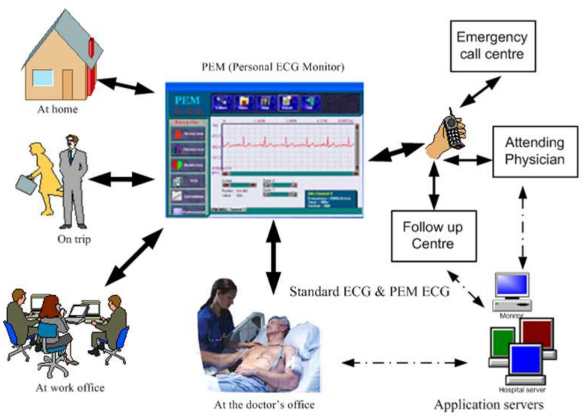


***Fig.1:*** *The structure of EPI-MEDICS project*

To offset the relatively slow speed of technology's transmissions (which depends on the quality of the transmission and the traffic intensity and may take from 30 seconds up to a few minutes), we developed a software application running on the call center personal computer to display the incoming information

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as soon as the information is received [4]. The data transmitted by the PEM are sent in the following order:

1. Alarm message indicating the reason and the severity of the alarm;
2. Patient demographics and localization;
3. ECG that triggered the alarm (hereafter called the last ECG);
4. The patient's PHR, especially his cardiac history and risk factors;
5. If available, the most recent baseline ECG (also called the reference ECG);
6. Clinical symptoms (if the patient or an assisting person had the time to document them); and
7. The second last ECG (if available and specified in the settings).

The coordinating physician in the ambulance coordinating center and the cardiologist in the emergency center can display or print on demand any received information, call back the patient on his mobile phone, and forward the received ECGs and the PHR to the relevant cardiac center for action or advice [13]. In case of a medium alarm level (suspicion of ischemia or abnormal arrhythmia), all information is sent to and temporarily stored on an alarm server, shown in Fig. 2, that automatically sends an SMS to the attending health professional cardiologist or general physician stored in the patient's contact list of the memory card. The SMS provides information about the reason and the level of the alarm, the patient's mobile phone number, the URL of the alarm server. The structure of hospital's monitoring center is illustrated in Fig. 2 while the block diagram is shown in Fig. 9.

For a medium alarm scenario, the PEM system sends the alarm message together with the last recorded ECG, the reference ECG, and the patient's electronic health record (EHR) to the PEM alarm server, which in turn sends an SMS to the attending physician. The latter accesses the alarm server that automatically formats the data according to the type of equipments (PC, Notepad, etc) used to connect to the alarm server and takes the appropriate actions.

## 2. SYSTEM IMPLEMENTATION

We have developed a portable medical data acquisition system that includes heart rate, blood pressure, body temperature, ECG, and SPO2. This system allows the physician able to understand patient's scenario on the computer screen by GPS engine board as show in Fig. 4. It also includes emergency help function. When the patient feels uncomfortable, he could press the emergency help button for help and asking for the physician immediate assistance.

In the same time, the vital signs data recorded will be sent to hospital's monitor center in the physician's computer via UHF radio transmitter or GSM cellular

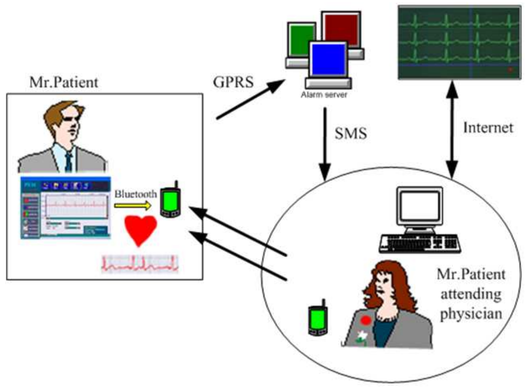


***Fig.2:*** *The structure of hospital's monitoring center*

mobile phone. In Fig. 3 shows the monitoring and transmission system of the vital signed data of chronic patient at home site.

