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Bimodal-Shared Control Interface for Assisted Mobility Application

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ABSTRACT- The paper presents (Electro-oculography) EOG- (Electroencephalography) EEG- Radio Frequency Identification (RFID) based Bimodal-Shared Control Interface for mobility assistance application by controlling a mobile robotic arm. EOG-EEG based bio-signal based bimodal interface has been used to move the robot following a predefined path to reach at an object placed at initial predefined position (Zone 1). RFID has been used as shared control interface for object identification and for sending trigger signal to gripper arm to pick the object and place it at another predefined position (Zone 2) automatically. A threshold based algorithm has been developed for horizontal eye movement (HEOG) detection. Minimum Energy Combination (MEC) method has been used to recognize the Steady State Visual Evoked Potential (SSVEP) brain pattern of EEG. Combining shared control with bio-signal based bimodal system has improved the classification accuracy and increased the number of commands without giving extra effort by user. This reduces the chances of fatigue in users due to continuously performing the same task. Classification accuracy and Information Transfer Rate (ITR) have been calculated as performance parameters and compared with previous literatures for evaluation.

Keywords: Shared control, EEG, EOG, MMI, Bimodal, Robot Control, RFID, SSVEP.

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1. INTRODUCTION

A bimodal Man Machine Interface (MMI) system can be a combination of two systems that may be independent or dependent on each other. The mono-modal systems can be EOG [1], EMG [2], EEG [3], etc. if a bio-signal-based bimodal interface has to be designed. Combining modalities in MMI systems give us an opportunity to choose separate modalities for distinct tasks which makes the system more flexible and independent that provides more functionality, and a higher number of control commands. In a bimodal MMI system, users need not do the same operations continuously, results less mental and physical demands and consequently less fatigue for users. It makes the system less complex and more efficient [4]. There can be a massive opportunity for combining more modalities to make a bimodal system for more intense applications in different areas [5]. However, the increase of control signals in any bio-signal based MMI systems whether it is single modal or bimodal may create fatigue and exhaustion in users and results in the incapability for real-time control applications.

Further increase in the number of control commands and robustness of the system without causing more fatigue in users can be achieved by incorporating shared control technology [6]. When total control task for an application is shared between two or more control techniques, the approach is called as shared control approach. RFID technology has been combined with EOG interface earlier as a shared control approach [7]. RFID technology is very useful for tracking and object identification applications.

In the present work, an EOG-SSVEP-RFID- Bimodal Shared Control Interface has been developed to control the movements of a prototype robot and to perform a pick/place application. The proposed model has two interfaces: *(a)* EOG-EEG based bimodal interface, and *(b)* RFID interface. Both interfaces have been combined to develop a shared control interface.

2. MATERIALS AND METHODS

The experimental procedure for designing EOG-SSVEP-RFID based bimodal and shared control interface model has been described in this section. The algorithm used for the smooth switching between EEG interface and EOG interface to develop a bimodal interface has been described. The RFID based shared control interface for object identification has also been discussed.

2.1 Data Acquisition

EEG (SSVEP) and EOG bio-signals had been recorded from nine participants (aged betwixt 20 and 35 years), healthy and having normal and corrected to normal vision both using *g.USBamp* (a bio-signal amplifier provided by g.tec) with active Ag/AgCl wet electrodes. The impedance on the electrodes were kept below 5kΩ using conducting gel. The sampling rate has

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been chosen as 256Hz. For pre-processing, a bandpass filter (cut off frequencies 0.5–30Hz) removes the effect of baseline drift and eliminates high-frequency noise. Horizontal EOG signals were acquired using one electrode placed on left side of the eye and EEG (SSVEP) signals were acquired from positions ‘O1’, ‘O2’, and ‘Oz’ (in the left, and right cerebral hemispheres and on the central line respectively), on the scalp as per the international 10-20 system [8]. Common ground and common reference electrodes were on the forehead at Fpz position and on the right earlobe respectively.

