The Implementation of a Wireless Electroencephalogram Information System using WLAN

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Summary

Recent technological advances in sensors and wireless communications have enabled the design of inexpensive, portable and intelligent physiological sensor nodes for healthcare or patient monitoring. In this study, we proposed an Internet based Electroencephalogram (EEG) information system using wireless local area network (WLAN), and developed a tiny WLAN-based portable EEG sensor node (named pEEG, up to 16-channel). With this system, EEG signals can be monitored by physicians in real-time via Internet, and the monitored EEG data is stored in the designed EEG database which is online and shared with researchers to analyze it via Internet. To manage pEEG nodes and client viewers, a server program has been developed. The developed client viewer serves researchers or physicians to access EEG database and provides some basic analysis tools. The EEG signal conditioning part of pEEG is verified and comparable with a commercial one. The whole system test shows that this system is helpful for acquiring clean real-time EEG in daily life remotely. With this system, remote EEG monitoring and analyzing can be realized more easily. The online EEG database also is helpful to understand EEG correctly.

Key words:

Pervasive healthcare, EEG sensor node, EEG monitoring, Wireless LAN, TCP/IP chip

1. Introduction

The human brain's structure and functions have become a great source for researches due to its important role in our body. The scalp Electroencephalogram (EEG) is used for such researches as it is a representative signal containing information about the conditions of the brain; and its shape may contain useful information about the state of the brain. Nowadays, the EEG is widely used in clinical settings to investigate neuropathology. Moreover, EEG signals recorded from the scalp have small amplitude of approximately 10~100μV with the frequency range from 0.5 to 100Hz highly dependent on the activity degree of the cerebral cortex. Generally, EEG signals are categorized in four specific categories of brain activity based on different rhythm commonly discussed in EEG literatures: Delta (below 4Hz, when brain is in unaware or deep unconsciousness state), Theta (4~7Hz, appears when in drowsiness, unconscious or optimal meditative state), Alpha (8~12Hz, appears when in deeply relaxed or passive awareness state) and Beta (13~30Hz, appears when brain in fully awake state). A research history of EEG is listed by B. E. Swarz et al. [1].

Since EEG signals contain a wealth of information about brain functions and real-time EEG monitoring also enables easy recognition/detection of events (e.g. epileptiform discharges, lateralized changes) in the EEG background activity [2], it is necessary to build a real-time EEG monitoring system for collecting and analyzing EEG signals, and EEG signals should be included in healthcare or patient monitoring system. Recently, many new telemedicine applications for health monitoring using different communication infrastructure, such as cellar phone systems [3-5] was developed. With the spreading of WLAN, WLAN-based health monitoring systems and web-based applications were also reported [6-11]. Wireless sensor network can also be employed for personal health monitoring [12-13]. Moreover, there are some other wireless EEG signals collection devices and integrated front-end were developed [14-18].

In order to study normal person's EEG changes in daily life without the effects on mentality during measuring, a senseless EEG collecting scheme is necessary to acquire pure EEG signals as the traditional one may not be effective. However most of above mentioned monitoring systems were designed for Electrocardiogram (ECG) monitoring. Thus, the development of low-cost and portable EEG sensor node is necessary for EEG monitoring.

This study aims to develop a WLAN compliant sensor node for EEG data acquisition and build a real-time Internet-based EEG information system. Considering the increasing broadband Internet penetration rate in the whole world (statistic document shows that 77.8% households with access to broadband Internet in Korea [19]), it would be the most convenient communication

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infrastructure for patient monitoring to reduce the cost of healthcare services using WLAN.
In this study, the above mentioned wireless EEG device is expanded by using WLAN technology instead of Radio Frequency (RF) technology to design and implement an EEG sensor node named pEEG. An EEG information system for real time EEG monitoring is also built. As shown in Fig. 1, the real-time collected EEG data will be stored in our designed database as an EEG data bank shared with researchers online. A server program is developed acting as a manager to manage EEG sensor nodes, and viewer which is a client program in physician's side to monitor EEG waveform and consists of some basic analysis tools in real-time via the Internet.

