UACEE International Journal of Advancements in Electronics and Electrical Engineering
Volume 1: Issue 1

Advanced Optimized Cooling System for Air-cooled and Coolant-cooled IC Engines using Fuzzy Logic

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***Abstract*— Now a days it is very important to increase the efficiency of Internal Combustion (IC) engines due to many factors such as fuel economy, fuel crisis and ultimately to increase the output. This paper proposes an effective cooling system in IC engine. During the process of combustion a large portion of heat is transferred to various engine components and the engine may be damaged unless the excess heat is carried away and these parts are adequately cooled. Adequate cooling is then a fundamental problem associated with internal combustion engines. In the present paper, efforts have been made to highlight the concept of an intelligent cooling system. The intelligent cooling concept is proposed to overcome the shortcomings arising when applying conventional cooling methods. The basic principle behind this is to control the flow rate of coolant and speed of thermo fan by regulating the valve controlled using fuzzy PID logic. The design was modeled and simulated using the MATLAB/Simulink platform. The intelligent cooling system i.e. implementation of fuzzy-PID logic will overcome the drawbacks associated in the present technique.**

***Keywords*— IC engine, fuzzy logic, Fuzzy-PID controller, Cooling system**

I. INTRODUCTION

Need of increase the efficiency of IC engines is essential due to many factors such as fuel economy, fuel crisis and ultimately to increase the output. For this purpose optimized cooling systems in IC engine is required. At present, the traditional control of temperature of coolant can't satisfy the needs of its dynamic characters. The problems with traditional cooling system and dynamic characters are (1) if the coolant level is less than required, the engine characteristics are affected.(2) If the coolant flow is not sufficient or speed of thermo fan is not sufficient than heat production is very high i.e. cooling process is not exact, the engine characteristics are affected. (3) If the coolant flow and thermo fan speed is more than required then it is also loss of power. It is difficult to obtain the ideal control effects .But practice prove that because fuzzy control needn't build mathematical model of controlled objects, it has benign robustness and non linear control characteristics and can take more effective control of time varying, nonlinear and complex controlled objects. However, the conventional two dimensional fuzzy controller is lack of integral action and cannot eliminate the system's steady-state error alone, control accuracy being not high, which limits its use in those which require a higher steady-state accuracy process control [1]. Therefore, the literature [3] presents a fuzzy controller with a correction function and the literature [2] suggests increasing the role of intelligent integration algorithm to eliminate the steady-state error. This study proposed a new fuzzy controller with intelligent integration on the basis of literature [2] and literature [3] and, make simulation experiments through MATLAB. Simulation results show that the intelligent control system has good quality and strong adaptive ability, and control method is simple, reliable and easy to implement, achieving a satisfactory control effect in the Advanced Optimized Cooling of coolant.

A. *Purpose of fuzzy control*

The purpose of control is to influence the behavior of a process by changing the value of the appropriate variables of that system according to a set of rules that models how the system operates. Control theory uses a mathematical model to establish a relationship that transforms the observed state (controlled variable, measured variable) toward the desired state (manipulated variable) to alter the future state of the process through the final element.

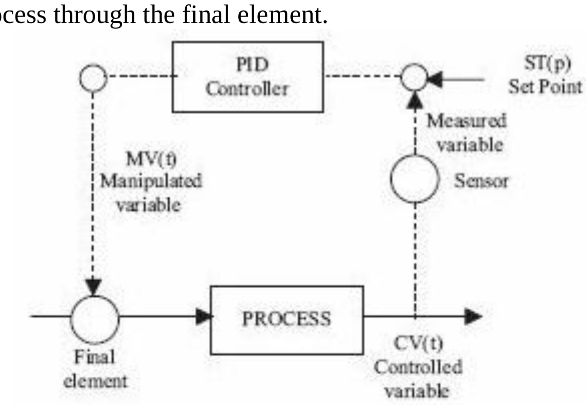

Figure 1. Overview schematic of a classic control loop

The most common control model is the PID controller. The PID controller takes the output of the system (observed state) and compares it with the required set point (reference). It adjusts through the final element the input value of the system (desired state) according to the following equation.

$$MV(t) = K_c\left(E(t) + \frac{1}{T_i}\int_0^t E(t')dt' + T_d\frac{dE(t)}{dt} \right) + I \quad (1)$$

Where E(t) is the error term between the controlled variable CV(t) and the set point SP(t), K, Ti, and Td are constants, and MV(t) the manipulated variable.

The major drawback of this system is that it normally assumes that the process is led by linear behavior or at least behaves in some way that is more likely to be considered as a monotonic function. Moreover, as the complexity of the process increases, it is obviously more difficult to draw up a coherent model of the process function. Moreover, as the complexity of the process increases, it is obviously more difficult to draw up a coherent model of the process.

Fuzzy logic control may partially replace the role of the mathematical model. It replaces it with another built from a number of rules that describe only a specific and more often a small section of the whole process.

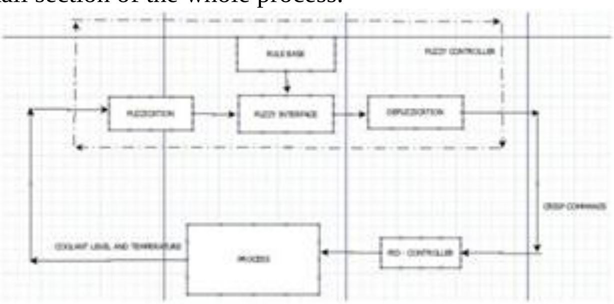

Figure 2. Block diagram of the proposed system

II. THE STRUCTURE AND CONTROL RULES OF INTELLIGENT FUZZY CONTROLLER

- To check the quantity of coolant in engine there is small tank in which coolant is filled. That coolant is flow in the engine through the pipes with the help of motor. This motor can be controlled by fuzzy-PID controller which is already discussed. To measure the quantity of the coolant we used a ultrasonic level detector which can measure the range of level of coolant dynamically.
- If the level of coolant is low then engine should be stop otherwise engine may be burnt.
- To measure the temperature of engine dynamically a temperature detector is used, it can be thermocouple.
- If the temperature is extremely high then engine should be stop otherwise engine may be burnt.
- Thermo fan and Coolant flow is used to keep cool the engine, the optimization is done so that thermo fan speed is modified according to temperature and running status of engine.

In recent years, fuzzy logic control has really proved its potential in various industrial automation applications. The control strategy is based on proven concepts that merge the fuzzy logic system and traditional automation techniques such as Programmable Logic Controller (PLC). The focus of the optimization strategy realized by both fuzzy logic control systems is to ensure an optimal operation of the application. Analysis of the online behavior of the coolant level and temperature is necessary in order to find the efficient cooling potentials.

A. *Industrial Automation*

In industrial automation the PLC is used not only for sequential operation but also for the regulation loops with the PID controllers. When the PID controllers work properly the process under control is in a stable condition but they cannot assure stable conditions in the following cases:

- the presence of strong disturbances (non-linearity)
- time-varying parameters of the process
- presence of dead times.

Even though most technical processes are non-linear and PID controllers are a linear model, this works relatively well. This is because within a continuous process, the behavior of the process can be well-approximated linearly near the operation point. The main reason for this is that a PID controller assumes the process to behave in a linear way. This relative simplification can be made in a stable condition but when strong disturbances occur, the process operation can be pushed far away from the set operating point. In this case the usual linear assumption does not work anymore. The same things happen when the process changes its parameters over time. In these cases the extension or the partial replacement of PID controllers with fuzzy logic has been shown to be more feasible than using sophisticated state controllers or even adaptive or predictive controllers [4]-[13].

