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A Method to Assess Individualized Driver Models : Descriptiveness, Identifiability and Realism

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Introduction

Mathematical models of human driver control behavior are critical to the success of driver support systems [Mes04, Abb11] and driver assessment and profiling [All05]. These systems require identification and classification of human behaviour using computational driver models that are sensitive to environmental/human changes [Ame15], such that the automation can be made adaptive to the drivers dynamic time variations. With each driver having their own driver style and a continuously changing driving environment, ensuring a good mental model match between automation and the human requires *online identification*, which is far from straightforward.

Therefore, research is performed on how human sensors pick up information from the environment through visual, vestibular and somatosensory receptors to form a deeper understanding by developing relevant models. Many models focus on the visual receptors of the human, selecting environmental triggers (inputs) from the complex three-dimensional visual scene, with both a perception of road path geometry through feedforward and the perception of optic-flow [Gib50] through feedback paths. For example, most driver steering models are based on the hypothesis of parallel high- and low-frequency compensation [Don78, Hes90], often coupled to dedicated "far" and "near" preview/tangent points [Sen09, Mar11], respectively. Driver steering models currently implemented in driver-assistance systems are often, for practical reasons, simple – e.g., two-parameter (single preview point) – driver models [Sai16, Mul08].

Despite previous reviews of driver models focused on model identification [Ste11], a structured approach to assess the appropriateness of a certain model's capabilities in capturing different driving styles, and how that is linked to success in model identification, is still missing. Such an approach is elaborated in the next section on assessment criteria.

Assesment Criteria

Fig. 1 presents our proposed assessment procedure for driver models through three main criteria in graphical form. A given driver model is first assessed in terms of *descriptiveness* : the criterion which reflects upon how good the model can capture different driver styles. This is done by evaluating all the realistic trajectories of the model (i.e. trajectories that are within road boundaries and are not resulting from oscillatory steering deflections), thereby producing the the model capabilities area and comparing this area to the total hypothetical descriptiveness area that an ideal model would be able to capture. The descriptiveness criterion is then quantified as a percentage area of the total hypothetical descriptiveness area.

Secondly, *identifiability* : the criterion that evaluates how effective this model would be in terms of unique parameter retrieval. This is realized through evaluating the Variance Accounted For (VAF) for a full parameter space (parameter combinations) based on either the model outputs given a model parameter set, for inherent identifiability or based on a real data reflecting a particular driver style, for driver style identifiability. The model outputs that are compared in this study are δ_s and e_{lat}. From this matrix of VAF values a heat map is constructed, where the parameter combinations that result in a VAF between 95-100% are visually illustrated as the identifiability area on the heat map.

Thirdly, *realism* : the criterion that maintains realistic and comfortable interface parameters, in this study we focus on only steering angle. This criterion provides a constraint on the parameter solution space of steering deflections based on the steering reversal rate as a filtering metric. This is important as all models, given certain parameter points will have oscillatory behaviour.

Finally, a verdict is given as to whether the model can be used to identify a variety of driver styles in a realistic way.

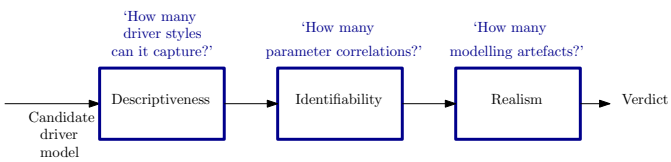

Figure 1: Illustration of the relationship between the driver model criteria

Driver Model used for Assessment

The model that is assessed in this paper as an example is used for identification of curve driving in the paper of [Boi14]. It is one of lowest-order and most simple models of curve driving behavior available, similar to the two-parameter driver models used in [Sai16] and [Mul08]. This one-point model tracks curves based based on proportional control (with control gain K_y) on a linearly predicted future lateral position error (modeled with a look-ahead time t_{LH}) $\hat{e}_{lat}(t+t_{LH})$ as given in Eq. (1).

$$\delta_s(t) = K_y \hat{e}_{lat}(t+t_{LH}) \tag{1}$$

Sample Results

In this abstract, only a sample of the attained results is shown, namely the descriptiveness plot, which best illuminates the limitations of the two parameter linear prediction model.

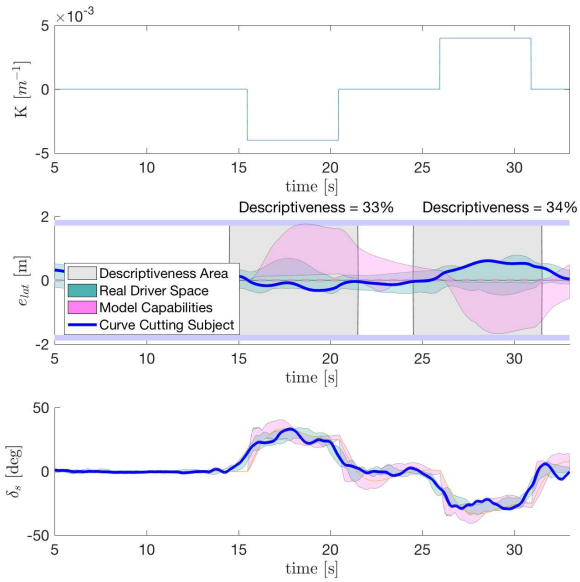

Figure 2: Top Figure : curvature profile, Middle Figure : Model Descriptiveness of Curve-Negotiation in e_{lat} domain with real data from a curve cutting subject from [Boi14], Bottom Figure : corresponding δ_s

Fig. 2 gives an example of the driver model descriptiveness test, where the descriptiveness of the model is shown through the shaded model capabilities area. In the e_{lat} domain it is clear that this model is only able to reproduce over steering driver behaviour without being able to track the exact center of the curve. This is made clear by comparing a real driver run, Subject 5 from [Boi14] given in blue, which illustrates curve-cutting behaviour, along with the span of 12 different subjects given in the *real driver space*.

Both the inherent identifiability and curve-cutting (driver style) identifiability was assessed. The results show that the model has inherently a very large steering angle δ_s identifiability space, and a smaller e_{lat} identifiability space, indicating that optimizing for e_{lat} would inherently provide more reliable and unique identification results. For curve cutting identifiability, it was found that there was no identifiability space in the e_{lat} domain (which defines trajectory), surprisingly, there was a steering angle identifiability space. Therefore, when optimizing only for steering angle as was done in [Boi14], a high VAF in this domain can be quite misleading. With low descriptiveness, identifiability becomes questionable and driver-style dependent, making the question of being able to individualize, quite controversial.

The importance of filtering out non-realistic solutions was illustrated by picking a solution that was within the identifiability space, however, outside of the realistic range. This solution had slight oscillatory steering behaviour, which would not provide a comfortable interaction with the human.

Conclusion

This paper provides a method by which the effectiveness of a given driver model for the application of driver assistance systems, can be assessed. As an example, a two-parameter model used for individualisation of Haptic Shared Control in [Boi14], is evaluated using the three criteria. The following general conclusions can be made :

— A model with poor descriptiveness will suffer during identification of different driver styles, making reliability of the identified model and parameter values, questionable.
— Considering only the VAF on a non-discriminative (low inherent identifiability) metric such as the steering angle can be misleading. Small variations in steering angle that may slightly effect VAF, can have larger implications in the trajectory driven. Instead, the lateral error output has better inherent identifiability capabilities, therefore during identification, including lateral error during optimization is essential.
— Identification should be performed within the contraints of realism, as within an identifiability space, there may be solutions of equal VAF that result in different δ_s oscillations.

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