

CONTROL THEORY PREDICTION MODELS FOR SIMULATING DRIVER INTERACTIONS WITH ADVANCED IN-VEHICLE SYSTEMS

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Abstract

IVIS (In Vehicle Information Systems) and ADAS (Adaptive Driver Assistance Systems) modify driver's behaviour and in risky situations may affect driver's SA (Situation Awareness). In the HUMANIST (IST-507420-NoE) and AIDE (IST-1-507674-IP) projects, models for joint driver-vehicle-environment (DVE) interaction are under analysis in order to enhance design process, safety expectations in these new technologies, and embed consideration for the "joint" Human Machine Interaction (HMI) system. Few studies analyse behaviour alteration arisen from the IVIS and ADAS intervention. Within this study, a preliminary attempt to simulate DVE interactions is based on modelling centre of lane path following. A selection and adaptation of well established models based on control theory has been done in order to design tests and simulations of HMI in terms of prediction and security. The actual models and tests will be able to deal with "disturbance" input variables which should allow to emulate ADAS and IVIS intervention.

Keywords: In Vehicle Information Systems, Adaptive Driver Assistance Systems, Behavioural Adaptation, Control Systems, Stability, Human Factors

1 Introduction

The aid of IVIS (In Vehicle Information Systems) and ADAS (Adaptive Driver Assistance Systems) modify driver's behaviour and their intervention in risky situations may affect SA (Situation Awareness). In the HUMANIST (IST-507420-NoE) and AIDE (IST-1-507674-IP) projects, models for joint driver-vehicle-environment (DVE) interaction are under analysis in order to enhance design process, safety expectations in these new technologies, and embed consideration for the "joint" Human Machine Interaction (HMI) system. Actually few studies analyse the behaviour alteration arisen from the IVIS and ADAS intervention (Salvucci, 2001, Salvucci et al, 2001), due also to

the difficult experimental set up and the amount of parameters to be considered. This is particularly true for the crucial issue of long term behavioural adaptation.

Within this study, a preliminary attempt to simulate DVE interactions is based on modelling centre of lane path following. A selection and adaptation of well established models based on control theory that describes the limits of stability (accident avoidance) of the HMI process have been done in order to design tests and simulations of HMI in terms of prediction and security. The actual models and tests will be able to deal with "disturbance" input variables which should allow to emulate ADAS and IVIS intervention. The models used are McRuer et al., 1969, Weir et al., 1968, McRuer et al., 1974, and some adaptation are now under analysis in order to add "disturbance" input variables conveyed by the intervention of ADAS and IVIS. The choice of these robust models will also help to cut away the roughest situations in which a driver can be involved.

Certainly, moving from a control theory model extracted from assessed real data and designed in the continuous time domain to the implementation in discrete time domain without real mechanical constraints implies some tricks in order to ensure the consistency between the cross-over model evaluated on test and the simulation. First of all the formulas were all merged from the Laplace S Transform to the time domain. Following the Astrom-Wittenmark book, an anti-windup regulator has been added. This filter is necessary in order to avoid that in certain condition (discontinuity due to U turn or so on) the output angle becomes wider than the maximum mechanical angle allowed.

At present, considerations in terms of driver prediction e.g. how does the model change due to different speed changes, are the driver vehicle transfer function parameters changing or not and so on, have been left out of the discussion of this paper. Due to this for the purpose of this experiment the model has been taken into account considering that no changes will occur in the cross-over parameters of the driver. A simple path considering a series of round turns similar to possible real multiple lanes roundabouts trajectories has been evaluated in terms of lateral deviation towards angle deviation.

The simulations of the model are conducted by means of Matlab and will be integrated in a tool, under construction by KITE Solutions with the collaboration of JRC; this tool is designed in order to add new scenarios and behavioral control models. This study will discuss the basic underlying assumption of the simulation under development and will show some preliminary results on a sample case.

