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A Study on Brain Computer Interfacing

Prof S.S.Patil[1], Ms.P.S.Shaikh[2]

Professor, Dept. of Electronics, Tatyasaheb Kore Institute of Engineering and Technology, Warananagar, Maharashtra, India[1]

PG Student, Dept. of Electronics, Tatyasaheb Kore Institute of Engineering and Technology, Warananagar, Maharashtra, India[2]

ABSTRACT*:* The human brain is the most complex physical system we know of, and we would have to understand its operation in great detail to build such a device. An immediate goal of brain-machine interface study is to provide a way for people with damaged sensory/motor functions to use their brain to control artificial devices and restore lost capabilities. By combining the latest developments in computer technology and hi-tech engineering, paralyzed persons will be able to control a motorized wheel chair, computer painter, or robotic arm by thought alone. In this era where drastic diseases are getting common it is a boon if we can develop it to its full potential. Recent technical and theoretical advances, have demonstrated the ultimate feasibility of this concept for a wide range of space-based applications. Besides the clinical purposes such an interface would find immediate applications in various technology products also.

KEYWORDS: Brain–computer interface (BCI), electroencephalogram(EEG),online, drowsiness detection, wireless.

I.INTRODUCTION

Biomedical signal monitoring systems have been rapidly advanced with electronic & information technologies in recent years. In this system we proposed a novel brain-computer interface system that can acquire & analyze EEG signals in real time to monitor human physiological as well as cognitive states, & in turn, provide warning signals to the users.A brain-machine interface is a communication system that does not depend on the brains normal output pathways of peripheral nerves and muscles. It is a new communication link between a functioning human brain and the outside world. These are electronic interfaces with the brain, which has the ability to send and receive signals from the brain. BMI uses brain activity to command, control, actuate and communicate with the world directly through brain integration with peripheral devices and systems. The signals from the brain are taken to the computer via the implants for data entry without any direct brain intervention. BMI transforms mental decisions and/or reactions into control signals by analyzing the bioelectrical brain activity An immediate goal of brain-machine interface study is to provide a way for people with damaged sensory/motor functions to use their brain to control artificial devices and restore lost capabilities. By combining the latest developments in computer technology and hi-tech engineering, paralyzed persons will be able to control a motorized wheel chair, computer painter, or robotic arm by thought alone. In this era where drastic diseases are getting common it is a boon if we can develop it to its full potential. Recent technical and theoretical advances, have demonstrated the ultimate feasibility of this concept for a wide range of space-based applications. Besides the clinical purposes such an interface would find immediate applications in various technology products also.

II.SYSTEM ARCHITECTURE

A. Description of the system

The block diagram of the developed EEG-based BCI system is shown in Fig. 1, which includes five units:

1) Signal acquisition and amplification unt

2) Wireless data transmission unit

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3) Embedded signal processing unit

4) Host system for data storage and real-time display

5) Warning device.

