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Intelligent energy management control of vehicle air conditioning system coupled with engine

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HIGHLIGHTS

► AC interacts: vehicle, environment, driver components, and the interrelationships between them.
► Intelligent AC algorithm which uses three integrated fuzzes controllers to improve fuel consumption.
► Intelligent AC controller is a more efficiently since it integrated with the engine operation.

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ABSTRACT

Vehicle Air Conditioning (AC) systems consist of an engine powered compressor activated by an electrical clutch. The AC system imposes an extra load to the vehicle's engine increasing the vehicle fuel consumption and emissions. Energy management control of the vehicle air conditioning is a nonlinear dynamic system, influenced by uncertain disturbances. In addition, the vehicle energy management control system interacts with different complex systems, such as engine, air conditioning system, environment, and driver, to deliver fuel consumption improvements. In this paper, we describe the energy management control of vehicle AC system coupled with vehicle engine through an intelligent control design. The Intelligent Energy Management Control (IEMC) system presented in this paper includes an intelligent algorithm which uses five exterior units and three integrated fuzzy controllers to produce desirable internal temperature and air quality, improved fuel consumption, low emission, and smooth driving. The three fuzzy controllers include: (i) a fuzzy cruise controller to adapt vehicle cruise speed via prediction of the road ahead using a Look-Ahead system, (ii) a fuzzy air conditioning controller to produce desirable temperature and air quality inside vehicle cabin room via a road information system, and (iii) a fuzzy engine controller to generate the required engine torque to move the vehicle smoothly on the road. We optimised the integrated operation of the air conditioning and the engine under various driving patterns and performed three simulations. Results show that the proposed IEMC system developed based on Fuzzy Air Conditioning Controller with Look-Ahead (FAC-LA) method is a more efficient controller for vehicle air conditioning system than the previously developed Coordinated Energy Management Systems (CEMS).

1. Introduction

A classical Air Conditioning (AC) system consists of an engine powered compressor activated by an electrical clutch. AC imposes an extra load onto a vehicle's engine by increasing its fuel consumption, which leads to greater emissions. To the best of our knowledge, there has been no comprehensive study to quantify the effect of vehicle air conditioning system coupled with engine, under various operating and driving conditions. Therefore, this study investigates what operating conditions contribute to a greater fuel consumption accounting for the air conditioning system. Lambert et al. [1] reported that the mechanical compressor can increase fuel consumption by up to 12–17 percent for subcompact to mid-size cars. Also they showed that optimising the energy consumption of the AC system of a vehicle, would help improve the overall energy efficiency of the vehicle.

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According to ASHRAE [2], general considerations for air conditioning design should include such factors as cabin indoor air quality and thermal comfort, ambient temperatures and humidity, the operational environment of components, vehicle and engine parameters, electrical power consumption, cooling capacity, the number of occupants, insulation, solar effect, and vehicle usage profile. AC stability and control are concepts concerned with the cabin indoor air quality and thermal comfort characteristics of an AC system. Therefore, inherent in the system are its dynamics and complexity. The control of ventilation and AC system is a difficult problem, because even the simplest AC models are multi-variable and nonlinear [3]. Finally, these systems are influenced by multiple uncertain disturbances.

A number of methods have been developed to improve the energy efficiency associated with operating the vehicle AC system individually. Several methods have been developed to control AC in vehicles, such as PID [4] and Fuzzy [5–12] controller. Khayyam et al. [4] presented a coordinated energy management system to reduce the energy consumption of a vehicle's air conditioning system while maintaining the thermal comfort. The system coordinates and manages the operation of evaporator, blower, and fresh air and recirculation gates to provide the desired comfort temperature and indoor air quality under various ambient and vehicle conditions. The Coordinated Energy Management System (CEMS) was developed using a PID controller to control AC, and three stepper controllers to adjust gates and set points. In the PID controller, a neural network tuner was employed to automatically adjust the parameters of the controller. They illustrated that, it is extremely difficult to control the nonlinear and complex AC system using a classical PID controller. Fuzzy logic controllers, in contrast have the capability to address the inherent nonlinearity of AC and engine components, which allow the control to be expressed in heuristic terms that an occupant would use in describing the level of comfort [5]. Durovic et al. [13] considered the vehicle air conditioning system as a very complex multiple-input multiple-output system. They presented an algorithm on how to design a simulator to generate enough data necessary to train a neural network. The architecture and the training algorithm for the neural network that control the air-conditioning actuators were also given. As reported in the literature in [7–11], fuzzy logic has been a popular method for controlling the operation of AC. It has been shown that fuzzy method requires fewer computations and achieves better performance compared to a nonlinear control scheme [14,15]. The latest fuzzy approach that alleviates fuel consumption has been examined by Khayyam et al. [12]. They presented a method for designing a fuzzy logic-based nonlinear controller for a vehicle air conditioning system equipped with a Look-Ahead system. They also provided the following new energy management system features: a prediction of road power demand by using the look-ahead control of the vehicle, an intelligent control strategy to manage the operation of the AC, the blower, and the gates, in order to provide the optimum comfort temperature considering in-cabin air quality, while minimizing energy consumption. The results of fuzzy air conditioning control using the look-Ahead system demonstrated that it is capable of saving 12% and 3% more energy compared to CEMS and ordinary fuzzy air conditioning system, respectively. The aim of this study is to optimise the integration of engine and the AC system under various driving patterns. But nonlinear behaviour arises when the AC system is coupled with the engine. The main dynamic sources can be cited as (1) driver behaviour (2) environmental conditions and (3) vehicle operation. Various nonlinear problems turned up when we connect these sources [16]. One appropriate tool to tackle complex and nonlinear systems that are subject to regular disturbances is the artificial intelligence. Soft computing is a key methodology for designing intelligent control systems. Soft computing employs human expert knowledge to

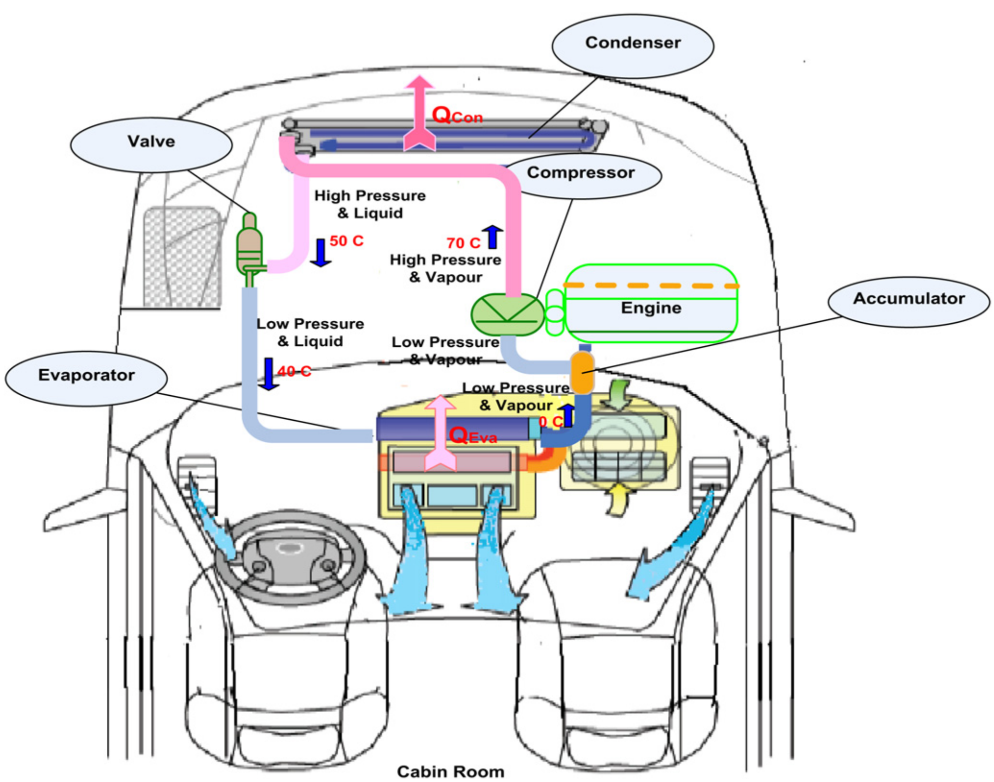

Fig. 1. Air conditioning system overview.