Design and Implementation of Multi-parameter Healthcare System with Positioning Function

Hanlin Chen¹,a, Jingyi Yin¹

¹Department of Electronics and Communication Engineering, Beijing Electronic Science and Technology Institute, Beijing 100070, China

a Corresponding author: hanlin_chen@sina.com

Abstract: Based on multi-parameter physiological module CSN808 and GSM/GPRS engine SIM508 supporting GPS function, this paper presents a multi-parameter healthcare system with positioning function. The system can acquire ECG, respiration, blood pressure, body temperature signals and GPS position information of patients, analyse signals quickly and feedback diagnoses to patients. Under the circumstance of a sudden heart attack, the system can alarm automatically, and doctors in the healthcare center can guide patients’ self-treatment via GSM audio communication and take quick rescuing measures on the basis of patients’ GPS position information. To ensure the correctness of data transmission, Grøstl hash algorithm is realized to verify the integrity of data. This system can provide a round-the-clock, rapid-response, stable and reliable monitoring.

1. Introduction

The aging of the population has become a prominent social problem. The number of deaths caused by the cardiovascular disease, which is the greatest threat to the health of the elderly, accounts for one-third of the global death toll [1]. Electrocardiogram (ECG) can accurately reflect the status of cardiovascular disease and has become main diagnostic basis for cardiovascular disease. Recently, the research on ECG applications develops rapidly and receives more and more attentions. In these ECG applications, ECG sensors are attached on clothing or implanted in human body to acquire ECG signals of patients. Then, the recorded ECG signals and the control commands are wirelessly transmitted between sensor nodes and the healthcare center, and the healthcare center can give detailed analysis and diagnosis. Benefiting from rapid technology advances in wireless communication, signal processing, biomedical sensing, and integrated circuits, a large number of ECG applications have been developed for the improvement of human lives [2-4].

The timing of treatment for cardiovascular disease is critical, and the loss of timely treatment can lead to disability and even death. But the onset of cardiovascular disease is sudden and unpredictable, so patients need a real-time, all-weather monitoring service. In addition to ECG signals, other physiological signals, such as body temperature, breathing, blood pressure, etc., are needed for more accurate diagnosis. Besides, the location information of patients is also very important for the rapid rescue. In this paper, a multi-parameter healthcare system with positioning function is designed and implemented. Based on multi-parameter physiological module CSN808 and GSM/GPRS engine SIM508 supporting GPS function, the system can conveniently obtain ECG signals of patients and other physiological parameters, timely analyse and process them, get patient's comprehensive
conditions, and give diagnosis results. When the disease attacks, an alarm is issued and quick rescue measures can be taken based on the patient's GPS positioning information.

The rest of the paper is organized as follows. Section 2 describes overall design. According to the requirements of overall design, hardware design and software design of the system are presented in Section 3 and Section 4 respectively. Finally, Section 5 concludes the paper.

2. Overall structure and working principle of the system

The overall structure block diagram of the system is shown in Figure 1. The system consists of a healthcare center, a plurality of portable monitoring terminals, and GSM/GPRS networks. The monitoring terminal is mainly composed of FPGA A2F200 chip with embedded 32-bit ARM hardcore, SIM508 module and CSN808 module. A2F200 receives the physiological parameters of the patient through UART 1, receives the GPS information through UART 2, and controls the SIM508 to perform GSM/GPRS data communication. The healthcare center consists of a server, SIM508 module, physiological parameter waveform display, database, GPS positioning display and alarm circuit.

Multiple physiological parameter signals of the patient are collected by CSN808 and transmitted to A2F200 through the serial interface. A2F200 performs correlation process to get physiological information of the patient, and obtains the GPS position information from SIM508 module, and then physiological information and the GPS information are transmitted to the healthcare center through the GPRS communication of SIM508 module. The healthcare server quickly analyses and evaluates received physiological information, and feeds back diagnosis results and precautions to the patient through GSM audio communication. If immediate medical attention is required, the healthcare center will alert and direct the patient to self-rescue through GSM audio communication, and immediately dispatch emergency rescue based on the patient's GPS positioning information. When a patient is in a coma or is unable to express his or her position through GSM voice communication, GPS positioning is particularly useful for determining the patient's position and taking timely rescue measures. In order to ensure the correctness of data transmission, the digest of the data is generated by Grostl hash algorithm, and transmitted to the healthcare center together with data, so as to verify the integrity of the transmitted data. Therefore, the system can correctly complete the collection, transmission, display, storage and real-time processing of multiple physiological parameters of the patient, and collect and display GPS position information, realizing a round-the-clock, rapid-response and reliable monitoring.

