Intelligent Automated Vehicle Gear Switching Simulation Software based on Fuzzy Reasoning

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Abstract- **The goal of this project is to develop an automatic gear switching simulation agent which makes its decisions in a more intelligent manner compared with legacy systems. While legacy automatic gearboxes base their decisions on vehicle RPM, speed, and applied throttle levels using traditional mathematical models usually based on exact reasoning, this design employs approximate reasoning using fuzzy logic computations. This design also factors in additional parameters such as car gas levels (full, half-full, and/or empty tank) and terrain nature (uphill/downhill and/or turns) for more rational/subtle decision-making and optimal fuel efficiency and comfort/aggressiveness in driving (following the driver's preferences).**

I. INTRODUCTION

With the development of computer aided automation systems and their increasing use in automobile technology in the few past decades, car manufacturers have been able to significantly improve the automation of gearboxes: aiming to make driving simpler and more enjoyable. However, despite the progress made in recent years, automatic gearboxes still cannot conclusively best their manual predecessors, with many drivers finding that gearbox automation reduced their control of their vehicles and lowered their fuel efficiency. This has led to the introduction of alternate solutions, namely "tiptronic" gearboxes, which are a hybrid of both manual and automatic gearboxes. Reaching the next phase in automatic gearbox performance is ushering in yet another technological breakthrough: extending existing automation systems capabilities with the use of Artificial Intelligence (AI).

This paper describes the design and development of an intelligent software agent simulating an automatic vehicle transmission system. This paper will explain the development process from start to finish, from the simulation of the chosen car (i.e., Corvette C5) to the development of additional features, such as a smart braking system that will assist the gearbox in ensuring an optimal and safe driving experience, especially for adrenaline-loving sports car enthusiasts. Preliminary simulation tests are promising.

II. BACKGROUND

2.1.Conext

Automatic transmissions were developed relatively recently to simplify driving: these transmissions change the car's gear autonomously and automatically during travel, sparing the driver the burden of having to switch gears manually. These transmissions work with the objective of keeping the vehicle's engine in its optimal range of revolutions per minute (RPM) so as to drive maximum performance of out the car.

Legacy automatic gearboxes base their decisions on vehicle RPM, speed, and applied throttle levels, using traditional mathematical models usually based on exact reasoning [1].

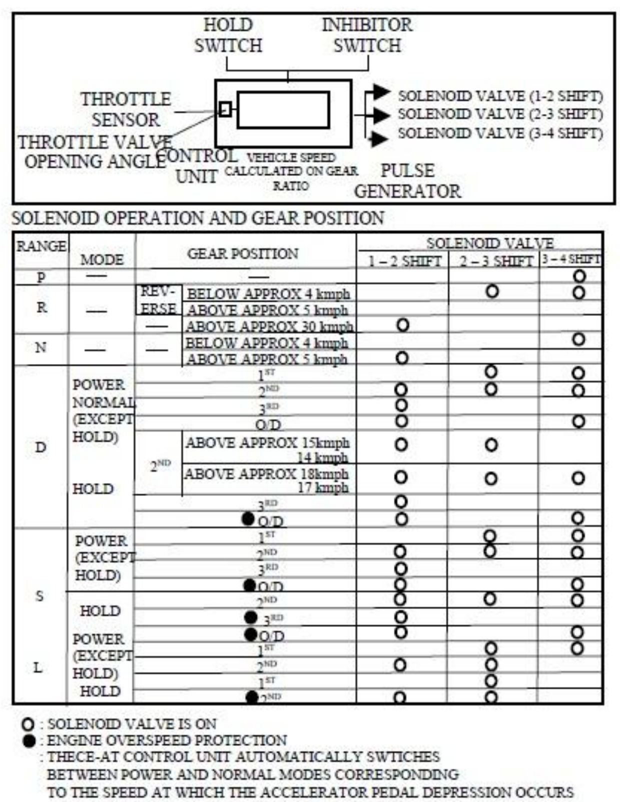

Figure 1: A Sample set of crisp rules governing the operation of a legacy automatic transmission.

