Design of a Fuzzy Expert System for Electric Vehicle Speed Control

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Abstract

Fuzzy logic systems have demonstrated through numerous application areas, to be an effective procedure for hardware control problems. The basic concept of fuzzy controller is to formulate the control protocol of a human operator in a way that is tractable for microcomputer-based controller. The present paper describes the fuzzy expert system applied to control the speed of the autonomous electric vehicle (EV). The parameters of the speed to be followed by the vehicle during the driving operation at each moment are defined by a set of fuzzy rules and have two inputs and one output. The following two points are the main points of this control. The accelerator pedal position that governs the vehicle speed and the speed categories to be used. The experimental result obtained proves the merit of the control method as the controller accomplishes a satisfactory speed control of three categories.

Key Words: Electric vehicle, fuzzy expert system

1. Introduction

As an alternative to conventional control technique, fuzzy control is gaining increased interests, both in the academic world as well as in the industrial field. For those systems whose accurate mathematical models are not available or are difficult to formulate, fuzzy control can often provide a good solution by incorporating linguistic information from human expert and which is considered as an efficiency tool for hardware control. Due to its efficiency, many researchers have used it in the domain of robot speed control and vehicles speed control in the open literature [1, 2, 3]. In the proposed method of [4], the fuzzy approximator and sliding mode control scheme are considered. The fuzzy logic theory is applied to design the sliding mode controller then a simple adaptive law is used to approximate the unknown function f that defines the motor parameters via fuzzy logic system. However, its only drawback is that the controller does not provide a continuous performance of the motor, due to the considerable number of overshoot. In [5] the paper presents the speed and position control of a permanent magnet (PM) motor, with a sinusoidal flux distribution using fuzzy Logic. Two approaches were proposed and compared with each other; one was based on the voltage model of the motor and other was based on the current model. This control was very successfully in the open loop control of fuzzy control system. But unfortunately the starting procedure from standstill was very difficult under the proposed method, due to the use of both voltage and current for estimation of the rotor position by sensor drive. Therefore no information was available before starting. The other reason is that some incremental control inputs to the motor have been not determined from the fuzzy logic subset. Normally, to well control the speed of any system with a complex hardware such as for example, robot, EV as in our case etc., the choice of the parameters for decision making is the most important part. In this paper, we develop a fuzzy expert control system algorithm for electric vehicle speed, which allows the EV to adapt to three speed levels, based on the knowledge acquired from fuzzy rules base. This method provides, in addition to the well-known efficiency of the fuzzy system in control a continuous running performance of the vehicle.

2. Drive system of the electric vehicle

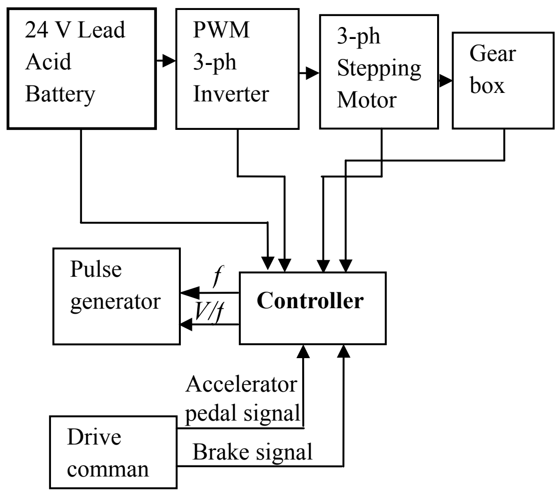

Fig.1 Block diagram of the drive system

The stepper motor use in the electric vehicle is a variable speed; multi-task three phase permanent magnet with 16 stator teeth per stack.. Its maximum output is 5.2 KW at 72V, 50 Hz. The rated slip is only 2 percent to minimize the motor copper loss and to behave stiffer characteristic. The rated iron loss is only 15 W; the reduction of iron is an important factor because of the high frequency harmonics induction by the PWM. The motor frame is made of aluminum alloy to minimize the weight and the frame size is 130. The drive system of the electric vehicle is shown in fig.1.The PWM inverter converts the battery pack dc voltage into a variable voltage, variable frequency ac in-sinusoidal voltage for supply of the three-phase stepping motor. The motor then drives the wheels through a variable ratio gearbox assembly. The power path is reversed in the case of regeneration i.e., the motor becomes an induction generator and the inverter rectifies the ac power into dc and recharges the battery. In the battery system, a range prediction device (RPD) has been connected to the battery. The device provides a real-time estimation of the remaining battery capability as well as residual range of the EV by means of compensated ampere-hour measurement method. The device takes care of the recharging case; it renews the value of remaining ampere-hours by adding the value of recharged ampere-hours, which are obtained by integrating the recharging current. The device also was proven to be essential for providing reliable information to the EV about the state of the charge of battery and the EV residual. The drive command, gear box, etc., are slaved under the controller. The controller gathers the information of voltage, current, brake signal, accelerator pedal position, motor speed and other signals; then the controller gives a proper control to the motor according to the designed control strategy.