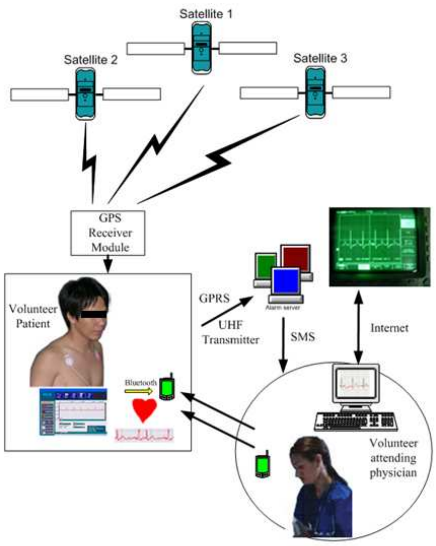


***Fig.3:*** *The structure of the developed system*

The system measures vital signs such as the heart rate, blood pressure, SPO2, ECG and body temperature of the patient and records them into computer memory. Subsequently, all vital signs data will be sent to the physician's computer at the hospital's monitor centre by cellular mobile phone. The vital signs data in the physician's computer will be rearranged and kept in the vital signs data files. It will become useful information for the physicians.

### 2.1 PEM Structure

The overall structure of PEM system is shown in Fig. 5. The vital signs monitor is located at the user's home and the central monitor at the hospital. Information is exchanged between the home user and the treating physicians through the cellular mobile phone network. The home unit consists of four components are ECG detector and transmitter that

***Fig.4:*** *The GPS receiver engine board for transmitting the position of patient*

is carried by the user, a body temperature monitor, heart rate monitor, and a personal digital assistant monitor. The vital signs detectors are development by the research group at Chiang Mai University; but the PDA monitor and GPS engine board are commercial products.

The ECG detector used in this system is a three-lead wireless device, capable of transmitting ECG signals within a 1 km radius, which is the typical apartment size in Chiang Mai University. The heart rate monitor was projected from R-R intervals of ECG and computed by computer software, and then the last 10 measurement information including the time is stored in the memory. The PEM monitor has a GPS's antenna to receive the navigation signal from 3 satellites and send signal transmitted from the PEM carried by the user.

There are 3 input and output ports on the PEM: the input body temperature wire, the communication wire for the cellular phones network, and the ECG data input wire. The prototype of the PEM home monitor is shown in Fig. 6. The data stream of the monitoring on a physician computer screen is shown in Fig. 7. When the monitor receives the vital signs information, it is first digitized. Then, the digitized vital signs such as ECG data are displayed and processed by an arrhythmia analysis algorithm to search for abnormalities in the current ECG.

The on-line arrhythmia analysis algorithm is able to recognize seven abnormalities. A set of alarm thresholds is pre-determined for the individual user. Whenever an abnormality of the ECG data currently being analyzed exceeds the alarm threshold, the data transmission process is initiated. This transmission process includes packing the data into a specified format, and initiating the modem that transfers the data packet via cellular phones network to the monitoring center at the hospital. For heart rate monitoring, it is calculated from R-R interval and sent to the hospital's monitoring center at the same time with body temperature. After receiving the both heart rate data and body temperature data, the monitor packs the data into a specified format and transfers the packet to the hospital's monitoring center. The patient can switch the operating status of the monitor via a push buttons.

