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On Driving Assistance using Forearm Vibrotactile Feedback for Wheelchair Drivers

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Abstract: Welfare devices are getting more popular along with the growing population of elder and disable. The significance of an easy to use wheelchair is rising recently. The authors have developed a new wheelchair STAVi which has a unique piggybacking design. Because of the growing importance of environmental safety, new driving assistance systems are required. A superficial vibrotactile feedback mechanism is designed to transmit environmental information to the wheelchair driver unlike the visual or audible signals that distract attention. Our goal is to develop a driving assistance system using vibrotactile feedback to the driver and to guarantee the safety. As a first step we evaluate simple vibrotactile system for the newly designed electric wheelchair. In this paper, we clarify the concept of vibration generation and propose a vibration feedback system. Also, we analyze the cognitive characteristics of vibration in order to show the effectiveness of the obstacle localization using vibrotactile feedback. It is expected that the drivers can easily estimate the location of environmental obstacles just by using the vibrotactile feedback. The effectiveness of the proposed system is confirmed by experiments.

Keywords: Electric wheelchair, vibrotactile feedback, driving assistance, obstacle detection

1 INTRODUCTION

By the increasing demand on the welfare devices, it has been a requirement to focus on the safety of those. Wheelchair drivers need extra information about the environment around them, regardless of their disabilities. These may be the obstacles around, or the road conditions such as the inclination and curves. In the case of electric wheelchairs, the driver needs to spend less effort to move the vehicle than the traditional manual steering methods. Wheelchair can easily be driven on to an obstacle when the driver didn't perceive it especially when he/she has visual deficit or mobility impairment. Also, precise perception of the obstacles such as the stationary bodies or pedestrians is difficult for the disabled. These difficulties make the situation dangerous, because the driver won't run into any physical difficulty to move the vehicle even in an unsuited environment when there is no visual or audible feedback.

Commercially available driving assistance systems use predominantly visual or auditory channels to communicate with the driver. Environmental factors such as the direct exposure to sunlight and background noise makes the driver's distraction increase. Yu et al. discussed and implemented a driving assistant system for automobiles, containing ultrasonic sensors and various indicators including tactile vibrators placed on the steering wheel, a buzzer and an LED display [1]. A similar approach in navigation to provide distance to the destination is presented by Tsukada et al. by changing the pulse interval of the vibration motor [2]. Bial et al. proposed a vibrotactile feedback system for the motorcycle drivers, providing distance and turning direction using vibration motors attached gloves [3]. The connection between the gloves and the control system is not comfortable for the driver.

Previous studies on vibrotactile feedback are generally focused on navigation systems providing basic directions. Audiovisual systems have been studied for driving assistance but vibrotactile feedback systems have not been studied in detail. We have developed a new electric wheelchair "STAVi" [4] and focused on driving assistance using vibrotactile feedback [6] because the obstacle detection for the wheelchair users is an important issue. As the STAVi has a piggybacking design and several body supports such as the chest support and arm rests, it will be effective to construct the vibrotactile feedback system without annoying hard-wiring devices.

We propose a vibrotactile feedback system using arm rests providing environmental information through vibration stimuli. The obstacle distance and direction detected by laser range finder are transferred to the wheelchair user in order to assist him/her. Proposed vibrotactile feedback system is located onto the arm rests in order to provide convenience to the driver. In this paper, we aimed to provide the ability of environmental recognition to the wheelchair driver. Environmental obstacles' location and distance will be attended to the driver just by vibration stimuli. Experiments are conducted to show the accuracy of drivers' obstacle position estimation by using prerecorded data instead of real-time sensor data. The estimation of the obstacle's position and moving trajectory is evaluated by experiments.

