

Smart Controller Design of Air to Fuel Ratio (AFR) and Brake Control System on Gasoline Engine

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Abstract — Development of internal combustion engine control system is currently oriented on exhaust emissions, performance and fuel efficiency. This is caused by fuel prices rising which led to a crisis on the transport sector; therefore it is crucial to develop a fuel-efficient vehicles technology. Gasoline engine fuel efficiency can be improved by several methods such as by controlling the air-to-fuel ratio (AFR). AFR technology currently still has many problems due to its difficulty setting characteristic since AFR control is usually as internally engine control. Fuel efficiency can be improved by influence of external engine system. Brake control system is an external engine system that used in this research. The purpose of this research is to design and implement the AFR and brake control system in a vehicle to improve fuel efficiency of gasoline engines along braking period. The basic idea is the controller has to reduce the consumption of fuel injection along braking period. The applied control system on vehicle works using smart controller, such as Fuzzy Logic Controller (FLC). When the vehicle brakes, fuel injection is controlled by the ECU brake control system. This control system works in parallel with the vehicle control system default. The results show, when the engine speed exceeds 2500 rpm, AFR value increased infinitely, so that maximum efficiency is achieved. At engine speed less than 2500 rpm, AFR value reaches a value of 22. The fuel measurement has been able to show a decrease in fuel consumption of 6 liters to 4 liters within the distance of 50.7 km. Improvement of fuel efficiency can be achieved by approximately of 33.3%.

Keywords—AFR, brake control system, efficiency, fuel injection, gasoline engine.

I. INTRODUCTION

The development of control systems in the field of internal combustion engines of the world's automotive technology over the last 30 years were oriented on exhaust emissions, performance and fuel efficiency [1]. This was motivated by rapid annual growth of vehicles number that increases fuel demand. Based on data from Indonesia Statistics Board in 2013, the number of vehicles has reached 104.118.969 units. On the other side, the world's fuel supply has not increased. Global crude supplies has been stagnant since 2005 [2] and even in the later period has decreased. The impact of this situation became the cause of the rise in fuel prices. The data from the Organization for Economic Co-operation and

Development (OECD) show that crude oil price from 2004 to 2014 has increased significantly [3]. This price increase has become the main cause of the economic downturn in various sectors especially the transport sector. In the field of transportation, to cope with rising fuel prices, it is crucial to develop a transportation technology that has high efficiency to save fuel.

There are several methods to improve fuel efficiency in gasoline engine vehicles. The first is the optimization methods of Spark Advance - SA [4]. SA optimization method is a method for controlling the ignition at the spark plug with high voltage at a few degrees before top dead point of the piston in accordance with the condition of the engine. The second is Air to Fuel Ratio settings - the ratio between the AFR or fuel mixture with air [5][6][7]. Their studies control AFR to be able to achieve the ideal ratio, so that the achievement of the fuel efficiency can be improved. However, all the research are still internal engine controls. The third is the development of hybrid technology system [8]. In improving fuel efficiency they use the hybrid system. This method collaborate between a gasoline engines with an electric motor to drive the vehicle with fuzzy logic controller. Disadvantages of hybrid engines method are the generated performance is smaller than that of gasoline engines and they still have a very expensive price. The fourth is the use of alternative energy such as by the addition of ethanol [9], the addition of methanol [10] and the use of other systems as well. The use of alternative energy for gasoline engines are now starting to be developed to improve fuel efficiency and improve engine performance. The disadvantage of this method is that alternative fuel resources amount is limited. Among several existing methods, the most appropriate way in this country in improving fuel efficiency is the AFR settings because this method requires lesser cost and can be widely applied on the vehicle.

