Automatic Gearbox and Cruise control system for Motor Vehicles using a hierarchical fuzzy system

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***-Abstract.* Various fuzzy systems have been used to control automatic gear boxes in motor vehicles. Part of these systems use rules to estimate the driver intention to aid in gear selection. The hierarchical fuzzy system in this paper aims to combine a cruise control system with the mentioned automatic gear selection system, with the aim to reduce fuel consumption vs a standard cruise control and automatic gear box. The results shows a slightly worse fuel efficiency for the fuzzy system when tested in a simulator. Tuning of the rule-base could result in fuel efficiency improvements, and would be valuable for future work.**

I. Introduction

AUTOMATIC transmission control for vehicle gearboxes is a previously and well-researched application for a fuzzy system, along with cruise control systems for maintaining a set speed for a vehicles. In this paper, it's suggested that these two systems can be implemented using a hierarchical fuzzy system. By using an expert rule base, and Fuzzy rules based on the performance characteristics of the vehicle engine, this paper investigates the potential advantages of lower fuel consumption as compared to a driver or other non-fuzzy based control systems. Fuzzy logic has advantages in these types of controller applications as it has the ability to express non-rigid inputs and outputs. For example, by using a fuzzy system, it is possible to express a temperature as "cold" or "slightly warm" instead of having to give a range of discrete values and interpolate between them.

A gearbox control system needs to have the ability to select the correct gear for the situation, depending on engine load, required acceleration/deceleration. Another important property is that the system does not change gear too rapidly or commonly, as this can increase additional wear on the gearbox and associated systems.

While fuzzy logic can seem like a good use-case for transmission control, it may not be the best solution. Since engine efficiency can theoretically be calculated from a given complete list of inputs (such as engine load, engine RPM, temperature, air density, fuel type, turbo RPM, and others), it may be possible (given all inputs are available to the system and are accurate) to calculate the most efficient gear using a conventional algorithm, by simulating a gear change and the associated change in engine/turbo RPM and engine load. However for this application, it is assumed that these inputs are unavailable. For cruise control, a fuzzy system is good method as it can express the variance between "slightly incorrect speed" and "very incorrect speed" and give an fuzzy output for the system for the input of the second fuzzy system (which will control the gearbox).

Sections covered in this paper are as follows; Sections 2 and 3 will contain current research on systems to control Transmission and Cruise control. Section 4 will cover the methodology and implementation. Section 5 will cover testing and conclusions.

II. Existing Fuzzy Transmission Control Systems

The job of a Transmission control system is to select the best gear available from the gearbox based of a range of inputs/conditions. Standard inputs to a system like this would be

The control system by (H. G. Weil, G. Probst and F. Graf, 1992, p. 716-721) uses parameters throttle, change in throttle, RPM and change in RPM, as well as force on the engine, brake force, and the current gear as inputs to the system to select the correct gear. A large part of this is to guess the drivers acceleration/braking intent as to what gear is required by the vehicle. Since the system proposed in this paper will by using the output from the cruise control unit to get the driving acceleration/braking intent, so only the one input parameter for intent is required. This output from the cruise control system will also be used as the input to throttle in the model.

Research by (M. M. M. El-Ashwah, W. Abbas, T. M. Farid, M. R. A. Atia, 2014, p. 1003-1005) shows that they can control a gearbox effectively by only using the two input parameters of throttle and wheel RPM. A problem with their testing however is they never simulate a slowing of a car, such that would necessitate a change down in gear. They also have very basic sequences for throttle control, which in a real driving scenario, would be much more complex.

The paper by (A. Casavola, G. Prodi, G. Rocca, 2010, p. ThC12.3) found that using a method that always selected the highest gear possible was able to get within 2.5% of their estimated maximum efficiency in their tests. This comes at the cost of reduced engine performance however. In real-world driving, its common for maximum power output for an engine to be required, meaning a lower gear ratio is required. The proposed system in this paper will select the highest gear ratio when acceleration intent is low/medium, but will select a lower ratio when maximum power is required by the cruise control system. The also tuned their fuzzy system by use of a generic algorithm to evaluate at what inputs to the engine required a gear change.

In the new proposed system, the membership functions are based of real engine performance graphs. Unlike the membership functions for RPM being defined as "low RPM" "medium RPM" and so on, we have functions named "idle", "efficient" and "max power" which closely resemble real engine efficiency and power curves. This allows the fuzzy system to directly change the gear until RPM reaches the "efficient" membership function when desired, and can change to target a different function such as "max power" when required, as dictated by the rule base.

The paper by (S. Mehta, K. Soundararajan, U Eranna, B SH, 2014, p. 7) uses different metrics such as road quality and traffic conditions to select appropriate gear, however these parameters are not available in the simulator being used, so would not be able to be implemented in to the system. Incorporating a radar sensor to measure the distance between the vehicle in front and the current vehicle and feeding this in to the cruise control network would be a good candidate for future work.

III. Existing Fuzzy Cruise Control Systems

Standard cruise control systems should only require a very basic fuzzy system to implement effectively. The research in (H. Asere, C. Lei, R. Jia, 2015, p.2211-2215) used three inputs for their fuzzy control system to control the vehicle. These are "speed", "error", and "change-error", which describe the current vehicle speed, the difference between the current speed and the target speed, and the change in difference between the current speed and the target speed. In their simulations, they were able to accelerate vehicles between 1000kg and 3000kg from a speed of 25mph and maintain a speed of 30mph. These tests show that once the correct speeds are achieved, the speed is held constant with a ripple in speed of less than +-1%.

A design with only two inputs or even fewer may also be possible, since by using only the difference between desired and actual speed would be able to tell if and how much acceleration or deceleration is needed; The sign would indicate acceleration or deceleration, and the magnitude would indicate the amount required. (T. Shishaye, n.d.) was able to demonstrate a cruise control system with only two inputs (by removing the "speed" input from the previous example), and demonstrates roughly equally good system as compared to the previous example in regards to ripple. Once this two input fuzzy system reached near target speed, ripple and overshoot are not visible in their graphs, showing a very good performance in respect to maintaining a constant speed.

IV. Methodology and Implementation

The proposed system will be comprised of two halves, one fuzzy system for cruise control, and another for gear selection. Based on the research in the previous two sections, the proposed system will have two inputs for the cruise control system, being comprised of "speed_err" calculated by current `speed / target speed`, and "acceleration" calculated by $((C_o - C_t)/T)/10$ where C_o = current speed, C_t = previous speed and T = the time elapsed between past measurement. The fuzzy system uses the following membership functions. See figure 8 and 9 for details.

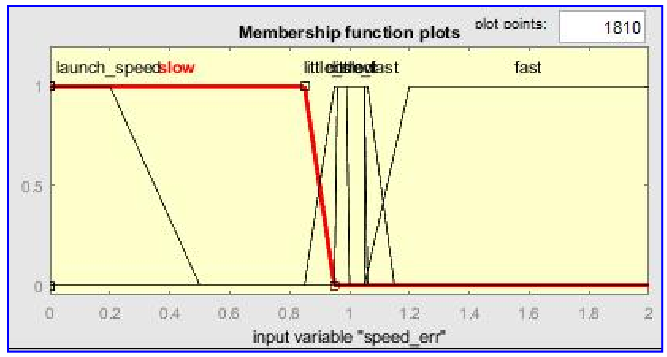

Figure 1. The speed_err membership functions (input)

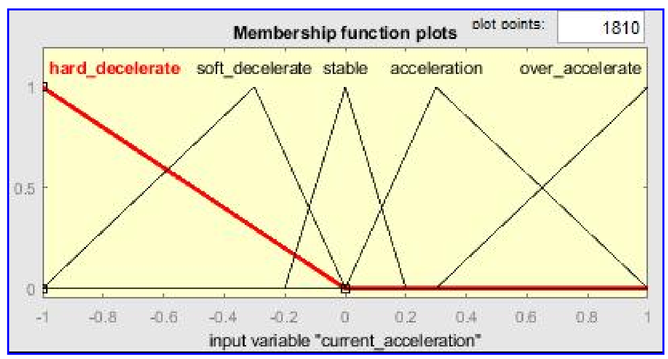

Figure 2. The current_acceleration membership functions (input)

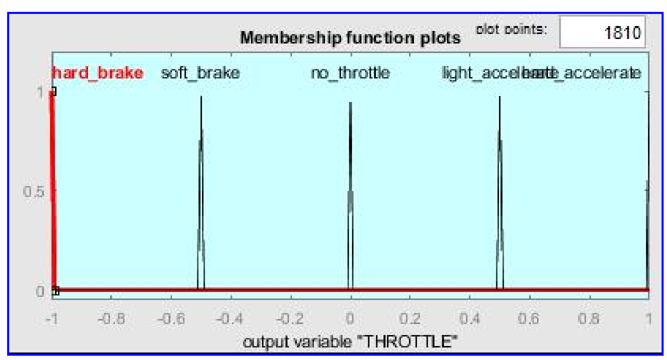

Figure 3. The THROTTLE membership functions (output)

The gear selection system will use the output from throttle as an input, along aside engine RPM and current speed. See figure 8 and 9 for details. The purpose of current speed is to aid the gear selection to not use the higher RPMs when in lower speeds and gears as this could cause unnecessary acceleration that would waste fuel.

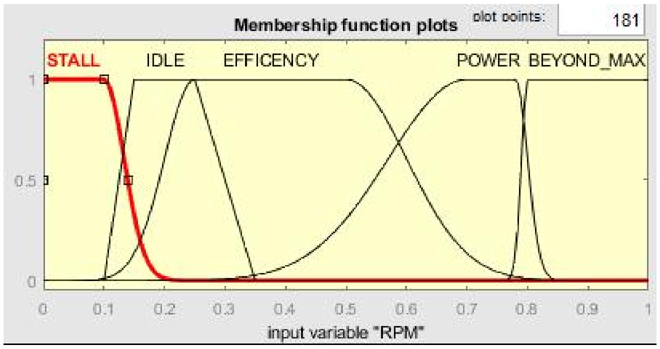

Figure 4. The RPM membership functions (input)

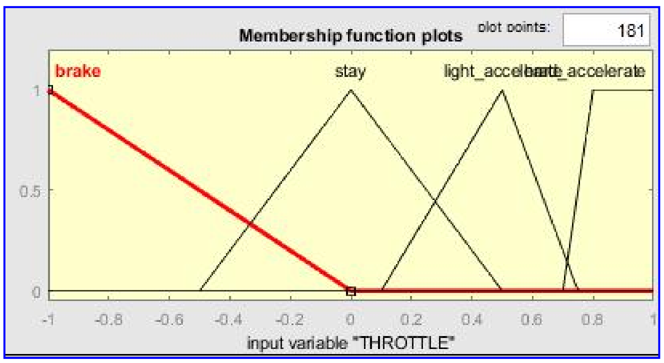

Figure 5. The THROTTLE membership functions (input) (output from cruise control fuzzy system)

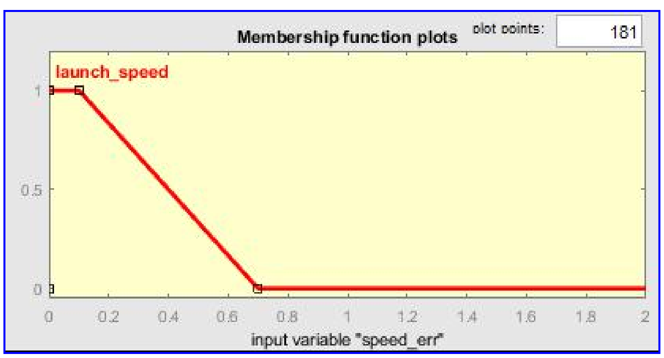

Figure 6. The speed_err membership functions (input)

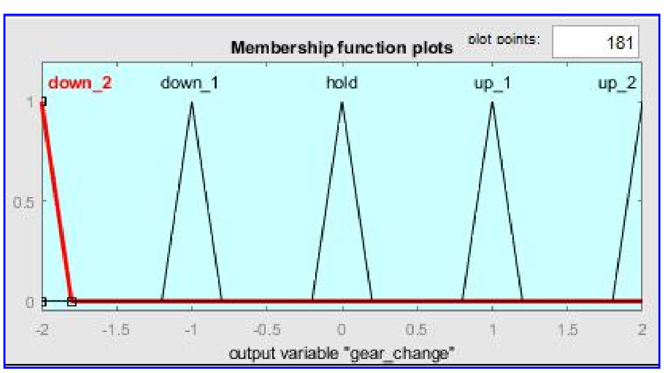

Figure 7. The gear_change membership functions (output)

Figure 8 below shows how the system put together.