This project aims to create a software that intelligently emulates automatic gear shifting, such that gear changes are made more efficiently and optimally, using approximate reasoning with fuzzy logic computations [2].

2.2. Prerequisites

Developing an automatic gearbox required knowledge of a car's inner workings, mainly the operation of an electronically controlled transmission (ECT) and the physical model of a vehicle's movement (acceleration and deceleration) [3].

III. PROPOSAL

3.1. Building Blocks

At the most basic level, this software decides whether to raise, lower, or maintain the gear the simulated car is running on based on fuzzy logic. The software agent's inputs are: the vehicle's engine's revolutions per minute (RPM), throttle and brake values to emulate application of brake and/or throttle by driver, as well as acceleration, and gas level. Since the agent is fuzzy, these parameters have to be fuzzified and converted into several fuzzy partitions. Hence, fuzzy membership functions had to be created for all the aforementioned inputs. The defined membership functions for three of the six inputs to the fuzzy agent (RPM, acceleration and throttle) are shown in the figures below:

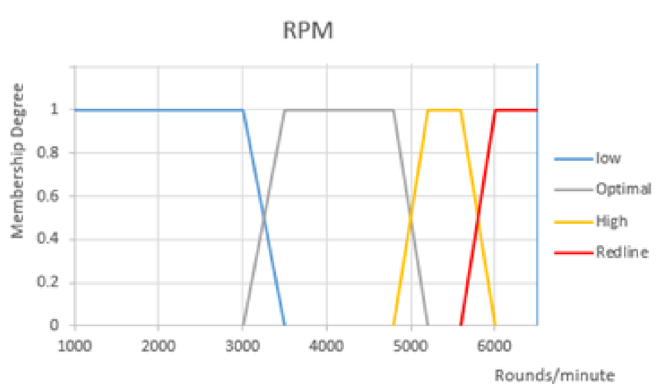

Figure 1: Revolutions per minute (RPM) fuzzy membership functions.

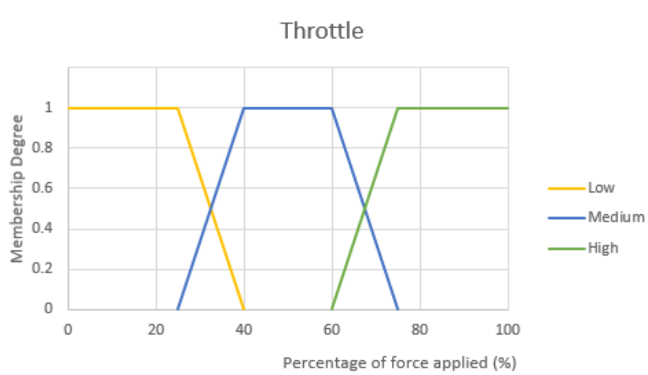

Figure 2: Throttle fuzzy membership functions.

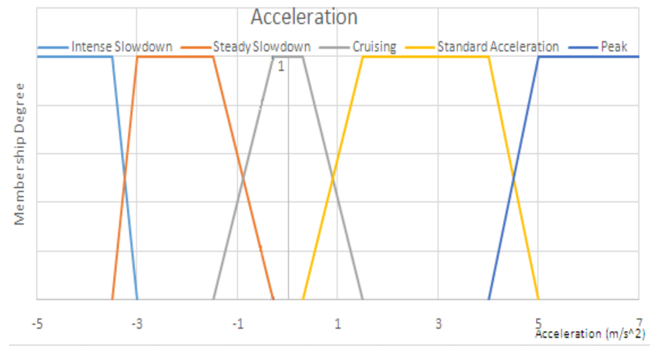

Figure 4: Acceleration fuzzy membership functions.

