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ZigBee based multi-purpose electronic score design and implementation using EOG

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ABSTRACT

This study uses ZigBee wireless sensor network technology to build a Multi-purpose Electronic Score system based on the electro-oculogram (EOG). As a requirement when learning to play a musical instrument the most commonly seen scores are available in paper copies. The disadvantage of the paper music score is that pages must be turned manually by the performer while playing music. An alternative is to prepare a miniaturized copy of the score, but this makes the score difficult to read clearly. Electronic scores have recently become available and are expected to become mainstream in the future due to the rapid growth in ebook readers and tablet PCs. Tracking the upward, downward, leftward, rightward and clockwise/counterclockwise eyeball movements and eye blinking, an amplified, bandpass filtered electro-oculogram (EOG) signal is converted into digital form. This signal is further transmitted through a ZigBee wireless module on which an electronic score program is installed, including the following operating modes; go to the previous/next page, recording, tuning and tempo modes. Detected eyeball movements allow a score to be viewed conveniently while playing. In the future, the proposed technology can be applied to flexible paper, flexible displays and the like.

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1. Introduction

A music performer might get distracted when turning the pages of a music score. The performance quality may be degraded accordingly. An EOG based electronic score is proposed in this work as an auxiliary tool to assist musical performance in a concert. According to the creative Economy Report published in 2008 by the United Nations Conference on Trade and Development (UNCTAD), the global turnover from the creative industry, including creative products and services, was up to US$424 billion in 2005. This represents an increase of 87% relative to US$227 billion in 1996. This is evidence that the development of creative products is a mainstream area of technology development [1]. Past major EOG applications can be found in the development of auxiliary tools for the disabled. This work extends EOG application to concert music performers.

In recent years ebook readers, tablet PCs and related products have become hot merchandise in the 3C market. The Executive Yuan, Taiwan approved a "Development Strategy for the Digital Publication Industry" on August 31, 2009. This act will invest more than NT$1.2 billion in the next 5 years to promote the ebook reader sector, a business with a turnover up to NT$100 billion. As ebook readers and tablet PCs become accepted as alternatives to conventional books [2], there is no doubt that traditional paper copies will be offered in digital form, motivating us to address this issue. An EOG signal is a substantially low frequency and time varying physiological signal, vulnerable to noise interference. The stability of EOG signals is subject to the placement of electrodes mounted in the vicinity of the eyes. An EOG signal acquisition system involves a power supply, a preamplifier, noise reduction, system stability, ground shift and signal variations due to the placement of various electrodes.

An EOG signal must be converted from analogue into digital form for ZigBee wireless transmission, where the packet size, bandwidth, operating frequency and communication protocol must be taken into account. Tablet PCs are equipped with Wi-Fi, Bluetooth, 3G or 4G wireless communication modules supporting ZigBee, a multipurpose for Multi-node control communication protocol. The EOG analog signal is therefore converted into digital form as the first step in this work. There are a wide variety of tablet PCs available supported by operating systems (OS) such as Windows 7, Android 2.2, and equipped with various amounts of memory operating at different frequencies. Considering the amount of memory required and system stability, the developed program, designed to cross platforms, covers the following operating modes; previous/next pages, recording, tuning, tempo and skip to an arbitrary page. All popup windows must be made user friendly for easy operation.

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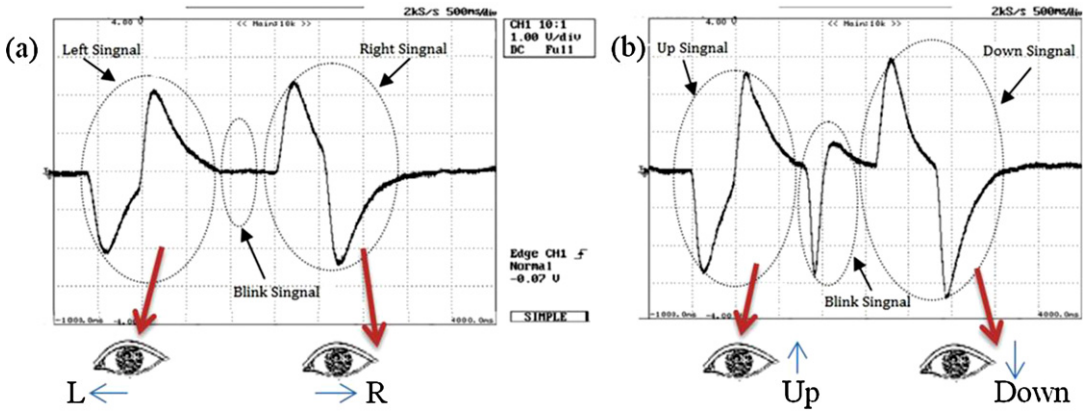

Fig. 1. EOG signal change waveforms.

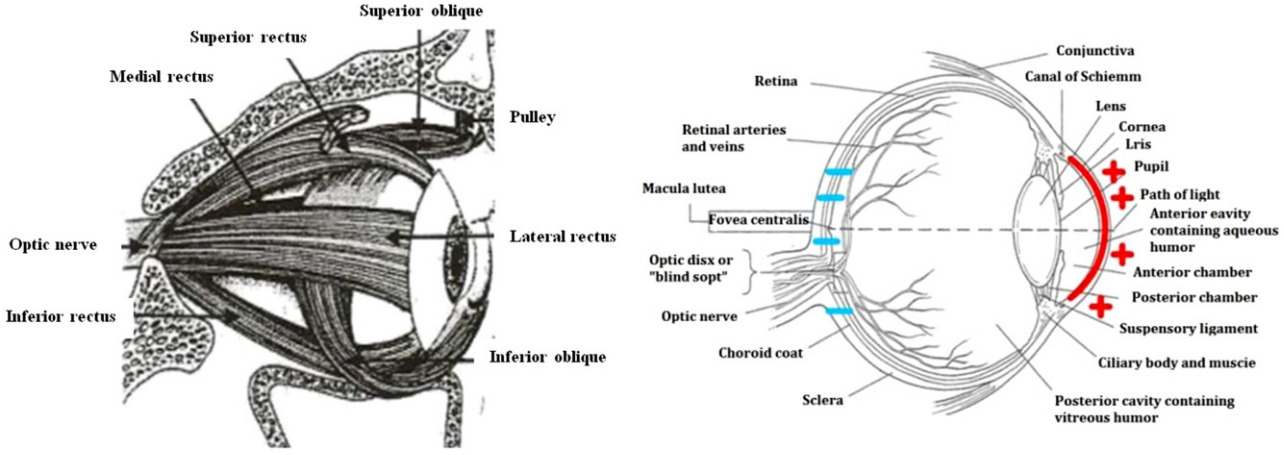

Fig. 2. Cross section of an eyeball.

2. Literatures review

Physiological signals encompass Electro-encephalography (EEG), Electro-myography (EMG), Electro-cardiography (ECG), Electro-oculogram (EOG), and so forth. In comparison with EEG and ECG, an EMG signal can be misinterpreted due to the musician's hand movements while playing a musical instrument, meaning that EMG is not a good choice for this issue.[3]

In Fig. 1, this study cited the reference [3] to indicate EOG signal change waveforms. When the user's eyes move to the left and right, the electronic score system can measure a left signal and right signal in different phases, as shown in Fig. 1(a). Fig. 1(b) shows that when the user's eyes move up and down the electronic score system receives a negative pulse (down signal) and a positive pulse (up signal). The blink signal indicated the eye is blinking.

As illustrated in Fig. 2 eyeball movements are controlled by three pairs of muscles; the inner lateral rectus, upper and lower rectus, and upper and lower oblique muscles. The mutual contraction of the first pair actuates the eye to move horizontally, while the second vertically, and the third rotates the eyeball such that the eyeball can stare straightforward. The eyeball is actuated in the opposite direction to the image movement. That is it moves rightward/downward as the image moves leftward/upward so that the image remains captured in the central part of the eyeball.

As illustrated in Fig. 2 the cornea and the retina of an eyeball carry positive and negative charges respectively. A zero output voltage is seen when the human eyes stare straightforward. However, a little voltage drop is detected as soon as there is relative movement between both eyes. Therefore, with EOG electrodes are mounted in the vicinity of the eye in such a way that positive/negative voltage drops are induced by rightward/leftward eye movement and detected accordingly [4].