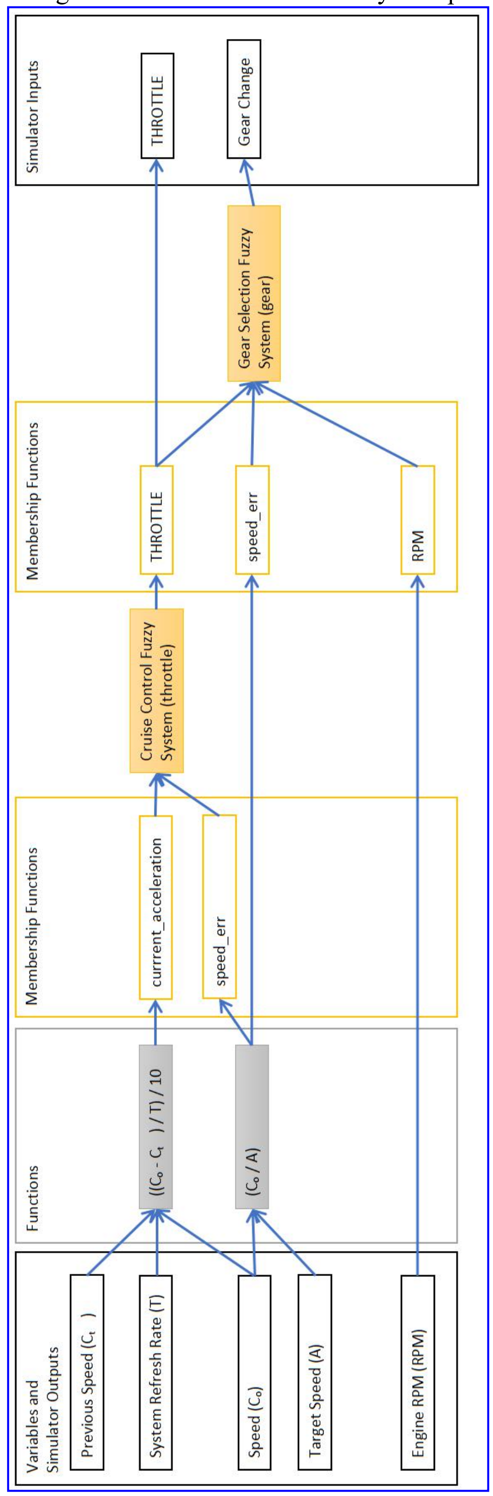

Figure 8. Full System Diagram

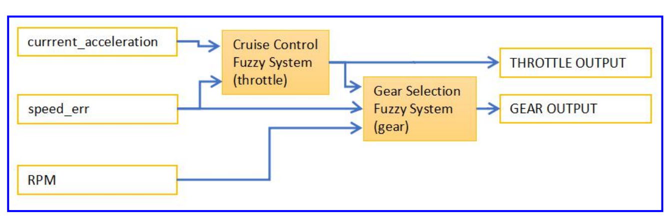

Figure 9. Fuzzy System Diagram

As figure 9 shows, the output from the Cruise control system is throttle which gets fed as an input to the second fuzzy system. Also note that speed_err is fed as an input to both systems.

