Design of an Idle Stop and Go System using Fuzzy Control

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***Abstract*—The Idle Stop and Go(ISG) system is a technology proposed as a solution for improving fuel efficiency and reducing exhaust gas in the traffic jam. A typical ISG system turns on or off the engine automatically depending on whether the host vehicle starts or stops. This type system can make fuel efficiency more badly because of frequent engine on/off operation. In this paper, the new Idle Stop and Go system is proposed using the fuzzy control algorithm. The system uses the information reflected the states of driving and traffic jam. It is more flexible to control the engine on-off along traffic conditions. The simulation is carried on to verify the performance of proposed system using actual driving data. It is compared with other systems designed by simple rule-based algorithm and another fuzzy control based system. It shows that the performance of the proposed system is superior than others.**

***Index Terms*—Automotive Control, Fuzzy Control, Intelligent Knowledge-based Systems, Idle Stop and Go, Rule-based systems.**

I. Introduction

As the oil price has been increased recently and air pollution has been getting worse, energy efficiency and environmental problem have become the most important issues. Also, the traffic jam and exhaust gas have become very serious problems as the number of vehicles increases more and more. Especially, unnecessary fuel consumption on driving is a problem to be improved necessarily. DoE(U.S Department of Energy) and EPA(U.S Environmental Protection Agency) announced that only 12.6% of consumed fuel on driving is used to drive the vehicle and the rest is wasted unnecessarily. In here, 17.2% of one is wasted by engine idling, which is mostly caused by the traffic jam.[1] To solve these problems, many automotive companies are trying to produce technologies that are both energy efficient and eco-friendly. The Idle Stop and Go(ISG) system is a technology proposed as a solution for improving fuel efficiency and reducing exhaust gas in the traffic jam. It is very useful in the traffic jam because it keeps the state of engine off for idling time.

A typical ISG system turns on or off the engine automatically depending on whether the vehicle starts or stops. Mostly the hybrid cars are equipped with ISG system. It reduces unnecessary fuel consumption using the electrical motor engine for idling time additionally. However, it is difficult to be applied to pure gasoline/diesel engine vehicle directly. In case of the internal combustion engine, frequent engine on/off operation can make fuel efficiency more badly. For example, a driver whose a driving style such as a quick start or sudden stop makes ISG system operation more frequently. These situations are occurred because the system operates along only a driver behavior or the host vehicle information. In case that more information such as traffic conditions or the motion of the frontal vehicle are used, the performance of ISG system can be improved.

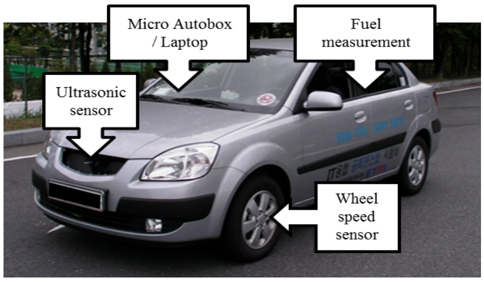

Fig. 1. Test Vehicle

In this paper, the new Idle Stop and Go system is proposed. The proposed system uses the ultrasonic sensor, which is equipped on the center of the front grill of the vehicle. It provides the distance information between the host vehicle and the frontal vehicle. Also, wheel speed sensors are used to obtain the velocity information of the host vehicle. Through these sensors, the system uses not only the state information of the host vehicle but also the state information of the frontal vehicle. These are reflected by driving or traffic jam conditions. Therefore, the system operation becomes more flexible under a variety of driving conditions than the existing one. To design the system, the fuzzy control algorithm is used because simple rule-based control algorithm cannot reflect several traffic conditions.

The organization of this paper is as follows. Section 2 discusses the analysis of the experiment data. Section 3 describes the proposed idle stop and go system. The performance and accuracy of the proposed system are demonstrated by simulation results using experimental data in Section 4.

II. Analysis of Experiment Data

The experiments have carried on to measure fuel consumption and engine idling time on driving in traffic jam region. The test vehicle and equipped sensors are shown in Fig.1.