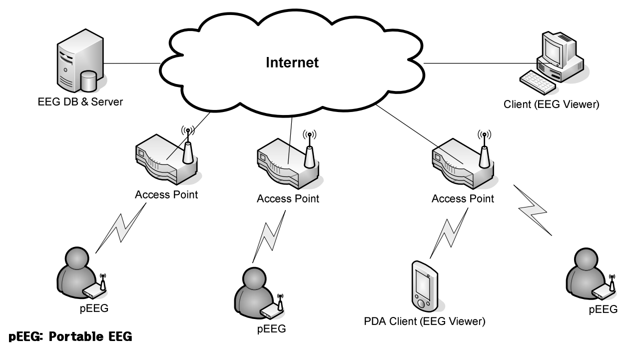

Fig.1 Framework of EEG information system using WLAN

The paper makes the following contributions:
- development of a portable, WLAN compliant 16-channel EEG sensor node for healthcare monitoring (introduced in Section 2)
- implementation of a real time EEG information system (described in Section 3)

2. Design and Development of pEEG

The pEEG, as proposed here, consists of three main parts: EEG data conditioning, TCP/IP packet processing and power management. These parts will be described in the following subsections and the block diagram of pEEG is shown in Fig. 2.

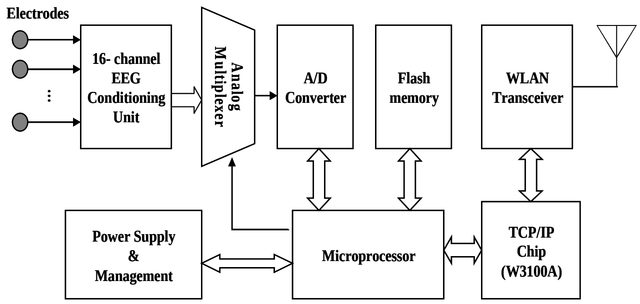

Fig. 2 Block diagram of pEEG

2.1 EEG Signal Conditioning

Since the scalp EEG signal is very weak, typically with an amplitude in range of 10~100uV, thereby requiring conditioning prior to any signal processing. Furthermore, the human skin typically provides source impedance on the order of 1~5Mohm. To acquire the signal effectively, the amplifier must match or have greater input impedance than the source impedance. In order to reject 60Hz (or 50Hz) power line interference from the signal, a relatively high Common Mode Rejection Ratio (CMRR) is desired consequently. In our design, a low power instrumentation amplifier is selected which has high CMRR of 120dB and a differential input impedance of 10Gohm || 2pF. To get the whole efficient EEG signals (frequency band about 0.1Hz ~ 100Hz), we have to implement some filters to service signal filtering well. From the instrumentation amplifier, a Low Pass Filter (LPF) is employed to attenuate frequencies up 100Hz, where the cut-off frequency is 100Hz at -3dB and gives 0dB gain. Then, the signal is filtered by a High Pass Filter (HPF) to attenuate frequencies below 0.1Hz, where the cut-off frequency is 0.1Hz at -3dB and gives 40dB gains. After that, the signal goes to a 60Hz notch filter to reject 60Hz interference. Finally, the signal is gained by the 2nd non-invert amplifier with 12dB. The operation amplifier chip used here is also a low power Operation Amplifier (OpAmp) with Rail-to-Rail input and output. One channel signal conditioning structure of pEEG is shown in Fig. 3.
The total gains of our designed signal conditioning part are about 85dB and the frequency pass band is between 0.1Hz and 100Hz, and the amplified signals' voltage level can serve the Analog-to-Digital converter (ADC) well (Table 1).

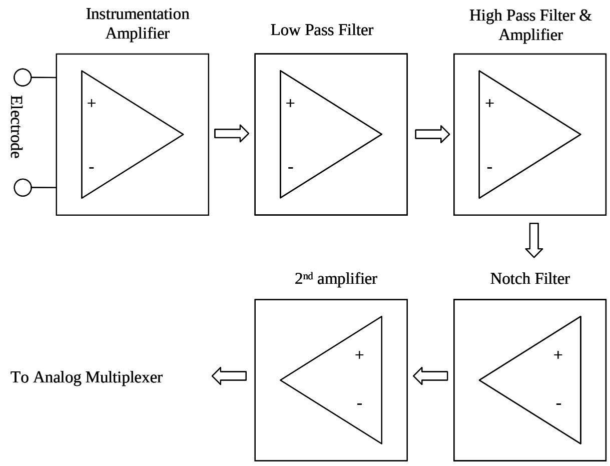

Fig.3 Structure of amplifiers and filters

Table 1. Specifications of EEG signal conditioning part

Part name	Character	Gain (dB)
Pre-amplifier	Differential input impendence: 10Gohm||2pf, CMRR: 120dB, input bias current: 1nA input offset voltage: 25μV	33
Low pass filter	4th-order Bessel filter Cut-off frequency: 100Hz	0
High pass filter	2nd-order Butterworth filter Cut-off frequency: 0.1Hz	40
Notch filter	60Hz Twin-T notch filter	0
2nd amplifier	Non-invert amplifier	12

To develop a multi-channel EEG device to be used in our proposed information system, an analog multiplexer is employed for channel selection. The EEG signals of selected channel are converted digital one with 12-bit resolution for the next TCP/IP packet processing.

