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Genetic programming approach to predict torque and brake specific fuel consumption of a gasoline engine

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ABSTRACT

This study presents genetic programming (GP) based model to predict the torque and brake specific fuel consumption a gasoline engine in terms of spark advance, throttle position and engine speed. The objective of this study is to develop an alternative robust formulations based on experimental data and to verify the use of GP for generating the formulations for gasoline engine torque and brake specific fuel consumption. Experimental studies were completed to obtain training and testing data. Of all 81 data sets, the training and testing sets consisted of randomly selected 63 and 18 sets, respectively. Considerable good performance was achieved in predicting gasoline engine torque and brake specific fuel consumption by using GP. The performance of accuracies of proposed GP models are quite satisfactory (R^2 = 0.9878 for gasoline engine torque and R^2 = 0.9744 for gasoline engine brake specific fuel consumption). The prediction of proposed GP models were compared to those of the neural network modeling, and strictly good agreement was observed between the two predictions. The proposed GP formulation is quite accurate, fast and practical.

1. Introduction

Experimental investigations to measure the performance of a gasoline engine are complex, time consuming, and costly. To predict the performance parameters from the engines, one approach is to use mathematical models. However, their accuracies may not be sufficiently high [1]. The alternative to a mathematical model is the experiment-based approach.

Genetic algorithm (GA), which is based on solutions of fixed-length chromosomes, usually consisting of binary genes, organized into sequences, often termed schema is the most commonly used evolutionary-computation algorithm [2]. Mimicking nature, the algorithm starts its search from an initial population of solutions, in which the performance of each individual is evaluated using a fitness function, with the most efficient chromosomes having a higher probability to reproduce. In synthetic evolution, biological reproduction is mimicked by operators like crossover (pairing) and mutation, thus creating a generation of offspring solutions. Crossover generates new features in the solution space by combining genetic information, while mutation does this by adding random perturbations. Fitness-proportional selection, combined with these genetic operators produce generation after generation of offspring solutions. Since the more appropriate solutions are given higher probabilities to reproduce, one would expect a growing improvement of the solutions over generations.

GA as an optimization technique is widely used for optimization of engineering problems. Many engineering design problems are very complex and therefore difficult to solve with conventional optimization techniques [3]. Numerous studies have been undertaken by using GA for optimization of engine characteristics, neural networks and genetic algorithms have been used to predict and reduce diesel engine emissions [4], genetic algorithm and artificial neural network for engine optimization of efficiency and NOx emission [5], a group method of data handling type neural network and evolutionary algorithms for modeling the effects of intake valve timing and engine speed of a spark ignition engine on both engine torque and fuel consumption [6], genetic algorithms for hydrogen-fueled engine optimization of power, economy, emission performance and operating parameters [7], multi-objective optimization of diesel engine emissions and fuel economy using genetic algorithms [8], performance prediction and optimization of liquid rocket engine nozzle using genetic algorithm [9], genetic algorithm and its application to diesel engine optimization [10], optimization of system parameters for the gas-generator engines using multi-objective methods [11].

GA is employed by [13] to optimize the capacity and operation strategy of CCHP system on the basis of energy flow. Fuel consumption of a gasoline engine can be minimized through dynamic optimization [14]. Neuro-fuzzy interface system (ANFIS) to study the effect of boost pressure on the engine perfor-

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mance parameters of a single cylinder diesel engine has been studied in [15].

However, they are unsuitable for generating empirical model structures, since they manipulate populations of solutions of fixed-length chromosomes, while the optimal complexity of empirical models is unknown in advance. Because of this perceived need for more intelligent construction of empirical models, a new family of evolutionary computation methods has emerged, based on established GA ideas. These new algorithms, referred to as genetic programming (GP), rely on tree-like building blocks, and therefore support populations of model structures of varying length and complexity. Activity in genetic programming was introduced by Koza [12], who demonstrated their applications in fields such as robotics, games, control, and symbolic regression.

Numerous studies have been undertaken by using GP, a member of the evolutionary computation field, to a nonlinear identification of aircraft gas turbine engine [16–18], nonlinear model structure identification [19], identification of a dynamic system [20,21], gas turbine engine identification [22], mechanical system identification [23], dynamic system modeling [24] and steady-state process modeling [25]. Yang [26] used an intelligent approach by using GP to construct mathematical model for diagnosing the engine valve faults correctly and quickly.

