Brain Activity Estimation with Precise Motor Measurements of Visual Synchronization Task of Hands

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***Abstract*— Visual synchronization tasks are difficult. We need intensive brain activity for completing visual synchronization tasks. Recently, we can measure the precise movement of a human with cheap and easy to use sensors. We propose a method to estimate the total brain activity using the precise measurement of the motor of a human body. This paper measures the movement of hands of a human synchronizing the example movement presented on a display. With the Fourier analysis of the movements, we propose to measure the synchronization of hands. This measure helps to detect a small change of the brain activity that might be indicative of brain diseases. As a result, the measure helps to detect a small symptom of brain diseases.**

Keywords-motor measurement; cerebral dysfunction.

I. INTRODUCTION

There are many motor tasks that measure the abilities of motor functions of a human. They are the Purdue pegboard task, a seal affixation task, a tray carrying task, etc. [1][2][3]. These tasks estimate the ability of a motor function of a human based on the results of the tasks. There is no observation of the process of the tasks.

There are also some synchronization tasks used to measure human abilities. For example, they are synchronization of finger taps with periodically flashing visual stimuli and synchronization with an auditory metronome. In these tasks, the timing between the stimuli and the tapping is measured. There is no observation of the process of the tapping [4][5][6][7][8][9][10].

Recently, many cheap and easy measurement methods for the movements of a human body have been developed. For instance, some of these sensors include Kinect sensor, and Leap motion sensor [11][12]. There are many applications that use those sensors for controlling computers. For instance, there are many video games that use those sensors for controlling an avatar in the games [13].

Many researchers report that many kinds of brain disorder affect motor functions. In this paper, we propose a method measuring motor functions that are reflections of many brain functions. If we can measure the motor functions that reflect all the brain functions, the measurement reflects the total brain activity. As a result, in case of any brain disorder, the measurement of motor functions will reveal some symptom about the disorder.

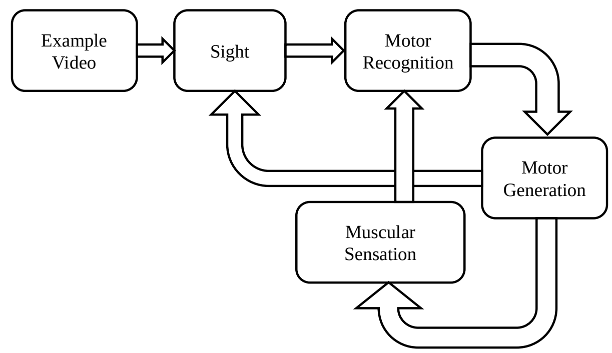

Figure 1. Relations among brain functions for performing the proposed synchronization task.

The human hands are the parts of a body that can make the most complex movements. This paper proposes a method that measures the precise movements of hands synchronizing the movements of hands on a display. The synchronization needs visual perception of the displayed hands' images and precise control of the arm muscles.

We can now precisely measure the movement of hands. This paper proposes a new synchronization task and the evaluation method. The resulting measure is very sensitive. With this measure, we can observe the developments of the motor function and infer on brain activity.

First, we discuss the synchronized hands' movements with visual presentation. Then, this paper proposes the outline of the proposed observation system for visual synchronization of hands' motions. Next, we show our implementation of the observation system. Then, we discuss the brain function estimation method using the measured visual synchronization. Next, we show our experimental results and conclude this work.

II. VISUAL SYNCHRONIZATION TASK

There are many motor tasks that intend to measure the motor function of a human. However, most of these tasks measure the results of the tasks. There are some tasks that measure the synchronization between a finger tap and stimuli. With human observations, it is difficult to measure the process of synchronizing movements. Now, we can use a Kinect sensor and a Leap Motion sensor. Those sensors

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measure the three-dimensional movements of a human body. With these sensors, we can measure the precise movements of a human body.

