Analysis of Motion Sensation of Car Drivers and Its Application to Posture Control Device

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Abstract: Driver tilts his/her head to the direction of the curve center. Beside, it is pointed out that the head movement of the passenger is opposite to the driver. Moreover, it is known that the driver does not get carsickness comparing with the passenger. Therefore, we investigate the effect of the driver's active head movement. We build the mathematical model of the motion sickness and simulate the severity of motion sickness using driver's head movements measured in the real-car experiments. From the result, it is shown that the driver's head movement has an effect to decrease the motion sickness. Then we proposed a novel posture control device based on the results. It is shown that the developed device changes the passengers head tilt toward the driver's direction, which can decrease the motion sickness.

Keywords: Motion sickness, carsickness, head movement, lateral acceleration, posture control device.

1. INTRODUCTION

Carsickness decreases comfort of humans in a vehicle. It is necessary to clarify its mechanism and to develop a reduction method. Many research studies have been conducted on motion sickness. Experiments involving human exposure to whole-body vibration were conducted to examine the susceptibility to motion sickness under vibrations at various frequencies. For example, a vibration analysis with a subjective evaluation revealed some characteristics of human susceptibility to motion sickness [1], and these results were successfully applied to design a vehicle control system [2][3].

We focus on behaviors of vehicle passengers and drivers. The car occupants are received acceleration and rotational stimulations when they run in a curve. It has been shown that the drivers tilt their head to the direction of the curve turns while passengers tilt their head toward the centrifugal direction that is opposite to the drivers[4][5][6]. It is also well-known that the driver is less susceptible to the motion sickness than the passenger. From these facts, we supposed that the head movements of the driver and the passenger relate to the motion sickness while there are other interpretations including to obtain better visual information [4]. Therefore, it is thought that the systematic methodology to reduce motion sickness can be established by investigating relationship between driver's head-tilt strategy and susceptibility to motion sickness.

Authors have proposed a mathematical model that estimates motion sickness incidence (MSI) from head movement based on the neuro-physiological knowledge of vestibular system and central nervous system [7]. This model employs the subjective vertical conflict (SVC) hypothesis, in which the motion sickness is occurred from the accumulation of discrepancy between the vertical direction sensed by the sensory organs and that estimated by the internal model of the organ [8]. The present study shows that the head-tilt strategy of the driver has the effect to reduce motion sickness by investigating the differences of MSIs between the head movements of drivers and passengers using the mathematical model. Based on the results, we aims at reduction of motion sickness of passengers by controlling their posture during car driving.

In this paper, we introduce the mathematical model of the motion sickness that can estimate MSI in 6 DOF head motion. Then, we measure head movements of drivers and passengers. The effect of the driver's head movement to reduce severity of the motion sickness is shown by inputting the measured results into the mathematical model. Finally, we develop a new posture control device of passengers, in which the airbags are installed in the passenger's seat to decrease the head roll toward centrifugal direction. The effectiveness of the device is shown by the experiments.

2. MOTION SICKNESS SIMULATION

2.1 Mathematical model of motion sickness

The sensory conflict hypothesis or sensory rearrangement theory is the well-known as the mechanism of motion sickness [9]. In the hypothesis, it is thought that the motion sickness is provoked by accumulation of the conflict between sensory information and the past experiences. Bles et al. proposed a subjective vertical conflict (SVC) theory by employing errors between sensed and estimated vertical or gravitational directions as the conflict in the sensory rearrangement theory [8]. Bos et al. built a mathematical model of the SVC theory for the head translational movement, and it was shown that the model can estimate MSI obtained from the vibration experiments well. In our previous study, we proposed a mathematical model of SVC theory for six-degrees-of-freedom motion in three dimensional space called 6DOF-SVC model by expanding the Bos's model. The block diagram of the 6DOF-SVC model is illustrated in Fig.1. In this model, inputs are the head acceleration and the head angle, and output is MSI (Motion Sickness Incidence). In this model, OTO is otolith as the head angular velocity sensor. $\overline{OTO}$ is the internal model of OTO that is built in the central nervous system. Both of OTO and OTO are given by unit matrix. The block SCC is the semicircular canal, and $\overline{SCC}$ is its internal model.

