Evolutionary Multiobjective Optimization for Vehicle Trajectory Planning relying on a Vehicle-Driver-Road Modeling

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ABSTRACT

The objective of this study is to present an innovative trajectory planning algorithm relying on Vehicle Driver Road (VDR) modeling. This algorithm is able to compute a feasible, safe and efficient (in terms of energy consumption) trajectory and the corresponding commands required (acceleration and steering angle) to follow this trajectory.

Recently, several works have been published on trajectory optimization. They mainly rely on safety, comfort or energy aspects but separately. They can plan a trajectory:

- purely longitudinal (jerk, acceleration and speed optimization) for safety and comfort improvements (ACC, C-ACC, ISA).
- purely longitudinal for energy's consumption reduction (EDAS).
- purely lateral (lateral acceleration, side slip angle) for safety and comfort improvements (LKAS)
- coupled longitudinal and lateral for safety.

Here, a Vehicle-Driver-Road modeling has been developed for an isolated car on a rural road for a coupled longitudinal and lateral trajectory for safety, energy consumption and travel time. Considering the definition of a human driver model by [1], only the tactical and operational level of the driver are represented. Each element of the VDR modeling can be detailed as follows:

- Vehicle: modeled with a two degree of freedom dynamic model associated to the Burckhardt tire model. These models have been selected for their trade-off between accuracy and simplicity. Movements of the vehicle's body can be sensed by the driver through his kinetic perception.
- Driver: modeled in three steps: visual and kinetic perception, spacial anticipation and temporal delay. During the spacial anticipation step, an evolutionary multiobjective optimization is performed for lateral and longitudinal planning. The temporal delay takes the first points (corresponding to the reaction distance) of the planned trajectory from the spacial anticipation and sends them to the vehicle control.
- Road: Detailed road properties (curvature, slope, superelevation) are sensed by the visual perception of the driver over the perception distance.

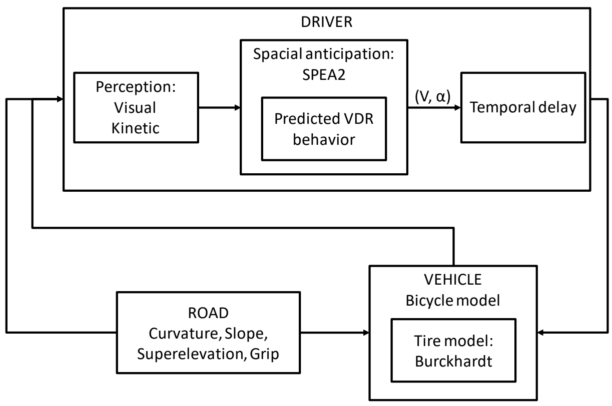

Figure 1: Synthesis of Evolutionary Multiobjective Optimization Trajectory Planning Algorithm

The evolutionary multiobjective optimization performed in the spacial anticipation step consists in building the Pareto frontier with a modified version of a SPEA2 (Strength Pareto Evolutionary Algorithm) detailed in [2]. The main idea is to find the Pareto frontier with an elitist strategy and a fitness function enabling the algorithm to minimize the density of solutions in the Pareto space. A first implementation was done with a mono-objective strategy in [3]. This method has been completed to take into account several objectives. The main idea is that each tested solution is constituted of two vectors (acceleration and steering command versus time) coded in decimal. Each solution is then evaluated through three cost functions corresponding to each objective (energy, time, safety). Finally, a fitness function sorts the solutions according to their dominating properties and to their density in the Pareto space. This guarantee the maximum variety of solutions and a faster convergence to the Pareto frontier. The three objectives taken into account are: the energy consumption, the safety (vehicle is on the road, side slip angle and lateral acceleration are limited) and travelled distance. A schematic description of the algorithm is provided in Figure 1. An example of a computation scenario on a circular road is presented in Figure 2.

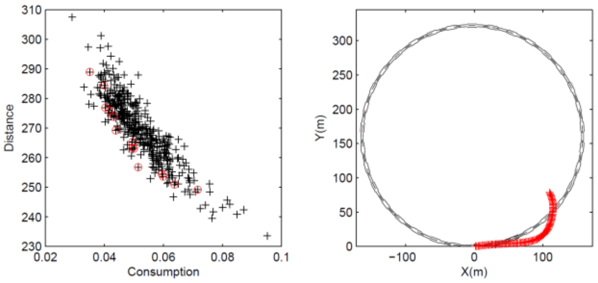

Figure 2: Construction of Pareto frontier: Left, Pareto frontier in red, all solutions in black; Right, an unsafe trajectory.

Results, as shown in Figure 3, presents a trajectory that is feasible and optimal in terms of energy, time and safety. Some improvements need to be investigated considering the computation time. The possibility of parallel computing will be particularly studied.

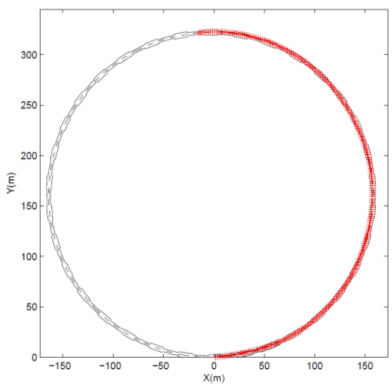

Figure 3: Trajectory of the vehicle on a half circle

The main advantages of such a strategy are:

- a multiobjective optimization that takes into account safety, energy consumption and travel time.
- a modeling relying on realistic VDR model. This make the reaction of this algorithm more compatible with human behavior and for ADAS implementation.
- The computation time is linearly linked to the road length contrary to other optimization methods.

CONCLUSION

This paper presents an evolutionary multiobjective optimization algorithm performing a trajectory planning for a road vehicle. It calculates an optimal trajectory (and steering and throttle commands) to minimize energy consumption, travel time and to maximize safety. This algorithm is relying on Vehicle-Driver-Road modeling that takes into account the vehicle handling, the tire behavior, the road characteristics and the driver tactical and operational levels. Simulation results show promising use of this method for ADAS implementation or autonomous driving.

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