Human Brain Activity Measurement Using EEG

EEG を用いた人間脳活動計測

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Abstract : Brain activity measurement has become a useful tool to deepen our understanding of human beings as well as to develop new applications to improve the quality of people's life. Though EEG (electroencephalogram) has a history of about 90 years in measuring human brain activities, it is still a popular method nowadays in both medical fronts and other research fields, such as neuroscience, psychology, physiology and engineering. The EEG devices have evolved dramatically in different directions to fit the measurement requirements with high spatial resolution or portable convenience. In this paper, the history of the non-invasive human brain activity measurement is looked back briefly. Then the mechanism of EEG and its evolvement are reviewed. Different types of EEG as well as their typical applications are introduced. Finally, the potential prospects of EEG are surveyed.

Keywords: brain activity measurement, EEG, electroencephalogram, dense array EEG, portable EEG

要約 : 脳活動計測は人間を理解するための有効なツールであり、その応用は生活の質を向上するにも役立つ。EEG は約 90 年の歴史を持ちながら、現在でも医療現場や神経科学、心理学、生理学、工学などの研究分野で活用されている。EEG 装置は高い空間分解能や持ち運び便利さなどの要求に応じて、異なる方向に進化してきた。本論文は、人間の非侵襲脳活動計測の歴史を振り返し、EEG の仕組みやその進化を説明する上、異なるタイプの EEG 及び応用を紹介する。最後に EEG の将来を展望する。

キーワード : 脳活動計測、EEG、脳波計測、高密度脳波計測、携帯型脳波計測

1. Introduction

The human brain is one of the largest mysteries beyond our complete understanding. Recently, brain activity measurement has become an important tool to help us to reveal what happened in the brain -- What do we see? What feeling do we have? Are we happy? ..., etc. Researches have been conducted to try to answer these questions based on the brain activities. Because the specific brain activities were able to be observed when certain tasks were conducted, cognitive processes in the brain may be inferred reversely by measuring the brain activities. The methods to measure the human brain activities can be divided into two types: invasive and non-invasive. The former type is accompanied with surgery operations and is limited for patients. The non-invasive type can be applied for both healthy persons and patients, and is widely used in many fields besides of the medical diagnosis. Till now there have been several non-invasive methods developed to measure the human brain activities, such as EEG (electroencephalogram), fMRI (functional magnetic resonance imaging), MEG (magnetoencephalography), and fNIRS (functional near-infrared spectroscopy). Among them, EEG has the longest history and is still a popular method. In this paper, the history of human brain activity measurement is looked back briefly and the mechanism of EEG is explained. As the technology advanced, the EEG devices have evolved toward different directions. Different types of EEG and their applications are introduced. Finally, the potential prospects of EEG are surveyed.

2. History of non-invasive human brain activity measurement

The first *electroencephalogram* (EEG) system for human beings was reported by Hans Berger (1873–1941) in 1929 (Berger, 1929). In his first experiment conducted in 1924, human EEG signals of one to three minutes duration were recorded on photographic paper. In this recording, only one-channel bipolar method with fronto-occipital leads was used. This invention was described "as one of the most surprising, remarkable, and momentous developments in the history of clinical neurology" (Millet, 2002). Because EEG signals reflect the potentials on the scalp and change instantaneously, EEG measurement usually has high temporal resolution. On the contrary, because the number of measuring channels usually is not so large, the spatial resolution of EEG is generally poor. This is the reason why some modern EEG systems increase their measuring channels to improve the spatial resolution. On the other hand, those EEG systems with a small number of channels are portable and low-cost.

Another popular method of human brain activity measurement is *functional magnetic resonance imaging* (fMRI) and it appeared more than 60 years later after EEG was invented. The primary form of fMRI using the blood-oxygen-level dependent (BOLD) contrast was discovered by Seiji Ogawa and his colleagues (Ogawa, 1990). The first experiment of fMRI on human beings was reported in 1992 by Kenneth Kin Man Kwong and colleagues (Kwong, 1992). The fMRI measures the BOLD changes by scanning the brain slice by slice. Because the changes from everywhere in the brain can be detected from the scan, the spatial resolution is very high. On the contrary, because a scan of the whole brain takes time and the BOLD signals usually change slowly, the temporal resolution of fMRI is rather low.

As for other methods, *Magnetoencephalography* (MEG) signals were first measured by physicist David Cohen of University of Illinois in 1968 (Cohen, 1968). Like fMRI, MEG needs to be measured in a shield room and the apparatus is very large without portability. The basis of fNIRS that brain tissue transparency to NIR light allowed a non-invasive and continuous measuring of tissue oxygen saturation was reported in 1977 (Jobsis, 1977), and the first study on cerebral oxygenation was conducted by M. Ferrari in 1985 (Ferrari, 1985). Because fNIRS systems use optical technology to detect the oxygenation changes in the blood of the superficial brain areas, the spatial resolution of fNIRs is poor and similar to EEG. Though some fNIRS devices are portable, the motion artifact is a big obstacle to improve the measuring accuracy.