A fuzzy agent handles its fuzzy inputs through condition-action rules, so this software utilizes over 80 different rules, some of which are given in Table I, to produce fuzzified outputs based on Larsen's product inference. When these outputs are computed, they are then aggregated using the weighted sum rule. The aggregated output is then defuzzified using maximum to the left defuzzification, which will produce a discrete decision (gear up, gear down, or maintain gear): due to the output's singleton membership functions, shown in Fig. 5, the output will be a set of 3 singletons of different weights. The singleton with the highest weight is chosen and its corresponding action is performed.

TABLE I:
Sample Condition-Action Rule.

RPM	Throttle	Brake	Gas	Acceleration	Action
Redline	Low	High	Any	Any	Maintain
Optimal	High	Low	Any	Peak	Maintain
Optimal	High	Low	Any	Cruising	Gear Up
High	Medium	Low	Any	Intense Slowdown	Maintain
Low	Low	Low	High	Steady	Gear Down
High	High	Low	Any	Cruising	Gear Up
Low	Low	Any	Low	Intense Slowdown	Maintain
Low	Low	Medium	High	Steady Slowdown	Gear Down
Redline	Low	Low	Any	Peak	Gear Up
Optimal	High	Low	Any	Steady Slowdown	Gear Down

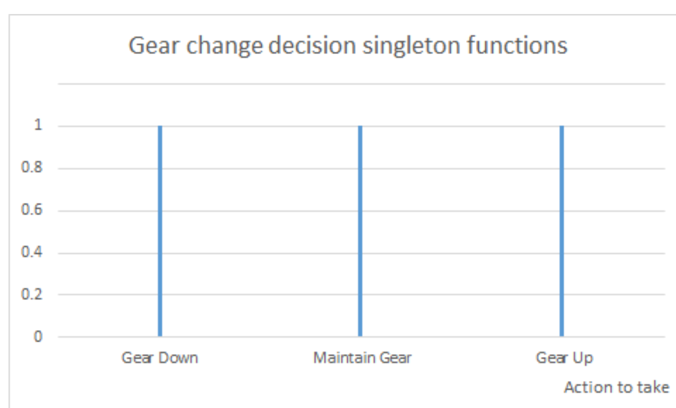

Figure 5: Gear change decision singleton functions.

It is important to note that, while the steepness of the road being driven on (uphill or downhill) is not a direct input to the fuzzy agent, it does indirectly affect decision-making, since this parameter can affect the car's movement via an additional gravitational force that supports/opposes the car's movement.

In order to make the project more realistic and intelligent, a Smart Brake agent was introduced to apply a brake in potential emergency situations, for instance when the car is speeding up with a sharp turn coming up or when the car is uncontrollably or dangerously accelerating downhill. When this agent is enabled, it assumes control of throttle and brake, but will cede it when its job is complete. Based on the situation, the agent will apply a low, medium, or high brake, also based on fuzzy logic. Initially, turn intensity (an angle in degrees) and vehicle speed (in km/h) are fed into the system and fuzzified based on membership functions shown in Fig.6 and Fig. 7. The agent then uses the fuzzified intensity of the turn (Slight, Regular, and Sharp turns) and fuzzified speed (Low, Medium, High) to produce, based on some logical rules, fuzzified outputs based on Larsen's product inference. These outputs are aggregated using the weighted sum mechanism and the aggregated output is defuzzified using center of gravity defuzzification, which will produce a certain intensity with which the brake is applied while, of course, setting throttle to zero. After that, smart brake is turned off and control is returned to the driver.

The Condition-Action Rules of this agent, as well as the membership functions for turn intensity and speed, are shown in the table and figures below:

TABLE II:
Smart Brake Agent Condition-Action Rules.

