Using a Smart Device and Intelligent Control to Reduce Green Vehicle Emissions

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Received June 15, 2013; Accepted December 10, 2013

Abstract: Soaring oil prices and challenging emissions regulations demand significant efforts on the part of engine researchers to bring down emissions levels and to contribute to green vehicle technologies.

This work constitutes a phase of research by the authors on green vehicle technology. A Mitsubishi automotive engine was utilized and experiments were carried out at different loads and speeds. The smart device and neuro-fuzzy controller were effective in greening the car, enhancing energy sustainability and reducing the main pollutants, namely NO_x, CO and HCs.

Keywords: Smart device, neuro-fuzzy controller, emission reduction, green car technology

1 Introduction

The automobile industry and the industries that serve it constitute the backbone of the world's economy and employ the greatest share of the working population. They have made great contributions to the growth of modern society by satisfying the need for mobility in everyday life.

However, the large numbers of automobiles around the world have caused, and continue to cause, serious problems for the environment and human life. Air pollution, global warming, and the rapid depletion of the earth's petroleum resources are now of paramount concern [1].

In Europe, 73% of the oil consumed is used in transport. In Jordan the energy invoice is equivalent to 20% of the gross national product and equal to total exports. The transport sector takes up 37% of this consumption. It is expected that passenger cars will double within the next 20 years. Hence, there is an urgent need to find

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DOI: 10.7569/JSEE.2013.629523

alternatives to fossil fuels to secure future energy supply and to develop high-efficiency, clean and safe transportation with lower greenhouse gas emissions [2].

Presently, all vehicles rely on the combustion of hydrocarbon (HC) fuels to derive the energy necessary for their propulsion. Recent European green car initiatives are concentrating on advanced internal combustion engine (ICE) research with emphasis on: a) new combustion techniques such as stratification with direct injection in gasoline engines, b) using alternative fuels (bio-methane, ethanol, hydrogen etc.), c) intelligent control systems, d) mild hybridization and e) special tires for low rolling resistance [3].

This work represents the third stage of efforts by the authors to contribute to green car technology concentrating on ICE research. The first was on using a neuro-fuzzy controller for boosting the power output and lowering fuel consumption, which made the engine more compact (thereby reducing cost) and less costly in terms of fuel consumption [4]. The second effort was in developing a smart device with the neuro-fuzzy control to contribute to further boosting engine performance. This current work is intended to cover the improvement in controlling the greenhouse gas emissions and other potential environmental impacts. Throughout all stages of research, experimental results from tests on real automotive engines formed the basis for analytic comparison.

2 Pollutants in Spark Ignition Engines

Ideally, the combustion of an HC yields only CO_2 and H_2O, which do not harm human bodies when inhaled. Indeed, green plants digest CO_2 by photosynthesis. CO_2 is a necessary ingredient in plant life. Animals do not suffer from breathing CO_2 unless its concentration in the air is such that oxygen is almost absent. Actually, the combustion of HC fuel in combustion processes contain certain amounts of nitrogen oxides (NO_x), carbon monoxides (CO), and unburned HCs, all of which are toxic to human health [1].

2.1 *Nitrogen Oxides (NO_x)*

Temperature is by far the most important parameter in NO formation. Once released into the atmosphere, NO reacts with O_2 to form NO_2. This is later decomposed by the sun's ultraviolent radiation back to NO and highly reactive oxygen atoms that attack the membranes of living cells. NO_2 is partly responsible for smog. It also reacts with atmospheric water to form ground level ozone and nitric acid (HNO_3) that creates acid rain and contributes to the destruction of forests and the degradation to historic monuments [5]. Both acid rain and ozone exposure cause respiratory system problems.

2.2 *Carbon Monoxide (CO)*

CO results from the incomplete combustion of HCs due to lack of oxygen. It is poisonous to human beings and animals. Once CO reaches blood cells, it attaches

DOI: 10.7569/JSEE.2013.629523

to the hemoglobin in place of O_2, thus reducing the quantity of O_2 that reaches the organs and thereby reducing the physical and mental abilities of affected living beings. The first symptom of poisoning is dizziness, which can rapidly lead to death. CO has an attraction to hemoglobin about 200 times that of O_2 and normal body functions cannot break the strong bond. Patients should be treated in pressurized chambers where the pressure facilitates the breaking of the CO-hemoglobin bonds.

2.3 *Unburned HCs*

HCs are the result of the incomplete combustion of HCs. Some of them may be direct poisons causing cellular mutations or carcinogenic chemicals such as particulates, benzene or others. The sun's ultraviolent radiation interacts with HCs and NO in the atmosphere to form ground level ozone and other products. Ozone is a molecule formed of three oxygen atoms. It is colorless but very dangerous and poisonous because it attacks the membranes of living cells causing them to age prematurely or die. Older people and asthmatics suffer greatly from exposure to high ozone concentrations [6, 7]. Engine exhaust after treatment using the three-way catalyst is the most widely used method for emissions control irrespective of the engine's running conditions. NO_x is reduced to O_2 and N_2, CO is oxidized to CO_2 and UHCs are combusted to CO_2 and H_2O.

2.4 *Sulfur Oxides (SO_x)*

The combustion of sulfur releases sulfur oxides where sulfur dioxide SO_2 is the major product. On contact with air it forms sulfur trioxide, SO_3, which reacts with water to form sulfuric acid, a major component of acid rain. It is noteworthy that SO_x originates mainly from transportation sources, power plants and steel factories.

3 Global Warming (GW)

Global warming is the result of the "greenhouse effect" induced by the presence of CO_2 and other gases such as methane (CH_4), in the atmosphere. These gases trap the infrared radiation reflected by the ground, thus retaining the energy in the atmosphere and increasing the temperature. This causes major ecological damage to the ecosystems and many natural disasters that affect the human population [6].

The transportation sector is the major contributor to CO_2 emissions (about 33%) [8]. It is important to note that CO_2 is digested by plants and sequestrated by oceans in the form of carbonates. However, these natural assimilation processes are limited and cannot assimilate all of the emitted CO_2, which results in an accumulation of CO_2 in the atmosphere. In general, a lot of research involves neural analysis tackled emissions from internal combustion engines [9–14].

DOI: 10.7569/JSEE.2013.629523

4 Techniques for Improving Engine Performance and Emissions

Engine performance including emissions [15–18], torque, power and efficiency [19–23] could by controlled by different design and operation parameters such as the following:

The forced induction by variable intake manifold and supercharging, gasoline direct injection and lean-burning multi-and variable-valve timing, throttle-less torque control, a variable compression ratio, exhaust gas recirculation, intelligent ignition at any operating speed and load for optimum performance and emissions, and high-temperature and light-weight materials.

In this work, the performance and emissions were controlled, once by using a smart device to improve the engine breathing and volumetric efficiency, and second by using an adaptive neuro-fuzzy inference system (ANFIS) control instead of proportional-integral-derivative (PID) control.

The smart device is a method of control developed by the first author and his students. It is used to create the optimum conditions for high volumetric efficiency, especially at a high range of RPM. This controller 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 partially opening according to the loading condition, consequently influencing the exhaust mass flow and the air mass flow that affects volumetric efficiency at different loads and speeds. Finally, power and fuel consumption will be modulated.

5 Experimentation

In this research, a 4-cylinder direct injection gasoline Mitsubishi engine (GDI, SG93) with a displacement volume of 1834 CC, Bore x Stroke (81x 89) mm and compression ratio of 12 was used. Test runs were made at speed and load combinations simulating road-load operations, namely, full throttle to 25% load with their corresponding speeds, 3500–1500 rpm. The engine power was absorbed by a hydraulic dynamometer of 100-kW capacity. A schematic diagram for the test facility is shown in fig.1.

The experimental data of the engine at different loads and the corresponding speeds in the road-load test were the dynamometer readings including speed, power and torque. Fuel consumption was measured using a sensitive scale. Consequently, the engine's torque, power and BSFC were calculated. Simultaneously, scan tool readings were taken, namely ECT, MAP, EGO, injection timing, TPS and ignition angle. A gas analyzer was also used in this test, where the pollutant and gaseous concentrations namely NO, CO, CO_2, HC, O_2 in addition to the excess air (λ) ratio and air-fuel mass ratio were measured [26–30].

The following experimental results were obtained from the gas analyzer: NO ppm, CO%, CO_2%, HC ppm, O_2%, excess air ratio, therefore the A/F. These

DOI: 10.7569/JSEE.2013.629523

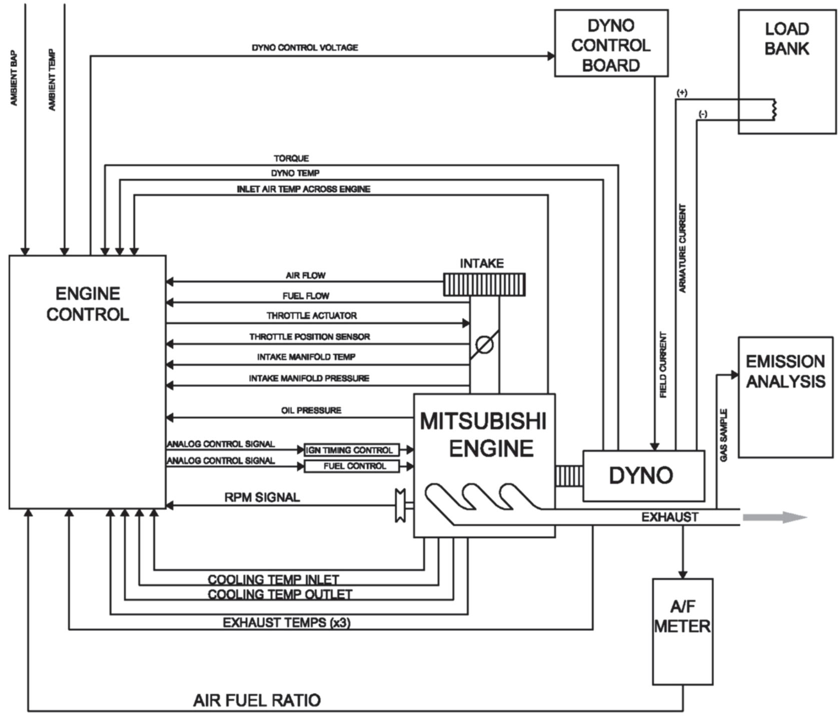

Figure 1 A typical experiment setup for measuring the pollutants emitted from the tested engine.

readings were obtained for the basic engine at four different loading conditions covering from 25% load up to 100% load with their corresponding speeds. Then these tests were repeated with the smart device controlling the exhaust pipe opening according to load and speed signals from the engine PID controller. This will improve the volumetric efficiency at certain loads and speeds. Finally, the adaptive neuro-fuzzy inference system (ANFIS) controller was introduced with the basic engine and again with the smart device supported engine. The neuro-fuzzy controller governs the optimal engine operation by determining the optimal fuel injection time that yields the optimal air-fuel ratio. The neuro-fuzzy controller (NFC) has many attractive features. First, it has better performance than the conventional controller such as PID. Second, it combines the features of both fuzzy logic and neural networks. Third, it has the ability to model and learn the behaviour of complex nonlinear systems based on vague information and tunes its parameters in order to minimize the prediction errors. Finally, the NFC appears to be more applicable for the determination of the optimal operating point of the engine because it has the potential for providing better, faster and more precise predictions of fuel injection time than the conventional methods. The performance results in terms

DOI: 10.7569/JSEE.2013.629523

of smart-device pollutants, with and without the fuzzy controller, in comparison with the basic engine for different cases of air-fuel ratio were determined.

6 Discussion of Results

Figures 2–6 show a graphical comparison between the emissions emitted by the basic engine, basic engine with ANFIS controller, basic engine with smart device and basic engine with smart device and ANFIS controller. The Y-axis represents the pollutant concentration (NO ppm, CO%, CO_2%, HC (ppm) and O_2 %) whereas the X-axis represents the engine loading conditions, 25%-100%, which are inversely related to A/F.

The strategy for ANFIS control is to run the engine with a stoichiometric fuel-air mixture within ±0.5%, to match the requirements of the 3-way catalyst at the exhaust pipe, which needs λ=1 to achieve the highest conversion efficiency. There are some basic methods to control engine emissions that include the manipulation of the combustion process such as fuel injection, spark timing, fuel-air mixture control and exhaust gas recirculation, optimizing the choice of operating parameters and using after-treatment devices such as a three-way catalyst. In this research, a smart device, which is an electronically controlled valve installed in the exhaust pipe that opens partially according to the engine loading condition, was defined by electronic signals of engine speed and manifold absolute pressure. This device

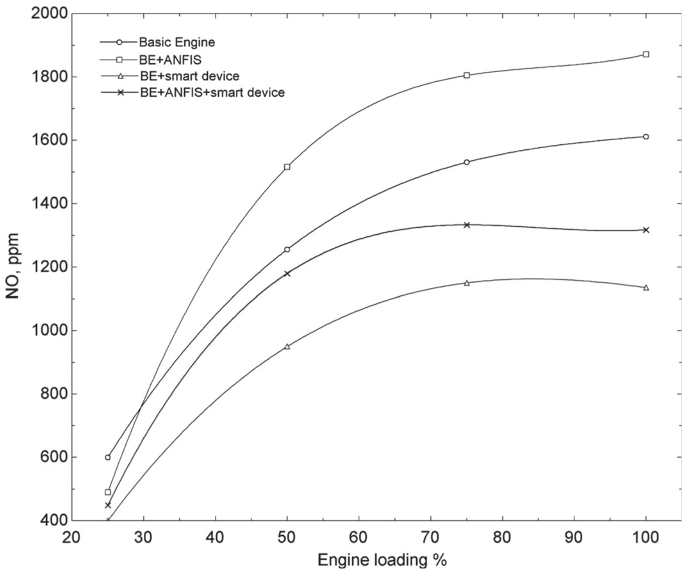

Figure 2 The variation of NO_x with varied loading conditions for different cases of control.

DOI: 10.7569/JSEE.2013.629523

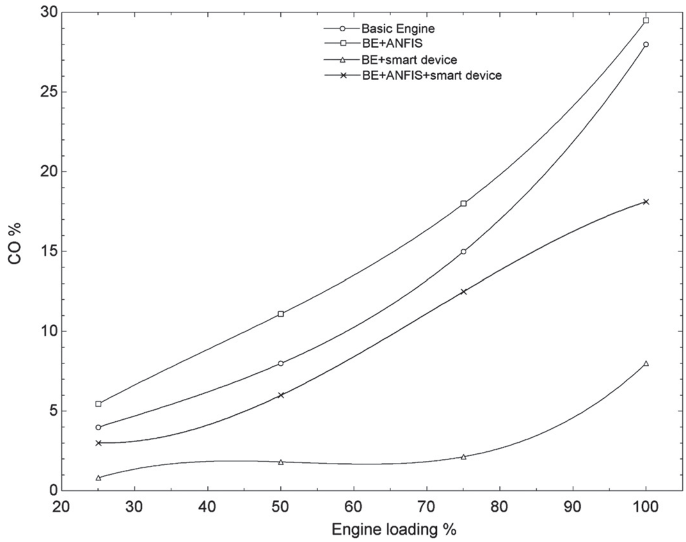

Figure 3 The variation of CO with varied loading conditions for different cases of control.

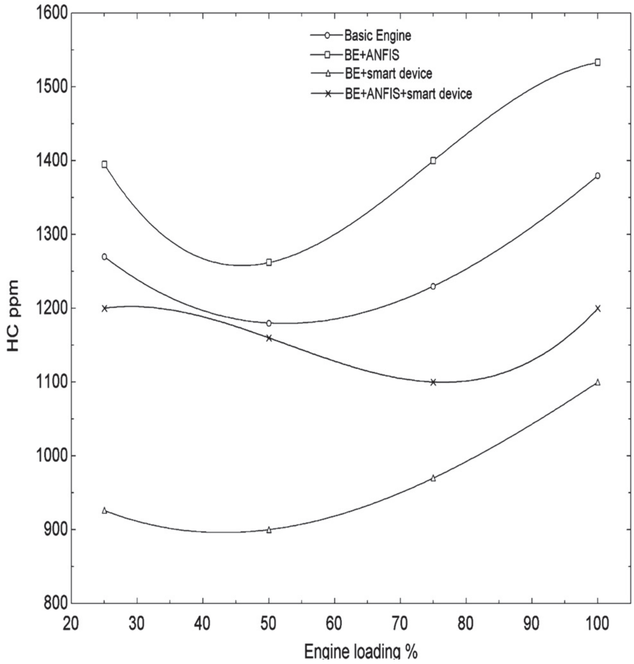

Figure 4 The variation of HC with varied loading conditions for different cases of control.

DOI: 10.7569/JSEE.2013.629523

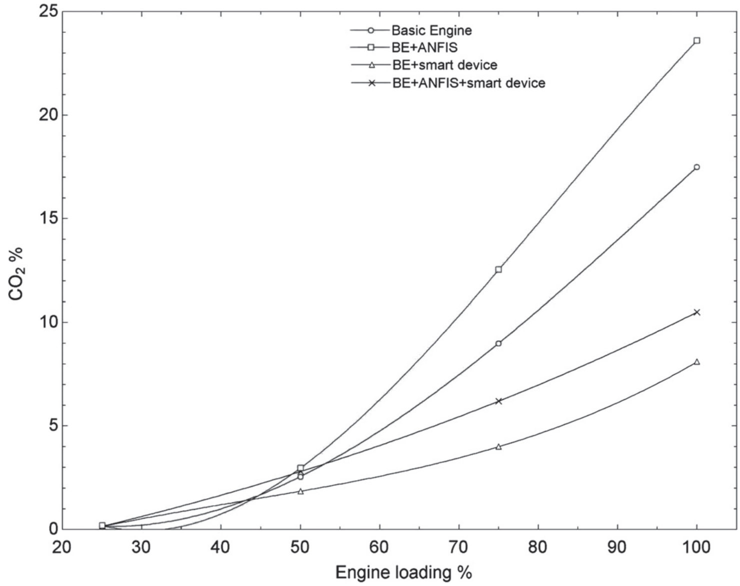

Figure 5 The variation of CO_2 with varied loading conditions for different cases of control.

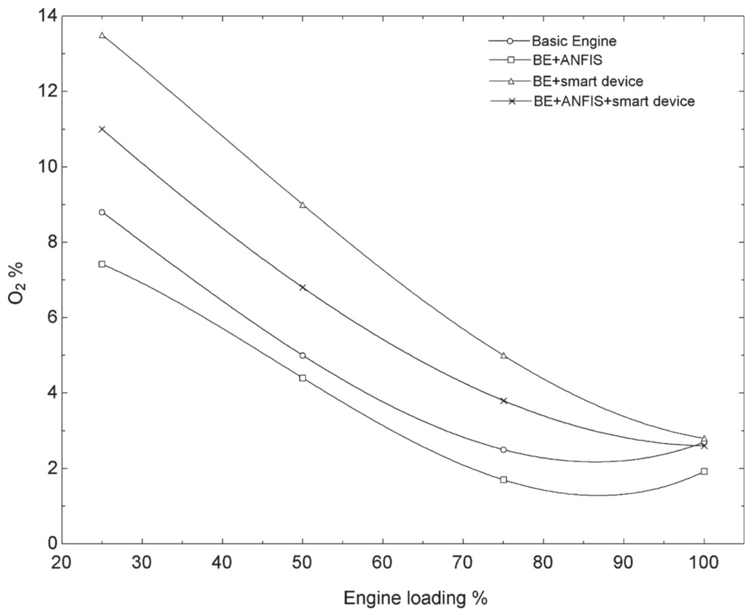

Figure 6 The variation of O_2 with varied loading conditions for different cases of control.

DOI: 10.7569/JSEE.2013.629523

affects the volumetric efficiency due to the change of air mass flow inhaled by the engine due to the relaxation of backpressure at the exit of the exhaust pipe [6].

Nitrogen Oxides (NO_x) form through reactions which are very temperature dependent, therefore NO_x emissions are proportional to engine load. However, the formation rate is also affected by the oxygen concentration, hence, it peaks at the lean side of the stoichiometric as shown in fig. 2. Comparisons will be considered at 75% load, where the smart device performs very well. At other loads relative values may be different. It is also clear how the general level of concentration was reduced when using the smart device by 27%, and increased when the ANFIS controller is adopted by about 20%. As noted, NO_x increases with engine loading. It also increases with ANFIS due to approaching the stoichiometric condition (λ=1) when the gas temperature is at a maximum. However, it decreases with the smart device as it makes the mixture leaner.

Carbon monoxide results from rich running engines due to insufficient oxygen to convert all the carbon in the fuel to CO_2. The most important parameter which influences CO is the fuel-air equivalence ratio. Therefore, to minimize CO emissions, times of running rich should be greatly reduced. However, since the running conditions are lean, CO increases by 20% near the stoichiometric [27–30], when using ANFIS. As shown in fig. 3, the level drops drastically with the smart device as the mixture becomes much leaner.

Hydrocarbon emissions result from the unburned fuel in the exhaust of an engine. Usually, about 9% of the fuel supplied to the engine is unburned during the combustion and expansion processes. However, 7% is usually consumed during the other three strokes, leaving 2% that goes out with the exhaust [10]. Hence, engine efficiency decreases and HCs appear as pollutants. HCs are usually greatest during engine start and warm-up due to decreased fuel vaporization and lower oxidation rates [6]. Fig.4 shows the reduction from a basic engine when using the smart device at about 25%, but increases by about 12% when utilizing ANFIS.

Fig. 5 shows how the CO_2 concentration increases with load as the temperature increases and O_2 is relatively available until the reaction proceeds to completion. Using the smart device reduces CO_2 by 20% as the mixture gets leaner but increases it by 15% with ANFIS, as it approaches the high temperature region where the reaction rate is enhanced towards completion.

Figure 6 shows the decrease of O_2 with the load increase. Its concentration increases 30% by using the smart device as it improves the air inhalation to the engine but decreases 12% when utilizing the ANFIS as it approaches the stoichiometric mixture.

7 Conclusions

1. This paper introduces emissions control in spark ignition engines as a part of green-car technology that uses smart devices and an adaptive neuro-fuzzy inference intelligent control system, ANFIS.

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2. The obtained results at 75% of the load showed that the smart device reduced NO_x by 27% whereas the ANFIS increased it by 20%.
3. When considering unburned hydrocarbon HC_s, the smart device reduced it by about 25% but it increased with ANFIS by about 12%.
4. When CO is considered, CO is increased by the ANFIS (by about 20%) when the mixture approaches stoichiometric but is reduced by the smart device (by about 30%), because the mixture becomes leaner.
5. CO_2 increased 20% with the smart device and 15% with ANFIS. O_2 increased by about 12% with ANFIS and by about 30% with the smart device.

Acknowledgment

Thanks to engineer A. Malkawi who helped in drawing all the figures.

Nomenclature

A/F	Air fuel ratio
ANFIs	Adaptive neuro-fuzzy inference system
BSFC	Brake specific fuel consumption [kg/kWh]
CC	Cubic centimeters
ECT	Engine coolant temperature [K]
EGO	Exhaust gas-oxygen sensor
ICE	Internal combustion engine
MAP	Manifold absolute pressure [k Pa]
PID	Proportional-integral-derivative controller
SIE	Spark ignition engine
TPS	Throttle position sensor

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What are the next steps in the program?
Experimental data similar to what is shown in this paper are interesting, but not compelling. Ultimately a statistically significant set of ex-periments on a number of engines under different conditions, with ex-tended runs, etc. will be required, along with actual multi-vehicle test-ing. This is expensive and time consuming and not expected from a university based research operation. It would be valuable to develop a future plan including developing an intellectual property portfolio, con-tacting engine manufacturers, etc.

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