2014 Middle East Conference on Biomedical Engineering (MECBME)
February 17-20, 2014, Hilton Hotel, Doha, Qatar

Electrical Capacitance Volume Tomography for Human Brain Motion Activity Observation

Warsito P. Taruno,
Muhammad F. Ihsan, Marlin R. Baidillah
Center of Medical Physics and Cancer Research, CTECH Laboratories
Jl. Jalur Sutera Kavling Spectra Blok 23C No.10-12,
Alam Sutera, Tangerang, Indonesia
Email: wsito@yahoo.com

Timothy Tandian, Mahdi Mahendra
Bandung Institute of Technology
Bandung, Indonesia

Mohammed Aljohani
Dept. of Nuclear Engineering, King Abdulazis University
Jeddah, Saudi Arabia

Abstract— **In this study we performed brain activity observation related to simple tasks of executed movement (EM) and imagined movement (IM) using Electrical Capacitance Volume Tomography (ECVT). ECVT has been previously applied to brain activity imaging and brain cancer detection. This study is intended to elaborate further the previous studies on the brain functional imaging. Experiment on human subjects was conducted by measuring brain signals using ECVT during five conditions: (1) relax: baseline condition, (2) actual movement with the right hands and left hands, (3) imagined movement with right and left hands. Signal normalization was used to extract the ECVT brain activity signals related to a particular condition. Qualitative and quantitative analysis was performed on the ECVT images of brain activity related to EM and IM tasks. The results indicate that lateral brain activation can be observed using ECVT in concordance with fMRI studies.**

I. INTRODUCTION

As early as the end of 18th century German physician and neuroanatomist named Franz Joseph Gall argued that particular regions of the cerebral cortex controlled specific functions[1]. Scientists have been interested in knowing where brain activity related to a specific function occurs in the brain. There are many advantages in knowing where this signal originates. For example, the signal obtained from the brain activities related to hand movement can be used to control a prosthetic arm. Another use of brain activity imaging is in guiding brain surgeries such as in removing cancers, so the brain function can be preserved. Brain functional imaging related to motor function can also be useful in designing and monitoring stroke physical therapy. The advances in brain activity imaging tools have helped us identify multiple regions and their temporal relationships with the performance of a well-designed task[2].

Many attempts and methods have been done to investigate the work mechanism of the human brain. Methods for investigating the work mechanism of the brain generally can be classified into three techniques: optical, hemodynamic, and electromagnetic[3]. Example of optical imaging modality is functional Near Infrared Spectroscopy (NIRS). However, the diffuse nature of photon transmission through tissue limits the spatial resolution of this optical imaging [3], [4]. Hemodynamic method is based on indirect measurement of brain activity, for example by observing alteration in the nature of blood flow inside brain. Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI) are examples of hemodynamic modality. Meanwhile electromagnetic method is based on direct measurement of electrical or magnetic activity of the brain. Examples of electromagnetic modality are Electroencephalography (EEG) and Magnetoencephalography (MEG).

Modalities for brain functional imaging includes of PET, functional MRI (fMRI), or EEG. The signals obtained with both PET and fMRI are based on changes in blood flow, oxygen consumption, and glucose utilization for neuronal activity in the brain[5]. Both PET and fMRI are able to reconstruct an image with excellent spatial resolution, yet poor temporal resolution. Some basic facts about functional human brain imaging with PET and fMRI are presented by Raichle[6]. EEG working principle is based on electrical potential measurement from brain (invasive) or scalp (noninvasive). EEG has strong temporal resolution but poor spatial resolution. Researchers have suggested the integration of fMRI and EEG to obtain a high spatiotemporal resolution. This, however, has caused another problem of mismatch between the different multimodal signals[7].

Electrical Capacitance Volume Tomography (ECVT) is introduced recently to map the permittivity characteristic of dielectric objects[8]. One indication of brain activity is a change in brain electrical potential at certain regions inside and/or on the scalp[5]. ECVT utilizes nonlinear difference of electric field distribution to find permittivity distribution inside the sensing region, i.e. every electrical potential change within the domain covered by electrode pairs of sensor is incorporated into the capacitance data. With a proper image reconstruction algorithm, the measured capacitance data is mapped into a 3-D permittivity image. In addition to its capability in mapping 3-D permittivity image, ECVT also leads other imaging technologies in terms of real-time feature, reduced cost, and low profile sensors[9].

