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Physiological signal acquisition system based on wireless sensor networks

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Abstract: Based on wireless sensor networks, a physiological signal acquisition system is proposed. The system is used in classroom education in order to understand the physiological changes in the students. In the system, the biological electrical signal related to student attention and emotion states can be measured by electrocardiography signals. The bioelectrical signal is digitalized at a 200 Hz sampling rate and is transmitted by the ZigBee protocol. Simultaneously, the Bluetooth technology is also embedded in the nodes so as to meet the high sampling rate and the high-bandwidth transmission. The system can implement the monitoring tasks for 30 students, and the experimental results of using the system in the classroom are proposed. Finally, the applications of wireless sensor networks used in education is also discussed.

Key words: wireless sensor network; physiological signal; education

Although the attention state and emotional state of students during the learning process belong to the psychological domain, it can be indirectly measured by physiological signals, such as electrocardiography signals and pulse signals. Students and teachers' mental states of attention and emotion in the classroom may be changing during teaching progress, which can physiologically activate the sympathetic and parasympathetic division of the autonomic nervous system(ANS)[1-2]. These measurable physiological signals can be recorded for the analyses of psychological arousal of social rewards and punishments, such as positive feedback by the teacher's praises or higher examination grades, even the amount of a scholarship, although the arousal of the autonomic nervous system reactions may be a complex indirect relationship to emotion[3-4]. Interactions between states of the autonomic nervous system and cognitive performance have a long tradition of being a topic of psychological research. Classic concepts from motivational psychology have suggested an inverted u-shaped association between unspecific activation and mental functioning[5-6]. According to this, the best functional conditions are expected at midrange arousal, and both over arousal and under arousal are accompanied by declines in performance. Cardiovascular psychophysiology has also contributed to this line of research, the respective models relating changes in cardiovascular activity to facilitation, inhibition of information processing[7] or energetic mobilization of the organism when faced with a situation requiring behavioral adjustment[8]. However, although this certainly constitutes a beneficial approach, empirical work in this field remains relatively sparse[9]. Both the sympathetic system and the parasympathetic system contribute to cardiovascular regulation[10]. Sympathetic influences are transmitted through efferent fibres to the sinus node, the myocardium and the vascular musculature, and their activation leads to an increase in heart rate, cardiac contractility and vascular tone. Parasympathetic influences are widely, but not completely, restricted to the modulation of heart rate through inhibiting sinus node activity. In addition, the cardiac baroreflex is involved. In this negative feedback loop, changes in the activity of the arterial baroreceptors due to fluctuations in blood pressure are responded with compensatory changes in heart rate and contractility. A complex network of brain stem units subserve cardiovascular autonomic control, e. g., the nucleus of the solitary tract(NTS), the dorsal motor nucleus(DMN), the nucleus ambiguous(NA) and the rostral ventrolateral medulla(RVLM)[11]. Bilateral direct and indirect connections exist between this network and cortical areas, which form an important link between cardiovascular regulation and cognition[12-13]. The present study aims at investigating relationships among features of sympathetic, parasympathetic and baroreflex cardiovascular control and attentional performance.

To collect these physical and mental states data in real time and objectively, a hybrid wireless sensor network is designed as the subjects of a teacher and students are mobile. For medical and home usage, license free ISM(industry, science, medical) radio frequency(RF) of 2. 4 GHz ZigBee wireless sensor node technology is useful[14-18].

1 System Description

As a secondary aim, the study investigates inter individual differences in task induced cardiovascular modulations. Porges[19] postulated an association between resting cardiac vagal tone and the extent of cardiovascular reactivity. This is consistent with studies that have revealed more pronounced heart rate responses to various stimuli in children and adults with higher baseline heart rate variability[19-21]. Cardiovascular reactivity to cognitive demands may also relate to task performance. Duschek[22] found a positive correlation between systolic and diastolic blood pressure increases during the execution of five attention tasks and the performance on each of them. In infants, greater decreases of RSA during mental testing are related to higher functional levels[21]. Inter individual differences in cardiovascular modulation possibly reflect different degrees of autonomic adjust-

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ment as well as motivation on a task, both of which may contribute to performance. However, inconsistent findings, i. e., missing or even inverse associations between cardiovascular reactivity and mental performance, have also been reported[23-24]. Thus, the current state of research does not allow definite conclusions. The hardware of the wireless sensor networks(WSNs) consists of the data collecting and transmitting parts which will be attached to students and teachers. To respect these students and teachers' willingness to try this new device, the nodes can be connected by ECG leads, but also can be rejected by the connection of leads. The system is auto-configured in the classroom. The application of WSNs for physiological signal acquisition in the classroom is shown in Fig. 1.