There are several methods used in AFR setting. The first method is with AFR setting controlled by vacuum generated from the engine. The weakness of this method is difficult to achieve the ideal ratio, so that the fuel tends to be wasteful. This is caused by uncertain process of mixing fuel with air using a vacuum system resulting from the piston in the engine. The second method is injecting fuel into the engine either directly (direct injection) [11] or indirectly (in direct

injection). This method has the advantage of achieving the ratio between air and fuel under ideal conditions can be easily achieved, but it requires special care and treatment. The achievement of the ideal ratio causes the fuel to become more efficient, large torque and low exhaust emissions.

The ratio of the heat engine specifications [12] could affect the AFR. AFR can affect exhaust emissions [13] on certain conditions to reduce exhaust gas emissions coupled with the added ingredient [14][15]. This study was to investigate the influence of water to fuel ratio with additional material added in lowering exhaust emissions. The development of AFR control is very rapid through the application of fuzzy logic controller [16][17][18][19]. Fuzzy logic controller has the advantages, stability of the system is relatively well controlled, can settle the problems of a black box system and can be applied by the method of multi input multi output (MIMO). Another method is neural network applications [20][21]. This method has the disadvantage of requiring a lot of training to obtain optimal results.

Currently there are problems in technology of AFR. One of the problems is that the existing technology is controlled by developed countries and is a black box. AFR setting process largely within the scope of the internal engine has not been integrated to external systems engine. Understanding these issues there should be a research to develop science and technology which could integrate AFR setting to external engine system.

Braking control system is one part of the vehicle system used to control vehicle movement, slow down, accelerate and stop. Basically when the brake system (brake control system) works the machine does not function as a driving force but standby. In this condition the engine is used to slow the vehicle down. Based on this condition brake control system can be used as one of the AFR control in the engine. It works when the brake system is operated, the engine does not require power to propel the vehicle, but power needed to stop the vehicle. This condition can be used to improve fuel efficiency. This the crucial point to study the integration of AFR control system and brakes control system to improve fuel efficiency of gasoline engine.

In controlling fuel efficiency by AFR in gasoline engine so far is still internal control, hence the fuel efficiency is not maximized. There should be a research to improve fuel efficiency. Improving fuel efficiency by controlling AFR could be integrated to external control system engine. One of the external systems is a brake control system.

The purpose of this research is how the design and implementation or integration of the AFR system and brake control system in a vehicle to improve fuel efficiency gasoline engine when braking system works.

II. METHODOLOGY

Fuel consumption is the amount of fuel needed by the engine in every minute. Controlling fuel efficiency the air-fuel mixture AFR is less (lean) when braking is the target of this

study. With a lean mixture, the gasoline that goes into the engine is reduced. By the time the machine requires a very large force, the engine must operate on a mixture of air-fuel more. Efficiency of AFR gasoline engine is the crucial topic. AFR setting is one method of increasing the fuel efficiency of gasoline engines. Brake control system is one part of the vehicle that is used to slow and stop. In a certain conditions the engine is used to slow the vehicle.

AFR is the ratio between the air with the fuel, gasoline with a certain ratio. AFR idea ratio is 14.67: 1. This condition has a characteristic that the internal combustion engine the most optimal, good engine performance and low exhaust emissions [22]. Ratio of 14.67: 1 means comparison between 14.67 air unit and one unit of fuel. AFR on the vehicle engine is expressed with the symbol lambda (λ). Lambda (λ) is the amount of ideal air required. Lambda (λ) = 1 is the amount of air goes into the engine cylinder in the same as the amount of ideal air required. Lambda (λ) < 1 the amount of air that is smaller than the amount of ideal air required, in this situation the engine needs more air, the mixture is fat, within certain limits can increase engine power. Lambda (λ) > 1 the amount of air that enters more than the ideal air requirement, the engine is excessive of air, the mixture is lean and there is less power. Lambda (λ) > 1.2 is in a situation that the air-fuel mixture is very low so it might be possible to combust on a wider range.

