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Research Article

A Systematic Review on EEG Signal Processing for Imagined Speech Recognition

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Abstract

Imagined speech is the inner pronunciation of words (unspoken speech, silent speech, or covert speech) without emitting sounds or making movements of face. Speech is the simple, normal and effective way people can communicate with one another. But some brain injuries caused by brain stroke, traumatic brain injuries, brain paralyses, stroke and ALS(amyotrophic lateral sclerosis) restrict vocal speech, even when the patient is completelyconscious. People that cannot communicate due to neural conditions will benefit from adevice that can specifically infer brain impulses from internal expression. For this speechimpaired population, Brain Computer Interface(BCI) may be a possible communicationalternative. A Brain Computer Interface that uses brain impulses to manipulate electronicequipment by a detection of complex variations of brain electrical activity needs to be applied in order to provide quiet communication skills between the two individuals to gather datarelating to imaginary talk. This study document focuses on BCI research on the identificationof imagined expression and explanations of end-to-end EEG signal processing methodology.

Keywords *Electroencephalography (EEG), covert speech, Unspoken speech, Imagined Speech, BCI (Brain computer Interface)*

Introduction

Imagined speech means words' inner pronunciation without any facial or sounds expressions. Research has shown that imagined speech has multiple cognitive functions, including comprehension, the processing of tasks, vocabulary and memory. Brain computer interface

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(BCI) enables users to interact as easily as possible with computers, applications as well as people using speech interfaces, but without the overall loudness of saying. In order to be used as a coordination device for imagined vocal identification due to non-invasiveness, portability and inexpensively, EEG has the greatest capacity, between other methods. Current approaches to the identification of imaginary expression can be divided widely into three- word based, vowel-based and syllable based. The following 2 goals are based primarily on this review paper: a) understanding the imagined speech production mechanism in the brain,

b) BCI system for recognizing speech from covert speech utilizing brain signals. This paper illuminates experiments, which utilizes BCI technology for detecting the imaginary voice and the comparison between various techniques utilized for brain signals classification and feature extraction.

History and background

Scope and relevance of the topic

Communication is an act that allows one to share one's emotions with another. Using the widely understood words (audio), normal people can communicate easily with them (visual). However, certain cases are preferable for unspoken speech. First, there are circumstances in which speaking is unnecessary or often impractical, for example fire fighters and scuba divers, where speech is unlikely in calm conditions or ecosystems. Second, there are individuals who can't express speech because of physical inabilities which contain traumatic brain injury, brainstem infarcts, stroke as well as ALS (amyotrophic lateral sclerosis) etc. In such situations Brain-Computer Interfaces (BCI) has a growing interest to control external devices or applications using brain waves as given in figure.1.

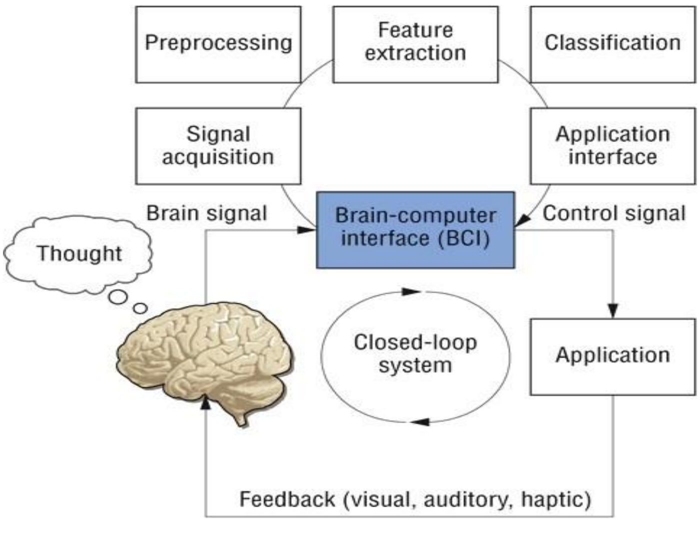

Figure 1. BCI System

Brain and neurons

Our brain is the most complicated signal processor. The brain is a component of the central nervous system that's morphologically speaking specialized in information acquisition, delivery, storage and processing. In order to allow behavior, cognition, and behaviors, the human brain can interpret as well as convert a multitude environment signals along with information extraction. Neurotransmitter transmits information about 10^6 times slower compared to transistors, the essential aspect of brain signal processing. Although the advantages of the brain are that this has a large number of parallel neurons and a widely dispersed synapse memory structure (over 100 trillion in the cerebral cortex). [7].