Fig. 1: Appearance of STAVi#2

2 CHARACTERISTICS OF WHEELCHAIR STAVI

In this study, we developed a new electric wheelchair "STAVi", shown in Fig.1 [4]. Users can get into STAVi by piggybacking from a bed or wheelchair. While driving, user weight is supported at three points: seat, chest pad, and arm rests. This serves to distribute user's weight and to reduce the load on any particular point. After the user is safely seated, the seat escalates to the user's standing position so that their eye line is at the same height as it would be in their standing position. The elderly and disabled persons who took a test ride stated that they do not feel inferior because they are at the same height as their care personnel.

In this paper, a stationary experimental setup that has the same frame structure with STAVi such as the seat, chest support and arm rests, was used. Fig.2 shows the experimental system mimicking the STAVi's frame.

3 VIBROTACTILE FEEDBACK SYSTEM

3.1 Concept of vibrotactile feedback

Extra attention is needed by the drivers of STAVi because the target users are the elder and disable. Proposed system provides this extra attention by scanning the environment for the obstacles that may collide with STAVi. In order to warn the driver, our system uses superficial stimuli applied to the driver's arms.

For superficial stimuli, Johansson clarifies the mechanoreceptors' frequency response in his fundamental study that implies a tactile stimulation at frequencies under 100[Hz] improves spatial resolution of vibrations perception [5]. In our previous studies, we analyzed the frequency response of human skin with multiple subjects and confirmed that the vibration frequencies over 100[Hz] are inefficient [6].

Fig. 2: Experimental system and vibration motors with eccentric mass on the shaft

We encoded the environmental information in a pattern to transmit distance and direction as shown in Fig.3. Johansson et al. gives the maximal cycle response of slowly adapting (SA II) units of skin as 0.5[Hz] even at the low stimulus amplitudes [5]. Therefore, by taking the SA II receptor's sensitivity into consideration, the control period was taken as 1[s] which is the maximal cycle response time, in order to differentiate the pause between vibration stimuli. The maximum vibration frequency was chosen below 100[Hz] in our experiments. Stimulation on-time was varying according to the obstacle's direction detected by the sensor. Maximum on-time interval was chosen as 1[s]. A time delay between vibration signals was used to provide the direction. In light of these information, we created the unique vibration pattern shown in Fig.3.

3.2 Vibration generation method

Environmental information was encoded in two parameters: obstacle distance and direction. We adjust the vibration magnitude in order to indicate the obstacle's distance. Direction indication uses a similar method of interaural time difference (ITD) model to mimic the perception of sound.

The difference on the arrival times of the sound waves

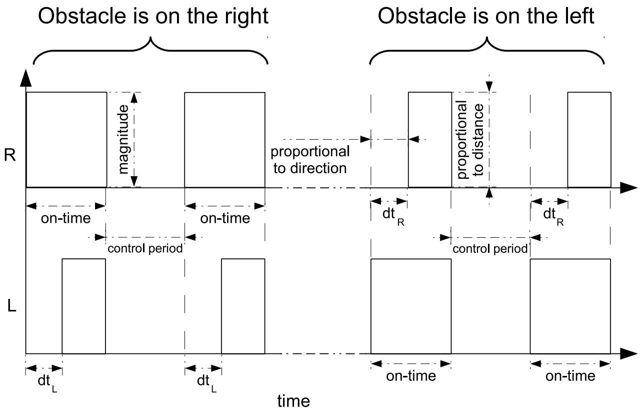

Fig. 3: Vibration pattern

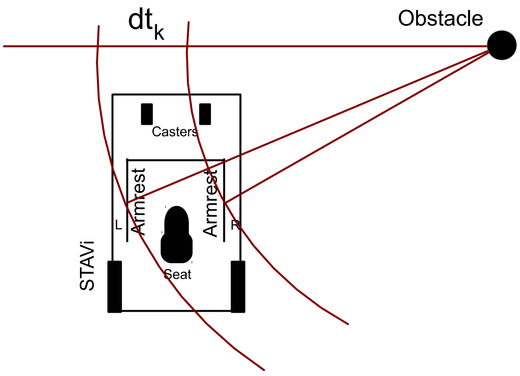

Fig. 4: Vibration time difference model inspired by ITD

is the key feature of the perception. According to this difference, sound source can be localized by the subject. We mimicked this concept in our study and applied a delayed vibration stimuli to one of the arms according to the position of the obstacle as shown in Fig.4. The time difference between the right and left arm vibration signals was adjusted similar to the arrival time of the sound waves to ears. Fig.4 represents the time difference model inspired by ITD. Using this method, subject could get the rough position of the obstacle and protect himself from the collision.

