Eye Controlled Mobile Robot with Shared Control for Physically Impaired People

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Abstract—Physically impaired and disabled people are an integral part of human society. Devices providing assistance to such individuals can help them contribute to the society in a more productive way. The situation is even worse for patients with locked-in syndrome who cannot move their body at all. These problems were the motivation to develop an eye controlled robot to facilitate such patients. Readily available commercial headset is used to record electroencephalogram (EEG) signals for classification and processing. Classification based control signals were then transmitted to robot for navigation. The robot mimics a brain controlled wheelchair with eye movements. The robot is based on shared control which is safe and robust. The analysis of robot navigation for patients showed promising results.

Keywords—Locked-in syndrome; EEG; shared control; eye controlled robot

I. INTRODUCTION

Brain Computer Interface (BCI) provides direct communication between computer and human brain by detecting electromagnetic brain signals and converting them into appropriate command signals[1]. The recorded brain activity can be used for assistive devices, gaming, and robotics. Signal recorded by brain is categorized as invasive or noninvasive. In Invasive BCIs electrical signals are recorded directly on or inside the cortex which require surgery to implant these electrodes. Different methods are used for recording these signals. Electroencephalogram (EEG) signals are recorded which involves electrical signals for its subsequent analysis[2]. Another method uses an array of multiunit electrode placed in the cortex to record the natural activity for small population of neurons[3]. Both methods have greater signal-to-noise ratio, but require very less training of the user and are suitable for restoring the damaged neurons of the patients[4]. In non-invasive BCIs electrical activity of brain is recorded by placing the electrodes on the scalp so it does not require surgery[5]. Non-invasive BCIs use various types of signals form brain as inputs, such as electroencephalograms (EEG), blood-oxygen-level-dependent (BOLD), deoxyhemoglobin concentrations, and magnetoencephalograms (MEG) which detects weak magnetic fields due to the current flow in the cortex[6]. EEG signals are most popular among all of them due to their low cost and convenient to use[7].

Recently robots are not only used in industry but also in daily life activities to provide assistance especially for the people suffering from disabilities like locked-in syndrome which is a neurodegenerative disorder [8]. In this syndrome person is fully aware of the environment but is not able to convey his/her commands so brain computer interface helps in providing a promising means to regain their mobility. Locked-in syndrome which leads to amyotrophic lateral sclerosis (ALS)[9] effects the motor neurons of the patients so the conventional EEG signal from motor imagery is not enough to control the robot which requires a lot of training and can be a tiring and stressful process. EEG signals from eye movements can provide aid for people suffering from such disorders. In previous work, electrooculogram (EOG) was used to detect eye movements which captures the corneal-retinal potential (CRP)[10]. The EOG varies from 0.05 to 3.5 mV and is proportional to eye movements. Electrodes are placed near the frontal part of brain near the eyes to measure electrooculographic potential (EOG), which is a function of eye position with respect to the head[11]. The strength of signal captured by this method is good but it causes discomfort for the user.

BCI robots based on EEG signals are most widely used in robotics and in assistive devices. The objective of BCI-robots is to convert the human intentions into appropriate commands so robots can perform various complex tasks which allows user to control robots naturally without any external signal. BCI robots are categorized into two main classes as mobile robots and brain-controlled manipulators[12]. Recently due to the development in brain computer interface mobile robots have gain the attention of most researchers due to their ability to transport disabled people [13] [14] but at the same time these mobile robots require higher safety as they are designed to provide transportation for disabled people. To implement these robots in real life much higher accuracy is required.

In this proposed method EEG based non-invasive BCI is used to detect the eye movement. Instead of using conventional high cost multiple channel EEG systems, low cost non-invasive EEG system is presented. On the basis of...
the signals received by the physical movements of eye, the
decisions are taken and hence the robot navigates accordingly.

The paper is organized in a way that related work
discusses the previous methodologies used for brain signal
extraction and shared control implementation. System model
explains the overall proposed system and robot setup.
Methodology section discusses the signal acquisition and its
processing for the detection of eye movements and also the
shared control implementation.

Robot movement under different scenarios explains the
robot navigation under various situations. Experiments and
results section describes the experiments designed to evaluate
its performance and results are also shown. The conclusion
section summarizes the results and discussions made in the
paper. Finally the future works explains the future aspects of
this work.