In the brain active nerves produce change in voltages and magnetic field in scalp when impulse is given. The measurements and records can be calculated and reported respectively in EEG (Electroencephalography) as well as EMG (Electromyography). In Hans Berg's Electroencephalography (EEG), brain activity can be seen at no health hazards or also at a smaller price than other approaches. In order to identify electrographic designs, electrical source and fields must be recognized [4]. Nearly 100 billion nerve cells or neurons make up the brain. We can see when a new neuron is off when we are relaxing and on during the electrical signal propagation when we consider that a switch has state of on and off. The signal is transmitted by a wire named an axon, in which ions with an electric charge are carried by the membrane, like Ca^{2+} (calcium), Cl^{-} (chloride), K^{+} (potassium), Na^{+} (sodium). The electrical charge produced by any axon in these billion neurons helps the neurons relay information through chemical as well as electrical signals. It can be possible to bind neurons to each other in neural networks.

A cell body (soma), axon and dendrites are usually found in the neuron. Dendrites come from cell body whereas move from micrometers to meters of several divisions of various species. There are often several dendrites in a neuron's cell body, never more than one axon, although an axon will branch hundreds of times until it terminates. At most, signals from the axon of a neuron can be transferred to the dendrite of another. The neuron's signal distribution and delivery to the next neuron are explained in figure.2. In the case of transmission of information, a neuron produces electro-chemical signals. This behavior of neurons is measured at the frequency spectrum and at microvolts (μV). The EEG amplitude is about 100μV, measured on the scalp and about 1-2mV measured on the surface of the brain. This signal's bandwidth is from below 1Hz to approximately 50Hz. Because of its cyclic wave-like nature, the combination of the brain's electrical activity is generally called a brainwave pattern. Synchronized electrical signals from masses of neurons generate brainwaves.

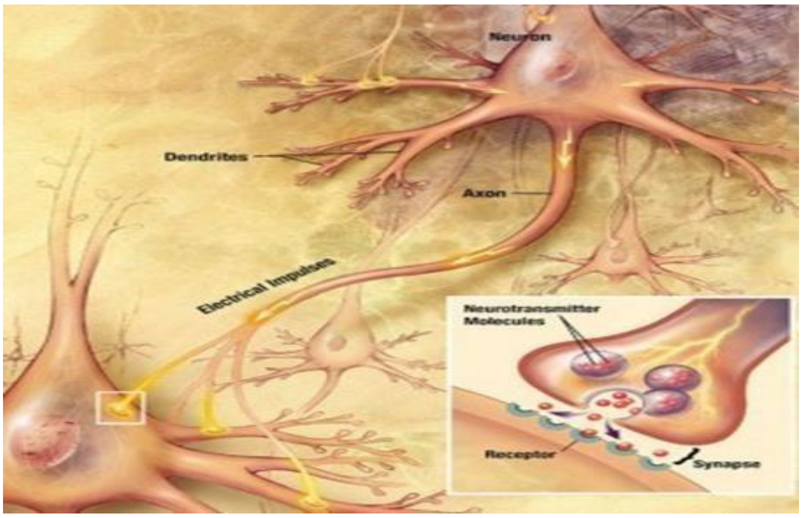

Figure 2. A signal propagating down an axon to the cell body and dendrites of the next cell.

Brain waves

Sensors placed on the scalp monitor brain waves. They are categorized into 5 bandwidths as Delta, Theta, Alpha, Beta, Gamma which describe their functions and are a consciousness and relaxation metric. Delta waves are slow, for instance, whereas gamma waves are complex, sensitive, as well as fast. Our brainwaves shift in line with what we do andexperience. We feel sleepy, sluggish, lazy, or dreamy when slower brainwaves dominate. As we feel wired, or hyper-alert, the higher frequencies are dominant. The frequency bands of brain waves are shown in table 1 and the different brain waves are shown in figure.3.

