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Comparison of Lateral Control in a Reconfigurable Driving Simulator

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ABSTRACT

The UCF driving simulator was designed to be reconfigurable so that either a commercial truck cab or entire passenger vehicle (Saturn with engine and transmission removed) can be mounted on a motion platform. Several vehicle dynamics models are available for various truck/trailer combinations as well as different passenger vehicles. A study was performed to assess whether there are significant differences in driving patterns, specifically with respect to lateral control for both class of vehicles.

Subjects were instructed to drive through a visual database in the truck and Saturn. Driver inputs, gas, brake and steering wheel along with vehicle position was logged at 30 Hz. A test section of two lane road approximately 1350 meters in length with several bends was used to compare the lateral displacement from the centerline in the truck and Saturn.

Tests of hypotheses involving the differences in population parameters (mean and variance) for each of 15 driver's lateral position while driving in the truck and Saturn were conducted. The driver's steering behavior for both types of vehicles was also compared using frequency domain analysis. Results are presented in the paper.

THE MARK II SYSTEM FROM GE-DD

The Mark II system is manufactured by GE-DD, which has been making driving simulators for many years. The truck vehicle cab is a mid-sized, late-model manufacturers' cab shown in Fig.1.

FIGURE 1 The Vehicle Cab Of The Mark II System

The cab is installed on a 6-degree-of-freedom motion base. Three channels of vision are projected on 3 flat white walls in front of the vehicle cab as shown in Fig.2. Two channels of vision are dedicated for rear view mirrors which are actually two LCD monitors. The image generation software is running on 6 personal computers. One of them installs the vehicle dynamics model and calculates simulator position data and motion of the cab. The other five computers generate image sequences for the five channels. A 7th PC is equipped with the operation console and is for loading the vehicle dynamic models and the existing traffic scenarios. The Scenario Editor is used to design new driving scenarios.

FIGURE 2 The Driving Environment

GE-DD also delivered and installed a Saturn re-configurable cab on the motion base (see Fig.3).

FIGURE 3 The Saturn On The Motion Base

EXPERIMENTAL DESIGN

We did not have any prior knowledge about how the lateral control of trucks compares the lateral control of passenger cars, but according to the observations in our previous study with the simulator, it was easy to tell that the subjects normally perform differently in keeping the simulator on the center of the lane when driving the truck and the passenger car. Totally, fifteen subjects participated in this study, ten of which were males and five of which were females. Every one of them had Florida driver license. The distribution of age will be reviewed later in this paper. No simulator sickness happened to any of the subjects. The subjects were instructed to drive on a segment of road whose approximate geometric shape is shown in Fig.4. Each driver was instructed to observe the posted speed limit and maintain appropriate lateral control in both the Saturn vehicle and truck. For each subject, the two experiments, in the truck and in the Saturn were separated by at least two months. Besides, each of the subjects was given a short orientation, acting as the training about the simulator before the real simulation.

From vehicle dynamics point of view, we used two models. The truck's dimensions are 7.09-meter long and 2.4-meter width. The wheel width is 1.79-meter wide. Another one is passenger car. Its dimensions are 4.97-meter long, 1.81-meter wide. Its wheel width is 1.63-meter wide.