The utilization of ECVT to study brain function has been done in our previous study through simulations and actual experiments[10]. Our previous research shows that ECVT is able to reconstruct dielectric objects with and without charge density. We have also extracted the brain region which was activated while the subjects performing some motoric movement.

Many fMRI studies attempt to observe brain activation during hand movement tasks, both in actual and imagery motions. It was reported that cerebellum, supplementary motor area (SMA), the premotor cortex (PMC), and the primary motor cortex (M1) showed significant activation during both executed movement (EM) and imagined movement (IM), while the somatosensory cortex (S1) was significantly activated only during EM[11]. A slightly different result was reported in IM task. Although it observed that both left- and right-hand MI activated SMA, dorsal premotor area (PMd), M1, postcentral area, inferior parietal lobule (IPL), and superior parietal lobule (SPL), much more activation was involved during left-hand IM, than during right-hand IM[12]. Another fMRI study, which related to preferred handedness to lateralization hemisphere activation, showed that in both left- and right-handed subjects, the preferred hand is controlled mainly by the hemisphere contralateral to that hand, whereas the non-preferred hand is controlled by both hemispheres[13].

In this study, we attempted to observe brain activity during executed (EM) and imagined movements (IM) using the ECVT. However the image reconstructed by ECVT has limitation in its spatial resolution. Therefore this study was emphasized on qualitative analysis on contralateral and ipsilateral brain hemisphere activation, instead of locating specifically activated brain area.

II. METHODS

A. Subjects

Six right-handed human subjects (3 males, ages range from 21-26 years old) were involved in this study. All subjects were informed of the purpose of the experiment. The subjects involved have no records of brain abnormalities.

B. Brain activity recording using ECVT

The ECVT system consists of 3 parts: a helmet-shaped sensor, data acquisition system, and a computer[9] (Figure 1). The helmet-shaped sensor comprises of a number of electrodes which are installed in such a way to emit electrical field around object and to act as a probe for receiving voltage signal. Data acquisition system is used to retrieve measured voltage and translate it into capacitance data. A computer is used as system control and to process the image reconstruction.

ECVT works by mapping an object's permittivity distribution based on measured capacitance. The variation of measured capacitance value depends on the variation of the permittivity distribution inside the brain. The relation of permittivity and capacitance value can be written in an integration form of the Poisson's equation as

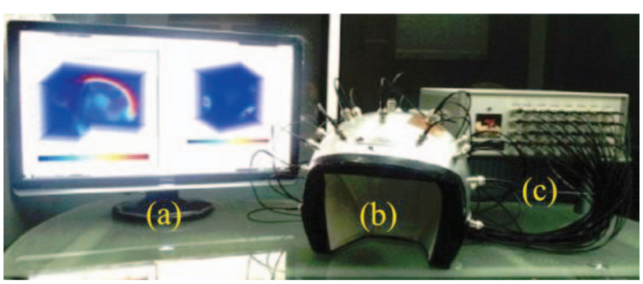


Figure 1. ECVT consist of (a) computer act as controller, processor, and display; (b) helmet-shaped sensor; (c) data acquisition system.

$$C_i = -\frac{1}{\Delta V_i} \oiint_{A_i} \varepsilon(x,y,z) \nabla V(x,y,z)\, dA \tag{1}$$

where C_i is measured capacitance value of the i^{th} electrode pair. A is the electrode's area, while ε and V are permittivity and electrical potential distribution. ∇ is del operator.

Equation (1) needs to be linearized in order to simplify calculation process as follow:

$$\mathbf{C} = \mathbf{SG} \tag{2}$$

where **C**, **G**, and **S** are capacitance, permittivity, and sensitivity matrices respectively. The sensitivity matrix **S** is obtained by finite element method (FEM)-based simulation. Further details on ECVT and its calculation technique are found in [8].