2.2 TCP/IP Packet Processing

As mentioned above, one of the study purposes is to make good use of the abundant Internet resource to build a remote EEG monitoring system. We adopt WLAN as the wireless transmission media in order to support mobility to the patients. To provide higher processing speed in an easier operation, a hardwired TCP/IP stack chip, named W3100A, is used to process packets instead of a software TCP/IP stack performed in our previous study [20, 21]. As shown in Fig.4, this chip includes the hardware internet protocols such as IP version 4, Address Resolution Protocol (ARP), Internet Control Messages Protocol (ICMP), Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) as well as the hardware Ethernet protocols such as Data Link Control (DLC) and Media Access Control (MAC). And the protocol processing speed is up to full-duplex 20Mbps. Moreover, as the most useful protocols are integrated in this chip, no OS is required for developing. And it offers a socket Application Programming Interface (API) that is similar to the traditional windows socket API, so it makes that the application programming easier for developers.

Fig. 5 shows the microcontroller interface of the W3100A. It uses 15-bit address bus (ADDR) and 8-bit data bus (Data). The interrupt (/INT) from the W3100A indicates that the W3100A requires microcontroller attention after reception or transmission.

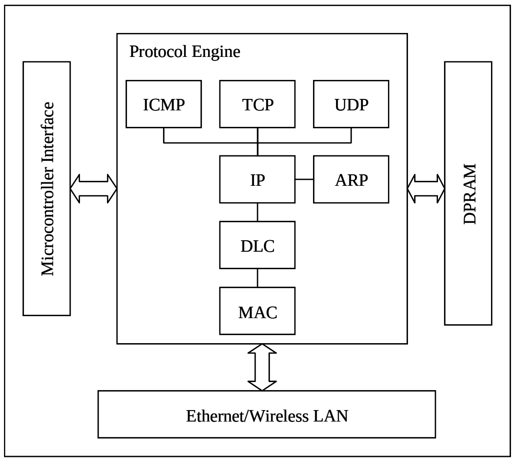

Fig.4 Block diagram of TCP/IP chip

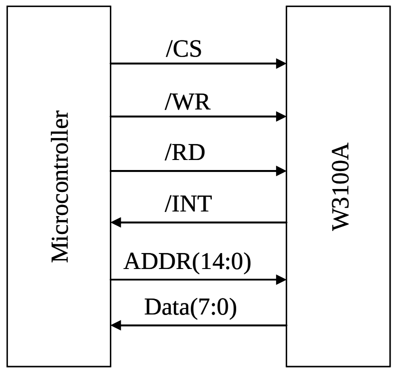

Fig.5 Microcontroller Interface of W3100A

After the collected EEG data is processed and encapsulated by TCP/IP chip, it will be sent by a WLAN transceiver. Here, we use a developed module as the WLAN transceiver which can connect W3100A by Multimedia Independent Interface (MII) directly.

2.3 Power Supply and Management

Generally, the power consumption is a very critical factor in a portable system. In our system, we use a single 9V battery causally. And we are considering using a Li-Ion rechargeable battery as a substitution. It is expected to make a monitoring device more lightweight, miniature and portable. Moreover, for enhancing the battery operating life and guarantee the safety of system, a battery protection circuit is designed to over-discharge voltage limit and protect the circuit shorted and over-temperature.

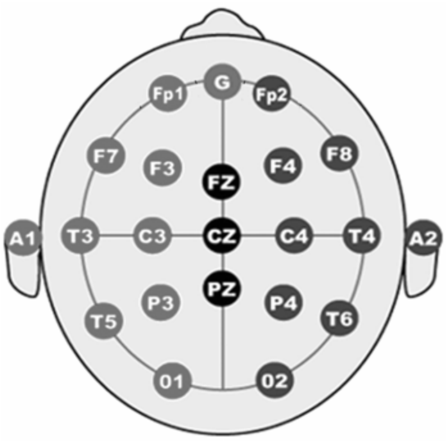

Fig.6 International 10-20 EEG electrode system

Additionally, the PCB (Printed Circuit Board) artwork of pEEG is ongoing, and the expected size is about 65mm × 60mm × 20mm without battery. In order to make the pEEG easy to use by the patients, we designed a cap-like EEG electrodes head band following the international 10-20 system which is shown in Fig. 6.

