1.
Introduction

The automobile as it is known was neither invented in a single day nor an idea of a single inventor. The history of cars reflects an evolution that took place worldwide and it is estimated that over a hundred thousand patents gave origin to modern automobiles.

In 1771, the French engineer and mechanic Nicolas Joseph Cugnot drove one of his road vehicles into a stone wall, becoming the first person involved in a motor vehicle accident. Although Cugnot's vehicles were steam-powered, many historians accept they could be considered automobiles and also that Nicolas Cugnot was the inventor of the car.

A hundred years later, just after the invention of petrol-fuel autos in 1876 by Nicolaus Otto, a contest was organized by Paris Magazine in 1884. It turned to be the first official record of a car race in history, anticipating the tendency of migration to the streets of racing technology developments.

Far from those days, only forty years ago, artificial intelligence techniques were developed as a relevant alternative solution to control and optimize engineering problems. Some computational methods inspired in nature had been researched and also published in the early decades of the nineteenth century. However, most real-life applications appeared only in the 70s and 80s.

Bremermann [1] to [3] published a series of papers in the 1950s and 1960s, in which a set of solutions was adopted as an approach to solve optimization problems, evolving them by using algorithms inspired on natural selection, gene recombination and mutation. In addition, in 1965, Zadeh [4] proposed a logical system that supported an infinite value mapping, and, in opposition to the binary logic used in computational systems until then, inspired on human's imprecise linguistic statements.

Artificial evolution became a widely recognized optimization method as a result of the works of Rechenberg [5] and Schwefel [6] in the early 70s, using genetic algorithms to solve complex engineering problems. Not until 1987, a fuzzy-logic-based control system for train operation was built in a Japanese subway line.

1.1. Objectives and Motivations

The main objectives of this work are to analyze and simulate the human driving behavior through computational intelligence techniques. An evolutionary optimization algorithm was used to determine the minimum time trajectory of a racing car in a pre-defined track. In addition, to control the vehicle through the obtained path, a fuzzy logic controller was designed.

The initial purpose of applying those techniques is to analyze and mime the responses of a human driver when submitted to the extreme driving conditions of a car race, such as high speeds and critical accelerations. Analytical methods have never provided better results than those of an experienced human driver. The non-linear characteristic of the steering system and the multidisciplinary aspect of trajectory determination are the main complexities found in the design of high performance driving systems.

Some applications to an intelligent driving system go beyond the design of unmanned land vehicles. Automatic drive assistance mechanisms, such as traction control, parking sensors, and anti-breaking system were developed on racing tracks and are safety equipments commonly found in mini-vans now.

1.2. Literature Review

The search for the minimum time trajectory involves some parallel optimization problems.

The lateral accelerations minimization intends to keep the friction limits of the inner tires, without reducing the car's speed. On the other hand, maximization of longitudinal speeds and minimization of the driven distance are directly responsible for the lap time reduction. It is not easy to achieve all those goals at the same time and some strategies can be found in the literature.

Velenis et al [7] propose the trajectory optimization during corner paths. The multi-objective of minimizing time and maximizing the exit velocity is analyzed. Due to this duality, some problems are pointed out, such as the possibility of obtaining an optimal path by drifting. Although this condition is not contemplated by the models developed here, the boundary conditions treatment used by the authors, apply perfectly to the track model used as a restriction to optimization. Another interesting and inspiring strategy adopted by Velenis [7] is the use of a simplified vehicle model, which makes implementation and response analysis easier.

In a research of Velenis and Tsiostras [8], acceleration limits are used to generate an optimal velocity profile. This approach is also adopted here and supported by the concept of the Friction Ellipse; it is stated in the Vehicle Models chapter and detailed [9].

Trajectory optimization is also treated by Cossalter et al [10], evaluating handling and maneuver of land vehicles. Similarly to the optimization method developed here, Cossalter [10] uses the track lateral limits as a restriction, and presents a penalty-based method to optimize the path, minimizing the travelled distance. In spite of simply evaluating the travelled distance, the optimization algorithm developed here uses a multi-objective function that focuses on the lap time minimization. Then, it allows this methodology to identify non-intuitive longer trajectory parts in which the car can achieve higher speed due to lower lateral accelerations.

The Group of Modeling and Simulation of Vehicle Systems of PUC-Rio has also developed some studies on trajectory determination. Hernan et al [11] have applied Classic Optimization Methods in order to minimize a car's lap time in a pre-defined track through optimizing of its acceleration inputs. This paper also uses the acceleration profiles to obtain the trajectory.

Concerning trajectory control, several methods have been applied to the complex vehicle kinematics. In [12] a Proportional Double Derivative (PDD) controller was proposed, that receives as reference a closed-circuit trajectory. The higher the speeds considered, the harder it is to reduce the reference offsets and oscillations. The fuzzy logic based controller allied to the analysis and emulation of humans' perceptions minimized those problems.

Fuzzy Inference Systems are quite widespread when it comes to intelligent control systems. Bastian et al [13] present a Fuzzy Automatic Transmission Expert System (FATE). A shift scheduling method for transmission systems using Fuzzy Logic is detailed in Sakaguchi [14]. Both references analyse the fuzzy sets and rules definitions, an especially difficult task when the steering system is considered

Many of the subjects and techniques shown here have been previously explored. However, comparative analysis and developed computational models' assemblies are very important in order to understand and reproduce human behavior. Moreover, the concepts of modularity and simplicity prepare the path for future works.

1.3. Methodology

In order to improve simulation analysis, modularity and systematic validations were essential. Those are the main characteristics of the adopted methodology. The following chapters detail all the stages of problem modeling, simulation development and analysis of results.

A modular structure based on the theory of Bond Graphs and Block Diagrams was applied to all implemented models. Hence, the first chapters describe the vehicle models, the path determination evolutive algorithm and the trajectory control inference system.

In those chapters the model or algorithm is presented first, detailing the assumed hypotheses and constraints. Afterwards, the computational implementation is briefly overviewed in order to provide a complete documentation of operational procedures and configurable parameters. Finally, each model is submitted to a set of tests to evaluate its viability; parameters are adjusted in order to guarantee a representative description of the physical behavior.

The methodology not only minimizes the debugging process of the complete assembly, but also enables the easy replacement of any part of algorithm for performance comparison. For example, it allows a direct confront between the Fuzzy Controller and a PDD linear controller, developed by Hey et al [12].

Some possible applications are simulated by assembling the models in different configurations. Moreover, results are plotted and discussed, focusing on the miming of a human driver perception and responses. Final considerations are presented in the last chapter, where future works are suggested, so as to increasethe database built by the Group of Modeling and Simulation of Vehicle Systems of PUC-Rio.