There are 2 problems in respect to the ECVT: forward problem and inverse problem [7]. The forward problem relates to how to determine capacitance matrix **C** given permittivity matrix **G** and sensitivity matrix **S**. The inverse problem is addressed to find permittivity distribution **G** given measured capacitance **C** and sensitivity matrix **S**. The inverse problem of (2) is:

$$\mathbf{G} = \mathbf{S}^T\mathbf{C} \tag{3}$$

where **G** is the permittivity distribution which is to be reconstructed. $\mathbf{S}^T$ is the transpose of sensitivity matrix **S**. **C** is capacitance value measured by each of electrode pair. The measured capacitance data was processed into permittivity distribution using iterative linear back projection (ILBP) method through inverse modeling process.

C. Experiment

We used data acquisition system (DAS) DAQ01201205V manufactured by CTECH Labs Indonesia. Which is able to measure capacitance as high as 5.5 pF and as low as 0.05 fF.

In this study, the subjects were given tasks involving motoric functions of the brain while seated on a chair with closed eyes. Data acquisition was performed on five different conditions:(1) relaxing or no motion is used as baseline condition, (2) actual movement with the right hand, (3) actual movement with the left hand, (4) imagined movement with the right hand, and (5) imagined movement with the left hand. There was a pause of half minute in data acquisition between each condition. Each measurement was done 75 times for each condition which took two minutes. In the actual-movement task, subjects were asked to flex and extend their forehand slowly. In the imagined-movement task, subjects were helped focus by looking at an arrow pointing to the same direction as their imagined-moving hand.

D. Data Analysis

The data obtained from the experiment were preprocessed before being analyzed. First, the average capacitance from all electrode pairs for each condition was calculated. The average values were used as a range in normalizing the data.

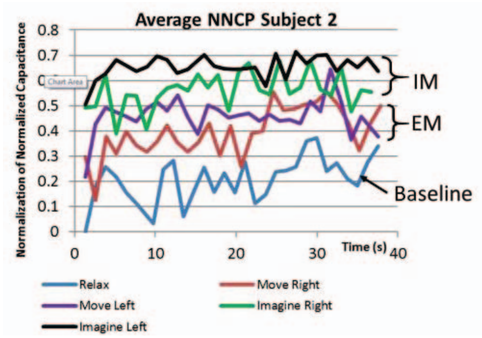


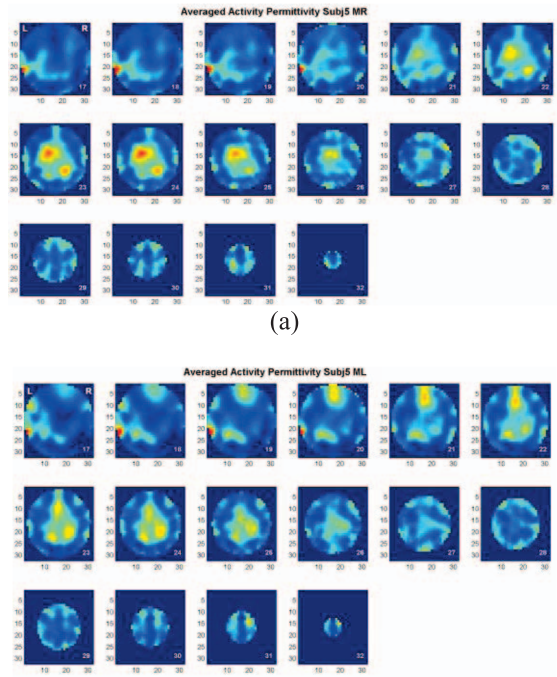
Figure 2. Average normalized capacitance subject 2

Then the capacitance data were also averaged over time and used as subtraction from the raw capacitance data. Finally, the baseline was used to subtract the activity data. Therefore the subtracted data only represented the brain activity that was changed during the motoric tasks. The subtracted data then were reconstructed using the ILBP. The reconstructed images were analyzed by calculating how many pixels were active in a particular brain region to show where brain activity occurred during a specific task.