From the above, we can see that EEG was applied the earliest to non-invasive human brain activity measurement. Today it is still actively researched and applied in various fields. In this paper, we focus on EEG and its mechanism. Its evolvement and applications are reviewed in the next two sections.

3. Mechanisms of EEG

As we know, the brain consists of billions of neurons. When we interact with the outside world, neurons produce spikes of voltage to form electrical pulses travelling in the brain. These electric currents produce electric potentials which can be detected by the electrodes on the scalp. Recording these potentials over time gives us the EEG signals. By analyzing these data, the corresponding brain activities can be inferred.

Nowadays, multiple electrodes are utilized to acquire the EEG data, unlike only one channel was used in Berger's first experiment. The international 10–20 system is an internationally recognized standard method to describe and apply the location of scalp electrodes in an EEG measurement (Jasper, 1958). This system was developed to ensure standardized reproducibility so that a subject's studies could be repeated and compared over time and the measurement of different subjects could be compared with each other. The locations of electrodes are based on the relationship to the underlying area of cerebral cortex. The "10" and "20" describe the actual distances between adjacent electrodes which are either 10% or 20% of the total front-back or right-left distance of the skull, respectively.

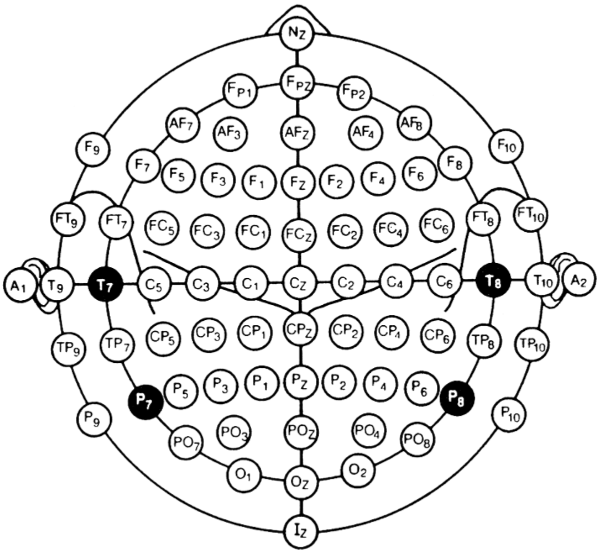

Fig. 1: A combinatorial nomenclature for the 10-10 system modified from the international 10-20 system (from Guideline 5: Guidelines for standard electrode position nomenclature, American Electroencephalographic Society. http://www.acns.org/pdf/guidelines/Guideline-5.pdf)

In addition to the international 10-20 system, intermediate 10% electrode positions are also used (Fig. 1). The locations and nomenclature of these electrodes are standardized by the American Electroencephalographic Society (1991). Fig.1 shows the latest version of a combinatorial nomenclature for the 10-10 system modified from the international 10–20 system.

These electrodes detect not only the electrical signal from brain activities, but also the signals from non-cerebral origins, which are called artifacts. EEG data are almost always contaminated by such artifacts. The amplitude of artifacts can be quite large compared with that of the cortical signals of interest, which are usually very weak. Removing these artifacts is a big issue for the EEG data analysis.

The artifacts include the biological artifacts and environment artifacts. Some of the most common types of biological artifacts include eye-induced artifacts (including eye blinks, eye movements and extra-ocular muscle activity), cardiac artifacts, muscle activation induced artifacts, and glossokinetic artifacts. Recently, independent component analysis (ICA) techniques have been developed to correct or remove EEG contaminants.

4. Different types of EEG

As the EEG measuring technology developed, the number of electrodes or sensors used to detect the brain activities became larger and larger. Dense array EEG was invented to purse the high spatial resolution. At the same time, a different trend of EEG is to keep the number of channels small but make the system portable and easy to connect with other systems.

4.1 Dense array EEG

Dense array EEG is a method of recording electroencephalography (EEG) with large number of electrodes (up to 256), much more than those utilized in standard techniques that typically employ the international 10-20 system scalp electrodes. The rationale for this approach is to improve the spatial resolution of EEG.

In conventional scalp EEG, the recording is obtained by placing electrodes on the scalp with conductive gel or paste. The electrodes are usually embedded into a cap or a net so as to be set up easily. This is particularly common when high-density arrays of electrodes are applied. By this means, the positions of electrodes are relatively fixed so that the electrode setting time is saved greatly. EGI (Electrical Geodesics, Inc) is a company known as providing EEG systems with dense array electrodes, which are embedded in a scalp net and up to 256 channels.

Fig. 2: A sensor net of 64ch Dense Array EEG from EGI

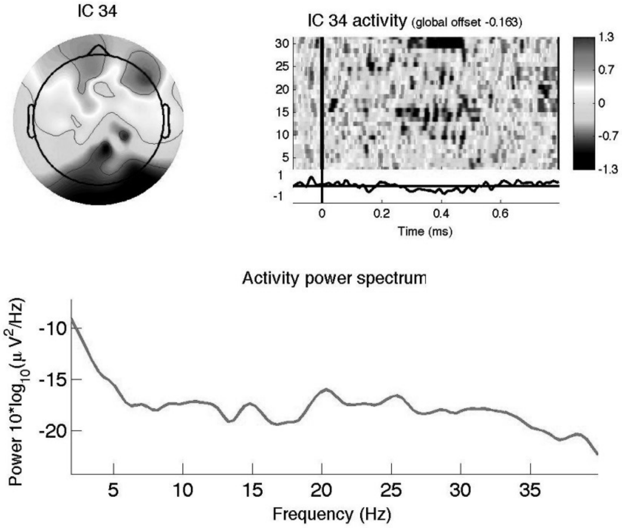

Fig. 3: An example of the analysis results of the brain activity based on the acquired EEG data. The ICA (independent component analysis) was applied.

As an example, an EGI Geodesic EEG system with 64 channel sensors was employed in the author's EEG experiments (Zhang, 2009). A sensor net of EGI EEG system is shown in Fig. 2. For the EEG data analysis, the ICA (independent component analysis) was conducted. An example of analysis result is shown in Fig. 3, where the brain activity for one independent component is displayed on an expanded scalp map (upper-left), a time changing ERP map (upper-right), and a power spectrum graph (bottom). By this way, both the spatial and temporal information of the brain activity was inferred.

4.2 Portable EEG

Dense array EEG apparatus are usually very expensive and difficult to move. In contrast to increasing the number of electrodes for dense array EEG systems, some other EEG systems prefer using small numbers of electrodes. They are inexpensive and designed for the low-cost research and consumer markets. Usually dry electrodes without the need of any conductive gel or paste are applied in these systems. So they are very easy to set up and suitable for long term measuring. These EEG systems have high portability.

As an example, in 2009, Emotiv Inc. released a portable EEG system with 14 channel electrodes (as shown in Fig. 4). This system is the first commercial EEG to not

Fig. 4: The portable EEG system from Emotiv, Inc.

use dry sensor technology. It requires users to apply a saline solution to electrode pads (which need remoistening after an hour or two of use). The electrodes are located at the positions of AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4, according to the international 10–10 system shown in Fig. 1. It is a wireless EEG system and able to be applied for researches in entertainment, market research & usability testing and neurotherapy. This system is also equipped with APIs and detection libraries for Facial Expressions, Performance & Emotional Metrics, and Mental Commands (Emotiv Inc., 2014).

The EEG system is also popularly used in developing BCI systems. Several research groups have applied this device in their projects. Olga group employed it to conduct emotion recognition (Olga, 2011). A brain-computer interface was created based on the brain activities of generating visual images (Bobrov, 2011). Another research applied the wireless communication function to realize a BCI using smartphone (Stopczynski, 2011).

5. Discussions

Among the non-invasive human brain activity measurement methods, EEG has the longest history. The reason why it is still popular is because the limitation of the method is the minimum. In particular, the portable EEG devices make the brain activity measurement much cheaper and easier.

However, there are still limitations for EEG. The poor spatial resolution is the most important one. Though the dense array EEG has improved the spatial resolution to some extent, it is still difficult to detect the brain activity from the deep areas of brain. In addition, the electrodes cannot pick up the electric potential generated by an individual neuron because it is far too small to be distinguished. EEG signals therefore always reflect the summation of the synchronous activity of thousands or millions of neurons that have similar spatial orientation. In addition, since EEG signals represent the averages of thousands of neurons, a large population of neurons with synchronous activity is necessary to generate a significant deflection on the recordings.

In spite of these limitations, EEG still has a bright future. Benefiting from the low-cost of the portable EEG systems, it is expected that there will be more and more researches appearing to extend the usage of brain activity into other fields such as entertainment.

Finally, the ethics issues are necessary to be considered when the brain activity is measured easily using such portable EEG systems. Regulations, rules and guidelines need to be established accordingly.

6. Conclusions

In this paper, the history of non-invasive human brain activity measurement was reviewed. Among the many different types of measuring methods, EEG which has the longest history was focused. The mechanism of EEG was explained and different types of EEG were introduced. Dense Array EEG has increased the electrode sensors up to 256 channels for high spatial resolution. On the other hand, the portable EEG only uses a small number of sensors but is low-cost and designed for practical contextualized research applications. Though there are limitations in EEG, it is still a popular and useful brain activity measuring method. The developments of EEG will surely bring forward the further understanding of the human brain. At the same time, more and more interdisciplinary researches will extend brain activity measurement to other fields besides of medical and neuroscience.

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