An Overview of Brain-Computer Interface Technology Applications in Robotics

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ABSTRACT
A Brain-Computer Interface (BCI) translates the electrical signals produced by brain activity without the need of neuromuscular control. As studies progress on how technology can help impaired individuals, different recent advances in research have emerged with promising results in prosthetics, computer interfaces, mobility and artistic expression in robotics. Other recent advances involving BCIs could also benefit people without major neuromuscular disorders and have appeared as commercial products. This article presents a survey of current and past BCI-technology applications in robotics in invasive and non-invasive studies as well as their commercial applications. This technology offers effective tools for employment in many areas including assistive robotics for the disabled and the elderly for which the current research is developed.

Keywords
Brain computer interfaces, Brain machine interface, BCI, BMI.

1. INTRODUCTION
For over 20 years, researchers have been studying intensively how the human brain functions [4]. Brain computer interfaces (BCIs) have emerged from those studies to provide assistive technology for people with severe motor and neuromuscular disorders. Such disorders include, but are not limited to, amputations, brainstem stroke, spinal cord injury and Amyotrophic Lateral Sclerosis (ALS). A BCI is capable of translating in real-time the electrical signals produced by the brain on the scalp, cortical surface or the brain itself to create a human-computer interaction into outputs without depending on the participation of peripheral nerves and muscles [9]. In other words, if the user thinks of moving their arm or an arm, their brain wave signals will be transposed into the mechanical component thus simulating their desired task.

Current and past BCIs have demonstrated experiments as both invasive and non-invasive devices. Invasive studies require intrusive surgery whereas non-invasive experiments require an external device, thus providing a more risk and contamination free environment. Furthermore, non-invasive BCIs use electroencephalographic (EEG) activity on the scalp whereas invasive BCIs obtain their information from the cortical surface or brain [21,22,23]. However, EEGs measure the integration of the outgoing signals for the neurons instead of the initial action potentials and it also has low-special resolution [17,18].

Further research and development of this device may help individuals with locked-in disorders to live a more comfortable life as they would be able to communicate to their caregivers and become more independent by the means of robotics. The development of BCIs could lead the user to control prosthetics, speech synthesizers, computer interfaces and mobility devices as a synergy of engineering, robotics, medicine, mathematics, computer science and neurobiology is created and developed.

Figure 1. BCIs in Robotics flowchart.

2. BRIEF OVERVIEW ON ROBOTICS RESEARCH AND ACTIVITIES IN BCIs
2.1 Invasive BCIs
Invasive BCIs require direct contact with the cerebral cortex or other parts of the brain itself. This is achieved by a direct intrusive neurosurgery as it is implanted directly unto the patient. Usually, the implantations of chips or intracortical microelectrode arrays are needed [22]. Nonetheless, invasive BCIs face technical
challenges and clinical risks as experienced neurosurgeons are required and continuous monitoring is needed in case of contamination or obstruction. Current and past invasive studies include monkey, rats and human users.

2.1.1 Prosthetics
The first ones to demonstrate direct robotic control using brain signals by invasive studies were John Chapin and his colleagues. In their experiment, they successfully trained rats to move a robotic arm in one-dimension [5]. Meel Vestille and his colleagues demonstrated how two monkeys successfully used a three dimensional robotic arm and gripper to perform self-feeding tasks via the implantation intracortical microelectrode arrays [22]. Current advancements in invasive devices include human users and direct control of robotics. Leigh Hochberg and his colleagues successfully trained a human user with a cortical implant to manipulate a simple robotic arm in two dimensions and a prosthetic hand [8].

![Image 64x385 to 286x513]

Figure 2. Example illustration of experiment environment for an invasive BCI study [22].

2.1.2 Cursors
Two and three dimensional movement of cursors has been accomplished from the signals obtained from the motor cortex by monkeys to obtain rewards [19,5]. In the study of the 3-D cursor, sharper turns and precision was noted in comparison to using a robotic apparatus [5].

2.2 Non-Invasive BCIs
Non-invasive BCIs offer low-cost and less-intrusive methods by recording the sensorimotor rhythms produced in the scalp via electroencephalographic (EEG) technology [9]. However, rapid sequence of actions may be limited in non-invasive devices as EEGs usually reflect on slow changes in the mental state of the user [4].

2.2.1 Prosthetics
The movement of prosthetics has been a large accomplishment for non-invasive BCIs. Gert Pfurtscheller’s team trained a tetraplegic patient to control a hand orthosis to open and close their paralyzed hand [16]. Gernot Müller-Putz and his team, however, accomplished training a spinal cord lesion patient to move an implanted neuroprosthesis to control hand gripping [13].

2.2.2 Computer Interfaces
The World Wide Web, via the use of web browsers, provides individuals with disabilities ways to continuously connect and communicate to the rest of the world. As shown in Figure 2, the BrainBrowser allows individuals the capabilities to browse the internet by using a non-invasive, P300-based BCIs [12].

![Image 340x501 to 537x650]

Figure 3. Example of BrainBrowser application snapshot [12].

2.2.3 Mobility
One of the future and current goals for BCI integration would be to increase the mobility in individuals who have challenges in the area. The Aware ‘Chair Project provides the user the control of their wheelchair by providing them with gross-grain navigational capabilities and special prediction based on their habits and preferences [1]. Toyota Central R&D labs created a neural-controlled wheelchair that operates in real-time with an accuracy of 95% [20]. Other progress in mobility includes the “BrainDriver” car from Autonomos Labs. This vehicle allows the user control of the steering and acceleration via the use of a non-invasive BCI [3].

