A new approach to the Intelligent Gear Shift using Artificial Intelligence and Fuzzy Logic

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Abstract: - Although vehicles automatic transmission engineering is rather developed, the speed selection in automatic gears does not always provide good results especially in some particular driving situations. In this work an alternate method based on artificial intelligence techniques implemented with Fuzzy controllers is proposed. The aim is to supply an intelligent control system able to interpret always correctly the driver’s intentions and to content them in the respect of the characteristics of the vehicle so as to make possible a simple and flowing driving.

Key-Words: - automatic transmission, artificial intelligence, Fuzzy, automotive application, man-machine interaction

1 Introduction

The state of art in the gear control systems of motor vehicles is based on different approaches. The classical approach [6, 7] to gear control consists in the synthesis of a controller, optimizing system parameters (the fuel consumption or the overall efficiency of the vehicle, driving comfort etc.). The best gear is calculated minimizing a behavior index according to the linear speed of the vehicle and the fuel flowing to the engine, accomplishing the so-called gear maps. This approach requires a complete mathematical model of the controller synthesis system; we must point out that the interactions vehicle-environment-driver are too complex to be adequately represented and, if we want to use the system for another vehicle, the controller must be planned again. Besides, this approach does not consider the driver's intentions, requires complex calculations and does not employ a priori knowledge of the system. Finally, the optimality vanishes as soon as we leave the project hypotheses, since the driver does not always manage to use the vehicle in the best way. In fact, he may have different intentions which require different gears under the same speed and fuel flowing.

A more up-to-date approach to the problem is based on the identification of the working conditions of the system vehicle-environment-driver with techniques typical of soft-computing. The Neural Nets are used to recognize the situations on the basis of fuel flowing, positions of the pedals etc.. These nets are trained beginning from training examples and they are also used to recognize (and consequently to select) the gear, in the same way of the gear maps. In [9, 10] we can see a similar implementation which makes use of Fuzzy Controllers as deciders. Also this kind of approach presents both advantages and disadvantages. An advantage is the plainness both of the project and the realization with regard to the best approach; in fact, to train the net, we can use experimentally based data employing an experienced driver (human) from whom the net learns. Among the disadvantages we can mention that, once the net has learned to recognize a situation or a driving style, it always proposes the same solutions and so, if the driver's driving style changes, the system reacts with too frequent, slow or even inopportune changes, such as selecting a higher gear before a turn. As we can note from the above-mentioned considerations, the decision systems still present some disadvantages which are not checked by the human driver.

In this work we propose an approach based on artificial intelligence techniques which implement the human reasoning scheme in order to utilize all the advantages deriving from the following considerations:

- the driver can be used as a sensor that gives information about the environment (route, traffic and weather conditions);
- The human controller, though he is not excellent from the point of view of the efficiency, is extraordinarily versatile in almost all the driving conditions and these capabilities can be employed in a control low.
2 Fuzzy Intelligent Control for Gear Shift

Before proceeding any further it is suitable to make clear the kind of system we want to plan: a system able to replace the driver in the operation of gear selecting during the driving of the vehicle in order to come up to his expectations as far as the system and the conditions permit. This statement implies the planning of an agent which is defined "intelligent" in Artificial Intelligence or rather a system able to interact with the world (or with a controlled system) through actions, on the basis of the perceptions it has of the world and trying to attain its goal.

In this case the world is the environment in which the agent is acting (the vehicle, the driver and the scenery), the actions are the selection of the gears, the perceptions are the events the agent is able to monitor (namely the current gear, the vehicle speed, the engine rotation speed, the pedals positions displacement etc.), the goal is the substitution of the driver.

To attain this purpose our agent will have to imitate his reasoning, so the first question is: how does the driver reason? Why does the driver change gear? An answer could possibly be:

- to increase the engine torque and to have a better rise or to reduce speed the gear is reduced (by increasing the gear ratio)
- to increase speed when the engine rotation running is high the gear is increased (by reducing the gear ratio)

Other necessary considerations concern the calculation and memory resources the agent dispose of, the agent's answer speed and the tolerance to his errors. The resources are minimal so we can suggest those typically offered by a low cost integrated Microcontroller. The actions must be timely since the agent must act in real time in a quickly developing "world" so we must demand answer times lower than a second.

All these remarks bring us considering for our agent a Stimulus-Response architecture (S-R) which reacts to stimuli with actions obtained from a set of behavior rules calculated in advance. Without considering past actions and without anticipating future events, the agent will have only to verify each time which rules are the most suitable to the situation and to deduce from them the best chose. A possible structure for our agent can be built using the Fuzzy Logic.