II. RELATED WORK

BCI is most widely used in real time applications like
gaming [15], [16], virtual reality [17] and in robotics [18],
[19], [20]. Apart from these applications BCI can provide
assistance for the individuals suffering from severe mobility
disorders such as brain controlled wheelchairs for people
suffering from disabilities [21], [22], telepresence robots to
provide aid for disabled persons[23], and exoskeletons
[24],[25].

In the past image processing techniques were used to
detect the eye movements [26]. Eye gaze tracking technique
which consist of camera and computer, by computing the
distance traveled by pupil, the movement of eye is tracked[27]
videooculography systems (VOG)[28] or infrared oculography
(IROG) [29] based on position of eye were also used. These
previous techniques increase the complexity of the system but
with the recent advancement in the brain computer interface
researchers are now working on brain signals to capture the
desire brain signal for BCI applications[30].

Apart from the signal extraction shared control anatomy is
very important for all the assistive devices. It is very essential
to develop such a design in which system is aware of the
environment and capable of deciding that when to give control
to human, machine or both[7]. Research work is being done to
establish a shared control that can be implemented in real time
environment. A key feature in these shared control design is
the use of several assistance modes[23]. Most researchers
[31], [32], [33] used autonomous approach in which the user
only specify the destination and the navigation system plans a
short and safe path.

Zhang[31] presented autonomous navigation in which user
selects the destination by using P300 based BCI. Obstacle map
is constructed in 2D with the help of webcam and laser range
finder sensor and the way-points are generated using
generalized Voronoi diagram. The research work [32]
presented the autonomous approach in which user selects the
destination point from the screen which displays real time
scenarios constructed by a laser scanner which is transmitted
to autonomous navigation system. It helps user to navigate in
an unknown environment with the help of sensors. Once the
destination is selected, user can relax which reduce the mental
workload. Rebsamen and Cuntai Guan [33] also presented
autonomous approach where paths are already defined and
user can select only from these paths. This method require
continuous update in the predefined paths in case of any
change in environment. It is only suitable for a room equipped
with webcams and not suitable for real time environment.
Autonomous approach has a serious drawback that the user
has no control on the robot and it does not work well in the
situation where the environment stochastic so under these
circumstances it is better to control the robot by the user and
use semi-autonomous approach instead of autonomous
approach.

Leeb and Robert [23] used semi-autonomous approach in
which user control high level commands (turn left, right)
while low level commands (avoiding obstacle) are
implemented by the robot. Only two classes are used and the
default behavior of the robot is to move forward with a
constant speed. In case of repellers or attractors (representing
obstacle and target) the motion of device changes in order to
avoid them. In this proposed shared control semi-autonomous
approach is implemented. Instead of using two classes, four
classes (forward, backward, left, right) are used to give
maximum control to the user. The default behavior of the
robot is to stop in order to avoid any dangerous situations.

In this paper EEG is used to capture brain signal
corresponding to the eye movements. Four classes are used for
the movement of robot. Forward command is executed when
the user lift his eyebrows. Left and right movement is
implemented by the pupils movements to the left and right
receptively. Eye blink is used to stop the robot. In order to
differentiate from normal blinking of eye user have to blink
three times. In this proposed shared control method semi-
autonomous approach is implemented to give the maximum
control of robot to the user.

III. SYSTEM MODEL

The proposed BCI system consists of three main
components: Signal acquisition unit which records electrical
signals corresponding to the eye movements; the control unit
which decides the desired motion commands on the basis of
EEG signal received from EPOC headset; and the shared
control unit ensuring the safety of user by avoiding obstacles.
The block diagram of the system is shown in the figure 1.

A. Robot Setup

The test robot is made from readily available and open
source equipment to demonstrate the proof of concept. Short
range ultrasonic sensors are used to detect the obstacles in
front of robot. Each sensor covers a 15° of range in front of it
so to cover more range in front of the robot, three sensors have
been used. While only one sensor has been used on rest of the
the three sides. To control the motor an H-Bridge is implemented
in between the motors and microcontroller. The
communication of the robot and control unit is done using
Bluetooth.
All the above mentioned setup is implemented using cheap and readily available components. An image of the developed robot is shown in figure 2. The robot has custom made wheels which are developed in order to make it very stable and aligned to move in a straight path. The wheels are also lightweight and already have an O ring which has reduced its surface friction.