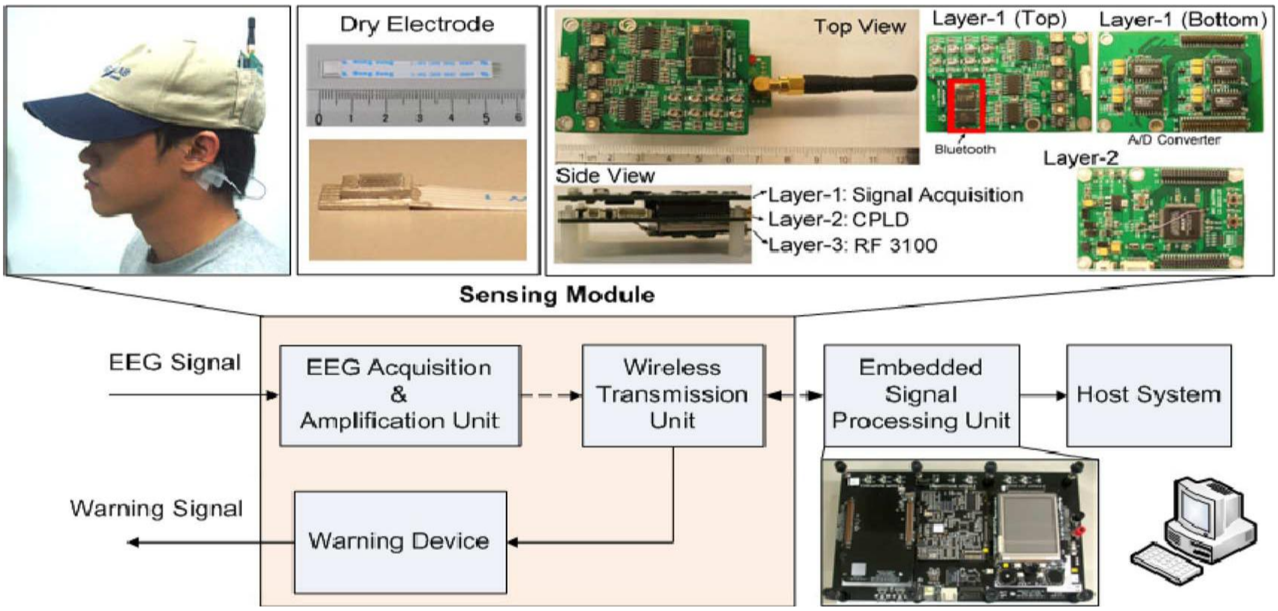

Fig1. Block diagram of the proposed BCI system.

The three-layer sensing module provides 4-ch biomedical signal acquisition, amplification, and wireless transmission functions. The signal acquisition and amplification unit is placed on the top-side of layer 1, and the 8-b A/D converters are designed on the bottom side of layer 1. Layer 2 is the complex programmable logic device (CPLD) module that controls A/D and wireless modules. For wireless transmission, RF3100 module is arranged in layer 3, and the Bluetooth module is placed on the top-side of layer
1. The size of the sensing module is 4.5 cm × 6.5 cm × 2.5 cm,and the weight of the module with a Li-ion battery is 51 g.

The sensing module (including signal acquisition, amplification, and
wireless units) is designed to operate at 400 mA with 3.7-Vdc power supply, and its power consumption is about 1.11 W. The module can continuously operate for at least 45 h with a commercial 16 000 mAh Li-ion battery. In addition, the EEG signal processing unit (OMAP 1510) and the host system (PC) are powered with ac.

III.DESCRIPTION OF THE DETAIL ARCHITECTURE BCI SYSTEM

In this paper, the dry electrodes [22] based on microelectromechanical systems (MEMS) technologies were placed on the subject's forehead to acquire the EEG signal because they can overcome the comfortableness and inconvenience (e.gusing electrolytic gel) of traditional EEG sensors. After signal acquisition, the amplification unit is applied to filter out the artifacts, as shown in fig The EEG amplifying circuit consists of a preamplifier (a differential amplifier) with the gain of 100, an isolated amplifier to protect subject, a bandpass filter that was composed of a low-pass filter and a high-pass filter to reserve 1–100 Hz signals, a differential amplifier that had the gain of 10 or 50 (that can be chosen by a switch).

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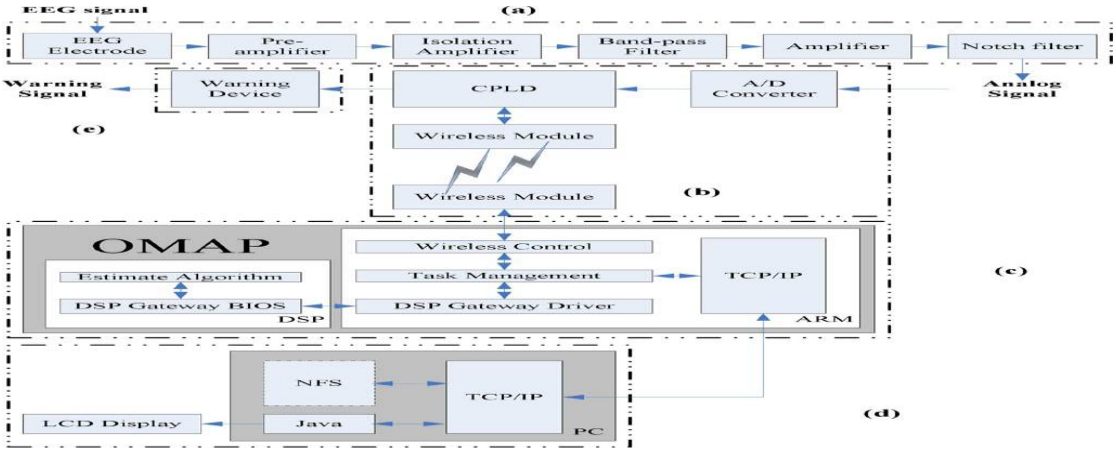

