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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (21): 5999-6004, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.5999.6004

Design and Implementation of Human-machine Interface Oriented to Space Service Robot

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Abstract: Electroencephalogram (EEG) and electromyography (EMG) are used to control manipulator in human-machine interface. Steady-state Visual Evoked Potentials (SSVEP) in EEG and common EMG coding are the control of information for detail tasks. Experiments under the simulated space environment are done to test the reliability of manipulator controlling in key operation on a panel.

Key words: Electroencephalogram, electromyography, manipulator, human-machine interface, SSVEP, space

INTRODUCTION

It is essential for training astronauts to control manipulators or communicate with robots in the space. Thanks to the technology of brain-machine interface (BCI) (Faust *et al*., 2010; Yang *et al*., 2010; Yang *et al*., 2009; Kramer *et al*., 2007; Sherman *et al*., 2011; Acharya *et al*., 2011), it enables astronauts to control the machine through their minds. The most representative research in this field is G. Pfurtschellers' series of study based on Events Related Potential (ERP) of BCI system, which realized two representative brain-machine interface systems named Graz I and Graz II.

In this study, EEG and EMG based human-machine interface are developed and tested. There are differences in controlling objectives between EEG and EMG. The Steady State Visual Evoked Potential (SSVEP) is the stimulus paradigm in the use of EEG and simple coding of bits based on the recognition of EMG is applied. Two sets of signal regulation circuit are designed to sample weak EEG and EMG from human being's skin surface (Yang *et al*., 2010; Sherman *et al*., 2011). Digital signal processor is used to process EEG by embedded Fast Fourier Transform (FFT) algorithm and EMG by Energy Distribution (ED) algorithm. As FFT demonstrates the frequency spectrum of EEG, it is used to extract the characteristics of SSVEP. ED extracts the characteristics of muscular EMG by the difference of energy when specific action of muscle takes place or not.

Differential control instructions are formed to control the movement or operation of a robot (Acharya *et al*., 2011; Osterhage *et al*., 2007). In our work, we focus on the operation of buttons on a panel. EEG and EMG patterns based human-machine interface have achieved the following objects. With specific instruction, the manipulator selects the corresponding button and controls it. In order to mark the processing of the above operation, speech recognition function based on several fixed Chinese vocabulary is added to the device to packet the whole instruction series. Under the simulated space environmental condition, Basic tests of SSVEP and manipulator control experiments are included in this study.

CONFIGURATION

The multi-mode human-computer interface includes five parts: the developed device for signal acquisition and processing, the steady-state visual stimulator, wireless data transmission module, robot and its control system, cameras and video transmission equipment.

The developed device completes the data acquisition of EEG and EMG. The algorithm solidified in the device realizes the characteristic extraction of EEG and EMG. The output instructions are the subject's control ideas. The device structure as Fig. 1 shows.

MCU: As Fig. 2 shows, there are two boards ,one is signal modulation module (board I) including weak signal modulation, multi-channel selector and analog to digital converter (ADC) .The other is digital processing module (board II). There are two processors in the developed digital processing module. Digital Signal Processor (DSP) of TMS320LF2812 is applied to deal with the EEG and EMG acquisition and processing. Micro-controller Unit (MCU) of SPCE061B runs with the algorithm of speech recognition. Speech recording and recognition algorithms are embedded directly through SPCE061B. DSP reserves

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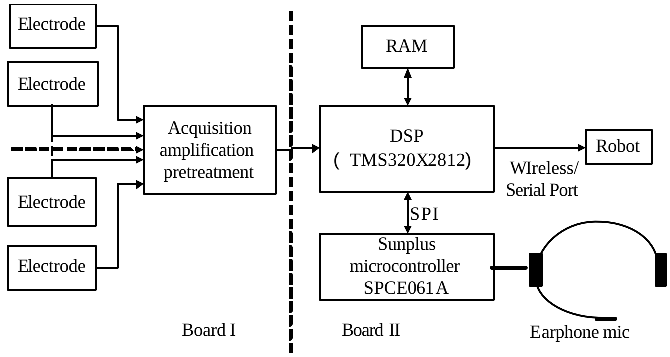

Fig.1: Device structure

Fig. 2: Picture of device

Fig.3: EEG and EMG electrodes

two channels of RS-232 communication interfaces, in which one accomplishes the communication between the device and the robot and the others ensure data sharing with other equipments or Personal Computer (PC).The interact between two processors via Serial Peripheral Interface (SPI).