Fig. 2. Eye Controlled Mobile Robot

IV. METHODOLOGY

The proposed system provides a method to detect the muscle activity of eyes through EEG signals which filtered the acquired signal for identifying eye movements. Emotiv API processes the acquired signals and performs classification. Once classified the control signals are transmitted to the robot. A high level system perspective is shown in the figure 3.

A. Signal Acquisition and Processing

A widely used and commercially available wireless EEG headset Emotiv EPOC\(^1\) with 14 channels is used for BCI application. Software Development Kit (SDK) from Emotiv is also used for signal acquisition and classification. The application consists of three emotiv suites which are named as affectiv, cognitiv, and expressiv suite. These suites are developed to recognize the user’s emotional state, thoughts and facial expressions respectively.

This experiment focuses on expressive suit which filters out the facial expression and hence eye blinks. The specific signals related to eye movement are classified from a wide range of facial expressions. This classification mainly uses the electroencephalogram (EEG) for eye blink and for the detection of muscle movements for looking right and left. Since all the users have same facial expressions so it does not need training. Sensitivity of the signal can be changed through the classifier. Certain facial expressions for some users are weak to detect so the sensitivity was tuned accordingly. Since every expression is a different expression so the sensitivity of each and every action was also fine-tuned accordingly.

B. Shared Control and Robot Movement

One of the most important and tedious task of controlling through BCI is its accuracy and high latency in processing the signals which can be tedious for the user sometimes. Also user’s safety is very important. To ensure the user safety and to reduce the mental work load from user shared control is implemented. Shared control takes over the user in case of any obstacle is critically close. To implement the shared control, signal received from brain is classified into 4 classes (forward, left, right, and stop). The shared control implements the lower level control like obstacle avoiding, critical distance handling and collision prevention while the user controls the high level commands. The default behavior of the robot is to stop. To move the robot from its position either the obstacle has to be moving and the robot will counter for it accordingly or the robot must receive a signal from brain. As the robot receives signal, it keeps on moving in the respective direction until the user sends a signal again or an obstacle is detected. The flow chart of the algorithm implemented on the robot is also shown in the figure 4.

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1. https://www.emotiv.com/epoc/.
V. ROBOT MOVEMENT UNDER DIFFERENT SCENARIOS

The shared control along with safety and other very promising features also comes with difficult control and working situations under different circumstances. The basic obstacle avoidance of the robot is shown is shown in figure 5.

Fig. 5. Obstacle detection through ultrasonic sensor

The robot in presented work also behaves on different scenarios which are explained as follows:

A. External Signal

The robot moves forward as soon as the forward command is received from BCI. Whenever an object comes within the safe range the robot stops so that the safety of the user is maintained.

B. Moving Obstacle

After danger range robot will not move any further irrespective of forward signal received. It is also demonstrated in figure 6. When left signal is received from BCI the robot turns left at some radius and continue to move in circle unless next signal is received and when an object comes in safe range the robot stops. As soon as the safe range is reached robot stops irrespective of the signal received from the user. Similar is the case when the right command or signal is received.

An important feature of the robot is to differentiate between the obstacle and target if the user wants to move towards target the robot will move further after reaching safe range till danger range is reached which is very small distance as compared to the safe range.

Fig. 6. Robot movement in case of external signal received

Fig. 7. When obstacle is moving towards robot

When left signal is received from BCI the robot turns left at some radius and continue to move in circle unless next signal is received and when an object comes in safe range the robot stops. As soon as the safe range is reached robot stops irrespective of the signal received from the user. Similar is the case when the right command or signal is received.

B. Moving Obstacle

In the case when no external signal from the user is received, robot does not move at all, if un-disturbed it behaves...
like an obstacle avoiding robot. If the obstacle is coming towards BCI robot front sensor detects the obstacle and robot starts moving backwards and maintains a safe range from the obstacle similarly if obstacle is following the robot it will move forward and maintains a proper distance from the obstacle which is shown in figure 7.

