Evaluation of a new intelligent speed advisory system using hardware-in-the-loop simulation

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***Abstract*—In this paper we present a recently developed speed advisory system for ITS applications. A real vehicle embedded in a large scale SUMO simulation is used to demonstrate the efficacy of such a system.**

I. Introduction

Intelligent Speed Adaptation (ISA) systems have become a fundamental part in designing Advanced Driver Assistance Systems (ADASs) with the aim of improving traffic safety and efficiency [1]. ISA systems rely on the calculation of safe recommended parameters to be either presented to the driver using an appropriate display system [2], or event used for the enhancement of Adaptive Cruise Control (ACC) systems. In [3], we proposed such an ISA system based on a cooperative method for vehicular density estimation and on the intelligent determination of traffic scenarios. To validate the proposed system, we used SUMO (Simulation of Urban MObility) [4] to simulate a scenario which included thirty-one vehicles that travelled on a predefined road. The drawback of such an offline simulation is the missing feedback of the drivers who are involved in the recommendation loop. On the other hand, a real world evaluation would require the availability of a considerable number of vehicles supplied with the same recommendation algorithm and communication system. In this paper, we extend and evaluate the advisory system given in [3]. Extensions beyond [3] include incorporating more realistic road scenarios (e.g. a road with curves), and evaluating the efficacy of the system in scenarios with real human feedback using the hardware-in-the-loop emulation platform described in [5], which involves a smartphone serving as a user interface in a vehicle coupled to a real time SUMO simulation. In Section II we briefly describe the underlying method for scenario determination and calculation of the recommended parameters. Section III describes the SUMO-smartphone integration and in Section IV we present the experimental results.

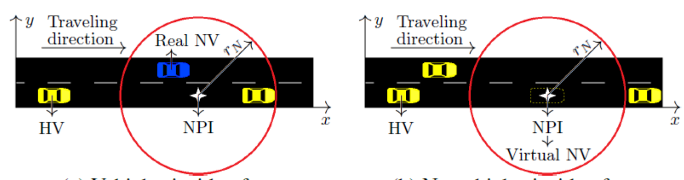
II. Advisory System

The intelligent speed advisory system to be evaluated is the one proposed in [3], which provides recommendations to drivers regarding their cruise speed and safe travelling distance with respect to a certain point of interest. Two main stages can be distinguished, which are briefly explained as follows.

A. First stage

The first stage is dedicated to determining the traffic scenario in which the Host Vehicle (HV), i.e. the vehicle receiving the recommendations, is traveling. As determining the traffic scenario is a spacial-temporal problem, we have to choose a point of interest along the future trajectory of the HV, which will serve as an additional source of environmental information. This point of interest will be represented by a vehicle referred to as the Next Vehicle (NV), which can be a real vehicle or a virtual vehicle depending on the compliance of certain conditions. With an estimate of the vehicular density and the speed information from both the HV/NV, the traffic scenario is determined using a rule-based inference engine.

1) The next point of interest and the Next Vehicle: The next point of interest (NPI) is chosen as a point of reference placed along a future trajectory of the HV as shown in Fig. 1. The closest vehicle to the NPI inside a circle with radius r_N is chosen to represent it (Fig. 1.a); otherwise, the NPI is represented by a virtual vehicle (Fig. 1.b).



(a) Vehicles inside of r_N (b) No vehicles inside of r_N.

Fig. 1. NV location: a) the closest vehicle to the NPI inside a radius r_N is chosen as the NV (the blue one), and b) a virtual vehicle is chosen.

2) Vehicular density estimation: The vehicular density can be estimated from V2V communication. In this way, density is easily calculated as the number of detected vehicles inside a certain pooling radius r_D, using the formula

$$\delta\left(t\right)=\frac{n_r+1}{A},\quad A=\begin{cases}\pi r_D^2, & \text{if } 2r_D\leq W_L N_L\\ 2r_D W_L N_L, & \text{otherwise}\end{cases}$$

where n_r is the number of vehicles inside the polling area A, W_L is the lane's width, and N_L is the number of lanes.