Turn Intensity	Speed	Brake Applied
Slight	Low	None
Slight	Medium	Low
Slight	High	Medium
Regular	Low	None
Regular	Medium	Low
Regular	High	High
Sharp	Low	None
Sharp	Medium	High
Sharp	High	High

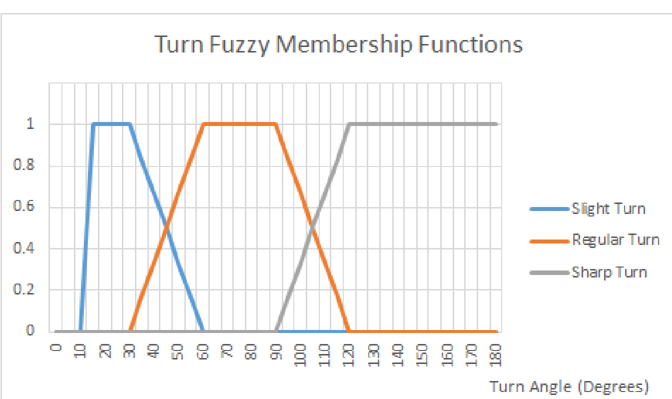

Figure 6: Turn fuzzy membership functions.

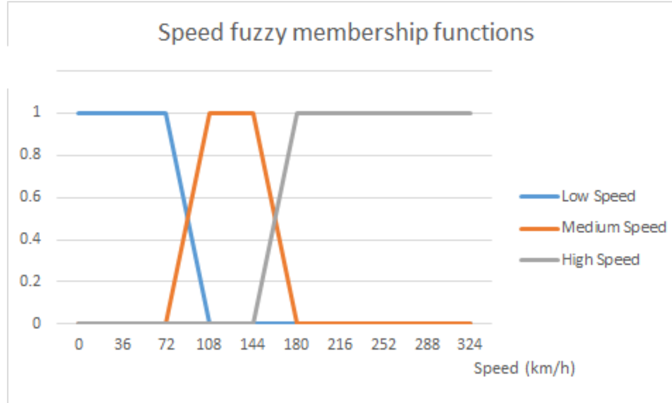

Figure 7: Speed fuzzy membership functions.

3.2. Design and Conceptual Model

This model is based on fuzzy logic since a gear change decision in itself is fuzzy (non-crisp) and depends on several inputs that cannot be processed analytically. Some inputs are more important than others in decision making (For example, engine revolutions per minute are more important than gas level.).Therefore, these inputs are represented and handled with more rules and linguistic variables. The design of the fuzzy membership functions corresponding to these linguistic variables required great attention to detail and meticulous testing, since inaccurate or unreasonable functions would lead to undesirable agent behavior(such as excessive gear switching and alternation). The fuzzy membership functions were also normalized. In other words, for any given value for an input, the sum of all membership degrees for all corresponding linguistic variables will equal one. This will simplify the conceptual analysis of the system and render it more intuitive and relatable to what traditional logic offers. With the functions in place, the rules had to be set in a way that would not undermine the agent's operation. This task proved to be particularly difficult: Since this agent can be modeled as a 6-Degrees-Of-Freedom system, it must handle a 6-dimensional input vector, and do so perfectly, lest the software get stuck in a limbo state (continuously switching between two neighboring gears) or behave incorrectly. Hence, the rules had to be set such that they do not interfere with one another or overlap on each other's trigger state.

Should this software be implemented for a real-life application on the streets, the Performance/Environment/ Actuators/Sensors model (i.e., PEAS model) will be as follows:

- Performance Measure: Percentage of decisions produced that the driver agrees with during agent testing.
- Environment: Roads that can be flat, downhill or uphill, which can also be straight or left and right turns of variable intensity.
- Actuators: a transmission system similar to the one implemented in automatic vehicles is used for the basic agent and smart valves connected to the hydraulic pressure that in turn are connected to the wheels are used for the Smart Brake agent.

