Monitoring System for Sports Activities Using Body Area Networks*

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ABSTRACT
The body area networks (Bodynets) are increasingly becoming plausible solutions for on-body sports monitoring. In this paper, we introduce the meanings of Bodynets in daily physical and competitive sports, analyze the systematic structure, and design a Bodynets system for sports activities, which can be applied to daily activities and physical exercises. By means of collecting physiological parameters such as pulse rate, blood pressure, blood oxygen from portable sensors, and of using RFID technology to identify people, analyzers can achieve real-time physiological parameters to make specialized sports plan, which would promote the development of physical sports.

Keywords
Body Area networks (Bodynets), Sports Monitoring, Heart Rate, Oxygen Saturation (SpO2), Photoplethysmography (PPG)

1. INTRODUCTION
Body area networks (Bodynets) consist of a number of independent wireless sensors located in the clothes on the human body or in close proximity such as on everyday clothing. The Bodynets typically extends over the whole human body and the sensor nodes will communicate with a Bodynet base station by some wireless communication techniques, such as wireless sensor networks (WSNs), wireless mesh networks (WMNs) and cellular networks [1]. A Bodynet offers many promising, new applications in home/health care, medicine, sports, multimedia, and many other areas, all of which make advantage of the unconstrained freedom of movement a Bodynet offers.

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Typical application for Bodynets is mainly to monitor still and slow moving persons, such as the old man and patients in the hospital [2, 3]. With the development of wireless communication technologies, the Bodynets could widen their range of possible application scenarios [4]. To monitor daily activities and physical exercises in several sports, the feasibility for Bodynets has been investigated in many literatures [5-7]. This paper focuses on Sports monitoring system using body area networks.

According to the preceding definition of Bodynets, the combination of Bodynets technology and sports science will dramatically promote the development of athletics on both professional sports and amateur sports. Athletics is a term encompassing the human competitive sports and games requiring physical skill, and the systems of training that prepare athletes for competition performance [8]. Professional sports, as opposed to amateur sports, are sports, in which athletes receive payment for their performance. On the other hand, amateur sports are sports, in which participants engage largely or entirely without remuneration and have a lower standard of play [9, 10]. Both of them reflect outstanding physical skills and highly competitive, not only to beat other participate but also to conquer themselves in the maximum extent. Only by struggling and sweating, they will get medal or good ranking for their own team. So, it is very essential to monitor physiological data for players during the whole process of the training to prevent some injury accidents or sports-related risks, and it is necessary for athletic trainers and doctors to control the specific situation. In addition, for amateur sports the Bodynets systems are still essential, which could provide people with safe healthcare services anytime and anywhere.

There have been other considerable researches on sports monitoring using Bodynets. In [11], the authors outline the development of a fluid handling system and wireless sensors for the real-time analysis of sweat pH and sodium levels during exercise. According to authors' introduction, liquid is drawn into the system using a moisture wicking material and passive pump. The sensor then displays pH induced colorimetric changes, which are recorded using an optical detection system. However, this system is very inconvenience in sports monitoring since it contains liquids. In [12], the authors combine research in textiles materials, and wireless sensor and actuator networks in the context of human body monitoring with statistical methods for the data analysis and treatment. Besides, they provide a hierarchical communication system that allows the delivery of the data collected from the garment. For monitoring team sports, the authors in [13] propose a novel mobility model. In this paper, the definition of specific interaction rules between team players is of primary importance to obtain accurate mobility patterns. The comparison with real mobility tracks highlights the need for a more accurate modeling of players behavior.

In this paper we propose a novel sports monitoring system for daily physical exercises and professional sports based on Bodynets. For this monitoring system, we build the system networking architecture, in which there contain some sub-systems, such as Bodynet, WSN, WMN, and RFID. Through this system, multiple physiological parameters are measured at each point of interest, and signal processing algorithms running on the sensors can estimate heart rate, blood pressure, oxygen saturation (SpO2) that can be obtained by the photoplethysmography (PPG) signal. Analyzers can collect and achieve these real-time physiological parameters to make a decision to help the people of daily physical exercises and professional sports.

The paper is organized as follows. Section II presents the system architecture of the Bodynets. In section III we provide the details about sports monitoring platform. In section IV performance evaluation of this Bodynets system is performed. Finally, Section V draws conclusions.