III. Experiment Results and Discussion

Figure 2 shows the averaged of normalized capacitance from subject number 2 for all five conditions. The capacitance values for all 496 electrode pairs from each experiment condition were averaged and then plotted against time. The graphs of averaged normalized capacitance for other subjects are similar. The blue curve in bottom of the graph indicates the average capacitance used as the baseline. The subject's actives in a relaxed condition without doing any motion, showed a lower intensity as compared than the signal during motion and active thinking. Red and purple curves are above the blue line. This shows that the brain is more active during hand motion as we have expected. The red and purple curves are almost in the same level and similar although occurred on different sides of the body. The green and black curves which respectively show the averaged capacitance signals for thinking about moving right and lefts hand are above all other curves. It suggests that thinking involves higher brain activity than motion, and both of the curves almost overlap since they are associated with two similar activities.

The reconstructed images were displayed in axial slices for easy analysis. By visual inspection we can see in Figure 3(a) that the brain left hemisphere of subject 5 is more active during moving right hand (slices 31-32). On the other hand, in Figure 3(b) we can see that the right hemisphere is more active when the subject is moving left hand (slices 31-32). This result is also supported by a quantitative analysis was done by calculating a number of pixels with high normalized permittivity value from the ECVT reconstructed image in ROI around motor cortex (Figure 4). Contralateral brain hemisphere is significantly activated during the EM task. This result agrees with fMRI study on hand motor control, which stated that in right-handers, movements of the preferred hand activate mainly was the contralateral hemisphere [13].



(a)

(b)

Figure 3. The top 16 out of 32 slices of reconstructed ECVT image for brain activity related to moving: (a) right hand and (b) left hand

As shown in Figure 4, brain is more activated during the EM than IM in ROI around motor cortex, which agrees with Martin Lotze et al. [11]. They found that activated pixels in primary motor cortex and somatosensory cortex are higher in EM than IM.

Another study led by Qin Yang et al. [12] reported that IM task activate primary motor cortex and supplementary motor area, with higher activation was achieved by IM of left hand. By using ECVT, we found that IM task also activate brain in motor cortex area, although we cannot tell accurately for sure where the activation area precisely because of a relatively low spatial resolution limitation. Here, we found that the brain activity is lower in IM of the left hand than right hand, which contrast to the result reported by Qin Yang et al. This may be caused by different imagery movement task. Here, we imagine the movement (flexion and extension) of forehand, while Qin Yang et al. perform a more complicated task by tapping fingers in random sequence with visual stimuli.

If we plot the value of normalized permittivity between slices 21-24, which is averaged across all subjects, we found that ipsilateral activation is slightly stronger than contralateral activation of the cerebellum during EM task (Figure 5). Although the difference between ipsilateral and contralateral activation was little, we can notice the difference more clear in ECVT reconstructed image as seen i.e. in Figure 3. The left hemisphere of the brain was more active than the right one during EM of left hand, and the opposite also true during EM of right hand. This result is in concordance with findings of fMRI study carried by Martin Lotze et al. [11].

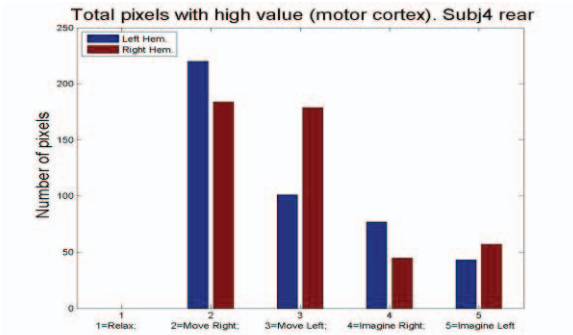


Figure 4. Total pixels with high normalized permittivity values in each brain hemisphere during different conditions. Images above is taken with ROI around motor cortex

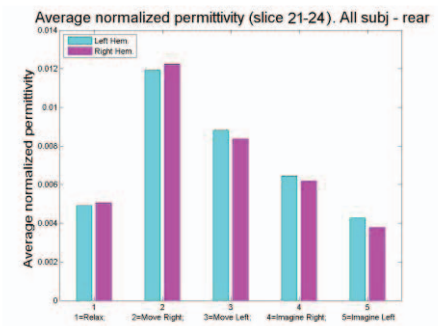


Figure 5. Normalized permittivity which is averaged across all subject with ROI between slice 21-24. We suggest that cerebellum lies beneath that ROI.