- Sensors are required to measure inputs: a speedometer for speed, a tachometer for RPM, valves to measure the levels of throttle/brake applied, an accelerometer for acceleration and a gas sensor for gas measurement. Road curvature and steepness can be measured and used for gearbox control via speed comparison done at the wheel level (on all vehicle wheels) [4]

3.3. Implementation

This project was developed from the ground up. The first part implemented was a mathematical model to simulate the Corvette C5's operation. Data concerning engine performance and torque are withheld by Corvette, so the model had to be based on empirical data found for the Corvette's acceleration, deceleration and braking, in a way that minimizes error [5]. With the car model in place, a manual gearbox using the C5's actual gear ratios was coded: later on, this gearbox will be controlled by the intelligent agent. With the gearbox now ready, the building blocks for the fuzzy agent (aggregation/ condition-action rules/defuzzification, etc.) were combined so as to eventually be used to make gear switches automatic. Next, a user interface was developed such that a user can evaluate all aspects of the car's operation (nature of the upcoming road, car's current gas level, speed and rpm) and take control of throttle and brake, as any driver can on the roads. The interface offers data similarly to the cockpit of an actual car.

The main agent now complete, the second intelligent agent, the Smart Brake, designed to make the vehicle safer especially given the high speeds which it can reach, was implemented using the previously discussed fuzzy logic techniques and membership functions. This smart brake agent will act as a last resort defensive agent that will apply the car's brake should the driver put himself in a dangerous situation (like speeding at a sharp turn). For the sake of testing and demonstration, turns, downhill, and uphill are generated based on a Poisson distribution in the code, so as to emulate real turns and slopes in driving as accurately as possible.

Finally, for the sake of testing and flexibility, all agents in this software can be disabled. In other words, the user can drive his car in manual mode, disable smart brake and even disable the random generation of turns and uphill/downhill.

All in all, the final project consists of four components:

1) A car mathematical model which simulates the Corvette C5's operation and produces acceleration, RPM, speed and gas values from the gear, throttle and brake inputs
2) A Poisson-based random terrain generator to test the car on several road configurations of variable difficulty
3) The main fuzzy logic-based intelligent gearbox, which controls the vehicle's selected gear
4) The additional smart brake agent, which can optionally control the vehicle's braking in emergency situations.

A diagram illustrating the project design and its inner components is shown in Fig. 8:

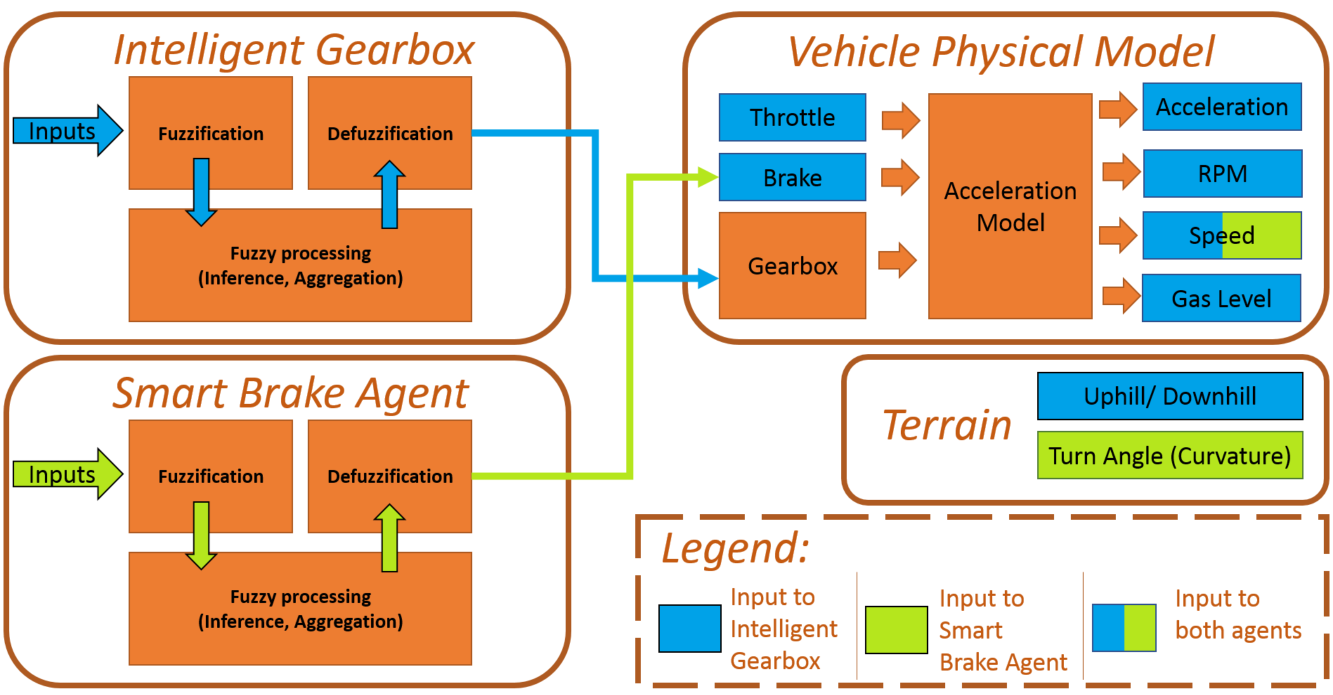

Figure 8: Project Operational Diagram.

IV. TESTING

This software makes decisions which can potentially place drivers at risk, so testing its decision-making is a crucial part of development. To test this software, manual simulation of critical situations had to be made in its code. The agent's response was then observed and recorded. If the action observed, if any, is logical, sensible and, crucially, fast, then the agent will have successfully handled the situation and changes would not need to be made. However, should the agent act incorrectly or slowly, then the condition-action rules responsible for this, as well as any computational overhead slowing the system down are to be reviewed, evaluated and rethought.

4.1. Test Cases

This software comprises of two agents: the gearbox and an additional smart brake agent, so testing encompassed a very large range of situations in which both agents are called into action. The intelligent gearbox was continuously throughout its development phase and under a variety of different conditions, to very satisfying results, some of which are shown in the following table:

TABLE III:
Sample test cases and results

Situation	Response
Redline RPM, low throttle and a regular brake applied	Agent maintains same gear
Low RPM, throttle and gas level. Car decelerating rapidly	Agent maintains gear
Low RPM, throttle and high gas level. Car decelerating rapidly	Agent lowers gear
RPM in optimal range, high throttle application, low (no) brake, but car decelerating	Agent lowers gear
RPM in optimal range, high throttle application, low (no) brake, car is cruising	Agent raises gear

The agent's response with respect to the fourth test mentioned in Table III is also shown in Fig. 10. As for the smart brake agent, it was tested in critical situations and yielded highly satisfactory results. For instance, if the car redline RPM and is going downhill, the smart brake agent is activated to protect the engine. This situation is shown in Fig. 9.

Crucially, neither system lagged when responding to a particular situation. Indeed, both intelligent agent successfully handled test cases without any delay in response (all responses seem to happen in real-time), which is vital for an application in which changes occur in fractions of a second.

V. CONCLUSION

The gearbox agent, car model, smart brake agent, and Graphical User Interface (GUI) were each designed with a view to making the most of the Corvette C5's power while maintaining safety and ease of use. Implementing this project required a lot of reading about cars' internal mechanisms and tiresome number crunching for the computation of physical constants, and this is without mentioning the challenge of implementing a coherent and logical agent for the car which can successfully handle multiple inputs of different nature and dimension. Yet ultimately, all the work bore fruit and eventually, a reasonable set of condition-action rules and a mathematical car model simulating the Corvette C5 with remarkable accuracy were developed, which led to a solid and reliable intelligent agent. This project is a testament to the power of fuzzy logic as a foundation for intelligent agents whose applications can certainly go beyond vehicle gearboxes.