Stoichiometry is an ideal condition mixing system between air and fuel. The fuel-air mixture ratio is 14.7: 1 which could optimize engine power, low exhaust emissions and fuel efficiency can be increased. Based on the measurements, AFR Stoichiometry on a real vehicle can be achieved when the engine has reached the working temperature, as well as the traveling average speeds ranging from 50 km/h. It is influenced by future vehicles, road conditions and the way of driving.

The brake system is an important system of a vehicle. The brake system serves as a safety device in a vehicle that is designed to regulate the movement, to reduce the speed and stop the vehicle. In the brake system, the braking power is generally obtained from the friction of brake shoes on the field of friction rotating together with the wheel. The working principle of the brake system is changing the energy of motion into heat energy. In the hybrid technology system brake system is used to improve the charging battery through state of charging. When the vehicle brake works the generator will charge the battery in large numbers, so the battery will quickly filled. In condition where the battery is fully charged the electric motor can propel the vehicle longer. In this study, the brake system was used to improve the efficiency of fuel.

In this research, we used an gasoline engine with engine specification as shown in Table 1. For realizable design, we used wiring layout design as shown in Figure 1, as ECU Brake Control System was designed using microcontroller (with Fuzzy Logic Controller) and Programmable Logic Controller.

TABLE 1. ENGINE SPECIFICATION

| <i>Item</i> | <i>Specification</i> |
|--------------------|-------------------------|
| Vehicle | Toyota Soluna |
| Number of Cylinder | 4 |
| Type | 4 tag, injection system |
| Volume | 1500 cc |