3) Traffic scenario determination: Once density information is estimated, it is used together with speed information (also from V2V communication) to deduce the current traffic scenario using rule-based reasoning with rules R_k of the type

$$R_k:\ \text{IF}\, input_1=\bullet\ \text{AND}\ldots input_i=\bullet,$$

$$\text{THEN}\ (output_1=\bullet\ \text{AND}\ldots output_j=\bullet)*w_k.$$

We use the normalized speed/density of the HV/NV and the variation on the HV speed as inputs, and have five outputs with the same range $[0, 1]$: Free Traffic (FT), Approaching Congestion (AC), Congested Traffic (CT), Passing Bottleneck (PB) and Leaving Congestion (LC). A set of $k = 28$ rules as presented in [3] was defined to relate the inputs with the outputs. Finally, traffic scenario is determined by using

$$T(t) = \text{argmax}(\text{FT}(t), \text{AC}(t), \text{CT}(t), \text{PB}(t), \text{LC}(t)).$$

B. Second stage

The second stage is devoted to the calculation of the recommended speed/distance based on the traffic scenario information, the current HV/NV speed, and a decision matrix. Due to the dependence of the recommended speed on the NV speed and the fact that the NV can be eventually a virtual vehicle, then first we have to define a model to update the speed of such a virtual vehicle.

1) Virtual vehicle model: The model for updating the speed of a virtual vehicle is based on the simple formula of the type

$$V_N(t) = \alpha_{NV}(t) * \tilde{V}_N(t-1),$$

where α_{NV} is a time-variant evolution parameter which depends on the previous value of the determined traffic scenario, and $\tilde{V}_N$ is a bounded version of the previous V_N.

2) Recommended speed: We proposed a scheme to calculate the recommended speed as a weighted sum of the NV/HV speeds as follows

$$V_R(t) = (\alpha_R(T(t))) * V_N(t) + (1 - \alpha_R(T(t))) * V_H(t),$$

where the value of the α_R depends on a decision matrix according to the current traffic scenario.

3) Recommended distance: Distance recommendation is based on a widely known policy for safe distance

$$D_R(t) = h_0 + h_1 V_H(t) + h_2 \left(V_H^2(t) - V_N^2(t)\right),$$

where h_0 is the minimum safe distance to the NV, h_1 is the reaction driver time, usually taken as $h_1 = 0.6s$, and h_2 is a problem-dependent parameter, here chosen as 0.01. For its part, h_0 is calculated using

$$h_0 = \left\lfloor \frac{D_{H-N} - G_{min}}{L_V + G_{min}} \right\rfloor * (L_V + G_{min}) + G_{min},$$

where D_{H-N} is the distance between the HV and the NV, $L_V = 4.2$m is the mean longitude of a vehicle in the network, and $G_{min} = 2.5$m is the minimum allowed gap. Finally, we provide recommendations with respect to the value of the error signal $e = D_{H-N} - D_R$ (whenever the NV is not a virtual vehicle), according to this convention: (1) "OK" if $e > 0$, (2) "Close" if $-1 < e \leq 0$, and (3) "Very close" if $e \leq -1$.

III. Evaluation using SUMO-phone integration

In order to evaluate the system using the platform described in [5], first we made the following modifications.

A. Matlab-SUMO communication

The SUMO simulation is interfaced using TraCI (Python), while the recommendation algorithm to be evaluated with the simulation is developed using the Matlab FL Toolbox.

In order not to be forced to port the recommendation algorithm developed in Matlab to Python, we integrated Matlab directly in the loop. For this purpose, we created a Remote Procedure Call (RPC) frame work based on TCP-Sockets, which allows for directly calling Matlab functions from Python scripts.

B. Python-to-smartphone messaging modification

Due to the nature of the proposed ISA system (an advisory system), it is necessary to show recommendations to the driver. So the smartphone not only can be used to collect information from the HV but it can be also used to display the recommendations. This step is achieved by sending back messages to the smartphone using the *pipe* tool from the Multiprocessing package for the Python environment.

IV. Preliminary Experimental Results

We performed a preliminary experiment where we drove a real Toyota Prius, as described in [5], around the north campus of the NUI Maynooth. This vehicle was represented by an avatar in a SUMO simulation that created a traffic bottleneck for the Prius and simulated vehicles. The driver received speed recommendations for dealing with the bottleneck as per our speed advisory system described above. The test drive confirmed to us that even challenging situations can be easily monitored/tracked under safe conditions using a hardware-in-the-loop simulation, thus allowing a more comprehensive evaluation of the presented advisory system. However, tests must be conducted in controlled scenarios (e.g. on empty roads) to avoid as much as possible external elements not represented in the simulation (e.g. other real vehicles or pedestrians).

V. Conclusions and Future Work

After a successful first test, the next step is to evaluate the performance of the system through more specialized tests.

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