2 Material and Methods: from Scenario Descriptions to Identification of Related Control Theory Models

The DVE model of interaction developed in the AIDE project is based on Scenarios and Dynamic Interaction. The attempt of the research is to expand the analysis described in the Scenarios of the DVE model, illustrating how the Driving Task Analysis can be modeled in terms of control theory in order to assess driver stability in the domain of the AIDE objectives. The Task Analysis is conducted in terms of sets of elementary functions and actions performed by the driver and the correlations between tasks and elementary functions. The "*Scenario 1: Normal driving*" has been analyzed and three Elementary Tasks were successfully modeled.

Here below is the description of the reduced Scenario 1 (Table 1):

“Journey from A to B on a country road with two lanes in opposite directions. The main goal of the driver is to reach B as fast as possible respecting constraints in terms of speed limits, surrounding traffic, road surface condition, road geometry, accepted perceived risk etc. No ADAS or IVIS are operated.”

Table 1: Scenario1 Description

| Elementary functions/tasks of Scenario 1 | Present Modelised Status |
|---|---------------------------------|
| Get perceptual input for control task (look at far- and near point on the road ahead) | McRuer and Weir, 1969 |
| Keep lateral safety margins | McRuer and Weir, 1969 |
| Keep longitudinal safety margins | McRuer and Weir, 1969 |

This scenario has been described in terms of common control system models in order to be feasibly implemented. The model, already implemented in the core part of this study (Re et al. 2005), is the Crossover Model (McRuer et al., 1974, Weir et al., 2005) which is then described in terms of Model for Driver and Steering Control (Weir et al., 2005) and Model for Steer Control with Acceleration Pedal (Weir et al., 2005).

3 Preliminary Results: Applications in the Case Studies.

From the previously described analyses the outcomes resulted both in terms of a set of simplified control theory models and driver behaviour rules.

3.1 Simplified Control Theory Models

In the following lines and figures are indicated the description of simplified models, which are then applied in the case studies (see also Re et al. 2005).

- lp_d : input that indicates the Desired Lane Position in terms of deviation from the centre of the lane
- U_d : input that indicates the Desired Speed Profile in terms of attaining to maximum speed allowed (see Figure 1).
- $T_{lp_const_speed}(t)$: Open Loop Transfer Function for Lane Position Regulation with constant speed (the driver desired speed is almost constant in highways) (described in Figure 3)
- $T_{speed}(t)$: Open Loop Transfer Function for Speed Regulation (Figure 3).
- $T_{lp_speed}(t)$: Open Loop Transfer Function for Lane Position and Speed Control Model (Figure 3)
- $T_{ha}(t)$: Closed Loop Transfer Function for Heading Angle Regulation (Figure 3)

All the time constants, time delays, gains and crossover frequency were calculated from Weir et al. (2005)

- Control Delay or Control Freezing Model: as illustrated in Figure 4, this is one of the core models under examination (Salvucci, 2001) which tries to explain what happens when the driver is distracted from any occurring event (Driving Stability Analysis). In particular, it has been assumed that the driver will not correct the heading angle by means of the steer controller and will not decrease the speed for a certain time ($t_{distraction}$). Possible models of driver recovery actions or other inadequate behaviour are still under analysis and will result from the experiments under development in AIDE.

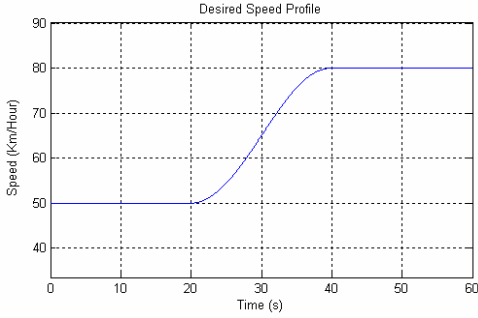


Figure 1: Desired speed profile during transition from 50Km/h to 80Km/h speed limitation with a t_{style} of 20 seconds