We can deduce that the controller synthesis presents us a rather complex problem mainly with regard to Fuzzy rules drawing up. Therefore, before going into details, it is necessary to define a synthesis strategy and to proceed in succession:

Strategy: Selecting the most adequate gear in accordance with the driver's intentions and the state of the system.

This strategy suggests the following block scheme of the control system (Fig. 1)

3 Driver's Intentions Estimator (DIE)

The pilot drives the vehicle on the grounds of the overall system conditions (route course, traffic conditions, vehicle speed and charge etc.) acting on the car through the accelerator and brake pedals; we overlook the clutch pedal, as we consider it automatic, and the wheel as we suppose it has not movement sensors. The Driver's Intention Estimator (in future DIE) must have as input the driver's actions, namely the Accelerator and Brake pedal position displacement (in future A and B), the Differential Accelerator pedal position displacement (in future DA). For these variables we define the set of belonging Fuzzy Membership Functions:

- A: Zero, Low, Medium, High
- DA: Negative, Zero, Positive
- B: Zero, Medium, High

with regard to the output driver's Intentions (in future I) we define the MF:

- I: Brake, Slow, Steady, Quicken, Speedy

With these choices for the MF we can write down 4x3x3=36 rules corresponding to all the possible MF configurations of the entrance variables; in fact, if we fix a rule for each configuration, we find all the rules of the kind "if… and… and… then" that we can write down using all the possible cases that the division in MF permits. Therefore, if we do not consider the Brake, we have 4x3=12 fuzzy rules. In effect we may unify some rules which present the same exit value, as in the Karnaugh maps, simplifying the system.

Let us begin to formalize the fuzzy inference rules: the entrance variables are three but, at first, we do not consider the Brake as its effect can be added soon after assuming that the Brake pedal is not pressed simultaneously to the Accelerator pedal and however considering that its action must be prior to
the Accelerator. Consequently, while drawing up the rules where the variable Brake (non Zero) appears, the Accelerator is not considered which makes simpler the choice of the rules, as we will see later, as the variable Brake distinguishes the situations clearly.

In order to draw up the rules, we imagine to find ourselves in a standard situation and we try to think logically like the driver: let us suppose to be on the go with the Brake released, and let keep it as starting condition; let us consider how to interpret the remaining variables (Accelerator and Differential Accelerator) to perceive the driver's intentions; to this order we note that the "decisive" variable is the Differential Accelerator since it tells us from the start the direction the Accelerator moves towards and the driver's short term intentions. The Accelerator intrinsic value can be considered as the actual state or memory of the past which helps us to interpret better the intentions (up to that very instant) already expressed by Differential Accelerator so, in accordance with the values of Differential Accelerator, we can already assert that the driver's intentions are to increase, to keep steady or to reduce speed. In order to discriminate better among the possible situations, we use the value of Accelerator: Driver Slow down if B is Zero and:

- A is Zero and DA is Negative
- A is Medium and DA is Negative
- A is High and DA is Negative

Driver Steady if B is Zero and:

- A is Zero and DA is Negative
- A is Low and DA is Negative
- A is Zero and DA is Zero
- A is Low and DA is Zero

Driver Quicken if B is Zero and:

- A is Medium and DA is Positive
- A is High and DA is Positive
- A is Medium and DA is Zero
- A is High and DA is Zero

Driver Speedy if B is Zero and:

- A is Zero and DA is Positive
- A is Low and DA is Positive
- A is High and DA is Zero

Of course these remarks lead us to formulate the 14 fuzzy rules to be inserted in the controller.

The definitive Drivers Intentions rules are:

1. if (A is Zero) and (DA is Zero) and (B is Zero) then (I is Steady)
2. if (A is Low) and (DA is Zero) and (B is Zero) then (I is Steady)
3. if (A is Medium) and (DA is Zero) and (B is Zero) then (I is Steady)
4. if (A is High) and (DA is Zero) and (B is Zero) then (I is Steady)
5. if (A is Low) and (DA is Zero) and (B is Zero) then (I is Steady)
6. if (A is Medium) and (DA is Zero) and (B is Zero) then (I is Steady)
7. if (A is High) and (DA is Zero) and (B is Zero) then (I is Steady)
8. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
9. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
10. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
11. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
12. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
13. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
14. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
15. if (A is Zero) and (DA is Zero) and (B is Zero) then (I is Steady)
16. if (A is Low) and (DA is Zero) and (B is Zero) then (I is Steady)
17. if (A is Medium) and (DA is Zero) and (B is Zero) then (I is Steady)
18. if (A is High) and (DA is Zero) and (B is Zero) then (I is Steady)
19. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
20. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
21. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
22. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
23. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
24. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
25. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
26. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
27. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
28. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
29. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
30. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
31. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
32. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
33. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
34. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
35. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
36. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
37. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
38. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
39. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
40. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
41. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
42. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
43. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
44. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
45. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
46. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
47. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
48. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
49. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
50. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
51. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
52. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
53. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
54. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
55. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
56. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
57. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
58. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
59. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
60. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
61. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
62. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
63. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
64. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
65. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
66. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)
67. if (A is Zero) and (DA is Positive) and (B is Zero) then (I is Speedy)
68. if (A is Low) and (DA is Positive) and (B is Zero) then (I is Speedy)
69. if (A is Medium) and (DA is Positive) and (B is Zero) then (I is Speedy)
70. if (A is High) and (DA is Positive) and (B is Zero) then (I is Speedy)