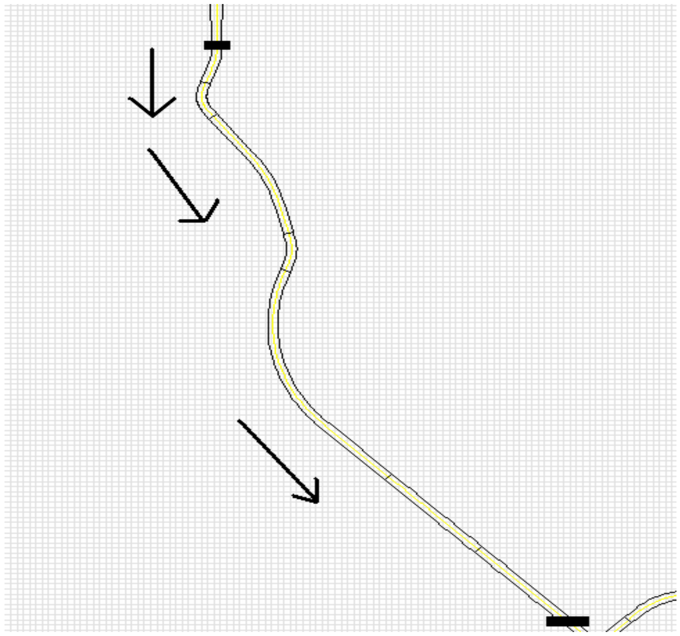

FIGURE 4 Test Segment of Road

The arrows indicate the direction of travel and the two black bars indicate the starting point and ending point of data logging, which consisted of the 2D vehicle coordinates and the following driver inputs: brake, steering wheel angle and accelerator. Data logging was performed at a rate of 30 Hz. Each simulation required from 1 minute to 2 minutes, depending on different drivers' speeds. The amount of raw data varied from 1800 to 3600 numerical values for each logged variable.

DATA ANALYSIS

To compare lateral control of the Saturn and truck, deviations from the center of the lane in the simulation world were calculated. The lane width was 12 feet. The deviation profiles are a measure of how well the drivers could maintain lateral control of the vehicles. Excessive deviations are an indication of possible flaws in the lateral dynamic response of the simulator. Fig. 5 is the histogram of the lateral deviation of a subject, driving the passenger car. It is easy to tell that this subject kept the car near the center of the lane most of time, but the large lateral deviation did happen. This should be due to people's normal driving habit.

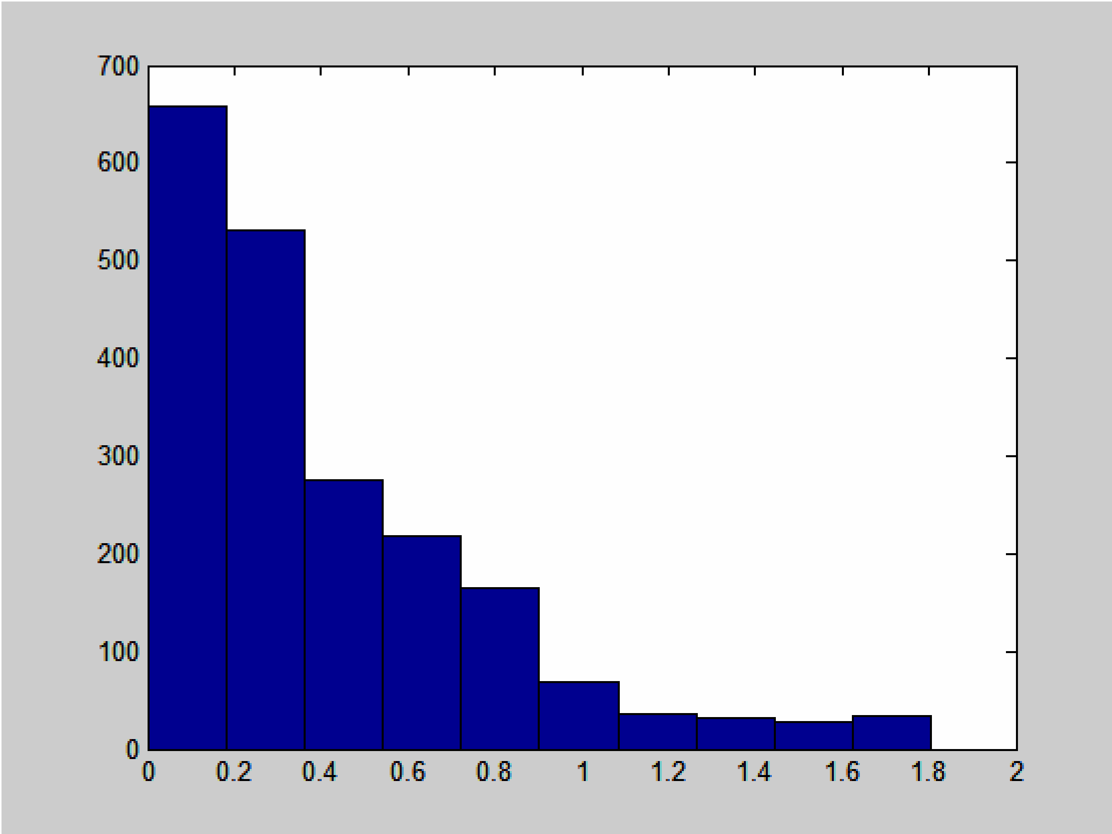

FIGURE 5 The Histogram of Lateral Deviation (count vs. lateral deviation in meters)

The following table introduces the variables used in the statistical analysis of the calculated centerline lane deviation data.

