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Application of ECoG and Electrode in BCI

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Abstract. The brain-computer interface (BCI) is a new technology that connects a computer or other electronic devices to the brains of humans, animals, or even brain cell cultures. It creates a link between the brain and technology so that messages can be sent immediately. It does not rely on the muscles and peripheral nerves that generally aid in the transmission of brain information. It is widely used in rehabilitation medicine, artificial intelligence, neuroscience, and other fields. Nowadays, with the development of neuroimaging technology, brain imaging technologies recording activities on different scales have been emerging. Electrocorticography (ECoG), which is involved in semi-invasive BCI and depth electrode, which is involved in invasive BCI, has greatly promoted the development of BCI. This paper, through a method of literature review, provides general perspectives on the application of ECoG and depth electrode in BCI; describes the advantages and disadvantages of ECoG and depth electrode; and finally discusses chances for further research. Representative research findings regarding ECoG and depth electrodes in recent years were reviewed. In summary, though ECoG and depth electrode still have some limitations, their importance in the future is undisputed.

Keywords: brain-computer interface(BCI), human computer interaction, electrocorticography(ECoG), depth electrode

1. Introduction

The brain-computer interface (BCI) is regarded as a revolutionary technology today. It has recently become a hot topic in society and a hotspot of scientific and technological innovation due to its immense potential.

When compared to the typical brain information transmission channel, brain-computer interface technology is more efficient and can connect directly with external equipment, offering a wide range of potential applications. In the interim, human beings have conducted more extensive research on the functions of the brain, including movement, vision, audition, and language, as a result of ongoing exploration of the architecture and functions of the brain in contemporary medicine. Through analysis, BCI technology can learn these facts and use them for the diagnosis, monitoring, screening, and treatment of neurological illnesses.

The main goal of brain-computer interface technology is to precisely record brain activity. The brain-computer interface can be categorized into three types: non-invasive, invasive, and semi-invasive depending on the electrode position and implantation manner. In this essay, our attention was drawn to invasive and semi-invasive ones. The most representative and possible electrodes for invasive and semi-invasive BCI are the depth electrode and the electrocardiogram

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(ECoG). The signals on the surface of the brain are captured by ECoG. For brain-computer interfaces, ECoG is an appropriate instrument. Its traits support the BCI and lay the groundwork for its steady implementation. In comparison to EEG, it has better spatial resolution and is more accurate at detecting high-frequency brain activity. Deeply implanted electrodes are what were done to the brain. It resembles the characteristics of ECoG. However, because it only records the activity of a select few neurons as opposed to the entire surface, it produces images that differ from those produced by ECoG, acting as a substitute for ECoG. Through the use of a literature review, this paper offers broad viewpoints on the use of ECoG and depth electrodes in BCI, outlines their benefits and drawbacks, and then suggests opportunities for future research. Recent research on ECoG and depth electrodes was reviewed, highlighting some of the key findings. This paper identifies the direction for future studies on brain activity recording for BCI.

2. Application of ECoG in BCI

2.1. Introduction

Electrocorticography has gained widespread acceptance during the past 20 years as a potential signal platform for BCI research and implementation. Penfield and Jasper created electrocorticography (ECoG) in the 1950s with the intention of assisting medical professionals in mapping focal interstrange spikes and determining the extent of excision. It is obtained by implanting electrodes either above (epidural) or below (subdural) the dura mater underneath the skull, but not inside the brain parenchyma [1]. Implanting electrodes into the surface of the brain requires surgery for ECoG. Then, electrical activity is recorded using these electrodes. ECoG sensors are more accurate at detecting high-frequency brain activity, which is imperceptible to EEG electrodes, and have superior spatial resolution than EEG sensors. Once implanted, the electrode can be ready for BCI or other tasks without needing to be ready before every use. Since ECoG requires surgical insertion into the surface of the brain, it mostly benefits those who are severely disabled. This causes some physical harm to patients' bodies and places a financial burden on them.

2.2. Previous research results of application of ECoG in BCI

Yao et al. studied the feasibility of using Riemannian space features, ECoG signals, and modern machine learning tools together for motor imagery of individual fingers[2]. The results of their model show a classification accuracy of 77.0%, an average Pearson's correlation coefficient(r) of 0.537, and a low time complexity. When employing densely connected 3D convolutional neural networks to speech synthesis, Angrick et al. found that the new and original logMel spectrograms showed an average Pearson's correlation coefficient(r) up to 0.69 [3].