3. Real-time EEG Information System

The main objective of this research is to build a wireless EEG information system with WLAN based pEEG. To share the real-time collected EEG data and the status of subjects with different researches, we employ a database server to store the collected data from pEEG named EEG bank. Authorized researchers or physicians can access the database online via Internet to view the real-time data or offline one with our provided program. A server program is developed to communicate with pEEGs and deliver acquired EEG data to database, and manage pEEGs as well as viewer clients. A review client program is also designed with some EEG analysis tools, which is the program for authorized viewers to access our database via Internet. As the Internet is used as the communication infrastructure of this system, it is very flexible for patient monitoring with high rate speed. The following subsections will introduce the main three units of the EEG information system in detail.

3.1 EEG Bank

It is an online database which is shared by researchers to monitoring or analyzing EEG signals in real-time. Not only the EEG data collected from each pEEG is stored in the EEG bank, but also the device and its user's information. The data can be indexed at its acquired time or pEEG identification number. Furthermore, analysis results can also be saved with raw EEG data.

3.2 Server Program

The server program acts as a daemon program in server side which runs in 24×7 hours to listen to the pEEGs and clients connection request. Three main modules are included in the server program, they are:

- Connecting module: to listen to the connection requests from both pEEGs and EEG viewer clients. For pEEG, once a pEEG's connection request is found, it will communicate with the pEEG and store received EEG data. For clients, a login module is used to identify users, after that, the server will send the connected pEEG list to the client. Moreover, the clients can select the number of channel of their monitored pEEGs.
- Data pre-processing module: it collects the EEG data from connected pEEGs and divides them into each channel indexed by different EEG sensor ID, then stores them into database.
- Management module: this module provides the authorization for viewer client program to access database, and manages connected pEEGs/viewer clients. It also maintains the database such as user/device's information and client's identification data.

3.3 Client Viewer

The client program communicates with server to monitor selected pEEGs according to the client's authorization. Multiple pEEGs can be monitored concurrently by this program. Moreover, the most important functions of client program are such displayed the monitored EEG waveform in real time, and Fast Fourier Transform (FFT) analysis results are also can be displayed together with EEG waveform. In order to develop more useful tools in client side, we also developed a Finite Impulse Response (FIR) digital filter designer for analysis EEG data.

And now, we are planning to develop some statistical programs and other offline tools, such as nonlinear analysis methods, to help physician analyze EEG signals.

4. Implementation and Test Results

The pEEG and the whole monitoring system have been tested extensively in our laboratory to ensure overall functionality and robustness. We have tested the performance of pEEG's EEG signal conditioning unit alone firstly, and then the whole integrated monitoring system has been tested.

In order to verify the EEG conditioning part of our proposed device, we compared it with a commercial one, QEEG-4 (LAXTHA Inc.) [x], under the same conditions. The QEEG-4 and our device share the same ground, reference and measure electrodes with the same sampling rate (256Hz). Fig. 7 shows the 4 second one channel acquired EEG signals from QEEG-4 and our device, respectively. The EEG conditioning unit of our device achieves comparable results with the commercial one. In this figure, the Alpha wave can be clearly viewed from 1 second to 2 second as the subject closed eyes. The specifications of QEEG-4 and our conditioning part are introduced in Table 2.

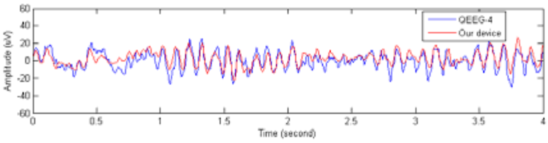

Fig. 7 One channel EEG signals (eyes closed)

Figure 8 shows the power spectrum of the above 4 seconds acquired EEG signals after Fourier Transform from our device and QEEG-4, respectively. We can also find that two devices achieved similar results, and the power concentrates on the 8-12Hz (Alpha wave). These results show that the amplifier and filter circuit of our device works well for EEG signals acquisition.

Table 2. Specifications of QEEG-4 and our device

	QEEG-4	Our device
Operational input voltage	±5V	±5V
Lower frequency response	0.7Hz	0.1Hz
Upper frequency response	45Hz	100Hz
Output signal range	blew 5V	±2.047V
ADC resolution	8 bits	12 bits

To verify the whole integrated monitoring system, the similar test methods to previous verification are employed. The key difference is that the server program and client program are verified concurrently. The screen snapshots of experiment results are shown in the following figures.

