A Computer Based Flexible Real Time Fuel Controller System Implementation for Four-Cylinder Internal Combustion Engines

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Abstract: In this study, a computer and microcontroller based fuel control system for four-cylinder internal combustion engines has been designed and some applications have been implemented. Fuel control system designed for real time control the amount of fuel in alternative fuel applications. System is suitable to use with both diesel and petrol engines. A Graphical User Interface has been designed in computer side. The pc programme uses Fuzzy Logic, Neural Networks and Curve Fitting calculation methods. The percentage of the fuel to be sprayed has been defined according to the engine speed, load and fuel rack or throttle position got from the engine. These physical signals have been controlled and read by microcontroller based electronic circuit. Communication has been set using RS232 standard between PC and microcontroller.

Introduction

Energy as the most important input for economic and social development, has been took place in all world countries as an important agenda about 1970's (Tekin et al.,2004). Having limited amount of oil resources, which is decreasing rapidly, economic and political differences, dependence on foreign countries and the air pollution are important problems for all countries. To reduce the dependency on oil and to minimize the problems about potential oil crisis in the future has brought up the researches about alternative fuels (Çetinkaya et al.,1997, Salman et al, 1990). Using of fossil fuels and environmental awareness, has made the engineers and scientists to oriented develop of clean, renewable and sustainable energy system (Yüksel et al., 2002, Borat et al., 1992)

The reduction of harmful and pollutant emissions and the improvement of the engine performance are today's most popular research subjects. For this purpose, many studies are performed by researchers and automotive manufacturers. Lots of researches can be found in literature about using alternative fuels instead of petrol or using alternative fuels with petrol. These researches have such aim like fuel costs lowering, increasing engine performance with the same cost and eliminating or lowering percentage of exhaust gases, harmful to atmosphere . These alternative fuels or substances are mostly alcohol, alternative fuels, liquefied petroleum gas (LPG), biomass, natural gas, hydrogen, water and water vapour. These substances are alcohol, LPG, natural gas, hydrogen, and biodiesel for engine performance and emissions are widely used as an alternative fuel.

While using the substances mentioned above, the effects on engine performance and engine emissions should be well analyzed. According to the various researches it is clear that to have good results, it is very important to use the correct fuel mixture amount or spray correct amount of fuel.

In other application, the alternative fuels are sprayed with a nozzle to the intake manifold by vacuum effect. Unlike other studies, an injection system supported by on electronic programme has been developed to spray alternative fuels with a certain rate. This system uses solenoid injectors to spray the fuel. It is targeted that, to build a such compatible fuel control system for all four-cylinder engine using alternative fuel. Since using alternative materials in the engine is not dependent on a single parameter linearly. The injection signal cannot be produced by a mechanical way. Because of nonlinear engine operating conditions and dependency of these conditions more than one variable makes difficult to produce the injection signal by a typical electronic circuit without a programme. In the system, the calculation methods, Fuzzy Logic, Neural Networks and Curve Fitting, have been used to achieve high accuracy for all working conditions

The general structure of the system

The fuel control system designed consists of a computer programme and an electronic circuit controlled by a 8051 based microcontroller. The connection between the microcontroller and the PC is provided with RS232 serial protocol. Reading and controlling the physical data are carried out by the microcontroller. Calculating of the fuel amount, the injection signal's length and timing are performed by the computer programme. Block diagram of designed system can be seen in Figure 1.

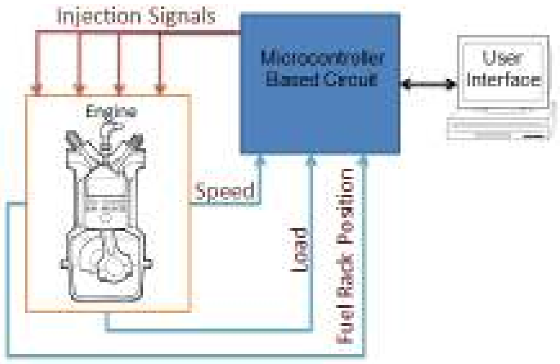

Figure 1: Block diagram of the fuel control system

During the operation, mcu reads the inputs load, speed and fuel rack position momentarily and sends them to the programme. According to these three values, the fuel amount is calculated and the injection signal's timing and length will be determined by considering the injector parameters and advance angle and sent to the mcu. After data is received mcu will constitute the injection signal related to angle read from encoder. So that the desired amount of fuel is sprayed.