As a natural response, eye blinking, either conscious or unconscious, is seen at a frequency between 2 and 3 Hz [5], usually ten odd per minute. Fig. 3 shows a significant eye blinking signal. [6]

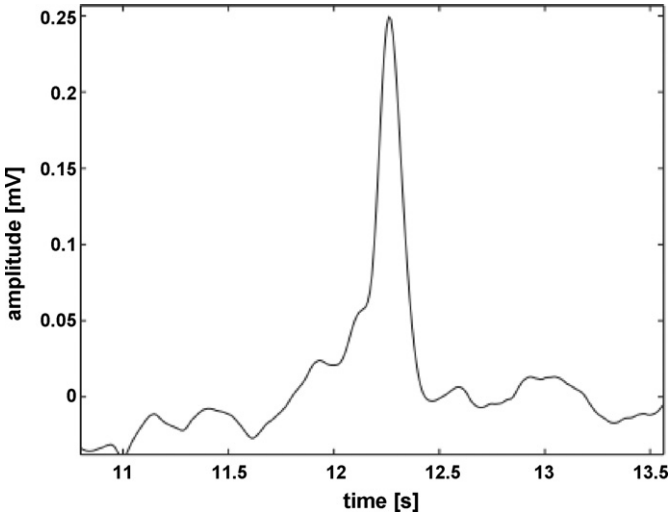

Fig. 3. An eye blinking signal.

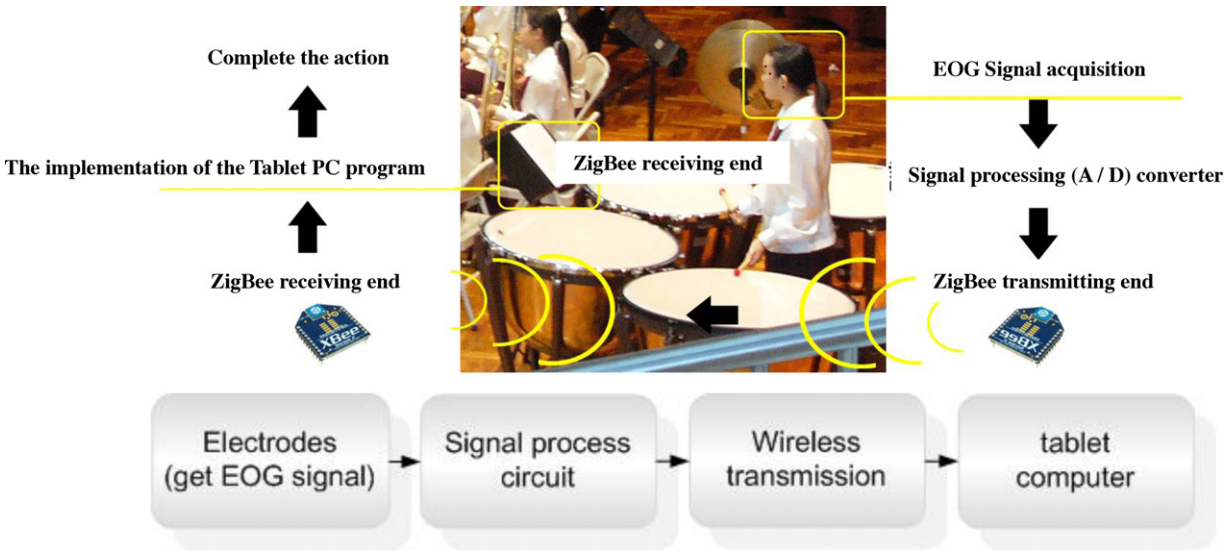

Fig. 4. A schematic diagram of signal processing.

An experiment dated back to the 19th century involved a small piece of glass, or metal, implanted into a paralyzed eyeball to observe the linkage between the detected electronic signal and the eyeball movement [7]. The charge distribution around the eyeball was not discovered until 1840 by Emil du Bois-Reymond [8]. This discovery was not widely applied to meet the needs of the disabled until 1990 [9]. A number of large hospitals in Taiwan, e.g. the National Taiwan University Hospital, currently take advantage of EOG signals in diagnosis [10]. Eye diseases [11] are characterized by EOG in the "Eyes vibration diagram manual" published by Drs. Jianbang Lu and Taivei Wang with the Veterans General Hospital. A large number of EOG research applications can be found in the wheelchair [3], computer mouse [12], man-computer interface [13,14], TV and household life [15] fields.

In contrast to Bluetooth and Wi-Fi, ZigBee provides a reliable, low power, highly efficient, low cost wireless transmission that covers a large number of transmission nodes. In compliance with the IEEE 802.15.4 protocol, ZigBee is a short range wireless communication standard, aimed to improve Bluetooth (802.15.1). In comparison, Bluetooth can handle only seven wireless modules, while ZigBee can handle up to 6000 odd transmission nodes. As required in a Wi-Fi system, 3 to 4 seconds are required to receive a Bluetooth device signal after being powered on. It merely takes 30 ms for a ZigBee network to receive signals. A wide variety of ZigBee applications can be found in the communication links of a great number of commercial products with compatible interfaces such as mobile phones, remote control devices, building automation, personal health care, industrial control, residence automation, computer peripheral remote control and home automation [16]. Up to now ZigBee has been successfully applied to home appliance control, building access control, staff attendance records, information and communication systems security, environmental monitoring systems, lighting control system, real time information transmission system, global position system, and the like.

3. System architecture and research methods

As illustrated in Fig. 4, the presented system signal processing is divided into four blocks, the first of which is EOG signal acquisition from electrodes mounted in the vicinity of the eyeballs. The second block is the circuits involved, e.g. an instrument amplifier, an ADC, etc. The third block is the ZigBee wireless transmission and reception unit. The fourth block is a decision criterion installed into a tablet PC for electronic music score control. Presented in Figs. 5 and 6 are the signal processing flows at the transmitting and receiving ends, respectively.

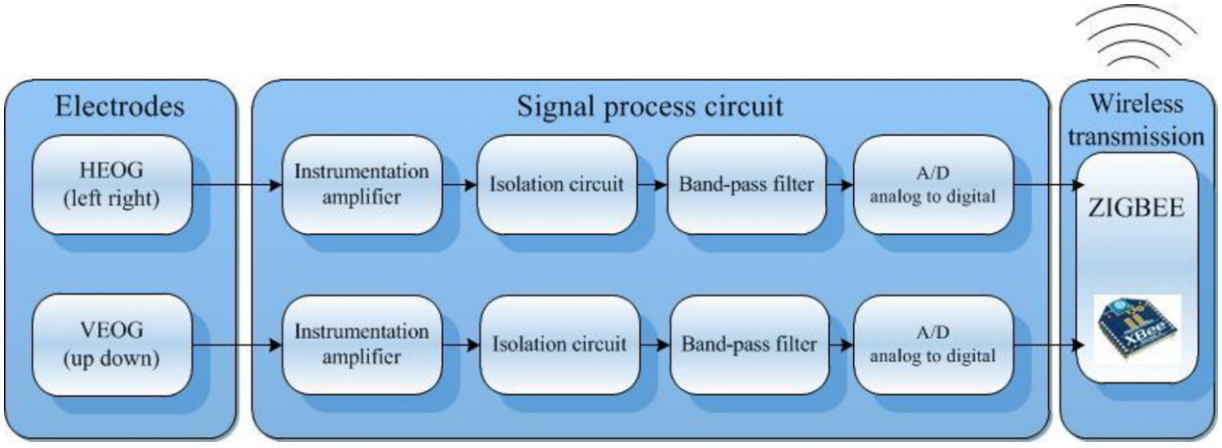

Fig. 5. A detailed schematic diagram of the signal processing ahead of a ZigBee wireless module.