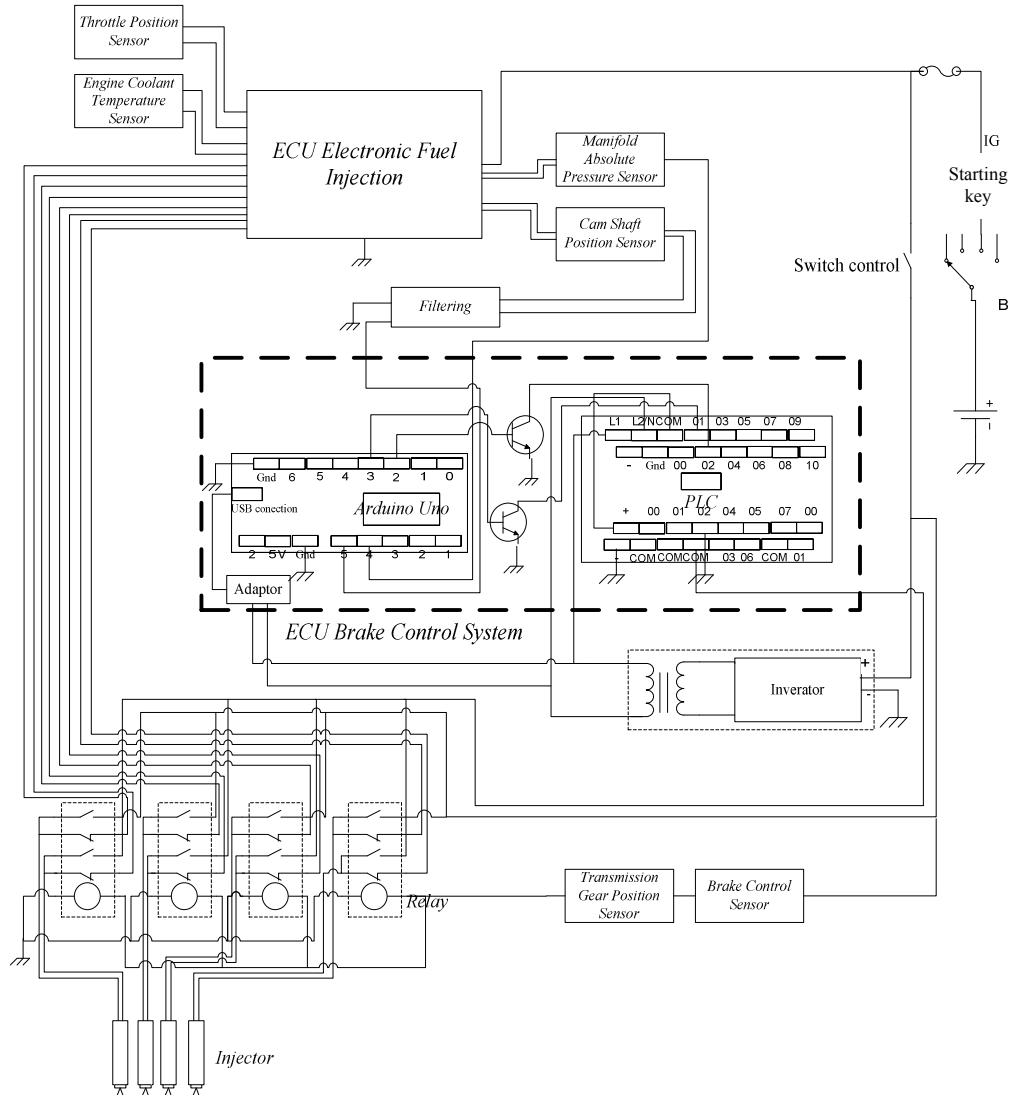


Fig. 1. Wiring layout design implementation

Fuzzy logic controller (embedded in Arduino microcontroller system) was designed based on the input of the camshaft position sensor and the manifold absolute pressure sensor. Camshaft position sensor generates a voltage signal Alternating Current (AC) with the amount of voltage of 0 to 5 volts. The signals from these sensors are noisy so that the signal issued result is not applicable. These problems can be solved by changing the AC voltage, converting into a

voltage Direct Current (DC) and given a series of filtering. PLC was designed to generate some pulse signal to activate fuel injector. This PLC works based on fuzzy logic controller command and length of its pulse signal describes how much fuel to be fed into engine. By controlling fuel injection (to be poor fuel concentration or high AFR) along braking period, it will reduce much fuel consumption than default system.

The main principle work of this system control design is replacing ECU default by ECU Brake Control System when brake was activated by the driver, such that fuel efficiency will be reached. Otherwise, vehicle will operate ECU default normally.

Figure 2 describe Fuzzy Logic Control input membership functions design that was implemented into embedded system. The output membership functions use Takagi-Sugeno system with constant type of 0 or 1 with parameter of switching is 5.

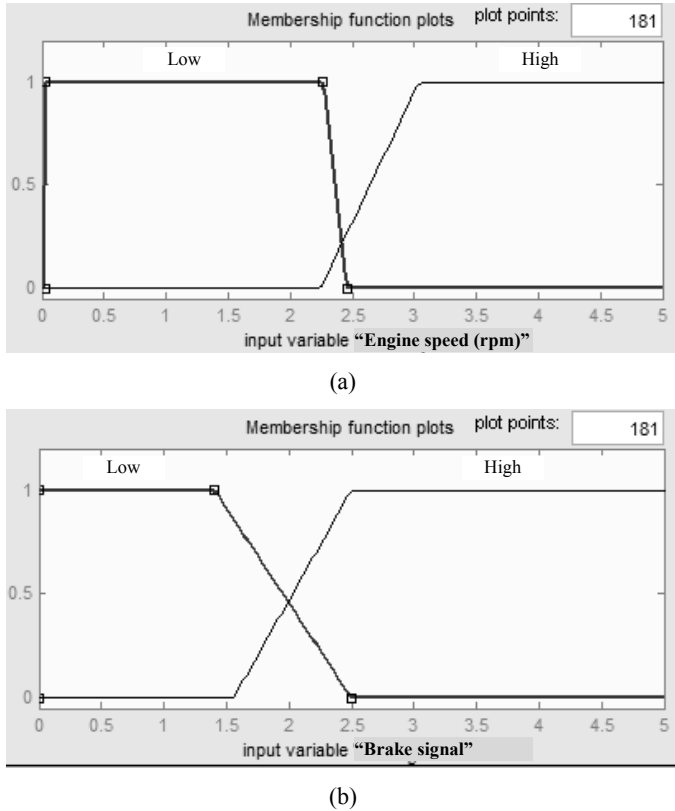


Fig. 2. Input membership functions, (a) Engine speed input (from camshaft position sensor), (b) Brake signal (from manifold absolute pressure sensor)