Romanelli et al. found a neuroprosthesis that used direct cortical stimulation(DCS) and ECoG[4]. ECoG monitors the signal for epileptics while DCS helps to prolong the recording period for ECoG. According to Liwowski et al., using a deep learning model to decode ECoG signals can improve the accuracy of the BCI system [5]. They tested different deep learning models and found that deep learning models have higher average cosine similarity than the current state-of-the-art multilinear models by up to 60%. Delfino et al. demonstrated that more closely placed electrodes provide more superfluous information using three different micro-electrocorticographic devices. Meanwhile, neuronal signals are able to predict speech onset [6].

Table 1. Summary of ECoG-BCI research findings (continue).

Reference	Task	Tools	Findings
Yao et al.[2]	Motor imagery	Riemannian space, modern machine learning	By combining Riemannian space, ECoG and ML, the classification accuracy, average Pearson's

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			correlation coefficient (r) and time complexity improved.
Angrick et al.[3]	Speech synthesis	Densely connected 3D convolutional neural networks	The new and original logMel spectrograms exhibit correlations up to r = 0.69 when 3D convolutional neural networks with dense connections are used.
Romanelli et al.[4]	Epilepsy monitoring	Direct cortical stimulation(DCS)	Develop a neuroprosthesis combined ECoG and DCS to record long-term signal.
Śliwowski et al.[5]	Motor imagery	Deep learning(DL)	For tetraplegic subjects, DL-based model can increase the accuracy of ECoG-BCI when translating their 3D hand.
Delfino et al.[6]	Speech arrest	/	Create a novel model that is well known to subjects and recording equipment. The publicity demonstrates how reliable the model is.
Spüler et al.[7]	Motor intentions recognition	Support vector machine(SVM)	Using support vector machine, the average accuracy of hand movement intentions decoding can reach 61%, and when reducing number of classes, average accuracy can reach 88%.
Bundy et al.[8]	Three-dimensional reaching movements decoding	Hierarchical partial-least squares(PLS) regression model	The use of hierarchical partial-least squares regression model proved that ECoG recordings can predict three-dimensional movements in human.
Potes et al.[9]	Auditory processing	Granger causality	The results of the experiment support the hypothesized processes

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	of alpha and gamma activity.

As shown in table 1, the feasibility of the ECoG-BCI technology can be proved by recent research findings based on ECoG-BCI. ECoG has higher accuracy and sensitivity than EEG signal recording, and can be implanted before, during, and at any stage after surgery, providing much convenience. Also, due to closer neural activity, ECoG has a high ratio of resolution and signal-to-noise. Moreover, it allows electricity to directly stimulate the brain and identify key areas of cortex that need to be avoided during surgery. With the development of ECoG, it can help more patients and make a contribution to AI in the future.

However, there are still some limitations that exist in ECoG currently. The recording period of ECoG is still short, which may miss important information such as epileptic seizures. Limited horizons may also cause sampling errors because the placement of the electrode cannot be long. Meanwhile, the recording of ECoG will be affected by anesthetics, analgesics, and surgery itself. Any of these factors may cause an error in recording.

3. Application of depth electrode in BCI

3.1. Introduction

A depth electrode is an electrode that goes deeply into the brain through surgery to record brain parenchyma's activity. It offers a sensitive recording method with bare artifact and records a limited volume of brain activity that occurs near the electrode. Although depth electrode technology records activity from a limited population of neurons, its characteristics are comparable to those of ECoG technology. As a result, the two approaches offer various perspectives on brain activity. Due to the constriction of intracranial techniques, activity originating from afar and propagated to a brain region may be wrongly recorded. Depth electrodes have a long history and have been widely used to study the mechanism of brain activity in the state of disease. Depth electrodes have shown even broader prospects in recent years with the development of brain-computer interfaces. Recent research has already shown that the signal recorded by the depth electrode can not only play an essential role in understanding the mechanism of cognition but also in designing medical equipment and neural prostheses.

3.2. Previous research results of application of depth electrode in BCI

A new algorithm model called Spikedeeptector was created by Saif-ur-Rehman et al. in 2019 and is based on a novel technique for realizing feature vector extraction and the deep learning model[10]. The model's overall evaluation accuracy increased to 97.2%.