While acquiring the horizontal EOG (HEOG) signal, the user has to move his/her eyes in horizontal left and right directions alternatively and without blinking. To acquire the EEG signal, users were sitting on a chair comfortably keeping *g.SSVEPbox* (Stimulating device provided by *g.tec* having four LEDs flickering at four different frequencies) in hand. They were instructed to fixate on all four LEDs one by one flickering at frequencies 10Hz, 11Hz, 12Hz, and 13Hz for 7s each sequentially with 2s rest in between. The acquired data has been sent to the PC via USB for feature extraction and classification. A multi-threshold-based algorithm has been developed to distinguish two HEOG signals and minimum energy combination with Linear Discriminant Analysis (LDA) classifier has been used to classify SSVEP signal.

Figure 1: Application Session for SSVEP Experimentation

Figure 1 shows the application session for SSVEP experimentation. Each detected frequency corresponds to a direction for robot movement. The volunteers have been informed about the experiment as well as the data acquisition procedure and consent has been taken before taking their data. The data recording and all other processing steps of the present experiment were performed in the laboratory at National Institute of Technical Teacher’s Training and Research, Chandigarh, India.

2.2 EEG-EOG-based Multimodal Interface

The EEG interface or EOG interface does not impact physical fatigue on the user if used for a short period. However, constantly looking at LEDs flashing at different frequencies or continuously moving eyeballs in different directions can create exhaustion and can affect the performance of the system. Combining EOG and EEG single modalities to develop EEG-EOG-based bimodal interface model may compensate for individual limitations and complement each other. Despite the fact that EOG is very easy to detect and simple to combine with EEG, the number of studies combining EEG and EOG is very less and gives opportunity to explore more in this field.

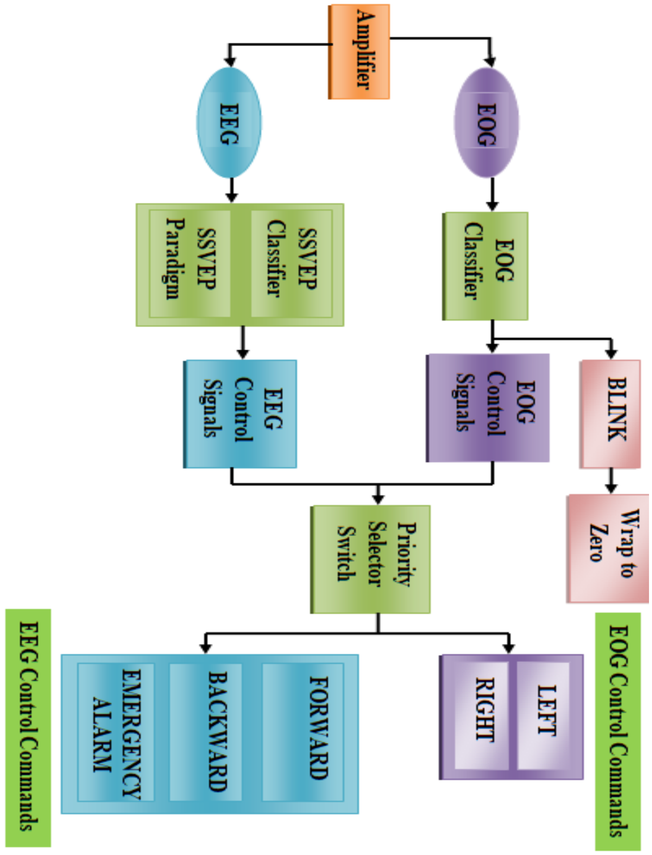

Figure 2: Block Diagram of EOG/SSVEP based Bimodal Interface

An EEG-EOG-based bimodal interface model has been developed in Simulink environment. *Figure 2* shows the block diagram of EOG/EEG-bimodal interface system described in the present section. It operates in two modes. EOG mode is responsible for robot movement in right/ left directions. EEG mode is used to move the robot in forward and backward directions. EEG mode was also used to ring an emergency alarm. Class 1 of EEG interface was not trained properly and consequently not shown good accuracy as compared to other three classes. Henceforth, class 1 was not found suitable for further application and omitted in bimodal interface and the threshold value for switching between two modes was chosen accordingly. The total control commands was five in bimodal interface, two from EOG interface and three from EEG interface. In EEG mode, the EOG mode is inactive. Similarly, EEG is inactive in EOG mode. However, the system continuously detects EEG signals for the reason that a predetermined EEG control signal is used to switch between two modes synchronously as per the requirement.