The design of hardware on board I is based on the characteristics of EEG and EMG and the requirements of signal processing. AD976 with 16 bits resolution is the selected for ADC. Although only one channel with three wires is used in EEG and EMG application, respectively, the device reserves 8-channel detection for further application. If one chip of AD976 is used in each channel, the volume of the device will increase. Also the power consumption and the cost of circuits steep rise. Multi-channel selector CD74HCT4067 is used to make the channels share one ADC. Because EEG and EMG are weak signal, the signal modulator is designed by amplifier circuits with high-precision, strong anti-jamming ability. The amplitude of EEG sampled from surface of a normal human being's brain ranges from 5 to 200 μV, but the potential of cerebral cortex may steep to 1 mV. The frequency of EEG varies from 1 to 100 Hz. EEG amplifier circuit with floating ground tracking technology is shielded to reduce electromagnetic interference. Common-Code Rejection Ratio (CMRR) of the amplifier is about 110 dB and the input impedance is about 1000 MΩ per channel. The main requirement of the amplifier is to overcome poor signal disturbances which caused by resistance of electrons touching the skin. Notch filter for 50 Hz signal, reduces power line's interference. The integrated circuits of amplifiers with low noising for biological signal modulation and the high qualified low pass filter, safeguard the whole device of outstanding performance (Fig. 3).

Difference in magnitude of EMG caused by different physical condition of persons different position of the body. In our work, the EMG is sampled from the forearm. Different EMG is generated through pressing forearm muscles when different action of the wrist takes place. The amplitude ranges from 20 to 200 mV and the frequency ranges from 30 to 400 Hz.The design of EMG amplifier is similar with the EEG amplifier circuit. Only the filter pass band is adjusted.

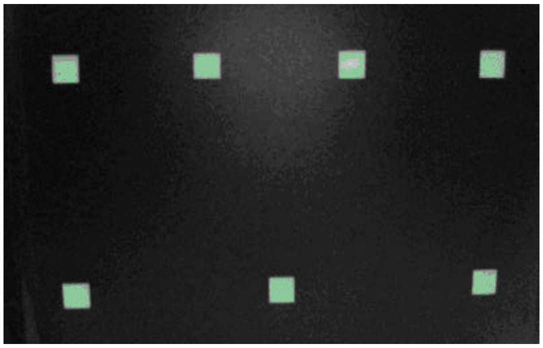

Fig. 4: Panel of steady-state visual stimulation

Steady-state visual stimulator: The panel is consisted of seven different white flash square of 1.5*1.5 cm 2 in black background. As Fig. 4 shows,these flashing blocks can be set by developed devices with different flashing frequency. Flash module is composed by LED highlighted lamp, which is covered by flat acrylic board. LED brightness is reduced by the semitransparent board and the light gets blur. The white LED light scattering from square panel, can effectively stimulate subjects to induce SSVEP.

Wireless data transmission: The control instructions are transmitted to control system of robot through wireless network. Wireless data transmission modules formed by wireless transmitter and receiver following IEEE 802.11b protocol named Wireless Fidelity (WIFI). Two computers are connected to wireless router respectively to establish the data route between the device and the robot control system. The device is connected to wireless data transmitter through RS-232 interface and the wireless data receiver is connected to the control system of robot by RS-232.

Robot and manipulator: Cyton Alpha 7D 1G is used as the manipulator.

Video transmission equipment: The camera, video card and desktop computer ensure the real-time video display of manipulator's operating in front of the panel. Subject can observe whether his issued instructions is right or not by watching video which forms the simple feedback.

DESIGN OF EXPERIMENTS AND DATA ANALYSIS

Basic test of SSVEP: Basic test is based on the EEG data acquisition and analysis. The test is used to work out the scheme for robot and manipulator control. 10 subjects attended the test.

The subject wearing EEG electrodes lies on the bed with angle of inclination of -6° which is usually used in space simulated testing. The bed can be adjusted in angle of inclination. The visual stimulation panel is fixed on a bracket which is located above the eyes of the subject by about 40 cm. The detail location should be adjusted to make the subject feel comfortable. The frequency of each flash block is preset. In each test, the subject closes his or her eyes and has a rest for about 30 sec. Then he or she gazes at the designated flash block for 60 seconds. The EEG is sampled and recorded by the developed devices. When the subject was having a rest, the EEG data can be transported to laptop computer for further analysis.