Fig.2 Detail architecture of the BCI system

The gain of the preamplifier (100) is larger than the amplifier (a gain of 10) because of the EEG signal is in microvolt level, and thus, larger amplification is needed before filtering. The capacity we used in the bandpass filter can compensate the dc-offset, thus there are no mechanism designed for the problem. The sensing module that carried by the subjects is designed to operate with a 3.7-Vdc power supply, and the dc voltage can be either supplied by a battery or ac power line. Therefore, a 60-Hz notch filter is also included to eliminate the effect of the line noise in case we have to run the system with ac power. Fig 1. Shows the wireless data transmission unit that includes8-b A/D converters (parallel output, sampling rate =768 Hz, AD-7575, Analog Device, Inc.), a CPLD, and wireless modules. The acquired signal is first converted from analog to digital, and then, transmitted through the wireless modules. The ALTERA FLEX10K EPM 7128STC100-7 CPLD is employed to control the A/D converter and encode the data for the wireless modules. Two different transmission methods can be selected in the wireless module of the designed BCI system according to the transmission distance in applications. Although Bluetooth module is most commonly used in medical/clinical settings where short-distance transmission is required, long-distance transmission is sometimes desirable in the settings.In addition to drivers 'drowsiness estimation, the system is expected to be applied in various fields such as home cares, clinical physiological signal monitoring, and exercise training. Thus, we also integrated a custom-made RF transmission module with longer operation range in the developed system. RF 3100/3105 (Ancher Technology,Inc.) module is a transparent module that integrates low transmission power and high transmission rate (76800 b/s) designs. The comparison of Bluetooth and RF3100/3105 is shown in Table I. The transmission rate is set as 19 200 b/s only in our final design to prevent transmission error, and it can still provide 295 Hz sampling rate for 4-ch signal transmission.

This setting is quite enough for general EEG signal acquisition since the most concerned frequency band of EEG signals is during 1–60Hz. The EEG signals are recorded at the higher sampling rate to preserve the original signal as well as possible for various applications in addition to drowsiness estimation. Thus, the signals are recorded at a higher sampling rate and down-sampled to 64Hz in the EEG signal analysis unit.

IV.DUAL CORE PROCESSOR

Description of the dual core processor. It is expected that the portable biomedical devices should provide more advanced functions such as real-time feedback to the users in addition to online monitoring. Therefore, more complex processing methods have been proposed for physiological analysis, and they will produce more Impacts if can be implemented in a real device or product. A dual-core processing unit is adopted as a platform that EEG signal processing methods as well as the intelligent technology can be implemented on it for different applications due to its powerful computation power. The operating core is Texas Instruments (TI) open multimedia architecture platform (OMAP) 1510, which is composed of an ARM925 processor and a TMS320C55x DSP processor.

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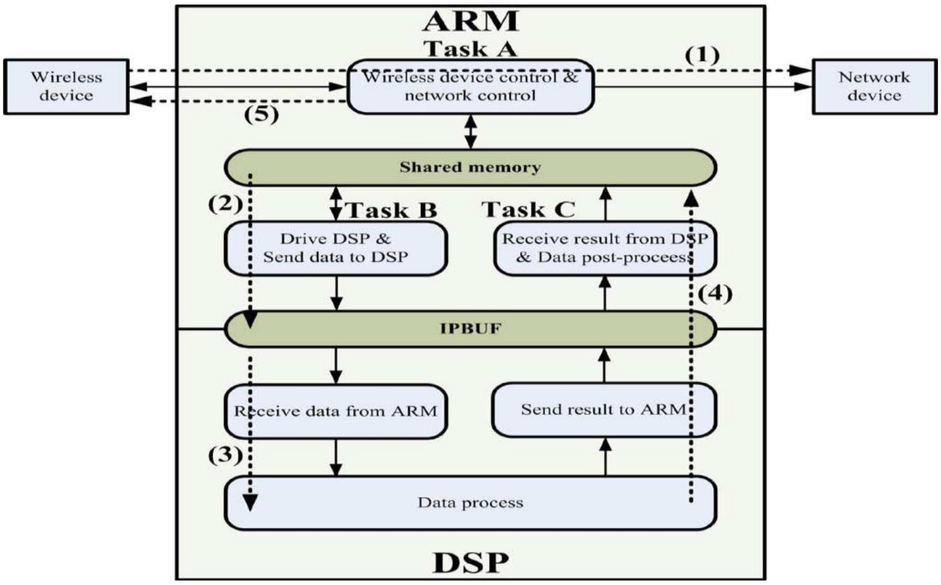

Fig.3. Software structure of the embedded system and the data processing flow.