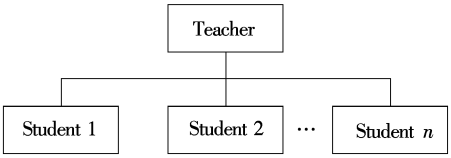

Fig. 1 The simple star configuration of wireless nodes in classroom

1.1 Data collecting and transmitting parts

This part is designed to collect and transmit physiological data from the subjects[3]. We collect two kinds of physiological signals: electrocardio signals and pulse signals from the subjects in this research. AD620 is chosen as the pre-amplifier for the amplification of the weak bioelectrical signals of 10 to 20 mV. The ECG uses three standard limb leads (left arm, right arm, right leg). The pulse sensor uses PVDF piezoelectric film with a temperature compensation component and an integrated signal circuit.

After pre-amplification of about 100 times, the signal is subjected to low pass and high pass filters (5 to 100 Hz). To reduce the 50 Hz power line interference, the additional notch filter is designed before the signal is promoted to a positive DC level of 1.5 V. The hardware block diagram and circuit are shown in Fig. 2 and Fig. 3. Fig. 4 shows the picture of the sensor node.

The analog signals are digitalized using an Atmega128 microcontroller's on-chip ADC at a 200 Hz sampling rate because

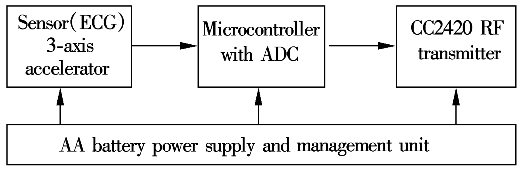

Fig. 2 Physiological signal acquisition hardware block diagram

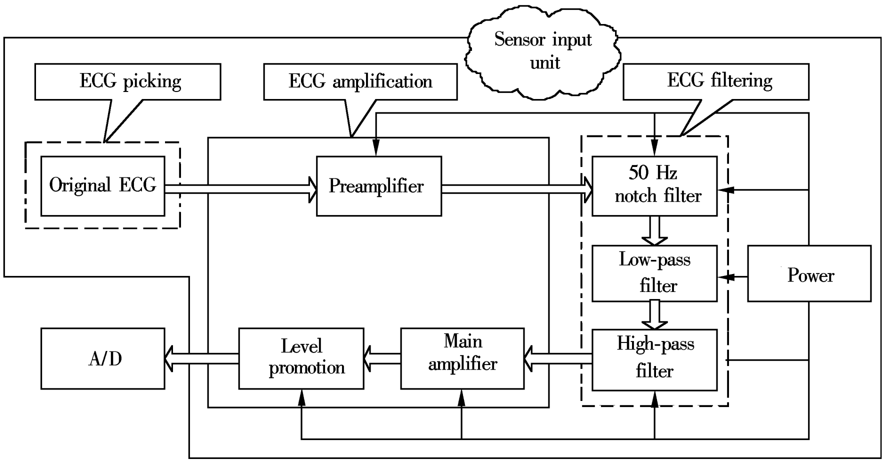

Fig. 3 Circuit principle block diagram of sensor input unit

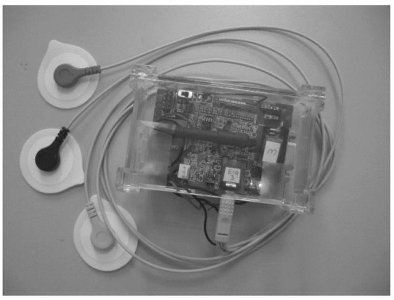

Fig. 4 Picture of the sensor node

the frequency range of the physiological signal is from 5 to 100 Hz. Using a hardware SPI interface, the collected data are transmitted by the wireless sensor network with the ZigBee protocol by a CC2420 RF chip. As the gateway to a personal computer (PC), the sink node communicates with the PC through a RS-232 interface.

1.2 Software chart of data collecting and transmitting parts

1.2.1 Topology configuration of the WSN

The WSN is expected to realize the dynamic management of nodes, such as the joint and leave of the nodes, service discovery, and device auto configuration. The topology control can adaptively organize certain numbers of nodes to a net by certain mechanisms. We establish a star network in the intelligent classroom. The sink node initializes the network, broadcasts its network address and scan channel, and receives responses from the terminal nodes, while the terminal nodes attempt to seek and join the net after initialization[4].

