Handling Quality Quantification of an Actively Controlled Narrow Track Vehicle

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Narrow track vehicles (NTV), characterized by a large height-to-track ratio, need to be leaned toward the inside of a turn to prevent them from overturning in case of high-speed cornering. Two modes have been proposed for active tilt control [1]. The Direct Tilt Control (DTC) consists in forcing the tilting of the chassis with respect to the suspension assembly, in reaction to the pilot steering (see Fig. 1.a). Conversely, in Steering Tilt Control (STC), the steering wheel is decoupled from the wheels. An actuator steers the wheels to lean the vehicle with an appropriate angle which consequently induces a desired turn (i.e. a steering wheel orientation given by the pilot). Several studies on DTC and STC separately showed the respective limitations of each mode, in particular the important energy consumption and the risk of wheel unloading of the DTC at high speed [2]. In this work, the relevance of using conjointly the steering and the direct tilt control (SDTC) is investigated. Such multivariable control process can be studied by formulating an Optimal Control Problem (OCP) for a given time interval. The optimization variables are then the torques applied on the steering assembly and the tilting system during this interval. Our previous investigations [3] showed that a combined strategy (SDTC) does not yield significant improvements in terms of energy consumption compared to the steering tilt control (STC) alone. The total electrical energy associated with both steering and tilting was minimized on the overall time interval while the lean angle tracking was handled as optimization constraints (see Fig. 1.b). The solution of the optimal control led to the exclusive use of the steering actuation for the SDTC (see Fig. 1.b). However, when constraints are applied to limit the vehicle counter-steering, the SDTC yields the use of the tilting actuator for the initiation of the vehicle leaning.

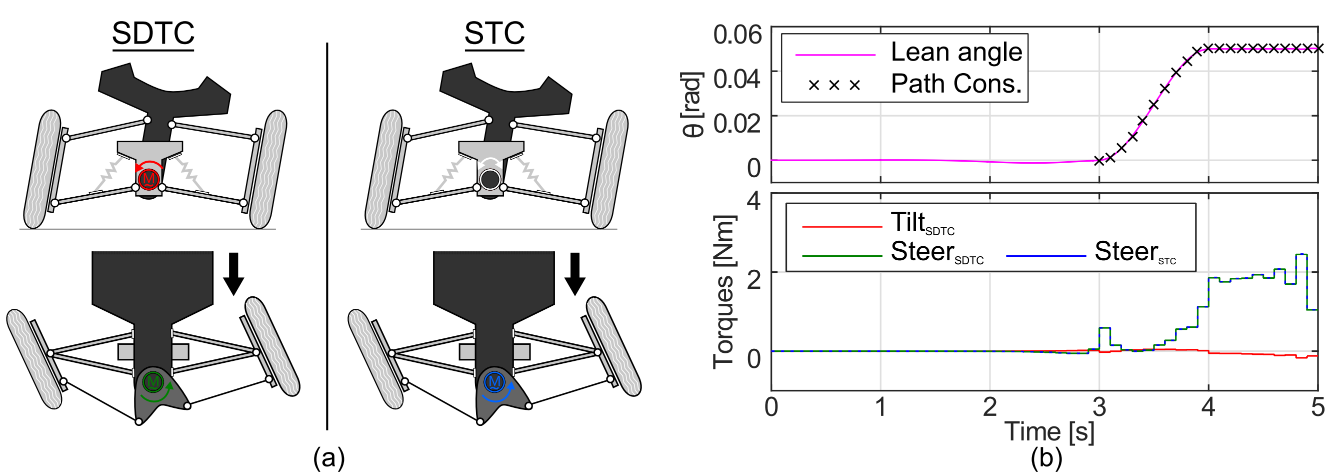

Fig. 1: (a) Vehicle morphology and actuators for the SDTC and STC mode alone (b) Path tracking of the lean angle for a vehicle speed of 3 m/s.