2. SYSTEM ARCHITECTURE

In this paper, we propose a Bodynets-based sports monitoring system. The main applicability of this system is used to monitor the daily physical exercises and athletes' physical condition by analyzing the collected data from the computer terminals. As soon as detecting any abnormal conditions, warning messages are produced to stop their abnormal exercises or sports, which can reduce the occurrence of incidents. The system can be applied to daily physical activities, training monitor, competitive sports monitor, and so on. These three different kinds of sports are clarified as follows:

1. Daily physical activities: daily physical exercise is any bodily activity that enhances or maintains physical fitness and overall health and wellness. Daily physical exercise can be performed for strengthening muscles and the cardiovascular system, weight loss or maintenance, as well as for the purpose of enjoyment. During the daily physical exercise, many people are amateurs. So it is highly necessary to monitor the physiological data for the persons of daily physical exercise in case of an accident.
2. Training monitoring: in athletes' daily training, various physical parameters need to be monitored. For example, in sports like 110-meter hurdle race and 100-meter dash, which require a high explosive power of athletes, hearts are in high speed operational status. So how to scientifically reasonably improve durability of athletes' hearts is an imperative issue to be considered. In addition, in high level training of track and field, the training of explosive power is important, and with the increasing training, durability of hearts is also strengthened. A scientific and reasonable training scheme would gradual increase the strength of training. Each training strength would not be equal. Under the insurance of hearts' withstanding levels of training, the amount of training should be maximized (which is the optimum training scheme), which require a ability to real-time monitor real-time data of athletes' hearts that can be used to make plans for each training strength [14].
3. Competitive sports monitoring: during competitive sports, athletes' are in status of high strength rivalry and so the incidents of sudden death frequently occur. Life is precious and these deaths remind us how fragile life can be. For instance, on Nov. 1st 2008, an Argentine football player was dead from sudden death of heart disease in one of local league matches; on Oct. 11th 2009, football player Best was dead in football court due to multiple organ failure. Until now, hundreds of excellent athletes have been dead of excessive exercise in courts. This is mainly because those during the competition, athletes' organs like hearts, livers and kidneys are in high excited status. If warning messages are produced before athletes' organs reach saturation, sudden death incidents can be effective avoided [15]. However, athletes cannot perceive their organs to see whether relay in abnormity by their own. Consequently, our proposed real-time Bodynets-based monitor scheme is needed.

The aim of this system is to design a feasible solution of competitive sports monitoring out of wireless communication technology, which is based on Bodynets. This solution will combine Bodynets, wireless mesh networks and wireless sensor networks, apply relative software and hardware platforms, such as IEEE802.15.4 protocols to build sensor nodes, router nodes and processing nodes.

As shown in Fig. 1, the system is composed of miniature gathering front-ends of wireless sensors putting on athletes, RFID identifiers, mesh nodes and routers, processing computer and central servers. The miniature wireless sensor nodes is mainly composed of physical information sensors, RF modules and microcontrollers, which can be put on athletes to monitor the working conditions of athletic tissues and organs (especially heart). These nodes comprise Bodynets, and transmit gathering information via RF modules to back-end servers to process through the converging mesh nodes of the Bodyntes. The transmission of information is consistent with IEEE 802.15.4 protocols, which by the means of multiple hops to transmit information. Meanwhile, people are indentified by RFID taggers to monitor multiples of monitoring objects.

At processing computer, mesh router nodes are responsible for converging information coming from Bodynets, A/D conversing RF information using high-performance of controller chips, and then undertaking of down conversion. Finally, processed information is put into computers via LAN port. At the same time, computers can be regarded as human-machine interfaces, and working personnel can monitor various physical indexes of athletes by watching specified software. As soon as abnormity of the persons occur, persons are forbidden from the current sports and remedy works can be undertaken. Consequently, incidents of sudden death during

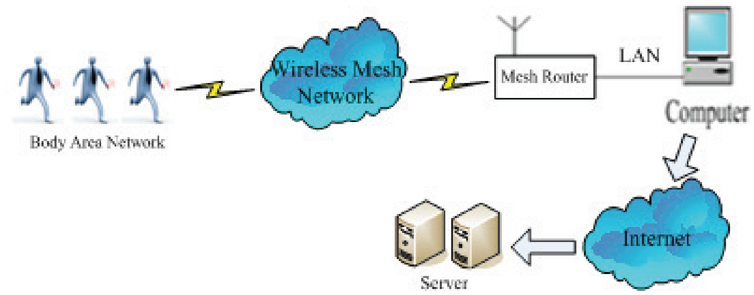

Figure 1: System Architecture.