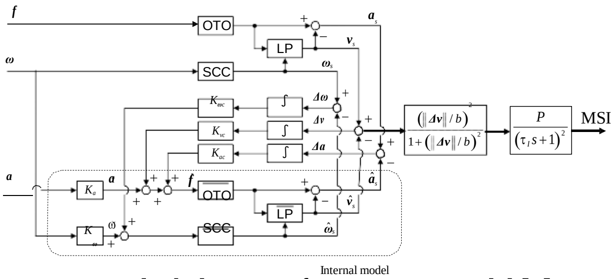


Fig.1 Block diagram of 6DOF-SVC model [5]

2.2 Analysis of driver's head-tilt strategy using 6DOF-SVC model

2.2.1 Experimental method

We conducted an experiment by a real car to investigate effect of head-tilt strategy on motion sickness [5]. In this experiment, we measured the head-roll angles of the drivers and the passengers, their head accelerations, the orientation and acceleration of the vehicle in curves and the slalom driving. A small passenger car with a 2.46 m wheel base and a 1300 cc engine was used for the driving experiments. An MTi-G sensor (Xsense Technologies) was attached to a flat place close to the shift lever of the automatic transmission to measure the 3-DOF acceleration and the 3-DOF orientation of the vehicle. A gyro-type orientation sensor Inertia Cube3 (InterSense) and a wireless accelerometer WAA-001 (Wireless Technology) were attached to the cap worn by the participants to measure the 3-DOF orientation and the 3-DOF acceleration of the head.

Six males aged from 22 to 24 yr who have driver's license and who gave informed consent participated in the experiments as both of drivers and passengers. The driver/passenger condition was treated as a within-subject factor. Each driver was asked to drive the pylon slalom on the straight road in the constant velocity. Each driver drove the test track for three times per each pylon-velocity condition after practice runs. At the same time, another participant sat in the navigator's seat as the passenger. The order of the slalom condition was also randomized among the participants.

The MSI was estimated using the 6DOF-SVC model by inputting the experimental results in the model.

2.2.2 Experimental results

It is found that the driver's head movement occurred in opposite direction to the vehicle roll. The passenger's head roll occurred in the opposite direction to or with large time lag to the driver's head roll in a passive manner though the synchronization with the vehicle motion was not well. The maximum head roll angles of the drivers and the passengers in the hard condition was larger than those in the mild condition.

Fig.2 shows the estimated MSI with the supposed head motion from the experimental results of 30km/h condition of a participant as an example. Definition of every head movement conditions are given as follows:

1) Driver condition: the head-roll of the driver measured in the experiments was used as the input of the model.

2) Passenger condition: the head-roll of the passenger measured in the experiments was used as the input of the model.

3) Vehicle condition: the roll angle of the vehicle measured in the experiments was used as the input of the model.

4) Reverse driver condition: the head-roll of the driver was used but the phase was changed as completely opposite.

5) Reverse passenger condition: the head-roll of the passenger was used but the phase was changed as completely opposite.

6) Vertical condition: the head is moved against the vehicle motion so that the head is always vertical.

It should be noted that the positive roll-angle denotes the head roll appears in centripetal direction. The results showed that the head roll in direction toward curve center or centripetal direction decreases MSI. The result is accord with the fact that the driver is less susceptible than drivers. The detail of the experiments was given in [5][6].

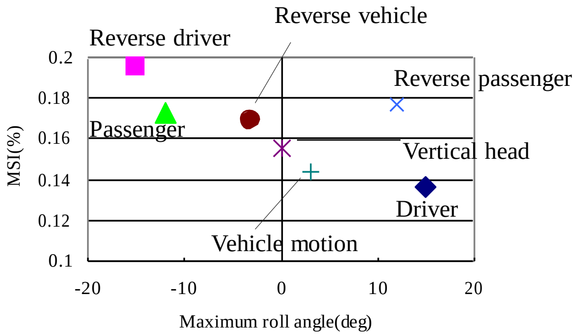


Fig.2 Peak MSI (30km/h)

3. POSTURE CONTROL DEVICE

3.1 Concept

From the results in section 2, we propose a posture control device that makes passenger to tilt their head like drivers. Here we suppose that active head movement of the passenger is important. In addition, the device intervenes only when the lateral acceleration by the curve is large, otherwise the system does not activate. In addition, the initiation timing of the device is determined by steering wheel operation so as to be synchronized with the onset timing of the lateral acceleration.