We can synchronize our movements with each other. For instance, in playing a dance, dancers can synchronize their movements with each other. A synchronization of movement is more difficult work than a simple imitation of movement. To generate synchronized movements, we need to observe the motion to be synchronized. We need to generate the motion to be similar to the motion synchronized. We need to observe the generated motion synchronizing the original motion. We need to estimate the divergence between the original motion synchronized and the motion synchronizing the original motion. We need to control the speed of the motion synchronizing. These functions make the feedback loop. However, for compensating our brain's processing delay, we need to estimate the delay itself and make feedforward.

This processing loop is shown in Fig. 1. For estimating the total brain function, we need to include all the functions of a brain. The visual synchronization task includes vision and motor functions. The vision includes not only the static sight, but also the dynamic sight.

The visual synchronization is more difficult than audio synchronization. So, we observe the wider brain functions with the visual synchronization tasks than the audio synchronization tasks.

Our proposed visual synchronization task is the synchronization between the position of stimuli on a display and the position of hands. Our synchronization task is not the synchronization between the timing of stimuli and the timing of action. The measurement of timing is only one scalar value. In our proposed synchronization task, the measurements of positions between the stimuli and the hands are the sequence of a triple of the position of the stimuli and the ones of both hands.

III. VISUAL SYNCHRONIZATION OBSERVATION SYSTEM

Classical synchronization tasks measure the timing between the result of action and the stimuli. We observe the process of synchronization between the stimuli and the motion.

A. *Stimuli*

For the motor task, we select the rotation of both hands. Rotation is a difficult movement of a hand. For analyzing the synchronization easily, we make the stimuli follow a precise sine curve. If stimuli form a precise sine curve, we easily evaluate the observed motion comparing with the sine curve. Fig. 2 shows the sequence of stimuli. The images are proposed on display with a constant interval from top to bottom. And then, they are proposed from bottom to top. These two sequences make one cycle of the stimuli of hands' motion. In the stimuli images, the right hand and the left hand are the same. The right one is the mirror image of the left one.

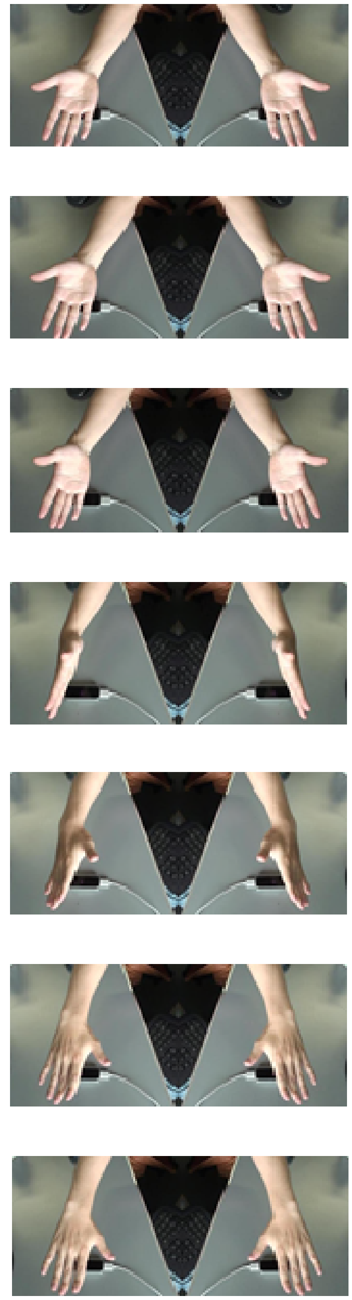

Figure 2. Stimuli Images.

B. *Stimuli generation*

Our stimuli are a displayed video of both hands' rotation. However, in a normal video, it is difficult to control precisely the motion of hands in the video to follow the sine curve. It is also difficult to evaluate the synchronization between the stimuli and the motions of hands. We propose the stimuli generation method that displays a proper image at the precise timing.

C. Hands' rotation measurement

We use the Leap motion sensor for measuring the position and the pose of both hands [12]. With the Leap motion sensor, the measurements are not performed at a fixed interval. However, the Leap motion sensor measures the position and the pose of hands about 120 times within a second. We determine the precise position and pose at every 1/100 S with interpolating linearly between two adjacent measurements.