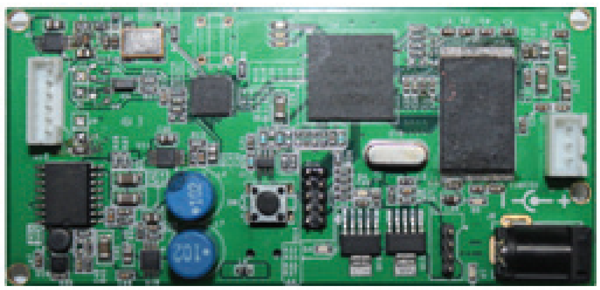

Figure 2: Front-end sensor board of Bodynets.

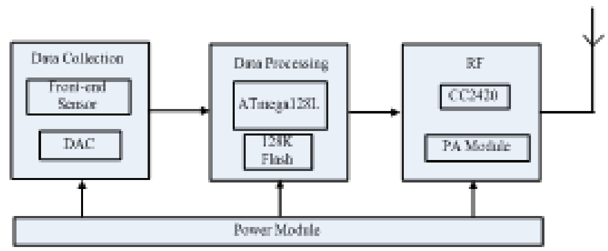

Figure 3: Systematical structure of wireless sensor networking sub-system.

the sports can be effectively avoided.

3. SPORTS MONITORING PLATFORM

3.1 Platform in Details

The proposed Bodynet-based sports monitoring platform mainly consists of four sub-systems, which are front-end body sensor sub-system, wireless sensor networking sub-system, wireless mesh networking sub-system, and RFID sub-system.

For the front-end sensor sub-system, it can sense three physiological parameters, including heart rate, blood pressure, oxygen saturation (SpO2). The body sensor PCB board of Bodynets is shown in Fig 2. This body sensor board mainly sense two parameters, which are blood pressure and SpO2. For the SpO2, we use the photoplethysmography (PPG) method to obtain this parameter. In addition, we could extract the parameters of heart rate and pulse rate from the SpO2 parameter.

For the wireless sensor networking sub-system, it is used to transmit the message collected by the front-end sensor subsystem over short distances. This sub-system adopts ATmega128L microprocessor as a core processor of the front-end physical data gathering nodes. ATmega128L is a low power consumption CMOS chip based on AVR core with 128KB flash memory and 4KB EEPROM memory. The sensor modules have general extension interfaces, which can be used to install various sensors, for example, the above front-end sensor sub-system. RF modules adopt CC2420 RF chips, which is a RF transmitter-receiver that works at 2.4GHz frequency band, can work at 19.7mA low power consumption, and has the high receiver sensitivity of -94dBm and good anti-jamming capability. The systematical structure and the PCB board of wireless sensor networking node are depicted in Fig. 3 and Fig. 4, respectively.

Wireless sensor network gateway nodes are the systematical centers of controlling and processing with abilities of route maintenance, data process, and operation management. Compared with front-end sensor nodes, gateway nodes require high processing ability and operating speed. Hence, to realize high performance gateway nodes, general ARM is used, and gateway nodes are connected through general interfaces. In data gathering nodes and gateway nodes, we adopt TinyOS operating system to implement system design and develop various hardware drivers and applications according to their different hardware structures and functional requirements. TinyOS operating system is a complete, multiple-task, multiple-thread real-time operating system with the merits of open-source code, easy transplanting and development.

In addition, RFID sub-system is also integrated into the wireless sensor networking sub-system to identify the different persons.

For the wireless mesh networking sub-system, it is used to transmit the message from WSN nodes over long distances. This sub-system adopts AMD CPU at 500MHz, 256MB DDR SDRAM, 2 miniPCI sockets for 802.11 wireless cards and other expansions. In addition, wireless module adopts Atheros IC, which supports 802.11 a/b/g/n protocols. The appearance of the wireless mesh router is shown in Fig. 5. In the wireless mesh router, software platform is based on

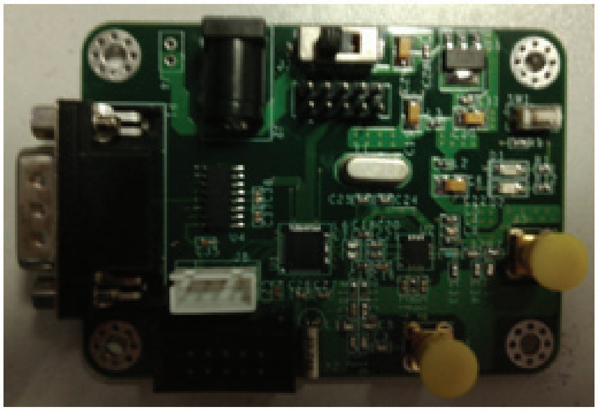

Figure 4: WSN node borad of Bodynets.