3. Fuzzy Expert System Control

A fuzzy expert system as you know or you may read somewhere is a collection of membership functions and rules that uses to reason about data. Unlike conventional control methods, whose strongly relies on the accuracy of the analytic control model, which are mainly symbolic reasoning engines, fuzzy expert systems are oriented toward numerical processing. Like other control mechanisms, fuzzy control is also a feedback control system as presented in Fig. 2

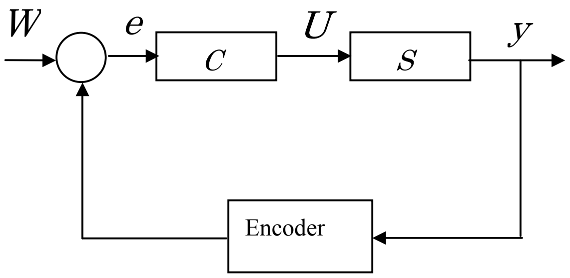

Fig.2 A feedback control system

The object to be controlled is called the *system*, denoted as *S*, which is the vehicle speed in our case. The controller denoted as *C*, is to generate a desired response of the output *y,* i.e., keeping the output *y* close to the reference point *W* (keeping *e* small). The output *U* of the controller *C*, is the control action in our application. In essence, the fuzzy control relies on a set of IF…..THEN inference rules which have the general form:

If x is A and B is y then z is C

Where, x is the input variable, and y is the output variable. The values A, B, C are expressed linguistically rather than numerical forms. Example of linguistics values is *very low, low, high, very high.* Using the concept of fuzzy set proposed by L.A Zadeh in 1965, these linguistics values can be translated into numerical values to perform calculations.

4. Control strategy using fuzzy expert system

In this section, our fuzzy expert system is described in detail. We first present the construction of its knowledge base, before describing the three main steps. The membership functions of the input variables, the membership functions of the output variables, and the creation of the rule base have been done

5. Construction of Knowledge Base

As mentioned before, the knowledge base rule in a fuzzy expert system consists of a data base and a rule base. The data base includes the membership functions of inputs and output, and the rule base contains the inference rules. Our fuzzy control system has two inputs and one output. The input variables are the speed level and the accelerator pedal position (current pedal position- desired pedal position) and throughout the rest of this paper we will note it AccPP. The accelerator pedal as for any road vehicle governs the motor speed and its position reflect the vehicle speed. The output variable is a vehicle speed that depends on the accelerator pedal position and we have used some error tolerance modulator to adjust the error speed. The input variable here is used to describe the level of the desired AccPP rate and to evaluate the perceived vehicle speed result, while the output variable is used to determine the required vehicle action. Next we need to create one set of membership functions for each input and output variable. The membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule premise. If a rule's premise has a nonzero degree of truth, then the rule is said to fire. Then we compute the truth value for the premise of each rule and applied to the conclusion part of each rule. This result is one fuzzy subset to be assigned to the output variable of the rule.

6. Membership functions of input variables

To define the membership function of the AccPP, we divided the range of the AccPP into five linguistic sets, Negative-Big (NB), Negative Small (NS), Zero (ZO), Positive Small (PS), and Positive Big (PB), and the membership functions are shown in figure 3. In the figure, the horizontal axis indicates the desired accelerator pedal position to be used, which is the difference between the the cuurent and expected position. The vertical axis denotes the membership value of a given AccPP. This value is used to indicate the degree to which a difference belongs to a linguistic set. For example, from the figure we can see that the degree of AccPP of 0.8 to PS is 0.6, and the degree of AccPP of 0.8 to ZO is 0.4. In this example a precise AccPP value is mapped to two linguistic sets. The objective of this research is to control the electric vehicle using on-board computer of which its operation will be done via mouse, therefore the choice of the speed to be used during each task is very important. So the speed level is divided into threecategories, "High (H)", "Medium (M)", and "Low (L)", and the membership functions are shown in figure 4. The value of 500 is the value of acceleration and deceleration time when accelerate or decelerate the motor and is set in millisecond.

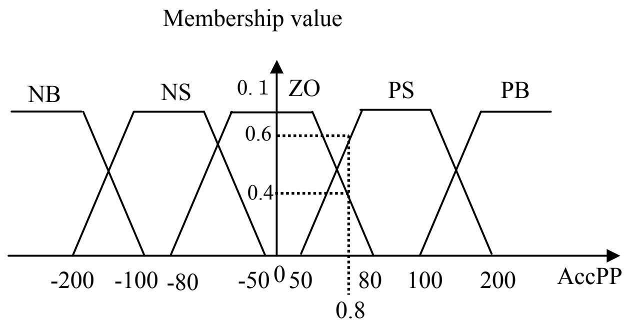

Fig.3 Membership function for input: Accelerator pedal position

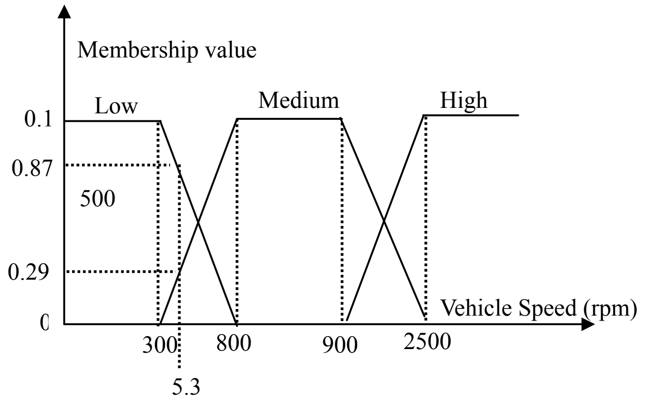

Fig.4 Membership function for input: Speed level

7. Membership functions of output variables

To define the membership function of the output variable, the value of the vehicle speed is categorized into fifteen linguistic sets, which are: LNB, LNS, LZO, LPS, LPB, MNB, MNS, MZO, MPS, MPB, HNB, HNS, HZO, HPS and HPB. We have used fifteen output linguistic sets because there are three levels of vehicle speed, L, M, H, and five levels of accelerator pedal position as follows, NB, NS, ZO, PS, PB. That results in fifteen different combination and we have used a singleton membership function to represent each of the linguistic set, as it is easy to perform defuzzification. Figure 5 shows five output singleton membership functions.

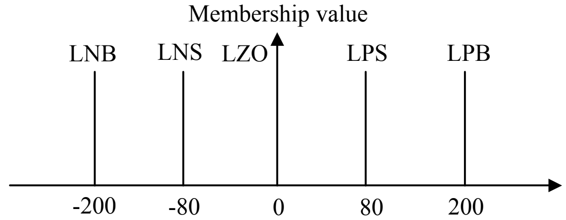

Fig.5 output singleton membership functions

To determine the singleton values for the linguistic sets, we need to perform the profiling runs. The singleton is an impulse function, and is defined by simply assigning a single numeric value to each sub-domain of the output. For example the "crisp "output of our control must be in the range between 0 and 2500 rpm and that allow us to define the speed as follows: Low speed = 300 rpm, medium speed = 900 rpm and high speed =1500 rpm. These values of the output singleton sets are used to get the exact desired speed in the linguistic sets for the three speed categories (Fig. 7, 8,9). If the values of the output singleton are not used it will be very difficult for the operator to know the speed to be selected for the vehicle navigation. Table 1 shows the parameters of the control. Column 1 shows that the speed level is categorized into three levels (H, M, L).. To obtain the singleton values for the output linguistic sets HNS, MNS, and LNS,we averaged the error tolerance modulation values for each of the three speed level categories (High, Medium, and Low). Other singleton values can be obtained in the same way.

8. Creation of rule base

In this step, we construct the fuzzy reasoning rules that governs the relations between the input and output variables. As our present system has two inputs and one output, the form of each rule is: " IF speed level is A and the accelerator pedal position is B, then the vehicle speed is C", where A is chosen from "L", "M", "H", B is chosen from "NB", "NS", "ZO", "PS", "PB" and C is a singleton output. A sample rule can be written as follows: If the speed level is L, and the accelerator pedal position is PB, then the vehicle speed is LPB. The following is the overall of the control base.