However, the energy consumption criterion has to be weighted against the vehicle safety, handling quality and comfort. To this end, the formulation of the OCP has to be adapted. The safety and the comfort of a vehicle during cornering can be partially quantified (e.g. via the wheel unloading and the lateral acceleration of the pilot respectively). On the other hand, evaluating the handling quality of a given vehicle is less trivial, as it implies the modelling of the pilot as a feedback controller. Nevertheless, there have already been many efforts, mainly for aircraft applications, to formulate metrics for vehicle handling quality [4]. Among them, the Handling Quality Metrics (HQM) or the Handling Qualities Sensitivity Function (HQSF) developed by Hess allow to quantify the amount of power in the output rate feedback signal $U_M = \ddot{\Psi}$ [4]. However, these metrics are defined in the frequency domain and utilize the transfer function of the vehicle which might be hardly available for the actively controlled NTV because of its non linearities inherent to its dynamics and its tilt Controller [3]. Nevertheless, these handling metrics have already been used to study bicycle handling [5] and seem to be appropriate for leaning vehicle.

The goal of this work is to quantify and compare the handling quality of different active tilt controllers (DTC, STC or SDTC). The metrics mentioned above require the modeling of the driver as a multi-loop pursuit controller characterized by a series of feedback gains [4] (see Fig. 2). The outer feedback loop ensures the following of a given trajectory by tracking a given lateral position in time. The inner feedback loop of the driver model, which consists in tracking the yaw rate, will be of particular interest as $\dot{\psi}$ is the primary vehicle response variable that is of fundamental importance from the standpoint of perceived vehicle handling qualities [4]. Such feedback pilot controller implies for the active tilt controller to compute its optimal input $[Q_{tilt}, Q_{steer}]$ at each time t based on a driver input (i.e. the steering wheel orientation δ_{SW}). Practically, it is achieved through Model Predictive Control (MPC) [3]. Hence, the procedure to assess the handling quality is the following. First of all, the active tilt Controller is implemented with MPC. Secondly, for any controller, the pilot model gains are determined following the methodology proposed by Hess [6]. Eventually, the handling quality metrics will be computed through time simulations [6]. The main challenges will be the determination of consistent laws for the active controllers. The analysis will not be limited to a comparison between DTC or STC but will also focus on the influences of the optimization criteria (e.g. the energy consumption or the perceived acceleration) on the vehicle handling quality.

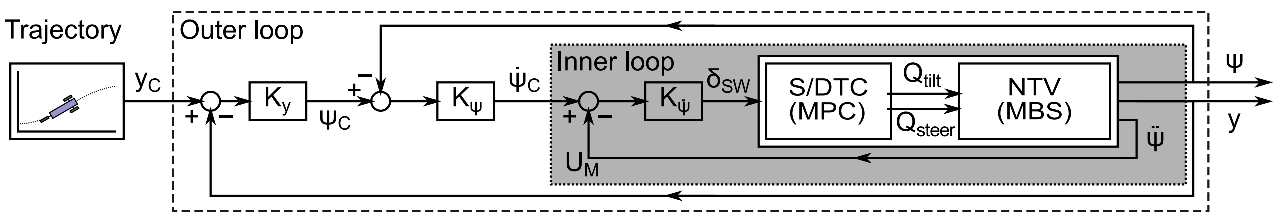

Fig. 2: Driver model with fixed gains for a trajectory tracking task (inspired from [4]).

Regarding the implementation, the vehicle is modeled as a multibody system through the MBS software Robotran [7]. To formulate and solve the Optimal Control Problem (OCP), the software CasADi [8] developed at KUL (Belgium) provides interfaces to state-of-the-art NLP solvers through a symbolic approach. Such symbolic framework favors the use and the interfacing of the symbolic equations of motion generated by Robotran. The implementation of the Model Predictive Control (online OCP solving), necessary to investigate the driver and vehicle interactions will be done in the Simulink environment as both CasADi and Robotran have interfaces with it.

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