III. IMPLEMENTATION AND RESULT

Data collection of engine AFR was done using the exhaust gases Engine Gas Analyzer; when the engine in operation condition, the vehicle in brake condition, and the vehicle in running condition. The process of collection engine data was the retrieval of data derived from the phenomenon that occurs in a gasoline engine as measured by the measuring instrument.

AFR data when the vehicle was on braking the speed transmission gear position 2 of these conditions produced some information, as shown in Figure 3, the value of AFR read at times of 5th second. There is a distance of approximately 3 meters between the exhaust from the engine vehicle with gas engine analyzer, so the instrument takes readings. At times almost close to 10th second shows the

steady state system, while the time more than 10th second the system runs normally. When the vehicle is braking at 5th second later it is seen increasing the value AFR. In the graph shown brake control system when braking the effect on the value AFR is already obvious or fuel mixture with the air is reduced.

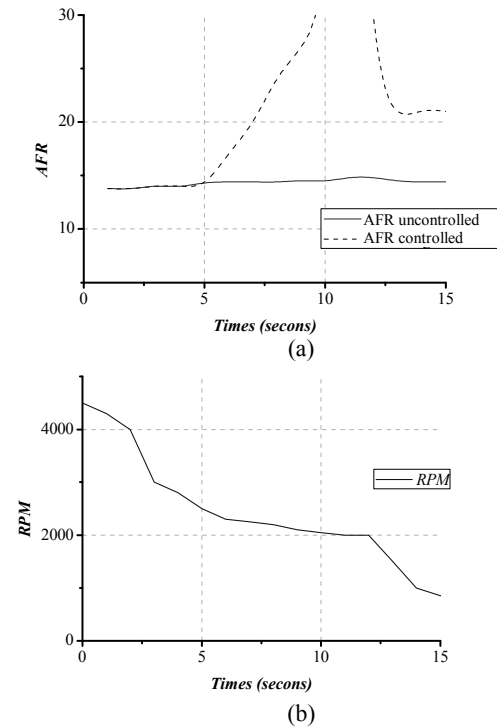


Fig. 3. Data AFR with 2 speed gear transmission position, (a) AFR output, (b) Engine speed output

AFR data when the vehicle is braking with transmission speed gear position 5 is in Figure 4. The data show between speed gear 5, 4 & 3 formed almost the same trend. Brake control system when braking shows the effect on the value of AFR or fuel mixture with the air is reduced. Rotation of 2500 RPM AFR value reaches the maximum limit on lean mixture, while the rotation from 3000 to 4500 RPM AFR value can reach an infinite value or fuel injected into the intake manifold terminated as a whole. This condition is resulted in the highest efficiency. Rotation of 2500 RPM engine speed without braking value AFR stoichiometry almost reached.

Summary result of a running experiment on normal asphalt road about 50.7 km is shown in Table 2.

TABLE 2. RESULTS OF MEASUREMENT OF FUEL CONSUMPTION

| No. | Distance | Fuel Consumption | Control |
|-----|-------------------------|------------------|---------|
| 1. | 50,7 km | 6 liter | - |
| 2. | 50,7 km | 4 liter | √ |
| | Consumption differences | 2 liter | |
| | Efficiency | 33,3 % | |

