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Article

DEVELOPMENT OF WIRELESS SENSOR NODE FOR SPORTSMEN

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Abstract

In last years, the vital data of sportsmen at the time of exercise and game have been used to plan efficient exercise and elude injuries and diseases, where a vital sensor node is frequently installed at the chest position of a sportsman. One of the major problems is that a tri-axis accelerometer sensor should be installed at a different position such as rear waist for exact energy expenditure (EE) evaluation whereas an electrocardiogram (ECG) sensor should be separately installed at a chest position for exact heart rate (HR) evaluation.

In this paper, afresh Development a wireless waist-mounted vital sensor node for both EE and HR evaluation. First of all, to select a microcontroller applicable for the data processing in the vital sensor node, we computationally compared three microcontrollers in requirements of energy consumption necessary for the vital data processing. The matching showed that LPC1768 is the most power- saving candidate, so then designed and realized prototype vital sensor node utilization LPC1768.

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Introduction

Recently, in the field of sports, the vital data of sportsmen at the time of exercise and game have been used for analyzing their physical strength and preventing injury. Wireless vital data collection system [1] has drawn much attention for realizing real-time monitoring of sportsmen' performance, which is helpful for their coach and trainer on the field. Here, important vital information includes heart rate (HR), energy expenditure (EE) and body temperature (BT).

Wan-Young Chung and his teams [4], had designed a non-intrusive healthcare system, This system was designed for a wide area coverage which is based on wireless sensor network to support RF transmission, Through this project, they developed a system that allows transmitting physiologic data in wireless sensor network using IEEE 802.15.4. The data were transmitted to a base station which is connected to a server PC from on-body wearable sensor device, which consist of wearable USN node, wrist pulse oximeter and chest sensor belt.

Tia Gao's team [5] designed their prototype of patient monitoring and tracking systems based on CodeBlue project This prototype consists of a wearable computer that attached to the patient wrist which known as smart dust or a mote which transmit the information to the first responder's tablet device continuously. This project allows data transmission uses the TinyOs Active Messages Protocol which is based on IEEE 802.15.4. To allow indoor and outdoor usage, they implement the system with GPS to provide geolocation and indoor location detection system. This system is portable and can be use everywhere.

Vital sensor nodes are often installed at the chest position of a sportsman because an electrocardiogram (ECG) sensor is used for HR estimation, like SPIHPU from GPSports [2]. One of the main problems is that an ECG sensor should be installed closer to heart for correct HR evaluation, whereas a tri-axis accelerometer sensor should be separately installed at a waist position for accurate EE evaluation [6].

To solve the problem, we have proposed a wireless waist-mounted vital sensor node, in which "HR evaluation using weak ECG signal sensed at waist position" is required. In our previous work, we have shown that such HR evaluation is possible, developing a time-domain signal processing technique for computing HR from the weak ECG signal and demonstrating its performance by an experiment [3].

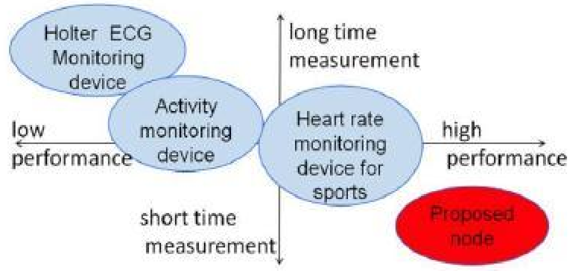
In this paper, we recently development a waist-mounted wireless sensor node for transmitting vital data sensed from sportsman using the 920 MHz frequency band. First of all, we discuss the signal processing capability necessary for the wireless waist-mounted vital sensor node. Then, we compare the productiveness of three candidate microcontrollers in terms of "power consumption" and "accuracy" for the HR evaluation, and also discuss the trade-off between selection of microcontroller and resultant energy efficiency. After selecting the best microcontroller out of the three candidates, we finally show the specifications of a prototype vital sensor node using the selected microcontroller.

The rest of the paper is organized as follows. Section II shows the overview of our vital sensor node. Section III shows the requirements for microcontroller in our vital sensor node and compares the three candidates. Section IV shows the design of our prototype vital sensor node. Finally, section V concludes the paper.