The flowchart for the proposed bimodal interface system and conditions for smooth synchronous switching between two modes has been shown in *figure 3*.

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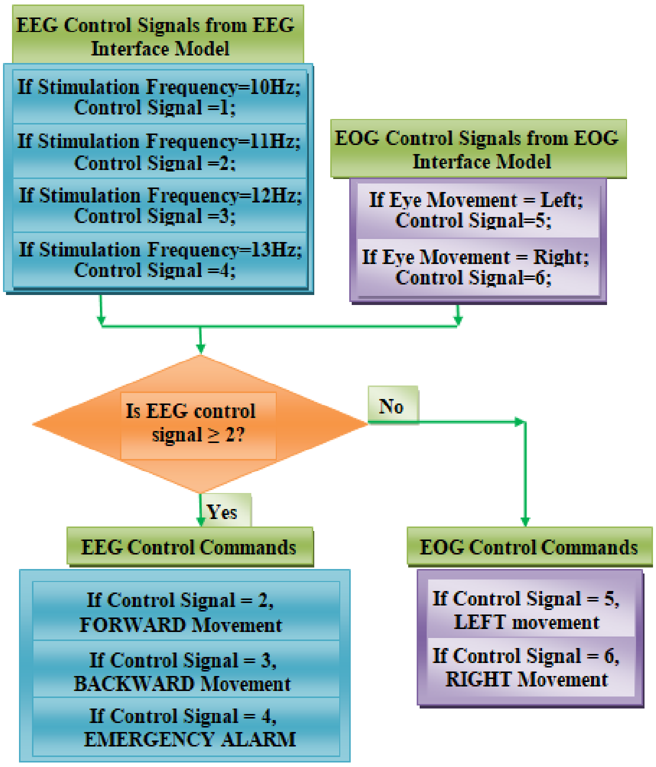

Figure 3: Flowchart for EEG-EOG Bimodal Interface System

2.3 EOG-SSVEP-RFID-Bimodal Shared Control Interface

A bimodal shared control interface by combining EOG-SSVEP and RFID has been developed to control a mobile prototype robot (described in section 2.3.1) for a real-time application. The EEG-EOG-bimodal interface controls the movement of the robot as explained in section 2.2. An RFID Reader MFRC522 Module identifies the object and helps in performing pick/place application task with the help of Arduino controller.

The operating frequency of the RFID Reader module is 13.56MHz and maximum data transfer speed is 10Mbps. Its read range is approximately 50mm from the tag. It is a low-cost chip-based board. RFID 1K Key Fob tag is used in this work which requires a 3.3V power supply. It can be directly connected with Arduino through an appropriate pin connection.

2.3.1 Prototype Robot Design, Development and Operation

A prototype robot has been designed and developed in the laboratory of the Electrical Engineering department at National Institute of Technical Teacher's Training and Research, Chandigarh, India. Arduino Uno has been used to establish an interface between Simulink and the robot. A lightweight gripper arm is attached as the end-effector of the robot. Two DC motors are used for robot movement and servo motors are for gripper control. Other different parts used in the robot are a DC motor driver, two chargeable batteries for power supply, a gripper arm, a robot body, connecting wires, a USB connector to connect with the CPU, LED to indicate that object has been identified, an alarm to indicate emergency call by the patient. A switch is used to 'ON' the robot and to connect it to the computer. The MFRC522 RFID reader is placed with gripper arm to read information stored in the tag attached to the object. Based on the information gathered, the gripper arm either picks the object and places it at a predefined zone or gives a warning alarm to indicate the wrong object.

2.3.2 Application Description

To validate and test the proposed bimodal-shared control model, an assistive application to pick and place a daily object (in this case, an empty glass), has been developed that may be useful for persons with motor disabilities. The assistive application has been tested with the developed prototype robot. Each session takes less than an hour to complete the application tests, including the EEG interface and EOG interface validation. Validated before the final test, the EOG interface showed 100% success rate for all users and EEG interface showed around 90% success rate. Rest 10% corresponds to either classification error. The glass is needed to be picked from zone 2 and placed in predefined Zone 1. The complete application process has been shown in *figure 4*.