Kalogirou [27] reviewed Artificial intelligence for the modeling and control of combustion processes. A number of AI techniques have been described in this paper. An explicit neural network formulation that predicts the torque and brake specific fuel consumption of a gasoline engine as a function of experimental parameters; spark advance, throttle position and engine speed, has recently been performed by Togun and Baysec [28]. However a GP based explicit formulation for gasoline engine performance parameters, to the best knowledge of the authors, has not yet existed in the literature. Therefore, the purpose of this study is to develop a GP based mathematical model for the prediction of gasoline engine torque and brake specific fuel consumption in terms of spark advance, throttle position and engine speed. The performance of the proposed models was compared to neural networks model developed by Togun and Baysec [28]. The data taken from experimental study were utilized in training and testing the developed models. An important advantage of the proposed GP approach is the simplicity of the formulation and its wide range of applicability to empirical formulation of various engineering problems where sufficient experimental results exist.

2. Description of the experimental setup

2.1. Experiments setup

In the present study, the Fiat Tofaş 131 type engine has four-stroke, fueled with carburetor and naturally aspirated four cylinders with a bore of 76 mm and a stroke of 71.5 mm was used. The maximum power output of the engine was 52.2 kW at 5500 rpm. Table 1 lists the details of the engine specifications, while Fig. 1 shows schematic representation of experimental setup of the engine and also experimental apparatus on the test engine schematically presented.

2.2. Instrumentation

Calibration checks of the devices were made two times, one before and one after each successive test. To transfer data into a computer, data logger systems were used. All measurements were conducted under steady state conditions. The measurement was not started until engine runs faultless. Since there were many measurement points, three different PC data logger combinations were used to reduce the errors resulting from measurements. The functions of computers, measuring equipments and method of measurement are briefly explained as follows to obtain mass flow rate of air, fuel entering the combustion chamber and engine speed.

Table 1
Test engine specifications.

Type	Fiat Tofaş 131
Engine type	Four-stroke
Fuel type	Gasoline
Swept volume (cm^3)	1297
Cylinder bore (mm)	76
Cylinder stroke (mm)	71.5
Compression ratio	7.8:1
Number of cylinders	4
Cooling type	Water cooled in closed circuit
Fuel supply system	Naturally aspirated carburetor
Maximum torque	12.5 kg m at 3000 rpm
Maximum power	52.2/70 kW/HP at 5500 rpm
Engine position	Vertical

Air flow rate was determined by difference in pressure. A high volume air tank, which was connected to the engine carburetor with a plastic pipe, was used to draw the air flow. Pressure difference formed by a pipe bowl at the entrance of the air tank was measured by a pressure transducer having analog output. Another analog/digital converter was used to convert this analog output into the digital signal and to transfer the signal to the PC for a definite time interval.

Mass flow rate of the fuel was measured by using one way RS 232 interface and a weighing machine having 0.1 g sensitivity and overloading security. The output of the weighing machine was transferred to the PC by RS 232 interface. These data were read by the software for a definite time interval and suitable format for calculations.

Engine speed is controlled by the position of the throttle valve. To control the throttle position, the butterfly is directly coupled to the shaft of a stepper motor. Position of the stepper motor is controlled in 1.8° increments by the control computer via conventional software.

2.3. Experimental procedures

The experimental work in this investigation was performed at various spark advance, throttle position and engine speed conditions. Before starting the engine, the spark advance has been adjusted to 10° crank angle (CA), which is a predefined design value for the engine. To start with, our computer-controlled gasoline engine, which is connected to hydraulic dynamometer, has been loaded, with the 50% throttle position. The engine has been tested in the ranges of 3500–1500 rpm at intervals of 250 rpm. Torque, fuel flow rate, air flow rate and specific fuel consumption have been recorded. Similarly, these measurements have been repeated for the throttle positions of 75% and 100%.

After the measurements, the engine has been left to cool. Then the ignition time has been adjusted to successively 5 and 0° crank angle, respectively and the above procedure has been repeated.

2.4. Uncertainty analysis

Any experimental result involves some level of uncertainty that may originate from causes such as the lack of accuracy in measurement equipment and approximations in data reduction relations. These individual inaccuracies eventually translate into uncertainty in the final results. Consider the result, F, to be a function of n measured variables $x_1, x_2, \ldots, x_n$ as