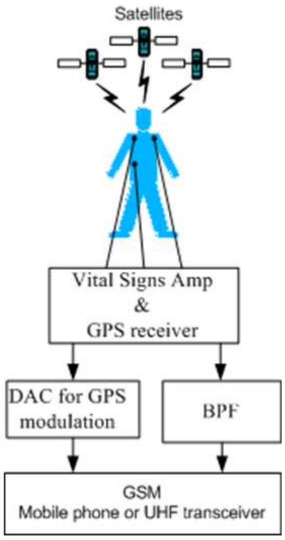


***Fig.5:*** *Overall structure of the PEM system.*

***Fig.6:*** *The prototype of the PEM system.*

### 2.2 GPS Navigator System

The GPS navigator system consists of 4 components:

1. GPS receiver engine board;
2. Digital to Analog converter (DAC);
3. Clock circuit for DAC;
4. Frequency of 930 MHz Transceiver/GSM cellular phones

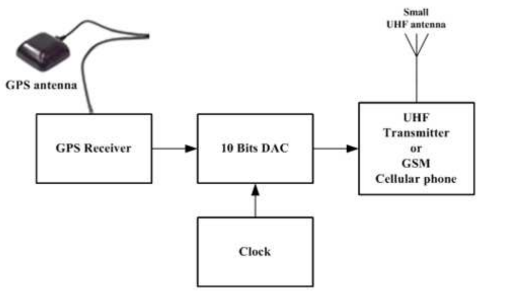


***Fig.7:*** *Block diagram of GPS transmitter system*

2.2.1 GPS receiver engine board

The system employs the GR-82 GPS module to interface with a microcontroller for acquiring position information, i.e., latitude N and longitude E. This module can receive information of 20 channels of satellite and use NMEA V2.2 (4800, 8, N, 1) protocol for interfacing with the microcontroller. Data output of module GR-82 has information of latitude N and longitude E in sentence as follows. "$GPRMC,103828.047,V,0753.4876,N,09821.0235,E, 0.00,,190806,,*05 " We can description sentence for all GPS data in Table 1.

***Table 1:*** *Description sentence for all GPS data.*

| Name | Example | Units | Description |
|---|---|---|---|
| Message ID | SGPRMC | | RMC protocol header |
| UTC Position | 161229.487 | | hhmmss.sss |
| Status | A | | A=data valid or V=data not valid |
| Latitude | 3723.2475 | | dd mm.mmmm |
| N/S Indicator | N | | N=north or S=south |
| Longitude | 12158.3416 | | ddd mm. mmmm |
| E/W Indicator | W | | E=east or W=west |
| Speed Over Ground | 0.13 | Knots | |
| Course Over Ground | 309.62 | degrees | True |
| Date | 120598 | | dd mm yy |
| Magnetic Variation | | degrees | E=east or W=west |
| Checksum | *10 | | |
| <CR><LF> | | | End of message termination |

The GPS receiver engine board used in the system is a commercial product. The frequency used is set at about 1.575 GHz which is in the super high frequency (SHF) band. The GPS receiver is capable of receiving positioning signals from 3 satellites within a 1 m tolerance, which is the typical apartment size in Japan. The portable GPS receiver engine board is shown in previous Fig. 4.

2.2.2 Digital to Analog converter (DAC)

The output of a GPS engine board consists of digital voltage waveforms from the MAX232 IC that is RS232 standard voltage. This digital waveform is received by the digital-to-analog converter (DAC) which converts it into analog, each representing the magnitude of the voltage at a particular instant of time. The analog signal can be either transmitted immediately to the host computer in the case of direct observation, or stored in the on memory chip for analysis at a later time.

2.2.3 Clock circuit for DAC

The clock signal that drives the DAC produces a considerable amount of signal at the fundamental and overtone frequencies. Depending on the crystal used, the clock frequency can oscillate with a range of 4MHz. This can be interfered with the sampling of higher frequencies, resulting in the clock being coupled with the data signal. A capacitor will reduce the effect, but it will still exist to some extent.