The cruise control (throttle) system can be represented by the following equation.

$$[N_{11}]\,(x_{11}^{1},\, x_{11}^{2} \mid y_{11}^{1})$$

The gear select (gear) system can be represented by the following equation.

$$[N_{11}]\,(x_{11}^{1},\, x_{11}^{2},\, x_{11}^{3} \mid y_{11}^{1})$$

However, once in the fuzzy system as a hierarchy, the system must be represented formally by the following equation.

$$[N_{11}]\,(x_{11}^{1},\, x_{11}^{2} \mid y_{11,\,12}^{1\,'1}) * [N_{12}]\,(y_{11,\,12}^{1\,'1},\, x_{12}^{2},\, x_{12}^{3} \mid y_{12}^{1})$$

It's possible for these two systems to be merged, to a single entity. The first step in this would be to create two identity nodes (one above $[N_{12}]$ and two below $[N_{11}]$ for each input to $[N_{12}]$, which can be immediately vertically merged with each other). The system requires augmented inputs on nodes such that all nodes in each layer have the same input. Then layer 2 can be vertically merged with each-other, followed by a vertical merge layer 1, then a horizontal merge of the two nodes, to make a single system. This will not be implemented as a single node in this paper, as it increases complexity in understanding the rule base, and so building and troubleshooting become more complex. The fuzzy rule base can be generated using expert rules, rather than a data driven approach, as changing gears is a simple concept. This comes with the advantage that the rule-base can be easily understood by a human expert, and rules can be tweaked during testing.

Rules for the cruise control (throttle) system are as follows:

- If speed_err is slow then THROTTLE is hard_accelerate
- If speed_err is little_slow then THROTTLE is light_accelerate
- If speed_err is correct and current_acceleration is hard_decelerate then THROTTLE is hard_accelerate
- If speed_err is correct and current_acceleration is soft_decelerate then THROTTLE is light_accelerate
- If speed_err is correct and current_acceleration is stable then THROTTLE is no_throttle
- If speed_err is correct and current_acceleration is acceleration then THROTTLE is no_throttle
- If speed_err is little_fast then THROTTLE is soft_brake
- If speed_err is fast then THROTTLE is hard_brake
- If speed_err is launch_speed and current acceleration is over_accelerate then THROTTLE is no_throttle
- If speed_err is launch_speed and current acceleration is accelerate then THROTTLE is no_throttle

A compete rule base would consist of (5x5) 25 rules, the partial rule base above contains 10 rules.

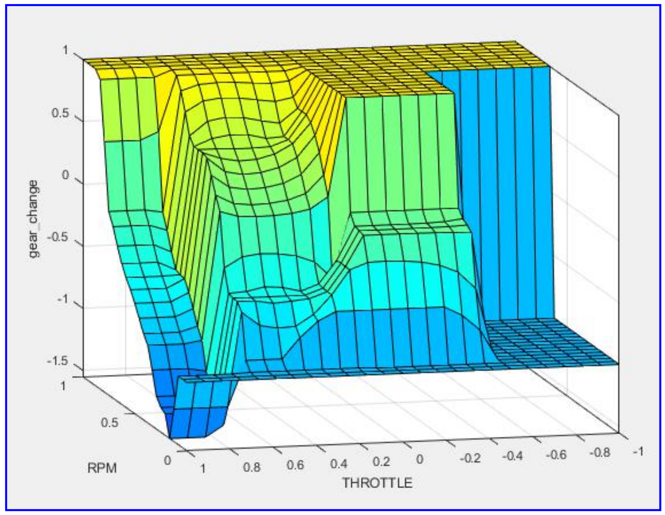

Figure 10. The cruise control (throttle) rule surface

Rules for the gear select (gear) system are as follows:

- If RPM is STALL then gear_change is down_1
- If RPM is IDLE and THROTTLE is stay then gear_change is hold
- If RPM is is POWER and THROTTLE is stay and speed_err is launch_speed then gear_change is up_2
- If RPM is IDLE and THROTTLE is light_accelerate then gear_change is down_1
- If RPM is POWER and THROTTLE is light_accelerate then gear_change is up_1
- If RPM is BEYOND_MAX then gear_change is up_1
- If RPM is EFFICENCY and THROTTLE is hard_accelerate and speed_err is not launch_speed then gear_change is down_1
- If RPM is POWER and THROTTLE is stay then gear_change is up_1
- If RPM is IDLE and THROTTLE is hard_accelerate then gear_change is down_2
- If RPM is POWER and THROTTLE is hard_accelerate and speed_err is not launch_speed then gear_change is hold
- If RPM is BEYOND_MAX and THROTTLE is light_accelerate and speed_err is launch_speed then gear_change is up_2
- If RPM is EFFICENCY and THROTTLE is light_accelerate then gear_change is hold
- If RPM is EFFICENCY and THROTTLE is hard_accelerate and speed_err is launch_speed then gear_change is hold

A compete rule base would consist of (5x4x2) 40 rules, the partial rule base above contains 13 rules.