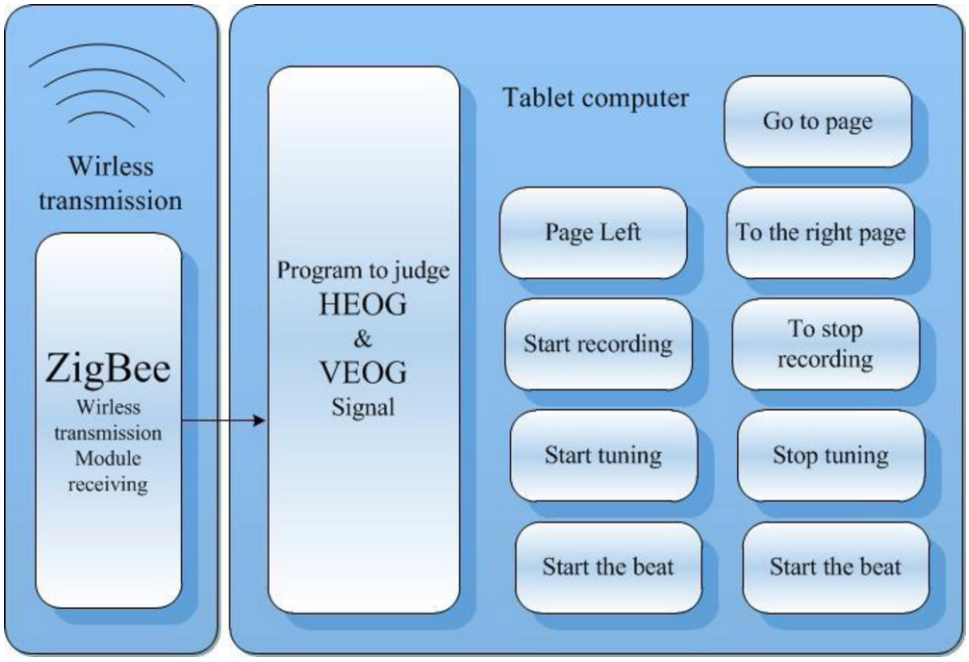

Fig. 6. A decision criterion installed on a tablet PC.

As demonstrated in Fig. 7, a vertical EOG signal is detected by a pair of electrodes, that is, electrodes 1 and 3, and a horizontal EOG signal is detected by electrodes 2 and 4.

The low noise signal amplifier is a critical component at the front end of the detection system used to boost the physiological, signal. It features a high common mode rejection ratio (CMRR), a power supply rejection ratio (PSRR), and so on [17].

The proposed program must be cross platform for use by various tablet PCs such that it can be run on diverse operating systems. The program is developed using JavaScript and HTML5, the latest web programming language version seen as mainstream in the future. This program implements multiple media and makes web pages available for offline viewing.

4. ZigBee wireless network performance

4.1. This study is divided into three sections:

(1) Communication reliability: It is important to ensure reliable wireless network communications - that is, to make sure the communications reach their destination uncorrupted. Communications corruption or loss of messages could result from radio interference or poor transmission/reception conditions. Reliability measures are employed to ensure that ZigBee messages are communicated without corruption or loss of data. ZigBee offers a range of techniques to ensure reliable communications. The transmission scheme used in ZigBee avoids transmitting data when there is activity on the chosen channel–this is known as Carrier Sense, Multiple Access with Collision Avoidance (CSMA-CA). This means that before beginning a transmission a node listens on the channel to check whether it is clear. If activity is detected on the channel the node delays the transmission for a random amount of time and listens again. If the channel is now clear the transmission can begin, otherwise the delay-and-listen cycle is repeated. An acknowledgement mechanism is built into ZigBee to ensure that messages reach their destinations. When a message arrives at its destination the receiving device sends an acknowledgement that the message has been received. If the sending device does not receive an acknowledgement within a certain time interval, it resends the original message (it can resend the message several times until the message has been acknowledged). In a Mesh topology the network has built-in intelligence to ensure that messages reach their destinations. If the default route to the destination node is down due to a failed intermediate node or link, the network can "discover" and implement alternative routes for message delivery. [18]

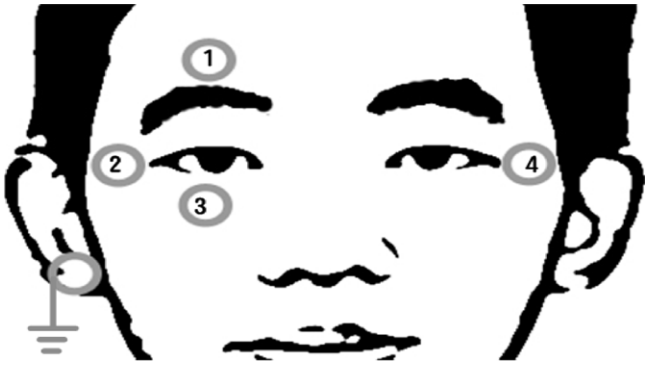

Fig. 7. Spots on which electrodes are mounted.

Wireless and wired mediums are different under a protected environment. In the transmission process a wireless medium will often decay, suffer interruption and be subject to a variety of defects, such as dispersion, multi-path delay, interference, frequency-dependent attenuation, Sleep node and safety-related issues. These factors affecting the quality of wireless transmission can be overcome through adoption of appropriate mechanisms in the ISO communication model layers. Not all of the mechanisms are compatible with other mechanisms and may negatively impact key performance properties. Therefore, the communication system must be based on specific real environment, with the mechanism used by the layers arranged in combinatorial optimization in order to achieve the best performance. A communication interrupt message is sent when the node cannot receive a message (for example, the node is in sleep state). Other equipment is used to store packets temporarily in the buffer zone. Once the sleeping device wakes the messages in the buffer zone are sent.

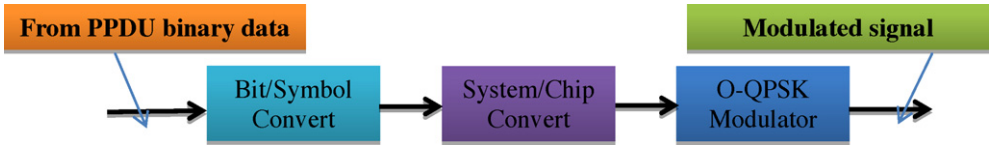

Fig. 8. A functional block diagram of the modulation and spread.

IEEE 802.15.4 (ZigBee) selected in the previous IEEE802 standard has been proven to ensure good reliability and will not seriously affect the performance of systems and devices using those mechanisms. They are: [19]

(1) Physical Layer Direct Sequence/Frequency Agile (DS/FA);
(2) MAC layer ARQ, AES - 128 encryption algorithms, network coordinator buffer temporary;
(3) Network layer mesh network (redundant path);
(4) Application support layer security.

Direct Sequence Spread Spectrum system with a pseudo-random noise (PN) pulse sequence modulates the narrowband information and carrier signal to be sent at the physical layer. Using the 2.4 GHz 16 quasi-orthogonal modulation method, i.e., four bits of information in each symbol (symbol) cycle are used to select one of them to be sent in the 16 quasi-orthogonal pseudo-random noise sequence. The next bit PN sequence of consecutive data symbols are connected together to form the chip sequence on the carrier with Offset Quadrature Phase Shift Keying (O - QPSK) modulation. As the pulse frequency (i.e., the chip rate) of the PN sequence is much higher than the information rate (i.e. symbol rate), the modulation result achieves spreading. Fig. 8 indicates a functional block diagram of the modulation and spread.

The spread spectrum processing gain of that chip rate/symbol rate ratio are related to the system's anti-jamming performance and anti-multipath delay spread parameters. The larger the processing gains, the stronger the anti-jamming and anti-multipath delay spread abilities. Exploring various literatures shows that the IEEE 802.15.4 (ZigBee) processing gains are higher than many IEEE802. 11b. and the so-called frequency agile is the ability to change the frequency to avoid the impact from a known interference or signal source. The experiment proved that IEEE 802.15.4 (ZigBee) can achieve an error rate of 10 – 9, especially in the SNR 4 dB case. The same BER is achieved when 802 .15 .1 SNR is 15 dB, 802 .11 b is 10 dB (see Fig. 9) [20]

The medium access (MAC) layer defines four frame types, i.e., a beacon frame, the data frame, confirmation frames and MAC command frame. A complete handshake protocol ARQ is used to send, receive and acknowledge. The frame control field indicates whether the received frame is confirmed. To confirm using the CRC checksum error-free data frames and MAC command frame, the receiver immediately sends an acknowledgment frame. If not received within the agreed time, the sender will again automatically send retransmission requests issued by the recipient. These are in the MAC sub layer to ensure a reliable transmission process. The beacon frames and acknowledgment frames are transmitted without reception confirmation.