1.2.2 Task scheduling mechanism

In our system, we realize tasks such as data acquisition, storage, processing and transmission, using the simple FIFO(first-in-first-out) task scheduling. The data structure used in the FIFO is a circular queue; each element in it is a function pointer, pointing to the head address of the relevant task. Any task must enter the task queue by a task submitting function and change the rear pointer, while it can only run the task running function when the front pointer points to its function pointer. The tasks in the queue will be executed successively. A task can appear as one kind of operation, which can only be interrupted by events such as clock interruption, A/D interruptions and so on, but not by any other tasks[14].

1.2.3 Design of data packet

The space nodes in the classroom can collect various physiological data of students and environmental data. In our system, we use six A/D channels for the collection of the signals of the ECG, 2-axis acceleration, pressure, temperature and humidity, respectively. We assemble the gathered data (Here it is the payload of the data packet) and some other control information into a data packet[15-16]. The frame control field with a 2-byte length defines the control information or frame format. The data sequence number identifies the data packets in an orderly fashion. The address contains the PAN ID, destination node's address and source node's address. The payload is the data of signals we collect from the students and the environment of the classroom. We put these data into an array, storing ECG, x-axis acceleration, y-axis acceleration, z-axis acceleration and pressure in sequence for 5 times of circular sampling, with temperature and humidity data at the end of the array.

The software design of our proposed system is based on the ZigBee protocol. However, our collected data has a high data rate compared to the home control system[25]. We take package transmission methods to improve network performance. Fig. 5 and Fig. 6 show the flowcharts of the terminal node and the sink node, respectively.

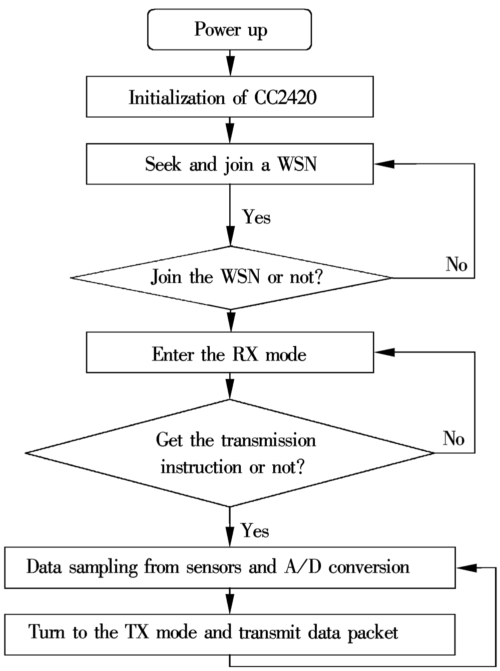

Fig. 5 Flowchart of the terminal node

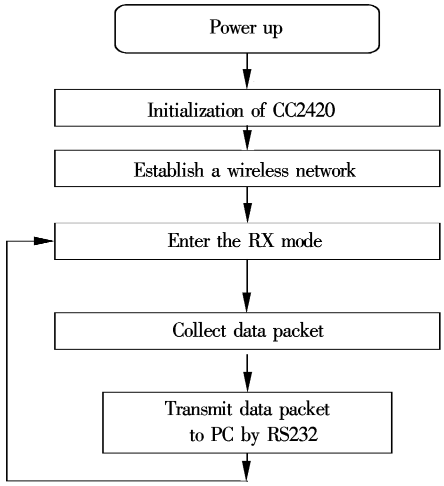

Fig. 6 Flowchart of the sink node

1.3 Graphical user interface design

The terminal display and the signal process are shown in Fig. 7 and Fig. 8. A real-time monitoring software implemented on the PC is created using the LabVIEW program. On the PC, the terminal display and signal process can show the data of electrocardio signals, pressure signals and acceleration signals which are all measured by the body sensors and transmitted by the wireless network system.