![Image 355x203 to 522x315]

Figure 4. BrainDriver user driving a car via an EPOC BCI [3].

2.2.4 Artistic Expression
Artistic expression via non-invasive devices is possible by the BrainPainting application and the Plymouth Brain-Computer Music Interface project (BCMI). In the BrainPainting application, visual art is created by imagining language tasks as the user simulates silent singing in their head [2]. In the BCMI project, specific EEG patterns help compose and generate real-time music.
As noticed in the figure below, the BCMI project requires an input EEG to produce the end product: MIDI music file by analyzing the information gathered and producing it via a music engine [11].

![Figure 5. Example of the BCMI algorithm used [11].]

2.3 Consumer Products of BCIs

BCIs have emerged as commercial products either by themselves or part of a complete package for entertainment use. Currently, all consumer BCI products are non-invasive devices and vary in the number of electrodes by means of adapting or catering to the product’s goal and use.

2.3.1 Emotiv EPOC

The Emotiv EPOC is an easy to use EEG cap with 14 inexpensive sensors. The main purpose behind the development of this non-invasive BCI is to provide a new controller for gaming applications [6]. EPOC uses three suites to determine the signal inputs: Expressiv, Affectiv, and Cognitiv. The Expressiv suite analyses the user’s facial expression, the Affectiv suite reads the emotional state while the Cognitiv suite analyzes the user’s intent for movement [17]. Currently, Emotiv encourages an open-source website where scientist, researchers and hobbyist can exchange code-source information and feedback. However, even if the product has been used intensively as in the BrainDriver and the iARM (7 degrees of freedom robotic manipulator arm) there are still challenges the item faces as its goal was to develop a BCI for gamers [17,3,7].

![Figure 6. Emotiv's EPOC headset [6].]

2.3.2 NeuroSky Mindset

The NeuroSky Mindset device is a single-channel EEG-based device for gaming applications which analyses the mental states of ‘attention’ and ‘meditation’. The current development package allows the user to have Bluetooth connectivity to their music while seeing the impact in their mood [19,8,14].

![Figure 7. NeuroSky MindSet Kit [14].]

2.3.3 MindFlex

The MindFlex is an interactive game where the user must navigate a small ball across an obstacle course by using their concentration power. This product contains a headset that measures the brain waves by the means of three electrodes.

![Figure 8. MindFlex Adult set [10].]

2.3.4 Star Wars Force Trainer

The Force Trainer uses the same technology provided by the NeuroSky Mindset with only three electrodes to read the brain signals. The purpose of this toy is to simulate a training regime that a future Star Wars Jedi would perform by the means of concentration. The harder the user concentrates the harder the fan will blow that is located at the base of the toy in order to simulate the ball to float [8,15].
3. FUTURE DEVELOPMENTS

Currently, many of the consumer products in the market are limited in their use and purpose. From children games to video game controllers, current BCI projects have low reliability; thus, inhibiting the use of this technology in a wider scale. Most projects that do help people with disabilities or the elderly are mainly in their testing stage and will most likely be in that step for a considerable while. Unfortunately, the trust factor with BCIs hinders wider possible applications.

Even though there is a significant amount of progress and testing that needs to be carried out, the emerging technology between BCIs and robotics offers us a tool to explore different areas and applications.

BCIs show a high promise in healthcare applications by addressing issues faced by patients with severe motor and neuromuscular disorders. A non-intrusive solution could be applied by the means of prosthetics to amputees or mobility could be granted to other patients with locked-in syndromes like ALS. Even though the people in these cases have lost their ability to move on their own, the inclusion of a robotic component and the translation of their thought process by the means of a BCI could provide relief and comfort their new lifestyle. The possible applications are not limited to prosthetics and motorized wheelchairs, but it could be applied to how a person could interact with their environment.

People with severe motor disabilities face challenges in carrying out every-day-tasks. An integration of the control of their environment—such as controlling their thermostat, lights or TV channels—could ease the everyday dilemmas they face. Some patients who have lost their voice due to a neuromuscular illness could finally be able to communicate with the world by the means of connecting and browsing the internet by themselves to find support forums or expand friendships. Not only would web-browsing be a form of expression but voice synchronizers could be another area that could be developed.

Safety is another promising area for the growth of BCIs and robotics. BCIs have the capability to translate what a person is thinking by means of their brainwaves. What if that input is used to prevent accidents in workplaces that require intensive concentration and large objects? BCIs could be placed in the heads of personnel who are employed in critical jobs such as pilots, construction workers and firefighters to make sure of their alerted state. As soon as these individuals experience boredom or fatigue, someone could be notified; thus, reducing the number of accidents in those areas.

4. CONCLUSION

Brain-Computer Interfaces have been used for various studies. From non-invasive to invasive cases, the BCIs have touched different ways on how to help individual with severe motor and neuromuscular disorders. Although current research has increased in the area, there is still a significant need for further investigation as most of the items are still in their experimental phase. The range of consumer products available in respect to BCIs are still limited and mainly used as a toy mechanism. However, current development promises a bright future for more applications available for non-entertainment purposes. The technology is evaluated for its possible use in robotics systems to aid mainly the disabled, elderly and those individuals who carry out dangerous or risky tasks.

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6. REFERENCES