The DSP core was used to process EEG data, and the ARM925 was used to communicate with other devices such as wireless transmission modules and transmission control protocol/ internet Protocol (TCP/IP) network. The DSP gateway is used as the cooperation structure for the communication between the two cores since these two cores have different functions, as shown in Fig.3.

The DSP gateway is software that makes ARM core possible to use resource of DSP core by application program interface (API), and works like a small real-time kernel that manages the resource and data flow in the DSP core. With this mechanism, the DSP processor is on only when the system needs to process the EEG data. The Linux operating system (OS) is built to manage the resource of ARM core [20].

The functions of ARM core can be divided into three parts:

1) Wireless module control;

2) TCP/IP control;

3) DSP gateway driver.

The ARM core was selected for these tasks due to its excellent interface control ability. The process flow and task distribution in the embedded system are shown in Fig. 3. There are two processing flows running at the same time including EEG data acquisition and communication and EEG signal processing.

The data processing flows are described as follows.

1) After receiving EEG data from wireless device, task A transmits the data to network. The EEG data are then stored in the shared memory.

2) After the EEG data are stored, task B enables the DSP module and sends data to DSP.

3) After DSP receives the EEG data, DSP processes the data with Hanning Window and short time FFT analysis.

4) After EEG analysis, DSP sends the result to ARM and ARM performs the other processes and saves the result to the share memory.

5) If the driver drowsiness is detected through EEG analysis, the embedded system will send the triggering signal to the warning device via wireless transmission.

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5. TABLE I
COMPARISON OF THE BLUETOOTH AND RF3100/3105

Mode	Bluetooth	RF 3100/3105
Frequency band	2.4GHz	915MHz
Transmission distance	10m	200-600m
Transmission direction	Full-Duplex	Half-Duplex
Modulation method	Frequency Shift Keying	Frequency Shift Keying
Transmission Power	0dBm (1mW)	12dBm
Interface	UART、USB	UART

It is expected that the portable biomedical devices should provide more advanced functions such as real-time feedback to the users in addition to online monitoring. Therefore, more complex processing methods have been proposed for physiological analysis, and they will produce more Impacts if can be implemented in a real device or product. A dual-core processing unit is adopted as a platform that EEG signal processing methods as well as the intelligent technology can be implemented on it for different applications due to its powerful

IV. HOST SYSTEM

Host System for Data Storage and Real-Time Display The structure of the host system is shown in Fig.3. The host system has two functions including data storage and real-time EEG signal display. The data size of continuous EEG recordings is beyond the storage capacity of the embedded system. Thus, we have implemented a network file system to store EEG signals. Additionally, we built a graphic user interface (GUI) to show the biomedical signals in real time, the connection between the host system and the embedded system is TCP/IP protocol.

V. WARNING DEVICE

The warning device is combined in our system, as shown in Visual signal and audio signal can be presented to the BCI users as the feedback warning signals. The audio signals are more effective in our prior study for driver drowsiness warning since it is easier to detect audio signals than visual signals for the driver when he/she is drowsy. The efficiency of audio signals with different frequencies, 500, 1750, and 3000 Hz, was tested in the prior study and the audio signal of 1750 Hz achieves the best results. The triggering signals are sending from the dual core EEG signal-processing unit to the warning device through wireless transmission modules. The RF3100/3105 modules are half-duplex, which means that the modules cannot transfer and receive signals at the same time. Since the signals are transmitted as packages, a package of warning signal can be transmitted in the time period between two packages of the acquired EEG signals for transmission. The time period between two packages might be too short for the reverse-direction transmission if the transmission frequency is set too high. To deal with the problem, the transmission frequency is set lower to leave some time duration for the data transmission from the other end.