Not all lateralization experiment result conforms to the literatures. For instance, subject number 6 showed neither contralateral dominance around motor cortex nor ipsilateral dominance around cerebellum. This anomaly might be caused by signal artifacts which are introduced when the helmet sensor slightly moved. Since the measurement of the capacitance from the subjects involving hand movement and pause, the helmet sensor might move a bit if the head of subject is small (loose).

IV. CONCLUSION

A study in the observation of the brain motion activity was done to elaborate further the application of ECVT for brain activity scanner. Qualitative and quantitative method was used in analyzing the reconstructed ECVT image. The results indicate that lateral brain activation can be observed using ECVT. Moreover, ECVT show concordance with several fMRI studies about brain activity that related to the executed movement or imagined movement of hand. However, there were some anomalies which might be caused by the sliding of the helmet sensor during data acquisition.

REFERENCES

[1] E. R. Kandel, "The Brain and Behavior," in *Principles of Neural Science*, New York, McGraw-Hill Companies, Inc, 2000, pp. 7-8.

[2] M. E. Raichle, "Functional Brain Imaging and Human Brain Function," *The Journal of Neuroscience,* vol. 23, pp. 3959-3962, 2003.

[3] A. M. Dale and E. Halgren, "Spatiotemporal Mapping of Brain Activity by Integration of Multiple Imaging Modalities," *Current Opinion in Neurobiology,* vol. 11, no. 2, pp. 202-208, 2001.

[4] D. Boas, L. Campbell and A. Yodh, "Scattering and Imaging with Diffusing Temporal Field Correlations," *The American Physical Society,* vol. 75, no. 9, pp. 1855-1859, 1995.

[5] R. Gafaniz and J. Sanches, "ATP Consumption and Neural Electrical Activity: A Physiological Model for Brain Imaging," in *EMBS, 2010 Annual International Conference of the IEEE*, Buenos Aires, 2010.

[6] M. Raichle, "A Brief History of Human Brain Mapping," *Trends in Neuroscience,* vol. 32, no. 2, pp. 118-126, 2008.

[7] Z. Liu and B. He, "A New Multimodal Imaging Strategy for Integrating fMRI with EEG," in *Proceedings of the 28th IEEE EMBS Annual International Conference*, New York, 2006.

[8] W. Warsito, Q. Marashdeh and L.-S. Fan, "Electrical Capacitance Volume Tomography," *Sensor Journal, IEEE,* vol. 27, no. 4, pp. 525-535, 2007.

[9] F. Wang, Q. Marashdeh, L.-S. Fan and W. Warsito, "Electrical Capacitance Volume Tomography: Design and Applications," *Sensors,* vol. 10, no. 3, pp. 1890-1917, 2010.

[10] W. P. Taruno, M. Baidillah, R. Sulaiman, M. Ihsan, S. Fatmi, A. Muhtadi, F. Haryanto and M. Aljohani, "4D Brain Activity Scanner Using Electrical Capacitance Volume Tomography (ECVT)," in *Biomedical Imaging (ISBI), IEEE 10th International Symposium on*, San Fransisco, 2013.

[11] M. Lotze, P. Montoya, M. Erb, E. Hulsmann, H. Flor, U. Klose, N. Birbaumer and W. Grodd, "Activation of cortical and cerebellar motor areas during executed and imagined hand movements: An fMRI study.," *Journal of Cognitive Neuroscience,* vol. 11, no. 5, pp. 491-501, 1999.

[12] Q. Yang, W. Huang, W. Liao and H.-F. Chen, "Analysis of Brain Activation during Motor Imagery Based on fMRI," *Journal of Electronic Science and Technology of China,* vol. 7, no. 1, pp. 74-77, 2009.

[13] A. Grabowska, M. Gut, M. Binder, L. Forsberg, K. Rymarczyk and A. Urbanik, "Switching handedness: fMRI study of hand motor control in right-handers, left-handers and converted left-handers," *Acta Neurobiologiae Experimentalis,* vol. 72, pp. 439-451, 2012