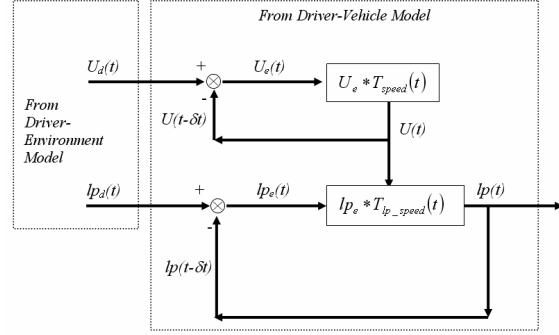


Figure 2: Control Model in terms of time-domain transfer function for the DVE Model of the simulation tool

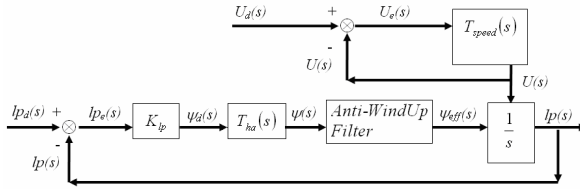


Figure 3: Control Model in terms of the equivalent inner open loop Laplace transfer function of heading angle control

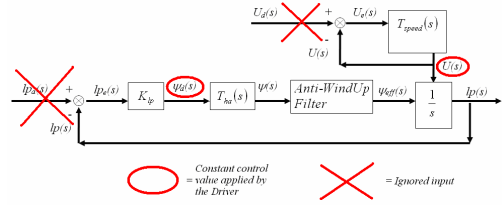


Figure 4: Control Delay or Control Freezing Model

3.2 Driver Behaviour Rules

The simplified driver behaviour rules applied in the case studies are indicated in the following.

- Rule applied for Desired Lane Position (l_{p_d}): the car maintains the centre of the lane. Among proposed models of centre lane estimation, in the near future the transect-based road model (Luliang et al., 2004) will be applied.

- Rule applied for Desired Speed Profile (U_d): while the rule for Desired Lane Position is regulated also in terms of driving good practice, to define the ideal speed profile is not equally simple. Taken into account the rule of minimising travel time according to driving at the maximum allowed speed (which means that after the transition U_d is almost constant in a highway), the desired driver speed profile will be obtained by means of a smooth profile. This allows to increase the speed after the permission of attaining higher speed and decrease it before the restriction of attaining lower speed. During the transition from a speed limit to the successive speed limit, U_d is modelled as $U_{Transition}$ (see Figure 1):

$$[5] \quad U_{Transition}(\tilde{t}) = \Delta V \left(\frac{1 + \sin(w\tilde{t} - p/2)}{2} \right) \text{ where } w = p/t_{style} \text{ and } \tilde{t} = 0 \div t_{style}$$

The profile of the speed increase or decrease is still object of discussion within the objectives of the simulation design. This is important especially for the attaining of a lower speed, which has a higher constraint in terms of anticipatory action. The reader

should also notice the choice of attributing to t_{style} a characteristic of the driver driving style.

3.3 Applications in the Case Studies and Conclusions

The desired path model and path actual outcome of the Driver Lane Control Model is reported in figure 5, where the red line is the desired path (the centre of the lane) and the blue line superposed on the red represents the actual position of the car.

