Analysis for Induced Movement using a Measurement System of Dynamic Posture Behavior

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ABSTRACT

Today, Virtual Reality (VR) technology has been widely applied in various fields. In past research, the influence of inducing VR in humans through the human senses or virtual effects has been studied. However the methods used to analyze human sensation have only involved measuring the center of gravity and questionnaire surveys. On the other hand, it is known that the sensation induced by VR affects the user's behavior. Therefore, a basic measurement method and experimental system for human behavior induced by VR is proposed in this study. In addition, various experiments are performed using the proposed system in order to evaluate its effectiveness. As a result, the ability to measure one kind of VR effect called "Vection" is confirmed. Furthermore, a novel evaluation algorithm of induction of Vection is proposed.

keyword Kinematics and dynamics, Human information processing, Wavelets and fractals

Index Terms: I.2.9 [Artificial Intelligence]: Robotics—Kinematics and dynamics; H.1.2 [Models and Princiles]: User/Machine Systems—Human information processing; G.1.2 [Numerica Analysis]: Approximation—Wavelets and fractals

1 INTRODUCTION

Recently, Virtual Reality (VR) technology has been used in various fields, such as in rehabilitation systems in welfare fields, and as driving simulators in vehicle related fields. VR technology is required to produce highly realistic sensations. Therefore, most VR systems apply visual and bodily stimuli to the user. In this case, various emotional and psychological effects of the user are produced and the perception of self-motion is induced mainly by presentation of visual stimulation that produces an effect called "Vection".

In order to make VR technology produce highly realistic sensations, using an effect such as vection is effective. Therefore, mechanisms for inducing vection using various methods have been studied. However, the instrument and measurement for vection and its phenomenon were conducted by using questionnaire surveys or by measuring changes in the center of gravity of the user. Hence, the dynamics of vection have not been analyzed in previous research from the viewpoint of their frequency. Therefore, if the mechanism of inducing this phenomenon is clarified, the applicable fields of VR can be extended widely.

"Vection" is one type of quasi-motion perception that occurs without actual body motion. We can have a similar experience when we are sitting in a stationary train and see another stationary train just beside us on the platform. When the other train moves, we may feel that we are moving in the opposite direction even though our train is not moving. This experience is regardless of physical motion, and is just a sensory feeling.

Vection is induced by sensory stimulation including visual stimulation. In particular, visual stimulation induces vection more easily compared with other types of stimulation. It can also result in actual body movement due to an error in the body's balance control. Therefore, in order to make realistic VR sensations using vection, the dynamics and mechanisms between human perception and vection need to be studied.

In previous research, several researchers tried to measure the degree of vection by visual stimulation and induced motion perception in the human body. An instrumentation of motion perception was conducted without considering the actual body motion. In cognitive science, experiments use visual stimulation like optical flow, and the center of gravity of the human subject is measured. Also the duration time of vection is analyzed using questionnaire surveys. It has been found that the frequencies of visual stimulation and induced motion occupy the same bandwidth, and there is a time lapse between the starting time of the stimulation until the induced behavior. However, the measurement results were not considered non-stationary of frequency and their dynamics[1]-[9].

On the other hand, vection induces not only perception but also changes in human posture indirectly. In fact, Tanahashi [8] and Thurrell [9] evaluated vection from postural behavior which were induced by vection. Takeda [3] investigated the relationship between body sway and visual wide-field images. These researches measured the center of gravity by a force plate when visual stimulation was presented. As a result, the visual stimulation induced vection in the subjects, and their postures changed. Thus it can be concluded that there is a relationship between vection and postural behavior. If these changes can be measured, dynamical analysis of vection can be performed. Moreover, by clarifying the dynamics and the relations between visual stimulations and induced behaviors, highly realistic VR technology can be produced. This is especially useful for rehabilitation therapy for patients who require improvement in their own gait after accidents or illnesses. In this case, the patients must recall their feelings for trips or the sway of their own bodies. This kind of rehabilitation therapy is conducted at the final stage with the subject's entire body supported by therapists. If highly realistic VR technology can be achieved in this application, it would be useful for decreasing this kind of hard work for therapists and increasing the patient's safety.