B. *Control rules*

1. If (level is full) and (temp is cool) then (fan_speed is off) (coolant_flow is slow) (engine_status is on).
2. If (level is full) and (temp is avg) then (fan_speed is slow) (coolant_flow is fast) (engine_status is on).
3. If (level is full) and (temp is hot) then (fan_speed is fast) (coolant_flow is v_fast) (engine_status is on).
4. If (level is full) and (temp is E_hot) then (fan_speed is v_fast) (coolant_flow is v_fast) (engine_status is off).
5. If (level is empty) and (temp is cool) then (fan_speed is off) (coolant_flow is slow) (engine_status is off).
6. If (level is empty) and (temp is avg) then (fan_speed is off) (coolant_flow is slow) (engine_status is off).
7. If (level is empty) and (temp is hot) then (fan_speed is off) (coolant_flow is slow) (engine_status is off).
8. If (level is empty) and (temp is E_hot) then (fan_speed is off) (coolant_flow is slow) (engine_status is off).

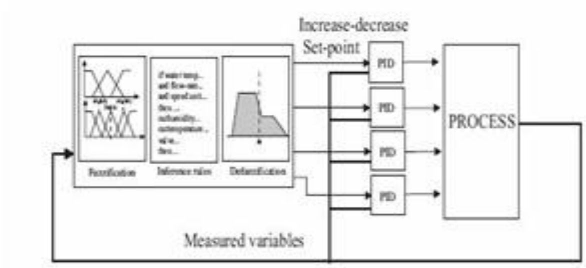

Figure 3. Structure of the system

III. DESIGN OF FUZZY CONTROLLER

Fuzzy mathematics forms a branch of mathematics related to fuzzy set theory and fuzzy logic. It started in 1965 after the publication of Lotfi Asker Zadeh's seminal work Fuzzy sets.[1] A fuzzy subset A of a set X is a function A:X→L, where L is the interval {0,1}. This function is also called a membership function. A membership function is a generalization of a characteristic function or an indicator function of a subset defined for L = {0,1}. More generally, one can use a complete lattice L in a definition of a fuzzy subset A [4]-[13].

Figure 4. Fuzzy FIS

A. *Fuzzy set definition*

In order to keep things simple, two basic membership functions are used: a triangle membership function and a trapezoidal membership function. The trapezoidal membership is used in input because engine is worked in predefined ranges and The triangle membership function is used in output so that PID controlled at certain points. There are two measured quantity which used as a inputs of fuzzy system.

1) Fuzzy control for level of coolant

It is measured by ultrasonic level detector. The range of level detector is divided into certain two parts named as full and empty.

Table 1. Range for membership function of coolant level

Fuzzy set	full	empty
Range	0.0 - 0.8	0.6 - 1.0

Figure 5. Membership function for coolant level

2) Fuzzy control for level of coolant

It is measured by thermo-couple. The range of thermo-couple is divided into certain for parts named as cool, avg, hot and E_hot.

Table 2. Range for membership function of temperature

Fuzzy set	cool	Avg	Hot	E-hot
Range	0.0 – 0.3	0.3 – 0.6	0.4 – 0.9	0.9 – 1.0

Figure 6. Membership function for temperature

3) Fuzzy control for level for fan speed.

The speed of thermo fan is divided into four parts off, slow, fast and V_fast. According to rules of fuzzy logic speed of fan is modified dynamically.

Table 3. Range for membership function of fan speed

Fuzzy set	off	slow	fast	V-fast
Range	0.0 – 0.2	0.1 – 0.5	0.4 – 0.8	0.7 – 1.0

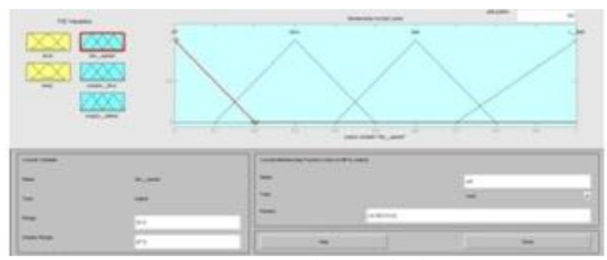

Figure 7. Membership function for fan speed

4) Fuzzy control for coolant flow speed

The speed of coolant is divided into four parts off, slow, fast and V_fast. According to rules of fuzzy logic speed of fan is modified dynamically.

