Brain Computer Interface-Based Smart Living Environmental Auto-Adjustment Control System in UPnP Home Networking

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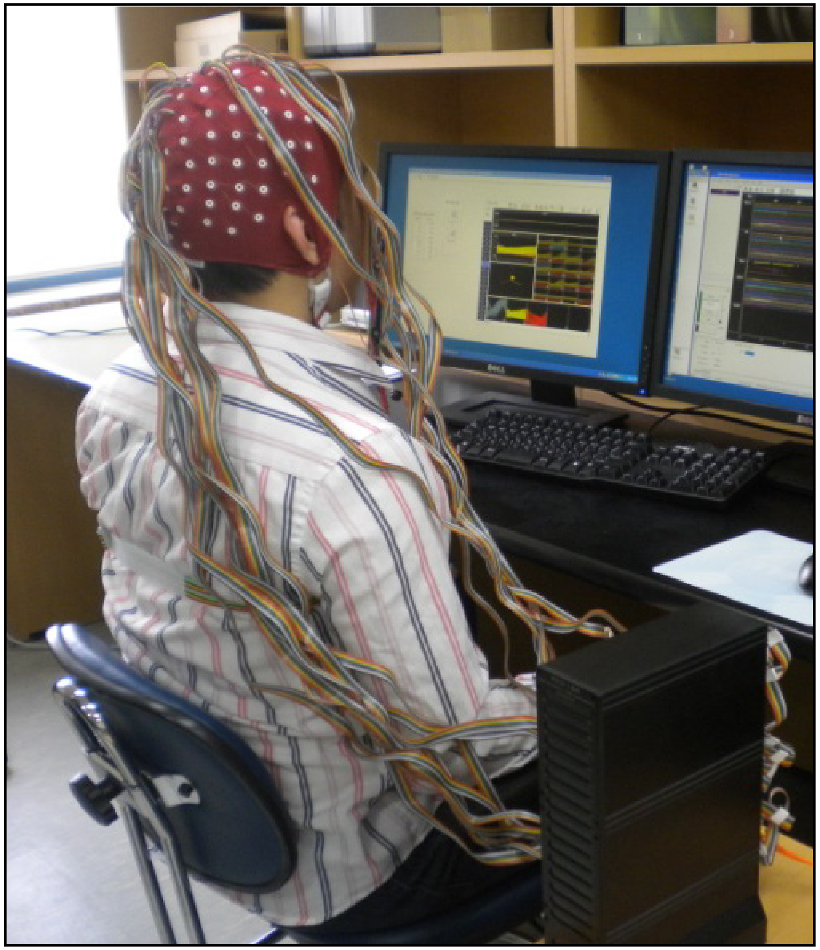
Background