Symbol	Explanation
m	Number of subjects, who drove the same segment of road using both the truck and Saturn.
i	Subscript denoting a specific driver
j	Superscript denoting the truck
T	Number of raw data points for subject i in the truck
S	Superscript denoting the Saturn.
n_i^T	Number of raw data points for subject i in the truck
n_i^S	Number of raw data points for subject i in the Saturn
c_i^T	The autocorrelation interval for subject i in the truck
c_i^S	The autocorrelation interval for subject i in the Saturn
r_i^T	Reduced size of data for subject i in the Truck
r_i^S	Reduced size of data for subject i in the Saturn
$d_{i,j}^T$	Deviation from the center of the lane to the position of the simulator (Truck)
$d_{i,j}^S$	Deviation from the center of the lane to the position of the simulator (Saturn)
m_i^T	Mean of the deviation of for subject i in the truck

m_i^S	Mean of the deviation of for subject i in the Saturn
$\overline{d_i^T}$	Sample mean deviation of fo r subject i in the truck
$\overline{d_i^S}$	Sample mean deviation of for subject i in the Saturn
$t_{\Delta,i}$	The t value according to the threshold for subject i and the t distribution
t_i	The actual t value for subject i

TABLE 1 The Definition of the Variables

Because the data logging occurred at 30 Hz, adjacent data values in the raw data are highly correlated. In order for the sample data to be independent observations from the same population, the autocorrelation function must be known. Fig.5 shows one of the empirically determined autocorrelation functions. The interval between independent observations is selected to be the time of the first local minimum or the first autocorrelation less than 0.05. Consequently, the original correlated sample is reduced in size by a significant amount.

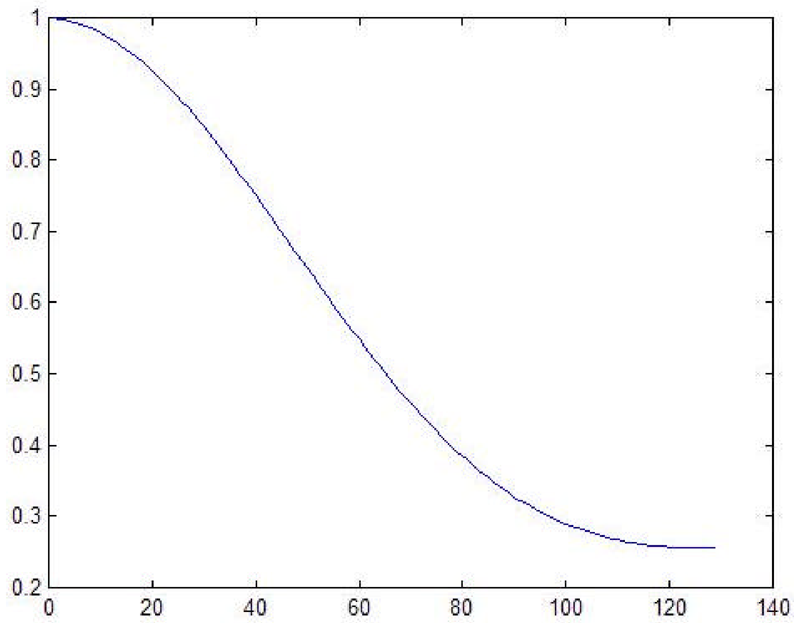

FIGURE 6 Autocorrelation Function for Subject 15 in the Truck

Autocorrelation for subject i and the truck with sampling interval k is

$$\frac{\sum_{j=1}^{n_i^T}(d_i^T - \overline{d_i^T})^2}{\sum_{j=1}^{n_i^T-k}(d_i^T - \overline{d_i^T})(d_{i+k}^T - \overline{d_i^T})}$$

Autocorrelation for subject i and the Saturn with sampling interval k is

$$\frac{\sum_{j=1}^{n_i^S}(d_i^S - \overline{d_i^S})^2}{\sum_{j=1}^{n_i^S-k}(d_i^S - \overline{d_i^S})(d_{i+k}^S - \overline{d_i^S})}$$

The following table contains the sampling intervals, which cause either the first local minimum or the first autocorrelation value less than 0.05, and the reduced sample sizes.

Subject	Length of correlated interval		# of independent observations	
	c_i^T	c_i^S	r_i^T	r_i^S
1	99	60	19	34
2	214	108	11	26
3	168	122	20	17
4	188	63	11	35
5	160	57	13	34
6	98	69	23	22
7	83	91	22	20
8	192	171	12	16
9	91	222	30	10
10	219	98	13	21
11	171	39	12	51
12	98	97	21	21
13	115	132	24	19
14	395	270	7	10
15	129	113	20	19

TABLE 2 Autocorrelation Function Results

None of the subject reduced sample sizes was greater than 30 in the truck or the Saturn. As a result, the *t*-distribution was chosen for use in the statistical analysis of the reduced size independent samples of lane deviations. [1]

The Null Hypothesis assumes that the mean lateral deviation in the truck is identical with the mean lateral deviation in the Saturn for each subject driver. That is,

Null Hypothesis H_0: $m_i^T = m_i^S, i = 1,2,\ldots\ldots, m$

Alternative: $m_i^T \neq m_i^S$

The null hypothesis is accepted if $|t_i| < t_{\Delta,i}$, otherwise it is rejected. The confidence interval is $[-t_{\Delta,i}, t_{\Delta,i}]$. Table 3 contains the degrees of freedom for different drivers, t_i, $t_{\Delta,i}$, and whether the Null hypothesis is accepted or not for each driver.

Subject	d.o.f.	t_i	$t_{\Delta,i}$, critical value	H_0 Accepted
1	26	-2.4020366	2.056	No
2	13	-3.1586486	2.16	No
3	35	-1.2484007	2.031	Yes

4	14	-2.7246909	2.145	No
5	14	-1.9614727	2.145	Yes
6	41	2.52008409	2.021	No
7	24	-2.7351666	2.064	No
8	26	-0.0308755	2.056	Yes
9	13	-0.2966632	2.16	Yes
10	19	-5.0417017	2.093	No
11	13	-4.1150275	2.16	No
12	35	-5.6095247	2.031	No
13	39	-3.9647561	2.021	No
14	15	0.52153946	2.131	Yes
15	26	-2.322875	2.056	No

TABLE 3 Null Hypothesis Test Results

The hypotheses are accepted for 5 subjects and rejected for 10 subjects. By observation of the t_i values in Table 3, it follows that the lateral deviations of drivers are less in the Saturn than in the truck.

SPECTRAL ANALYSIS OF THE STEERING INPUT

Nine out of ten times when the Null hypothesis was rejected, larger deviations from the center of the lane were observed in the truck than in the passenger car. However, results from a post simulation survey found that most subjects were satisfied with the response of the truck simulator and complained about the performance of the Saturn, especially with respect to the brake and steering wheel. Prevailing opinion was that the Saturn's brake did not feel like a real brake. With respect to the Saturn's steering wheel, subjects commented that the feedback was too loose and the wheel would not center when released. The brake's performance is unrelated to controlling the lateral position of the vehicle, however the steering wheel's performance does play an important role.

The spectral properties of steering wheel displacements in the Saturn and truck is summarized by their Fourier transforms. To be more specific, the FFT (Fast Fourier Transform) of each driver's steering input in the truck and in the Saturn is required. For each driver there are two FFTs, one for the truck and one for the Saturn. They are denoted by FFT_i^T and FFT_i^S.

To help decide whether the difference in the steering wheel's performance contributed to accepting or rejecting the hypotheses, the sum of the FFT power was computed for all five drivers where the hypotheses were accepted. In addition, the same was done for five out of the ten drivers where the hypotheses were rejected. The result is to calculate $\sum_{i=1}^{5}(FFT_i^T)^2$ and $\sum_{i=1}^{5}(FFT_i^S)^2$ for both sets of five drivers, the first where the Null hypotheses were accepted and the second set of five drivers for which it was rejected. The four FFT power plots are shown in Figure 7 and 8.