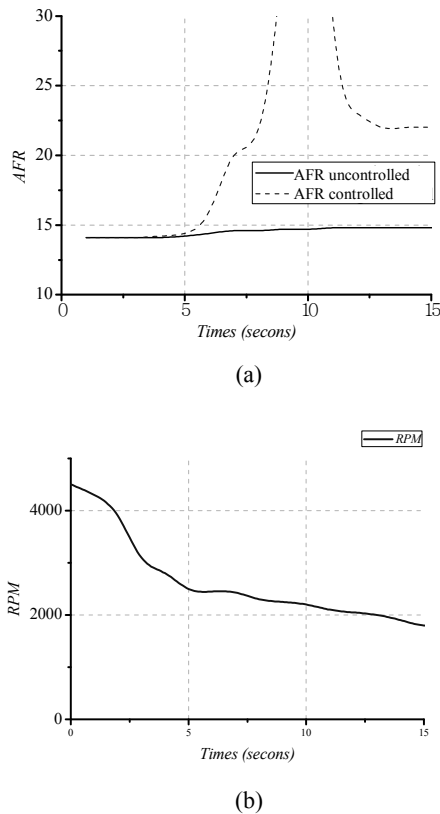


Fig. 4. AFR Data with speed transmission gear position 5, (a) AFR output, (b) Engine speed output.

IV. CONCLUSION

Vehicle in stop condition and running with speed transmission gear position 1 either on even road, a turn or decreasing road, either with brake control system or without the brake control system AFR values are regular. This shows economizer system in this area is not functioning. When the vehicle passes through horizontal, turning, downhill and uphill at speed transmission gear position more than 1 there is an increase in the value of AFR. Economizer in this area show functioning in stages, at 2000 rpm AFR value can reach 22, whereas when the rotation exceeds 2500 rpm AFR values increase infinity or fuel supply stopped as a whole.

In the measurement of fuel consumption when the vehicle runs by taking the distance of 50.7 km AFR system and brake control system developed has been able to reduce the fuel consumption of 6 liters to 4 liters. Improvement of fuel efficiency is approximately 33.3%. This study therefore has managed to improve vehicle efficiency. This developed control system is applicable to the vehicle operated on city streets or rural areas that often jammed and the drivers are busy with braking activities. Highest efficiency is achieved when the braking is done at the time of vehicle operation exceeds 2500 rpm.

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REFERENCES

- [1] S. Karagiorgis, K. Glover, and N. Collings, “Control Challenges in Automotive Engine Management,” *Eur. J. Control*, vol. 13, no. 2–3, pp. 92–104, 2007.
- [2] G. E. Tverberg, “Oil supply limits and the continuing financial crisis,” *Energy*, vol. 37, no. 1, pp. 27–34, 2012.
- [3] I. Kolesnikov, “Crude Oil Price Forecast: Long Term to 2025 | Data and Charts,” 2014. [Online]. Available: <http://knoema.com/yxtpab/crude-oil-price-forecast-long-term-to-2025-data-and-charts>. [Accessed: 26-Mar-2015].
- [4] J. Zhao and M. Xu, “Fuel economy optimization of an Atkinson cycle engine using genetic algorithm,” *Appl. Energy*, vol. 105, pp. 335–348, 2013.
- [5] B. Ebrahimi, R. Tafreshi, H. Masudi, M. Franchek, and J. Mohammadpour, “Control Engineering Practice A parameter-varying filtered PID strategy for air – fuel ratio control of spark ignition engines,” *Control Eng. Pract.*, vol. 20, no. 8, pp. 805–815, 2012.
- [6] Y. J. Zhai and D. L. Yu, “Neural network model-based automotive engine air/fuel ratio control and robustness evaluation,” *Eng. Appl. Artif. Intell.*, vol. 22, no. 2, pp. 171–180, 2009.
- [7] Y. Yildiz, A. M. Annaswamy, D. Yanakiev, and I. Kolmanovsky, “Spark ignition engine fuel-to-air ratio control: An adaptive control approach,” *Control Eng. Pract.*, vol. 18, no. 12, pp. 1369–1378, 2010.
- [8] N. Kheir, M. Salman, and N. J. Schouten, “Emissions and fuel economy trade-off for hybrid vehicles using fuzzy logic,” *Math. Comput. Simul.*, vol. 66, no. 2–3, pp. 155–172, 2004.
- [9] R. K. Maurya and A. K. Agarwal, “Experimental investigation on the effect of intake air temperature and air – fuel ratio on cycle-to-cycle variations of HCCI combustion and performance parameters,” *Appl. Energy*, vol. 88, no. 4, pp. 1153–1163, 2011.
- [10] A. M. Pourkhesalian, A. H. Shamekhi, and F. Salimi, “Alternative fuel and gasoline in an SI engine: A comparative study of performance and emissions characteristics,” *Fuel*, vol. 89, no. 5, pp. 1056–1063, 2009.
- [11] M. Gäfvert, K. E. Årzén, L. M. Pedersen, and B. Bernhardsson, “Control of GDI engines using torque feedback exemplified by simulations,” *Control Eng. Pract.*, vol. 12, no. 2, pp. 165–180, 2004.
- [12] M. A. Ceviz, “Temperature and air – fuel ratio dependent specific heat ratio functions for lean burned and unburned mixture,” *Energy Convers. Manag.*, vol. 46, pp. 2387–2404, 2005.
- [13] E. Zervas, X. Montagne, and J. Lahaye, “Influence of fuel and air / fuel equivalence ratio on the emission of hydrocarbons from a SI engine. 1. Experimental findings,” *Fuel*, vol. 83, no. 17–18, pp. 2301–2311, 2004.
- [14] E. Zervas, X. Montagne, and J. Lahaye, “Emission of specific pollutants from a compressionignition engine. Influence of fuel