3. Hardware design of portable monitoring terminal

3.1. Circuit design of A2F200
A2F200 is an intelligent mixed-signal FPGA chip from Actel’s SmartFusion series. A2F200 integrates a 100 MHz, 32-bit ARM Cortex™-M3 hardcore, 256KB Flash, 64KB RAM, 8/10/12-bit ADC, 12-bit DAC, UART, I²C, SPI, DMA, timer, as well as 200,000 Flash-based programmable gate arrays, 4,608 D flip-flops, and 36,864-bit programmable RAM. These rich resources allow the chip to work as an on-chip system. Unlike traditional FPGAs, Flash-based A2F200 provides micro-amp-level sleep-power and microsecond-level sleep-time, both of which are key to low-power operation [5].

Internal module diagram of A2F200 is shown in Figure 2. A2F200 includes the Cortex™-M3 processor, Grøstl algorithm implemented with programmable logic resources, UART and GPIO. The Cortex™-M3 processor connects with Grøstl algorithm via a high-bandwidth AHB bus that complies with the AMBA 3 AHB-Lite specification [6]. Through the conversion of AHB-APB bridge, high-speed Cortex™-M3 processor can access UART and GPIO through low-bandwidth APB bus conforming to the AMBA 3 APB specification.

![Figure 2. Internal module diagram of A2F200](image)

### 3.2. Circuit design of CSN808

Physiological parameter acquisition module CNS808 is shown in Figure 3. CSN808 is a six-in-one multi-parameter physiological module, which can measure and monitor ECG, heart rate, non-invasive blood pressure, oxygen saturation, respiration and body temperature. The module is compatible with all BCI-compatible probes and configures a dual temperature channel with (YSI) 400 Series temperature probes. CSN808 module receives control information and transmits detected multi-parameter data through the serial interface. Its operating voltage is +6 V, so four 1.5 V button batteries are used as its power supply [7].

![Figure 3. Physiological parameter acquisition module CSN808](image)

### 3.3. Circuit design of SIM508

SIM508 is a tri-band GSM/GPRS engine that operates at GSM 900 MHz, DCS 1800 MHz and PCS 1900 MHz, and supports GPS satellite navigation. SIM508 provides GPRS multi-slot class 10/8 (optional) functionality, and supports GPRS CS-1, CS-2, CS-3 and CS-4 encoding schemes. Designed with power-saving technology, current consumption of SIM508’s GSM part is less than 3 mA in sleep mode, and its size is 55 mm x 34 mm x 3.0 mm, which is ideal for low power and small size portable applications.

SIM508 and its accessory circuit are shown in Figure 4. SIM508 has two serial ports. Serial port A performs GPRS communication, and serial port B performs GPS information transmission. However, considering limited resources of A2F200, GPRS and GPS communication can be time-multiplexed, which means A2F200 needs only a serial port. By utilizing two relays, selection signal SELECT_A/B can realize the switch between GPRS and GPS communication. The accessory circuit mainly includes
a SIM card, a microphone and a speaker. Both 1.8 V and 3.0 V SIM cards are supported. In microphone and speaker circuits, electrostatic discharge (ESD) circuits are designed to prevent static electricity.

4. Software design

4.1. Software Design of the healthcare server

The healthcare center realizes the reception, analysis, processing, display and storage of patient’s physiological parameters and GPS position information, emergency treatment and patient’s information management. The program flowchart of the healthcare server is shown in Figure 5. Patient’s physiological parameter data and GPS position information are received by wireless communication module SIM508, and the correctness of data transmission is verified by Grøstl hash algorithm. After the verification passes, the healthcare server analyses and processes physiological parameter data, and returns diagnosis results to the patient. If the patient is in serious condition and needs urgent treatment, the healthcare server will alarm. The doctor will guide the patient to self-rescue through GSM telephone, and dispatch an ambulance according to patient's GPS position information, so as to provide timely and reliable monitoring.
4.2. Software design of Cortex™-M3 processor

The Cortex™-M3 processor is central processor of portable monitoring terminal, manages and coordinates the rest of the terminal. Its program flowchart is shown in Figure 6. After the self-test of the terminal is successful, the Cortex™-M3 processor receives physiological parameter data of the patient through serial port 1, collects GPS position information of the patient through serial port 2, and then compresses collected data by using Grøstl hash algorithm to generate a digest, which can verify the correctness and integrity of data transmission. The digest and original data are sent to the healthcare center. Based on μC/OS-II embedded real-time operating system, the software of Cortex™-M3 processor is designed. The μC/OS-II is a transplantable and tailorable real-time multitasking operating system, which can manage up to 64 tasks, and support semaphores, message boxes, message queues and other common inter-process communication [8].
4.3. FPGA implementation of Grøstl algorithm

Grøstl algorithm [9] is a kind of SHA-3 candidate algorithm for the third generation hash algorithm. It inherits the iterative structure of MD hash algorithm and follows the compression function of AES algorithm. Grøstl algorithm consists of three parts: data padding, compression function and output transformation. It supports four versions of 224-bit, 256-bit, 384-bit and 512-bit digest. This system uses 256-bit version. Its FPGA implementation block diagram is shown in Figure 7.