At the same time, the network coordinator will not be immediately send the data frame temporarily stored in the buffer store until it is dormant nodes wake up. Advanced encryption algorithm AES - 128 are issued from the U.S. Department of Commerce's National Standardization Institute Advanced Encryption Standard 2001 specification. This algorithm has 128-bit block length to be parameterized. The length of the key selection is also 128 bits. The network topology can constitute a mesh-shaped connection to allow sending data through multiple paths to reach the destination. If a device cannot transmit data, the initial path can form another path for transmission. This is transparent for the user concerned and the user does not need to perform any intervention. The applications support sub-layer security that supports other devices to avoid unreliable communication. The user's own security

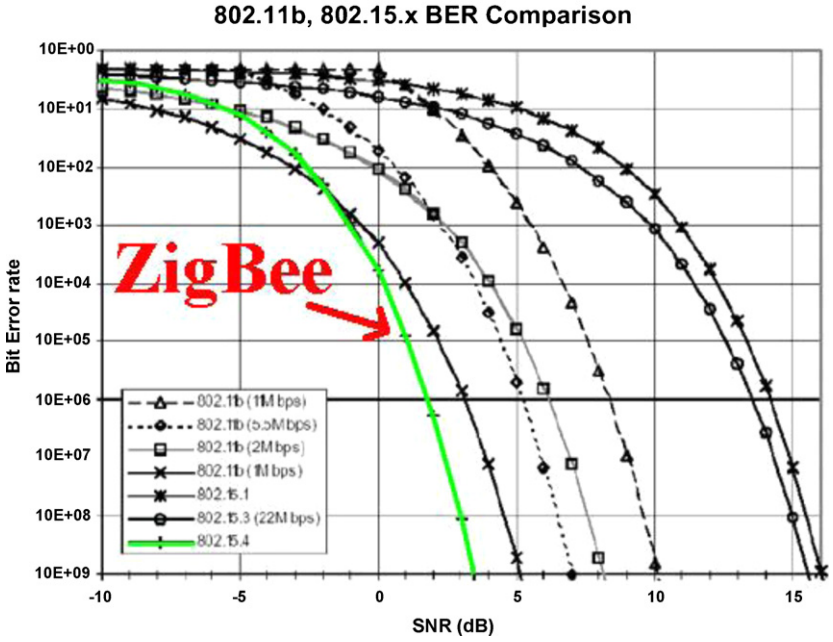

Fig. 9. 802.15.4(ZigBee) has excellent performance in low SNR environments.

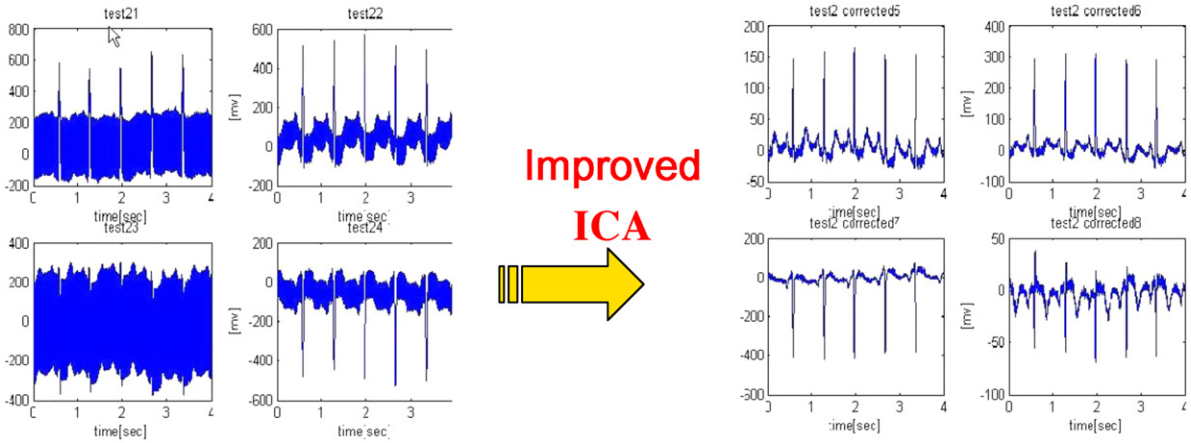

Fig. 10. An improved version of ICA to extract simulated features embedded in an EOG using MatLab ToolBox.

algorithms in the application layer can also increase the MAC security principles.

4.2. (2) Anti-interference between multiple nodes:

Immunity Characteristics of ZigBee technology mainly refers to the anti-same-frequency interference [21], that is, from interference by other technologies that share the same frequency band. For co-channel interference resilience is extremely important because it directly affects the equipment performance. ZigBee 2.4 GHz band with strong anti-jamming capability, the ZigBee system uses Direct Sequence Spread Spectrum technology [22,23] (DSSS) DSSS uses full-band transmit data, so that the higher the original power, the narrower the frequency becomes at wide low power frequency. In order to effectively control noise, strong anti-jamming capability, confidentiality, reliability, and high communication density are provided.

This study establishes a wireless transmission system based on ZigBee technology to achieve short-range wireless data transmission. To reduce power consumption and cost, and enhance data transmission security, the wireless communication module CC2530 RF chip is used as the core, allowing ZigBee network nodes to form a wireless data transmission system. In order to avoid the effect of interfering signals the system has an optimized modular design that greatly improves the data transmission and anti-jamming reliability, giving this system a wide range of applications.

When measured according to the wireless network nearby radio signal reception strength index (Received Signal Strength Indicator, RSSI) the string of eye movement signals used to distinguish each musician is are transferred to its unique node, which prevents the node from mistakenly receiving signals from other nodes transmitting data in the system.

4.3. (3) Low power consumption of nodes:

The IEEE 802.15.4 (ZigBee) physical layer and media access control (MAC) layer protocol take full account of the high reliability and also reduce the power consumption. To reduce the power consumption, the sent signal is lower than the overall system bandwidth, achieving very low average power producing a very low peak current P_{avg}. A high data rate and low symbol rate are produced in the physical layer. The peak current tends to track the symbol rate rather than the data rate. This means that a multi-level signal is sent. Sending a simple signal will result in loss of sensitivity to the detriment of the low-power goal. Therefore orthogonal signal transmission is used, slightly losing a little bandwidth to restore the sensitivity and coding gain. The data rate is 250kbps (4bits/symbol, 62.5k Baud), data modulation using 16 quasi-orthogonal modulation method, 16 symbols for 32–chip PN code pseudo orthogonal set of chip modulation pulse frequency 2.0Mchip/s O - QPSK (offset quadrature phase shift keying). A binary orthogonal modulation signal is used to send 16 quasi-orthogonal modulations of the signal transmitted in the bit error rate to be higher more than 5 dB at 10∼ 4. [24–26]

ZigBee wireless Internet can be set with a very short transmitter warm-up time. If the transmitter warms up longer there will be a significant power loss. The warm-up time is limited by the transitional process establishment in the signal path, especially the integrated active filter channel setup time. ZigBee Direct Sequence Spread Spectrum (DSSS) broadband technology has the advantage that the broadband channel filter itself has a very short set-up time. The DSSS frequency synthesizer also makes use of the higher frequency reference so that the lockup times are considerably decreased to reduce preheating power loss.

The ZigBee physical layer uses the following measures to reduce power consumption: The use of half-sine shaped O - QPSK modulation generated by a constant packet network lines to simplify the emitter amplifier design, reducing the effective current; Lowering the receiver's front grouping (blocking) requirements specification, allows the receiver to adopt lower active power consumption. The Duplex system transmits and receive simultaneously, reducing the peak current. The carrier frequency of 2.4 GHz was selected to avoid using the same channel 60 GHz ISM. Required output power Pout must have - 3dBm (mW dB, 1 mW zero level) of capacity, but as long as the actual chip design and manufacturing to ensure basic indicators allow for lower power output.[27]

5. Improved ICA method to extract accurate EOG signal

As exhibited in Fig. 8, an analogue EOG signal is converted into digital form, after which a physiological signal is reconstructed, say, through a FIR filter. A signal collection mechanism is important when it is imported into an embedded system [28–34].