- Wired BCI system



- Wireless BCI system

Introduction

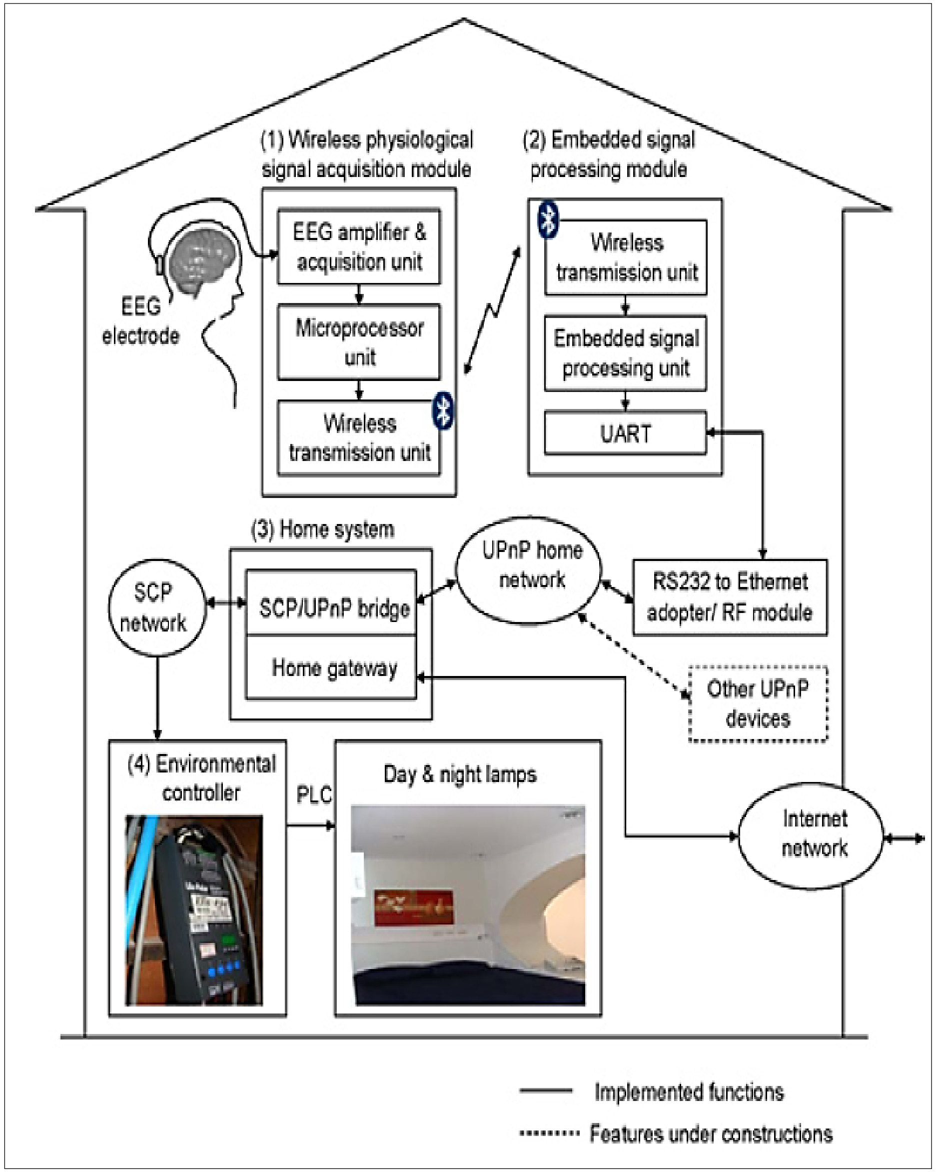
- Recently many studies are trying to develop commercial products to bring the convenience to people in their usual life.
- Some environmental control systems in a smart house employed radio frequency identification (RFID), external sensor modules, and voice recognition as the controlled signals.
- By combining with universal plug and play (UPnP) home networks, users could send out service requests from their personal digital assistant, mobile phones, a wearable appliance, or external sensors to home server, graphic user interface, or motion.
- With the development of BCI, it is an new option to apply the physiological signals as the stimulus of environmental control system in a smart house.
- However, Most of the existing BCI-based environmental control systems require the user's active mental command to control external device.

Introduction

- These systems lack the capability to control devices automatically and adaptively according to the user's current cognitive state.
- Most of current BCI-based environmental control system are inconvenient because bulky and expensive EEG machines and computer are both required for signals acquisition and backend analysis, which will limit the flexibility and portability of these systems.
- The goal of this paper is to propose a cost-effective, simply extendable and easy to use BCI-based smart living environmental auto-adjustment control system (BSLEACS) to control electric home appliances based on the change of user's cognitive state (drowsiness or alertness).
- Their proposed wireless physiological signal acquisition module and embedded signal processing module contain the advantages of small volume and low power consumption, and are more suitable for practical application.

