Toward predicting the subjective assessment of ESC in a driving simulator

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Abstract *– Previous works have sought to develop an evaluation method to describe loss of adherence episodes by means of subjective indicators and to propose a predictive model of the subjective evaluations. This study presents the use of the presented model and predicted evaluations when ESC is triggered. The results confirm the capabilities of the model and the potential of the presented methodology to evaluate and characterize ESC on a driving simulator in the early stages of the engineering design. However further studies will be necessary to improve the robustness of the model and its use in various situations.*

Key words: *Sensory evaluation, ESC, Driving simulators, Model prediction, Virtual engineering.*

Introduction

Loss of adherence (LOA) can lead to loss of vehicle control, a major factor in many accidents. Electronic Stability Control (ESC) is an advanced driving assistance system (ADAS) that dynamically corrects the vehicle trajectory according to the driver's intentions in emergency situations. It is useful in particular in case of loss of adherence (LOA) in bends due to excessive speed or alteration of road grip, which can lead to loss of vehicle control. Using electronic stability control (ESC) can limit the consequences of these situations [Lie1] [Erk1]. The calibration and validation processes of ESC are time consuming and require the use of physical prototypes and expert drivers at specific test sites, especially for very low-adherence situations. Consequently, driving simulators are being used to study LOA episodes and ESC performance [Wat1] [Pap1]. Driving simulators are useful tools in vehicle design and perception studies. They allow the safe exploration of critical situations with naive drivers and without environmental bias [Kem1]. The present study is a step of a research program that is aimed at understanding how drivers perceive and react to trajectory perturbations and to the intervention of an ESC system. This could be useful for using driving simulators to develop the engineering specifications of ESC and to evaluate how actual drivers perceive different system configurations.

Previous works [Den1] [Den2] have sought to develop an evaluation method to describe LOA episodes by means of subjective indicators using a non-structured-scaled questionnaire [Str1] and to determine to what extent objective and subjective indicators were related. In this paper, an explicative and predictive model of driver subjective assessment in LOA situations has been proposed. It is based on objective measurement of vehicle behaviour such as lateral acceleration, heading speed or slip angle [Den3]. The present study evaluated the influence of ESC activation on subjective ratings and the predictiveness of the model for ESC triggering cases in LOA situations.

An experiment was conducted on the high fidelity dynamic ULTIMATE simulator using the SCANeR©Studio software package with a real-time version of the MADA (Advanced Modelling of Vehicle Dynamic) vehicle dynamic software, developed by RENAULT. The intensity (0.1 to 0.3 adherence coefficient) and duration (250ms to 750ms) of the simulated LOA in the bend were manipulated as independent variables on the four wheels. Situations of LOA inducing a significant modification on the vehicle without involving a brutal road departure were chosen. ESC availability (on or off) was the third independent variable. All subjects experienced the same LOA situations with and without ESC assistance. They were not aware of the presence of the assistance.

The objective of the study is to evaluate the accuracy of the developed model on a new data set, with and without the presence of an ESC system. The first results show a good accuracy of the predictive model on the data set without ESC. ESC triggering seems to slightly perturb the model prediction. Although further experiment will be necessary to improve the robustness of the model and enlarge to various applications, the methodology proposed seems to have a strong potential to evaluate ESC strategy in the early steps of engineering design.

Method

Participants

Four female and ten male drivers between 27 and 59 years old (mean age of 43.6) participated in the experiment. They had held a driving licence for 20.6 years on average and drove between 1000 and 20000 km per year (mean = 13400). All of them had normal or corrected-to-normal vision.

Apparatus

The experiment was conducted on the high-performance dynamic Ultimate simulator [Dag1] at Renault Technical Center for Simulation (Fig. 1). It consists of a compact size passenger car based on a real Laguna interior design. The cab is mounted on a large X-Y table and a hexapod motion system to render physical accelerations and rotations. Transmission is carried out using a manual gearbox. A system of sound synthesis is used to reproduce engine noise and the audio environment for an interactive vehicle. Active steering force feedback is computed by a proprietary model and reproduced by a TRW electric power steering system.