This work adopts an improved version of ICA (Independent component analysis) to address the signal extraction issue under specific conditions. Covering mathematics, physics, probability, statistics, computer simulation and digital signal processing, the newly proposed ICA is an interdisciplinary research result to extract the original signal out of a mixture of independent signal components. As such a powerful tool in signal analysis, ICA algorithms successfully identified a great number of signals. Proposed in *Science* by Makeig et al. in 2002, the linkage between a brain ERP and finger movements was recognized by applying ICA

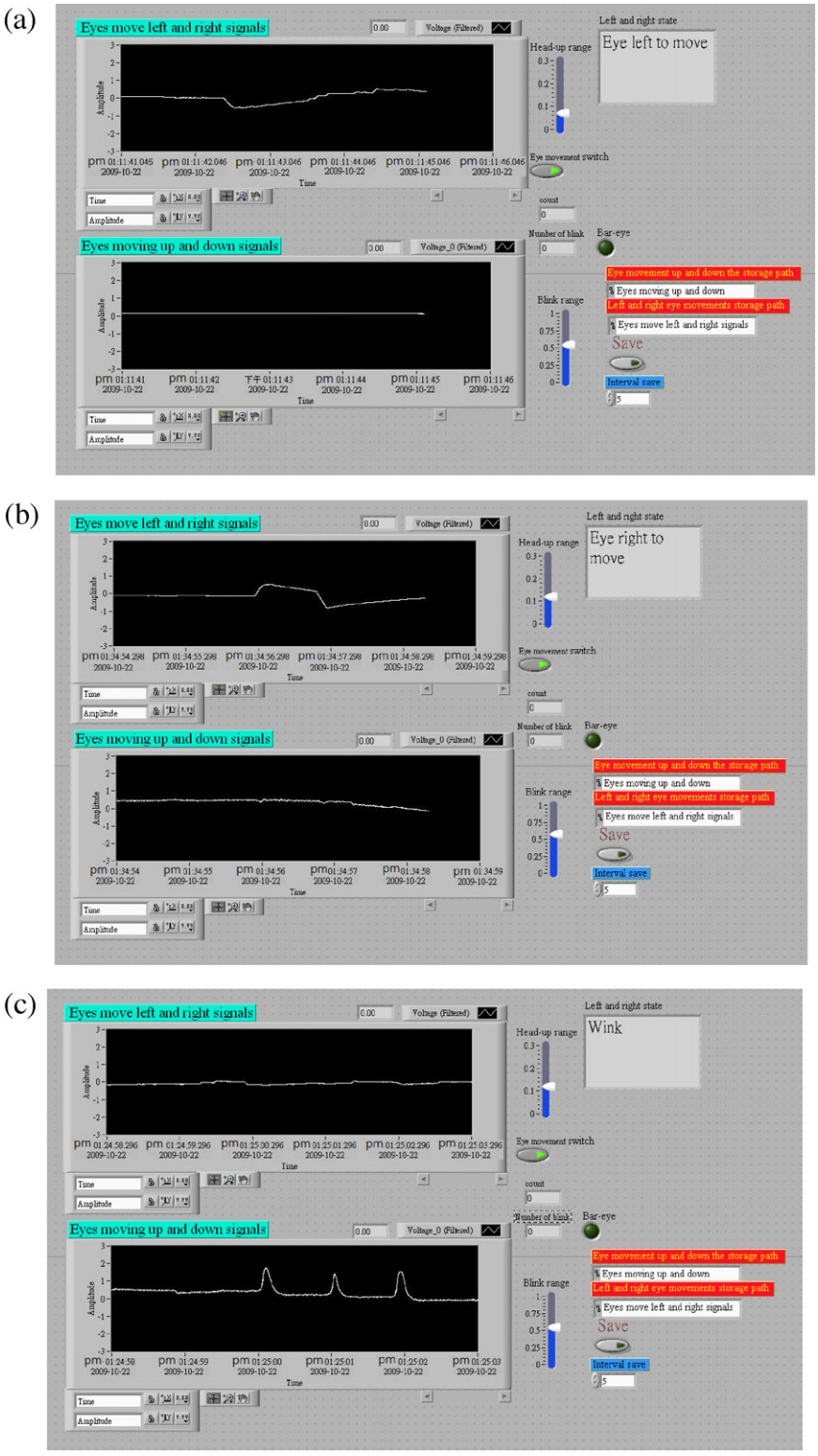

Fig. 11. Respective EOG signals for (a) leftward, (b) rightward eyeball movement and (c) three times of eye blinking.

to EEG. As suggested by Stögbauer et al. in 2004, ICA was modified to improve the quality of fetal electrocardiograms in an effort to separate the fetal heartbeat from its mother's. Since a conventional ICA algorithm might fail to recover the original signal, a modified version is employed in this work to reach that goal [31] (Fig. 10).

Researchers [34] gradually applied ICA electrophysiological signals to event-related potentials (Event Related Potentials, ERP). The task is done under the condition that the physiological signal is independent of the background EOG and the mutual information among the respective signal components is reduced through a linear transformation. In simple terms, an objective function is defined and then optimized in trying to decompose the detected signal into its' uncorrelated components for the purpose of physiological signal extraction or enhancement. ICA had been found in a number

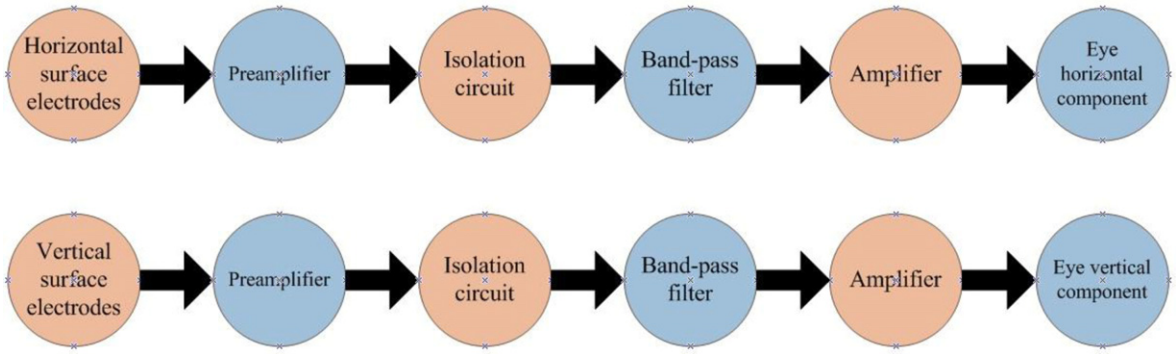

Fig. 12. A signal flow of an EOG acquisition module.

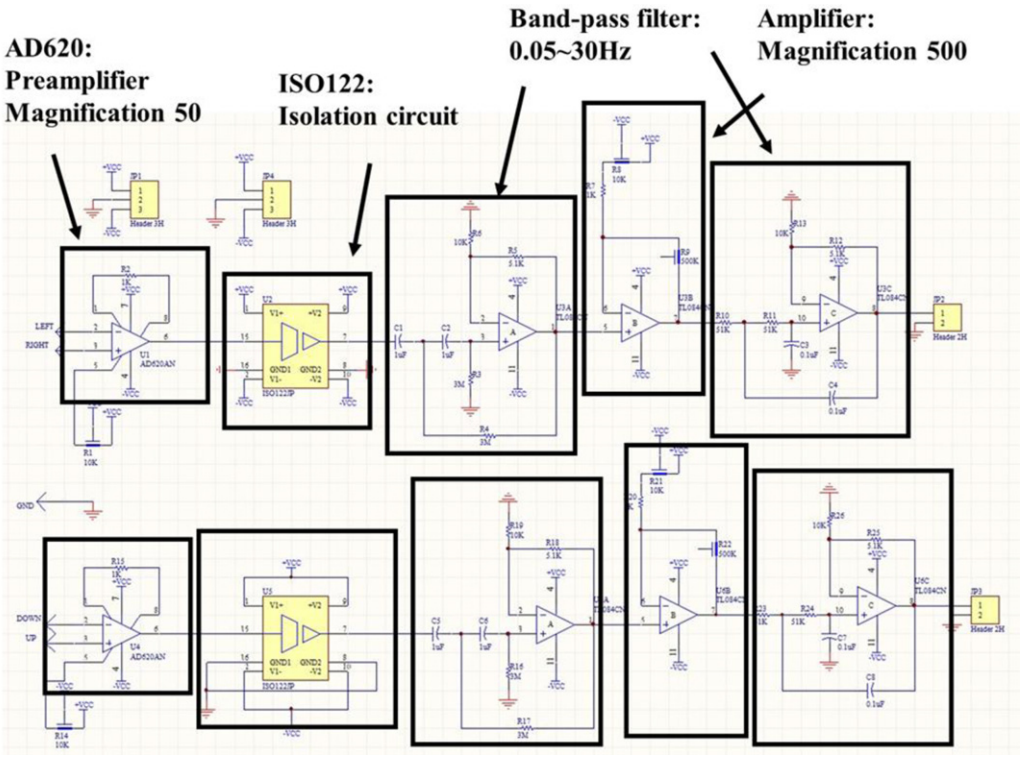

Fig. 13. An EOG acquisition module circuit.

of research activities able to identify evoked response ingredient out of an EOG background, according to which the number of trials required could be reduced. Therefore, it is adopted in this work for the sake of developing this novel EOG analysis approach [33].