The EEG is processed by FFT toolbox and Autoregressive Power Spectrum (ARPS) analysis toolbox of MATLAB in computer. The Frequency Spectrum (FS) and ARPS of the subject is shown as Fig. 5. FS shows the aliasing in evoked frequency and the surrounding. The more the FS of evoked frequency is outstanding with regard to the surrounding, the better the feature of the EEG is extracted. ARPS overcomes the frequency aliasing to some extent and picture the difference between the evoked frequency and the surrounding. ARPS also helps to distinguish the better evoked frequency from the others. The results help to select more effective frequency for SSVEP analysis.

As the FS and ARPS of EEG from the subject shows, there is not obvious difference in the EEG characteristics identification among the male and female subjects. When the frequency is higher than 20 Hz, it is not clear enough to distinguish outstanding frequency based on FS and ARPS because of the overlap. The ideal frequency of the steady-state visual stimulator is between 12 to 18 Hz. Therefore 12, 15 and 18 Hz are selected in this experiment.

Define the crowding distance: In the robot and manipulator control experiments, the robot runs from different position in the same room. Then the manipulator control tasks based on EEG and EMG by conducting button pressing, releasing. The experiment requires a subject and an assistant instructor. Subjects and robots in different rooms were shown as Fig. 1. The subject lies on the bed with angle of inclination of -6°.

In an experiment, the robot starts to run to the position in front of the panel without control. Then, the subject controls the manipulator to push or release a key on the panel by EEG and EMG. Assistant instructors set frequency of each flash block on the steady-state visual stimulator and memorize the relation between the flash block position and the detail buttons on the operation panel. After having a rest for 30 sec, subjects were issued voice commands "start".

The assistant instructor wears earphones, send order to the subject. One flash block is selected according to the related control task such as the designated button. The subject closes the eyes and has a rest for 30 sec. After subject is issued voice commands "start" by the assistant instructor, the subject must carefully gazes at the designated flash block for 10 sec. The assistant instructor observes the manipulator by real-time video which camera is installed in the room of robot to see if the operation on the panel is correct or not.

We select 12, 15 and 18 Hz to be the final frequency to stimulus SSVEP from the subject. As the algorithm is running in DSP, EEG is analyzed only by FFT. The frequency (12, 15 or 18 Hz) related to maximum in the frequency spectrum is the result of EEG feature extraction.

There are 10 subjects attending the experiment and 900 tests. The results of the experiments are divided into two groups, in which one is the accuracy of EEG feature extraction and the other is the accuracy of robot operation after feature extraction is obtained. Table 1 is the result of the experiments in feature extraction. "Sn" stands for "subject serial number.", "Cn" stands for "number of the correct results", "Ac" stands for "accuracy rate". There are 837 groups of data which forms the right command for button operation. The accuracy is 93%.

Only after the correct command based on EEG feature extraction is transmitted to the robot, the operation on buttons is executed. The number of right robot operation on buttons is 776. The accuracy rate is 92.7% with regard to 837 right commands and is 86.2% with regard to 900 tests.

In EMG experiment, the subject's arm wears EMG electrode and lies on test bed. Assistant instructor wears earphones and sends order. The order is the action of the wrist which is related to the button operation on the panel. The subject closes the eyes and has a rest for 10 sec. After assistant instructor says "start", the subject must pull the wrist once per second to produce the