- hydrotreatment and fuel/air equivalence ratio,” *Atmos. Environ.*, vol. 35, pp. 1301–1306, 2001.
- [15] C. W. Wu, R. H. Chen, J. Y. Pu, and T. H. Lin, “The influence of air-fuel ratio on engine performance and pollutant emissions of an SI engine using ethanol-gasoline-blended fuels,” *Atmos. Environ.*, vol. 38, no. 40, pp. 7093–7100, 2004.
- [16] A. Jansri and P. Sooraksa, “Enhanced model and fuzzy strategy of air to fuel ratio control for spark ignition engines,” *Comput. Math. with Appl.*, vol. 64, no. 5, pp. 922–933, 2012.
- [17] V. D. Efimov, O. V. Nikiforov, and H. Javaherian, “Control Engineering Practice Supervisory control of air – fuel ratio in spark ignition engines,” *Control Eng. Pract.*, vol. 30, pp. 27–33, 2014.
- [18] T. Bouarar, K. Guelton, and N. Manamanni, “Robust fuzzy Lyapunov stabilization for uncertain and disturbed TakagiSugeno descriptors,” *ISA Trans.*, vol. 49, no. 4, pp. 447–461, 2010.
- [19] T. S. Wu, M. Karkoub, S. H. Chen, S. W. Yu, and G. M. Her, “Robust tracking observer-based adaptive fuzzy control design for uncertain nonlinear MIMO systems with time delayed states,” *Inf. Sci. (Ny)*, vol. 290, pp. 86–105, 2014.
- [20] I. Arsie, C. Pianese, and M. Sorrentino, “A procedure to enhance identification of recurrent neural networks for simulating air-fuel ratio dynamics in SI engines,” *Eng. Appl. Artif. Intell.*, vol. 19, no. 1, pp. 65–77, 2006.
- [21] Y. J. Zhai, D. W. Yu, H. Y. Guo, and D. L. Yu, “Robust air/fuel ratio control with adaptive DRNN model and AD tuning,” *Eng. Appl. Artif. Intell.*, vol. 23, no. 2, pp. 283–289, 2010.
- [22] B. J. Heywood, *Internal combustion engine fundamental*. McGraw-Hill, Inc. United States of America, 1988.