Table 1 Fuzzy reasoning rule base

	NB	NS	ZO	PS	PB
H	HNB	HNS	HZO	HPS	HPB
M	MNB	MNS	MZO	MPS	MPB
L	LNB	LNS	LZO	LPS	LPB

9. Experimental Results

The proposed algorithm was carried out using a three phase stepping motor MFA05KEV connected to an oriental rotary encoder E6C2-CWZ62 for recording data during the test operation whose specifications is given in Table 3. The output of the encoder is directly input into IN04, IN05 and IN06 of the CPU unit for using these three points as built-in high-speed counter.

Table 2 Motor parameter specifications

Rate output	0.59 kw (1H)
Max. Output	5.2 kw (3min)
Max. Revolution	6000 rpm

Power supply	72 DC V
Rate torque	98 kgf
Torque constant	0.532 kg fcm

The single-phase response speed is 5 KHz, and the two-phase response speed is 2.5 KHz. The counter value is within a range between 65,535 in incremental mode, which uses only phase A and 32,767 in decrement mode. The electrical ratings of the encoder are as follows: current consumption 80ms, maximum response frequency 100 KHz, insulation increases 100M Ω min and output phases A, B and Z (reversible). We tested the effectiveness of our fuzzy expert control system under two different scenarios. Firstly the brake signal that determines the desire braking torque is sent to the controller allowing the operator to manipulate the gear i.e., changing it from Neutral position to Drive or Reverse. The brake control part is not reported in this paper but it will be reported in the coming month. We have mentioned here in order to well explain how the algorithm has been tested. Secondly the accelerator pedal signal that determines the required vehicle speed is sent to the motor driver through the controller to drive the vehicle. The controller is required to control the motor speed very accurately to achieve and maintain speed from 0 to 2500 rpm.

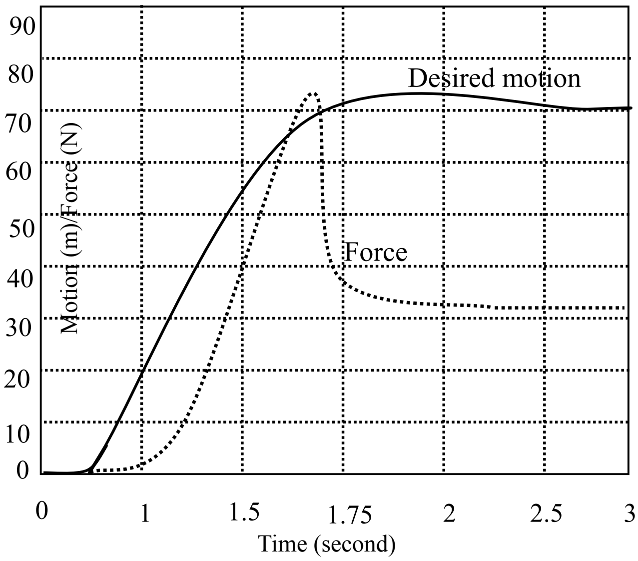

Fig.6 Motion and force trajectories

But during the test of our algorithm, we have limited the high speed to 1500 rpm in order to well control the vehicle. In the Fig.6 that shows the motion trajectory and force trajectory, the desire motion obtained consists of three segments. From the initial position of 0 m to approximately 75 m the vehicle moves progressively to the goal position in 3 minutes. The first segment from 0 m to about 67 m is the approaching phase having the fastest motion. In this phase the fuzzy reasoning created a rule base that selected the AccPP for medium speed in order to avoid producing a large impact force, which might results in loss of control. During this phase, the desired interaction force is increased from 0 to a value of 75 N at 1.65 second and decreased from 75 N to a value of 33 N at 2.3 s. The decrease of the force indicates that the vehicle is approaching to its target position, so the fuzzy reasoning again create the rule base that start to decrease the speed to a low speed before falling to zero. During the acceleration, the equilibrium position is maintained between 12.5 and 15.5 steps ahead of rotor position, and during the deceleration the equilibrium position is also maintained between 12.5 and 15.5 steps behind of rotor position, and the angle between the stator and rotor flux was kept close to 90°. The test practice has been done on the road in front of the department of electrical and electronic engineering till the venture business laboratory (VBL) that is built at the end of this road. The distance between the two buildings is approximately 150 m.

