Robust High Speed Autonomous Steering of an Off-road Vehicle

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Abstract
According to the National Highway Traffic Safety Administration of the USA, 21.7% of all fatal vehicle collisions occur while negotiating a curve and 15.3% are due to head-on collisions [1]. Driver assistance in the form of lateral collision avoidance systems may be able to reduce the number of fatalities in these instances. However, the wide range of operating conditions an off-road ground vehicle has to contend with provide a significant challenge to control engineers, especially when the vehicle is required to be stable at high speeds. A series of algorithms have been proposed by researchers to safely steer a vehicle through a dynamic manoeuvre, ranging from conventional techniques to intelligent systems theory, and some have been implemented with varying levels of success. An elegant solution to this non-linear problem may be the use of adaptive control. In adaptive control, the dynamic of the process is estimated on-line and the controller adjusted to deliver the optimal performance [2]. Although the use of adaptive control in vehicle steering is not a new concept, very little literature is available on the topic compared to other approaches. Adaptive strategies have been implemented to reject the disturbance caused by wind gusts on a vehicle [3], as well as a lateral controller capable of path following up to 25 $m.s^{-2}$ [4].

In this paper an adaptive strategy, known as the Linear Quadratic Self-Tuning Regulator (LQSTR), is considered for use as a path following steering controller for an off-road vehicle. The algorithm relies on an AutoRegressive model with eXogenenous input (ARX) fitted using measured input-output data to quantify the current dynamics of the vehicle. This model is then used in state space form to design a Linear Quadratic Regulator (LQR) responsible for controlling the yaw rate of the vehicle by manipulating the steering angle of the front wheels. By performing this update at a sufficiently high rate, a conventionally linear controller should be able to adapt to the non-linear dynamics of the vehicle system. An advantage of using this adaptive technique is that no explicit information about the vehicle or its operating environment is required by the controller. This will allow the vehicle to drive on various surfaces with different configurations without modifications of the original algorithm.

The performance of the proposed steering controller is verified in simulation using a fully validated 16 degree of freedom non-linear vehicle model of a Land Rover Defender 110 tasked with completing the ISO 3888-1 severe Double Lane Change (DLC) manoeuvre. A comparison is also made with the Freund steering controller, developed by Freund and Mayr [5]. The Freund controller is a well-known algorithm commercially used in software such as veDYNA [6] and consists of a non-linear vehicle model, tyre model and a steering saturation function. It was tuned at a speed of 60km/h to provide the same accuracy as the LQSTR strategy at this speed. This should deliver both low speed path following accuracy and high speed stability through the DLC manoeuvre. Figure 1 provides the root-mean-squared errors (RMSE) from the required path for both controllers as a function of vehicle speed.

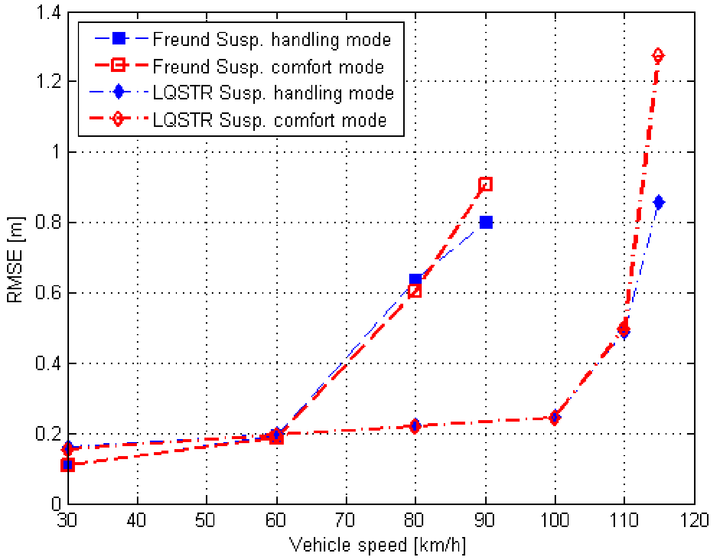

Figure 1: RMSE of the LQSTR and the Freund controller for different vehicle speeds through the DLC

Results show the LQSTR to be superior to the Freund controller in steering an off-road vehicle through a DLC manoeuvre at different speeds using the same set of tuning parameters. Although the same performance is achieved at a speed of 60km/h, the Freund controller quickly loses accuracy at higher speeds and is unable to maintain vehicle stability through the manoeuvre at speeds above 90km/h. The LQSTR is however able to accurately follow the required path up to 100km/h and maintain vehicle stability up to a speed of 115km/h. There is thus merit in using adaptive control approaches in the lateral control of an off-road vehicle, as it provides a robust response without the need for any prior knowledge about the vehicles operating parameters or driving environment and thereby eliminating the need for complex observers.

References

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