Proceedings of the 2009 IEEE
International Conference on Robotics and Biomimetics
December 19 -23, 2009, Guilin, China

Measurement of Brain Activity Using Optical and Electrical Method

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Abstract—**There are patients that cannot produce bioelectric signals such as patients with advanced stages of Amyotrophic Lateral Sclerosis or that have suffered severe spinal cord injury, are unable to use assistive devices such as the exoskeleton HAL. This paper proposes a non-invasive brain activity scanning method for collecting the patient's movement intentions by developing a hybrid sensor that can measure both optical and bioelectrical signal of a same spot simultaneously and to evaluate it. The developed sensor consists of holography lasers and electrodes. Holography laser contains emitter and receiver inside it. In order to evaluate the hybrid sensor two kinds of experiments were carried out: 1) Data Collection Experiment in which the optical density was found to be high when the participant was in relaxation state. On the other hand, while the participant was executing mental tasks such as algebraic calculations the optical density lowered. 2) Proof of concept Experiment in which the participant tried to move the upper limb assistive device 10 times. The upper limb movement was recorded 24 times during this period. However out of this 24 times, the upper limb movement corresponded to the participant's intention 7 times that was recorder 5sec before or after subject started calculation. We developed a hybrid sensor that can collect both kinds of optical and bioelectrical signal from the same spot on the scalp was developed and evaluated in order to measure brain activity by using optical and bioelectrical data.**

I. Introduction

In order to control assistive devices such as the exoskeleton HAL, bioelectric signals are used [1]-[6]. However, there are patients that cannot produce bioelectric signals such as patients with advanced stages of Amyotrophic Lateral Sclerosis (ALS) or that have suffered severe spinal cord injury, are unable to use such assistive devices. In order to provide those patients with the ability to control those assistive devices, it is necessary to use a brain activity scanning method for collecting the patient's movement intentions.

There are several methods for scanning brain activities. Methods such as MRI and PET require very large, heavy and expensive facilities in order to be executed. It is not possible for the patient to maintain a comfortable life style and use those devices for long periods of time simultaneously. However, brain activity can also be measured by using electrical brain waves that propagate through the scalp. Brain waves can be measured using portable, wearable devices. brain waves are, however, very susceptible to noise. Bioelectrical signals originated from eye movements, facial muscular movement and external power sources such as electronic devices are common noise sources. Furthermore, due to the fact the electrical signal produced by the brain have to travel through the skull and cerebrospinal fluid, it is difficult to find the place of origin of the signal.

Another portable method for scanning brain activity is by measuring hemodynamics using optical data. This method is known as Function Near-Infrared Imaging. Different cell activities require different amounts of blood flow. Different amounts of blood flow reflect different amounts of lights. By using non-invasive optical laser probes in order to measure the blood flow around the brain, it is possible to measure the cellular activity state of the brain. Combining the bioelectrical activity data collected through the brain electrodes with the cellular activity data collected by the optical probes, it is possible to measure the brain activity and infer the area of the brain that is active with a higher degree of precision then the methods currently available.

The objective of this paper is to develop a hybrid sensor that can measure both optical and bioelectrical signal of a same spot simultaneously and to evaluate it.

II. Method

A. Device Development

1) Hemodynamics Measurement

In order to measure hemodynamics using optical data, Lambert Beer method was used.

According to Lambert Beer's Law, there is a logarithm relationship between the incident light beam I and the transmitted light beam Io, absorption coefficient ε, distant the light travels d and concentration of the solution C.

$$I = I_o 10^{-\varepsilon C d} \tag{1}$$

The light absorbance for liquids is defined as:

$$Abs = -\log_{10}\left(\frac{I}{I_o}\right) = \varepsilon C d \tag{2}$$

The Lambert Beer, however, usually does not apply for very high concentrations or if the material is highly scattering. When light is applied to blood it is attenuated by both absorption and scattering phenomena. Furthermore, when light is used on the head, the light emitter and receiver