3.2 Structure of Posture Control Device

Fig.3 illustrates an overview of the device that we developed. The device consists of air packs expanded by the compressed air, an air tank, a pressure regulator, control valves, a flow meter, a rotary potentiometer measuring steering wheel angle, and a laptop PC. Two air packs are placed on the both sides of the seat so that the half of the packs are below the femur. The pack mounted on the side closer to the curve turning is expanded appropriately, so as to control the passenger's posture. It is expected that the device makes the passenger's head tilt toward centripetal direction like driver's head tilt or reduces head movement in the centrifugal direction. It is also expected that the expanded the air pack holds the passenger's body, and the device has the effect to control the posture.

3.3 Decision of the air packs volume for the lateral accelerations

Based on our preliminary experiments, we suppose that the volume of the air pack should be determined according to the lateral acceleration in the curve. In this subsection, the effect of the volume on subjective evaluation is investigated under various lateral acceleration conditions.

3.3.1 Experimental methodology

Now, we investigate the appropriate volumes of the air packs to the lateral accelerations from the experiment. First, we set the following 4 levels of the volumes, $V1 = 3.7 \times 10^{-4} m^3$, $V2 = 5.9 \times 10^{-4} m^3$, $V3 = 8.4 \times 10^{-4} m^3$, and $V4 = 1.1 \times 10^{-3} m^3$. Participants sat on the front passenger seat where the air packs were mounted and experienced the curve driving with the device. After the experimental runs, the participants were asked to evaluate whether the each volume of the air pack was appropriate for the lateral accelerations subjectively using the following 7 levels: 1.volume of the air pack was too large, 2.large, 3.little large, 4.just good, 5.little small, 6.small, 7.too small. During the experimental runs including straight or curve, the volumes of the air packs were kept constantly. Thus, the experiments investigated the effect of the volume on the subjective evaluation in a static situation. Fig.3 illustrated the experimental course. The following curves were used in the subjective evaluation: curve1 (R20m), curve2 (R11m), curve3 (R9m), curve4 (R13m), and curve5 (R8m). We measured the vehicle acceleration during experimental driving. Three male (aged 22, 23 and 39 yr) who had driver's licenses and gave informed consent participated in the experiments.

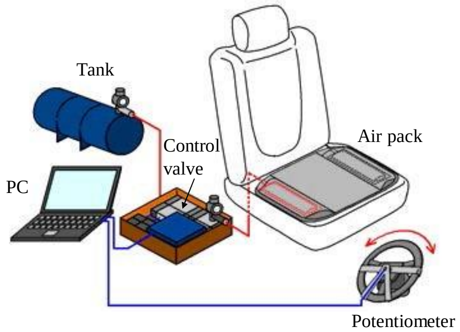


Fig.3 Overview of the Posture Control Device

3.3 Result of the experiment

Fig.5 shows the relationship between the peaks of the vehicle lateral accelerations in the each curve versus the volume of the air packs in each condition which obtain the assessment as "just good". Note that V1 did not appear in the assessment as "just good" because V1 was too small. The participants preferred larger volume in the larger lateral acceleration. It is thought that the tendency revealed that large volume of the air packs has an effect of holding body trunk. Determination coefficient was R^2=0.317 (p<0.01), thus we thought that proportionally changing the volumes for the lateral accelerations achieves better subjective assessment from the regression line in Fig.5. When the lateral acceleration was small, it is supposed that the large volume gives the experimental participants the uncomfortable feelings.

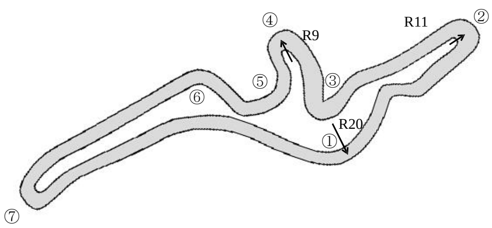


Fig.4 Course of the experiment

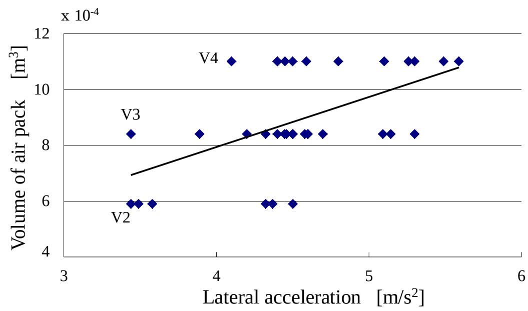


Fig.5 Lateral acceleration vs air pack volume

3.4 Control method

Figs.6 and 7 shows the control flow chart of the device and block diagram of the device, respectively. When the curve information inputs, the system predicts the lateral acceleration in the curve, and expand the air pack according to the acceleration.