D. Synchronization measure

We define the synchronization measure using FFT (Fast Fourier Transform) results of the estimated poses of both hands in each cycle. If a subject makes complete synchronization to the stimuli, the resulting pose of both hands follow a complete sine curve. As a result, at every cycle of the rotation of hands, the result of FFT has a zero value at the second term or higher terms. We define the measure as (1). This measure increases with the amount of the difference from ideal sine curve.

$$(\sum_{x=2}^{t/4} m_x)/m_1 \quad (1)$$

In (1), t is the number of terms. m_x is the absolute value of the x-th term of the result of FFT. m_1 is the power of the lowest frequency. This represents a one cycle of a hand's rotation. If the rotation of a hand follows the stimuli images precisely, the m_1 carries all powers of the hand's rotation. Other terms carry no power. In the case, the measure in (1) is 0.

m_0 is a value that represents the average of poses. This is not included in (1). As a result, this measure does not depend the absolute poses of hands.

We call this measure as Non-Smoothness-Measure (NSM). This measure may span from 0 to infinite.

Our proposed system observes two hands. So at every cycle, we have two NSMs.

IV. Implementation of the Proposed Sytem that Measures Visual Synchronization

A. System Overview

The visual synchronization measurement system has two major parts. One part displays the intended hand's motion, and the other part measures the position and the pose of hands with the Leap motion sensor. These two main parts must work smoothly. The stimuli must be updated at precise timing. The measurements of the position and the pose of hands must continue without interruption. To perform these requirements, our proposed implementation has two main processes. One process works to display stimuli images, and the other records the position and the pose of hands.

We use Python and Pyglet for implementing the system [14]. Pyglet is an object-oriented programming interface for developing games and other visually-rich applications [15].

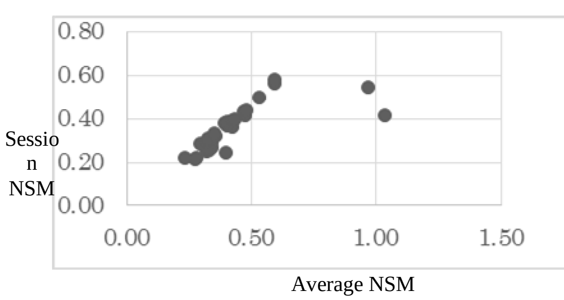

Figure 3. The distribution of the pairs of session NSM and average NSM.

B. Stimuli Image

For creating stimuli images, we recorded the hands' rotation images with the measured hands' positions and poses. Then, we selected the images that fit for the sine curve. The selected sequence of hands' images fits for the sine curve.

C. Stimuli Image Presentation

With the progress of time, our proposed system selects the most proper image and proposes on a display. This stimuli image presentation takes a one process. There is no intervention from other processes, for instance, hands' rotations measurement.

D. Hands' Rotations Measurement

We use the Leap-Motion-Sensor for measuring the hands poses. To measure the pose of hands, we can use attached type sensors. The attached type sensors have enough accuracy and measuring speed. However, we need longer setup time. This prevents the easy and fast measurement. The sensor measures the pose of hands at each 1/100 S. The measurement includes the positions and the poses of both hands. The measured record has about 700 KB in 25 second. The system must record all data without loss. This measuring shares a one process. As a result, there is no intervention from the Stimuli image presentation. The sensor works in enough speed.

V. Experiments and Discussions

We made two types of experiments. One experiment elucidates the distributions among normal people. The other does the changes on a person.

A. Experiments Setup

From the pre-experiments, the speed of the hands' rotation is best at one cycle per second. Subjects need about 10 S to synchronize their movements of hands to the proposed motion images. As a result, one session of an experiment needs at least 11 S. For getting reliable results, we decide that the length of a session is 25 cycles of rotations. This means that one session needs 25 S. Before starting a session, we instruct a subject to synchronize their hands to the displayed hands' images.

B. Session Non-Smoothness Measure

At each session, we have 25 cycles' measurements. As a result, we have 25 pairs of NSMs (Non-Smoothness Measure). Our observation shows that a subject needs about 10 S for synchronizing to the proposed images. So, we exclude first 10 cycles. As a result, at each session, we have a sequence of 15 pairs of NSMs.