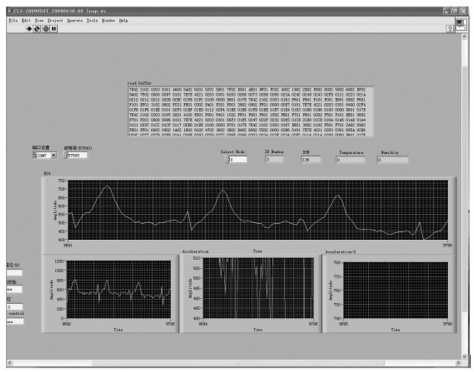

Fig. 7 An example of measured signals

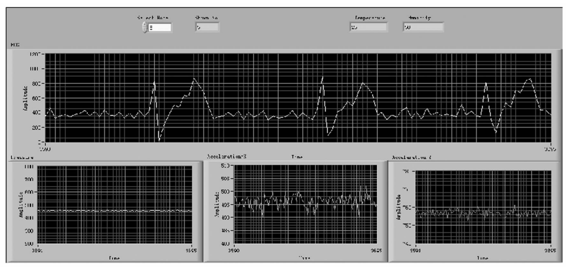

Fig. 8 The terminal display and the signal process

Interactions between states of the autonomic nervous system and cognitive performance have long been a tradition as a topic of psychological research. Classic concepts from motivational psychology suggested an inverted u-shaped association between unspecific activation and mental functioning[5-6]. According to this, the best functional conditions are expected at midrange arousal, and both over arousal and under arousal are accompanied by declines in performance. Cardiovascular psychophysiology has also contributed to this line of research, the respective models relating changes in cardiovascular activity to facilitation or inhibition of information processing[7] or energetic mobilization of the organism when faced with a situation requiring behavioral adjustment[8]. However, although this certainly constitutes a beneficial approach, empirical work in this field remains relatively sparse[9].

2 Results and Discussion

The attentional capacity is assessed using a classic letter cancellation test[23]. Tasks of this type address the cognitive components of selective and sustained attention that are undoubtedly of vast importance in everyday life[26–27]. In the test, subjects have to select and mark as many target stimuli as possible in a given amount of time, and, hence, it also creates a certain load on the speed of information processing. Autonomic parameters are recorded under resting conditions during the execution of the task. One may assume that features of autonomic control assessed during cognitive processing show the closest link to performance. On the other hand, on-task measures are influenced by factors such as mental effort, emotional stress or subjectively experienced task difficulty. In contrast, baseline measures are free of these confounding variables. The following predictions are made: 1) Taking an inverted u-shaped association between unspecific sympathetic arousal and mental performance into account, and assuming an experimental situation in which sympathetic over activity is unlikely to occur, an inverse relationship between RPI and attentional performance may be expected; 2) On account of Porges' model[19], we predict a positive correlation between the resting RSA and performance; 3) Our findings on the baroreflex function suggest that individuals with an increased BRS should exhibit poorer performance[28]; 4) Given the inverse association between oscillations in the MF band and the mental effort load, and supposing better performance in the case of higher effort, the MF power assessed during task execution should correlate negatively with performance; 5) Considering Porges' hypothesis[19], we expect higher cardiovascular reactivity in individuals with the higher resting RSA; 6) Even though the available database is somewhat controversial, the likely association between mental effort and autonomic reactivity suggests stronger reactivity to be related to better performance.

3 Conclusion

In this paper, we develop a real-time, physiological data acquisition system for education assessment, which combines LabVIEW and wireless sensor networks, and we fulfill the function of collecting, transmitting, displaying and processing physiological signals. In future work, we plan to add more functions to the terminal display and signal process such as the extraction of the special frequency spectrums, and further psychological researches on the physiological signals from more subjects. Finally, our subsequent consideration is to set up a more efficient method to obtain physiological signals for assessing emotional states and mental reactions during learning in the classroom.

References

[1] Rainville P, Bechara A, Naqvi N, et al. Basic emotions are associated with distinct patterns of cardiorespiratory activity [J]. *Int J Psychophysiol*, 2006, **61**(1): 5 − 18.

[2] Duschek S, Muckenthaler M, Werner N, et al. Relationships between features of autonomic cardiovascular control and cognitive performance [J]. *Biological Psychology*, 2009, **81**(2): 110 − 117.

[3] Stemmler G. The autonomic differentiation of emotions revisited: convergent and discriminate validation[J]. *Psychophysiology*, 1989, **26**(6): 617 − 631.

[4] Izard C E, Malatesta C Z. *Perspectives on emotional development*[M]. New York: Wiley, 1987: 494 − 554.

[5] Heeb D O. Drives and the CNS [J]. *Psychol Rev*, 1955, **62**(4): 243 − 254.

[6] Yerkes R M, Dodson J D. The relation of strength of stimulus to rapidity of habit formation[J]. *Journal of Comparative Neurology and Psychology*, 1908, **18**: 459 − 482.

[7] Lacey J I, Lacey B C. Some autonomic-central nervous system interrelationships[C]// *Physiological Correlates of Emotion*. New York: Academic Press, 1970: 205 − 227.

[8] Obrist P A. *Cardiovascular psychophysiology: a perspective* [M]. New York: Plenum Press, 1981.

[9] Hansen A L, Johnsen B H, Thayer J F. Vagal influence on working memory and attention[J]. *International Journal of Psychophysiology*, 2003, **48**(3): 263 − 274.

[10] Levy M N, Pappano A J. *Cardiovascular physiology*[M]. Philadelphia: Mosby Elsevier, 2007.

