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THE PERCEPTION OF OPTICAL FLOW IN DRIVING SIMULATORS

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Summary: Optical flow is generated when a driver's vehicle traverses a 3-D virtual environment in a driving simulator. Understanding the generated optical flow may help in lessening simulator sickness. Two experiments were designed to investigate the perceived optical flow in different driving environments using two driving simulators: 1) a fixed base simulator and 2) a turning cabin simulator whose turning cabin rotates around the y-axis. In the first experiment, the perception of optical flow when making left/right turns was studied using both simulators. Results revealed that subjects experienced a higher amount of optical flow when making right turns then left turns. In addition, the optical flow perceived by drivers in the fixed base simulator was greater than that in the turning cabin simulator. We designed the second experiment to investigate the optical flow perceived when driving straight ahead, driving on circular curves, and driving on curves with transitions (clothoids). Again, two simulators were used. The amount of optical flow was highest when driving on circular curves, and was lowest when driving straight ahead. While using the turning cabin simulator, the degree of optical flow decreased greatly on circular curves, and curves with clothoids as compared to that in the fixed base simulator. We conclude that optical flow in driving simulators can be lessen by using a turning cabin simulator.

INTRODUCTION

This research was partially motivated by the Asano and Uchida (2005) study, which used a "turning cabin simulator". Their turning cabin (a vehicle seat with steering wheel and pedals) rotated around the y-axis in correspondence to the heading (direction of travel) of the subject's virtual car. Thus, when executing a 90-degree left turn, a subject in the turning cabin simulator would rotate 90-degrees to the left. Asano and Uchida found that when drivers used the turning cabin simulator as compared to a conventional fixed based driving simulator, they experienced less simulator sickness when making left/right turns.

Park, et al. (2006) also reported more simulator sickness when drivers made left turns in a fixed based driving simulator. This may have been caused by the high amount of optic flow generated when the vehicle did not turn as it does in the real world (Mourant, et al, 2007).

Furthermore, Chrysler & William (2005) lessen the simulator sickness associated with driving on curves by increasing radii and having less objects aside roads. Their approach lowered the amount of optical flow experienced by drivers, thus suggesting a correlation between simulator sickness and amount of optical flow. As studied by Gibson (1979), the amount of optic flow depends on the environment. Objects such as buildings and trees close to the sides of the road generate more optic flow. Therefore, having less objects aside roads simply lowers the amount of optical flow generated.

Based on these results, we hypothesized that there is a relationship between the amount of optical flow perceived and the degree of simulator sickness reported. Studies of optical flow may help to reduce simulator sickness and improve drivers' performance when using driving simulators. This study was designed to investigate the perception of optical flow in several virtual scenarios using both a fixed base simulator and a turning cabin simulator. This study aims to 1) gain better knowledge of the effect of different driving simulators and various driving environments have on the perception of optical flow and 2) associate the perception of optical flow in this study with simulator sickness reported in previous works.

METHOD

Participants (Experiment 1)

Twelve subjects, all Northeastern University undergraduate engineering students, participated in this study. All of them had a valid driver's license and driven at least 5,000 miles in the last year. All subjects had 20/20 or corrected to about 20/20 vision. Ages of the participants range from 18 to 20. There were 9 male and 3 female participants.

Participants (Experiment 2)

Ten subjects, all Northeastern University undergraduate engineering students, participated in this study. All of them had a valid driver's license and driven at least 5,000 miles in the last year. All subjects had 20/20 or corrected to about 20/20 vision. Ages of the participants range from 20 to 25. All participants were male.