Obstacle distance and direction were given by laser range finder. A decision algorithm decides the position of the obstacle or the approaching object. According to the results of the algorithm, the driver was warned by a unique vibration stimuli that was created considering the obstacle’s position. The warning signal is applied using the motors located on the wheelchair’s armrests. The driver could have a chance to avoid collision.

3.3 Experimental setup

Experimental setup was conducted with 5 able participants. The average age was 23.16 (SD(Standard Deviation)$=$ 2.48), and the experiments lasted 30 minutes for one participant. Fig.4 shows the schematic diagram of time difference between the right and left arm vibration signals inspired by the ITD. $dt_k : k = \{L, R\}$ was varying according to the obstacle’s direction. When the obstacle is in front of the vehicle, dt_k becomes zero. In our experiments, dt_k was varying between 0 and 1[s] as shown in Fig.3.

Each participant was subjected to a training of over 50 random vibration signals and simultaneously was shown the obstacle position on the screen. During the training session, the subject gave response by moving the joystick to the direction of the obstacle and saw the correlation between his response and the actual position on the screen. After the training session, the subject was asked to guess where the obstacle is according to the vibration signal applied to the arms without seeing the actual obstacle position.

Vibration generators are placed on the armrests because the driver continuously contacts to the arms during the motion as shown in Fig.2. We didn’t attach the vibration motors directly to the driver’s body because of the inconvenience of the permanently attached type stimulators such as arm bands or bracelets which annoy and distract the driver.

Fig.2 shows the experimental system imitating the STAVi’s frame. Vibrotactile feedback stimulators made by DC motors (“28L28-416E” from Portescap) with eccentric masses on the shaft are placed inside of the armrests. Vibration motors were driven by TD12770-48W05 servo controllers from Tokushu Denso and provides a maximum power of 6.94[N]. Environmental information was taken by the laser range finder (“UTM-30LX” from Hokuyo Automatic) and processed by the microcontroller (Atmel AVR 328). Vibration pattern was decided according to the obstacles’ position and vibration signal was applied to the driver’s arms.

4 RESULTS OF PERCEPTION EXPERIMENTS

The effectiveness of the proposed system was measured by experiments. Using the pattern in Fig.3, 5 participants were subjected to a test of 4 moving object trajectories. In this experiment, subjects were asked to guess where the obstacle around STAVi is moving according to the applied vibration signal. A training session was given to the subjects before the actual experiment. Subjects used the same setup as the training session and replied by using the joystick to give their guess. Fig.5 shows the subject response for various trajectories. Solid line represents the actual obstacle trajectory. Colored dashed lines represent the subject responses.

Table 1: Correlation coefficient of the subject response

	Traj. 1	Traj. 2	Traj. 3	Traj. 4
Subj.1	0.987	0.867	0.896	0.968
Subj.2	0.951	0.892	0.869	0.975
Subj.3	0.992	0.911	0.975	0.967
Subj.4	0.988	0.915	0.977	0.971
Subj.5	0.977	0.972	0.965	0.987
Average	0.979	0.911	0.936	0.973

Table 2: Deviation for 2 subjects repating the test

		Traj.1	Traj.2	Traj.3	Traj.4
Subj.1	Trial 1	0.987	0.867	0.896	0.968
	Trial 2	0.983	0.927	0.963	0.983
	Std. Dev.	0.003	0.042	0.047	0.011
Subj.2	Trial 1	0.951	0.892	0.869	0.975
	Trial 2	0.987	0.941	0.952	0.952
	Std. Dev.	0.025	0.035	0.059	0.016