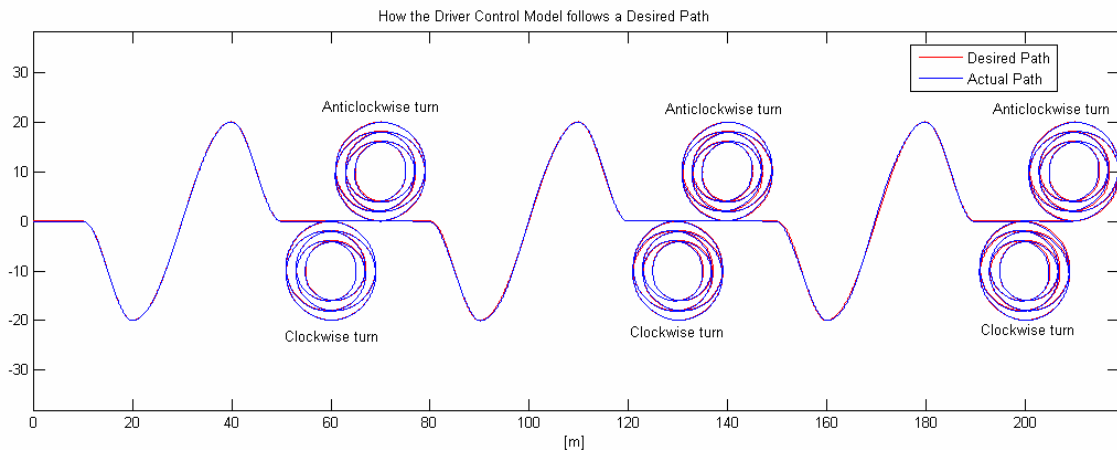


Figure 5: The PathModel under analysis

The path is composed of a template module replicated 3 times (for a more reliable analysis), with two turn paths, a clockwise and an anticlockwise, representing the behaviour of a driver changing several times lane on a 3 lanes roundabout. The turns are clockwise or anticlockwise (detail in Figure 6).

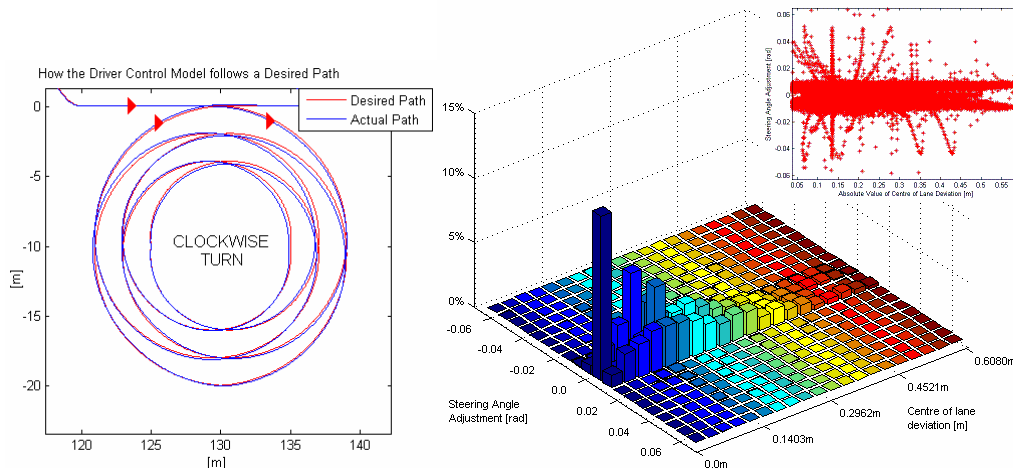


Figure 6: Detail of Clockwise Turn in the Path Model

Figure 7: Distribution of absolute value of centre of lane deviation against steering angle adjustment and in red 2D distribution of samples

For the purpose of preliminary experiments, the speed profile was chosen constant, in order to analyse only the effect of steering angle adjustment (negative values of steering angle corresponds to steers in the right direction) versus lateral deviation from

the desired centre of lane. As shown in Figure 7, there is not any particular trend in terms of steering angle adjustment and centre of lane lateral deviation: the small picture in red represents the bi-dimensional projection of the sample, while the histogram contains the distribution of the samples. The peak at 12% around (0.0; 0.0) represents the samples coming from straight sections of the path. Most of the samples (>90%) are concentrated in the angular adjustment interval -0.01 to +0.01 radian and more than 95% of samples have a centre of lane lateral deviation less than 0.5m.

In spite of these preliminary considerations the model can be considered stable and reliable. The study will continue in terms of deviation analysis during control delay and control freezing conditions for the purpose of the analysis of IVIS and ADAS intervention, considering also the curve entrance and exit speed variation.

4 References

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