The SCANeR© Studio software package was used with a real-time version of the MADA (Advanced Modelling of Vehicle Dynamic) vehicle dynamic software, developed by RENAULT. The visual environment was displayed on a cylindrical screen (radius 1.9 m) by three single-chip DLP projectors, each with a resolution of 1024 x 768. The system covers a visual angle of 150°.

Figure 1. Ultimate Renault driving simulator

The graphics database reproduced an open countryside driving environment (Fig. 3). Behavioural measures (lateral position, steering angle, lateral acceleration, etc.) were recorded during the trials at 20 Hz. All trials were performed on a short section of the driving environment, which comprised a straight line followed by a bend (total distance: 700 m; mean radius in the bend: 111 m) without traffic (Fig. 2).

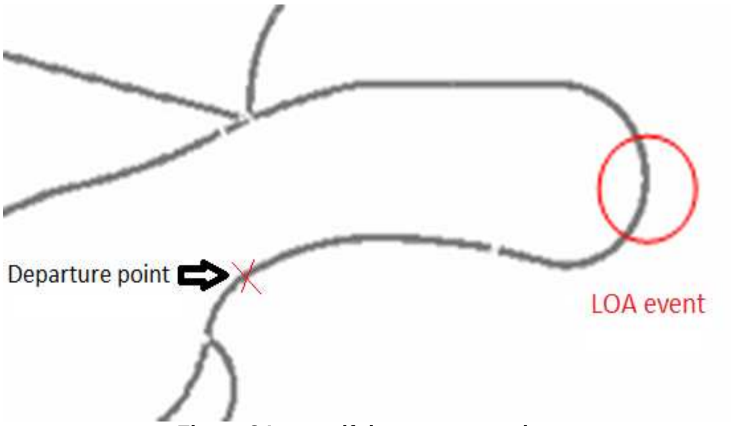

Figure 2.Layout if the country track

Figure 3. Visual environment in the bend

A software-in-the-loop generic ESC system was used (Fig. 4). The system was set up with the characteristics of the simulated vehicle, but the tuning did not reflect the supplier tuning mounted on the real car. The complex proprietary control laws to handle the vehicle stability will not be detailed.

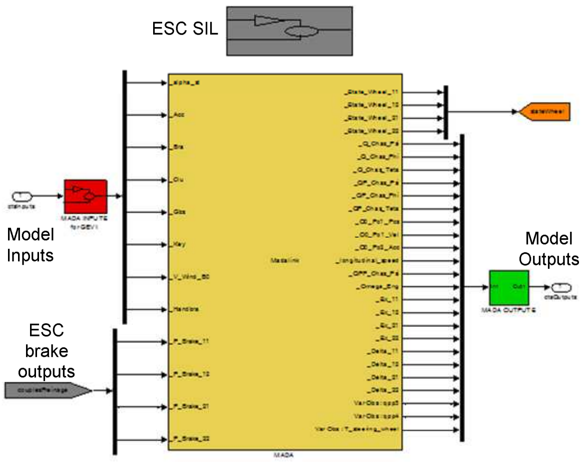

Figure 4. ESC software model integrated in the MADA vehicle dynamics model

Procedure

LOA was simulated by modifying the adherence under the wheels when the vehicle reached a defined point in the bend. The intensity (adherence coefficient) and duration of the simulated LOA in the bend were manipulated as independent variables (IV). An adherence coefficient decrease corresponds to an increase in the intensity of LOA. ESC availability (on or off) was the third independent variable. These values of intensity and duration were chosen to induce perceptible but controllable LOA simulated on four wheels (Table 1). The LOA situation induced a skid towards the outside of the bend. The environment did not give clues about a potential LOA (such as snow, rain or a mark on the road). Subjects faced each of the four conditions two times, with and without ESC. A Williams Latin Squares design [Wil1] was adopted to control rank and carry-over effects. After each experimental condition, the subject was asked to assess the LOA on a continuous unstructured scale according to 3 descriptors: perceived intensity, control feeling, danger.