After defining the structure of the estimator we must choose for all the MF mentioned so far all the distinguishing characteristics as type, form and position. With regard to this subject we also consider the possible optimization method we will can to use as we suppose that the device is implemented by a low cost fuzzy microprocessor; with regard to the input variables, we choose as MF the triangular function and the output variable and we consider the function constant. After choosing the form of the MF it is necessary to establish the parameters identifying them and, in the first place, their position. To this purpose, since the variables we are considering have values fluctuating in a wide space, we normalize them between [0,1] for ever positive variable (A and B) and [-1,1] for DA because it can be negative. As to the output variables they must be crisp so we can dislocate them on [0,1] interval. In conclusion we select the MF displayed in fig. 2,3 and 4.

![Fig. 2: Accelerator (A)](image)

![Fig. 3: Differential Accelerator (DA)](image)
The State Estimator (in future SE) is necessary to value the vehicle capabilities in a particular instant. The acceleration response of the vehicle is function of the load torque that opposes the vehicle advance. The resistant torque depends from many factor time variants and is difficult to quantify (aerodynamics resistance, road degree, vehicle load etc.). From the state estimator we need a simple information: the gear is correct (medium state) or we must change gear up or down (low state or high state). To have this output we make a simple consideration: if pushing accelerator increases the vehicle speed (and the engine rotation speed) the state is high, else the state is low. Using this statement and let S as state, DVS as differential vehicle speed, ERS as engine rotation speed, S as State we can chose these variables and their correspondent MF:

- **ERS**: Low, Medium, High
- **DVS**: Negative, Zero, Positive
- **DA**: Negative, Zero, Positive

As the output we choose:

- **State**: Low, Medium, High

Now the fuzzy rules can be written supposing one case (example ERS is Low) and then generalized to the other cases. Using this strategy we obtain 27 rules:

1. if (ERS is Low) and (DVS is Negative) and (DA is Negative) then (S is Medium)
2. if (ERS is Low) and (DVS is Negative) and (DA is Zero) then (S is Low)
3. if (ERS is Low) and (DVS is Negative) and (DA is Positive) then (S is Medium)
4. if (ERS is Low) and (DVS is Zero) and (DA is Negative) then (S is Zero)
5. if (ERS is Low) and (DVS is Zero) and (DA is Positive) then (S is High)
6. if (ERS is Low) and (DVS is Positive) and (DA is Negative) then (S is Low)
7. if (ERS is Low) and (DVS is Positive) and (DA is Zero) then (S is High)
8. if (ERS is Low) and (DVS is Positive) and (DA is Positive) then (S is Medium)
9. if (ERS is Medium) and (DVS is Negative) and (DA is Negative) then (S is Medium)
10. if (ERS is Medium) and (DVS is Negative) and (DA is Positive) then (S is Low)
11. if (ERS is Medium) and (DVS is Zero) and (DA is Negative) then (S is Negative)
12. if (ERS is Medium) and (DVS is Zero) and (DA is Positive) then (S is Medium)
13. if (ERS is Medium) and (DVS is Zero) and (DA is Zero) then (S is Medium)
14. if (ERS is Medium) and (DVS is Zero) and (DA is Positive) then (S is Low)
15. if (ERS is Medium) and (DVS is Positive) and (DA is Negative) then (S is Medium)
16. if (ERS is Medium) and (DVS is Positive) and (DA is Positive) then (S is Medium)
17. if (ERS is Medium) and (DVS is Positive) and (DA is Zero) then (S is Medium)
18. if (ERS is Medium) and (DVS is Positive) and (DA is Positive) then (S is Medium)
19. if (ERS is High) and (DVS is Negative) and (DA is Negative) then (S is Medium)
20. if (ERS is High) and (DVS is Negative) and (DA is Positive) then (S is Low)
21. if (ERS is High) and (DVS is Negative) and (DA is Zero) then (S is Low)
22. if (ERS is High) and (DVS is Negative) and (DA is Positive) then (S is Medium)
23. if (ERS is High) and (DVS is Zero) and (DA is Negative) then (S is Medium)
24. if (ERS is High) and (DVS is Zero) and (DA is Positive) then (S is Medium)
25. if (ERS is High) and (DVS is Zero) and (DA is Zero) then (S is Medium)
26. if (ERS is High) and (DVS is Zero) and (DA is Positive) then (S is Medium)
27. if (ERS is High) and (DVS is Positive) and (DA is Medium)

Now, like in the Driver's Intentions Estimator, we normalize the variable and choose the MF in this form:
The MF values of the output are 0, 0.5 and 1.