TABLE I
FUEL CONSUMPTION FOR ENGINE IDLING TIME

	Case1	Case2
Time(sec)	Fuel Consumption(ml)	
60	12.74	13.87
90	Engine Off	
150	25.80	
180	Engine Off	40.49
240	38.95	53.63
270	Engine Off	
330	52.13	
360	Engine Off	
420	65.27	92.20
450	Engine Off	
510	78.33	
540	Engine Off	
600	91.30	
Total	10 min	7 min

TABLE II
DRIVING DATA

Driving Distance	9.8km	
Driving Time	66 min	
Idling Time	24 min	(36.4%)
Idling Number	46 times	
Fuel consumption	1624.36ml	

A. Fuel Consumption for Engine Idling Time

The experiments have been performed as follows to measure fuel consumption for engine idling time and the results are shown in Table I.[2]

- **Case1:**
  The engine idling time keeps for 10 minutes. Six times of engine on/off operations are executed, where the engine off-state keeps for 30 seconds.
- **Case2:**
  The engine idling time keeps for 7 minutes without engine on/off operations.

The difference between Case1 and Case2 in fuel consumption has 0.90ml. It means that engine idling time for 30 seconds consumes average 0.15ml. In case that this situation is occurred frequently, more fuel is consumed unnecessarily.

B. Engine Idling Time on Driving

The another experiment has been performed to measure the engine idling time on driving in the heavy traffic jam region. The result of the experiment is shown in Table II. In case that fuel consumption on idling condition is 13.87ml/min, unnecessary fuel consumption is computed 332.88ml. In order words, 20.5% of fuel consumption can be saved by ISG system if it keeps engine off-state for idling time. Therefore, it shows that the ISG system is very useful to prevent unnecessary fuel consumption from engine idling.

III. IDLE STOP AND GO SYSTEM

The objective of ISG system is to prevent unnecessary fuel consumption caused by engine idling on driving. The system must keep engine off-state as possible as long. At the same time, the traffic flow must not be disturbed by engine on/off operation of ISG system. In case that the engine stop time is too long, it can make traffic flow more badly and a driver also can feel uncomfortable. Therefore, the key issue is to control the engine on/off operation along the traffic conditions properly. In other words, it has to execute engine-off operation more quickly and engine-on operation more slowly.

A. Simple Rule-Based ISG System

The ISG system is usually equipped on the hybrid car. In this paper, the simple rule-based ISG system is designed to compare with the performance of the proposed one. The rules are as follows and they are used in the existing hybrid car.

- **Velocity** (Host vehicle)
  If the velocity is faster than 1.67m/s, then engine must be turn on.
  Otherwise, engine must be turn off.
- **Distance** (between the host and frontal vehicle)
  If the distance is further than 2m, then engine must be turn on.
  Otherwise, engine must be turn off.

This system is very useful in the hybrid car because it uses the electrical motor engine for engine idling time. However, in case of the internal combustion engine vehicles such as gasoline and diesel engine, these rules make fuel efficiency more badly. The system can occur frequent operation unnecessarily because it uses only the velocity and distance information to determine whether the engine turns on or off. These information does not reflect dynamic factors such as the traffic flow and a driving style of drivers. In case that the driver of the host or the frontal vehicle has a dynamic driving style such as a quick start or sudden stop, this situation is caused more easily. Also, in case that the vehicles on driving stop and go repetitively, the system can make unnecessary operation frequently.

B. Fuzzy Control-Based ISG System

The new ISG system is proposed to improve the performance of the simple rule-based one.

The system is designed by fuzzy control algorithm. It is a proper control scheme to represent the characteristics of the ISG system because it is difficult to modeling the relation between two vehicles and system operation must be similar to the driver's driving style for comfort of the driver. The block diagram of the proposed system is shown in Fig. 2.

1) **Rules***:* The proposed system uses four input variables such as relative distance, host and frontal vehicle speed and frontal vehicle acceleration and one output variable such as engine on/off command. The factors to determine engine on/off command are as follows.

- **Engine On Command**
  Relative Distance($x(t)$) + Predictive Distance($x_d(t)$),
  F.V. Speed($v_f(t)$), F.V. Acceleration($a_f(t)$)
- **Engine Off Command**
  Relative Distance($x(t)$),
  H.V. Speed($v_h(t)$), F.V. Acceleration($a_f(t)$)