Fig.9 depicts the snapshot of server daemon program with the list of connected pEEGs in left box and connected EEG viewer clients in right. The connected EEG sensor nodes and viewers listed here are updated in real time. In this case, only one pEEG and one viewer are connected with the server. With the interface, administrator can easily manage or monitor the connected devices and viewer clients.

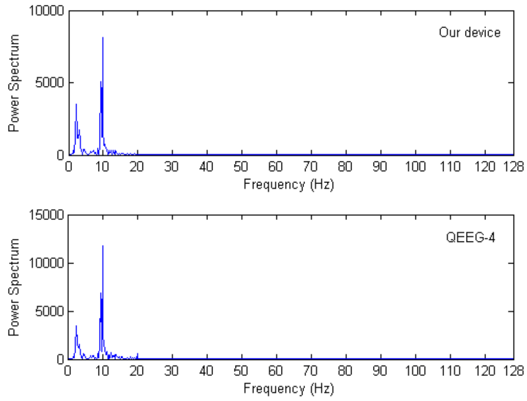

Fig. 8 Fourier Transform results (above one is from the proposed EEG sensor node and the below one is from QEEG-4)

Fig. 10 shows the EEG viewer program's user interface with picked raw EEG data by time after logged in. Some useful tools for EEG signal processing such as Fast Fourier Transform (FFT), digital filter and power spectrum analysis are integrated in this program. Authorized researchers can use it to access EEG bank via Internet, and physicians can use it to monitor their patients remotely via Internet. Moreover, with this system, one patient can be monitored more than one physician and vice versa. Therefore, physicians and researchers can exchange their analysis results via Internet timely.

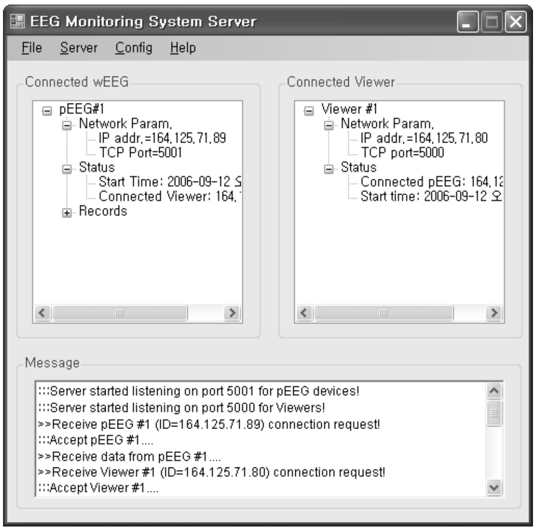

Fig. 9 The snapshot of server program

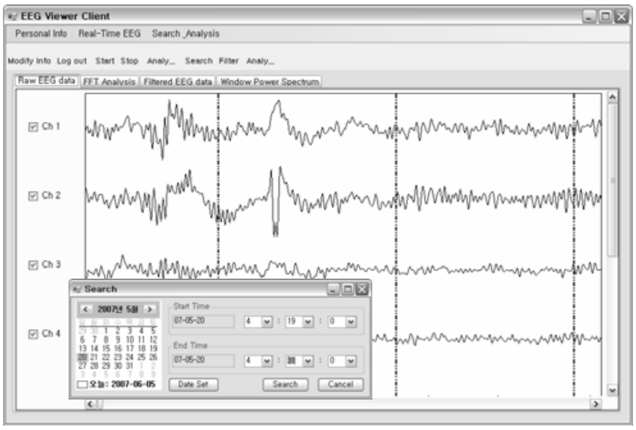

Fig. 10 The snapshot of EEG viewer program with searched data

4. Conclusion

This study implements a wireless EEG information system for remote real-time EEG monitoring and analysis. A WLAN compliant EEG sensor node named pEEG was designed and tested to acquire EEG signals and reject interferences. An Internet based EEG information system and EEG bank was also built with pEEG and developed programs. Test results showed the system works well and the hardwired TCP/IP chip can provide enough IP packets processing speed to transmit real-time EEG signals. With this system, the remote EEG monitoring can be realized easily via Internet. It also will be helpful for building other Internet based patient monitoring or healthcare system.

More useful tools for EEG signals analysis are to be developed in the near future so as to add more functions to this system. In current prototype system, as WLAN transceiver is a little power hungry, we have to employ an efficient mechanism for saving more energy and a more efficient communication protocol is needed. Furthermore, a Browser/Server (B/S) structure system is to be developed to substitute the proposed viewer client program.