Grøstl algorithm first fills input data \( M \), so that the size of data is an integer multiple of 256 bits, and each 256-bit data block is recorded as \( m_i \) (\( i = 1, 2, 3, \ldots, t \)). Then, the filled data block is compressed with a compression function. The process of data compression is as follows. Starting from the first block of data \( m_1 \), the compression function compresses the data block \( m_i \), obtaining a compression result \( h_i \). Then, the result is fed back as a parameter of the next iteration to realize the compression of next data block \( m_{i+1} \), and so on, until the compression of last data block \( m_t \) is completed, and the compression result \( h_t \) of entire data block is obtained. The compression function is mainly composed of permutation \( P \) and permutation \( Q \). Equation (1) is the expression of compression function:

\[
h_i = P(h_{i-1} \oplus m_i) \oplus Q(m_i) \oplus h_{i-1}
\]  

(1)

Where \( h_{i-1} \) is the compression result of \( i-1 \) data block, \( i=1, 2, 3, \ldots, t \). When \( i=1 \), the first block of data is compressed, and \( h_0 \) is initial vector, \( IV=00 00 \ldots 00 01 00 \). \( IV \) and \( h_{i-1} \) are selected by multiplexed data selector MUX. The result \( h_{i-1} \) of previous iteration is registered as a feedback parameter for next iteration by register 2. Both permutation \( P \) and permutation \( Q \) are subjected to 10 rounds of transformation, and the results \( P_i \) and \( Q_i \) of each round transformation are registered by register 1. Each round transformation involves four steps: AddRoundconstant, SubBytes, ShiftBytes and MixBytes. The AddRoundconstant step is to XOR permutation \( P \) and permutation \( Q \) with their corresponding round constants. The SubBytes step is only a non-linear operation in Grøstl algorithm, which replaces the element \( a_{i,j} \) with the corresponding elements in the S box that is the same as AES.
algorithm [10], where $a_{i,j}$ lies in the i row and the j column of permutation matrix. The ShiftBytes step performs a cyclic left shift operation for each line, and the first to eighth lines are shifted left by 0 to 7 bits, respectively. The MixBytes step is an operation on the GF($2^8$) finite field. The loop matrix B consisting of Maximum Distance Separable (MDS) codes is used to separately multiply the permutation P matrix and the permutation Q matrix.

![Diagram of Grøstl algorithm](image)

After all the data blocks are compressed by compression function, final compression result $h_t$ is transformed to output final hash value. The expression of output transformation is as shown in equation (2):

$$\text{hash} = P(h_t) \oplus h_t$$

The algorithm is programmed in VHDL hardware description language, and implemented in Actel’s Libero IDE 9.2 development environment. Final implementation occupies 53,496 gates of programmable logic gate arrays and 2815 D flip-flops, and achieves a maximum clock frequency of 201.5 MHz and a throughput of 4762 Mbps, which can fully meet the requirements of this system.

5. Conclusion
This paper designs and implements a multi-parameter healthcare system based on CSN808 and SIM508. The monitoring terminal has small size, low power consumption, low cost and high overall performance. The system can remotely acquire patients’ multiple physiological parameters and GPS position information, analyse them and diagnose in time, give quick rescue measures, so as to give a round-the-clock, rapid-response and reliable monitoring service. Besides, it can save the inconvenience of patients to the hospital, and reduce the workload of doctors. Therefore, it has high practicability and good application prospects.

References
[1] L Dakun, Z Fang, Real-time remote monitoring of out-of-hospital with high patients especially risk heart diseases, Proceeding of 2007 IEEE/ICME International Conference on Complex Medical Engineering, 332 (2007)
[2] Liu, Xin, Zheng, Yuanjin, Phyu, Myint Wai, An Ultra-Low Power ECG Acquisition and Monitoring ASIC System for WBAN Applications, IEEE Journal on Emerging & Selected Topics in Circuits & Systems, 2(1), 60 (2012)
[3] P. Bonato, Wearable sensors/systems and their impact on biomedical engineering, IEEE Eng. Med. Biol., 22(3), 18 (2003)
[4] S. Lee, L. Yan, T. Roh, S. Hong, and H. J. Yoo, A 75 µW real-time scalable body area network controller and a 25µW ExG sensor IC for compact sleep monitoring applications, IEEE J. Solid-State Circuits, 47(1), 323 (2012)
[5] Wikipedia, Field programmable gate array [EB/OL], http://en.wikipedia.org/wiki/Field-programmable_gate_array, 2010
[6] AMBA Specification (Rev 2.0) ARM IHI0011A, ARM, 1999
[7] Yuxiao Zhao, Zhiling Xu, Chuan Tang, Software design of wireless monitoring system for patients in hospital, Laboratory science, 14(1), 100 (2011)
[8] Beibei Shao, Embedded real-time operating system µC/OS-II, Beihang University Press, 2003
[9] Gauravaram P, Knudsen L, Matusiewicz K, Grostl – a SHA-3 candidate[EB/OL], http://groestl.info/Groestl.pdf, 2008
[10] Daemen, Joan, Rijmen, Vincent, The Design of Rijndael, Springer, 2002