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A multi-objective evolutionary algorithm for the tuning of fuzzy rule bases for uncoordinated intersections in autonomous driving

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ABSTRACT

This paper focuses on the application of Multi-Objective Evolutionary Algorithms (MOEAs) to develop a Fuzzy Rule-Based System (FRBS) dedicated to manage the speed of an autonomous vehicle in an intersection scenario.

Compared to other intersection scenarios, the main point here is that the autonomous vehicle is approaching an intersection that is being crossed by a row of manual vehicles those are not paying any attention to the presence of the autonomous vehicle, thus making coordination impossible. In this case, the autonomous vehicle bears sole responsibility for adapting its speed to the state of the other vehicles, with the aim of completing the maneuver safely and efficiently.

The specific conditions of this problem make it complex because of the large time requirements needed to consider multiple criteria (which enlarge the solution search space) and the long computation time required in each evaluation. In addition, the large number of variables involved increases the complexity of the scenario.

In this paper, a MOEA is proposed to obtain a more compact and efficient FRBS. The proposal is based on the well-known Strength Pareto Evolutionary Algorithm 2 (SPEA2) technique, but uses different mechanisms for guiding the search towards the desired Pareto zone. The MOEA uses specific operators to deal with the problem, to inherit fitness values from one generation to the next, thus arranging that it is only necessary to execute one scenario per generation to obtain an FRBS that works fine in many situations. In addition, the most important rules are identified in each FRBS, with the aim of realizing balanced crossovers.

1. Introduction

A substantial fraction of vehicle collisions occur at intersections: vehicle collisions at intersections are between 25% and 45% of all vehicular collisions [36]. Since intersections are only a very small portion of the roadway, this is considered a disproportionate amount. For this reason, intersection safety remains a challenge both for Advanced Driver Assistance Systems (ADAS) and autonomous driving [35].

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Statistical studies about the causes of accidents at intersections have shown that 90% of them are due to driver error [23]. The most common ones are perception failures (e.g. inattention), misunderstandings (e.g. misjudging the intentions of another driver), and wrong decisions (e.g. incorrect maneuver).

Intelligent Transportation Systems (ITSs) provide information and robotic techniques to achieve safe and efficient driving. In the automotive industry, sensors are mainly used to give information to the driver, or to advise the driver of the presence of a dangerous situation [43]. In some cases, they are connected to a computer that performs some guiding actions, attempting to minimize injuries and prevent collisions [4].

ITSs can play a key role in avoiding these hazardous situations, using two main technical structures: first, a communication or sensorial platform is required in order to allow the vehicles to interchange (or know) information about their position and driving parameters (speed, acceleration, direction). Secondly, a set of intelligent management algorithms, designed to minimize accidents by advising the driver of the presence of a dangerous area, or acting over the vehicle actuators are needed [31].

Intersection collision warning is a cooperative awareness application for improving active road safety, which can be deployed in both controlled and uncontrolled intersections [32,42].

Much research has been carried out on this topic. Most published papers assume full control of the intersection, usually in one of two ways: (i) by controlling the speeds of all vehicles involved (or sending speed references to all of them) [25,27,17] and (ii) by controlling signals in the intersection [39,22]. In particular, [25] uses a dynamic signal controller, [27] presents a fuzzy logic based system that coordinates a group of autonomous vehicles approaching the same intersection, and [17] develops a formal methodology to control two vehicles approaching an intersection. Research presented in [39] controls the traffic lights using fuzzy logic methods, while in [22], elements deployed in a road are used as sensors to gather information about the traffic flow, and feed a fuzzy system that defines the optimal signal status. In terms of vehicle control, intersection maneuvers assume cooperation between approaching vehicles, in order to control both speeds [24,12], or, when no cooperation exists, the autonomous vehicle yields to the approaching vehicle according with priority rules [45] or in a cautious way [26]. In more advanced systems, the autonomous vehicle calculates its own precedence regarding the approaching vehicle [41,3].

Fuzzy logic [46] is usually used in the development of systems designed to deal with the complexity deriving from traffic situations [19]. It allows the actions and decisions involved, as well as the driving-related maneuvers, to be described in terms of simple rules. For example: *if a vehicle is stopped in front of me and I am driving very fast then there exists a collision risk*. Fuzzy logic has proven to be a technique well suited to the treatment of all kinds of transportation problems [28,30].

Genetic Algorithms (GAs) are stochastic search techniques inspired by the principles of natural selection and evolution of species [18,16]. GAs are popular research subjects since they can deal with complex engineering problems which are difficult to solve by classical methods [21]. GAs have been also widely used in the literature for the tuning of Fuzzy Rule-Based Systems (FRBS) [2,29].

Multi-Objective Evolutionary Algorithms (MOEAs) are one of the most active research areas in the field of evolutionary computation because they are population-based algorithms capable of capturing a set of non-dominated solutions in a single run. Many of these algorithms have been proposed in the literature [8]. Among them, the Non-Dominated Sorting Genetic Algorithm (NSGA) [11] and the Strength Pareto Evolutionary Algorithm 2 (SPEA2) [47] are well-known and frequently used. Finally, regarding MOEAs applied to FRBSs, the interpretability–precision trade-off approach [7] is one of the most attractive fields, since it allows the balance between the precision and the complexity of the obtained FRBSs [6].

In the present paper, it is proposed an effective and efficient SPEA2 based strategy that incorporates specific mechanisms, in order to better optimize an FRBS capable of generating autonomously speed references to an autonomous vehicle that approaches an intersection situation where a group of vehicles is crossing. Since cooperation from the group of vehicles cannot be ensured, it is the responsibility of the autonomous system to complete the maneuver without risk. A strategy is implemented with the aim of satisfying the following restrictions: (i) to guide the vehicle across the intersection without any collision with other vehicles; (ii) to do so in the least possible time; (iii) to be able to deal with as many situations as possible, defined in terms of the speeds of the vehicles, the gaps between them, etc.

To deal with the problem, SPEA2 is provided with specific and original operators and mechanisms:

- Execution of the FRBSs in a different scenario in each iteration of the process, in order to test them under a wide set of conditions.
- A mechanism to infer the generality of the FRBS, based on its behavior over the actual and previous scenarios.
- A crossover operator that uses information coming from the simulation, with the aim of identifying the most important rules in each FRBS and combining them in a balanced way.
- An initialization operator to generate an initial population with general individuals which cover a high number of situations.
- Membership function codification variable over the time allows interpreting several similar situations as only one, thus reducing the number of input variables needed.

This paper is structured as follows: Section 2 describes some preliminary concepts, Section 3 details the problem to be solved, Section 4 explains the multi-objective evolutionary approach implemented, Section 5 shows the experimentation carried out and the analysis of results. Finally, Section 6 outlines the conclusions and further research.