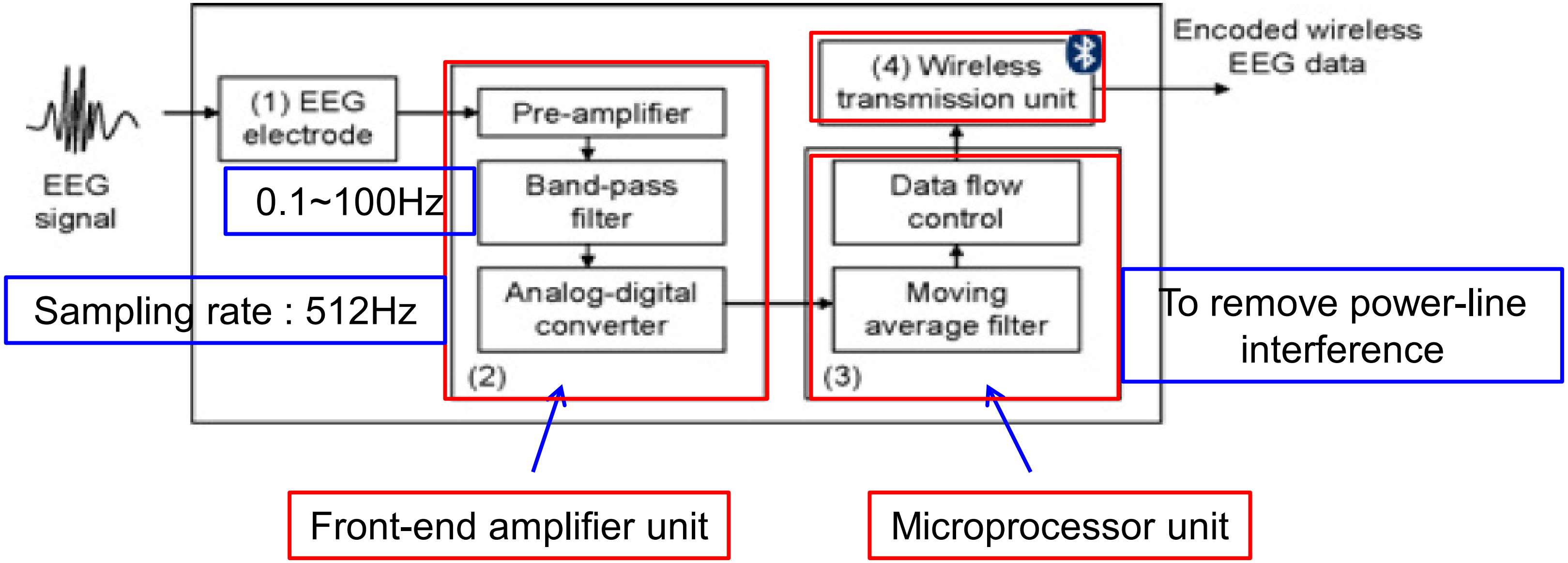
System Architecture

- (1) is designed to acquire and transmit an EEG signal to the embedded signal processing module via Bluetooth.
- (2) is designed to estimate the user's cognitive state from his or her EEG, and provides the estimated cognitive state to the host system.
- (3) is designed for data storage /display, and is also served as an UPnP control point to manage the request from UPnP control device.