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References

[1] B. E. Swarz and E. S. Goldensohn, “Timeline of the history of EEG and associated fields”. Electroencephalography and clinical Neurophysiology, vol. 106, pp. 173-176, 1998.

[2] C, E. Thomsen et al., “Collecting EEG signals in the improve data library”. IEEE Engineering in Medicine and Biology, pp. 33-40, 1997.

[3] C. S. Pattichis et al., “Wireless telemedicine systems: An overview”, IEEE antennas Propag. Mag., vol. 44, no. 2, pp. 143-153, Apr. 2002.

[4] B. Woodward, R. S. H. Istepanian, and C. I. Richards, “Design of a telemedicine system using a mobile phone”, IEEE trans. Inf. Technol. Biomed., vol. 5, no.1, pp. 13-15, Mar, 2001.

[5] K. Hung and Y. T. Zhang, “Implementation of a WAP-based telemedicine system for patient monitoring”, IEEE trans. Inform. Technol. Biomed., vol.5, pp. 101-107, June 2003.

[6] B. Fong, A. C. M. Fong and G. Y. Hong, “On the performance of telemedicine system using 17-GHz orthogonally polarized microwave links under the Influence of heavy rainfall”, IEEE trans. On info. Technol. biomed. vol. 9, no. 3, pp. 423-429, Sept. 2005.

[7] Y.-H. Lin et al., “A wireless PDA-based physiological monitoring system for patient transport” , IEEE Transactions on Information Technology in Biomedicine, vol. 8, no. 4, December 2004.

[8] S. Garawi, R. S. H. Istepanian and M. A. Abu-Rgheff, “3G wireless communications for mobile robotic tele-ultrasonography systems,” vol. 44, no. 4, pp 91-96, IEEE Communications Magazine, April 2006.

[9] I. Pavlovic and D. N. Miklavcic, “Web-based electronic data collection system to support electrochemotherapy clinical trial”, IEEE Transactions on Information Technology in Biomedicine, vol. 11, no. 2, pp. 222-230, March 2007.

[10] U. Varshney, “Patient monitoring using infrastructure-oriented wireless LANs”, Int. J. Electronic Healthcare, Vol. 2, No. 2, pp. 149-163, 2006.

[11] M. H. Williams, G. Venters, G. Venters and D. Marwick, “Developing a regional healthcare information network,” IEEE Transactions on Information Technology in Biomedicine, vol. 5, no. 2, pp. 177-180, June 2001.

[12] E. Jovanov, A. Milenkovic, C. Otto and P. C. D. Croen, “A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation” , Journal of NeuroEngineering and Rehabilitation, 2 (2005) 6.

[13] A. Milenkovic, C. Otto and E. Jovanov, “Wireless sensor networks for personal health monitoring: issues and an Implementation”, Computer Communications, vol. 29, no. 13-14, pp. 2521-2533, August 2006.

[14] X. Jiang and X. G. Wang, “Development of ultra small two-channel system of EEG radio telemetry”, Proceedings of 1st International Conference on Neural

Interface and Control Proceedings, Wuhan, China, pp. 60-63, 2005.
[15] A. Bastani et al, "Wireless brain monitoring in the emergency department", Proceedings of 27th Annual Conference of the IEEE EMBS, Shanghai, China, pp. 2502-2505, 2005.
[16] J. Ji, and M. S. Yu et al, "A wireless EEG sensors system for computer assisted detection of alpha wave in sleep", Proceedings of 27th Annual Conference of the IEEE EMBS, Shanghai, China, pp. 5351-5353, 2005.
[17] C. C. Liu, E. O'Connor, and K. P. Strohl, "A multichannel, wireless telemetric microsystem for small animal Studies", IEEE Sensors Journal, vol. 6, No. 1, pp. 187-202, 2006.
[18] R. F. Yazicioglu, P. Merken and C. van Hoof, "Integrated low-power 24-channel EEG front-end", Electronics Letters, vol. 41, no. 8, April 2005.
[19] OECD Factbook 2006: Economic, Environmental and Social Statistics, ISBN 92-64-03561-3, OECD 2006.
[20] K. Jin and J. Lee, "A design and implementation of high speed TCP/IP hardware", Proceedings of APCC'97 (The 3rd Asia Pacific Conference on Communications), vol.1, pp. 212-216, 1997.
[21] Wiznet, W3100A Datasheet, www.wiznet.co.kr

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