VI. REAL-TIME DRIVER'S DROWSINESS DETECTION AND WARNING

With combining online EEG recording and wireless transmission ability, the proposed BCI system is designed for real-time physiological signal analysis. Thus, a real-time drowsiness detection method combined with an online warning feedback is implemented in the developed BCI system for demonstration. A dynamic operating environment is also built up to test and verify the robustness of the BCI system. *A. Experiment Environment and Experimental Design* A virtual reality (VR) based highway-driving environment reported in our previous studies [18],

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[19] was used to investigate those changes on drivers' cognitive states in long-hour driving tasks. The VR driving environment includes 3-D surround scenes projected by seven projectors and a real car mounted on a 6-degree-of-freedom Stewart platform to provide the kinesthetic stimuli. The driving speed is fixed at 100 km/h, and the car is randomly and automatically drifted away from the center of the cruising lane to mimic the consequences of a non ideal road surface. The subject was asked to keep the car on the third lane (from left to right). Driving error is defined as the deviation between the middle of the car and the middle of the third lane. While the subject is alert, his/her response time will be short,and deviation of the car will be small; otherwise, the subject's response time will be slow and the car's deviation can be large. After 90 sec moving average, the driving error are then normalized to 0–100. The driving error is related to the driver's response time and is considered as the index of the driver's drowsiness level in this paper. Electrode caps are usually used for EEG signal acquisition inmost of applications. However, the traditional wet electrode requires electrical gel to increase the conductivity between the electrode and the scalp. Thus, it takes time for preparation, and the subjects need to wash their hair after recording. For the convenience in practical applications, we place four dry electrodes [22] on the driver's forehead and distance between two near electrodes is 1.5 cm to acquire the EEG signals for the BCI system. The EEG features related to alertness changes can be extracted from EEG signals acquired by the electrodes at the forehead according to our experiments. Therefore, placing electrode array on the forehead is a feasible and convenient strategy for drivers' drowsiness estimation. Six dry electrodes are used to acquire EEG signals from the driver including five electrodes placed on the subject's forehead and one placed behind the subject's left ear. The five electrodes we placed on subject's forehead including a common ground electrode and four EEG electrodes. The ground electrode is directly connected to the ground of power supply. The EEG signals we used in further analysis are measured between the four EEG electrodes and the reference electrode. The dry electrodes and the sensing module can be embedded in a hat, as shown in Fig. 1. The combination of the dry electrodes and the sensing module has gradually improved the convenience and the future applicability of the developed system. *Data Processing Flow and Analyzing System Design* The analysis procedure implemented in the dual-core signal processing unit is shown in Fig. 6 The acquired EEG signals are first down-sampled to 64 Hz to reduce the calculation loading of the system, and a 64-pt Hanning window is then applied to smooth the signals. The short-time Fourier transform is used to extract the time–frequency characteristics of the EEG signals, and a 90-sec moving average filter is applied to eliminate the noise. We use principal component analysis (PCA) on the EEG power spectrum to reduce the data dimension and the computational loading of the embedded system. The EEG features(dimension = 20) extracted by PCA are then fed into a linear regression model to estimate the driver's drowsiness levels. The EEG signals collected in the first session were used to constructhis/ her drowsiness estimation model including the PCA method through offline training by the PC. The model including the PCA matrix is then load into OMAP 1510 to process and analysis the subject's EEG signals in the other days in online and real-time for testing. The main tasks of the embedded processor OMAP1510 was to process EEG data, wireless receiver control, and TCP/IP control. Thus, we distributed these tasks into DSP core and ARM core to retain satisfied performance. According to characteristics of the processors, the calculation of driving error estimation needed to process a long period of EEG data, so it was implemented in ARM processor. On the other hand, the Hanning windowing and short-time FFT needs heavy computation, and thus is implemented in the DSP core to balance the computation load. The remaining processes were implemented in ARM because they need relatively less computations.

VII. MULTITASK SCHEDULING MECHANISM SYSTEM

A.. Description

Since the proposed BCI system is designed to work in real-time, the signal-receiving task should continue while EEG signal is on processing. An embedded multitask scheduling mechanism system is used to manage these tasks and to ensure the accurate sampling rate for EEG signal acquisition and data process/analysis in real time [21].

The tasks are divided into three types according to their working frequency:

1) task A—wireless device and TCP/IP control;

2) task B—call DSP task and transmit EEG data to IPBUF buffer;

3) task C—receiving data from IPBUF buffer and further processing of the DSP processed data. The time series diagram of the multitask scheduling system is shown in Fig. 4. The working frequency of buffer IPBUF data transmission is much smaller than the working frequency of wireless device and TCP/IP control. Thus, we allowed the system continuously to receive signals from the wireless module and output to the display unit through TCP/IP. The

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system can decide when to process other tasks by itself. With the architecture, the ARM core will not only hold and wait, but also keep transmitting data from the wireless module to the display unit when the DSP core is processing the EEG signals.Interprocess communication (IPC) is also an important issue for our scheduling system since the tasks in our system are not completely independent. In our system, ARM-Linux was used to manage tasks. Linux provides three methods for IPC: message queue, semaphore, and shared memory. Message queue and semaphore are not efficient enough for the proposed embedded system.