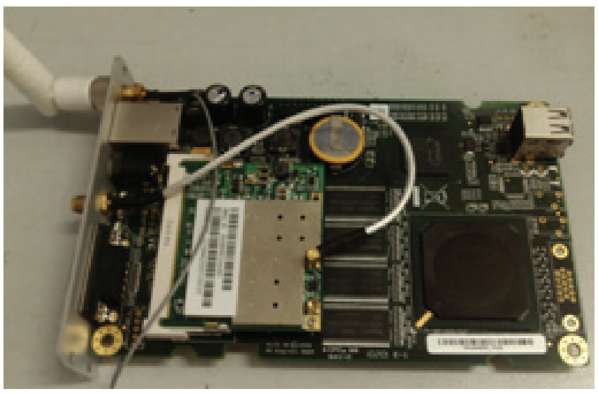

Figure 5: WSN node borad of Bodynets.

open source Linux system with OLSR routing protocol. We achieved the hybrid networking at 2.4GHz and 5.2GHz frequency bands. The PCB board of wireless mesh networking node is shown in Fig. 5.

3.2 PPG Signal measurement method

The PPG signal measurement is a simple, useful, and most important way of measuring several clinical parameters, including oxygen saturation, blood pressure, and cardiac output. PPG is especially suitable for wearable sensing, which could play an important role in Bodynets to monitor sports activities. Despite the attractive attributes of PPG and the ease of its integration into wearable devices, the PPG signal is known to be fragile and easily corrupted by motion. In most cases, the noise falls within the frequency band of the physiological signal of interest, rendering linear filtering ineffective. The following will introduce the PPG measurement method.

The PPG measurement system comprises a transmittance sensor, sensor electronics, and data acquisition board. The emitter of the sensor is a laser diode with a peak wavelength in the near-infrared region (850 nm), which matches that of usual PPG wavelengths. The emitter driver, further amplification and filtering stages, and timing and sample-and-hold circuits were connected to the fingertip probe by cables. The photodetector signal was filtered by an anti-aliasing analog low-pass filter at 300Hz, then sampled with a high-speed sample-and-hold circuit and fed into the analog inputs of a 12-bit ADC to be digitized at 1000 samples/s (Sa/s). Finally, a ten-sample moving average followed by a ten-to-one decimation was performed, which resulted in 100 Sa/s PPG data. The data from this system will be stored in the computer. Subsequent stages of the signal processing were carried out digitally. In this system the HR was monitored via electrocardiography (ECG) and used as a reference. The PPG sensor was placed on one finger with special care taken to avoid excessive compression of the tissues. The HR signal will be extracted from PPG signal. The PPG signals were performed using the Student t-test for paired data. Linear Pearson's correlation analysis was used to correlate quantitative variables. The Bland-Altman (B-A) method was used to compare the values of HR obtained by the proposed PPG technique and the standard ECG. Usually, the PPR value can be obtained by simply finding the highest peak in the spectrum. The algorithm design is based on the above observation.

In this algorithm the linear filter is employed to filter 100-Sa/s PPG signal $E(t)$ via band-pass Bessel filtering (cut-off frequencies f_1 and f_2, order $n = 6$) to get the pulsating component ($E_{ac}(t)$) and to suppress high-frequency noise and ripple. Cut-off frequencies are chosen in the ranges 0.1 0.3 Hz for f_1 and 5 30 Hz for f_2. After filtering, a frequency-domain analysis was performed by applying the FFT to a 10s, rectangular-shaped, sliding window of the aforementioned data signal, delivering spectrogram data $F(t_s)$, expressed in terms of power density (p_i) versus frequency (f_i). In this step, the electrical PPG signal is transformed into a sequence of FFT spectra. The instant in time t_s to which the spectrum is assigned corresponds to the end of the interval. A peak search algorithm is applied to the stream of spectra to select peaks that can order the peaks according to p_i value. The highest peak is the PPG signal that we need.

4. EXPERIMENTAL RESULTS

In this section, we present the performance evaluation of this Bodynets system. By experiments, the wireless communication data collision rate and packet loss rate between nodes of our system is illustrated in Table I. Experimental results have shown that our system has achieved the design goals of miniaturization, low power consumptions, flexibility, and extensibility, which satisfies the correctness and real-time required by monitoring athletic physical data.