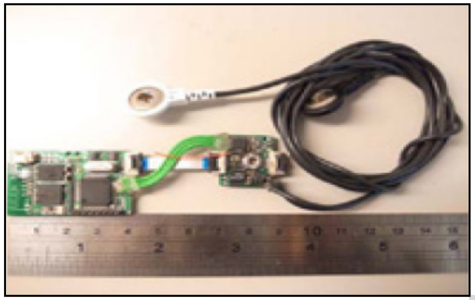


System Architecture

A) Wireless Physiological Signal Acquisition Module

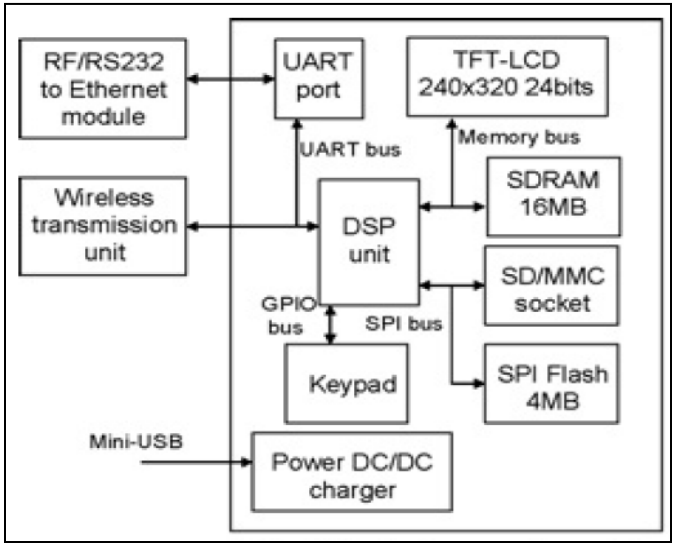


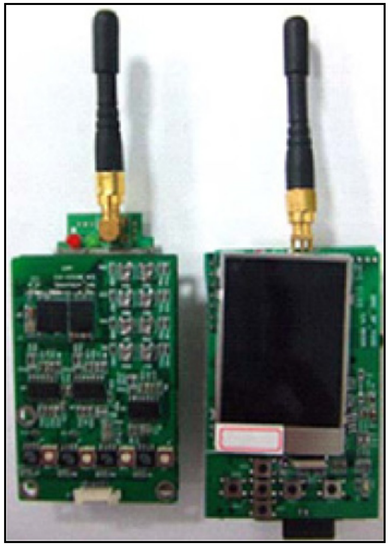
- EEG data digitized by ADC will be stored into memory.
- This module operates at 31 mA with 3.7V DC power supply, and continuously operate over 33 h with a commercial 1100mAh Li-ion batter.
- The volume is about 4 cm * 2.5 cm * 0.6 cm.



System Architecture

B) Embedded Signal Processing Module





3.7V DC power

Over 45 h

6.4cm*4.4cm*1cm

- This module contains a powerful computation capability and can support various peripheral interface.
- This module is developed to perform the real-time cognitive state detection algorithm.
- This module is also evaluated as the UPnP control device to send out the estimated cognitive state and EEG signal to host system to drive environmental controller via UPnP home networking.

System Architecture

B) Embedded Signal Processing Module

- The received EEG data will be real-time processed, analyzed and displayed by the embedded signal processing module.
- When the change of cognitive state of the user is detected, the corresponding command will be transmitted either by RF module or by Ethernet through UPnP.

C) Host System and Environmental Controller

- The host system is an UPnP/SCP bridge and is also served as the home gateway to internet network.
- A SCP-based environmental controller with four-channel AC/DC power line control output is used to control home equipment.
- The SCP-based environmental controller is used to control the day and night lamps in the showroom.