Table 1

Frequency bands of brain waves

Brain wave	"Range (Hz)	Occurrence	Location
Delta	0.5-4	Deep and dreamless sleep, deepest meditation	Frontally in adults and posterior in children"
Theta	4-8	creativity, intuition, daydreaming, and fantasizing	Limbic system and hippocampus regions.
Alpha	8-12	Awake at relaxation	Posterior head regions, both sides
Beta	12-30	Awake at activity, conscious thoughts, problem solving,	Symmetrical distribution on both sides of brain

		decision making, alertness, other cognitive tasks	
Gamma	30-100	Higher mental activity or visualization, learning, memory	Somatosensory cortex

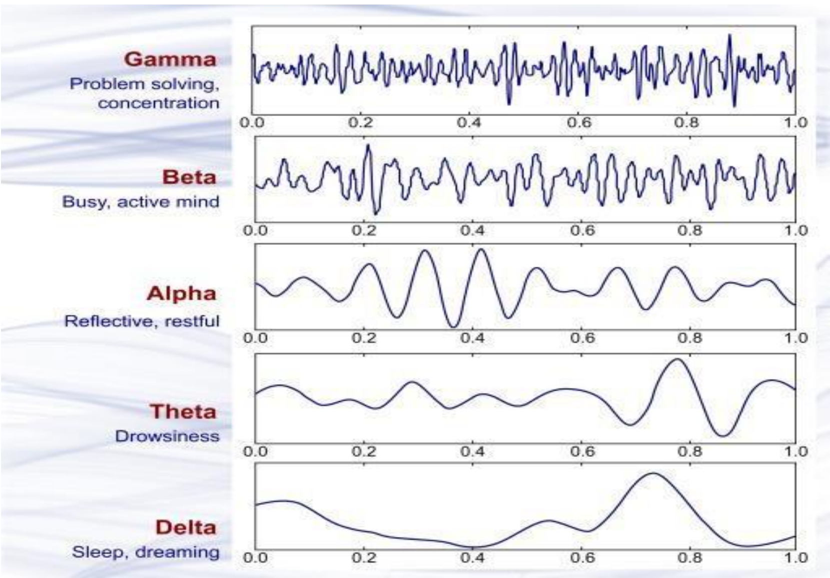

Figure 3. Brain Waves

Brain regions related to speech

Two minor focal points were triggered in the imagined speech in frontal and temporal brain areas. There are many places in this speech center. These are the region of Broca, the region of Wernicke and Angular Gyrus. The Broca Center has the responsibility to articulate and to pronounce terms correctly. It is mainly this core that creates expression. We may assume that the word patterns are very articulated. The auditory characteristics and consequences of remarkable language in the area of Wernick ensure language understanding. The Angular Gyrus is also present in humans, despite these two areas. The speech begins in the cerebrum of the Wernicke area, where before pronouncing the word's sound formula will be enabled. The word articulation will be translated in the Broca zone. This information is passed to the motor region where the term is communicated by the articulation bodies initiated. Comprehension of the word occurs as you first receive the auditory field that captures the word. In order to equate the recorded signal with the audio pattern of the expression, the Wernicke center further enables the capturing of the spoken word. The properly accepted formula unlocks the word's meaning. When the written text is recognized, first the main view field is stimulated and then the angular gyrus in the area of Wernicke connects the visual shape of the word to the audible pattern. The sense of the term is often recognized until its proper auditory pattern is identified. [1] [3] [4]. Speech centers in brain related to speech are given in figure 4.

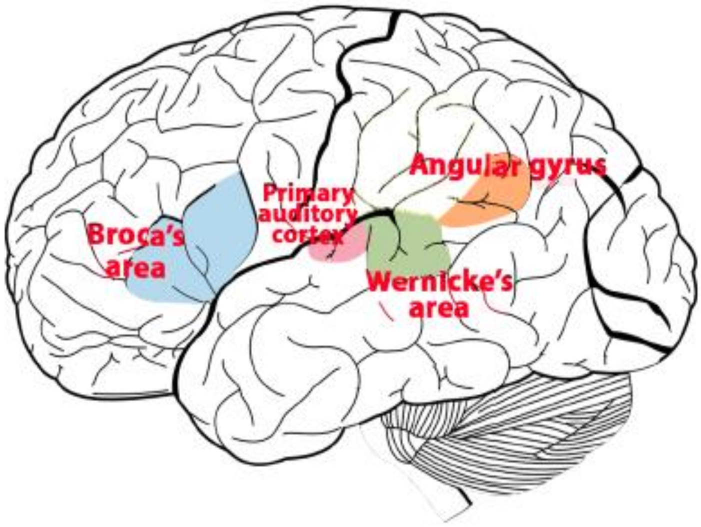

Figure 4. Brain regions related to speech

BCI classes

Generally, a BCI device will monitor anything that is being operated by a computer. Depending on the required accuracy as well as applications, speed, various types of BCI wereprovided for available equipment and patient status. Basically there are 3 kinds of BCI systems: noninvasive, partially invasive, along with invasive and the comparison between them is shown in Table 2.