When applying ICA to signal analysis a requirement must be met that distinct components in an original signal must be statistically independent with a non Gaussian distribution. Yet, according to the central limit theorem, a component out of cluster signal can be Gaussian distribution. It is requested that the number of linear mixed measurement signal be no less than that of uncorrelated components, a requirement that cannot be fulfilled in most ICA theoretic analyses and applications. For this sake, Independent component analysis of excess substrate is proposed as a means to address such issue with a higher computational complexity [28–30].

A linear equation in an ICA algorithm is defined as

$$X = AS \tag{1}$$

where S denotes m number of independent physiological signals, the matrix A is a linear combination thereof and X a combination of m detected signals. As stated in the "cocktail party problem" proposed by Broadly [35], the original signal can be reconstructed in principle using ICA provided that all of the components are statistically independent. The overall probability density function (pdf) is defined as

$$P(S) = \prod p(s_i) \tag{2}$$

where $p(s_i)$ symbolizes the pdf of component i. and then the output vector V is related to X by

$$V = UX \tag{3}$$

where V represents an estimated source signal. Yet, a signal can be reconstructed into its original form on the condition that the matrix U is the inverse of A or replaceable.

An ICA data model is assessed by operations on formula or function. For instance, it is either the clear or information among data, or

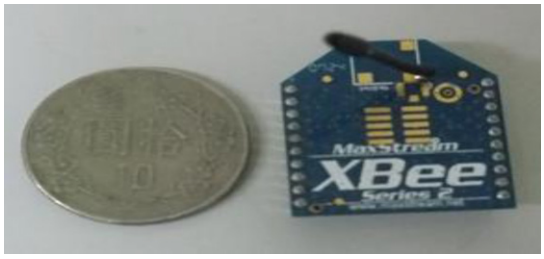

Fig. 14. A photo of an XBee wireless module.

data minimization/maximization, all affecting the transformation of ICA optimization problems [35].

An improved version of ICA is proposed in this work based on a Joint Approximate Diagonalization of Eigen-matrices (JADE) algorithm, which has been successfully applied to signal processing in the e.g. mobile communication, radar, biomedical engineering research fields. The improved ICA algorithm is presented as a series of steps, Initialization, Form statistics, Optimize orthogonal contrast and Separation. An input vector X representing a reconstructed EOG signal can be derived from $X' = UV'$, with V' expressed as

$$V = \begin{bmatrix} V_{11} & V_{12} & .... & V_{1n} \\ V_{21} & V_{22} & .... & V_{2n} \\ V_{31} & V_{32} & .... & V_{3n} \\ V_{41} & V_{42} & ..... & V_{4n} \end{bmatrix} \quad (4)$$

where the entries $V_{i,j}(i, j = 1, 2....n)$ denote signal sources, and n the number of samples.

6. Analysis and discussion of experimental results

The system is battery powered for safety and portability and is expected to provide high system stability because the EOG signal is amplified by an instrumentation amplifier and band pass filtered. The noise, ground shift and power supply interference are all reduced. Presented in Fig. 11(a) to (c) are the detected signals for leftward, rightward movements of an eyeball and eye blinking respectively.

As stated previously, the eyeball is actuated by three pairs of muscles. Respective signal variations can be sensed when the respective muscles are stimulated by brain signals. With the forehead as a reference in trying to avoid electric shocks due to leakage, electrodes are mounted to the left, right, top and bottom of the eye socket.

As illustrated in Fig. 12 both the horizontal and vertical components are acquired through a signal processing sequence. Each detected signal is input to a preamplifier with a voltage gain of 50. The signal is further input to an isolation circuit to obviate the risk of electric shock. The signal is then input to a bandpass filter with a passband of 0.05 and 32 Hz and then boosted 500 times. These signals are displayed on an oscilloscope or a PC.Fig. 13

Using analogue to digital conversion the system is designed to effectively deal with problems of oversize packets and high level data flow. The ZigBee module. ZigBee is employed to offer wireless connection to tablet PCs. This wireless linkage is expected to be expanded to related services in the future. Pictured in Fig. 14 is a Digi XBee wireless module.

Fig. 15
Fig. 16
Fig. 17
Fig. 18

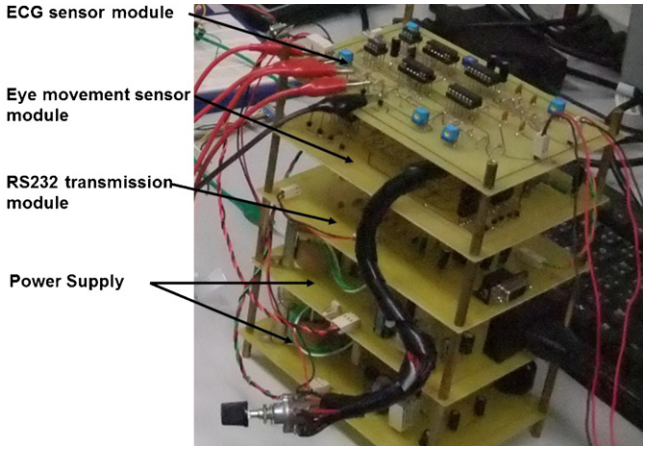

Fig. 15. A photo of the EOG acquisition system presented.

A XBee module features:(1) high performance, low cost,(2) low power,(3) advanced network protection measure, and

6.1. (4) Easy operation

This multipurpose system includes the following operational modes:

(a) Next page mode: go the next page when a rightward eyeball movement is detected and the eyes blink twice within three seconds, (b) Previous page mode: go the previous page when a leftward eyeball movement is detected and the eyes blink twice within three seconds, (c) Recording mode: this mode is activated when an upward eyeball movement is detected and the eyes blink twice within three seconds. This mode is terminated by a repetition of this move and the music is saved automatically in a specified holder, (d) Tuning mode: this mode is activated when a downward eyeball movement is detected and the eyes blink twice within three seconds. This mode is terminated by a repetition of this move and the music is saved automatically in a specified holder, (e) Tempo mode: this mode is activated when a clockwise eyeball movement from the top is detected and the eyes blink twice within three seconds. This mode is terminated by a repetition of this move and the music is saved automatically in a specified holder, and

(f) Skip mode: this mode is activated when a counterclockwise eyeball movement from the top is detected and the eyes blink twice within three seconds. A pop up window is displayed on a tablet PC. A wanted score can be selected by the times the eyes blink.

This system features a high degree of portability, low cost, small size, easy operation, wireless transmission, real time response and

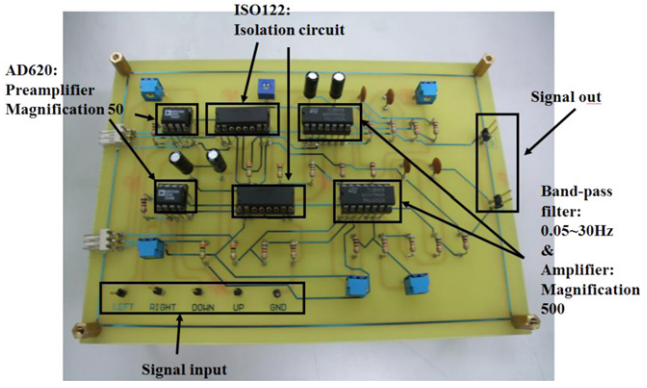

Fig. 16. Eye movement sensor module A decision criterion is developed and installed on a tablet PC with a user friendly interface as pictured in Fig. 17.