In this paper, an instrumentation device and method for vection and its related behavior are proposed from the viewpoint of mechanical measurement for postural behavior. Their calculation methods for degree of induction of vection considers their frequency characteristics. In the next section, the proposed device and experimental setup are described. Next, fundamental experiments using the proposed system are conducted. Finally, the effectiveness of the proposed system and its analysis method are discussed through the analysis of postural behaviors using the Wavelet Trans-

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form.

2 PROPOSED SYSTEM

In this research, the novel measurement device shown in Figure 1 is used. The device has a standing plate for the human subject with 2-degree-of-freedom rotational motion in the horizontal plane along axes X and Y. In each rotational axis, an AC Servo motor (Yasukawa Elec. Corp SGMAS C2ACA41, 150 W, Max. 6000 rpm with 1:100 harmonic drive speed reducer and rotary encoder) is installed. This device was designed to measure human behavior, and can accommodate a person with a maximum height and weight of 1.80m and 80kg, respectively. Mechanical movement of the device was defined based on the "balance board", used for rehabilitation therapy. In consideration of the safe area of the subject and the conventional device, the size of standing plate is set to 0.40 by 0.60 m.

AC servo motors in each axis are controlled to keep their initial position by their angular velocity during measurement, so that the system can be performed to support the human subject while it measures swaying postural motion. So, as the human subject changes their postural behavior, the rotational angle of the standing plate can be measured. Control gains in each AC Servo motor were set to perform their motion with spring component by using trial-and-error adjustment. In this device, the range of movement of the standing plate is set to $\pm$ 5 deg, and the rotational angle is recorded by personal computer with a sampling frequency of 20 Hz.

Figure 2 shows the experimental setup including the proposed device, where visual stimulation is applied to the human subject by using an LCD projector located behind the subject which projects onto a screen in front of the subject. System experiments can also be conducted using various human stimuli because the AC Servo motor installed in the proposed device not only provides the supporting force but also induces the actual motion in the rotational axis.

The main features of the proposed system are as follows. First, the system can measure the postural behavior while the subject experiences several stimuli, both visual and postural, by controlling and measuring the angle of the standing plate.

The second point is the measurement method. In past research, the data which could be measured from the subject was static information like questionnaire surveys. By measuring changes in the center of gravity, it is possible to reduce the effects of the induced perception. This is because the human subject also feels the reaction force from the floor on the soles of their feet when they change their center of gravity, and it makes the subject aware of the changes in their own posture. In the previous researches, many researches used force plates and push buttons [2][3][8][9][10][11] to acquire the behaviors of subject. However, there were few researches to quantify them and analysis the relations of human dynamics in time-domain. The purposes of the proposed system in this paper are to achieve the measurement and analysis them quantitatively, and then, to construct the numerical model for these kinds of human behavior.

In this paper the proposed system can measure natural behavior using actuation of postural support or by applying stimulation. Finally, the human subject's behavior is measured as time series data, which distinguishes this method from conventional methods. The measured data can be analyzed in the time-frequency domain and the relationship between the stimulation and induced sensation can be analyzed. Moreover, the proposed system is quite small compared with well-known VR systems or Simulator systems. If the dynamics of vection and its effects become clear, the proposed system can achieve more highly-realistic VR, while being compact enough for residential use.

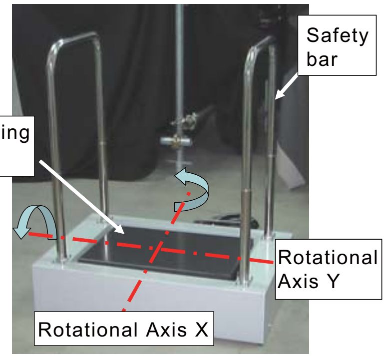


Figure 1: Photograph of the proposed system.

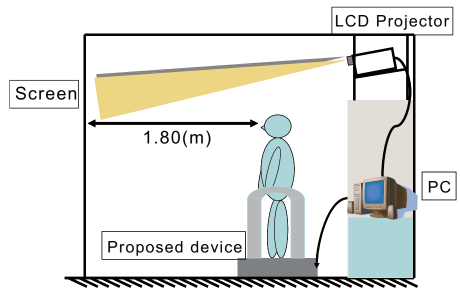


Figure 2: Experimental setup using the proposed system.