At a single cycle, there may be some distributions. We select three continuous cycles' average of NSMs to evaluate the synchronization. At each session, we select the minimum of three continuous cycles' averages of NSMs as the NSM for the session at each hand. The NSM is computed at each hand. We have two points that the average of continuous three NSMs is the smallest. At each point, we have a pair of the averages of continuous NSMs. They are the average NSMs of the left and right hands. As a result, we have four average NSMs.

A pair has the average NSM at left hand and the average NSM at right hand, when the average NSM of the left hand is minimum. And, another pair has the average NSM at left hand and the average NSM at right hand, when the average NSM of the right hand is minimum. From the four NSMs, we decide that the session's NSM is the minimum of all four NSMs.

TABLE I. EXPERIMENTAL RESULTS OF NORMAL PEOPLE.

	Cycle number where the NSM is the smallest.		NSMs at the cycle where the Right hand NSM is the small		NSMs at the cycle where the left hand NSM is the small		Session NSM	Average NSM	Average NSM|-Session NSM
Subject	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**			
M 22	7	8	0.31	0.36	0.32	0.32	0.31	0.33	0.02
M 24	1	5	0.24	0.83	0.26	0.24	0.24	0.40	0.15
M 24	7	1	0.37	0.33	0.40	0.32	0.32	0.35	0.03
M 27	2	6	0.31	0.36	0.32	0.29	0.29	0.32	0.03
M 20	2	2	0.43	0.51	0.43	0.51	0.43	0.47	0.04
M 20	0	9	0.44	0.51	0.47	0.50	0.44	0.48	0.04
M 24	8	3	0.31	0.32	0.39	0.27	0.27	0.32	0.06
M 27	11	11	0.29	0.39	0.29	0.39	0.29	0.34	0.05
M 19	9	0	0.39	0.38	0.47	0.37	0.37	0.40	0.04
M 19	4	4	0.62	0.56	0.62	0.56	0.56	0.59	0.03
F 19	8	9	0.39	0.44	0.44	0.42	0.39	0.42	0.03
F 19	9	7	0.43	0.43	0.47	0.40	0.40	0.43	0.04
M 27	2	10	0.22	0.35	0.28	0.27	0.22	0.28	0.06
F 20	1	1	0.22	0.25	0.22	0.25	0.22	0.23	0.01
M 21	6	0	0.29	0.35	0.31	0.33	0.29	0.32	0.03
M 21	2	0	0.26	0.41	0.34	0.32	0.26	0.33	0.07
M 20	1	2	0.27	0.43	0.29	0.39	0.27	0.34	0.08
M 20	8	8	0.38	0.41	0.38	0.41	0.38	0.39	0.01
F 21	1	2	0.29	0.31	0.29	0.30	0.29	0.30	0.01
F 21	8	0	0.34	0.32	0.38	0.25	0.25	0.32	0.07
M 20	7	6	0.21	0.35	0.23	0.30	0.21	0.27	0.06
M 20	8	8	0.30	0.37	0.30	0.37	0.30	0.33	0.03
M 20	0	0	0.33	0.37	0.33	0.37	0.33	0.35	0.02
M 20	7	8	0.30	0.34	0.34	0.31	0.30	0.32	0.02
M 18	10	9	0.46	0.39	0.49	0.36	0.36	0.42	0.06
M 18	0	6	0.55	1.62	1.13	0.56	0.55	0.97	0.42
M 20	2	2	0.58	0.60	0.58	0.60	0.58	0.59	0.01
M 20	3	5	0.53	0.53	0.57	0.50	0.50	0.53	0.03
M 19	5	5	0.42	0.39	0.42	0.39	0.39	0.40	0.01
M 19	10	10	0.54	0.41	0.54	0.41	0.41	0.48	0.06
M 25	6	0	1.06	1.17	1.49	0.42	0.42	1.03	0.62
Average	5.00	4.74	0.39	0.48	0.44	0.38	0.35	0.42	0.072
Normal distribution	3.45	3.58	0.16	0.27	0.25	0.10	0.10	0.17	0.123
M 58	0	0	2.43	2.43	2.43	2.43	2.43	2.43	0.0

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C. Distribution on Normal adult people

There are 19 subjects whose ages span from 18 years old to 27 years old. They include three females.