Fig. 6 shows the heart rate of dash athletes during training under four conditions, that is, low intensity (LI) (aerobic nature, having little effect on training improvement), middle intensity (MI) (aerobic nature, having some effect on training improvement), high intensity (HI) (hybrid nature of aerobic and anaerobic, can improve specified durability from short time training), and extreme high intensity (EHI) (pure anaerobic nature, can improve the ability of anaerobic lactic acid and of speed). By monitoring physiological parameters of athletes during training, advisors can master the conditions of athletes. For example, as shown in Fig. 6, the athlete is undergoing process of aerobic and anaer-

Table 1: Expermental results for Bodynets nodes

No. of Node	Total of Packet	Packet Loss	Collision	Packet Loss Rate (%)	Collision Rate (%)
1	4830	1	62	0.0207	1.284
2	4691	1	49	0.0213	1.045
3	4839	0	58	0.0000	1.199
1	9602	1	171	0.0104	1.781
2	9520	1	169	0.0105	1.775
3	9660	2	183	0.0207	1.894

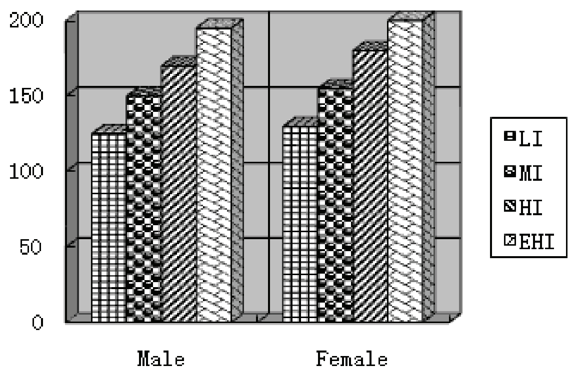

Figure 6: Heart rate of dash athletes during training under four conditions.

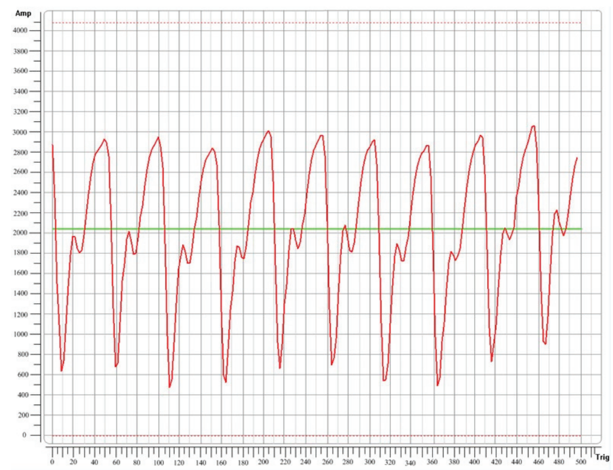

Figure 7: PPG curve before the sport.

obic hybrid sports, which can improve his specified durability from short time training; if the exercise surpasses a certain amount, however, abnormity of athletic physiological parameters occurs, which means that training should be stopped instantly.

Fig. 7 and Fig. 8 show the PPG curve before and after the sport. In the figures, X axis means time units and Y axis means normalized amplitude of PPG. From the PPG signal, we can obtain the heart rate and SpO2 value using the proposed Bodynets system. For the Fig. 7, we can measure the heart rate is 79 and SpO2 is 97. And from the Fig. 8, we can get the above values are 127 and 98, respectively.

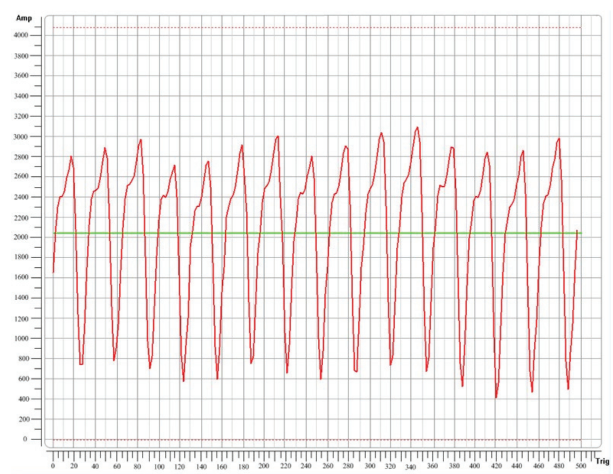

Figure 8: PPG curve after the sport.

5. CONCLUSIONS

In this paper, we propose a novel monitoring system for daily physical exercises and professional sports based on Bodynets. Through this system, multiple physiological parameters are measured at each point of interest, and signal processing algorithms running on the sensors can estimate heart rate, blood pressure, oxygen saturation (SpO2) that can be obtained the photoplethysmography (PPG) signal. Analyzers can collect and achieve these real-time physiological parameters to make a decision to help the people of daily physical exercises and professional sports. Experimental results show us that this system is convenient and effective to collect the real-time physiological parameters of amateur sports and professional sports.

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