CERTAIN INVESTIGATIONS ON HUMAN HEALTH MONITORING USING WIRELESS COMMUNICATION

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Abstract**—***The current paper presents an monitoring system for elderly people, which can transmit information on physiological signals and falling events to a healthcare center at any time and from any place. To detect simultaneously the occurrence of any falling event, as well as the relative electrocardiogram (ECG), oxygen and temperature is monitor of the user, the patient is sensed and transmit to the authorised user. If the patient is fall down means the air bag will protect the patients from the accidents and it send the signal to the hospital and the authorised person*

1. INTRODUCTION

Telemedicine information systems [1]-[4] have become increasingly essential, particularly intelligent systems used to provide high-quality healthcare monitoring, which save on medical and manpower costs [5]-[8]. Population aging is inevitable, and with the progress of civilization and medicine, the primary cause of death has changed from infectious to chronic diseases. Thus, rescuing elderly patients in the event of accidents and illness are of primary importance.

To address the needs of an aging society, a number of challenges should be overcome in developing a healthcare system, namely, 1) the timely and accurate delivery of

This work was supported in part by the China Postdoctoral Science Foundation under grant 2015M571960, and the Fuzhou University Foundation under grant 0110510084.

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Shuenn-Yuh Lee is with the Electrical Engineering Department, National Cheng Kung University, No. 1, University Rd., Tainan, 70101, Taiwan (e-mail: ieesyl@mail.ncku.edu.tw).physiological signals and the location of elderly patients to the healthcare center; and 2) the detection of any falling event of the elderly patients without the use of sensors through which a rescue notification is sent to the nearest healthcare center and to the families concerned.

Several healthcare applications have also been presented Lin et al. [9] proposed a real-time multiuser wireless physiological monitoring system with bidirectional communication. The system comprises mobile physiological examination devices that record body temperature, blood pressure, and pulse signals. Zhou and Hou [10] proposed a comprehensive cardiac monitoring system to support an ubiquitous computing and real-time cardiac monitoring service. Additionally, the system presented four operation modes and defined the transmission priorities of symptoms for different patients. However, the proposed instruments by both Lin and Zhou did not allow remote access from the healthcare center for immediate management of the system. An intelligent computer-aided nursing system proposed by Wang et al. [11] examined blood pressure and pulse signals using an intelligent healthcare box. A network simulator was used to an ubiquitous integrated biotelemetry system for emergency healthcare application. The system was used to monitor the patient before arrival to the hospital. The corresponding physiological signals and video were sent to the hospital through a wireless network. The system recorded the ultrasonic graph and skin image of the patient, as proposed by Cheon et al. [13], and real-time N-to-N network communication was used to enhance the transmission performance of videos and the continuous electrocardiogram (ECG) waveforms.

Vaidehi et al. [14] used a camera placed inside the room of a patient to detect a falling event. The drawback of the system was that the patient had to stay in the same place for a prolonged period. Hsieh et al. [15] presented a system that utilizes a wrist-worn motion-sensing device to detect falling events; the sensing device consists of a tri-axis accelerometer and a three-axis gyroscope, but the location of falling objects could not be determined immediately. Wang et al. [16] proposed an enhanced fall detection system based on a smart sensor worn on the body, for elderly monitoring and operating through consumer home networks. Bai et al. [17] used the accelerometer of a smartphone to design and implement a fall monitor with a global positioning system (GPS) function for

Fig. 1. Architecture of the healthcare system.

the user; the system analyzes not only the change of healthcare center and a family member to facilitate emergency acceleration but also the six typical actions of humans.

In the current paper, an intelligent healthcare system, which is both interactive and features automatic learning, is proposed to monitor the physiological signals and location of an elderly rescue. As shown in Fig. 1, the system includes an H-Box as a portable device to be carried by the elderly patient; thus, the H-Box functions as a healthcare center that serves as the relay station for processing responses to the emergency event, and a person. Besides, a healthcare box (H-Box), which is an family-notification device that can observe the status of the automatic detection system, is employed to monitor the ECG physiological signals of the patient, as well as the position information using an outdoor precision GPS. An ECG acquisition module in the H-Box detects the physiological signals and transmits these data to the healthcare center. The box can recognize the location of the elderly, as well as ECG information, to assist doctors and nurses in understanding the detailed health status of their elderly patients. The box can also send a rescue notification in case the elderly person experienced a fall.

The current paper is organized as follows: Section II presents the system architecture of the H-Box, including the ECG acquisition module and the fall detection scheme. Section III presents the system implementation that adopts a field programmable gate array (FPGA) verification board (FPGAVB) with 32-bit microprocessor combined with ECG, GPS, and Zigbee modules via serial ports. In Section IV, the experimental results of falling based on 4,000 samples are discussed. Finally, Section V concludes the paper.

2. SYSTEM ARCHITECTURE

A healthcare system is beneficial for elderly persons because it enables them to take care of themselves on a daily basis, because the occurrences of accidents when an elderly who is alone is very dangerous. Thus, a healthcare system is proposed to reduce medical costs. The proposed H-Box can be miniaturized as a watch or a portable device that can be carried easily, as shown in Fig. 1. The H-Box can constantly record the A global positioning system is a space-based global position status and ECG signals of the patient. In the event of a navigation satellite that can provide time and position fall or upon transmission of an abnormal ECG signal, the information for users. This system has been widely used device can send an emergency notification to both the around the world in traffic navigation and medical systems

A. Healthcare Box

The block diagram (Fig. 2) of the healthcare box shows an analog front-end module with ECG acquisition and GPS modules, an RF front-end module with a low-power ZigBee system, and a baseband module with 32-bit microprocessor and memory. An FPGA platform is adopted in the baseband to execute the functionality of healthcare monitoring. The GPS module with fall detection capability can supply location information on the elderly patient, and the ECG module can assist in understanding the physiological status of the elderly. The status can be wirelessly transmitted by the ZigBee module, which is suitable for short-distance and multi-hop applications.

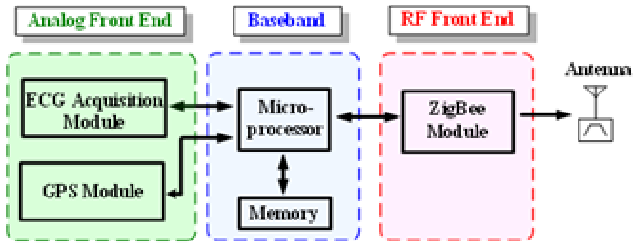

Fig. 2. Block diagram of the healthcare box.

B. Fall Detection Scheme

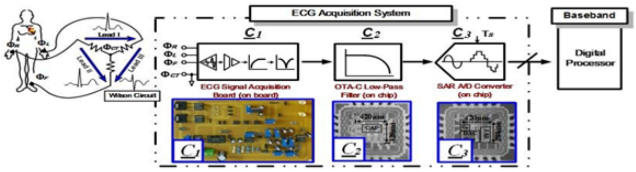

Fig. 3. Block diagram of analog front-end for ECG acquisition system.

[18] for free access by users with GPS receivers. Altitude difference and gravitational acceleration are adopted in the proposed scheme to assess the basis of fall detection. In Taiwan, the average height of adult men is 172.3 cm and that of adult women is 162.5 cm. Moreover, the corresponding chest height of men and women are approximately 135 cm and 120 cm, respectively. The GPS antenna is attached to the chest, linked to the GPS module, and connected to the H-Box via the universal asynchronous receiver/transmitter (UART) serial port. If the difference in detected altitude varies by more than 135 cm and 120 cm for men and women, respectively, a fall notification is transmitted by the H-Box. The fall can also be detected by the National Marine Electronics Association 0183 (NMEA 0183) and Recommended Minimum Specific GPS/Transit Data ($GPRMC/RMC) gravitational acceleration variation [19]. Based on the experimental result (in Section IV), the acceleration of gravity changed by over 0.06 knots, thereby exceeding 3.1 cm per second as refer to (1), where one knot is equal to 1851.8 meters per hour. In this case, the elderly patient is certainly experiencing a fall.

0.06 □1851.8 m □111.1 m □ 3.1 (1)

1)ECG signal acquisition board: In clinical ECG diagnosis, several leads, combined with signals from different body parts, are used to trace the activity of the

heart. As shown in the left section of Fig. 3, the electrodes are placed on the right wrist, left wrist, and left ankle, and each node combines with a resistor to form a common node called the Wilson central terminal. The body signal can be translated by six leads, including three main leads (I, II, and
III) and three minor leads (aVR, aVF, and aVL).
Aside from the Wilson circuit, the ECG signal acquisition board (C1 in Fig. 3) comprises a number of discrete components, including 1) an instrumentation amplifier (called a pre-amplifier), the primary function of which is to amplify the feeble ECG signals; 2) a high-pass filter with a cut-off frequency of 0.1 Hz, which is applied to eliminate the low-frequency noise on the ECG signal acquisition board; and 3) a notch filter, which is the last stage used to protect the circuits against the 60 Hz interference produced by the AC-110 V power supply [21].
Operational Trans conductance Amplifier-capacitor
(OTA-C) Low-pass Filter: Simultaneously, an on-chip low-
The average heart rate of a man is 70 to 90 beats per minute (bpm). To calculate the average heart rate in the first five seconds of system initial status for the elderly, if the measured heart rate is under 50 bpm or the measured heart rate is 40 bpm greater than the average heart rate, then it shows that the elderly person is falling down. Besides, the amplitude of ECG data is used to detect instances of falling.

C. Electrocardiogram Acquisition

The ECG acquisition is responsible for acquiring weak ECG signals sensed from the electrode leads with an amplitude range of 100 μV to 4 mV [20]. This module serves as the interface between the physiological signals and the digital processor to process the ECG examination data (amplifying, filtering, and digitizing). Additionally, the noise from the 60 Hz power lines and instrument interference should be rejected by this ECG acquisition module. The entire system block is shown in Fig. 3, and the details are described in the following subsections.
pass filter that is placed behind the ECG signal acquisition board is employed to filter the out-of-band high-frequency noise, and its bandwidth coincides with the ECG examination frequency range (0.1 Hz to 250 Hz). In the switch-capacitor circuits, the low sampling frequency in the kilohertz range results in leakage, and the power consumption is increased by the operational amplifiers. Therefore, the continuous-time OTA-based filters are preferred for low-power and low-frequency applications. Consequently, a fifth-order Butterworth filter with ultra-low power consideration and a corresponding cut-off frequency of 250 Hz was adopted to achieve the low-pass filter [21]. The low-pass filter was implemented with 0.18 μm CMOS standard process. The micrograph is also shown in C2 of Fig. 3, which is capable of precisely filtering the out-of-band noise and restoring the ECG signal, the details are presented in a previous study [21]. The measurement result revealed that a dynamic range of 50 dB and a power consumption of 452 nW can be achieved under 1 V supply voltage.

3) Low-power Successive Approximation Analog-to-Digital
Converter (SAADC): The ECG acquisition system requires a signal-to-noise and distortion ratio (SNDR) of at least 32 dB (that is, 6 bits) to detect heart activities precisely [20]. Therefore, the resolution of the ADC behind the OTA-C filter is designed as 8 bits for data conversion [22]. The basic architecture of SAADC comprises a sample/hold circuit, a comparator, a successive approximation register controller, and an 8-bit digital-to-analog converter. The 0.18 μm CMOS standard process was adopted to realize the SAR ADC, and the micrograph of the chip is shown in C3 of Fig. 3. According to the measurement results, the SNDR was 45.2 dB, with 7.2 bits as the corresponding effective number of bits. The power consumption of this 8-bit SAADC was 0.95 μW.

3. HEALTHCARE MONITORING IMPLEMENTATION

As shown in Fig. 4, a prototype of the healthcare box is adopted to monitor the ECG physical signals to record the position of the elderly and to transmit the data. An FPGA verification board (FPGAVB) with 32-bit microprocessor is used as a motherboard to integrate the submodule boards, including the ECG acquisition, GPS, and ZigBee modules, the details of which are described in the following subsections.

A. FPGA Verification Board

An FPGAVB is the system prototype used to implement the H-Box. The verification board includes a 32-bit microprocessor, a 128 MB synchronous dynamic random access memory (SDRAM), and a high-resolution video graphics array chip. The microprocessor is responsible for operating the H-Box and the control of the peripherals. The SDRAM stores the physical signals and position data of the elderly patient, as well as the control commands and communication protocol. The UART and general purpose I/O are adopted to connect the ECG, GPS, and ZigBee modules. Four serial ports (UART interface) embedded in the verification board are employed to communicate with other modules, including the network interface connected to the ZigBee module, the analog interface connected to the ECG and GPS modules, and the control interface connected to the console.

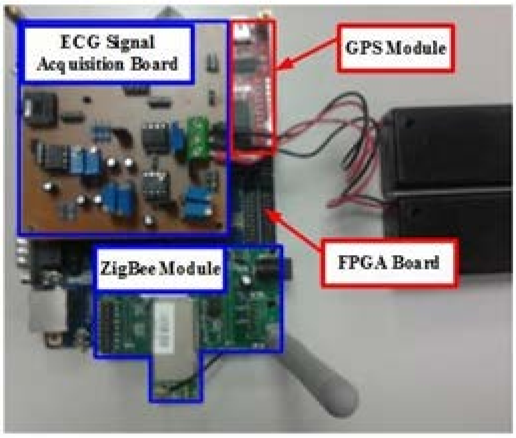

Fig. 4. Multi-function H-Box with FPGAVB multi-modules

Both on-chip ICs, a Butterworth low-pass OTA-C filter (C2 in Fig. 3), and a SAR A/D converter (C3 in Fig. 3) are integrated into the ECG acquisition system with other discrete components for ECG signal detection. Fig. 5 shows the measurement conditions where the electrode leads are placed on the wrists and ankles to observe the ECG signal. An oscilloscope and a logic analyzer are employed to analyze the physical signals at the filter output and the digitized code at the ADC output, respectively. The measured results are also illustrated in Fig. 5 (F1 – F3), where F1 is the output from the ECG signal acquisition board, and the signal has been injected with high-frequency noise and environmental interference. Generally, these unprocessed data are unsuitable for diagnosing heart disease. However, according to the analog signal processing by the low-pass filter and SAADC, the out- of-band high-frequency noise is rejected, and the clear baseline can be traced. The 8-bit codes behind the SAADC are used to diagnose the abnormal heart rate variability.

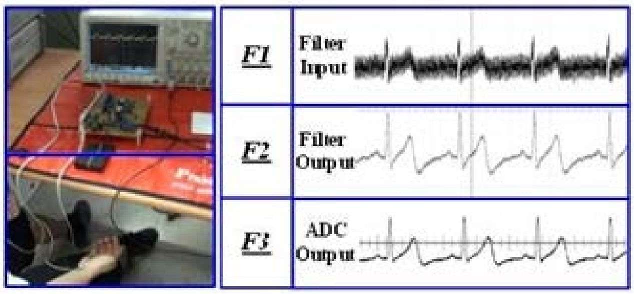

Fig. 5. Experimental set-up and measurement result of the ECG module.

4. GPS Module

An evaluation board with a GPS chipset is adopted to implement the GPS module. The position data of Global Positioning System Fix Data ($GPGGA/GGA) [19] and RMC parameters received from the GPS module are transmitted to the FPGAVB through a UART serial connector. The 32-bit microprocessor in the verification board detects the fall according to the GGA and RMC parameters, and the ECG examination data are stored in the SDRAM. The GPS receiver standard interface with NMEA 0183 [19] is used to estimate altitude difference and gravitational acceleration. The information on the elderly, including time, position, and related data, is recorded in GGA format. Moreover, the RMC can provide the minimum navigation information. According to the data format (GGA and RMC), the altitude difference and gravitational acceleration can be estimated. The data on GGA and RMC are also illustrated in Fig. 6.

5. ZigBee RF Transceiver Modules

The ZigBee transmitter is connected to the FPGAVB, and the ZigBee receiver is integrated with the computer server via Ethernet to communicate with the healthcare center. A ZigBee development board with an embedded chipset is adopted to establish wireless communication. The chipset is compatible high-mesh wireless controller to convey the captured ECG signal efficiently and correctly.

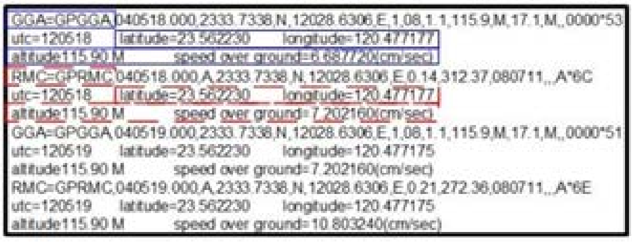

Fig. 6. GPS data for the detection of falling-down events.

6. System Integration

Before the ECG physical signal and GPS location data are collected, the devices in the H-Box are initiated. The detailed operation is shown in Fig. 7. The multi-thread techniques, including the ECG signal acquisition and GPS detection threads, are applied in the H-Box. The ECG physical signal is converted into x and y coordinates, which are subsequently displayed in the ECG receiving thread. Moreover, the received GPS data are adopted to analyze the Universal Time Coordinate (UTC), longitude, latitude, altitude variation, and gravitational acceleration. The analyzed data are employed to detect the fall of the elderly patient. Through multi-thread detection, the physical data are mutually verified by each thread to improve the accuracy of fall detection.

The antenna of the GPS module is attached to the chest of the patient, and the ECG electrode leads are placed on the wrists. Thus, the GPS and ECG data are collected and stored in the memory of the device. The data can be sent to the healthcare center via the wireless ZigBee modules and Ethernet.

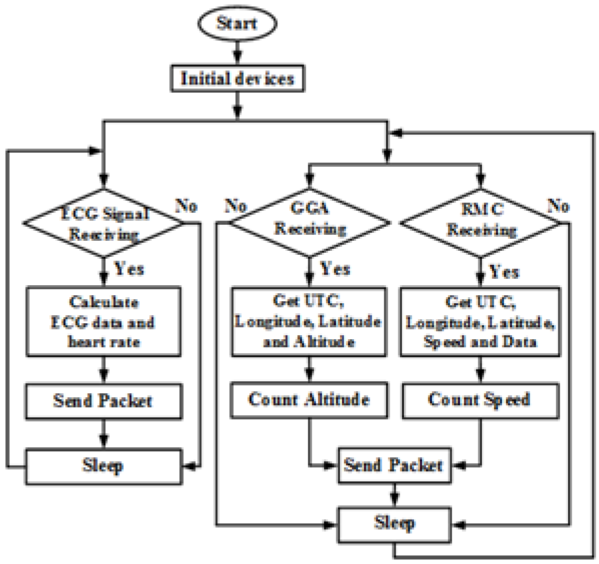

Fig. 7. System flowchart of the healthcare box with multi-thread technique.

The healthcare center receives the patient information including personal identification data (ID), name, and status, which are stored in the database. In the surveillance client doctors and nurses can monitor physical signals through the surveillance monitor, as shown in Fig. 8. If the patient falls, the rescue notification given by the H-Box is sent to the medical staff and family immediately.

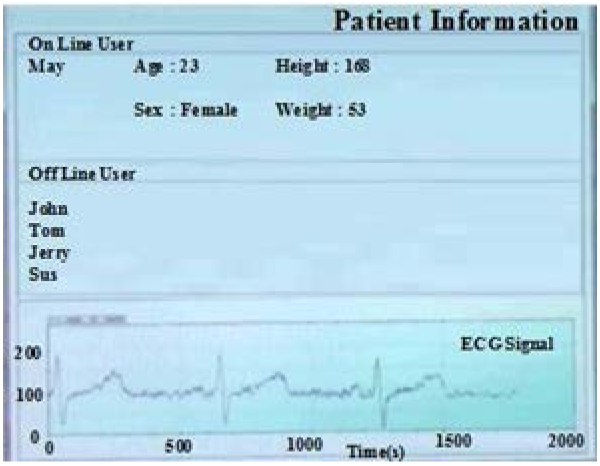

Fig. 8. Personal information and ECG examination data.

7. FAMILY CLIENT

The families of elderly patients are authorized to access the database from the healthcare center when they log on to the server, and the graphic user interface is easy to operate. The monitor displays the patient ID, the ECG examination signal, and the patient location map, which are synchronized with the detectors. Furthermore, a flexible online service tool [23] is integrated into the program to inform the user about the location of the patient, as illustrated in Fig. 9.

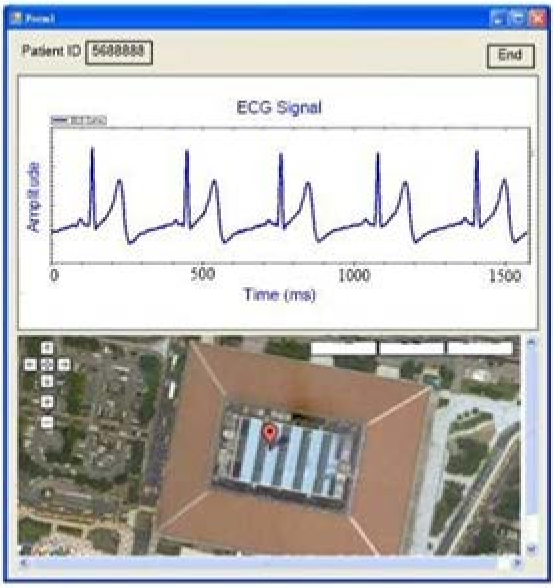

Fig. 9. Display interface for family client.

8. EXPERIMENTAL RESULT AND PERFORMANCE

The experiment on fallANAteLcYtiSoInS is based on observations of elderly behavior. The H-Box is an auxiliary apparatus that monitors the GPS and ECG data to evaluate the position and examine the physical signals, respectively. The fall is determined by the altitudinal change of the antenna position on the GPS module. Movement, location variation, and environmental interference present challenges to the successful probability and accuracy of detection.

The experimental results on GPS information with GGA parameters are shown in Fig. 10 (blue). The fall can be detected by the H-Box according to the change of altitude ranging from 144 cm to 142.1 cm. The acceleration of gravity changed by over 0.06 knots is shown in Fig. 10 (red).

Fig. 11 presents a successful case where the elderly was detected to be falling at the ninth second. After six seconds, the healthcare system sent out the message at the 15th second to notify the healthcare center. The fall conditions are determined by the height of the GPS antenna, which decreases to below 135 cm and 120 cm within six seconds for men and for women, respectively. In addition, the elderly patient fell at the 30th second and the notification was sent at the 36th second In Fig. 11, the altitude of the patient and the differential vertical position are shown. Since the GPS signal has variations, the system calculated the differential vertical position as six seconds to ensure that the patient was in fact experiencing a fall.

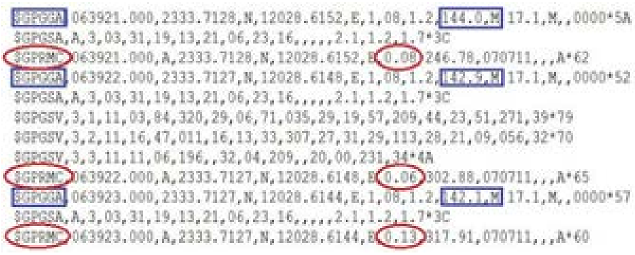

Fig. 10. Experimental result of GPS information with GGA (blue) and RMC (red) parameters.

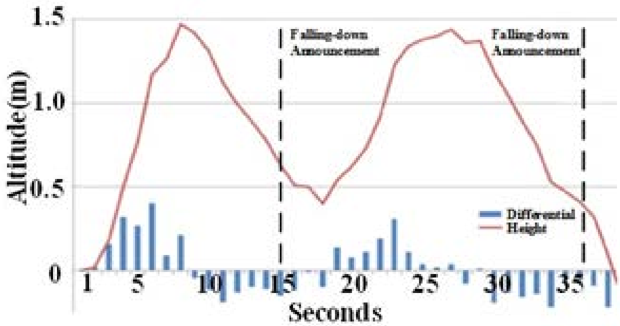

Fig. 11. Experimental result of fall detection for the elderly.

Four different heights were employed to verify the sensitivity and accuracy of the system. The experiment results are reported in Tables I to IV. The falling-down instances ranged from 25 to 82, and the standing-up instances ranged and 80.77%, and the corresponding accuracy for standing detection was between 15.14% and 91.67%. An 80% success rate could be achieved when the height of the detector exceeds 160 cm. However, the accuracy decreases rapidly when the height drops below 150 cm.

The ECG data are used to detect the fall. As shown in Fig. 12, based on the data on ECG_average, heart rate, and ECG_abnormal announcement, from the 9th second to the 14th second, the measured heart rate has an abnormal value such that the system detects the occurrence of falling.