Apparatus (Experiment 1 and Experiment 2)

Both experiments were conducted using the turning simulator at Northeastern University, shown in Figure 1. The basis of the turning cabin simulator is a cylindrical screen with a diameter of 12 feet. A racing seat is mounted on an AC servo actuator at the center of the cylindrical screen. The force feedback steering wheel, and gas and brake pedals were attached to the seat and connected to the simulator's computer via USB. The computer rendered the scene with inputs from these devices to calculate the heading and velocity of the vehicle. The yawing movement of the actuator was controlled by a digital servo-motor which received vehicle heading information from the computer. Three LCD projectors were combined to produce a 180 horizontal degree field of view (FOV). A distortion correction algorithm was applied for matching the images to the inside of the cylindrical screen. A software based edge blending algorithm was also implemented to eliminate banding across the display. The image resolution was 3840 x 960 pixels and the frame rate was approximately 100 frames per second. The turning cabin driving simulator and the fixed-base driving simulator used the same equipment. We switched from one to the other by enabling or disabling the yawing movement of the actuator.

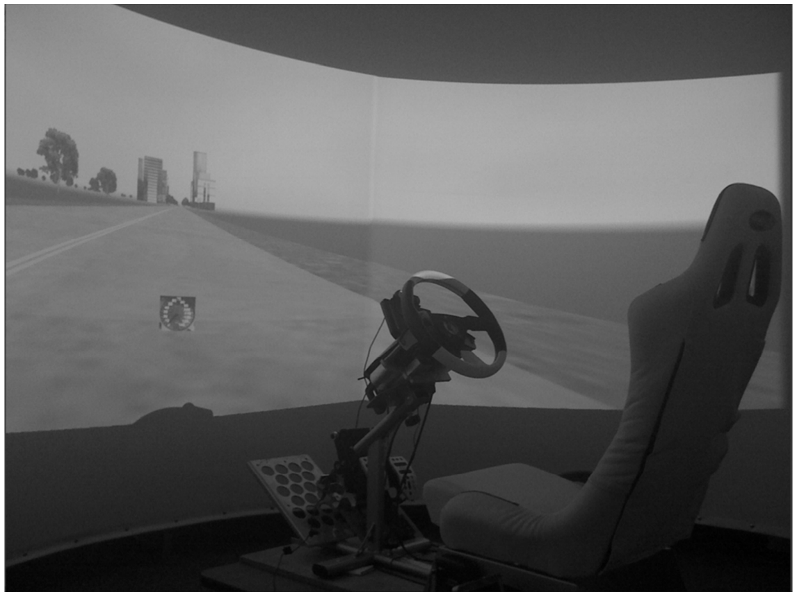

Figure 1. Northeastern University's turning cabin simulator

Procedure (Experiment 1)

Experiment 1 was divided into two runs: 1) using the turning cabin simulator and 2) using the fixed-base simulator. Each subject drove both runs. Half of the subjects were given run 1 first, and the other half were given run 2 first.

Upon arrival in the laboratory, subjects were given a training trial to become familiar with the steering, acceleration, and deceleration behaviors of the vehicle. Participants were then given either run 1 followed by run 2, or run 2 followed by run 1. We used the same virtual city environment for run 1 and run 2. Three left turn intersections and three right turn intersections were contained in the virtual city environment. Voice instructions were played before a driver came to an intersection as to execute either a left or right turn.

Procedure (Experiment 2)

We had the same procedure for experiment 2 with an exception of the virtual environment used. A suburban driving environment was used for run 1 and run 2. Four curved roads with clothoids and four curved roads without clothoids were contained in the virtual environment. A clothoid is a spiral whose curvature is a linear function of its arc length. They allow a smooth transition between straight roads and curves.

RESULTS

Optical Flow Field Example

Figure 2 shows an instance of the optical flow field part experienced by a subject when making a left turn in the simulator. In the optical flow field, each optical flow vector shows the magnitude and direction of optical flow. You can see the correspondence between the optical flow vectors and the image on the right.

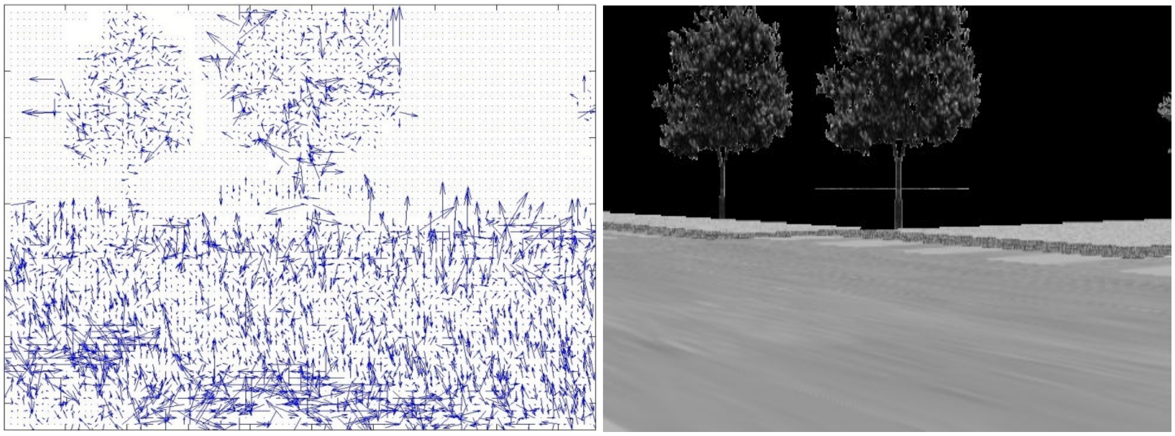

Figure 2. A portion of the optical flow field experienced by a subject when executing a left turn

Experiment 1

Figure 3 shows the quantity of optical flow per second for the left turns and right turns by type of simulator. We computed the quantity of optical flow per second by taking the normal of the j^{th} optical flow vector of the i^{th} image and summing over the number of image frames and number of flow vectors. For all drivers, the amount of optical flow is greater when making right turns then left turns. For both left and right turns, the amount of optical flow when using the turning cabin simulator is less than that experienced when using the fixed base simulator. The magnitude of this difference is greater for right turns than for left turns.

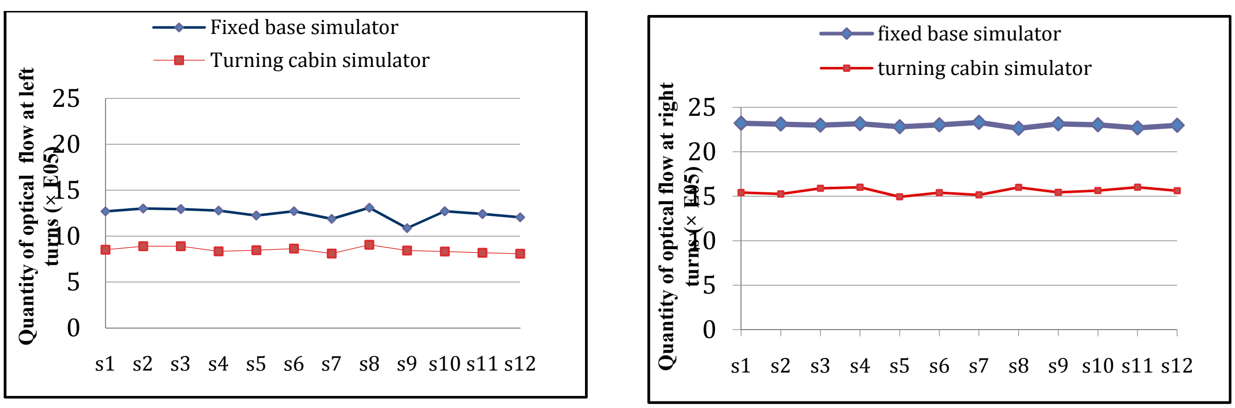

Figure 3. Quantity of optical flow experienced by 12 drivers per second when making left/right turns

Figure 4 shows the means of the amount of optical flow per second for 12 participated drivers when making left/right turns in both the fixed base simulator and the turning cabin simulator. It reveals that drivers experienced a higher amount of optical flow when executing left/right turns in the fixed base simulator. Also, the amount of optical during right turns is significantly higher than left turns, for both types of simulators.

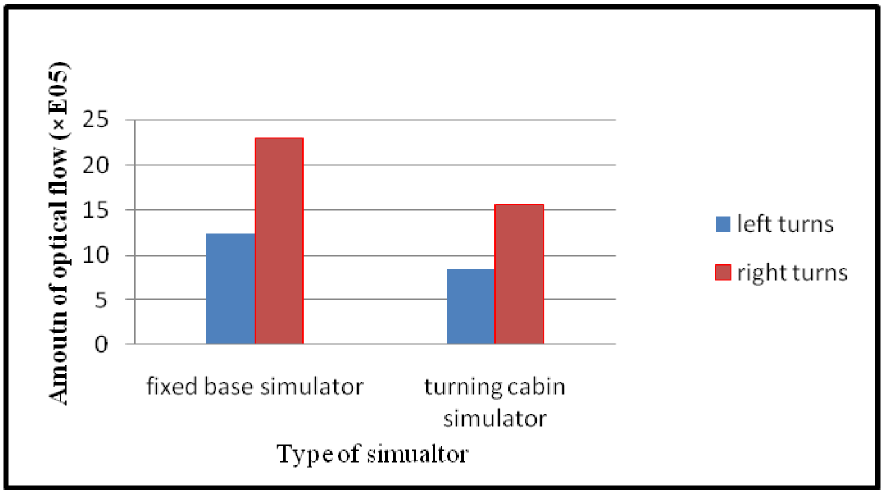

Figure 4. Means of the amount of optical flow per second when making left/right turns by type of simulator

Since the differences above were about the same for all subjects, the results shown in figure 4 are statistically significant.

Experiment 2

The quantity of optical flow per second on straight roads and on curves (with and without clothoids) by type of simulator is shown in figure 5.

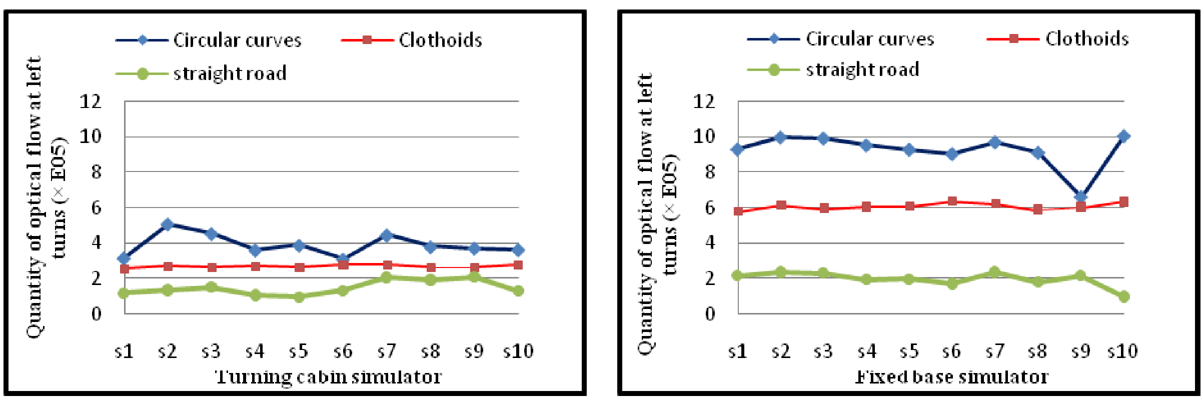

Figure 5. Quantity of optical flow per second experienced by 10 drivers when driving on circular curves, curves with clothoids, and straight roads.

Figure 6 shows the means of the amount of optical flow per second for 10 participated subjects when driving straight ahead, when driving on curves with clothoids, and when driving on circular curves for both simulators. Drivers experienced the highest amount of optical flow when driving on circular curves in both simulators. The lowest amount of optical flow was generated when driving straight ahead. In addition, it's quite clear that the optical flow associated with driving on curves (circular and clothoids) is significantly lessened in the turning cabin simulator.

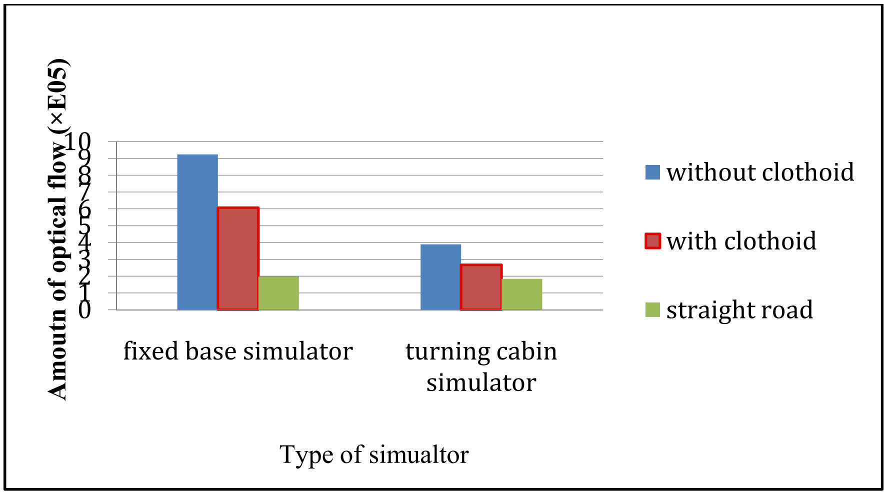

Figure 6. Means of the amount of optical flow per second by type of simulator

DISCUSSION AND CONCLUSIONS

The finding that less optical flow was generated for both left and right turns in the turning cabin simulator was expected. Asano and Uchida (2005) reported less simulator sickness in the turning cabin simulator and this may be attributed to drivers experiencing less optical flow in the turning cabin simulator. We also found that the optical flow perceived on right turns is much higher then that on left turns. The reason could be a much smaller turning radius when executing a right turn.

Optical flow associated with circular curves was found to be the highest regardless of simulator type. This suggests that transit curves (clothoids) are better for drivers because they result in less perceived optical flow. When driving on clothoid curves, drivers' vehicles maintain a constant angular acceleration, which is possibly the reason why less optical flow is perceived as compared to circular curves.

Moreover, our results found that the perception of optical flow in the turning cabin simulator is significantly different from that that in the fixed base simulator. Mourant, et al, (2007) have stated that in the case of driving on curves, the amount of optical flow in a driving simulator is always greater than that in the real-world. This is due to the vehicle actually turning in the real-world. In a conventional driving simulator, the vehicle remains straight ahead when drivers turn the steering wheel. In this study, however, by introducing the turning cabin simulator, the cabin is able to rotate as the virtual vehicle turns. This is very much like the case in the real-world. Therefore, a lower amount of optical flow is generated by a turning cabin simulator when making left/right turns, or driving on curves. We also found no noticeable differences in optical flow perceived on straight roads when driving in the fixed simulator as compared to driving in the turning cabin simulator.

In conclusion, the perception of optical flow in a turning cabin simulator is believed to be more similar to the optical flow found in the real-world. Results in this study are also helpful when modeling virtual environments with the purpose of reducing perceived optical flow. For example, less right turns, and more transit curves (using clothoids) would help to lower the amount of

optical flow generated, and possibly lessen simulator sickness.
We believe that the amount of optical flow generated plays an important role in simulator sickness. However, future studies need to be done, in order to more clearly demonstrate this relationship.

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