Table 2

Comparison of BCI Types

BCI Types	Advantages	Disadvantages
Non invasive	• Less requirements for training • required no surgical implantation • Inexpensive	• Interference from non-cortical stimuli • Low quality
Partially invasive	• Long term stability • Low clinical risk • High signal to noise ratio • No cortical damage • High resolution	• Neurosurgical implantation required

Invasive	• High performance rate • Direct recording of neuron potentials	• Lack of signal stability • Neurosurgical implantation required • Vascular and neuronal damage

EEG capturing tools in non-invasive BCIs

The International 10-20 analysis is a technique used in captured brain signals to identify the position of EEG electrodes on the head. Every electrode location is matched to the cerebral cortex specific region. 10 as well as 20 numbers mean the percentage difference between neighboring electrodes. Electrode positions shall be designated for the brain area where they register: occipital, temporal, crown (parietal), sulcus(central), and frontal. A reference or grounding point is often an electrode mounted on the earring. The electrode position in the 10-20 EEG cap is shown in figure 5.

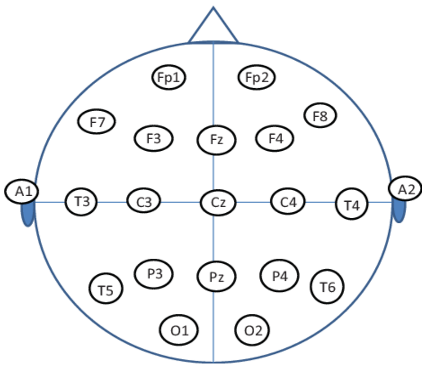

Figure 5. Electrode position in10-20 standard EEG cap of BCI

The electrodes record neuron activities, whether non-invasive or invasive. The activities are sent to a computer, where the brain impulses are translated into computer commands with software. Various BCI systems utilized various EEG headsets types with various EEG electrodes types as shown in figure.6

Figure 6. EEG headsets currently available in market

BCI STRUCTURE

A BCI is a framework that includes a way to quantify brain signals, an algorithm/method to decode such signals, as well as a technique to map an action or behavior to this decoding. BCI system represents a modern interface style that enables users to communicate with a machine/computer with a natural neurological mechanism.

The EEG brain signal processing consists of preparation, extraction of features and recognition steps as seen in figure.7. Various preprocessing strategies for the EEG signal reduction and removal of noise therefore provide a clean signal for the next phase. Therefore, using various methods, a features' series is extracted from the signal. This feature vector should outline the user's intentions. Then these intentions are categorized to produce a finite number of results. Each output is a separate user expectation or order for controlling the BCI.

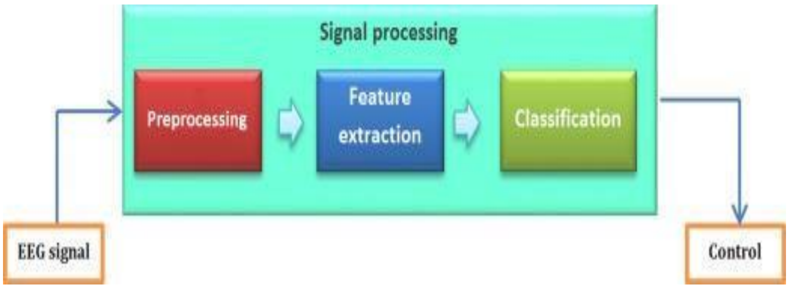

Figure 7. EEG signal processing steps

Pre-processing

An artifact may be referenced as any part of the EEG signal which is not produced directly by human brain activities. The neural EEG data is thus polluted by the noise recorded by the system. These noises needs to be filtered out while processing these signals. EEG artifacts are broadly classified into physiological and non-physiological types as shown in table 3 and 4. Physiological artifacts mainly include respiration, perspiration, cardiac activity, muscle activity, and ocular activity, while non-physiological artifacts are electromagnetic interferences, body movements, incorrect placement of reference, cable movement, and electrode pop.