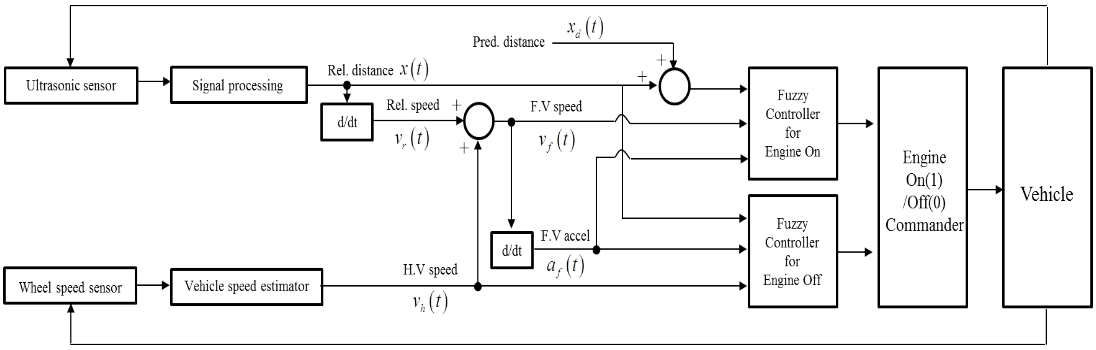

Fig. 2. Blockdiagram for ISG

TABLE III
LINGUISTIC VARIABLES FOR ENGINE ON

Distance	VC	CL	MD	FR	VF
$[m]$	1.0	1.5	2.0	2.5	3.0
FV Speed	VS	SL	MD	FS	VF
$[m/s]$	0.5	1.0	1.5	2.0	2.5
FV Accel	NL	ZR	PL	PM	PH
$[m/s^2]$	-0.2	0	0.2	0.4	0.6
Engine	MF	MB	MN	PN	ON
Center	0	0.25	0.5	0.75	1.0

TABLE IV
LINGUISTIC VARIABLES FOR ENGINE OFF

Distance	VC	CL	MD	FR	VF
$[m]$	1.0	1.5	2.0	2.5	3.0
HV Speed	VS	SL	MD	FS	VF
$[m/s]$	0.5	1.0	1.5	2.0	2.5
FV Accel	NH	NM	NL	ZR	PL
$[m/s^2]$	-0.6	-0.4	-0.2	0.0	0.2
Engine	OF	PF	MF	MB	MN
Center	0	0.25	0.5	0.75	1.0

HV:Host Vehicle, FV:Frontal Vehicle
VC:Very Close, CL:Close, MD:Medium, FR:Far, VF:Very Far
VS:Very Slow, SL:Slow, MD:Medium, FS:Fast, VF:Very Fast
NH/NM/NL:Negative High/Medium/Low, ZR:Zero
PH/PM/PL:Postive High/Medium/Low
ON/PN/MN: On/Probable/Maybe On, MB:Maybe
OF/PF/MF: Off/Probable/Maybe Off

The predictive distance, x_d is the distance for time delay to start up the engine. It is obtained using equation (1).

$$x_d(t) = t_d \cdot v_f(t) \quad (1)$$

where, t_d is the time delay to start up the engine, v_f speed of the frontal vehicle.
In case that the factors to determine the engine on or off are same, the system becomes simple.[3] However, it does not reflect time delay to start up the engine when it must be turned on from engine-off state. And it can occurs the erroneous command such that when the host vehicle is going/stopping, execute engine on/off operation. Therefore, it is better that the factors to determine engine on/off are discriminated such as proposed system.

The used linguistic values are shown in Table III and IV. There exists 125 rules for each engine on/off command. The rules are created by expert knowledge. The examples of used rule are as follows.

- **Engine On**
  If (Distance is MD)and (FVSpeed is MD) and (FVAccel is PL), then (Engin is PM).

- **Engine Off**
  If (Distance is VC)and (HVSpeed is VS) and (FVAccel is NH), then (Engin is OF).

2) **Membership Functions***:* The type of the used membership functions are triangular. This function is easy to implement for automotive control unit because it is the simplest membership function and it has small computation. Also, it is proper to represent the characteristics of the used input and output variables for ISG system. In case of using the gaussian function, it is difficult to implement on real-time system because of large computation.

3) **Fuzzy Inference System***:* The fuzzy inference system of the mamdani-type is used to formulate the mapping from a given input to an output. This method is proper to this system because it is known as intuitive and well suited to human input.

4) **Defuzzification***:* The centroid defuzzification method is used to determine the output of the fuzzy inference system. This method returns the center of area under the composed output membership functions.