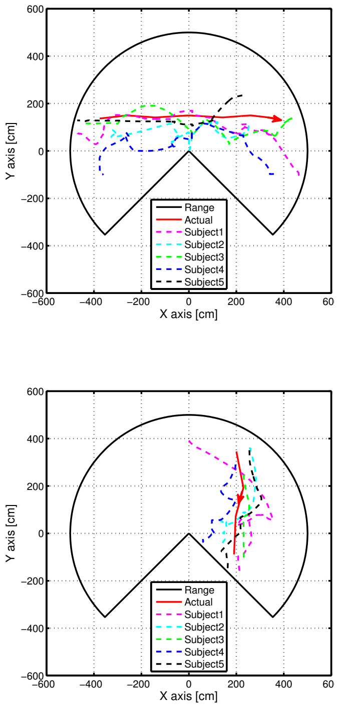

Fig. 5: Multiple user responses for various trajectories

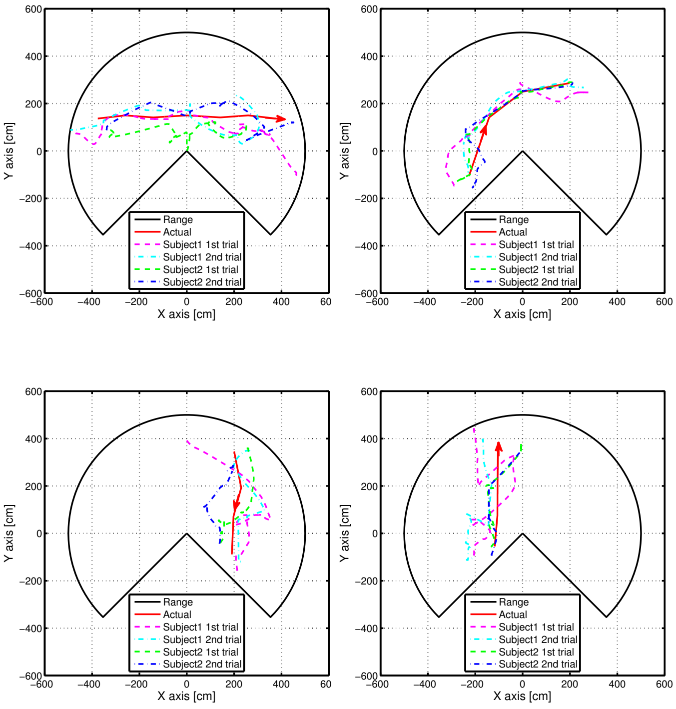

Fig. 6: Repeatability test by 2 subjects

Correlation coefficient for the each subject and average correlation coefficients to show the accuracy of the subject responses are given in Table.1. According to the results, subject’s guesses are accurate and the average correlation coefficient for all the different trajectories is 0.949.

Analysis of the repeatability is done by experiments. Two subjects took the same tests at different times and the subject responses are recorded as shown in Fig.6. Table.2 shows the correlation coefficient of the subject response and the standard deviation of the repeated tests to verify the repeatability.

Results show that deviation between each trial is very low and by using the proposed vibrotactile feedback system, wheelchair drivers could estimate the outline of the obstacle location. The estimated accuracy is confirmed by the repeated tests.

5 CONCLUSION

In this study, we proposed a driving assistance system using superficial vibrotactile feedback for wheelchair drivers. Primary goal in this paper is to show the accuracy and repeatability of the proposed system by multiple-subject experiments. Experimental results showed that subjects could estimate the obstacle’s position and the moving trajectory sufficiently. Repeated experiments verified the accuracy of the proposed method and showed that the subjects could locate the obstacle just by using the vibrotactile feedback.

In this setup, vibration motors were placed in the armrests. Therefore the accuracy would be low when the subject is not contacting the armrests completely. Support of vibrotactile feedback via the seat and chest support pad is a future work.

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