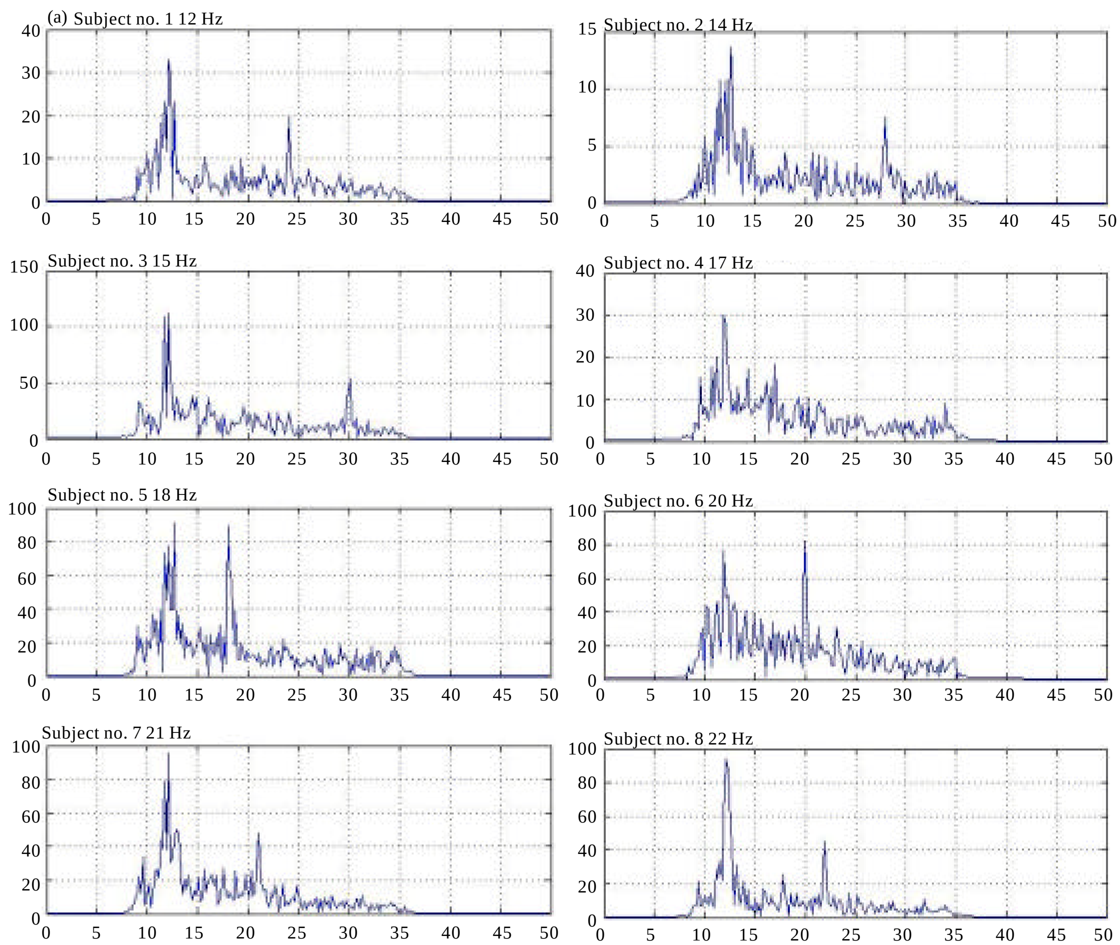

Fig. 5(a-b): Continue

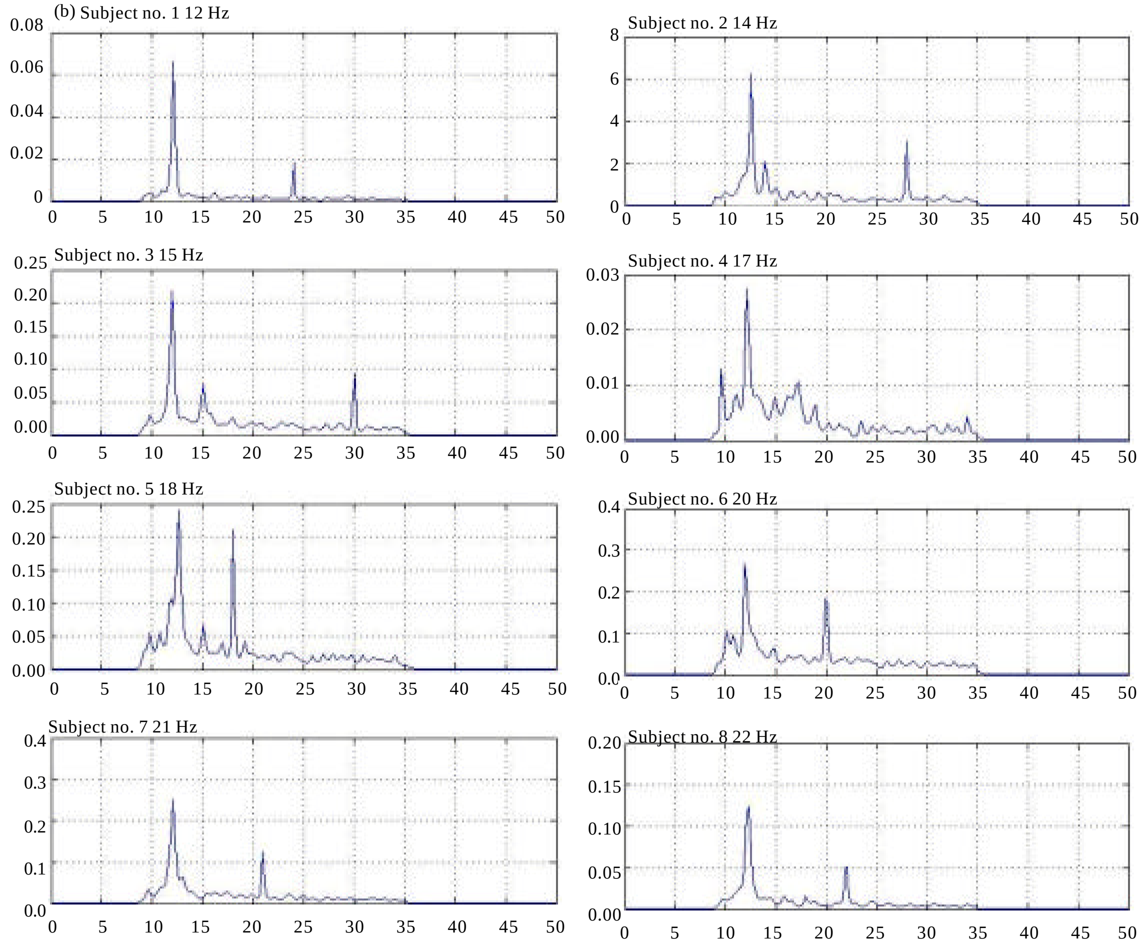

Fig. 5(a-b): (a) FS of EEG Subject No.10 and (b) ARPS of EEG Subject No.10

Table 1: Results of EEG feature extraction

	12 Hz		15 Hz		18 Hz	
Sn	Cn	Ac (%)	Cn	Ac (%)	Cn	Ac (%)
1	30	100.0	29	96.7	27	90.0
2	27	90.0	27	90.0	28	93.3
3	29	96.7	29	96.7	28	93.3
4	28	93.3	26	86.7	29	96.7
5	29	96.7	28	93.3	27	90.0
6	27	90.0	27	90.0	26	86.7
7	28	93.3	28	93.3	28	93.3
8	30	100.0	29	96.7	27	90.0
9	29	96.7	28	93.3	27	90.0
10	28	93.3	28	93.3	26	86.7

command. The assistant instructor observes the manipulator by real-time video to see if the operation on the panel is correct or not.

As the above describes, the way of EMG bits is used to be the instructions. By calculating the energy of EMG, if the value is more than the threshold, it is regarded as digital signal “1”, otherwise, it is regarded as “0”. To ensure the reliability of command output, different buttons are selected respectively. The series of “1”,“11”,“111” and “1111”are the final operating instructions. There are 10 subjects attending the experiment, in which 5 are males aged 20-28 (subject No. 1, 3, 5, 7, 9) and 2 are females aged 20-26 (subject No. 2, 4, 6, 8, 10). Each subject has 30 tests at every EMG series (“1”,“11”,“111” and “1111”).

There are 1200 groups of data.1102 groups of data are correct. The test result as Table 2 shows. The accuracy is 91.8%. 564 groups from male subjects and 538 groups from the female subjects are correct. Male subjects have obvious advantage over female subjects in EMG characteristic extraction by 94.0 to 89.7%.Table 2 is the results of EMG analysis. “Sn” stands for “subject serial number.”, “Cn” stands for “number of the correct results”, “Ac” stands for “accuracy rate”.