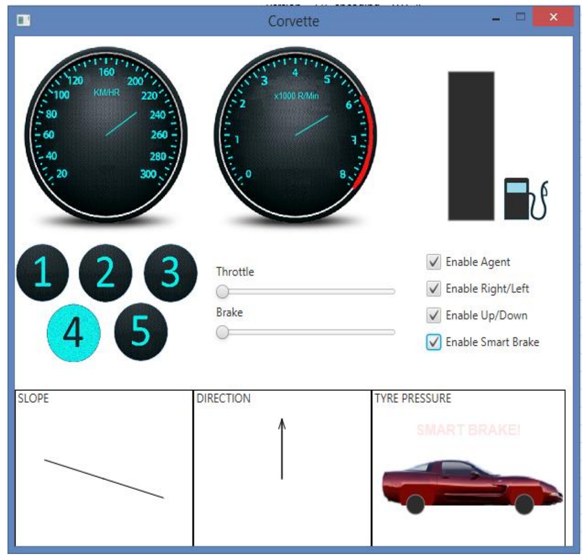

Figure 9: Smart Break activates at advent of risk.

VI. FUTURE WORKS AND PERSPECTIVES

Looking ahead, extend the scope of this project will be extended further. For instance, one could consider adding a learning element to the gearbox, such that it would "learn" the driver's style. This learning would be done by updating the membership functions or adding weights to the condition-action rules based on the learning agent's inputs. For inputs to the agent, the simplest and most effective means of input would be a learning phase in which the driver drives the vehicle in manual transmission or, should the driver opt otherwise, to allow driver feedback (the driver overrides a decision he deems wrong) that is used to update the gearbox model. Beyond this, we plan to extend this software such that it can successfully handle any vehicle model, such that, by a simple change in physical constants (gear ratios, friction coefficients, etc.), new adapted membership functions would be generated such that the agent can make intelligent decisions for a completely new vehicle. Hence, this would hopefully pave the way for a universal vehicle gearbox, which would simplify the maintenance and driving of all cars in the years to come.

ACKNOWLEDGMENTS

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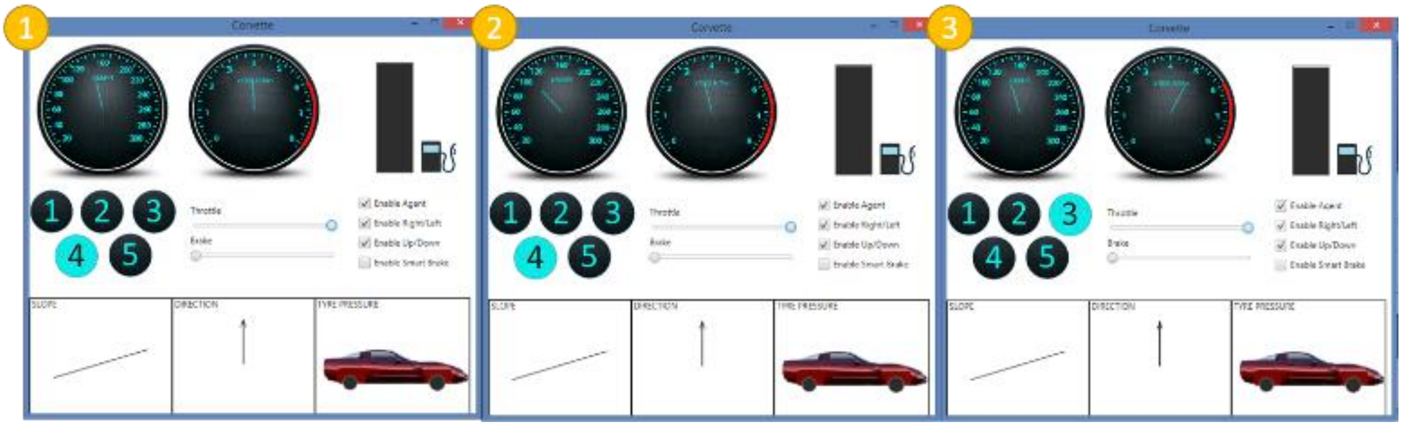

Figure 10: Test Case Number 4: From screenshot 1 to 2, one can notice the car decelerating despite full throttle being applied. In screenshot 3, the agent's response is shown. The agent lowers the gear allowing the car to regain acceleration.

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