Participants were asked to keep to their lane without cutting the corner, even if there was no oncoming traffic. After a 10-minute practice session, they drove around the test bend at a predefined speed (75 km/h). Subjects received verbal assistance from the person conducting the experiment in order to maintain a constant speed and stay focused on steering control. Four trials without any LOA were performed in order to allow the subjects to familiarize themselves with the task.

Table 1. LOA conditions

Conditions	C1	C2	C3	C4
Adherence coefficient	0.1	0.1	0.3	0.3
Duration (ms)	250	750	250	750

Data Analysis

Data were sorted out to identify situations where ESC has actually triggered. Predictive subjective responses were computed with a perception evaluation model of LOA situations that was developed previously by [Den3]. The models for each subjective descriptor (Yj) are reminded below (Eq. 1, 2 & 3). Actual subjective responses Yj were then compared with the values of the model $\hat{Y}_j$ in order to assess its accuracy as a function of ESC activation.

Perceived intensity = -17.90 + 6.62 lateral acceleration + 3.57 heading speed (1)

Control feeling = 26.64 - 0.86 slip angle - 6.90 heading speed (2)

Danger = - 13.57 + 4.71 lateral acceleration + 2.50 steering wheel angle (3)

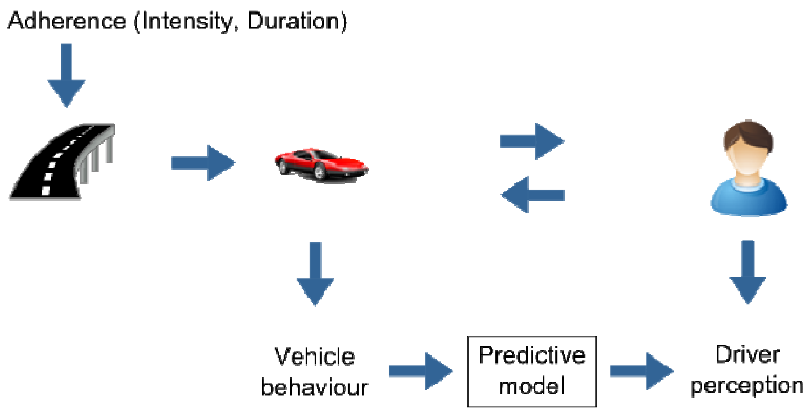

Figure 5. Input and Output data

Table 2: Input and output data for the predictive model

Input (objective indicators)	Output (subjective descriptors)
Lateral acceleration ($m.s^{-2}$)	Perceived intensity
Heading speed ($deg.s^{-1}$)	Control feeling
Slip angle (deg)	Danger
Steering wheel angle (deg)	

Two indicators were used to evaluate the predictions errors:

- The mean absolute error (MAE). It represents the forecast accuracy of the model (equation 4): the smaller the *MAE*, the better the forecast accuracy.

$$MAE = \frac{1}{N}\sum_{k=1}^{N}\left|\hat{Y}_{kj} - Y_{kj}\right| \quad (4)$$

where N is the data sample size

- The root mean square error (RMSE)

In order to evaluate the quality of the predictions, we also computed the Pearson coefficient correlation (r) between the predicted values $\hat{Y}_j$ by the models and the actual observed values Y_j.

Results

The followings tables give the results of the MAE, the RMSE and the correlation coefficients between predicted and actual values for each descriptor, without (table 3) and with ESC triggering (table 4). Situations where ESC has not triggered were excluded for the analysis. In order to have same data sample size for both group (ESC vs. no ESC), we also excluded the paired data in the "without ESC" group. Finally, we had 18 situations in each group.

Table 3. RMSE, MAE and correlation coefficients for model forecast without ESC triggering

Yj	RMSE	MAE	r
Intensity perceived	1.08	0.90	0.81
Control feeling	1.9	1.61	0.65
Danger	1.47	1.19	0.65

Table 4. RMSE, MAE and correlation coefficients for model forecast with ESC triggering

	RMSE	MAE	r
Intensity perceived	1.39	1.07	0.60
Control feeling	2.39	1.64	0.52
Danger	1.58	1.24	0.60

Figure 6 and 7 represent the correlation between observed and predicted scores for subjective indicators with and without ESC activation for the data sample.

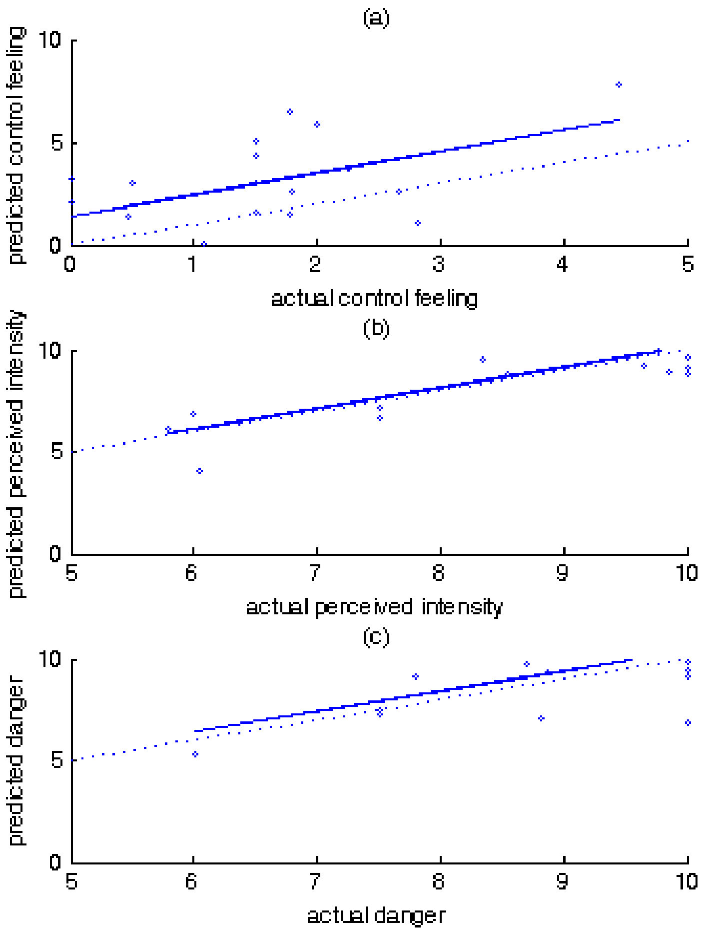

Figure 6. Correlation between actual and predicted scores for control feeling, perceived intensity and danger without ESC triggering (n=18). Solid line: actual correlation, dotted line: perfect correlation