Table 3

Physiological Artifacts

Physiological artifacts	Origin	Effects
Ocular activity	Eye (EOG-Electrooculogram)	Blinking, lateral eye movements

Muscle activity	Muscle(EMG-electromyography)	Clenching the jaw, shoulder and neck muscles tension, chewing and swallowing
Cardiac activity	Heart (ECG-electrocardiogram)	Cardiac activity, pulse
Perspiration	Sweat glands of the skin	Sweat glands, skin potentials
Respiration	Chest and head	Inhale and exhale

Table 4

Non-Physiological Artifacts

Non-physiological artifacts	**Effects**
Electrode pop	Contact failure between sensor and the scalp
Cable movement	Cable touch
Incorrect reference placement	Bad contact on the reference channel
AC electrical and electromagnetic interferences	AC power sources and wires
Body movements	Head and arm movements, walking ,running

Usual procedure for pre-processing EEG signal is given as:

1. Collect EEG Data
2. Import EEG into EEGLAB (interactive Matlab toolbox in order to continuous processing and event associated MEG, EEG, as well as other electrophysiological data)
3. Import event markers and channel locations
4. Re-reference/down sample if necessary
5. Use high pass filter(~0.5Hz-1Hz)
6. Examine the raw data
7. Identify or reject bad channels
8. Reject large artifact time points
9. Reject Components and Run ICA
10. Done

Feature Extraction

In the case of invasive methods, signals are decoded to the algorithm, and then the signals are controlled by the system. In the case of non-invasive techniques, features are take-out and converted to machine learning techniques to get the desired output. As EEG is in the form of multi-channel electrical signal, feature extraction methods for EEG can be divided to three classes based on extracting:

- temporal features [2], [3],
- frequency features [4], [5] and
- spatial features [6], [7]

A large number of features were attempted for designing BCI for example time frequency, AAR parameters (adaptive autoregressive), AR (autoregressive), PSD (power spectral density) values, BP (band powers), EEG signals' amplitude values [10-15]. The comparison between the major EEG feature extraction approaches namely Wavelet transform and FFT (Fast Fourier transform) is shown in table 5.

Table 5

Comparison between Performances of different EEG Feature Extraction Methods

Method name, domain, and suitability	**Advantages**	**Disadvantages**
In frequency domain, Fast Fourier transform suitable for narrow- band stationary signals.	Good for processing stationary signal.	Does not have good spectral estimation and cannot be used for short EEG signals analysis.
	Suitable for a sinewave, for example, narrow-band signal.	Cannot tell the complexesand localized spikes in EEG signals.
	Has increased speed in real-time applications above almost all other available methods	Suffers from large noise sensitivity
Wavelet transform in both frequency and time domain, appropriate for stationary and transient signal.	Has a different range- is large at lower frequencies and small at higher frequencies	Require an appropriate mother wavelet.
Eigenvector in bothfrequency and time domain,	Suitable for sudden and temporary signal changes analysis.	If the Pisarenkos approach is used, the lower value of its own will produce false zeros.
appropriate for noise signals.	Provides the appropriate resolution for the evaluation of the data sinusoid.	

Classification

A good BCI system generally requires a good pattern recognition as well as translation component, dependent on system classification algorithms [11]. An algorithm for classification is designed to develop a method to predict the class of the data input using its characteristics [15]. For a strong rating results, training samples are recommended rather thandimensionality at least five times [7]. Comparison between two basic classifiers such asSVM (Support vector machine) used and LDA (Linear discriminant analysis) in this area are given in table 6.

Table 6

Comparison between Performances of Different EEG Feature Extraction Methods

Linear Discriminant Analysis(LDA)	**Support vector machine(SVM**
LDA is generative and it focuses on all data points	SVM is discriminative and it focuses only on the points that are difficult to classify
LDA considers the covariance of the data points and assumes that the probability density is usually spread.	SVM has no such assumption**.**

Conclusion

The usefulness of EEG as a functional neuroimaging tool is incomparable. But various challenges still remain to be solved. In this review we highlighted current trends in the field of imagined speech recognition by analyzing several studies in Brain computer Interface using EEG data. This review shows that the end-to-end brainwave analysis makes sense and its application to imagined speech recognition is already producing positive results. In future BCI technology seems very applicable in a wide variety of areas whether it is medically or commercially. Possibilities of how far the BCI systems can go are virtually limitless.

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