Only after the correct command based on EMG bit sis transmitted to the manipulator, the operation on buttons

Table 2: EMG analysis results

	1		11		111		1111	
Sn	Cn	Ac (%)	Cn	Ac (%)	Cn	Ac (%)	Cn	Ac (%)
1	30	100	29	97	28	93	28	93
2	28	93	28	93	29	97	29	97
3	29	97	27	90	26	87	25	83
4	28	93	26	87	25	83	25	83
5	30	100	28	93	27	90	27	90
6	29	97	28	93	26	87	26	87
7	30	100	29	97	29	97	28	93
8	29	97	27	90	26	87	24	80
9	29	97	30	100	28	93	27	90
10	27	90	27	90	26	87	25	83

is executed. The number of right robot operation on buttons is 997. The accuracy rate is 90.5% with regard to 1102 right commands and is 83.1% with regard to 1200 tests.

CONCLUSION

The human-machine interface oriented to space service robot can accurately sample EEG and EMG with low noise. The designed algorithm can simply and efficiently extract SSVEP and EMG energy which are the characteristics for controlling the manipulator. It is a good taste in lab for the aerospace applications in the future.

ACKNOWLEDGMENTS

This study is supported by the National Natural Science Foundation of China (61178081), China Postdoctoral Science Fund (20090460501), Strategic Emerging Industry Project of CAS (2060303) and Science and Technology fund of Tianjin University of Technology and Education (YJS10-05, KJY11-08).

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