For determining the correct amount of fuel to be sprayed, it is very important to read momentarily working conditions such as engine speed, fuel rack position and engine load. Measurement of this data has been done by the microcontroller with a number of sensors. Angular velocity has been measured by digital absolute encoder fitted to crank of engine. At the working conditions, the instant measurement and control of angle are needed to provide a real time system. While the engine is running, encoder also has functions to determine upper dead point and to produce the right signal to spray the fuel on start and end at the correct angles. Position of the fuel rack of the engine has been measured with a potentiometer by mcu's ADC unit. Potentiometer's analogue output voltage is been changing linearly according to fuel rack position. Engine load has been measured with a load cell fitted to the engine dynamometer. Data acquired from the load cell have been read by mcu's ADC unit and digitally filtered by mcu programme.

Defining injector parameters

For a high precision control of fuel timing and amount, an injection signal must be produced according to the parameters of the injectors. System is designed to be used with solenoid injectors. As known there are opening and closing time delays in solenoid injectors caused by injectors coil windings (Zhao et al., 1999) These delays causes a problem in which to construct the right injection signal length and spray the fuel with the right advance angle. These delays must be well defined for the injectors. While the system is running for applying the fuel to the engine in the right advance angle, it has to produce the injection signal before the real advance angle.

There is no linear correlation between injection signal length and sprayed fuel amount (Zhao et al., 1999). In this work, it is aimed to control the amount of fuel as massively by a fuel control system. Hence, the correlation between sprayed fuel mass and signal length must be well known.

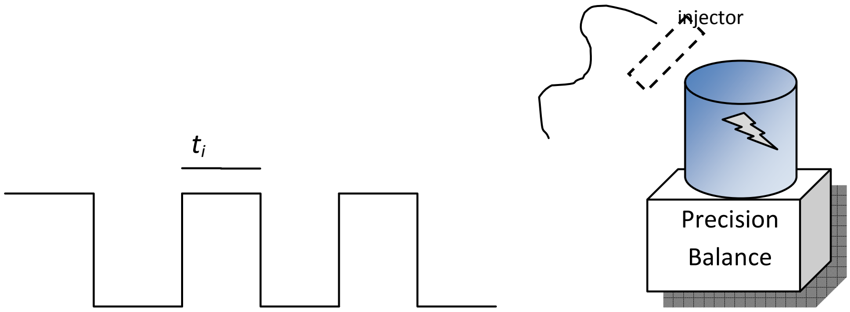

Figure 2: Injection signal and injector parameter measurement

While the system was designed, a set of experiments has been done for injector parameters measurement. The system is designed to work under 3 bar standard fuel pressure. Experiments for measuring injector parameters have been done under same conditions. For measuring correlation between the signal length and the fuel amount, the injection signal having 50 mS period, has been applied in 1000 times. When the engine is running on 1200 rpm single revolution takes 50 mS. Therefore, this period was accepted to fit the real working conditions. During the tests, injection signals increased step by step. After finishing every step sprayed fuel weight measured and divided to 1000 to find fuel consumption for each period (Fig. 2). The test results shown in Figure 3 give the correlation between the injection signal length and the sprayed fuel amount.

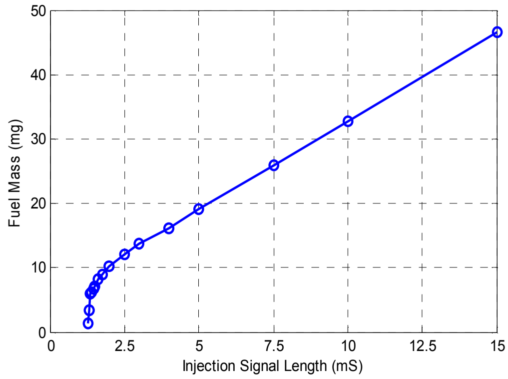

Figure 3: Correlation between the signal length and the fuel amount for a solenoid injector

While the system is running, the computer programme calculates the fuel amount with a selected calculation method. Finally the signal length has been calculated by using the injector parameters obtained by these results as shown in Figure 4. To produce the injection signal in a right time, the opening delays of the injectors have also been used by the system.