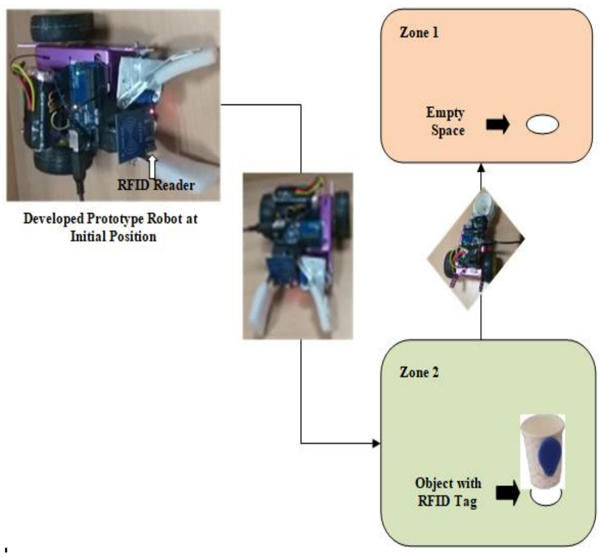

Figure 4: Complete Application Process

2.3.3 Control protocol

The movement of prototype robot and the assistive application for performing pick/place operation was controlled by the proposed Bimodal-Shared Control Interface model. It has two control modes: Bimodal control mode is executed in Simulink environment and shared control mode is executed at distant surroundings through RFID and Arduino Controller. The control protocol has been described as follows:

(i) The prototype robot is switched-on to connect it to the PC and place it at the initial position.
(ii) The Bimodal Interface controls the robot movement in four directions and generates an emergency signal if called by user, following the flowchart given in *figure 1*.
(iii) The robot follows a predefined path and reaches near the object placed in zone 1. The path has been predefined using Simulink State Flow Chart.

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(iv) The RFID reader continuously looks for the tag ID. When the object with prewritten tag ID comes in the range of RFID reader, a feedback signal has been sent to user by an indicating LED to acknowledge that the object has been identified.
(v) After object identification, a signal is sent to the servo motors controlling the gripper arm and the robot will automatically pick up the object from Zone 2, and place it in Zone 1.

If tag is not identified, a buzzer will ring to give audio feedback to the user for the same.

3. APPLICATION RESULTS AND DISCUSSION

In the present work, the classification accuracy and Information Transfer Rate (ITR) has been chosen as performance evaluating parameters and calculated for EEG-EOG-Bimodal Interface and EOG-EEG-RFID Bimodal-Shared Control Interface and compared with each other. The classification accuracy and ITRs are commonly used as evaluating measurement for BCIs. Task speed time has also been calculated for evaluating the Bimodal-Shared Control model. [9]. The classification accuracy is defined as the ratio of true classes Vs total classes Task speed is the total time to complete the application task. ITR denotes the total information transferred per unit time [bits/min] and can be calculated by Wolpaw et al. [10].

(a) Performance of EOG- EEG- Bimodal Interface

The bimodal system was first verified by glowing five LEDs using a breadboard in the offline environment successfully. Thereafter, its performance was verified online by controlling an educational robot '*e-puck*' provided by *g.tec* in four directions successfully. The control signals generated from the proposed EOG-EEG bimodal interface and the corresponding direction of the e-puck robot movement have been shown in *figure 5*.

Control signal	Robot movement direction
1 (EEG)	Forward
2 (EEG)	Backward
3 (EOG)	Left
4 (EOG)	Right
0(EEG+EOG)	Stop

Figure 5: Bimodal Control Signals and Corresponding E-puck Robot Movement Directions

(b) Performance of Bimodal-Shared Control Interface Model

The average (mean) of time taken and classification accuracy achieved by each subject in all sessions to complete the application task has been measured and shown in *table 1*.

Table 1: Performance of EOG- EEG-RFID Bimodal-Shared Control Model

User	Number of Sessions	Average completion Time (sec)	Bimodal-Shared Control model Accuracy
S1	2	29	98.75
S2	2	29	97.5
S3	3	30	97.5
S4	2	29	96.25
S5	2	27	99.75
S6	2	27	99.38
S7	2	27	98.25
S8	4	28	99.69
S9	3	28	99.75

The minimum time required to complete the application task was calculated as 27s. All users were able to complete the task with the average completion time of 28s. Some subjects (S5, S6, and S7) had experience in participating in EOG and EEG interface systems previously. Therefore, they had taken slightly lesser time than the average time. This indicates that the performance of the proposed system can be further improved with practice. At the time of testing, it has been observed that the speed of experienced subjects is more stable, whereas the other new users started with lower speeds and gradually improved. Finally, all users achieve an average speed above 90% of minimum time required (27s).

