International Reintegration Grants, Marie Curie Actions - Grant Agreement 239421

MIEDT: Modelling and Implementation of Expert Driving Techniques towards the Development of New Active Safety Systems for Passenger Vehicles

Project Coordinator: Dr Efstathios Velenis, School of Engineering and Design, Brunel University
Project Website: http://people.brunel.ac.uk/~mesteev/MIEDT.htm

Summary:
In this project we studied driving techniques used by expert race drivers to control their vehicles under extreme operating conditions. We envision that expert driver knowledge can be modelled mathematically and implemented towards the development of a new generation of active safety systems for passenger vehicles. These new systems will employ expert driving skills to assist the driver, or autonomously control the vehicle close to the limit of its handling performance. In this project we focused on driving techniques used by rally-race drivers, who clearly operate beyond the limits enforced by current active safety systems.

With the above vision in mind we set out to fulfil the following objectives:

- Collect expert driver knowledge in the form of empirical guidelines on the execution of expert driving techniques used in rally racing, as well as in the form of driver control commands and vehicle response data during the execution of such expert driving techniques by race drivers.
- Based on this newly acquired knowledge on rally driving techniques, design a control scheme, which uses driver control inputs (steering, throttle and brake commands), to reliably replicate the expert driving techniques recorded, and implement the control architecture in realistic simulation environments.

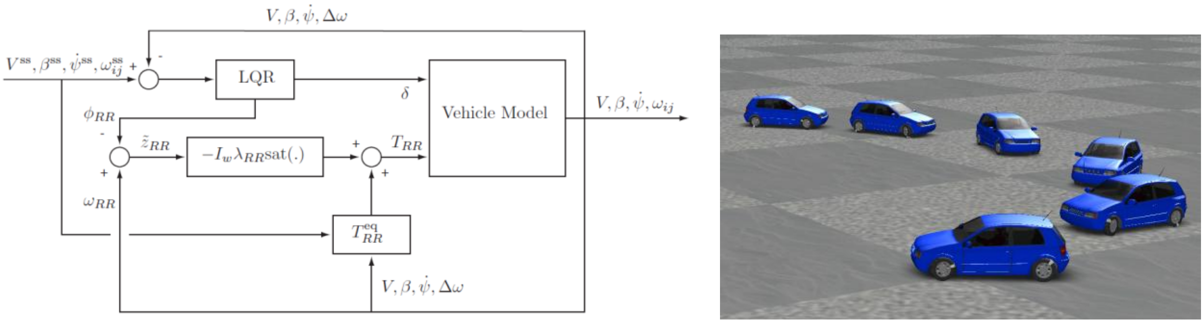
Collaboration with a rally driving school in the UK was established early on in the project. The rally school provided valuable empirical guidelines on rally driving, in addition to vehicles for testing, technical assistance during the instrumentation of the vehicles, access to their facilities (workshop and testing grounds), as well as expert drivers to perform the manoeuvres and driving techniques during the data collection experiments. Testing facilities and equipment were acquired and developed according to the data collection requirements of the project. A comprehensive sensor and data logging suite was compiled, consisting of a dual antenna GPS receiver, an inertial measurement unit, a CAN-bus interface to collect signals form factory installed sensors on the vehicle (e.g. wheel speeds, engine speed and throttle position), as well as externally fitted steering angle and brake pressure sensors. A base-station providing differential GPS corrections and increasing the position measurement accuracy was finally added to the testing equipment, allowing for studies of the vehicle trajectory with respect to the road limits geometry. A dedicated test vehicle was acquired and fitted with standard safety features (roll-cage, race seats and harnesses) and provided a permanent platform for calibrating the testing equipment and for data collection during the execution of driving techniques associated with Front-Wheel-Drive (FWD) vehicles. Driving techniques associated with Rear-Wheel-Drive (RWD) vehicles were also recorded using a test vehicle from the rally school. Testing of a Formula Student race car in a closed tarmac circuit was also performed for comparison of driving techniques associated with different types of racing.

The data revealed that rally drivers typically follow the so called “late-apex” line through a corner as opposed to the “racing” line favoured by closed circuit race drivers. The later takes advantage of the full width of the road both in the entry and exit of the corner. The “late apex” line requires that the vehicle returns to a straight line driving condition earlier, while the exit point is near the inner limit of the corner. The “late apex” line allows for alternative trajectories through the corner in the case that the entry speed of the vehicle is overestimated. This feature of the "late-apex" line is critical in rally driving, which involves racing unrehearsed, as opposed to the extensive practice in close circuit racing. Hence, the rally driver is often required to perform cornering manoeuvres in limited space and to maximise the rate of change of direction of travel. To this end, expert rally drivers use techniques such as "hand-brake cornering" (for FWD vehicles) and "power-slide" (for RWD vehicles), allowing them to achieve high vehicle yaw rates and to follow paths of high curvature. In agreement to the project objectives, we collected data of driver control inputs and the associated vehicle response during the execution of these techniques by expert rally drivers (Fig.1).

Figure 1: Data collection during the execution of rally driving techniques.

A closed loop control formulation of vehicle cornering near the limits of handling was proposed for the autonomous reproduction of the above rally driving techniques in a simulation environment. In particular, cornering equilibria near the limit of handling were numerically calculated using vehicle models with increasing level of fidelity. The calculation was initially tested using a low order single-track vehicle model and then extended to full-car dynamical models with realistic drive-train constraints and nonlinear tyre force characteristics. A nonlinear sliding-mode control architecture (Fig.2(a)) was developed to provide the steering, throttle and brake control inputs to stabilise the vehicle with respect to limit cornering equilibria. The controller was successfully adapted to both RWD and FWD vehicle configurations to perform the associated driving technique. The controller's performance was validated by implementation in a high-fidelity simulation environment (Fig.2(b)) and comparison to the expert driver performance as recorded during data collection.

The results of this project have significantly advanced our understanding of the operation of the vehicle close to the limits of its handling capacity, where the tyres have reached or exceeded their adhesion limit. This research will have an immediate impact on the areas of traction, braking and stability control of passenger vehicles. The contributions of multiple disciplines, such as vehicle dynamics, control, situational sensing and awareness and autonomous systems, will be essential in implementing the acquired expert driver knowledge towards the development of "intelligent" driving algorithms for accident avoidance. Our goals are in complete alignment with the aspirations of the European Commission with regards to road safety. Extending this innovative research to the design of new active safety systems can radically reduce car accident rates due to incorrect driver actions.



(a) **(b)**

Figure 2: (a) A control architecture used to replicate the actions of expert drivers; (b) Implementation of the control architecture using a high-fidelity simulation environment.