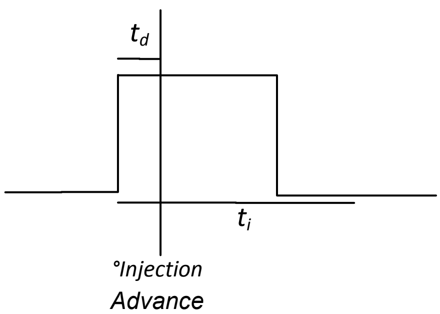

Figure 4 Produced injection signal, t_d corresponds injector delay, t_i corresponds injection signal length

User Interface

The core functions of the user interface is the setting a communication between pc and mcu and providing a practical and visual platform to the user. The user interface designed can be seen in Figure 5.

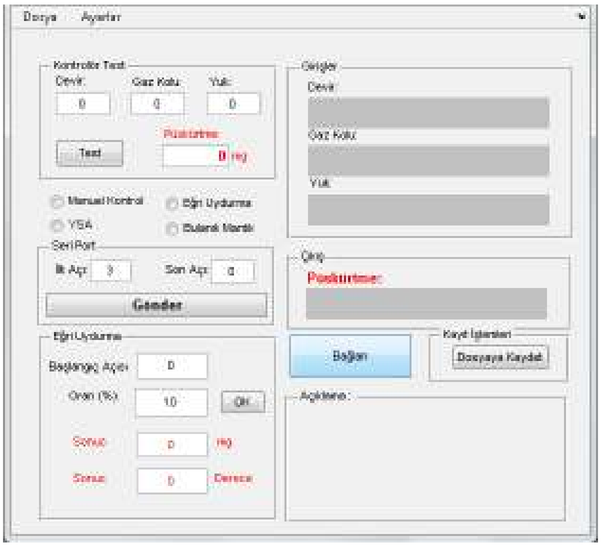

Figure 5: The User interface for the designed fuel control system.

Interface instantly shows input and output values in graphics to increase functionality and user interaction. In the operation, these graphs are always updated for each input and output data pair.

Engine's fuel consumption which can be found from engine catalogue data or obtained by experimental analysis, is a basis for all calculation methods. The user interface, designed uses fuzzy logic, neural networks and curve fitting methods to perform calculations. Calculation method can be selected by the user. After calculation, the fuel amount can be applied to the engine with different percentages defined by the user. However, it has a manual control option to apply the fixed amount of fuel, entered by the user. The user can also enter the injection advance. During the operation, the injection signal is generated according to the injector parameters and the advance angle.

Received input values and calculated data are displayed on the user interface are also updated for each input and output data pair. A test section, has been located on the user interface to test calculation method results without sending them to the microcontroller. User can check whether the calculation method gives expected results or not. Received input values and calculated data can be saved to the computer automatically by user interface and they can be used for evaluating of results. Serial port connection settings, the injector parameters and the engine fuel consumption data set can be changed by using the settings section of user interface. To use the system with another engine and injector, user only need to enter new injector's parameters and engine fuel consumption data set from settings section. Therefore the designed fuel control system can easily be adapted to all 4 cylinder engines.

The system is ready for use after entering settings and choosing desired control options. The system can be connected to mcu unit and started to control the fuel with real time data flow by clicking to connect button.

The calculation methods

In the designed fuel control system three different calculation methods have been used. All methods have been designed to adapt themselves to new values when the engine fuel consumption data set changed. In the calculation, artificial neural networks, fuzzy logic and curve fitting methods have been applied. All these methods have been tried to produce an output corresponding to the three input values. As mentioned previously, engine speed, load and fuel rack position are used as inputs. It is expected that the calculation methods will determine the fuel amount for every new input value with minimum error based on the engine's fuel consumption data set.

Engine Speed	Load(kg)	Fuel rack position	Fuel Consumption (mg)
1000	3,43	50	17,43
1000	4,45	77	29,24
1000	5,61	100	34,6

Table 1: Fuel Consumption Data set example

The above examples in Table 1 are part of the example fuel consumption data set. The fuel consumption data set can be obtained by the experiments that have been on the engine. The data set should be carefully obtained because of the nonlinear relationship between the engine fuel consumption and input values. Engine load and fuel rack position input are two values that can be changed by user. While data set is obtained by changing these two values step by step, so as to cover minimum and maximum values of them. The smaller step size the calculation method's error rate will be. Curve fitting method directly uses this data set to find what interim values. Neural Networks use this data set as training data and estimate this data with minimum error. This data set will be used for determining fuzzy logic rules by ANFIS method.