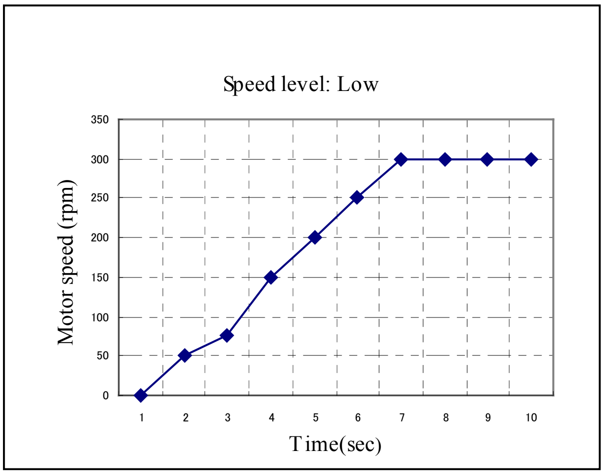

Fig.7 Low speed

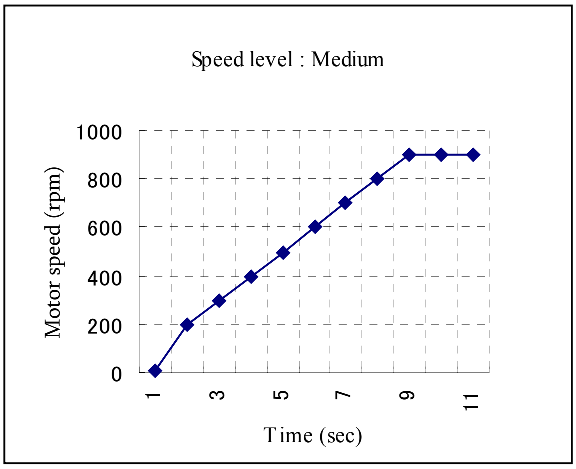

Fig.8 Medium speed

Fig.7, Fig.8 and Fig.9 show the three speed levels variation under the fuzzy expert controller and that agree with the membership function for input (speed level) shown in Fig.4 during the software design. Fig.7 and Fig.8 are the low and medium speed of which the motor increase gradually then stabilize at the corresponding limited speed level at 7 and 9 second respectively. At this stage, the vehicle keep moving smoothly without changing the speed rate till we released the acceleration pedal in order to bring the vehicle to a complete stop. When we released the acceleration pedal, the fuzzy controller through the inference rules sends a signal to the pedal. This signal is passed particularly through a sensor, which release the force applied previously to the accelerator pedal. Hence pedal release.

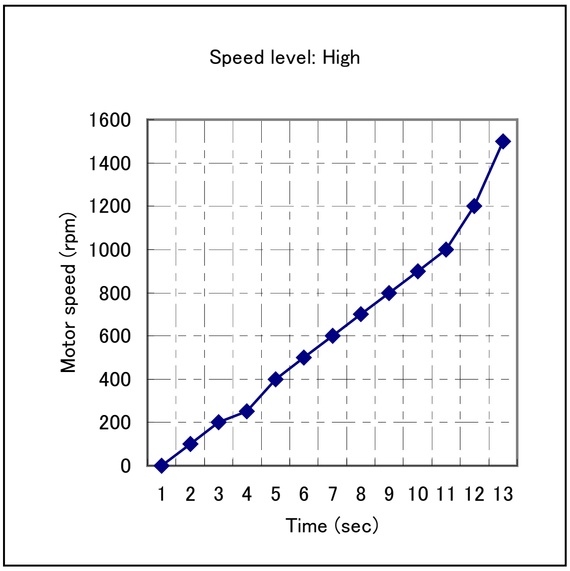

Fig.9 High speed level

In Fig.9, when the acceleration pedal signal is sent to the motor driver by the controller, again the motor starts and very quickly reaches 1000 rpm and gains its maximum peak speed of approximately 1500 rpm at around 13 Seconds, which is followed by the increase of the interaction force. The advantage of our technique is that, during the running test, if the hardware has some technical problems the controller notified the operator about the problem and stop the motor 2 second after the notification.

7. Conclusion

We have presented the EV motor speed control using fuzzy expert controller. Our algorithm allows the operator to control the vehicle without the need to have extensive knowledge about the data. It provides a continuous running performance of the vehicle, and can automatically select the desired speed level, when the speed is about to reach a certain level that can produce a large impact force, and that might results in loss of control. Since we have started to test the running perfornace of the vehice under the fuzzy expert, so far there was no overshoot and noise. In this paper the construction of the knowledge base of the fuzzy expert controlller and the following three main steps, fuzzyfication, fuzzy reasoning and defuzzification have been described.

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