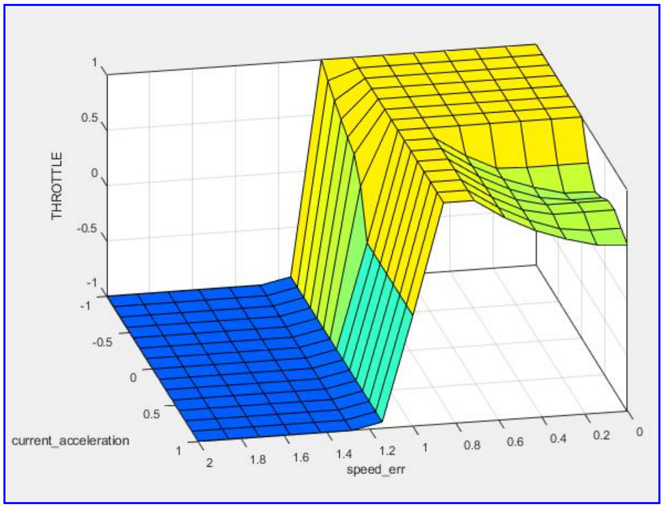

Figure 11. The gear select (gear) rule surface

A complete rule base should not be required for either system since the system should be able to interpolate between the two nearest rules when perfect rule isn't defined explicitly. However, a complete rule base may help in situations where the system gets an output which, when fed in to the simulator, would cause a different gear change when the system reads the information back from the simulator, resulting in a constant oscillation between gears. In testing, this was not observed, and so an compete rule base is not required for this implementation.

The simulator used for testing was SCS Software's ETS2 (SCS, 2019), because of its high quality physics and realistic fuel consumption simulation (when enabled in the settings), its available telemetry API interface for reading data out of the simulator (such as engine RPM) and its support for the vJoy emulated controller that was used to give inputs to the simulator via it's python API. MATLAB was used for the fuzzy logic engine as it has an available python interface, and strong tools for viewing and testing the created system.

The simulation will be controlled by using a python program to interface between the ETS2 simulation and MATLAB, via the telemetry API and vJoy as described above, and shown below in figure 12.

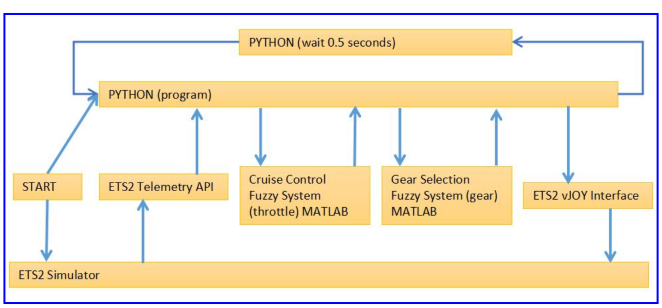

Figure 12. Simulation Diagram

V. Testing and Conclusions

The test circuit in the simulator was a stretch of road with variable speed limits, traffic lights, and a section of motorway to encompass a large range of scenarios, which is something that (H. Asere, C. Lei, R. Jia, 2015, p.2211-2215), (T. Shishaye, n.d.) and (M. M. M. El-Ashwah, W. Abbas, T. M. Farid, M. R. A. Atia, 2014, p. 1003-1005) lack. The test was around 8 minutes long.

Immediate results from the testing show that according to the simulator, 44+-0.5 Liters of fuel was used for the test of the standard Cruise Control and Automatic Gear box system. The hierarchical fuzzy system used 46+-0.5 Liters, a 2.2-6.9% increase. Initially this would indicate that the fuzzy system's fuel efficiency was worse, however because of the large error margins with the readings and small length of testing, no conclusions can be made from this test alone.