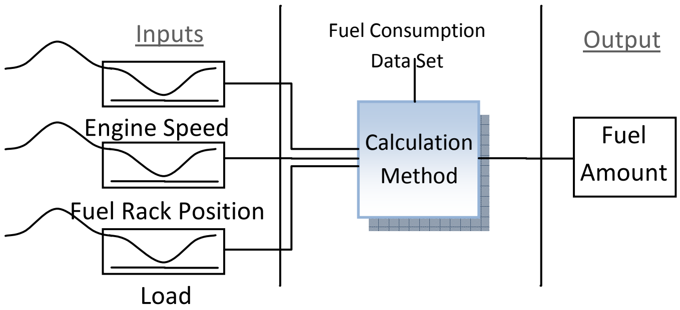

Figure 6: Calculation Methods

The fuzzy logic controller for the system is designed with the Sugeno fuzzy inference method in common structure, shown in Figure 6 .The designed fuzzy logic controller has three membership functions for engine speed input, three membership functions for fuel rack position input and four membership functions for load input. Fuzzy logic rules, for the controller have been determined by ANFIS method according to the engine fuel consumption data set mean absolute error of. $2x10^{-4}$ was obtained with the controller from a four-cylinder diesel engines date set. By experimental analysis it is achieved that the controller can find the values which are not been in fuel consumption data set with mean absolute error of 0.02. According to this explanation given above, the controller's accuracy has been accepted as suitable for this work.

The neural network controller for the system is designed in Feed Forward Back Propagation structure. Like other controllers the Neural Network controller has three inputs and one output. The Neural Network Controller has three hidden layers in a structure of 8,13,7. For neural network controller training Levenberg-Marquardt algorithm is preferred. Training was conducted with an error of 10^{-5} from a four-cylinder diesel engines data set.

As another option for calculation method, 3. order curve fitting algorithm has been used in the system. Corresponding fuel for interim input values, which are not in the fuel consumption data set, can be calculated with curve fitting method.

Conclusions and Evaluation

For testing the system, ethanol as an alternative has been fuel applied to diesel engine It is known that if ethanol is applied to diesel engines with appropriate percentages it reduces NO_X emissions(Jiang, Q. et al). During the experiments ethanol applied in a percentage of 3.75 %, 7.5%, 11.25% to the engine while the engine was running in maximum position of fuel rack. Measured NO_X emissions with ethanol injection and standard NO_X emissions are shown in the Figure 7. It can be seen that NO_X emissions have been reduced by ethanol injection as expected.

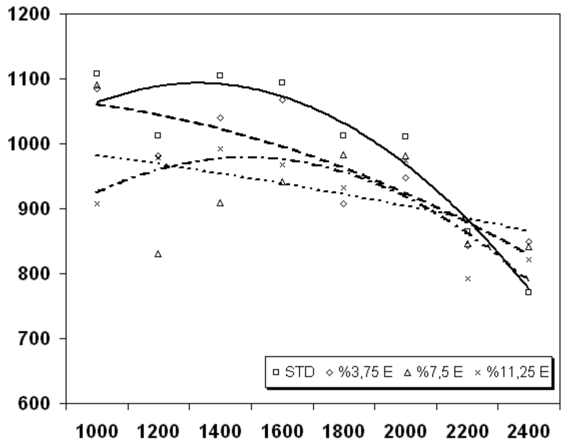

Figure 7: Ethanol applied and standard NO_X emissions

It is observed that the system can keep the fuel amount in fair values for optimum emissions and the engine performance. In addition suitability of system for all alternative fuel applications on both diesel and gasoline engines is another good result of this study.

To enhance the efficiency and accuracy of the system it will be better to transfer instant information such as measured emission values and specific fuel consumption to the user interface. In such a structure, the computer programme could be designed to optimize error rate in real time. Therefore it will not be required to create a training set, so that a higher-performance and more practical fuel control system can be obtained.

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