2.2.4 Frequency of 930 MHz Transceiver/ GSM cellular phones

The structure of GPS transmitter system is shown in Fig. 7. The GPS receiver engine board has antenna to receive the position signal from the satellite transmitted that signal to hospital's monitoring center. Before transmitting GPS signal, it first digitized. Then, the digitized position data are converted from digital into analog signal carried by the PIC family microcontroller, and reconverted to digital data for sending to GSM cellular phones or UHF transmitter. Fig. 8 shows the block diagram of receiver path at the hospital's monitoring center. It consists of a UHF receiver or GSM cellular phone, 10 analog to digital converter (used PIC family microcontroller), PC communication IC, and serial port of personal computer

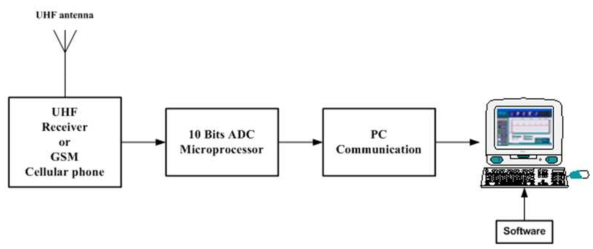


***Fig.8:*** *Block diagram of receiving system at a hospital's monitor center*

## 2.3 Structure of the Software

Computer software for displaying vital signs data and specifying the position of a patient consists of 3 stages:
1. Receiving all vital signs data and displaying on the physician's computer screen at the hospital's monitor center;
2. Displaying position information including latitude, longitude and corrected of GPS data;
3. Current scenario position of patient shows in map on a computer screen.

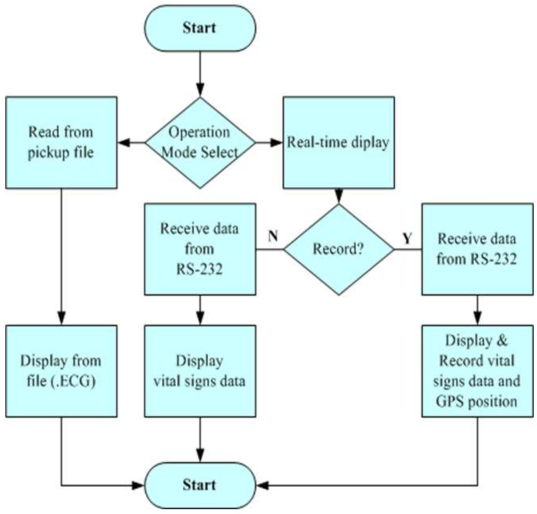


***Fig.9:*** *The algorithm of vital signs data processing*

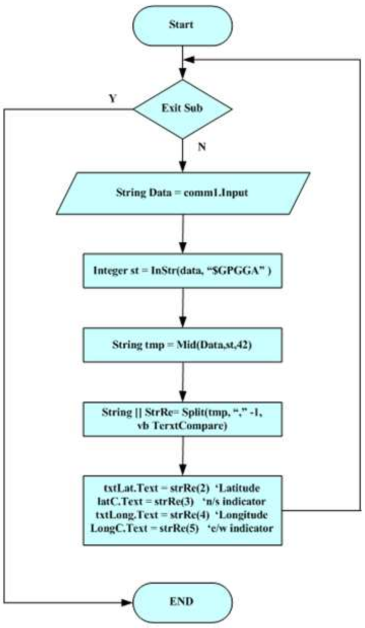


***Fig.10:*** *The algorithm of GPS data processing*

## 3. RESULTS AND CONCLUSIONS

A generic PEM circuit has been developed for acquiring data from a medical transducer and transmits the data locally to the home-based system. To date wireless vital signs monitoring over the cellular phone network have been implemented. Authorized users (medical personnel) may remotely access this system to view and edit multiple windows that display current medical data as graphs, longer term medical charts, patient care plans, current medication and a critical-limits file for alerts. It is also possible to provide automatic notification of unusual changes in monitored data. If certain parameter trigger levels are over, then alert messages may be initiated and displayed to designated medical staff. Because