VI. EXPERIMENTS AND RESULTS

In order to test the effectiveness of proposed system two experiments were designed. For this, two different paths were designed which differ on the basis of their path complexity. Each experiment had 3 trials. User is directed to go to the specified goal in the described path in the specified time period. Before the actual experiment randomized list of task was designed which included 20 trials of eye movements in order to test the correctness of BCI. The performance is evaluated on the basis of time delay between the eye movements and the execution of command. Workload as well as stress level on the user is also studied by the user feedback at the end of each experiment.

![Fig. 8. (a) Path designed for experiment 1 (b) Path designed for experiment 2](image)

The extent of control of user over robot is another important parameter for the evaluation of proposed system. Speed of the robot has no effect on the BCI but it affects the user in terms of mental workload. At high speed it was difficult for the user to control the robot effectively and it was very tiring and stressful for the user. So the speed of robot was kept low which decreased the workload as well as enabled user to completely control the robot.

In the first experiment only few obstacles were added. The user has to reach the goal by avoiding obstacles. The results showed that the user was fully able to control the robot without any mental workload. While in second experiment a complex path was designed which includes sharp turns and user has to issue more commands in order to reach the goal. Both of the path scenarios are also shown in the figure 8 and the performance evaluation which is on the basis of path 1 versus path 2 is also shown in figure 9.

![Performance evaluation](image)

The comparative analysis of both experiments is shown in table 1. The results showed that user was able to reach the specified destination with 80% accuracy and the time to reach the goal was very high although there were no collisions with the obstacles. The feedback of the user showed that this was a bit tiring and requires more attention of the user. This experiment also showed that this was very safe there were no collision due to the obstacles which suggest that this system can be implemented on wheelchair without any safety issues.

VII. CONCLUSION

As prototype of brain controlled wheelchair, brain controlled robot was developed. The experiments were conducted in order to test whether the robot moves in accordance with the provided command and the system accuracy was tested by letting a person to control the robot in different path scenarios of variable complexity. The results demonstrated that the robot was successfully controlled by the person using EEG signals from eye movement without a single collision. The shared control is very crucial in this regard and helps the user to avoid any obstacle coming its way. The mental work load from the user is reduced by making the robot autonomous on the basis of last received command which was confirmed by the feedback from the user. However the workload also depends upon the navigation path complexity. The proposed strategy can also be used on industrial robots which are controlled by physically impaired people.

VIII. FUTURE WORK

Authors are working on controlling the robot with different methods which include gestures, muscle activity and other brain signals. Further improvements in this work can also be
done by implementing a manual control for a third person along with the brain and shared control.

REFERENCES

[1] J. del R. Millán et al., “Combining brain–computer interfaces and assistive technologies: state-of-the-art and challenges,” Front. Neurosci., vol. 4, p. 161, 2010.

[2] B. J. He, “Electrococtrogram (ECoG),” in Encyclopedia of Computational Neuroscience, D. Jaeger and R. Jung, Eds. New York, NY: Springer New York, 2015, pp. 1070–1074.

[3] J. A. Wilson, E. A. Felton, P. C. Garell, G. Schalk, and J. C. Williams, “ECoG factors underlying multimodal control of a brain-computer interface,” IEEE Trans. neural Syst. Rehabil. Eng., vol. 14, no. 2, pp. 246–250, 2006.

[4] A. Nijholt et al., “Brain-computer interfacing for intelligent systems,” IEEE Intell. Syst., vol. 23, no. 3, 2008.

[5] J. del R. Millán and J. M. Carmena, “Invasive or noninvasive: Understanding brain-machine interface technology [conversations in hme],” IEEE Eng. Med. Biol. Mag., vol. 29, no. 1, pp. 16–22, 2010.

[6] J. R. Wolpaw, D. J. McFarland, G. W. Neat, and C. A. Forneris, “An EEG-based brain-computer interface for cursor control,” Electroencephalogr. Clin. Neurophysiol., vol. 78, no. 3, pp. 252–259, 1991.

[7] B. J. He, “Electrocorticogram (ECoG),” in Encyclopedia of Computational Neuroscience, D. Jaeger and R. Jung, Eds. New York, NY: Springer New York, 2015, pp. 3156–3164, 2005.