Table 2 shows that total control commands has been increased from 5 (bimodal Interface) to 12 by using proposed Bimodal-Shared Control interface model and without giving extra physical or mental effort by user. Less physical and mental demand by proposed model enhance the usability of the system.

Table 2: Control Commands by Proposed Bimodal-Shared Control Interface

Proposed Model	Control Commands
EEG-EOG-Bimodal Interface	Forward
	Backward
	Left
	Right
	Emergency Alarm
RFID and Arduino (Shared Control Interface)	Object Identification
	Indicating LED glow (If Object Identified)
	Gripper Arm Up (to lift the object)
	Gripper Arm Down (to drop the object)
	Gripper Arm Close
	Gripper Arm Open
	Ring a buzzer (If Object not Identified)

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A comparison between EOG-EEG-based Bimodal Interface and EOG-EEG-RFID-based Bimodal-Shared Control Interface in terms of classification accuracy and ITR has been shown in *table 3*. The corresponding mean and standard deviation of accuracy and ITR have also been shown in tables. There are three ways to get higher ITR, (i) to increase the number of classes, (ii) to improve the accuracy, and (iii) to decrease the detection time per class. Compared to bimodal MMI, the proposed Bimodal-Shared control Interface has increased number of targets as well as improved classification accuracy, so as higher ITR.

Table 3: Comparison between Bimodal Interface and Bimodal-Shared Control Interface in terms of Classification Accuracy and ITR

User	Bimodal Accuracy	Bimodal-Shared Control Accuracy	Bimodal ITR	Bimodal-Shared Control ITR
S1	97.5	98.75	76.48	231.66
S2	95.0	97.5	70.38	223.57
S3	95.0	97.5	74.92	237.99
S4	92.5	96.25	71.50	237.79
S5	99.5	99.75	87.74	254.62
S6	98.75	99.38	71.35	210.64
S7	96.5	98.25	67.77	209.29
S8	99.38	99.69	84.55	246.11
S9	99.5	99.75	90.66	263.10
Mean	**97.07**	**98.53**	**77.26**	**234.97**
Std	**2.49**	**1.24**	**8.32**	**18.40**

Figure 6 gives another comparison between EEG-EOG-based bimodal interface and EEG-EOG-RFID based Bimodal-Shared Control interface in terms of classification accuracy averaged on various trials and on all subjects. Vertical lines show maximum and minimum accuracies out of all the subjects and average values of both the models are connected by the green line. It indicates that all the subjects have shown improved accuracy in the case of the EEG-EOG-RFID-based bimodal-shared control system as compared to the EEG-EOG bimodal system.

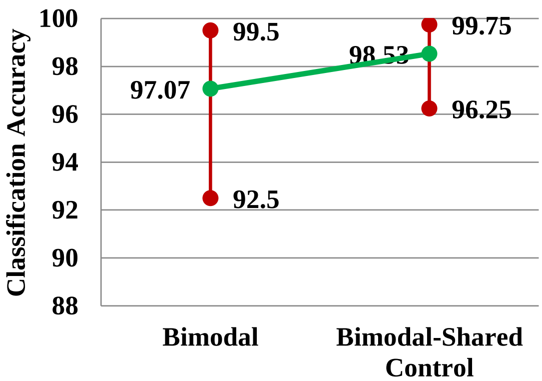

Figure 6: Classification Accuracy of Bimodal and Bimodal-Shared Control Interface

4. CONCLUSION

The paper presents a Bimodal-Shared Control Interface by combining EOG, EEG bio signals and RFID technology for a mobility assistance robot application. There was almost no training time for both EOG and EEG interface which makes it more usable for real-world applications. Experimental results prove that people with Quadriplegia can also use the proposed model for mobility assistance to get a tool to strengthen their self-dependency.

In further studies, a portable standalone system can be developed by using wireless electrodes and wireless communication in the present work. The model was tested with healthy subjects only and need to be tested with real potential users having motor disabilities to make it more usable as assistive system

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