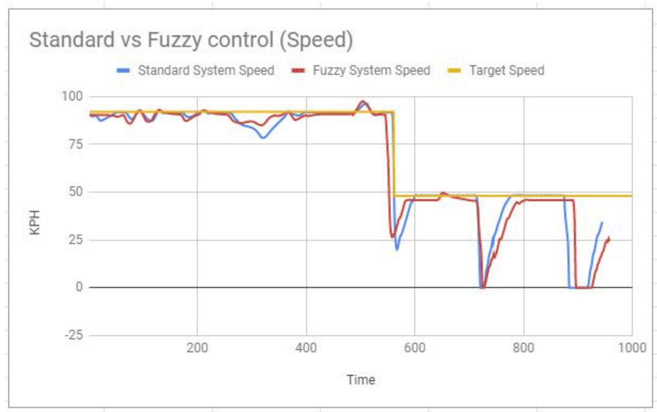

Figure 13. Standard vs Fuzzy control (Speed)

Figure 13 shows that, at higher speeds, the Fuzzy system is able to maintain speed better (for example around 300 on the time axis), because of its more aggressive shift-down pattern (see figure 14). At lower speeds however, the fuzzy system is programmed to limit fuel usage by limiting its acceleration at lower speeds and can be clearly seen at the two standstill starts.

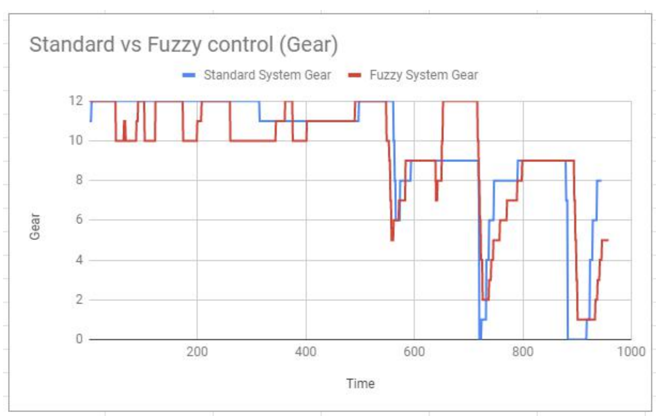

Figure 14. Standard vs Fuzzy control (Gear)

As above, figure 14 shows that the fuzzy system tends to change gear more often than the standard system to get the optimum gear, with the downside being less time spent with the gears engaged.

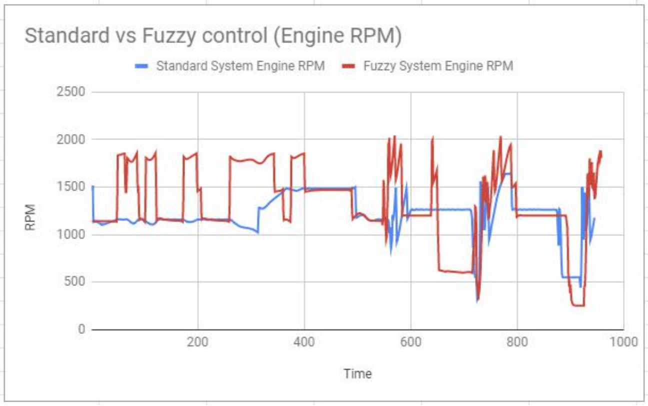

Figure 15. Standard vs Fuzzy control (Engine RPM)

Figure 15 shows that at the faster speeds in the first half of the test, the RPM (of the fuzzy system) has periods where it is greatly increased over the Standard System. As explained in figure 13, the aim of this is to provide a more constant speed at higher speeds. At lower speeds, the fuzzy system is able to provide lower engine RPMs at a constant lower speed as compared to the Standard System, although this is with higher RPMs while accelerating at these slower speeds.

To conclude, with some tweaking to the rule-base, and longer testing, the fuzzy system may be able to achieve measurably better fuel efficiency. With the rules and testing done in this paper, a superior system isn't able to be identified due to the error margins in the testing methodology.

Further research of interest relating to this project would be applying the cruise control system to a modified version of the gear select system for CVT gearboxes. The CVT gearbox does not have distinct gears, but instead can change the output ratio gradually, and so no de-fuzzification would be required. This would also eliminate the gear hunting and too-frequent changes to gear, because a CVT gear box can take a gradual input with an almost infinite level on granularity.

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