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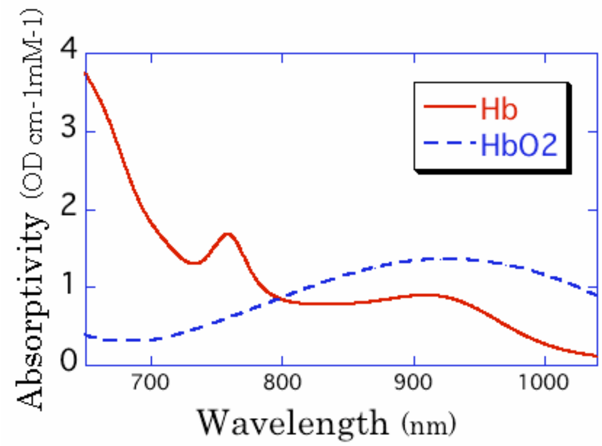

Fig. 1. Hemoglobin Absorptivity versus Wavelength. At 805nm the absorptivity of the Oxygenated Hemoglobin and the reduce Hemoglobin are the same. This wavelength has high permeability on human skin and is well absorbed by hemoglobin.

are not facing each other. Because of that, a modified version of Lambert Beer law is necessary. Modified Lambert Beer law is shown to (3).

$$\Delta Abs = \varepsilon \Delta C < d > + \Delta S \tag{3}$$

ΔAbs is the light absorbance variation, *ΔC* is the concentration variation, <*d*> is the average length of the path followed by the light and *ΔS* is scatter variation.

When a light beam is applied to a living organism, its intensity also varies according to the organic tissues that under the target region and blood flow. If we consider the intensity and wavelength of the incisive light constant and if we also consider that the variation caused by scattering can be ignored, we can evaluate the impact of each component on the formula:

•Organic tissues are static elements; therefore concentration, light path and absorption rate are constant.

•Venous blood flow has a constant flow rate. Therefore the shape of the veins is constant and the light path doesn't change. But because the blood under the beam of light is always changing and because the blood doesn't have a uniform concentration, fluid concentration and absorption rate are not constant.

•Arterial blood flow is periodically. Because of that there are changes of pressure, which are responsible for changes on the shape of the arteries. This variation of shape changes the light path. Similarly to venous blood, the presence of blood flow means that concentration and absorption rate are not constant.

The absorbance variation of the light that is incident on the living organism is shown to (4).

$$\begin{aligned} \Delta Abs = {} & \varepsilon_{tissue} C_{tissue} < d_{tissue} > + \Delta S_{tissue} \\ & + \varepsilon_{vessel} C_{vessel} < d_{vessel} > + \Delta S_{vessel} \\ & + \varepsilon_{artery} C_{artery} < d_{artery} > + \Delta S_{artery} \end{aligned} \tag{4}$$

ε_{tissue}, ε_{vessel}, ε_{artery} is the absorption coefficient of tissue, vessel and artery. C_{tissue}, C_{vessel}, C_{artery} is the concentration variation of tissue, vessel and artery. <D_{tissue},>, <D_{vessel},>, <D_{artery},> is the average length of the path followed by the light of tissue, vessel and artery. ΔS_{tissue}, ΔS_{vessel}, ΔS_{artery} is the scatter variation of tissue, vessel and artery.

Based on the facts above it is safe to assume that variation of light detected by the light receiver is a direct result of the blood flow and concentration variation.

2) Brain Wave Bioelectric Signal Measurement

Also known as Electroencephalography, EEG is the process of measuring electrical potential generated by several firing neurons simultaneously. Those electrical signals propagate through the skull, cerebrospinal fluid and scalp. A common method to measure brain wave is measuring voltage by placing non-invasive low-impedance electrodes on the scalp of the patient. Also it is important to note that voltages drop with the fourth power of the radius, so neural activities from deep sources are more difficult to register than activities from neurons near the skull [8].

In addition the bioelectrical signals on the head also reflect activation of the head musculature, eye movements, interference from nearby electric devices, and changing conductivity in the electrodes due to the movements of the subject or physicochemical reactions at the electrode sites. All of these activities that are not directly related to the current cognitive processing of the subject are considered noise [9].

Common brain waves are:

•DELTA- 3Hz and less (deep sleep, when awake pathological)
•THETA- 3.5- 7.5Hz(creativity, falling asleep)
•ALPHA- 8- 13Hz(relaxation, closed eyes)
•BETA- 14- 30Hz and more(concentration, logical and analytical thinking)
•GAMMA- greater than 30Hz(simultaneous processes)

Bioelectrical signals were analyzed by using common signal processing techniques.

3) Hybrid sensor

The objective is to develop a sensor that can capture both optical and bioelectrical data simultaneously by using a single sensor probe.

Holography lasers were used as light sources for the optical sensors. In order to keep the size of the sensor small, the light receiver and emitter were on a same device therefore the conversion of optical data into electrical data

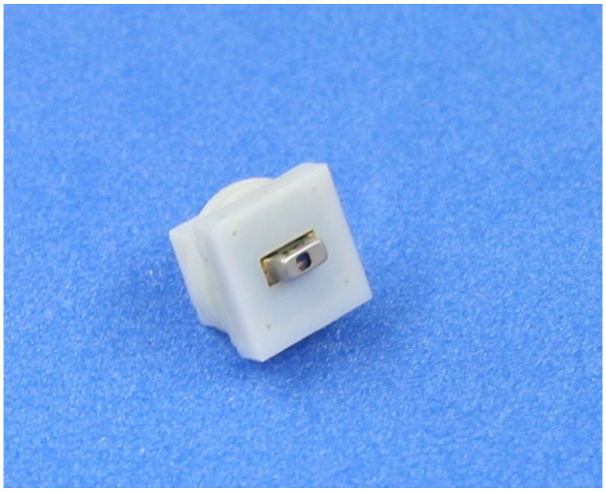

Fig. 2. Fully assembled hybrid sensor. The size of hybrid sensor is 19x19mm2 and weights is 2.73g. Hybrid sensor probe is in the center.

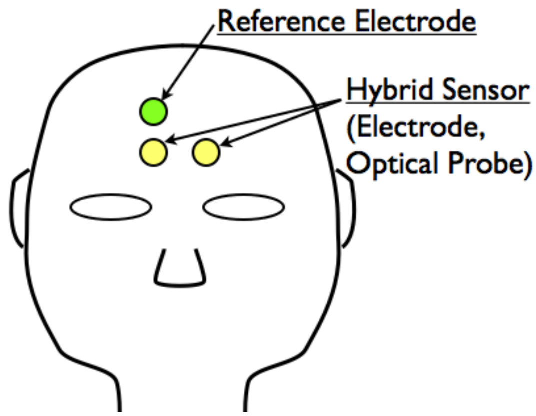

Fig. 3. Sensor position illustration. Two hybrid sensors are attached at the forehead of the participants as shown in the fig. A reference electrode is also attached measure the voltage difference between the two hybrid sensors.

was done inside the laser probe and the analog data transferred directly to the control board. Common Near-Infrared Imaging devices usually use collects the light by using optical fibers and the optical-electrical signal happens on the control board. A photo-diode was used as a receiver.

The chosen material for the electrode was silver chloride. Silver chloride was chosen because it's high price/performance. It has both very low impedance and can be acquired for relatively low prices. In order to minimize the impedance conductive gel was applied between the scalp and the electrode surface. A buffer circuit was also added to the electrode because electrical current drained from the scalp by the electrode may not be enough to overcome the relative high impedance from the cable might offer.

The electrode was placed all over the extra surface of the optical sensor with opening for the light emitter receivers.

4) Sensor Case and Sensor Array

In order to accommodate this hybrid sensor a 19x19mm^2, 2.73g plastic case was developed. The probes were placed on a soft but strong polyurethane sponge array for increased comfort and usability. The distance between the centers of each sensor was 20mm. The softness of the polyurethane sheet allowed the probes to be placed on any area of the head.

B. Control system

Triple stage amplifier/filter board composed the control system with variable parameters integrated to a microcontroller. The control board has a USB port to allow communication with an external device such as a computer or actuators. The microcontroller chosen was powerful enough to execute simple calculations and basic digital processing techniques. More advanced software technologies such as neural networks and genetic algorithms require an external PC.

The controller analog sampling rate was set to 1kHz and A/D conversion resolution was set to 12bit.

III. EXPERIMENT

In order to evaluate the hybrid sensor, bioelectrical and optical data were required. Also using only real-time, optical data controlled Proof of Concept experiment using an upper limb assistive device.

A. Data Collection Experiment

In this experiment two hybrid sensors were used. One sensor acted as emitter while the other acted as a receiver. The optical sensor emitted a wavelength laser of 805nm. This wavelength has high permeability on human skin. Furthermore at 805nm the absorptivity of the Oxygenated Hemoglobin and the reduce Hemoglobin are same. Hence it suffers little influence from oxygen saturation. Sensor is connected to amplifier/filter circuit and micro controller for A/D conversion. A/D converted signal is sent to the monitoring computer where it is saved.

Shown in Fig.3 the sensors were placed on the forehead of participant. ECG cream was applied to the electrode so as to reduce impedance. Participant was made to relax by sitting deeply on a chair with his eyes being close. The participant was given instructions to make some kind of mental task such as calculations.

During the Data Collection Experiment, high optical density was observed on the optical output in relaxing state. However the optical density decreased when the user switched from relaxing to mind-task state that shows that switching operation is possible with the current system.

B. Proof of Concept Experiment

The purpose of this experiment is to control of the upper

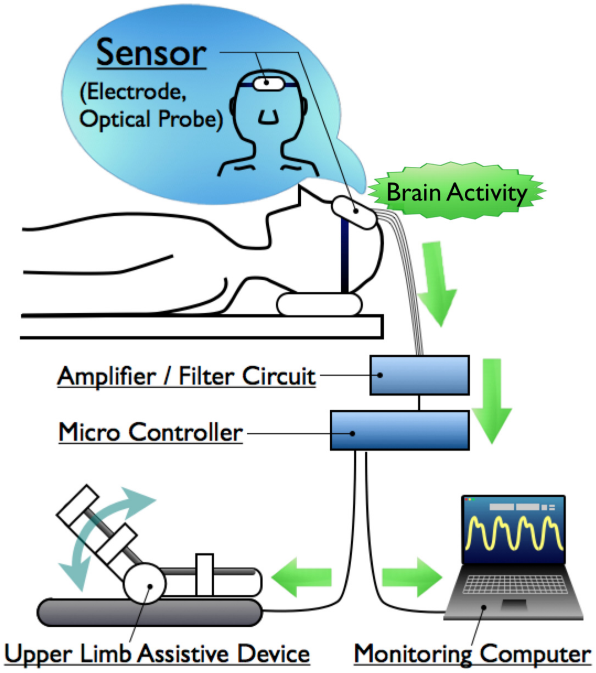

Fig. 4. Experiment System setup for Proof of Concept Experiment. Upper limb assistive device is connected to the control board. Hybrid Sensor is connected to amplifier/filter circuit and micro controller for A/D conversion. A/D converted signal is sent to the monitoring computer where it is saved. The sensors were placed at the forehead of participant.

limb assistive device based on the brain activity signal. In this experiment we implement the results achieved in the Data Collection Experiment for brain activity signal.

Instead a single binary signal created by the controller after analyzing the signal from the sensor turned the actuator inside the device on and off. The control board was programmed to invert the state of the actuator. Every time the max of optical value per 800 msec went over a predetermined value, it inverted the value of the output register that control the assistive device actuator. Ideally, every time, the participant focused on a mental task the assistive device would turn on or off.

For the experiment an upper limb assistive device was connected to the control board as shown in Fig.4. Sensor is connected to amplifier/filter circuit and micro controller for A/D conversion. A/D converted signal is sent to the monitoring computer where it is saved.

Shown in Fig.3 the sensors were placed on the forehead of participant. ECG cream was applied to the electrode so as to reduce impedance. Participant was made to relax by sitting deeply on a chair with his eyes being close. The participant was made free to make mental task such as calculations, and was handed a switch to notify the timing when he/she starts the mind task by pushing the switch.

TABLE I
THE NUMBER OF MENTAL-TASKS AND THE ASSISTIVE DEVICE MOVES

	Number of Times
The number of mental-tasks	10
The number of the assistive device moves (totally)	24
The number of the assistive device moves in 5 seconds before/after mental-tasks	7

The participant was made free to make mental-task such as calculations, and was handed a switch to notify the timing when he/she starts the mental-task by pushing the switch. While mental-tasks were made 10 times, the assistive device moves totally 24 times. In this experiment, the assistive device moves 7 times in 5 seconds before / after a mental-task was made.

IV. RESULT

A. *Data Collection experiment*

Shown in Fig.5, the optical density was found to be high when the participant was in relaxation state. On the other hand, while the participant was executing mental tasks such as algebraic calculations the optical density lowered.

EEG measured using electrode in fig.5. when the participant switch from relaxation mode to mental-task mode the voltage between the hybrid and reference electrode increases.

B. *Proof of concept experiment*

From Fig.6 the participant tried to move the upper limb assistive device 10 times. The upper limb movement was recorded 24 times during this period. However out of this 24 times 7 times, the upper limb movement corresponded to the participant's intention that was recorder 5sec before or after the switch was pressed.

V. DISCUSSION

A. *Data Collection Experiment*

Blood concentrates in the frontal cortex during task that requires concentration. Optical density decreases with the increase of blood and vice versa. From Data collection Experiment it can be know that the optical density is decreasing when the participant started mind-task. The brain activity can be measured using the sensor developed.

It is absorbed that α wave gets weaker and β wave get stronger when calculation is performed using EEG. This time there was no remarkable differences between α and β wave. The reason can be attributed to the sensor position attached on the forehead. There is a need to measure EEG at different position in future.

B. *Proof of Concept Experiment*

In Fig.6 the upper most graph is data for first 100sec

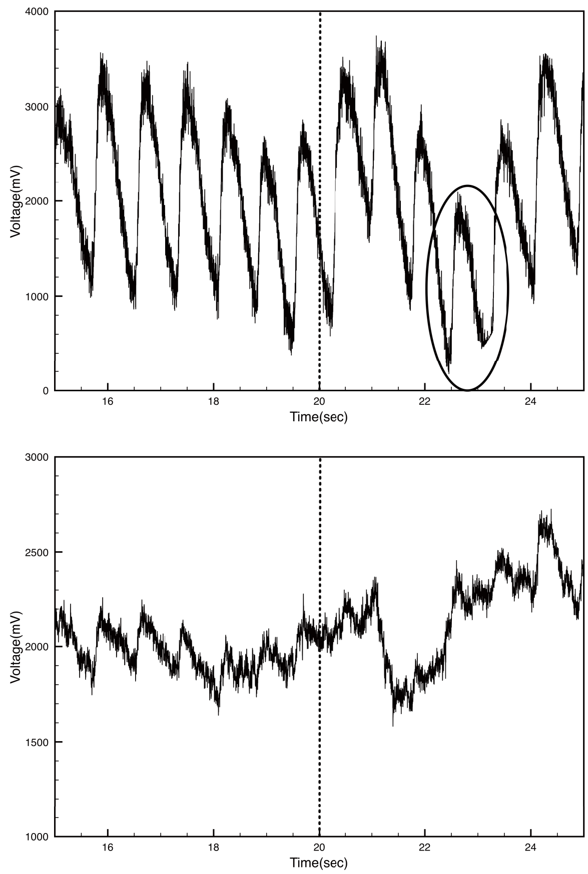

Fig. 5. Result corresponding to Data Collection Experiment
The above most graphs: Data is brain blood information measured using optical part of hybrid sensor. The circle shows that the optical density is lowered when the participant switch form relaxing mode to mental-task mode.
The below graphs: Data is brain nerve activity measured using electrode of hybrid sensor.
Dotted ling represents the start point of calculation. Portion on the left of the dotted line is for relaxing mode where as portion the right side is when the participant is performing mind task.

during which the participants tried to move the upper limb assistive device 4 times. However the assistive devise moved 15 times out of which two times the movement corresponded to the intention of participant by moving within 5sec before or after the button was pressed. For the experiment between 100sec to 195 sec the participant tried to move the upper limb assistive devise 6times however the devise moved 9 times out of which 5 times the movement corresponded to participants intention by moving within 5sec before or after the button was pressed.

During the first few tries chance of success was found to be low. But, as the participant practices for several trials, probability of success increased considerably.

The reasons for the low success rate in the initial stage of the experiment can be attributed to no learning history of the brain. However, the human brain can accustoms itself to unfamiliar conditions though repeated learning and can operate precisely. There were cases when the assistive device moved even before the participant pressed the button.

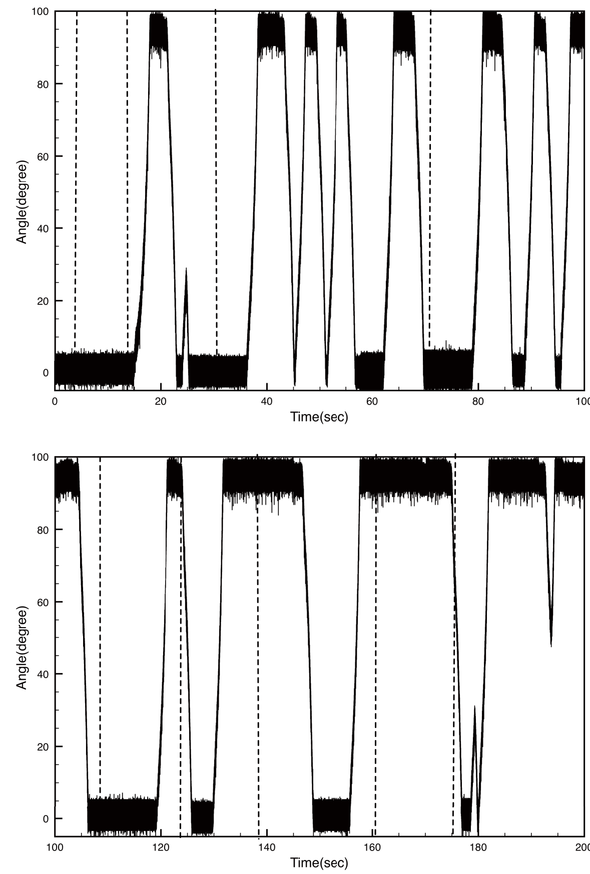

Fig. 6. Results graphs corresponding to Proof of Concept Experiment. Dotted line represents the start point of mind task, whereas the red line is elbow angle. Upper most graph is data from t=0 to t=100. The graph below is the data corresponding to t=100 to t=195

This may be attributed to the fact that because the participant is free to decide when to start the mental task, his brain is already prepared to calculated.

The user set the threshold value based on observation during the Data Collection Experiment. There was no learning process executed by the controller. Data Collection Experiment and Proof of Concept Experiment were executed in different periods of time. The human body biochemical state is dynamic therefore threshold value is varies according to different periods of the day. Implement a dynamic threshold value by using learning algorithms can potentially increase the success rate of the experiment. It is important to notice that bioelectrical signals from the brain was not used. The use the bioelectrical signals could increase the accuracy of the test.

VI. Conclusion

In this paper, a hybrid sensor that can collect both kinds of data from the same spot on the scalp was developed and evaluated in order to measure brain activity by using optical and bioelectrical data.

Data analysis during and after the experiments have shown that the bioelectrical data collected by the hybrid sensor was very similar to the data collected by an ordinary disposable electrode. Similarly, the optical data collected by the hybrid sensor was almost similar to data collect from a standard function near-infrared imaging device. Accordingly it can be shown that the hybrid sensor proposed in this paper can be used to measure brain activities, by using only two devices.

Our next step is to use this new technology to register with accuracy the user's movement intentions and use this data to accurately control assistive devices.

ACKNOWLEDGMENT

This work was supported in part by the Grant-in-Aid for the Global COE Program on Cybernics: fusion of human, machine, and information systems, University of Tsukuba and relevant organizations.

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