TABLE I
CASE 1 – HEIGHT ABOVE 180 CM

Condition	Success	Miss	Error
Falling down	80.77%	15.38%	3.85%
Standing up	91.67%	8.33%	20%

Statements: Falling down 25 times, standing up 24 times

TABLE II
CASE 2 – HEIGHT BETWEEN 160 CM AND 180CM

Condition	Success	Miss	Error
Falling down	80%	12%	8%
Standing up	88%	8%	4%

Statements: Falling down 25 times, standing up 25 times

TABLE III
CASE 3 – HEIGHT BETWEEN 150 CM AND 160CM

Condition	Success	Miss	Error
Falling down	70.45%	18.18%	11.36%
Standing up	64.52%	6.45%	29.03%

Statements: Falling down 82 times, standing up 53 times

TABLE IV
CASE 4 – HEIGHT BELOW 150 CM

Condition	Success	Miss	Error
parameters			
Falling down	63.64%	19.7%	16.67%
Standing up	15.14%	11.63%	30.23%

Statements: Falling down 66 times, standing up 43 times

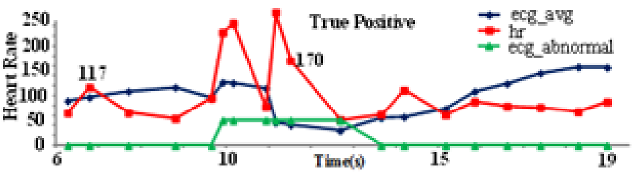

Fig. 12. ECG data of ECG_average, Heart Rate, and ECG_abnormal.

The emergency conditions monitored by the healthcare center are shown in Table V. The six statuses based on GPS data and normal/abnormal ECG signal are safe, falling down, standing up, lying down, at risk, and removed ECG tag. For various conditions, the standard operating procedure used by the healthcare center is either to continue monitoring or to issue a rescue notification immediately.

GPS	ECG	status	response
normal	normal	safe	keep monitoring
abnormal	normal	falling down	keep monitoring
abnormal-> normal	normal	standing up	keep monitoring
abnormal-> abnormal	normal	lying	rescue
Abnormal	abnormal	risk	rescue
normal	abnormal	removed ECG tag	rescue

Compared with related fall detection systems, as shown in Table VI, the image-based system [14] used a camera monitoring technique in patient fall detection. Rare cameras were installed outdoors, and a patient had to stay in the same place for a prolonged period. A system that used body acceleration data to determine whether certain objects were falling [15]. The system needs a large amount of data to determine the falling objects. The smart-sensor worn system [16] was used in elderly monitoring to detect human information. The proposed system can transmit both the position and the ECG information of elderly patients, which can help doctors to understand in detail the health situation of their patients.

TABLE VI
COMPARISON OF PROPOSED SYSTEM OTHERS

	Image-based [14]	Movement and Sound Data [15]	Smart sensor-worn [16]	Proposed System
Falling detection method	Camera monitoring	Acceleration data	Smart-senor	Altitude, acceleration (GPS)
Accuracy	-	95%	97%	80% GPS only 95% with ECG
Command	Outdoor cameras are needed	A database is needed	G-sensors are needed	Location ECG information assistant

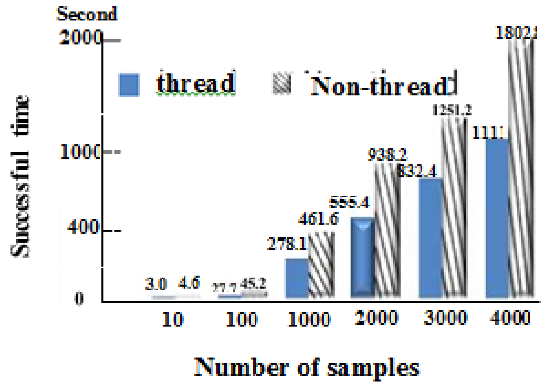

Fig. 13. Analysis of system performance

9. CONCLUSION

An intelligent healthcare system was proposed to monitor the condition of elderly persons using a multi-function healthcare box placed outdoors. The proposed system can implemented to collect the location data and examination signals using GPS and ECG acquisition modules, respectively.

The system can detect whether the person is falling by analyzing the collected GPS information. The ECG module is an auxiliary apparatus that is used to determine the status of elderly patients. The healthcare center would be notified of the need for rescue when the fall was continuously detected based on the GPS and ECG interaction monitoring information. Furthermore, a two-thread system was proposed to improve the successive probability of fall detection. According to the experimental results, the successful detection time can be improved by 38% based on 4,000 samples, as illustrated in Fig. 13, thereby increasing rescue opportunities for elderly patients.

10. ACKNOWLEDGMENT

The authors are grateful to the China Postdoctoral Science Foundation and the Fuzhou University Foundation for the technical support. The authors also thank Hong-Jie Lai, member of the Fujian Integrated Circuit Design Center Communication and Biologic Integrated Circuit Laboratory, for his assistance in conducting this study.

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