[11] Van Roon, Mulder L J M, Althaus M, et al. Introducing a baroreflex model for studying cardiovascular effects of mental workload[J]. *Psychophysiology*, 2004, **41**(6): 961 − 981.

[12] Dembowsky K, Seller H. *From the heart to the brain: the psychophysiology of circulation-brain interaction* [M]. Frankfurt: Europäischer Verlag der Wissenschaften, 1995: 35 − 60.

[13] Rau H, Elbert T. Psychophysiology of arterial baroreceptors and the etiology of hypertension[J]. *Biol Psychol*, 2001, **57**(1/2/3): 179 − 201.

[14] Zhang Wei, Jing Shenqi, Gui Lin, et al. Physiological data acquisition system for education assessment using wireless sensor network[C]//*Proceedings of the 5th International Conference on Information Technology and Application*. Shenzhen, China, 2008: 471 − 473.

[15] Ding Fei, Song Guangming, Song Aiguo, Home control system based on ZigBee wireless sensor networks[J]. *Journal of Southeast University: English Edition*, 2008, **24**(4): 420 − 423.

[16] Hong J H, Kim J M, Cha E J, et al. A wireless 3-channel ECG transmission system using PDA phone[C]//*Proceedings of International Conference on Convergence Information Technology*. Seoul, Korea, 2007: 462 − 465.

[17] Cerny M, Penhaker M. The homecare and circadian rhythm [C]//*Proceedings of the 5th International Conference on Information Technology and Application*. Shenzhen, China, 2008: 245 − 248.

[18] Carmen Lopez-Casado. Network architecture for global biomedical monitoring service[C]//*Proceedings of IEEE Engineering in Medicine and Biology 27th Annual Conference*. Shanghai, China. 2005: 2433 − 2436.

[19] Porges S W. Heart rate variability and deceleration as indexes of reaction time[J]. *Journal of Experimental Psychology*, 1972, **92**(1): 103 − 110.

[20] Porter F L, Porges S W, Marshall R E. Newborn pain cries

and vagal tone: parallel changes in response to circumcision [J]. *Child Dev*, 1988, **59**(2): 495 - 505.
[21] DeGangi G A, Laurie R S, Castellan J, et al. Treatment of sensory, emotional, and attentional problems in regulatory disordered infants[J]. *Infants and Young Children*, 1991 (3): 9 - 19.
[22] Duschek S. Essential hypotension is accompanied by deficits in attention and working memory[J]. *Behavioral Medicine*, 2005, **30**(4): 149 - 158.
[23] Backs R W, Seljos K A. Metabolic and cardiorespiratory measures of mental effort: the effects of level of difficulty in working memory task[J]. *Int J Psychophysiol*, 1994, **16** (1): 57 - 68.
[24] Gendolla G H E, Wright R A. Motivation in social settings: studies of effort-related cardiovascular arousal[C]// *Social motivation*: *Conscious and Nonconscious Processes*. London: Cambridge University Press, 2005: 71 - 90.
[25] Lee Mi-Hee, Yang Gyunghye, Lee Hyoung-Ki, et al. Development stress monitoring system based on personal digital assistant(PDA)[C]//*Proceedings of the 26th Annual International Conference of the IEEE EMBS*. San Francisco, CA, USA, 2004: 2364 - 2367.
[26] Johnson A, Proctor R W. *Attention*: *theory and practice* [M]. Thousand Oaks, CA, USA: Sage, 2004.
[27] Posner M I, Rafal R D. Cognitive theories of attention and the rehabilitation of attentional deficits[C]//*Neuropsychological rehabilitation*. Edinburgh: Churchill Livingston, 1987: 182 - 201.
[28] Yasumasu T, Reyes del Paso G A, Takahara K, et al. Reduced baroreflex cardiac sensitivity predicts increased cognitive performance[J]. *Psychophysiology*, 2006, **43**(1): 41 - 45.

一种基于无线传感器网络的生理信号采集系统

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摘要：提出了一种应用于课堂教育的无线生理采集系统，以了解学生在上课过程中的生理变化情况．系统中，反映学生的注意力和情绪状态的生理电信号可通过测量 ECG 来获得．生物电信号采用 200 Hz 的采样速率，并由 ZigBee 协议进行无线传输．同时，节点嵌入了蓝牙技术以适应高采样速率和高带宽的传输要求．本系统可以同时对 30 个学生进行监测，并且给出了系统在教室执行监测任务的实验结果．最后探讨了无线传感器网络在教育领域的应用．

关键词：无线传感器网络；生理信号；教育
中图分类号：TN92