In this paper, we prototyped the device that has following actions to confirm the proposed concept. Now the velocity of the experiment driving was constant, so we assumed the acceleration was known. First, in the entrance of the curve, the experimenter sat in the backseat manually inputted the form of the curve to the system. Then, the air pack volume was determined from V2, V3, V4 according to the predicted lateral acceleration based on the result in the subsection 3.3. Please note that each volume was realized by changing the inflowing time of the compressed air *T*. The expansion of the air pack was triggered if the steering wheel angle exceeded a certain value, which indicated the entrance of the curve. The inflow continued for T[s] by controlling two control bulbs through the relay from the DA board. After that, the device returned to the no expansion state by releasing the air when the steering wheel angle returned in a certain value. The times to air releasing were about 5 s without sitting and about 3 sec with sitting.

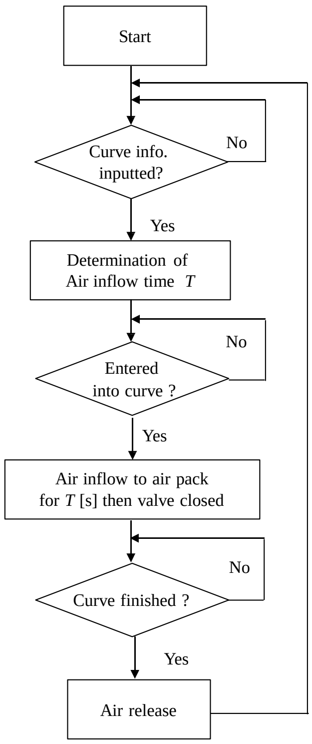


Fig.6 Flow chart of device control

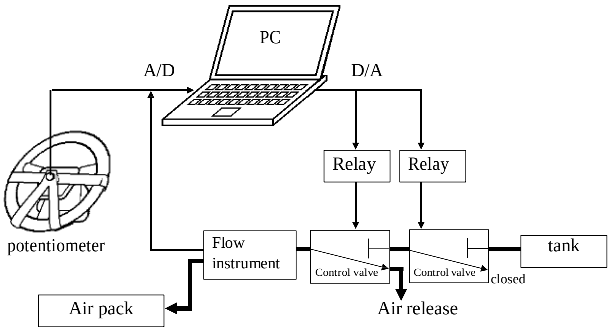


Fig.7 Block diagram

4. EXPERIMENTAL VERIFICATION OF POSTURE CONTROL DEVICE

4.1 Experimental condition

We investigated the difference of the passenger's head movement with/without the posture control device with a real car in order to show an effect of the device. The Curves 1, 2, and 6 in Fig.4 were used in the experiments. The seven male graduate students (average age: 22.6 yr, SD: 0.53) who had driver's licenses and gave informed consent participated the experiments as the passengers. They experienced the experimental driving by sitting in the navigator seat in the natural posture as usual. A within-subject experimental design was employed for two factors of car velocity and device. The car velocity conditions had two levels 30km/h and 40km/h. The device condition has two levels with and without the device. They experienced three runs for each velocity condition and device condition, thus totally experienced 12 runs (=two speeds conditions × conditions with or without the device × 3 runs). The four of the seven participants experienced from no device condition.

Form the preliminary experiments, we determined the air inflow time T to realize the desired volumes as shown in Table.1. In the experiments, we measured the vehicle accelerations and vehicle orientations using MT-G (Xsens technologies), and the head orientation using MTx (Xsens technologies). In addition, the participants were asked to give comments on the differences of feeling for each condition.

Table.1 Volume and Air Inflow Time

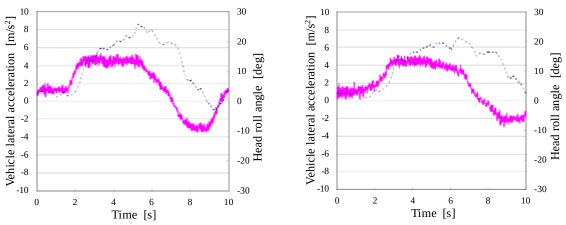
	30km/h		40km/h	
	volume	T[s]	volume	T[s]
Curve 1	V2	1.3	V3	1.7
Curve 2	V3	1.7	V4	2.1
Curve 4	V3	1.7	V4	2.1

4.2 Experimental results

A repeated-measure ANOVA for the lateral vehicle acceleration in the curve revealed that the main effect of the device was not significant (p = 0.316). Fig.8 shows the time series pattern of the vehicle lateral acceleration and head roll angle of the experimental participant C with and without the device in the curve 1 with 30km/h as examples. It is shown that the peak of the head-roll angle was reduced by the device, but the wave shape was not changed largely. This tendency was seen in many participants.