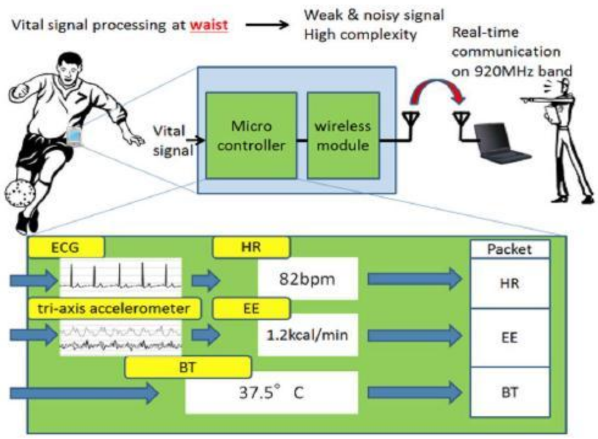
Overview of Vital Sensor Node

Fig. 1.a shows the interconnection of measuring time and signal processing capability (performance) required for the vital sensor node. The sensor node detects the ECG signal at a rear waist position far from heart, so the detected signal inevitably becomes very weak, resulting in requirement of a very high-gain amplifier in the analog part and a bandpass filter of higher order in the digital part. Therefore, our proposed sensor node needs a high performance microcontroller. On the other hand, the Holter monitor for the medical purpose should be workable with a small battery for more than 48 hours, and in addition the activity monitor for healthcare purpose needs much longer battery lifetime such as more than several months. However, taking into consideration that exercise and game periods in common sports are characteristically less than two hours, our proposed sensor node can select a high performance microcontroller as long as it can run for only few hours.

Fig. 1.b shows the functional overview of the vital sensor node. The sensed ECG signal, tri-axis acceleration signal and BT signal are input to the sensor node, the HR and EE are correspondingly evaluated by using the ECG signal and the acceleration signal, and finally, the evaluated data are transmitted to the data collection nodes put around a field with transmission power of 20 mW and the data transmission rate of 100 kb/s via a wireless channel in the 920 MHz frequency band. Note that all the functions of the sensor node, such as vital signal detection, processing and transmission, are driven by a small Lithium Ion Polymer battery for light weight.



(a)



(b)

Fig. 1.a Measuring time/signal processing capability for our sensor node, b. Functional overview of the vital sensor node.

Choice of Microcontroller

Matching Of Microcontrollers

The vital sensor node is composed of three parts: a microcontroller, an analog circuit for ECG, and a wireless module. The microcontroller has approximately 50 % of all power consumption if it does not sleep during an entire exercise or game period. Since the power consumption depends on microcontroller's architecture, operating frequency, voltage, and the amount of computation, it is important to select a microcontroller based on its performance. Therefore, we provide candidates of microcontroller's applicable for the vital signal processing.

Table I Specifications of the microcontrollers

Microcontroller	H8SX1655	PSoC5 CY8C5568	LPC1768
ROM	512KB	256KB	512KB
RAM	40KB	64KB	32KB(local)
A/D channel	8ch	DelSig1ch	8ch
A/D bit	10bit	8 - 20bit	12bit
Current(typ) @3.3V	50mA	37mA @63MHz	53mA
Voltage	3.0-3.6V	2.7-5.5V	2.4-3.6V
Clock on EVB	48MHz	60MHz	96MHz

The microcontroller for the vital sensor node requires at least an I^2C interface for the sensor of tri-axis accelerometer and BT, an A/D conversion channel for ECG, and a UART interface for the wireless module. Furthermore, it requires a sufficient capacity of RAM for the signal processing, and the high speed performance to be able to finish the signal processing within the vital data transmission interval. We list three candidates of 32-bit microcontrollers to satisfy the conditions; the first microcontroller is H8SX1655 of Renesas Electronics, where the development environment is Eclipse + KPIT GNU Toolchain, the second microcontroller is PSoC5 CY8C5568 of Cypress Semiconductor, where the development environment is PSoC Creator, and finally the third microcontroller is LPC1768 of NXP, where the development environment is embed. Table I summarizes the specifications of the microcontrollers. We numerically compared the three microcontrollers in terms of energy efficiency. Note that the source code was written in C or C++ and the software was implemented using compiler and math library of each environment.

