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Using a smart device and neuro-fuzzy control system as a sustainable initiative with green cars

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ABSTRACT

Engine gas exchange processes are characterized by overall parameters. The volumetric efficiency is the most important of these parameters, and depends, in addition to fuel and operating variables, on the design of manifolds, valves and the ports of the engine. Moreover, the gas dynamics of the flowing gases including the pressure waves and the boundary layer thickness of the flow due to friction play an important role.

A smart device is fitted to the exhaust pipe and used to improve the engine volumetric efficiency, power and fuel economy. This controlling valve takes its commands, depending on engine loading conditions, from signals of some sensors such as manifold air pressure, engine speed, air mass flow, and inlet air temperature. Hence, a suitable amount of air and fuel flow, achieves optimum performance conditions. Furthermore, this work was also intended to develop a neuro-fuzzy controller model for improving the performance of the spark-ignition engine (SIE) fitted with smart device. Experiments were carried out on a 4-cylinder, 1.8 L displacement volume, Mitsubishi engine using PID Controller. Full range of road-load test conditions were covered. A hydraulic dynamometer was used, in addition to a scan tool and exhaust gas analyzer.

The obtained results show that using the smart device improves power by 3–21% and bsfc by 9–21% between 25% and 75% load. Whereas, the neuro-fuzzy-based controller enhances engine power (30% – 60%) and reduction in brake specific fuel consumption (12%–35%) in comparison with the PID controller used in the basic engine.

1. Introduction

By using the internal combustion engine (ICE) it is possible to maximize the power produced and minimize the fuel consumed by the engine by adopting different modifications and adjustments in design. These modifications may apply to the systems attached to the engine such as intake and exhaust systems [1–10]. In this study, the work is focused on the exhaust system.

Researchers usually utilize volumetric efficiency η_v which equals mass of air entrained per second over the corresponding mass of air relevant to the displacement volume. It is possible to improve η_v by using different methods, e.g. fuel evaporation in the intake manifold [10] and reducing the intake pressure drop [10–12].

In this work, a different method of control is used to create the optimum conditions for having high volumetric efficiency especially at high range of RPM [13–15]. This controller is called ‘smart device’ which is a motored throttle valve fixed on a Y extension attached to the main exhaust line (Fig. 1). It receives signals from the engine control unit ECU, specifically the intake manifold pressure MAP, engine speed, air mass flow MAF and intake air temperature IAT. These signals will control the valve partial opening according to the loading condition, hence the exhaust mass flow and η_v at different loads and speeds and consequently power and fuel consumption.

In comparison with previous works which are the most relevant to this work [7,13–18], it was found that Morita [7] attempted to replace the conventional control by artificial neural network ANN to explain the nonlinear characteristics of combustion parameters in the car petrol

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Nomenclature

ANFIS	adaptive neuro-fuzzy inference controller, –
bsfc	brake specific fuel consumption, kg_f/kW h
BDC	bottom dead center
CFM	cubic feet per minute
EV	exhaust valve
F/A	fuel/air ratio
IV	intake valve
C	speed of sound, m/s
C_{pa}	specific heat of air at constant pressure, kJ/kg K
ECT	engine coolant temperature, K
EGO	exhaust gas oxygen sensor, –
FIT	fuel injection time, ms
IAT	inlet air temperature, K
ICE	internal combustion engine
k	specific heat ratio (1.4 for air), –
L	piston stroke, m
M_a	mass rate of air, kg/s
MAP	manifold air pressure, k Pa
MAF	mass air flow, kg/s
mfs	membership functions
N	engine speed, rpm
NFC	neuro-fuzzy controller
P_b	brake power, kW
PID	proportional-integral derivative controller
Q_{HV}	heating value, kJ/kg_f
r	compression ratio
RMSE	root-mean square error
R	gas constant (=287 for air), J/kg K
S_p	piston speed, m/s
T	temperature, K
TPS	throttle position sensor
V	velocity, m/s
V_d	displacement volume, dm^3
SI	spark ignition engine
TDC	top dead center
V	vapor

Greek letters units

η_v	volumetric efficiency, %
η_f	fuel conversion efficiency, %
η_m	mechanical efficiency, %
ω	angular velocity, m/s
Φ	equivalence fuel-air ratio, –
ρ	density, kg/m^3
θ	crank angle degrees
λ	excess air ratio = 1/Φ

Subscripts

A	after
a	air
atm	atmospheric
b	before
L	liquid
P	piston

engine, and found that ANN is better than conventional control. However, the ANFIS supersedes the ANN as it combines the relative merits of ANN and fuzzy logic. Sayin et al. [16] used a gasoline engine, but their control system was ANN and predicted values of bsfc much larger than those usually found obtained for such engines. Jahirul et al. [17] used a lower power gasoline engine and compared performance with the case when using the compressed natural gas CNG, using conventional control. Their values of bsfc compare with those of the basic engine in our experiments. Lee et al. [18] on the other hand used a neuro-fuzzy control but with a single cylinder diesel engine with small power in comparison with our realistic vehicular engine.

In conventional engines with an electronic proportional-integral-derivative PID controller, the amount of injected fuel is controlled by the frequency and width of pulses supplied to the fuel injector. The control map is nonlinear and stored as a look-up table. The main drawback of this type of control is that it requires significant period to determine the optimal injection time for optimal engine operation. Thus, there is a need for an intelligent controller based on intelligent soft computing techniques such as fuzzy logic and neural network that is able to provide better, quicker and more accurate control than the conventional PID controller [16–21].

Thus, the main objectives of this work are:

a) Improving the engine power, torque and specific fuel consumption by using a smart device, which causes variation in exhaust pressure and engine mass flow rate.
b) Designing a fuzzy controller, used with the smart device. Then, based on inputs from the engine sensors, fuel injection and consequently engine power and specific fuel consumption are controlled.

2. Gas-exchanging processes and tuning with the smart device

The gas exchanging processes are defined as the processes of removing the burned gases from the cylinder by the end of the power stroke and supply the cylinder with a fresh charge to start a new cycle.

As the engine pistons move up and down inside the cylinder, the inlet and the exhaust valves open and close creating a compressible flow process in which the pressure waves flow backward and forward through the inlet and exhaust system. Those waves propagate through the gases in the pipe at the speed of sound “C”. When this wave encounters a change in cross sectional area, such as the end of the pipe, a wave of negative sign will be reflected from that end. The speed and time needed for this wave to return back to the valve determines the length of the pipe.

The appropriate pipe length can be estimated through solution of compressible flow equations and the increase in the engine volumetric efficiency.

At the intake side, as the IV opens, the reflection wave is sent upstream from the valve. When it encounters a change in area such as the intake manifold, it reflects in a form of compression wave and moves downstream back to the IV. This compression wave increases the local density and the mass of inlet flow. The inertia of the gas at the intake port increases as the piston slow down near the BC and IV closes to start