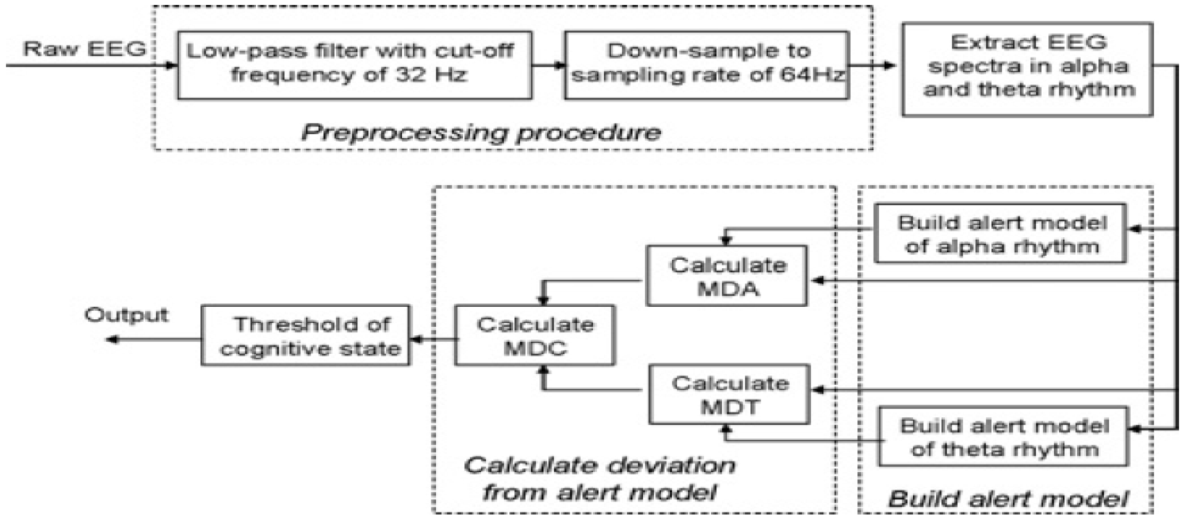
Methods

A) Real-Time Cognitive state Detection

- When alert person is becoming drowsy, his or her EEG power in both theta and alpha rhythms will increase.
- If the subject remains alert, his or her EEG spectra in theta and alpha rhythms should match the alert model. Otherwise, his or her EEG spectra will diverge from the alert model if the subject is under drowsy state.
- They observe that the alpha and theta rhythm of EEG spectra in the occipital midline (the location Oz in the international 10-20 EEG system) can provide discriminating power and they have high correlation with cognitive state.
- A single EEG channel is used in their system to monitor EEG signal in the occipital midline.

Methods

A) Real-Time Cognitive state Detection



- A 512-point FFT with 448-point overlap is used to obtain the EEG spectra, and then the EEG spectra in alpha and theta rhythms are extracted to build up the alert model.
- A new alert model will be constructed separately.
- The distribution of power spectrum in the alert state can be modeled by a multivariate normal distribution $N(\mu, \Sigma^2)$. μ : mean vector

Σ^2: variance-covariance

Methods

A) Real-Time Cognitive state Detection

- (μ_A, Σ_A^2): alpha rhythms, (μ_T, Σ_T^2): theta rhythms.
- After building the alert mode, the Mahalanobis distance from the alert mode of the alert mode of alpha rhythm (MDA) and that of theta rhythm (MDT) will be calculated.
- Mahalanobis distance is a distance measure based on correlations between variables by which different patterns can be identified and analyzed. It takes into account the correlations of the data set and is scale-invariant.

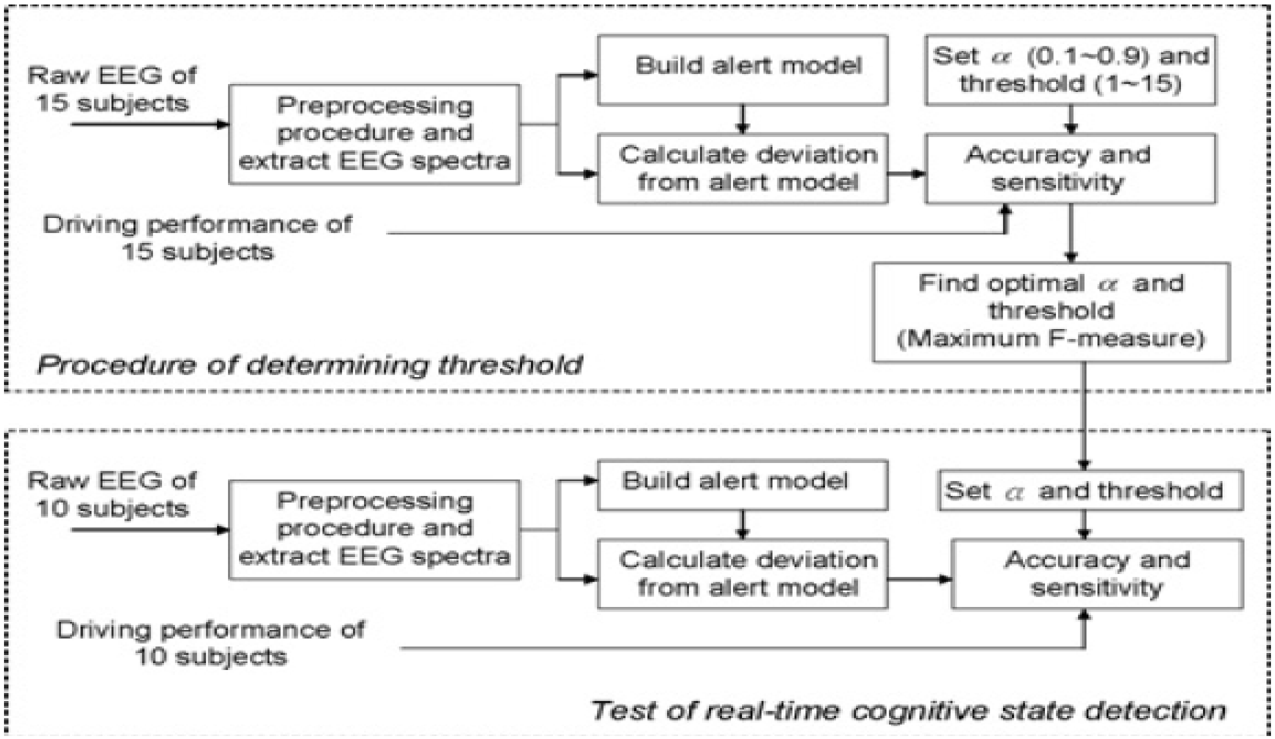
$$MDA(x_A) = \sqrt{(x_A - \mu_A)^T (\Sigma_A^2)^{-1} \left(x_A - \mu_A\right)} \quad , MDT(x_T) = \sqrt{(x_T - \mu_T)^T (\Sigma_T^2)^{-1} \left(x_T - \mu_T\right)}$$