Herff et al. point out that stereotactic-EEG is a potential research area in the future[11]. The electrical activity of the brain is recorded using local and incisive depth electrodes. According to Chandrasekaran et al., studies on intractable epilepsy might elicit very focal perceptions [12]. The one that used an sEEG depth electrode had better performance. Also, such stimulation can have the same somatotopic correspondence as the cortical one. Huang et al. suggest that using an sEEG-based BCI system to realize P300 will achieve an accuracy of 93.85% regarding average online spelling [13]. Meanwhile, the distribution of contacts with high accuracy is mainly distributed in fusiform gyrus (FG) and lingual gyrus (LG).

Choi et al. suggest that by putting the depth electrodes in place of the nucleus intercollicularis(ICo), pigeons can be induced to make movements when they undergo electrical stimulation [15].

Table 2. Summary of BCI based on depth electrode research findings (continue).

Reference	Task	Tools	Findings
Saif-ur-Rehman et al.[10]	Detection of neural spiking activity	SpikeDeeptector	By developing a new algorithm model called SpikeDeeptector, the

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			detection of neural spiking activity becomes more accurate.
Herff et al.[11]	Measurement electrophysiological brain activity	sEEG	Potential exists for sEEG that records electrophysiological brain activity using partial and incisive electrodes.
Chandrasekaran et al.[12]	Evocation of perception	sEEG	Use sEEG depth electrode can receive more focal stimulation, and show the same somatotopic correspondence as cortical stimulation.
Huang et al.[13]	Motor imagery	P300	BCI system based on sEEG has good performance. It is in connection with high decoding accuracy which mainly exists in fusiform gyrus and lingual gyrus.
Bouton et al.[14]	Motor imagery	Deep learning(DL)	Decoding brain's white matter and sulcal regions' neuronal activity. It is possible to forecast tactile stimulation and finger movement with accuracy.
Choi et al.[15]	Motor imagery	/	Place depth electrodes in the nucleus intercollicularis(ICo), and use electrical stimulation to induce pigeons to move.
Li et al.[16]	Motor imagery	sEEG	Numerous regions in the lateral and depth directions exhibit significant neuronal selectivity to the task of hand movement. The sensorimotor area, among these, offers the most abundant neuronal input for decoding.

As we can see from the research findings shown in table 2, though the application of depth electrode is still in the primary stage, its potential is without doubt. Depth electrodes are more accurate than other methods in detecting neural spiking activity. Besides, the deep learning model used in depth

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electrodes can increase the accuracy of some regions of the brain. Moreover, depth electrodes are often used in stereoelectroencephalography (sEEG), which is used to identify regions of the brain where seizures originate. Using an sEEG depth electrode, we can measure electrophysiological brain activity, evoke perception, and execute movement. It performs well in research and shows high accuracy.

Nevertheless, the risk posed by surgery cannot be ignored. Depth electrodes may cause negative impacts, including hemorrhage and infection. Although hemorrhage barely exists after the implantation, once it occurs, the patient may develop neurologic sequelae or even die.

4. Conclusion

As an interdisciplinary technology, BCI technology involves materials science, basic chemistry, alloy technology, physics, quantum mechanics, quantum computing, computer technology, and so on. It is a demanding technology and needs the help of the development of many different kinds of disciplines. In recent years, BCI has been applied to many different fields and is attracting more and more researchers' attention.

Through the summary of research findings in BCI, the maturing of BCI technology based on ECoG and depth electrodes can be seen from tables 1 and 2. It can help people with epilepsy and seriously disabled patients, and also contribute to the research on AI. The existing problems and challenges for BCI based on ECoG and depth electrodes are mainly focused on three aspects. First, the traits and physical conditions of patients will greatly influence the functioning of semi-invasive and invasive BCI technologies. Second, though semi-invasive and invasive BCI technologies have higher spatial resolution than non-invasive ones, it is still not enough for high-accuracy research. Finally, the invasive procedure itself imposes risks and burdens on patients (physically, mentally, and financially).

BCI technology has achieved great advancements in recent years but still faces a lot of limitations. Its time complexity, accuracy, adaptive ability, transmission speed, and high cost problems need to be further improved in future research. BCI will show greater prospects and bring more convenience to people in the future.

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