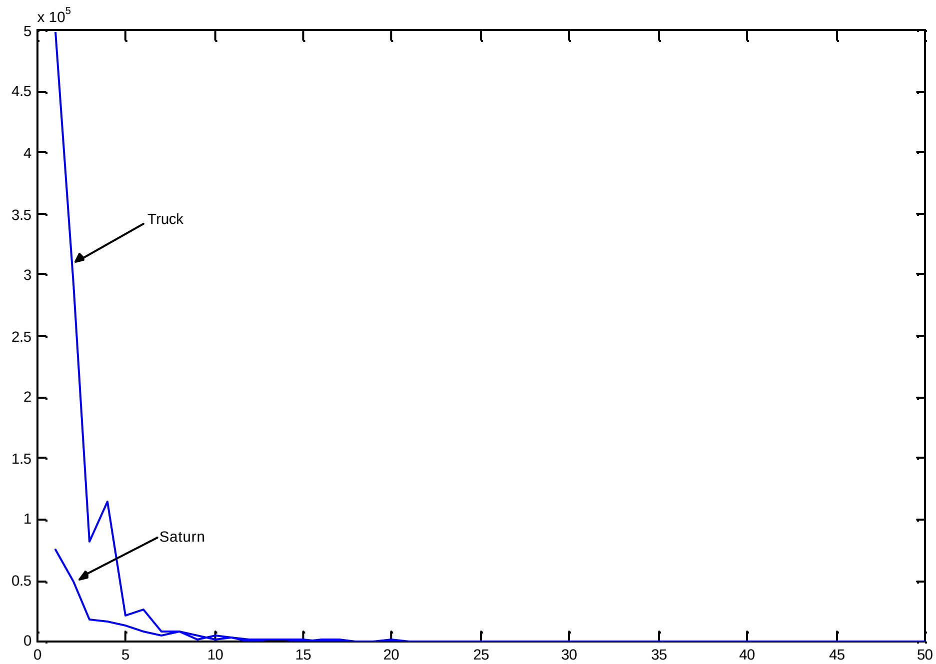

FIGURE 7 Steering Input Power (Null Hypothesis Accepted)

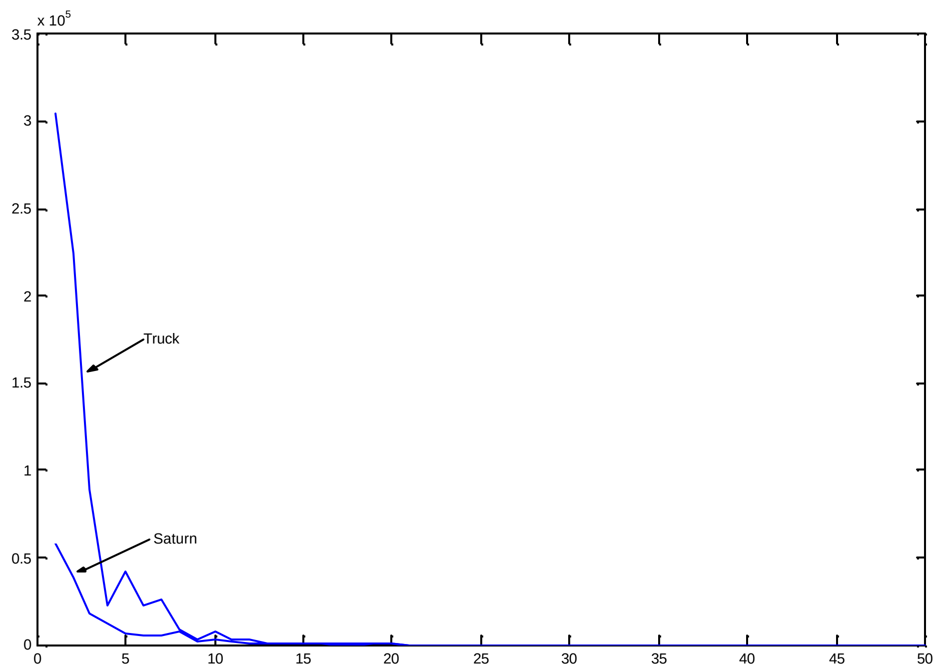

FIGURE 8 Steering Input Power (Null Hypothesis Rejected)