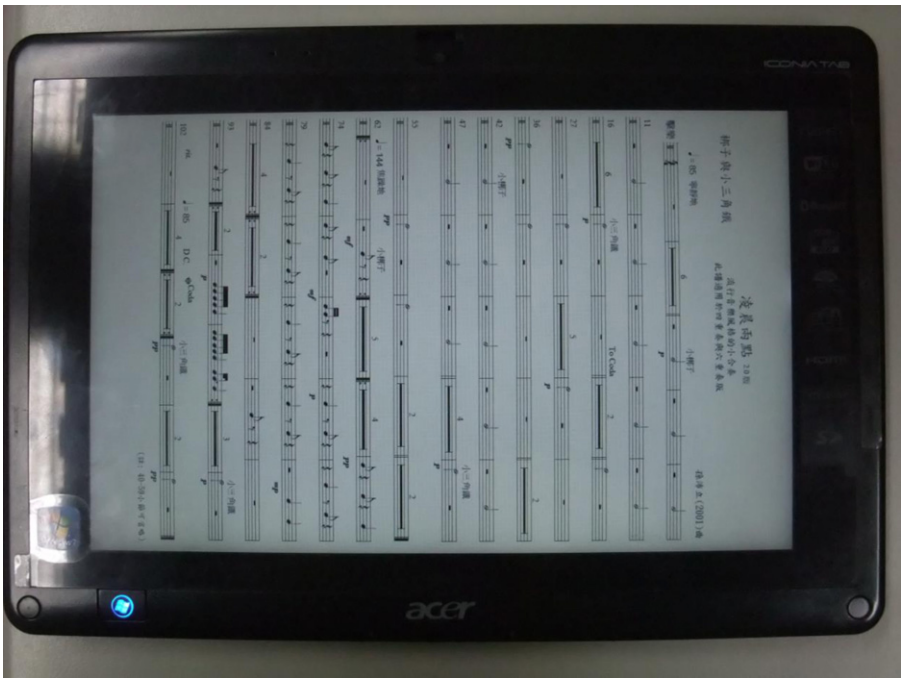

Fig. 17. A cross platform developed for tablet PCs.

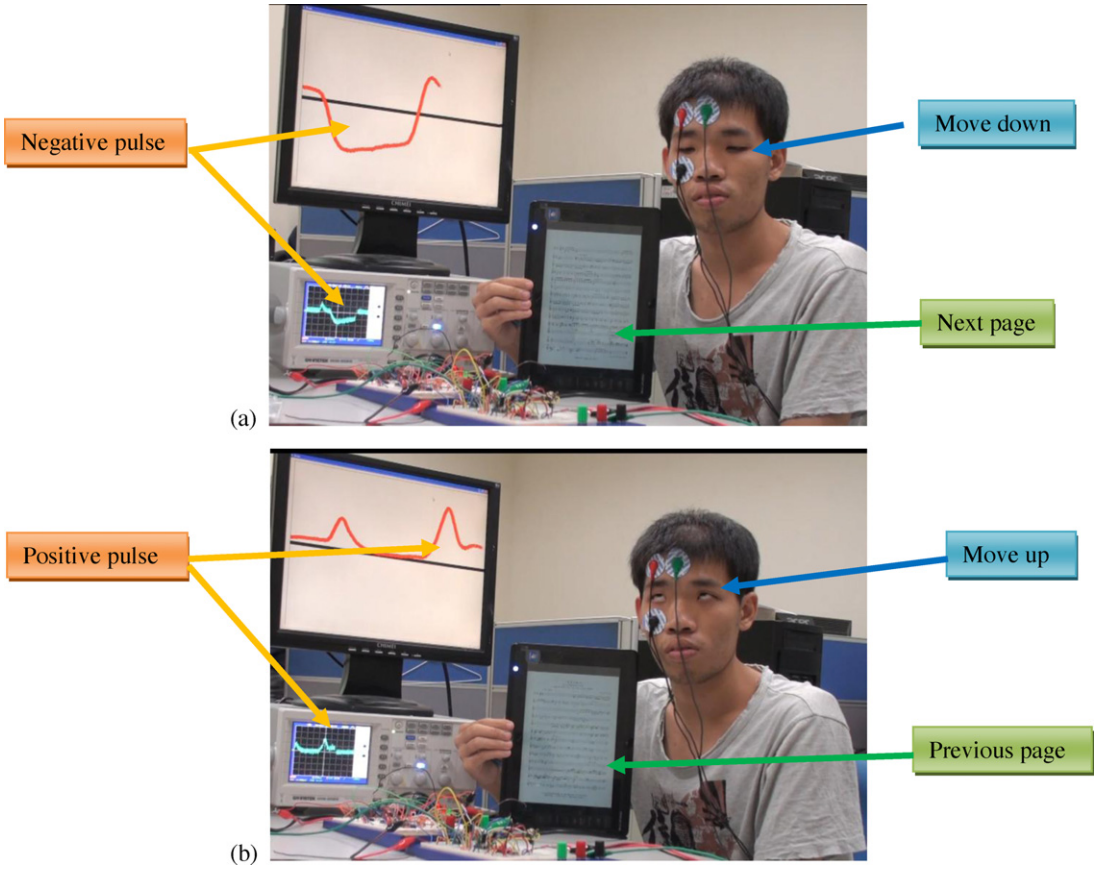

Fig. 18. An EOG acquisition experiment conducted using an automatic score page turner. (a) When the eye moves down the computer and oscilloscope detect a negative pulse that drives the score on the Tablet to turn to the next page. (c) When the eye moves up the computer and oscilloscope detect a positive pulse that drives the score on the Tablet to turn back to the previous page.

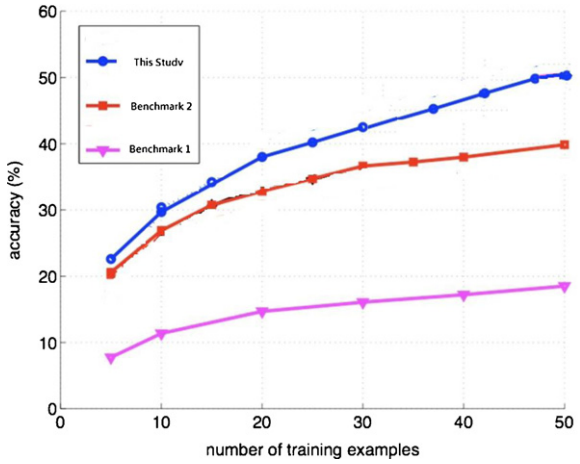

Fig. 19. Analysis on experiment results.

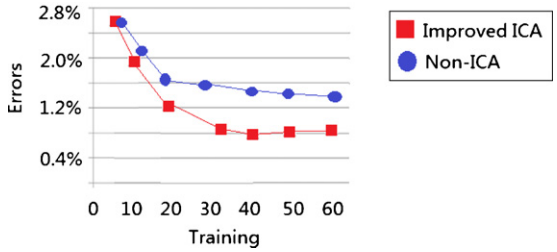

Fig. 20. Error experimental analysis.

easy maintenance, and is expected to be commercialized in the future with a high scalability.

Fig. 19 shows the categorization accuracy of various Identification results on EOG system benchmarks. As a result for a linear signal processing by use of binarized Identification, **Benchmark 2** denotes a linear curve using continuous Identification. It is noted that these simple classifiers achieve accuracies close to Multiple Kernel Learning (**MKL**) as implemented in reference [36]. **Benchmark 1** indicates a linear curve trained on the same low-level features that were used to create Identification. Accuracy over 50% is reached, which is lower than that achieved by Identification based linear curves. **As** a LP-β kernel combiner of the model reference [36] trained with low-level power and high accuracy features, this work is found to provide a superior accuracy relative to the other two EOG systems.

We use the electronic score system for error measurements with an improved ICA algorithm. The EOG signal has an improved ICA algorithm that converges around 0.8% on average when the training is more than 35 times. In the early stages the improved ICA and non-ICA present similar error values at about 2.3%. The experimental results are shown in Fig. 20, with average hit rate of 98.5%. This high hit rate shows that the user can move the electronic score system page via an eye movement.