Table 2. Range for membership function of fan speed

Fuzzy set	off	slow	fast	V-fast
Range	0.0 – 0.2	0.1 – 0.5	0.4 – 0.8	0.7 – 1.0

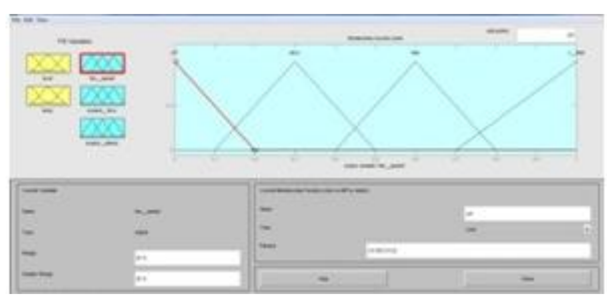

Figure 8. Membership function for coolant flow speed

5) Fuzzy control for engine status

According to rules the running status of engine may be changed between ON and OFF.

Table 2. Range for membership function of fan speed

Fuzzy set	on	off
Range	0.0 – 0.8	0.6 – 1.0

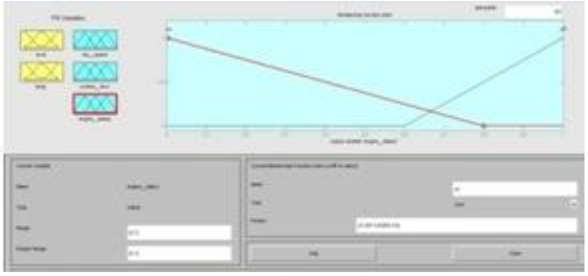
Figure 9. Membership function for engine status


Figure 10. Rule base

B. *Defuzzification*

1) Defuzzification function for fan speed

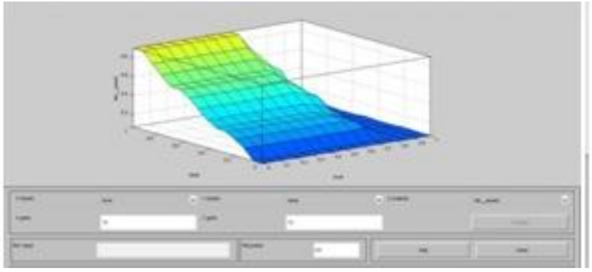
Figure 11. Surface rule for thermo fan speed

2) Defuzzification function for coolant flow speed

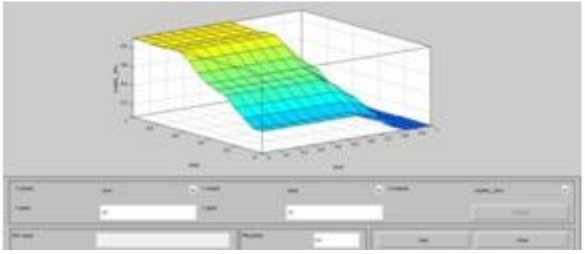
Figure 12. Surface rule for coolant flow speed

3) Defuzzification function for status of engine

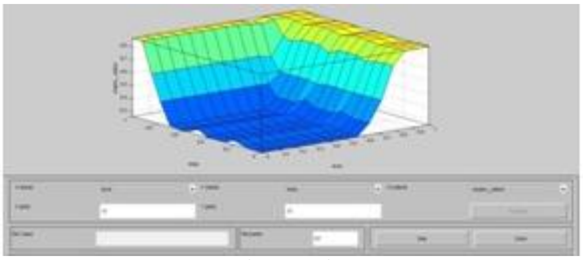
Figure 13. Surface rule for engine status

IV. RESULT AND CONCLUSION

After the testing of system using fuzzy logic algorithm was tested and it was found that the proposed cooling technique has efficiently incorporate fuzzy logic algorithm in optimization of power, wastage of cooling system in engine. In air-cooled and coolant-cooled system is used together for better cooling and both are controlled dynamically. The thermo fan and coolant flow is variables which can be changed according the heat generate in engine. The fuzzy logic system is self controlled and optimization is efficient.

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