Fig. 3 shows the relation between the session NSM and the average NSM. In many cases, the average NSM and the session NSM have linear relation.

Each subject tries two sessions. There are 38 sessions. However, at some sessions rotation measurements fail. As a result, we have 31 valid sessions of normal subjects. Table I shows 31 valid sessions' NSMs and one subject who declares weakness in sport. In the subject column, M represents a male. The number is the age. The 'Right' is the position where the right hand's NSM is minimum. The 'Left' is the position where the left hand's NSM is minimum. The 'Right/R' stands for the NSM of the right hand at the position where the right hand's NSM is minimum. The 'Left/R' stands for the NSM of the left hand at the position where the right hand's NSM is minimum. The 'Right/L' and the 'Left/L' do respectively.

The average is 0.35. The normal distribution is 0.10. The distribution is small. The range of NSM under 1.0 include over 0.9999999999. In most of the sessions, the session NSM and the average NSM are nearly same. However, at two sessions, they are different. We can conclude that the session NSM and the average NSM are nearly same in a normal person. If the average NSM and the session NSM are different, there may be a problem at the measurement or the subject.

D. Subject weak in sports

We have one subject who declares his weakness in sports. The last raw in Table I shows NSM of a subject who is weak in sports. The session NSM is very large, and it differs 21σ from the average of NSMs of the normal people.

E. Personal diurnal variation

With two subjects, we observe the diurnal variations. They are 25 years old and 27 years-old males. In this experiment, we measure the performance at every 30-minute interval from 9:00 to 18:00. Table II and Table III show the experimental results. There are some missing data. Figure 3 and Fig. 4 shows the session NSMs in time series. In the figures, the linear estimation form and R^2 are shown. Their linear approximation shows a little increase in the time course. This may show the accumulation of fatigue. However, the R^2 is lower than 0.5. The number of experiments is not large enough for concluding. In the afternoon, the two subjects show a large increase of the NMS. At the time, they may be a little sleepy. At the time, the brain activity may be a little lower than a normal state.

The averages are 0.30 and 0.31. The normal distributions are 0.07 and 0.04. The diurnal variation

TABLE II. DIURNAL VARIATION

Time	Right	Left	Right/ R	Left/R	Right/ L	Left/L	Session NSM
9	9	2	0.21	0.30	0.27	0.26	0.21
9.5	-	-	-	-	-	-	-
10	9	4	0.26	0.31	0.34	0.30	0.26
10.5	9	9	0.29	0.29	0.29	0.29	0.29
11	4	2	0.39	0.31	0.42	0.27	0.27
11.5	5	0	0.28	0.73	0.33	0.36	0.28
12	0	9	0.35	0.46	0.45	0.38	0.35
12.5	-	-	-	-	-	-	-
13	6	3	0.29	0.39	0.32	0.32	0.29
13.5	1	0	0.30	0.35	0.31	0.32	0.30
14	4	2	0.72	0.65	1.54	0.37	0.37
14.5	4	5	0.32	0.35	0.33	0.33	0.32
15	1	0	0.31	0.36	0.34	0.35	0.31
15.5	2	7	0.31	0.87	0.33	0.36	0.31
16	3	3	0.31	0.36	0.31	0.36	0.31
16.5	8	4	0.32	0.43	0.46	0.37	0.32
17	0	7	0.31	0.42	0.38	0.42	0.31
17.5	-	-	-	-	-	-	-
18	9	7	0.30	0.40	0.35	0.34	0.30
Average			0.33	0.44	0.42	0.34	0.30
Normal distribution			0.11	0.16	0.29	0.04	0.04