[8] F. Galán et al., “A brain-actuated wheelchair: asynchronous and non-invasive brain–computer interfaces for continuous control of robots,” Clin. Neurophysiol., vol. 119, no. 9, pp. 2159–2169, 2008.

[9] J. del R. Millán, F. Renkens, J. Mourino, and W. Gersten, “Non-invasive brain-actuated control of a mobile robot,” in Proceedings of the 18th international joint conference on Artificial intelligence, 2003, no. EPFL-CONF-82919.

[10] R. Leeb, D. Friedman, G. R. Müller-Putz, R. Scherer, M. Slater, and G. Pfurtscheller, “Self-paced (asynchronous) BCI control of a wheelchair in virtual environments: a case study with a tetraplegic,” Comput. Intell. Neurosci., vol. 2007, 2007.

[11] I. A. Mirza et al., “Mind-controlled wheelchair using an EEG headset and arduino microcontroller,” in Technologies for Sustainable Development (ICTSD), 2015 International Conference on, 2015, pp. 1–5.

[12] R. Zhang, Y. Li, Y. Yan, H. Zhang, and S. Wu, “An intelligent wheelchair based on automated navigation and BCI techniques,” in Engineering in Medicine and Biology Society (EMBC), 2014 36th Annual International Conference of the IEEE, 2014, pp. 1302–1305.

[13] R. Leeb, L. Tonin, M. Rohm, L. Desideri, T. Carlson, and J. del R. Millán, “Towards independence: a BCI telepresence robot for people with severe motor disabilities,” Proc. IEEE, vol. 103, no. 5, pp. 969–982, 2015.

[14] A. Frisoli et al., “A new gaze-BCI-driven control of an upper limb exoskeleton for rehabilitation in real-world tasks,” IEEE Trans. Syst. Man, Cybern. Part C (Applications Rev.), vol. 42, no. 6, pp. 1169–1179, 2012.

[15] J. Webb, Z. G. Xiao, K. P. Aschenbrenner, G. Herrnstadt, and C. Menon, “Towards a portable assistive arm exoskeleton for stroke patient rehabilitation controlled through a brain computer interface,” in Biomedical Robotics and Biomechatronics (BioRob), 2012 4th IEEE RAS & EMBS International Conference on, 2012, pp. 1299–1304.

[16] S. W. Wijesoma, D. F. H. Wolfe, and R. J. Richards, “Eye-to-hand coordination for vision-guided robot control applications,” Int. J. Rob. Res., vol. 12, no. 1, pp. 65–78, 1993.

[17] M. Lin, B. Li, and Q.-H. Liu, “Identification of eye movements from non-frontal face images for eye-controlled systems,” Int. J. Autom. Comput., vol. 11, no. 1, pp. 543–554, 2014.

[18] J. P. Hansen, A. W. Andersen, and P. Roed, “Eye-gaze control of multimedia systems,” Adv. Hum. Factors/Ergonomics, vol. 20, pp. 37–42, 1995.

[19] C. H. Morimoto and M. R. M. Mimica, “Eye gaze tracking techniques for interactive applications,” Comput. Vis. image Understand., vol. 98, no. 1, pp. 4–24, 2005.

[20] A. Vailabhaneni, T. Wang, and B. He, “Brain—computer interface,” in Neural engineering, Springer, 2005, pp. 85–121.

[21] R. Zhang et al., “Control of a Wheelchair in an Indoor Environment Based on a Brain–Computer Interface and Automated Navigation,” IEEE Trans. neural Syst. Rehabil. Eng., vol. 24, no. 2, pp. 128–139, 2016.

[22] I. Itrarte, J. M. Antelis, A. Kubler, and J. Miguez, “A noninvasive brain-actuated wheelchair based on a P300 neurophysiological protocol and automated navigation,” IEEE Trans. Robot., vol. 25, no. 3, pp. 614–627, 2009.

[23] B. Rebsamen et al., “A brain controlled wheelchair to navigate in familiar environments,” IEEE Trans. Neural Syst. Rehabil. Eng., vol. 18, no. 4, pp. 590–598, 2010.