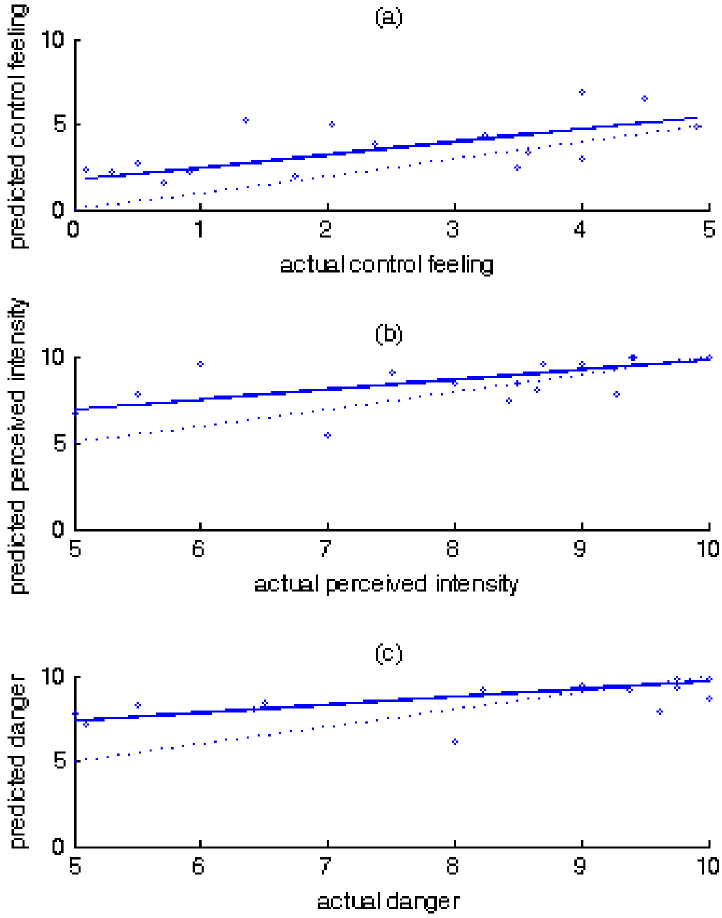

Figure 7 Correlation between actual and predicted scores for control feeling, perceived intensity and danger with ESC triggering (n=18). Solid line: actual correlation, dotted line: perfect correlation

Fisher's tests perform on the subjective variables show no significant effect of ESC triggering on "Danger" (F=1.209, p=0.28), "intensity perceived" (F=0.47, p=0.50), and "control of feeling" (F=1.58, p=0.22)

Fisher's tests perform on the objective variables show no significant effect of ESC triggering on maximum lateral acceleration (F=0.42, p=0.52), maximum steering wheel angle (F=2.12, p=0.15), maximum heading speed (F=0.32, p=0.58) and maximum slip angle (F=0.02, p=0.88).

Discussion

The present study shows the use of multiple linear models to predict driver subjective assessment in LOA situations with and without ESC triggering. For the data set without ESC, we observed good predictions of the models in the same range as seen as previously [Den3]. This confirms the capabilities of the model with a different panel of participants, which validates the methodology we used.

The same model was applied to characterize different situations in which ESC triggered. Results show that the prediction errors were more important with ESC activated. In this case, the predictive evaluations were also less correlated with the actual subjective evaluations. This probably means that the model parameters need adjustments to fit with the action of ESC. The correlation plots seem to show that the model overestimated the subjective evaluations compared to the observations. Unfortunately, results do not show a significant effect of ESC on subjective evaluation. This could be explained by the tuning of our ESC that provided limited trajectory corrections. Further investigations will be made on this question with different tuning of ESC and different LOA situations.

A traditional problematic with subjective evaluation on simulator is the simulation rendering fidelity compared to real perception. In our case, for obvious safety reasons, it would be difficult to reproduce the same experiment on a real track with non-expert drivers and compare the results. However, the global fidelity of a simulator can be estimated indirectly. On the Ultimate simulator, subjective evaluation campaign has been performed by Renault expert drivers. They have notably rated steering wheel, heading and pitch as "Satisfying" for a 0.2Hz / 0.2G slalom manoeuvres on Laguna simulation [Dag2]. We can also identify and compensate for the simulator motion cueing delays [Fan1] and adjust scale factor for lateral and yaw motion rendering [Fil1]. Moreover, the fidelity of the simulator has been evaluated within the framework of the Eureka Moves European Project [Ber1]. Thus, we are confident on the level of fidelity of Ultimate for this application.

This study shows the strong potential of this methodology to evaluate and characterized ESC with the help of a driving simulator, in particular in the early stage of the development process when no physical prototypes are available. It also adds the possibility to evaluate ESC system from a non-expert point of view, which may complement traditional methods. However, further studies are necessary to improve the quality and robustness of the model. A similar method could be applied on new projects like electrical vehicle [Fan2] for which drivers' reactions are not well known.

Conclusions

A model presented in this paper allows predicting subjective evaluations of loss of adherence in driving simulator experiments. Further studies will allow improving the robustness of the model and its application in various situations. This study shows the strong potential of this methodology to evaluate and characterized ESC on a driving simulator in the early stages of the engineering design.

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