TABLE III. DIURNAL VARIATION

Time	Right	Left	Right/ R	Left/R	Right/ L	Left/L	Session NSM
9	0	6	0.27	0.32	0.38	0.27	0.27
9.5	-	-	-	-	-	-	-
10.5	7	0	0.31	0.34	0.39	0.32	0.31
11	3	1	0.25	0.38	0.28	0.31	0.25
11.5	0	0	0.32	0.36	0.32	0.36	0.32
12	8	7	0.22	0.40	0.23	0.33	0.22
12.5	-	-	-	-	-	-	-
13	10	10	0.46	0.45	0.46	0.45	0.45
13.5	11	11	0.49	0.46	0.49	0.46	0.46
14	1	1	0.30	0.27	0.30	0.27	0.27
14.5	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-
15.5	3	5	0.33	0.28	0.34	0.27	0.27
16	7	7	0.90	1.10	0.90	1.10	0.90
16.5	8	8	0.32	0.28	0.32	0.28	0.28
17	8	4	0.33	0.91	0.34	0.34	0.33
17.5	6	6	0.32	0.34	0.32	0.34	0.32
18	1	12	0.30	0.37	0.40	0.32	0.30
Average			0.36	0.44	0.38	0.38	0.31
Normal distribution			0.16	0.23	0.15	0.20	0.07

of a person is smaller than the inter-individual variation. As a

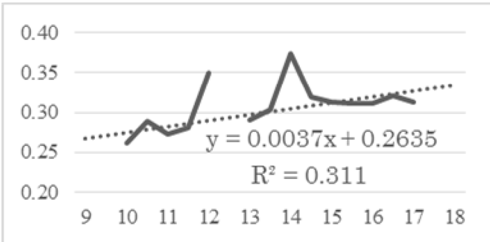

Figure 4. Personal diurnal variation of subject 1.

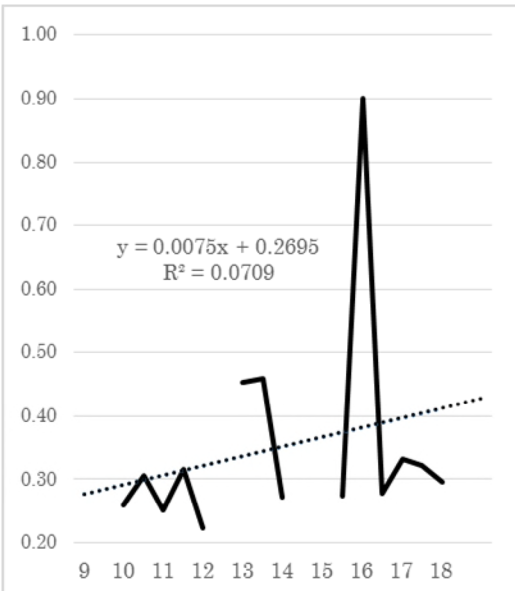

Figure 5. Personal diurnal variation of subject 2.

result, we have the reliable NSM of a person with a small number of trials.

F. *Discussions about Brain Activity*

In subsection D, the NSMs of healthy peoples converges on 0.35. In subsection E, the diurnal variation is smaller than the inter-individual variation.

If the NSM is large, there is a problem of the motor functions. The cause of the problem may not only be the disorder about brain functions, but also be the disorder about nerves, muscles, etc. Our proposed method cannot find the cause of the motor disorder. However, if there is no change in the functions about nerves, muscles, etc., the increase of the NSM shows the disorder about the brain.

If we have the NSMs about a person in a long term, the increase of the NSM shows the new disorder about brain function.

VI. CONCLUSION

The pair of the proposed synchronization task and the evaluating method enable to measure the precise performance of the motor function of hands. The task is easy to perform. For instance, it needs merely 25 S. The proposed Non-Smoothness Measure has enough power of discrimination between normal people and people that has some motor problems.

This NSM can be used for evaluate the development of the motor function of children. This NSM detects very small disorder of the brain activity. For normal people, the NSMs concentrate on a small range. The personal diurnal variation is small enough for detecting small disorder of brain activity. We will perform larger scale experiments in the next step.

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