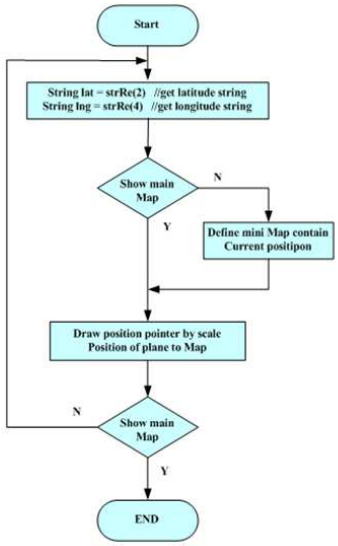


***Fig.11:*** *The algorithm of the patient's position display*

of the increasing numbers of the chronic patients, it becomes an important topic to develop a complete system. Having a PCM system not only allows the patient's physical condition is under control, but also can decrease the cost of taking care of the patients. It will also give the patient family a relief. However, there are many kinds of long-term illness. The physical condition of the chronic patients is quite different from one another. Our future prospect is to invent different kind of supervising systems for different kinds of long-term illness patients.

***Fig.12:*** *A patient equipped with the wireless PEM.*

Fig. 14 shows the relationship of the data stream of direct measurement (upper) of vital signs, and poor condition when modulated with transmitter (middle), and good condition (lower) on the computer screen when using computer program for editing information. To ease ECG signal analysis and improve decision-making, we developed a multi-platform ECG processing tool.

Fig. 15 show the major's map with GPS naviga-

***Fig.13:*** *The vital signs display on the monitor screen*


***Fig.14:*** *The vital signs data stream output.*

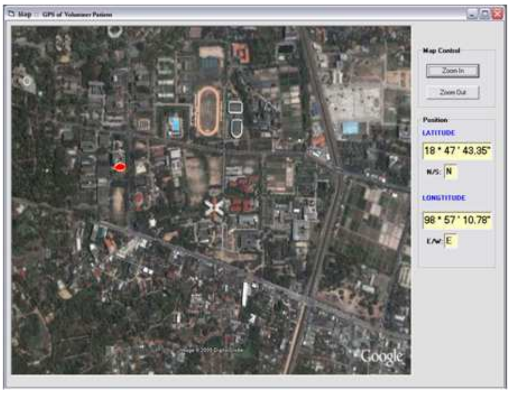


***Fig.15:*** *A screen of the major's map displaying a patient's position.*

tor on physician's computer screen at hospital's monitoring center (developed at the applies computer for Biomedical Engineering Laboratory, Chiang Mai University). This system includes GSM cellular phone, PEM receiver, and a desktop computer. Fig. 16 shows the minor's or sub-map with GPS navigator on physician's computer screen. It shows the map displaying of patient's position in Chiang Mai province, Thailand.


***Fig.16:*** *A screen of the virtual map displaying a patient's location*

## 4. DISCUSSION

The wireless PEM system provides a wireless solution to the conventional method of measuring vital signs from a patient. The system allows for remote monitoring of patients which provides numerous advantages to both patients and physicians. The current system does not provide a real-time vital signs monitoring; however, the wireless link implemented provides a reliable and robust communication link to the transfer of data. The system developed and implemented presents a promising result for further development and design to obtain a complete health monitoring system via wireless networks. This demonstrates that the PEM system can be implemented as the PEM system can provide a large number of benefits.

After decades of development of information systems and telemedicine applications dedicated to hospitals and health professionals, medical informatics is evolving to take account of new electronics health requirements, especially in the domain of home care, self-care, and cyber medicine. We can imagine a near future in which citizens and patients will use, as in this research, smart wearable technologies to produce, transmit, or access information anywhere and anytime and, above all, to act as health consumers who are responsible of their own health. They will be able to perform medical tests at the early stage of the onset of their symptoms without involving skilled personnel and call for assistance only when needed. Additional services like the flow management process of the PEM alarm messages requests to and between health professionals are also being implemented in emergency call centers or in the informatics departments of several hospitals. All our software components will be driven by intelligent mobile agents to facilitate their communication via the XML format and to update the databases storing patient data with new data collected at home or in ambulatory recording conditions and for efficient data retrieval. A new era for electronics health to become personalized, wearable, and ubiquitous has started.

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