7. Conclusions and Future Work

A multi-purpose electronic music score is implemented on a chip for experiments in improving EOG signal quality with analysis made automatically. For instance, an evoked potential is detected and analyzed. In clinical experiments on either an original or quantified EOG, evoked potential monitoring applications can be found in many fields. EOG can serve as an objective measure for physiological signals. The physiological measurement system presented in this work adopts an FPGA hardware interface module of a PXA 270 embedded system as a platform for realization of a portable real time multi-channel system. On the user end a KL-720 multipurpose physiological learning module is exploited for the front signal processing. The collected signal is analyzed in real time together with the embedded system through the Internet. The greatest challenge is to design an FPGA based EOG signal detector with Σ-Δ AD converters, differential amplifiers and bass pass filters. The embedded features are then extracted from the detected signals through an ICA algorithm. A platform was developed using the NI LABVIEW graphical programming environment for designing and building a complete embedded system.

This work implemented a high precision EOG signal acquisition system with features extracted from detected physiological signals and collected in a diagnosis data base for medical research purposes. As an outcome of interdisciplinary research covering medicine, physiology and electronics, this work is expected to serve as a significant tool for neuroscience and brain research.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.sna.2012.11.028.

References

[1] Ministry of Economic Affairs, Government Information Office, Council for Cultural Affairs, creativity - cultural and creative industry development program action plan 2009-2013 (approved), (2009) 4.
[2] Ministry of Economic Affairs Industrial Development Bureau Information Office of the technology industry, e-book industry boon Industrial Bureau will invest 1.2 billion yuan out to promote. (2008).
[3] S. Yathunanthan, L.U.R. Chandrasena, A. Umakanthan, V. Vasuki, S.R. Munasinghe, Controlling a wheelchair by use of EOG Signal, Information and Automation for Sustainability ICIAF 2008 (2008) 283–288.
[4] Zhao Lv, Xiaopei Wu, Mi Li, Chao Zhang, Implementation of the EOG-based Human Computer Interface system, Bioinformatics and Biomedical Engineering, (ICBBE 2008) (2008) 2188–2191.
[5] Hong-Hui Liu, intelligent analysis for medical automation-Fundamental the EEG and the EOG Signals, research in the sleep and drunkenness, the National Science Council - research report, NSC 90-2212-E002-180, (2002).
[6] Tomasz Pander, Tomasz Przybyia, Robert Czaba'nski, An application of detection function for the eye blinking Detection, HSI 2008 Krakow, Poland 25–27 (2008).
[7] Li-Wen Lv, An intelligent system for the eye-tracking device, Feng Chia University, Automatic Control Engineering 1 (2000) 2.
[8] J.R. LaCourse, F.C. Hludik Jr., An eye movement communication-control system for the disabled, IEEE Transactions on Biomedical Engineering 37 (1990) 1215–1220.
[9] Wen-Yi Liu, disabled people to control eye telecommunications man-machine interface design, National Taiwan University, Institute of Electrical Engineering, Master's thesis, (1996).
[10] Yi-Lun Lai, Clinical visual nervous system stimulation and diagnostic instruments, National Cheng Kung University, Institute of Electrical Engineering, Master's thesis, (1996).
[11] Tai-Fei Wang, Jian-Bang Lu, Eyes vibration Figure manual, Hop Kee Book Press (1986) 10–13.
[12] Zheng-Jie Wang, Ming-Yi Wang, Zhi-Cheng Hong, An eye for dynamic signal to control the mouse function prototype production, the National Science Council grants college students to participate in the thematic research project research report, the NSC 96-2815-C-161-001-E, (2008).
[13] Min Lin, Bin Li, A wireless EOG-based Human Computer Interface, Biomedical Engineering and Informatics (BMEI), 2010 3rd International Conference (2010) 1794–1796.
[14] Xiaoxiang Zheng, Xin Li, Jun Liu, Weidong Chen, Yaoyao Hao, A portable wireless eye movement-controlled Human-Computer interface for disabled, Complex Medical Engineering (2009) 1–59.

[15] H. Harun, W. Mansor, EOG signal detection for home appliances activation, 2009 5th International Colloquium on Signal Processing & Its Applications (CSPA) (2009) 195–197.
[16] M. Cardei, M.T. Thai, Y. Li, W. Wu, Energy-efficient target coverage in wireless sensor networks, Proc. IEEE INFOCOM (2005) 1976–1984.
[17] Yu-Ting Dai, Design Concept of the Bio-medical Signal Acquisition, the System, Institute for National Applied Research Laboratories Chip Implementation Center Newsletter 107 (2009) 3–8.
[18] S. Ashton, Ember Corporation. Zigbee network performance, typical results and implications for application design. Presented at ZigBee Developers' Conference (2006).
[19] Jae Yeol Ha, T.H. Kim, Hong Seong Park, Sunghyun Choi, Wook Hyun Kwon, An Enhanced CSMA-CA Algorithm for IEEE 802. 15, 4 LR-WPANs, in Proceedings Communications Letters, IEEE (2007) 461–463.
[20] A. Qayyum, L. Viennot, and A. Laouiti, Multipoint Relaying for Flooding Broadcast Message in Mobile Wireless Networks, in Proc. Of Hawaii Int'l Conf. System Sciences, (2002).
[21] Victor Lesser, Charles L. Ortiz Jr., Milind Tambe, Distributed Sensor Networks: A Multiagent Perspective (Multiagent Systems, Artificial Societies, and Simulated Organizations), Kluwer Academic Publishers, (2003).
[22] Y. Tseng, S. Ni, E. Shih, Adaptive Approaches to Relieving Broadcast Storms in a Wireless Multihop Mobile Ad Hoc Network, IEEE Transactions on Computers 52 (2003) 545–557.
[23] J. Zheng, M. Lee, Will IEEE 802.15.4 Make Ubiquitous Networking a Reality?: A Discussion on a Potential Low Power, Low Bit Rate Standard, IEEE Communications Magazine 42 (2004) 140–146.
[24] I. Akyildiz, W. su, Wirdess Sensor Networks: A Survey, Computer Networks 38 (2002) 393–422.
[25] G. Wang, G. Cao, P. Berman, T.L. Porta, Bidding protocols for deploying mobile sensors, IEEE Transactions on Mobile Computing 6 (2007) 515–528.
[26] A.S. Ibrahim, K.G. Seddik, K.J.R. Liu, Improving connectivity via relays deployment in wireless sensor networks, in: Proceedings of the Global Telecommunications Conference, Washington, DC, USA, November, 2007, pp. 26–30.
[27] S. Mahlknecht, M. Roetzer, Energy Supply Considerations for Self Sustaining Wireless Sensor Networks. Wireless Sensor Networks, 2005 Proceeedings of the Second European Workshop on, Jan/Feb. (2005) 397–399.
[28] Hattie Spetla Biomedical Signal IC Evalution, IEEE Trans. On Biomedical Engineering,(2007).
[29] Jia-Sheng Lu, electrocardiography essential, Hop Kee Book Publishing, Taipei, 2003.
[30] Jin-Ching Luo, Designing Low Power Of Sigma Delta Modulator For Biomedical Application, Biomedical Engineering Applications, Basis & Communications,(2005).
[31] K.L. Park, J. Lee, K.J. Lee, ECG Signal Processing using Basis Function of Independent Component Analysis, Biomedical Engineering Proceeding, 2005.
[32] Eldad Klaiman, Application of ICA in Removing Artifacts from the ECG, Ollendorf Minerva Center Report,(2005).
[33] Yong Hu, Li, X.H. Xie, X.B. Pang, L.Y. Yuzhen Cao, Kdk Luk, Applying Independent Component Analysis on ECG Cancellation Technique for the Surface Recording of Trunk Electromyography, Engineering in Medicine and Biology Society 2005. IEEE-EMBS 2005. 27th Annual International Conference 01 04 (2005) 3647–3649.
[34] Zhi-Dong Zhao, Min Pan, work of the Independent component analysis (ICA) for the signal denoising of EMG from the ECG the signal, Journal of Zhejiang University (Engineering Science), (2004).
[35] A. Hyvarinen, Survey on Independent Component Analysis, Neural Computing Surveys 2 (1999) 94–128.
[36] J.F. Cardoso, High - order contrasts for independent component analysis, Neural Computation 11 (1999) 157 – 192.

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