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Publication date
2016

Objective Comparison of Motion Cueing Algorithms for Driving Simulator

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Introduction

Inertial or motion cue plays a significant role for the achievement of an immersive feeling in driving simulators. The control loop is responsible for mimicking as close as possible the real vehicle accelerations as the inertial feedback to the driver, while keeping the motion system within its physical limitations. Several algorithms have been designed for this purpose, seeking for the optimal compromise between realistic accelerations fidelity and actuation dynamics restrictions. Motion cueing algorithms can hence vary depending on the dynamics of the maneuver, computational efficiency required and motion system configuration. Several algorithms can be found in literature, from the classical approach, based on a combination of high and low-pass filters on the vehicle accelerations, to more recent strategies based on Model Predictive Control (MPC). Assessing the success of one solution is a complex task that would involve the prototype implementation on hardware as well as the availability of several test subjects. Nevertheless the result would be a subjective evaluation of the performance. This study proposes instead a preliminary analysis of the performance of motion cueing algorithms with objective evaluation by means of a human motion perception model.

Motion cueing algorithms adopted

In the context of driving simulators, a 6 degrees of freedom motion platform is typically adopted in the form of an hexapod supporting a vehicle(-like) cockpit. This cost-effective architecture imposes significant limitations on the available working-space of the moving base which has to be mediated by the control algorithms as a trade-off with respect to a one-to-one accelerations feedback. Among the several motion cueing algorithms developed in the last years, we focus in this study on a classical and on a model based solution.

The classical motion cueing is based on a series of frequency filtering blocks and simple numerical operations on vehicle acceleration and rotational velocity signals. The resulting trade-off between motion sensation and respect of constraints can be manipulated directly by manually tuning the filters parameters and saturation blocks. Nevertheless this algorithm presents some limitations on optimally handling the physical systems limitations and requires in depth expertise for being correctly tuned. The algorithm adopted for this study is based on [1].

The second motion cueing developed is structured in a MPC loop. It is built around a motion perception model that aims at computing the reference motion as result of an optimization problem in which the dynamics and the physical constraints of the motion system are taken into account. The gains of the cost function can be scaled by the user, which can hence bias the optimization problem towards either motion fidelity or constraints' compliance. The algorithm adopted for the MPC in reported in [2].

Objective evaluation and comparison criteria

The metric used for the comparison of the cueing algorithms is based on a model of the human organs responsible for motion perception: the otolithic membrane and the semicircular canals. The evaluation is made by comparing the cueing errors of the control algorithms. The cueing error is computed according to the scheme shown in Fig. 1.

The idea behind is to objectively compare the motion perceived by the driver when driving the real car with the sensation perceived when driving the simulator. The perception model and the vehicle dynamics input used are identical but the results will change depending on the motion cueing strategy adopted.

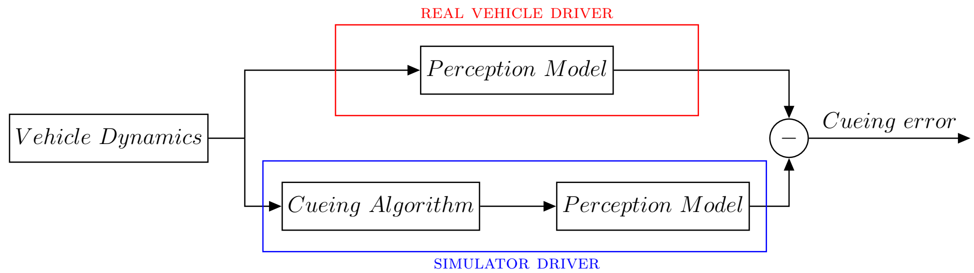

Fig. 1: Cueing error evaluation

High-fidelity vehicle dynamic model

The vehicle signals can either be obtained by simulation of an high-fidelity model or from measurements on a real vehicle. For this study the considered dynamics is the result of a real-time simulation of a high-fidelity car model. An initial investigation is performed separately on longitudinal and lateral dynamics by simulating respectively a straight-line acceleration and braking maneuver and a slalom and double lane change maneuver in order to asses separately the response of the cueing algorithms in different scenario. Finally a more complex scenario of driving over a (virtual) race track is achieved.

The motion perception model

In the process of self-motion perception many sensors are involved in the human body, requiring the neural combination of visual cues, vestibular cues, somatosensory and proprioceptive cues. Neuro-biological studies [3] seem to agree about the dominating importance of the (coordination of) visual and vestibular cues over the others. In this study the focus is hence on the vestibular cues for the assessment of motion, assuming that the visual cues will be deployed by a separate projection system.

The organs responsible of detecting linear and rotational movements are the inner ear otolithic membranes and semicircular canals. The numerical model adopted in this study is the one used in [1] and serves as a realistic approximation of the primary sensations interpreted by the human brain.

Conclusions

The comparison carried out in this study showed that the use of advanced control techniques result in an averaged lower cueing error with respect to classical techniques. In particular the MPC based strategy shows a taking advantage of the complete motion system working space.

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