IV. SIMULATION

The simulation has been carried on to verify the performance of the proposed ISG system. A variety of the experimental driving data mentioned in Section 2 have been used to perform the simulation. The proposed ISG system is compared with the simple rule-based ISG system. And another fuzzy control-based ISG system is compared with the proposed one.[3] It shows the difference along using different factors and same factors to determine whether engine is on or off. It uses same input variables such as relative distance, the frontal vehicle speed and acceleration to control engine on/off. Two cases of a variety of situations are shown in this paper. In legend of all figures, 'Smpl rule' means simple rule-based ISG system, 'Proposed' the proposed ISG system, and

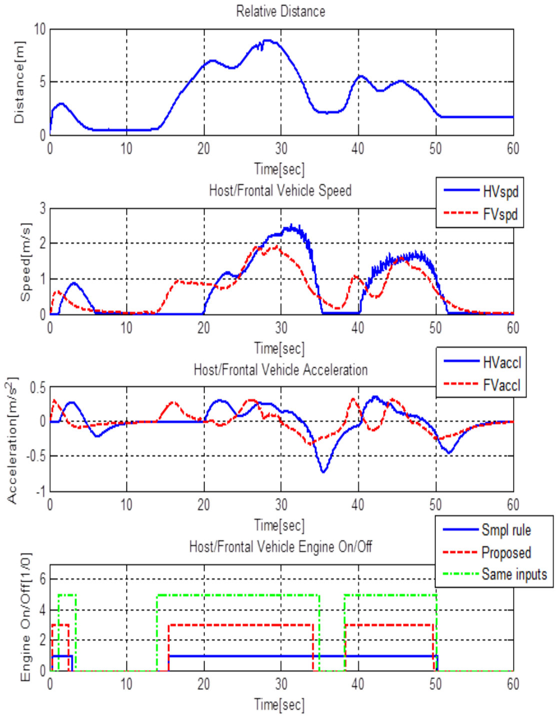

Fig. 3. Simulation Results: Case1

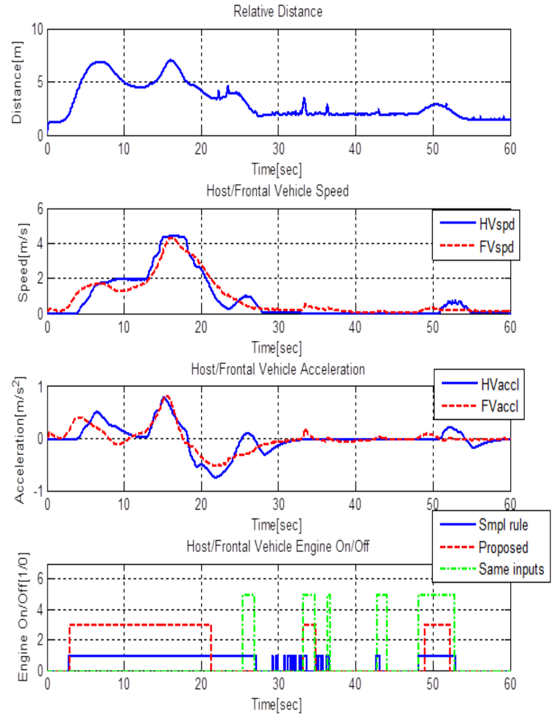

Fig. 4. Simulation Results: Case2

TABLE V
ENGINE OFF TIME ON DRIVING

Commander	Case1	Case2
By driver[sec]	26.565	32.081
Smpl rule[sec]	12.539	-
Proposed[sec]	27.658	36.871
Same inputs[sec]	23.209	-

'Same inputs' another fuzzy control-based ISG system using same inputs to determine whether engine is on or off. In 4th sub-figure of each figure, high value(1,3,5) means engine-on command and zero value engine-off command.

It shows that the proposed ISG system is superior than others. Case1 shows that the proposed ISG system makes engine more quickly turn-off and more slowly turn-on than others. Case2 shows that simple rule-based system and the system using same inputs can make engine on/off operation frequently by small variation of distance or speed, whereas the proposed system is operating properly. Table V represents that the proposed ISG system has the longest idling stop time. Therefore, the proposed ISG system shows the best performance to prevent unnecessary fuel consumption more efficiently.

V. CONCLUSION

This paper has proposed the new ISG system which is considered time delay to start up the engine. It uses different variables to start up the engine or turn off the engine. The simulation results shows that it operates more flexibly when it is compared with other systems. The performance of the proposed system has been verified in a variety of driving situations. In this paper, the simulation results of only two cases are shown. It shows that the proposed system has high performance than others. It keeps the longest idling stop time and it does not disturb the traffic flow. However, the system must be optimized to be more simply because the system has many rules and large computation. Also, the road slope must be considered. In case that the vehicle is driving on slope, a fatal defect can be occurred. The information provided by sensors and signals such as a inclinometer, an accelerometer, gear position and a brake signal can improve the performance of the system highly.

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