The mean of the peak values of the head-roll angle in the all conditions at curve 1 are shown in Figs.9 and 10 as examples of volumes V2 and V3, respectively. From the figure, it is found that the head-roll angle was reduced by introducing the device for many participants. A paired t test in the head roll angles showed that the main effect of the device condition was marginally significant (p=0.051). Then, the Wilcoxon signed rank test in the head roll angle was conducted for each participant and for each velocity condition because it is found that the tendencies were different. The test in 30km/h condition revealed that the head-roll angle was significantly reduced by the device in three participants while it was significantly increased in a participant. The test in 40km/h showed that the head roll was significantly reduced by the device in two participants while it was not significant in the other participants.

In the result of the subjective assessment for the device, it is found that all experimental participants answered that the device led comfortable feelings, and the device holds their body appropriately. On the other hand, in the 40km/h conditions, some participants answered that the accelerations were too large to hold the postures, or the body was swung much by the accelerations regardless of the device.



(a) Without device (b) With device

Fig.8 Time history of head roll and vehicle acceleration at curve 1 in 30km/h

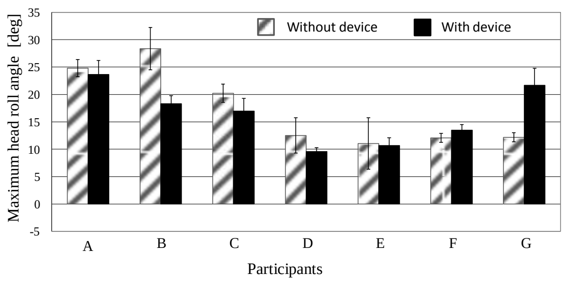


Fig.9 Head roll angle (30km/h, curve1)

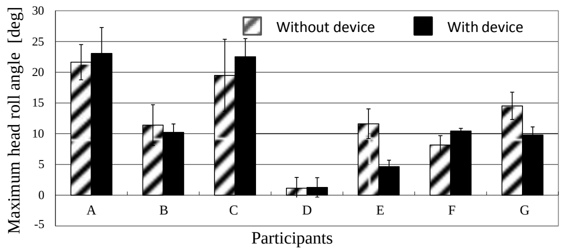


Fig.10 Head roll angle (40km/h, curve1)

4.3 Discussion

From the experimental results indicate that in the 30km/h condition, more than half of the participant's head roll angles with the device were smaller than without that. This showed that the expansion of the air pack device successfully support their body to the lateral acceleration or the participants actively moved their head toward centripetal direction. Thus, it is expected that the device has an effect to reduce MSI, and we can say that this device has an effect to decrease carsickness.

In the 40km/h condition, such effects were not found remarkably. The reason is thought that the lateral accelerations were larger than the predicted accelerations, and the expansion of the pack was small for the accelerations, from the questionnaires. In addition, we found that the passengers hold on their bodies their own very actively because the bodies were shaken too much in the test runs due to large lateral acceleration. Furthermore, the passengers were supported by not only the device but also the seat belt because the accelerations were too large. This means that the effect of the proposed device was not so large in such very large acceleration situations.

5. CONCLUTION

We introduced a mathematical model of motion sickness based on SVC to investigate the relationship between the head movement and the motion sickness. It is shown that the driver's head movement has an effect to reduce motion sickness by investigating the motion sickness incidence in the different head movement using the proposed model. Based on the results, we developed the posture control device to reduce the passenger's motion sickness by inducing the head movement toward driver's. From the verification experiment for the effect of the device, the head-roll angle of most passengers decreased in the curve running with the device except for the large acceleration situation. From these results, we expect that the device has an effect to reduce MSI, and we can say that this device has an effect to decrease carsickness. The subjective assessments showed that the device was effect to increase stability of the posture and increase the comfort in curve driving.

As the future study, the onset timing and the location of the device will be investigated in more detail so that the passengers tilt their head like the drivers without an uncomfortable feeling. In addition, we will investigate the effect of the system from the viewpoint of postural maintenance of the driver as well as the decrease of the motion sickness to realize comfortable vehicle motion.

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