$$MDC = \alpha \times MDA + (1-\alpha) \times MDA, 0 \le \alpha \le 1$$

- They use the linear combination MDC of MDT and MDA to estimate the user's cognitive state.
- If the value of MDC is larger than the threshold, the subject can be treated as his or her cognitive state trends to drowsy state; otherwise, it trends to alert state.

Methods

B) Performance Evaluation



- F-measure, the harmonic mean of precision [positive predictive value (PPV)] and recall (sensitivity), is used to find out the threshold of Mahalanobis distance to decide the cognitive state.

$$F = 2 \times \frac{precision \times recall}{precision + recall}$$

Results

A) Performance of BSLEACS for cognitive state Detection

Subject	F-measure (%)	PPV (%)	Sensitivity (%)
1	77.7	75.5	80
2	72.2	78.8	66.7
3	89.1	80.4	100
4	87.5	77.8	100
5	87.4	77.6	100
6	88.9	80	100
7	83.5	78.7	88.9
8	81.1	77.9	84.6
9	66.1	65.5	66.7
10	86.8	76.6	100
Average	82	76.9	88.7

- A total of 1370-trial response time and Mahalanobis distances from 15 subject were analyzed to determine the maximum F-measure value. $(\alpha = 0.1 - 0.9, threshod = 1 - 15)$
- The maximum value 77.6% of F-measure (PPV=69.2% & sensitivity = 88.3%) was determined with $(\alpha = 0.9, threshod = 7.5)$
- 1000-trial response times and Mahalanobis distances from ten subjects for testing session were used to test the performance of this system.

Results

B) Performance of BSLEACS for controlling Home Application

- BSLEACS is used to control day and night lamps.
- Criterion 1) when the trend of cognitive state is alert, the major day lamp is on and the night lamp is off.
- Criterion 2) when the trend of cognitive state is drowsy, the major day lamp is off and the night lamp is on.
- A total of 75-trial system responses and questionnaire results from 15 subjects were cross referenced and analyzed.
- The F-measure of system control performance is 75.27% (PPV = 70% & sensitivity = 81.4%).<effectively control home appliance>

		System Control Output	
		Control Criterion 1	Control Criterion 2
Cognitive state (questionnaire)	Drowsy	8 (FN)	35 (TP)
	Alert	17 (TN)	15 (FP)

Conclusion

- In this paper, they proposed a BCI-based smart living environmental auto-adjustment control system (BSLEACS).
- BSLEACS only needs single EEG channel to recognize cognitive state by monitoring EEG signal in the location of Oz.
- BSLEACS has been verified in a practical environment and shows that the light/lamp can be adjusted in real time based on the change of the user's cognitive state.
- BSLEACS provides a system prototype for environmental control, and can be generalized for other applications and constructed in an UPnP-based smart house.

Thank you!