3 EVALUATION OF THE PROPOSED DEVICE

In this section, fundamental experiments are conducted to evaluate the mechanical functions of the proposed system and to confirm the basic behaviors of human subjects. Table 1 shows the experimental conditions used in this section. Five healthy male human subjects in their twenties (labeled A to E) were used after we obtained their informed consent.

3.1 Evaluation of Mechanical Function

At first, a basic experiment was conducted to confirm the mechanical conditions. In this experiment, the measurement procedure for human behavior in the proposed system is defined as shown in Figure 3. It is divided into 5 periods as follows. First, to calibrate the standing plate to be horizontal, rotational movements of the plate between -4 deg to +4 deg are applied in period 1. Then, the human subject stands on the plate to prepare for the experiment during periods 2 and 3. In period 4, the proposed system tilts the plate axis to provide postural stimulation to the subject. Finally, the postural behavior of the subject in response to the persistent induced tilting is measured by using the plate angle in period 5. From the results, we confirmed that the mechanical system of the proposed device works well with the control input, and the rotational angle can also be measured while the human subject is standing on the plate.

3.2 Confirmation of Human Behavior

Figure 4 shows an expanded graph of periods 2 and 3 in Figure 3. This area is set before applying the tilting movement of the standing plate in order to check the natural behavior of the subjects when they are standing on it. As a result of testing each human subject, it was seen that the subjects needed approximately 10 seconds to compensate their postural behavior in order to stand steadily. Consequently, we set the preparation time to be 10 seconds in period 2 before applying the stimulation in the measurement procedure as described in Section 3-A. In addition, through this experiment of human behavior, it was confirmed that it was possible to measure

Table 1: Basic experimental conditions

Visual stimulation	No stimulation
Tilting frequency (Hz)	0.3
Tilting angle of X-Axis (deg)	+/-3
Operation time (sec)	16.7
Measurement time (sec)	20

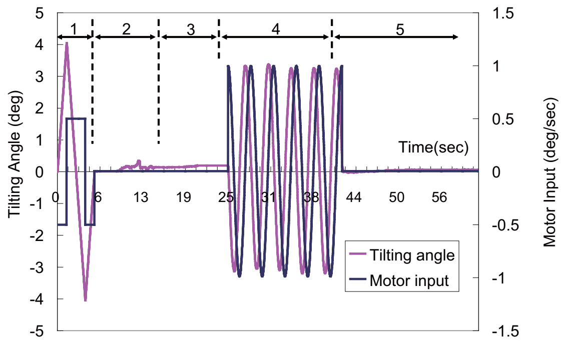


Figure 3: Experimental results for checking the system operation.

the postural behavior of the subjects with persistent induced body perception after postural stimulation in period 4. In past research, this kind of duration analysis for the induced perception or motion was conducted by measuring the center of gravity and using questionnaire survey results. Also the commonality of the frequency components of both the input stimulation and output behavior was clear. In the proposed system, the applied stimulation and induced behavior can be measured as time series data. Therefore, the relations identified in past research can also be validated by using time-frequency analysis[12].

In this paper, the Wavelet transform is applied as an analysis method for changes of postural behavior. The Wavelet transform is able to analyze several frequency components at once and also check the changes in the power of each component. The analysis and comparison of the stimulation and postural behavior of the subjects were conducted using the postural behavior in periods 3 and 5 with the Gabor function as the Mother Wavelet.

Table 2: Experimental conditions used for visual stimulation

Rotational Frequency (Hz)	0.25
Rotational angle (deg)	$\pm$ 30
Operation time (sec)	20
Measurement time (sec)	30

3.3 Experiment with Visual Stimulation

In previous research, it was clarified that the result of human behavior under visual stimulation contains the same frequency components of stimulation applied to the human subject by using frequency analysis[1] using the FFT (Fast Fourier Transform). However, the frequency component of human behavior always changes during the application of stimulation, so, steady signal analysis such as the FFT may not be enough to analyze their behavior. Because, the FFT analysis only handles the stationary signal which has constant frequency components. In this research, the analysis method

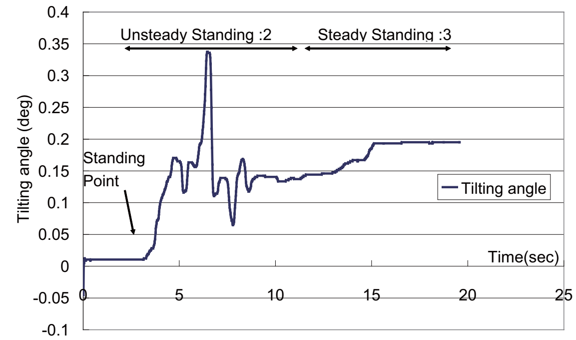


Figure 4: Part of experimental results before applying tilting stimulation.

Figure 5: Sample image with rotational motion used for visual stimulation.

using Wavelet transform is applied in order to analyze the human behavior in the time and frequency domain. Especially, the dynamics of human behavior which has several changes or reaction according to the input stimulation is focused. Additionally it aims to clarify the relations of time and intensity between the applied visual stimulation and the induced vection considering their dynamics. Proposed method in this paper using Wwavelet Transform has the possibility to acquire this kinds of dynamics from human behavior. And, it also has an possibility to construct the human behavior model using the parameters in time and frequency domain calculated by the proposed method.

The experiments in this section were conducted to examine the possibility of induction and measure vection by the proposed device through comparison with previous researches. The experimental conditions used are as shown in Table 2. During the experiment, the human subject stands on the plate of the proposed device as in Figure 1, and is asked to maintain balance on the plate. After standing on the plate, we start the device along section 3. In particular, visual stimulation is applied to the subject for 20 seconds after starting the motion of the device for 40 seconds (this was later decreased to 30 seconds). We use the wavelet transform for analysis of posture behavior. An example of visual stimulation is shown in Figure 5 which shows a 2-D scenery image. The axis of rotation of stimulation is the center of the image, and rotation proceeds side to side to a set angle.

Figure 6 shows an example of the analysis result of human behavior for subject A. The upper chart of Figure 6 shows the Wavelet analysis result of the posture behavior and the lower one is the tilting angle as posture behavior. The color bar on the upper chart indicates the strength from lower values (blue) to higher values (red) of the frequency components by the relative value in each figure after this. The deep red area in the upper chart corresponds to a

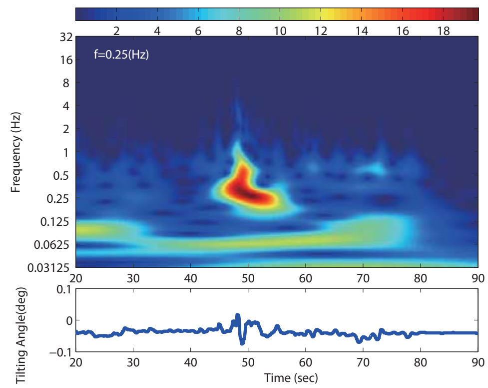


Figure 6: An example of an analysis result of human behavior using the wavelet transform with the Gabor function.

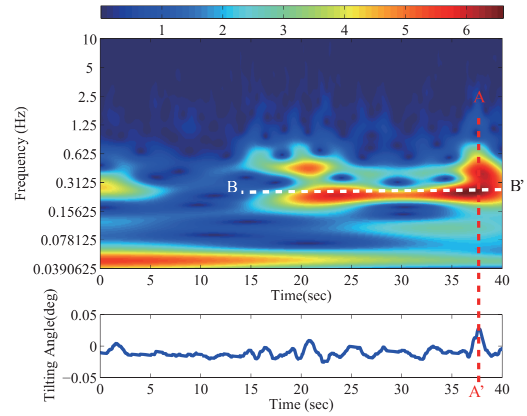


Figure 7: Analysis result of human behavior using wavelet transform with Gabor function.

stimulation frequency of 0.25 Hz. From these results, the proposed device with the confirmed analysis method has the possibility to realize the analysis of vection, and its induced behavior considering its dynamics using several stimuli.

4 Proposition of the Detection Algorithm of Vection

At the beginning of these experiments, we could only evaluate the induction of vection from the results of Wavelet analysis visually. However, it was very difficult to clarify the relations between the stimulation and the resulting behavior. In this section, a quantitative and objective evaluation method for vection is proposed.

The proposed method is constructed based on our knowledge for the phenomenon conducted by vection and its frequency commonality with stimulation. In addition, posture behavior is changed by this phenomenon[1][2][3]. According to previous research[2], the frequency component for the center of gravity of the human subject is below 0.1 Hz and it is generally called the "Trend component" as shown in Figure 6. Therefore, in the proposed method these components were checked off from the analysis target.

4.1 Calculation flow of the proposed algorithm

In this subsection, the proposed method for detecting the vection is related to the phenomenon using the frequency component of posture behavior. Its phenomenon may have several kinds of frequency components and intensities. Therefore, the algorithm will detect the deviation of human behavior as the first step and the time until the occurrence of the maximum deviation from the average behavior is assumed to be the induced time for vection. Then, the algorithm chooses the candidate of frequency components by using the peak point as one of the characteristics of behavior at the induced time using the wavelet transform. Finally, determination of the main component is made done through tracking for their changes of intensity around the time of visual stimulation using a threshold value. Hereinafter, mainly three parts of the proposed algorithm are described by using another experimental result as shown in Figure 7 as an example.

4.1.1 Detection of the induction time in human behavior

At first, the algorithm calculates the average value of posture behavior using the tilt angle of the standing plate from the time before stimulation. This average value is defined as the base point to keep balance on the standing plate. The algorithm decides the analyzing area from during stimulation of posture behavior which separates at 10 seconds. So, variance calculate of separate area. After this, the

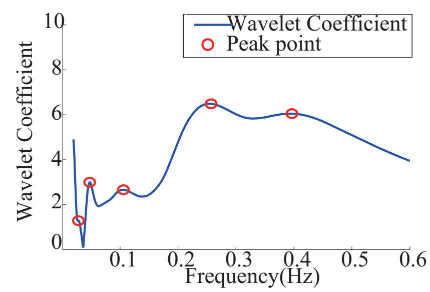


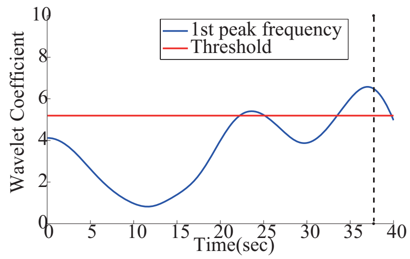
Figure 8: Results for peak points in frequency domain at induction time.

algorithm analyzes the area in which the variance value is a maximum. Next, deviations of posture behavior from the base point are calculated in each sample time during stimulation. The sample time when the deviation has maximum value is defined as the time until the induction of temporary vection. In this research, defined time is time constant. For example, approximately 38 seconds of experiment time in Figure 7 is the candidate for induction time in this calculation.

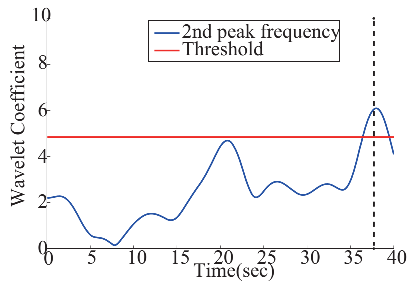
4.1.2 Selection of the peak values of frequency components

By using the induction time calculated in the previous step, the peak values of frequency components at the induction time are selected. Figure 8 shows an example of the intensity of the frequency component at the induction time which means one section of wavelet analysis as shown in Figure 7 (line A-A'). In this case, visual stimulation which has 24 degrees of rotational angle with rotation in 0.25 Hz are applied as the experiment conditions. The vertical axis of this chart represents the wavelet coefficient which has the same significant strength for the component, and the horizontal axis represents the frequency of the component. A blue circular marker shows the peak point of the variance of the wavelet strength. At the second step of the algorithm, these peak points are defined as induction-frequency components by the visual stimulation, and they are numbered from the maximum value of peak points.

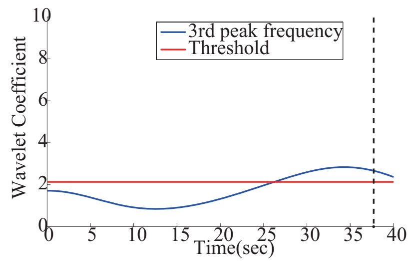
In the case of Figure 8, the first peak of induction-frequency at 0.25 Hz, the second one at 0.4 Hz and the third one at 0.05 are candidates for induction-frequencies respectively. In the next step, their changes of intensity are tracked during the experiment in order to determine if they are an induced frequency component or not.



(a) result of 1st peak



(b) result of 2nd peak



(c) result of 3rd peak

Figure 9: Analysis results of tracking for candidate frequencies (1st to 3rd peak) in time domain.

4.1.3 Determination of induction-frequency

Past research has reported that various components were confirmed in the center of gravity of human standing behavior. And it was clear that a few seconds are needed for them to appear in the subject's behavior by the induction of vection after stimulation was applied. Based on this result, the proposed algorithm must consider the elapsed time for the frequency changes. Figure 9 shows the analysis results of the first, second, and third peak frequencies in the time domain of the result shown in Figure 7. They also represent one section of wavelet analysis as shown in Figure 7 (e.g. line B-B' shows the tracking line for the first peak frequency) in each frequency. In these charts, the vertical axis and the blue line represent the wavelet coefficient as the strength of frequency component, the horizontal axis represents the experimental time and the dashed line shows the induction time calculated in the first step of this algorithm. The red line shows the threshold level of the wavelet coefficient determined as 80 percent of the wavelet coefficient at the induction time.

From these results, the intensities of the frequency components have changed according to the time elapsed. In this experiment, the time period for stimulation is from experiment time zero to 20 seconds. In the results of Figure 9, it is clear that each component has increased after stimulation. Furthermore the intensity of the first peak is larger than the second and third peak results with respect to the integrals of their values which exceed the threshold, so the first peak frequency is estimated to be the frequency of stimulation. From these results, it can be confirmed that the proposed method is capable of estimating the occurrence and the main frequency component of the induced behavior by using their characteristics in the time-frequency domain.

Table 3: Experimental conditions used in Section V

	Average of angular velocity ω(deg/sec)				
	6	9	12	18	24
Frequency(Hz)	Applying angle (deg)				
0.125	12	18	24	36	48
0.25	6	9	12	18	24
0.5	3	4.5	6	9	12

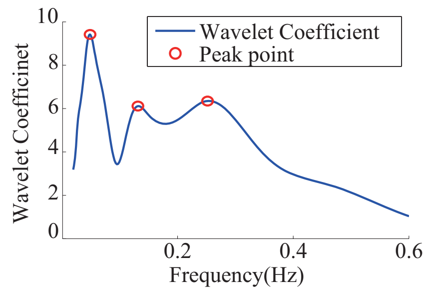


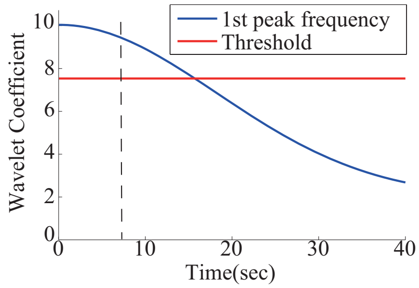
Figure 10: Induced frequency by applying stimulation of human subject B.

5 Characteristics of Rotational Angle of Applied Stimulation

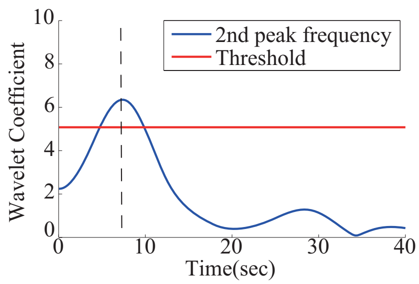
In the previous section a method for detecting induced behavior was proposed. In this section, this method is used to examine the relations of the components for visual stimulation. For these relations, it was reported that the induction frequency was nearly the same as the applied frequency when several rotational angles of visual stimulation were used and the average angle velocity of visual stimulation was ω=12 deg/sec[10]. The experimental conditions used in this section are shown in Table 3 referred from the experience of past research. The evaluation for the experimental results are conducted using the proposed algorithm for detecting the induction frequency. Figure 10 shows the result for induction frequency, and its peak frequencies are as follows: 1st peak : 0.0485 Hz, 2nd peak : 0.2516 Hz and 3rd peak : 0.1314 Hz. Their tracking result in the time domain are shown in Figure 11. From these results, the first and third peak frequencies are higher than the threshold before the applied stimulation. On the other hand, the second peak increased at the induction time. As a result, it is estimated that the second peak frequency was induced by visual stimulation.

These experiments were conducted with three subjects, and their results for induction frequency are shown in Table 4. In the results of subjects A and B, the applied frequency component could be detected, and it could not be detected for subject C. In past research, human behavior was found to have a natural frequency[11], and it exists in the range of 0.1-0.3 Hz for males generally. However, the frequency components of subject C disagree with the area of natural frequency. Therefore, it is thought that the visual stimulation for subject C was not effective to induce a behavior effect.

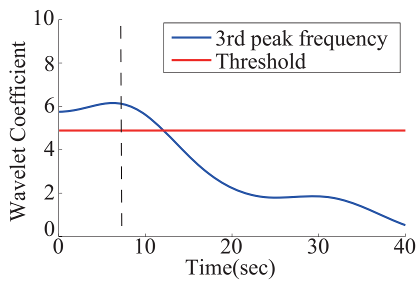
Moreover, it is confirmed that the proposed method in the previous section can estimate the correct induced frequency in 30 percent of experiments. Figure 12 shows one of cases of estimation failure when ω=6 deg/sec for subject A. In this case, each peak frequency is quite lower than the minimum frequency component. Thus it is clear that the determination of the threshold value must consider



(a) result of 1st peak



(b) result of 2nd peak



(c) result of 3rd peak

Figure 11: Analysis results of tracking for peak frequencies in time domain.

Table 4: Evaluation results of induced frequency in each subject

Subject	ω6	ω9	ω12	ω18	ω24
A	0.124	0.148	0.139	0.128	0.120
B	0.264	0.275	0.208	0.156	0.209
C	0.293	0.225	0.302	0.190	0.278

the largest value of the frequency component in order to achieve the analysis at the case of weak occurrence of stimulation and its reaction.

6 Conclusion

In this research, a novel experimental device and detection method for human behavior induced by visual stimulation was proposed. Additionally, the mechanical design of the proposed device and a basic algorithm of a proposed analysis method were examined and their effectiveness was confirmed through several experiments. In particular, the proposed analysis method clarified the relationship between human behavior and the characteristic of visual stimulation from the viewpoint of frequency components and their intensities. Unfortunately, it performed successfully in only 30 percent of experiments with temporal evaluation parameters such as the threshold of the frequency component. However, the possibility of the proposed method to estimate the characteristics of human behavior in time-domain have been confirmed. Therefore, an improvement of the algorithm which determines the evaluation parameters by considering the differences between subject persons is needed. Further work should investigate the characteristics of human behavior under the various frequency components of frequency in order to evaluate the proposed system. And to construct a input-output model of human behavior, the estimation method of the human behavior gain from the input stimuli is also needed.

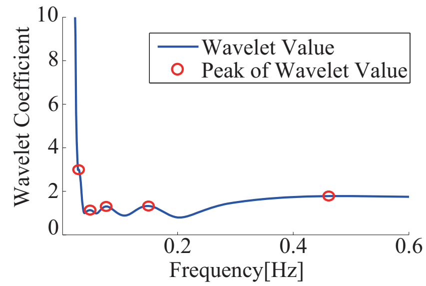


Figure 12: An example of a result where induced frequency estimation failed.

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