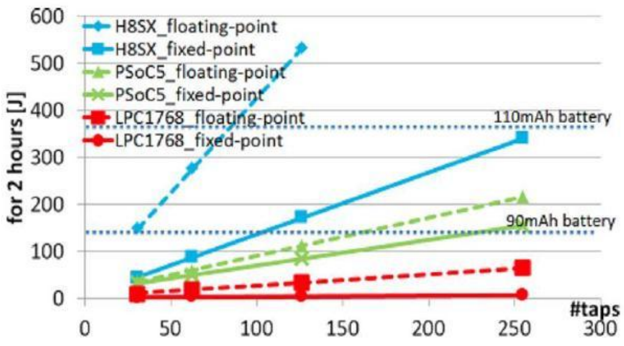
Evaluation of Microcontrollers

The evaluation has two steps as follows. In the preparation step, in order to prepare reproducible ECG signal data, some data samples were experimentally recorded to PC files with 10 bits in 100 Hz format. Each sample has 15-minute digital data with 5 sets of 2-minute walk and 1-minute break. In the evaluation step, one of the samples was sent to a microcontroller via the audio I/F of PC. After the reproduced ECG signal is sampled again in 100Hz by the microcontroller, the HR value is calculated every second. In more detail, the ECG signal is passed through an FIR filter, then an HR value is calculated by a time domain threshold method, and finally, an HR value averaged over 10 seconds is output [3].

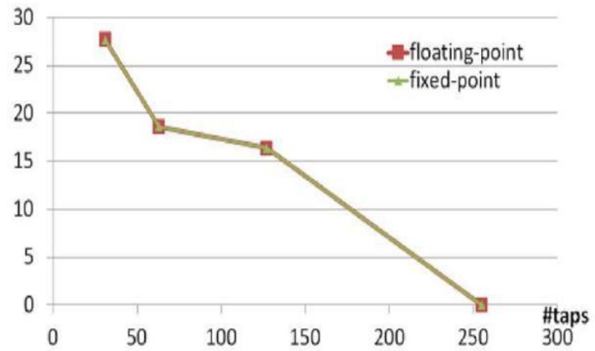
We implemented the software with both a fixed-point and floating-point computations. The computation time was measured by the internal timer. Here, as the numbers of taps of the FIR filter increases, the more the energy consumption increases, because the microcontroller can go to sleep when it does not have to execute the computation.

We assumed that the sum of the energy consumption at the wireless module and the analog circuit was 930.4 J in 3.3 V 40 mA for 2 hours. Since a 110 mAh battery has 1306.8 J, the rest of the battery (376.4 J) can be used for the microcontroller for 2-hour processing. On the other hand, if small

90 mAh battery is chosen, the microcontroller can use 138.6 J for 2 hours.



a



b

Fig. 2.a Energy consumption for 2 hours versus the number of the taps of the FIR filter, b. The RMSE of HR versus the number of taps of the FIR filter.

Fig. 2.a shows the energy consumption for 2 hours versus the number of taps of the FIR filter. When we implement the FIR filter of 127 taps for floating-point computation, LPC1768 gives the lowest energy consumption of 34 J, PSoC5 gives the second lowest energy consumption of 112 J, and H8SX1655 gives the highest energy consumption of 534 J. The order of microcontrollers is the same for the energy consumption for fixed-point computation, namely, LPC1768, PSoC5 and H8SX1655 give the energy consumption of 5 J, 85 J and 172 J, respectively. Consequently, from the result, we can conclude that LPC1768 is the most energy efficient among the three microcontrollers.

We also studied how the fixed-point computation affected HR. In the HR calculation, rounding off errors are stored in the coefficient parts of the FIR filter, so we compared the root-mean-square error (RMSE) of HR between the fixed-point and floating-point computations. Fig. 2.b shows the RMSE of HR versus the number of the taps of the FIR filter. We can see that the fixedpoint calculation does not affect much the HR calculation accuracy in the region from 31 to 255 taps.

Development of Vital Sensor Node

We have designed and implemented a prototype of the vital sensor node using LPC1768 on a printed circuit board (PCB). Table II shows the specifications of the vital sensor node.

Table ii. The specifications of the vital sensor

Size	60 x 75 mm
Weight	33 g
Wireless frequency	920 MHz
ECG sampling rate	< 100 Hz
Tri-axis acceleration sampling rate	< 100 Hz
Tri-axis acceleration measurement range	± 16 g
Temperature accuracy	±0.5 ^{0} C

Fig. 3 shows the photo of the vital sensor node on the PCB. There are the wireless module in the left, the tri-axis acceleration sensor in the upper left, and the LPC1768 in the center. The upper connectors are for BT sensors, etc.

Fig. 3. Photo of the vital sensor node on the PCB.

Conclusion

In this paper, to realize a wireless vital sensor node workable at a waist position with a small battery, which is applicable for sportsmen in sports exercise and game, we discussed the capability of required microcontroller and evaluated the energy efficiency for three microcontroller candidates. Based on the numerical result, we designed a prototype vital sensor node and finally implemented it on a PCB. Our future investigation is to experimentally evaluate the wireless vital sensor node put to sportsmen during exercise and game.

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