By observation of Figures 7 and 8, it appears that drivers turned the steering wheel more frequently in the truck than they did in the Saturn, independent of acceptance or rejection of the Null hypothesis. One explanation is that the steering in the Saturn was easier (looser) compared to the truck. The actual reason

why the spectral powers are different is not important. What is important is this difference is not a factor in deciding whether the
Null hypothesis was accepted or rejected because similar differences between Saturn and truck) existed in both cases (acceptance and rejection of Null hypothesis). We conclude that the difference in lateral position when driving the truck and the passenger car can be attributed to a combination of the subjects driving habits and the inherent differences in the Saturn and truck vehicle dynamics.

On another aspect, the null hypothesis accepted group put a lot more effort into steering both vehicles. That is because this group of drivers intended to keep a good lateral position, so they kept adjusting the steering wheel, which results in high spectral power.

FUTURE WORK

Table 4 presents the facts of ages, average speeds and standard deviations of speeds of the fifteen subjects.

Number	Gender/Age	Average Speed (mph) Truck/Saturn	Std Deviation of Speed (mph) Truck/Saturn	H_0 Accepted
1	Male/27	49.4/45.7	9.4/4.5	No
2	Female/27	37.8/33.0	9.5/7.0	No
3	Male/39	26.6/43.8	15.4/10.4	Yes
4	Male/21	42.4/42.3	8.7/5.3	No
5	Female/19	43.9/47.7	6.6/9.1	Yes
6	Male/21	41.1/59.5	12.3/7.5	No
7	Male/18	50.9/49.0	10.5/10.2	No
8	Male/42	38.3/33.4	9.2/9.1	Yes
9	Male/41	33.6/39.1	11.0/12.0	Yes
10	Male/32	32.2/43.6	6.8/8.2	No
11	Female/37	42.2/46.6	9.6/12.7	No
12	Female/36	44.5/44.6	8.6/7.6	No
13	Male/21	33.1/36.5	5.7/9.7	No
14	Male/36	30.7/34.3	15.6/14.6	Yes
15	Female/35	35.0/43.3	6.9/8.4	No

TABLE 4 The Facts of Age and Speed

For those six male hypothesis-accepted subjects, the average age is 39.5 year-old. For those four male hypothesis-rejected subjects, the average age is 23.3 year-old. For those four female hypothesis-rejected subjects, the average age is 33.8 year-old. There is only one female hypothesis-accepted subject, whose age is 27 year-old. There exists somewhat difference between the average ages, but this could be caused by small sample size. In the future, we are going to invite more subjects with a certain age distribution and repeat what we did in this study. Then we will be able to put the factor of age into concern.

Additionally, we could analyze the causal relationship between the speed and the lateral position. From the data above, some subjects' average speeds in the truck and the Saturn vary significantly, like No. 3 and 6. Some of those vary not much, like No. 5 and 7. What is interesting is that the hypotheses are rejected in No. 3 and 5 and accepted in No. 6 and 7. Therefore, we need more subjects and analyze the relationship between speed or the standard deviation of speed and lateral control.

Besides, the vehicle dynamics may also play an important role in controlling the lateral position. Therefore in the future, we also can compare the dynamics of these two models.

In this study, we used a curve road. In the future, we also plane to conduct similar lateral control studies on different road segments to see whether the results are repeatable, i.e. independent of road geometry.

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Conclusion

In this study, 15 subjects drove along a segment of road in a driving simulator in both a Saturn passenger car and a truck. Based on statistical analysis of lateral position, two thirds of the drivers responded differently in the Saturn compared to the truck. Furthermore, the deviation from the center of the lane in the truck was greater than in the passenger car.

Reference:

[1] Mendenhall W. and Sincich T. Statistics for Engineering and the Sciences. 4th Edition, Prentice-Hall, Inc. New Jersey, 1995.