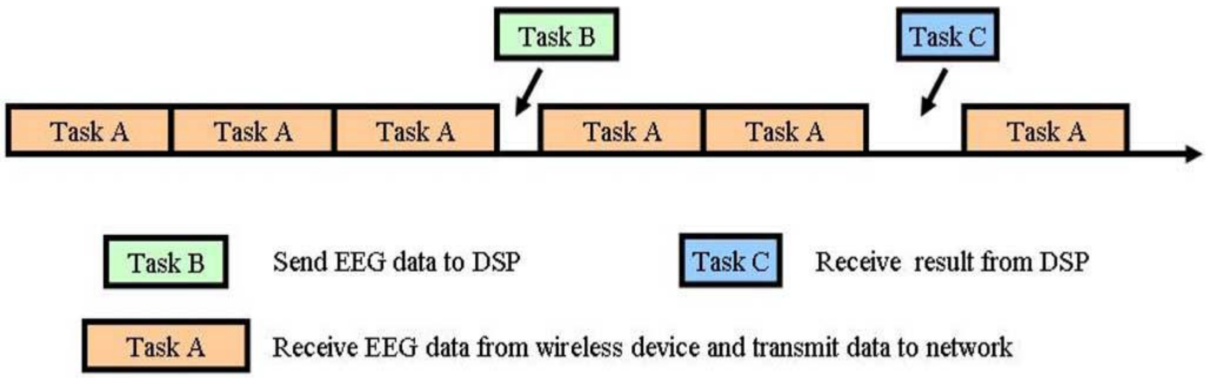

Fig..4. Time series diagram of multitask scheduling mechanism

Three modified communication methods are employed in the proposed BCI system for IPC:
1) A novel synchronization mechanism;
2) Arbitration method
3) Sharing memory buffer (IPBUF) between processing cores.

Traditional, the synchronization procedure is enabled when two tasks are accessing one memory block at the same time. The memory is blocked when one task is writing or reading on it, thus no other task can access to the memory. The synchronization procedure unlocks the blocked memory when the first task finishes writing/reading, and then, sends a signal to inform other waiting tasks. It is obvious that the mechanism can largely decline the processing speed of the processor. A new synchronization mechanism is designed to deal with the simultaneous memory access by both receiving EEG data from EEG acquisition system (task A) and sending EEG data to DSP (task B). When task A is accessing the memory, task B will be idle and waste some time in waiting.

Therefore, we use two blocks of memory with the same size to reduce the waiting time. When task A is storing EEG data on memory M1, task B can get the EEG data from memory M2 at the same time. With the modified procedure, these two tasks can execute concurrently and reduce the waiting time caused by synchronization control. Although the method consumes double memory size to complete the procedure, the required extra memory is less than 4K B. Besides, we use arbitration flag register instead of semaphore due to that the speed of flag register based on shared memory is the fastest IPC method in Linux platform. In addition, using flag register can reduce the amount of memory

VIII. CONCLUSION

A wireless embedded BCI system with real-time bio signal processing ability is proposed in this paper. It consists of a four-channel physiological acquisition and amplification unit, a wireless transmission unit, a dual-core signal-processing unit, a sensing real-signal display and monitoring unit, and a warning device. The EEG signal was first acquired by signal-acquisition and amplification unit, and then, transmitted from wireless data transmitter to wireless data receiver. The wireless-transmitted EEG signals were processed by the data processing unit, and the processed results were further transmitted to the sensing system for data storage, real-time display, or triggering the warning devices by TCP/IP. A multitask scheduling procedure was employed in the dual-core signal-processing unit to

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enhance the efficiency of the embedded system and make sure the BCI system can properly work in real-time. A real-time drowsiness detection method combined with an online warning feedback was also implemented in the developed system for demonstration. This research provides the following important technologies:
1) A sensing module for signal acquisition, amplification, and
Wireless transmission;
2) A dual-core embedded system for real-time
EEG signal processing;
3) An automatic bio-feedback loop for online warning and reminding. With combining all the
technologies, a flexible BCI platform is developed and can be applied to various applications.

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