5 The Controller

The optimal gear-shift strategy is determined by using a fuzzy control system which employs the driver's intention, the vehicle state and the present gear to determine the optimal gear shift strategy. The Controller is the fuzzy system that chooses the optimum gear using, as input, the Estimated State ES, the Estimated driver's Intention EI and the Current Gear CG. The output of that system is used to control the actuator that shifts gear (upshift or downshift). After describing that the choice of the Fuzzy MF is very simple, so for the input variables we can choose:

- CG : 1st, 2nd, 3rd, 4th
- ES : Low, Medium, High
- EI : Slow, Steady, Quicken

About the output we chose (the MF is crisp):
- Gear : G1, G2, G3, G4

To simplify the writing of the fuzzy rules, we consider a gear and the changing state condition. With this technique we obtain:

1. if (CG is 1st) and (S is not High) and (EI is not Quicken) then (Gear is G1)
2. if (CG is 1st) and (S is not High) and (EI is Quicken) then (Gear is G1)
3. if (CG is 1st) and (S is High) and (EI is not Slow) then (Gear is G1)
4. if (CG is 2nd) and (S is not High) and (EI is Steady) then gear is G2
5. if (CG is 2nd) and (S is High) and (EI is not Slow) then (Gear is G1)
6. if (CG is 2nd) and (S is Low) and (EI is Quicken) then (Gear is G1)
7. if (CG is 3rd) and (S is not High) and (EI is Steady) then gear is G3
8. if (CG is 3rd) and (S is not High) and (EI is Slow) then (Gear is G2)
9. if (CG is 3rd) and (S is High) and (EI is not Slow) then (Gear is G4)
10. if (CG is 4th) and (S is not High) and (EI is Steady) then (Gear is G4)
11. if (CG is 4th) and (S is not High) and (EI is Slow) then (Gear is G3)
12. if (CG is 4th) and (S is not Low) and (EI is not Slow) then (Gear is G4)
13. if (CG is 2nd) and (S is Low) and (EI is Quicken) then (Gear is G1)
14. if (CG is 3rd) and (S is Low) and (EI is Quicken) then (Gear is G2)
15. if (CG is 4th) and (S is Low) and (EI is Quicken) then (Gear is G3)
16. if (CG is 1st) and (EI is Slow) then (Gear is G1)
17. if (CG is 2nd) and (S is High) and (EI is Slow) then (Gear is G2)
18. if (CG is 2nd) and (S is Medium) and (EI is Quicken) then (Gear is G3)
19. if (CG is 3rd) and (S is High) and (EI is Slow) then (Gear is G3)
20. if (CG is 3rd) and (S is Medium) and (EI is Quicken) then (Gear is G3)
21. if (CG is 4th) and (S is High) and (EI is Slow) then (Gear is G4)

6 Simulation Results

The Fig. 11 shows the Matlab model used to simulate the control system. That simulation employs a simulated predetermined pedal pressure (accelerator and brake) and the dynamic vehicle load to test the performance of the fuzzy control system.
The Fig. 12 shows the MatLab simulation results of the Fuzzy control system. The magenta line displays the gear position during a driving simulation. It starts from the 1\textsuperscript{st} gear when the vehicle starts its motion at time zero second. To start, the driver releases the brake and simultaneously pushes the accelerator pedal. This action determines the increment of the engine rotation speed and the of vehicle speed. When the ERS is sufficient the Fuzzy Controller changes, by upshift, the gear that reduces consequently the ERS and increments the vehicle speed. If the road load change (for example increasing road degree) the Fuzzy control reacts and downshifts the gear to increase the ERS and the torque engine. The simulation demonstrates the optimality of the Fuzzy control strategy in all situation both for the driver’s intention estimation and for the load variation.

**7 Conclusion**

This paper presents a Fuzzy control system, a promising approach to interface between a vehicle operator and an automobile. Simulation driving tests are achieved by this Fuzzy optimal gear-shift control. The test results show that this approach gives a smoother driving, less fuel consumption, and less harmful exhaust gas emission than the conventional approaches. This is also applicable to downhill driving with variable loads and for flat road.

References:


