

## Develop an ECU for Controlling Fuel Injectors Using Arduino and LabVIEW for Training Purposes

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### ABSTRACT

The technology of electronic motor control is now advancing rapidly. Many studies and applications have been done on automatic system control in vehicles. The automatic fuel injection control system for automobile engines is a unique area of study and instruction in universities. The engine will run more efficiently, use less fuel, and emit fewer emissions when the fuel injection system is precisely controlled. It is challenging for student research to evaluate improvements to engine performance on real engine controller units (ECUs). Since their ECUs are already set for specific automotive duties, it is challenging to run tests by modifying the ECU's input parameters. In this study, a programmable ECU was created to explore the characteristics of the fuel injection system using the open-source, low-cost Arduino microcontroller. Using LabVIEW software, the algorithmic program computes and graphically simulates the injector characteristics. This study determines the injector opening time and fuel volume injected using the data from the intake manifold pressure sensor, lambda signal, engine temperature, throttle position, engine speed, and exhaust gas sensor. The primary objective of this study was not to replace a real ECU. It was more beneficial for students to be able to equip themselves with tools and apply methodologies to perform many experiments at home rather than utilizing commercially available ECUs at exorbitant rates, thanks to the development of a low-cost ECU based on Arduino and LabVIEW in this study.

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### 1. Introduction

To increase efficiency and accuracy, automatic control of mechanical and electronic systems is becoming more popular as smart gadgets proliferate. Electronic fuel injection is one of the concepts that is gaining traction in the automotive industry. To design a control system that satisfies the needs of injection flow and injection timing while improving the operating efficiency of the engine and lowering emissions into the environment, the electronic fuel injection system is still in the development stage. New engine technology has been progressively introduced into the global auto industry throughout the years [1], [2]. Cars are becoming increasingly smarter thanks to significant advancements in platform-based automotive intelligent control systems [3], [4], and embedded systems [5]-[7].

The major influence today is the source of carbon dioxide (CO<sup>2</sup>) emissions coming from vehicles that pollute the environment heavily [8]-[10]. The cause of this emission comes from the inferior performance of car engines. To solve this problem, a lot of research has been conducted around the world to improve the working efficiency of engines. Some studies revolve around the problem of calculating and optimizing the optimal operation of fuel injection control systems in cars. In [11], the authors performed optimal calculations of the suitability of fuel injectors to the combustion chamber geometry for diesel engines. In the study [12], the authors performed experiments that adjusted different fuel injection timing and pressure to produce a variety of emissions levels under engine operating conditions. Test results showed that increasing fuel injection pressure improved combustion characteristics and reduced emissions. In [13], the authors performed the study by replacing the

carburetor system with a closed-loop EFI system for 4-stroke gasoline engines. Experiments conducted by comparing fuel consumption and engine performance showed that the EFI system improved fuel economy by an average of 13% across most speed ranges.

From the efficiencies obtained by optimizing the fuel injection control system, cheap open-source microcontrollers such as Arduino are very widely used. The construction, testing, and development of fuel injection control systems using Arduino microcontrollers have many advantages over genuine ECU units. These advantages come from the price, which means that everyone, even students, can equip themselves with an Arduino to study. Another advantage is that the hardware is easy to program and can be used to build control algorithms on many different software platforms besides the Arduino IDE, such as LabVIEW, MATLAB, and C# software. Through visual programming software such as LabVIEW and MATLAB, learners can easily calibrate experiments and observe results through charts. In [14], the authors developed a programmable ECU based on the Arduino Mega 2560 to control common rail fuel injection and engine operating parameters. This study concluded the injector parameters, including opening time, low time, and duty cycle, were optimized using the reaction surface method. The ignition controller and fuel injection driver are built on Arduino hardware [15]. In this study, the driver allowed the Arduino to combine with the camshaft position sensor used to generate a shut-off signal to control both ignition timing and fuel injection with reliable results.

In Vietnam, many studies on fuel injection system control solutions based on low-cost Arduino microcontrollers have been conducted. In [16], the authors made a design for a high-resistance gasoline nozzle test tape. The control circuit uses the Arduino Uno R3 type. The research results have developed a method of using test tapes to determine the parameter set of nozzles, and from there can determine the amount of gasoline sprayed according to the control pulse time. In [17], the authors built a model of the Toyota Hilux common rail electronic diesel engine control system for teaching and learning. However, a limitation of the studies [16], [17] is that there has not been developed a visual control and monitoring system that allows learners to adjust parameters and observe the results through a computer at home. Some indicators to observe must be using waveform meters that are too expensive for learners to equip themselves, and indicators through 7-segment LEDs are also limited for those who do not have access to these models at home. In [18], the authors built an electronic fuel injection engine teaching model based on LabVIEW software. However, the limitations of this study are limited to the presentation of the results. The research article has not presented computational parts and experimental methods so that learners cannot conduct repeated experiments.

In this study, the authors collected the input and output signals of the actual ECU with values such as throttle position, intake air flow sensor, air intake efficiency, engine speed, injector opening, intake manifold pressure sensor, etc. Lambda signals, engine temperature, and exhaust sensors are used to calculate the timing of opening the injectors and the volume of fuel to be injected. The authors also used the air-fuel ratio function table of engine speed and torque as the basis for the calculations in the study [19], [20]. The results after conducting the study showed that the application of the input values of the ECU used for simulation in LabVIEW and the implementation of fuel injector control from the Arduino module achieved reliable results. This research, after its completion, has been applied in building learning models and experiments for teaching subjects related to automatic control systems in cars to engineering students at a low cost. The main objective of this study is to introduce students to one more method and tool so that they can learn through the project. From the signal collection and control results shown through LabVIEW software visually, learners can easily observe, evaluate, and adjust parameters for different experiments, so learners can quickly access good applications for practical exercises and carrying out scientific research.

## **2. Materials and Methods**

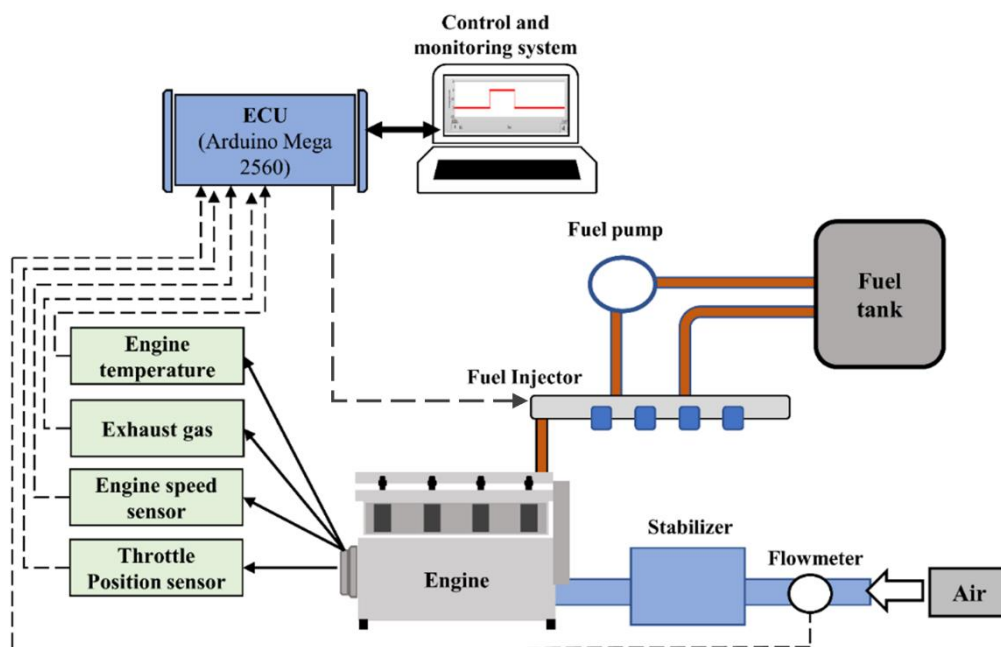
### **2.1. Materials**

In this study, the authors used the Arduino Mega 2560 module to collect sensor input data and process the outputs to control the fuel injectors. After being processed by LabVIEW calculations, the output of the Arduino will be utilized to drive the MOSFET module, which enables the opening of four fuel injectors by the calculated time by coordinating prior input parameters. One engine with a displacement

of 1.4 liters and four cylinders was used in related experiments. Device specifications are described in Table 1, and model settings are presented in Figure 1.

**Table 1.** Specifications of the materials

Rank	Name	Specifications
1	Engine	1.4 L
2	Arduino Mega 2560	54 DI/DO (12 PWM pins), 16 AI/AO
3	RPM Sensor Engine speed	Volvo S40/V40 1.9 L
4	Throttle Position Sensor	5VDC, Electrical rotation angle 100°
5	MOSFET DC	Input 5VDC Logic, output 24VDC/30A
6	Fuel Injector	Bosch Fuel Injectors (12.1 OHM's, 264 CC/min, 25.1 Lb/hr)



**Figure 1.** Test bench Setup. ECU: Electronic Control Unit

## 2.2. Methods

The authors used input data from the engine speed sensor, throttle position sensor, and engine working parameters as the basic components to be able to control the fuel injectors. The engine's operational performance determines when to open the injectors and how much fuel to inject. In addition, to achieve the desired target metrics such as the lambda and intake air efficiency, we established calculations based on the reference to the air-fuel ratio (AFR) function table of engine speed and torque. The components of the calculation are described in detail below.

### 2.2.1. The air-fuel ratio (AFR)

The air-fuel ratio is a key indicator and a crucial measurement for gasoline engine performance control and tuning, as well as for reasons related to reducing vehicle exhaust emissions pollution. The AFR is referred to or recognized as a stoichiometric mixture when the air supplied is precisely sufficient to burn all the gasoline fuel. Rich air-fuel mixtures are those with lower air-to-fuel ratios than stoichiometric ratios, which are less efficient, produce more power, and burn at a lower temperature, which is easier on the engine. Lean air-fuel combinations are more efficient but harm the engine and

emit more nitrogen oxide (NO<sub>x</sub>) than stoichiometric mixtures do. Air-fuel ratios higher than stoichiometric mixtures are referred to as lean air-fuel mixtures. When an engine is powered or operated at a stoichiometric air-fuel mixture, the combustion process produces a very hot flame that can harm engine parts and components. The air-fuel mixture may detonate immediately after reaching the maximum cylinder pressure under a heavy load, which will generate knocking, due to the high temperature of the mixture. Detonation of the air-fuel combination can result in serious and significant engine damage because the uncontrolled combustion of the air-fuel mixture can produce extremely high pressure in the engine's cylinders. To minimize overheating and detonation of the engine's cylinder heads, a richer mixture is employed instead of stoichiometric air-fuel mixes during light load situations. This richer mixture also produces cooler combustion products. In gasoline-fueled internal combustion engines, the air-fuel ratio is the most often used indication and measure for air-fuel mixtures, and it is computed using Equation 1 [21].

$$AFR = \frac{m_a}{m_f} \quad (1)$$

In Equation (1), the mass of air =  $m_a$  and the mass of fuel  $m_f$

For complete gasoline fuel combustion, the stoichiometric AFR for a gasoline-fueled engine is roughly 14.7:1. One kilogram of gasoline requires 14.7 kilograms of air to be burned entirely. Even when the air-to-fuel ratio deviates from the ideal mixture, combustion can still take place. The AFR must be at least 6:1 and can occasionally reach a maximum of 20:1 for the combustion process to occur in a gasoline-powered engine. When the AFR is higher than the stoichiometric ratio, the air-fuel combination is known as a lean mixture, and when it is lower than the stoichiometric ratio, the air-fuel mixture is known as a rich mixture. For a gasoline-powered engine, for instance, a lean mixture is 16.5:1, and a rich mixture is 13.7:1. Depending on the engine's operating circumstances, such as speed, load, temperature, etc., the air-fuel ratio for spark ignition engines can range from 12:1 (rich mixture) to 20:1 (lean mixture). The moderate or new internal combustion engines operate as much as possible around or near the stoichiometric AFR, mostly for emission gas treatment purposes.

### 2.2.2. Air-fuel equivalence ratio or lambda ( $\lambda$ )

The real ratio of the actual AFR to the stoichiometric AFR is called the air-fuel equivalency ratio or lambda ( $\lambda$ ).  $\lambda = 1.0$  is at stoichiometric AFR, rich air-fuel mixture has  $\lambda < 1.0$ , and lean mixture has  $\lambda > 1.0$ . The AFR and  $\lambda$  have a direct relationship. To calculate the AFR from a given  $\lambda$  value, multiply the measured  $\lambda$  by the stoichiometric AFR for that fuel. Alternatively, to recover  $\lambda$  value from an AFR, divide AFR by the stoichiometric AFR for that fuel. Equation 2 is often used as the definition of  $\lambda$  [22]:

$$\lambda = \frac{AFR_{actual}}{AFR_{stoich}} = \frac{(m_a/m_f)_{actual}}{(m_a/m_f)_{stoich}} \quad (2)$$

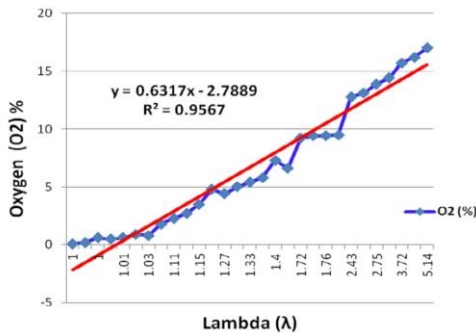
Where  $AFR_{actual}$  = actual AFR,  $AFR_{stoich}$  = stoichiometric AFR

### 2.2.3. The relationship between the lambda or air-fuel equivalency ratio and the proportion of exhaust emissions

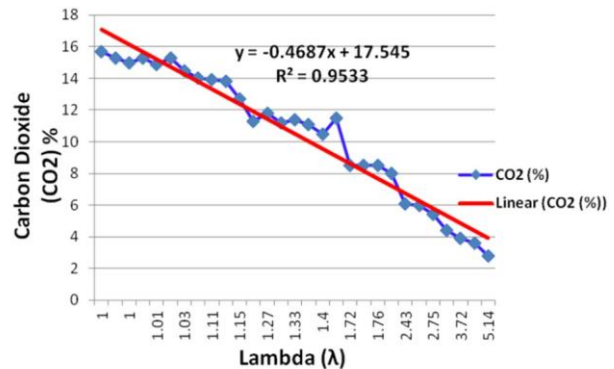
The following studies and discussions examine the relationship between measured  $\lambda$  and exhaust emission gases, such as oxygen (O<sub>2</sub>), carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), nitrogen oxide (NO), and hydrocarbons (C<sub>x</sub>H<sub>y</sub>). In [19], the authors study the relationship between  $\lambda$ , the percentage and value of exhaust emissions, and the AFR for a 1.6 L gasoline engine. Data for each car, such as Nissan and Toyota, including manufacturing company, manufacture year, AFR,  $\lambda$ , and exhaust emissions percentages and values, were compiled. Following the experiments, the authors provided the following observations regarding the connection between  $\lambda$ , AFR, and emission rates.

- *The relation between measured lambda and exhaust-emitted oxygen (O<sub>2</sub>) percentages:* According to the measurement results, oxygen (O<sub>2</sub>) emission rises as  $\lambda$  values rise (see Figure 2). All

the oxygen (O<sub>2</sub>) will be consumed along with the fuel in the ideal or full combustion, leaving only carbon dioxide (CO<sub>2</sub>) and water behind. An accurate linear relationship between the measured values and O<sub>2</sub> percentages was found with a high R-squared (R<sup>2</sup>) value of 95.67%.



**Figure 2.** Relation between oxygen (O<sub>2</sub>) exhaust emission percentages and air-fuel equivalency ratio, or lambda values of 1.6 L engine size



**Figure 3.** Relation between carbon dioxide (CO<sub>2</sub>) exhaust emission percentages and air-fuel equivalency ratio, or lambda values of 1.6 L engine size

- The relation between measured lambda and the percentages of carbon dioxide (CO<sub>2</sub>) emitted from exhaust: The measurement results show that the carbon dioxide (CO<sub>2</sub>) emission increases with increasing lambda values (see Figure 3). Fuel is completely burned, only leaving behind carbon dioxide (CO<sub>2</sub>) and water. A linear relation between the measured lambda values and CO<sub>2</sub> percentages was found, with a high R-squared (R<sup>2</sup>) value of 95.33 percent.

The results obtained in the study of the authors [19] and the AFR function table of engine speed and torque to determine the desired target parameters [20]. In this study, the authors relied on the engine speed and throttle opening surveyed including the lambda values and air intake efficiency (%). We have built the desired target values, and these data will be fed into the processing algorithm inside LabVIEW software to perform calculations and controls. The AFR reference table is used to construct calculations to achieve the target indicators and target load performance shown in Figure 4. Target intake efficiency based on throttle position and engine speed is presented in Table 2.

		Engine speed [rpm]												
		500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500
Engine torque [Nm]	10	14	14.7	16.4	17.5	19.8	19.8	18.8	18.1	18.1	18.1	18.1	18.1	18.1
	20	14	14.7	14.7	16.4	16.4	16.4	16.5	16.8	16.8	16.8	16.8	16.8	16.8
	30	14	14.7	14.7	14.7	14.7	14.7	14.7	15.7	15.7	15.3	14.9	14.9	14.9
	40	14.2	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	13.9	13.3	13.3	13.3
	50	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.5	12.9	12.9	12.9
	60	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.3	13.3	12.6	12.1	11.8
	70	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	13.6	12.9	12.2	11.8	11.3
	80	14.1	14.2	14.7	14.7	14.7	14.7	14.7	14.7	13.3	12.5	11.9	11.4	10.9
	90	13.4	13.4	13.8	14.3	14.3	14.7	14.7	13.6	13.1	12.2	11.5	11.1	10.7
	100	13.4	13.4	13.4	13.4	13.4	13.6	13.6	12.1	12.1	11.6	11.2	10.8	10.5
	110	13.4	13.4	13.4	13.4	13.1	13.1	13.1	11.8	11.8	11.2	10.7	10.5	10.3
	120	13.4	13.4	13.4	13.4	12.9	12.9	12.5	11.6	11.3	10.5	10.4	10.3	10.2
	130	13.4	13.4	13.4	13.4	12.9	12.9	12.5	11.6	11.3	10.5	10.4	10.3	10.2
	140	13.4	13.4	13.4	13.4	12.9	12.9	12.5	11.6	11.3	10.5	10.4	10.3	10.2

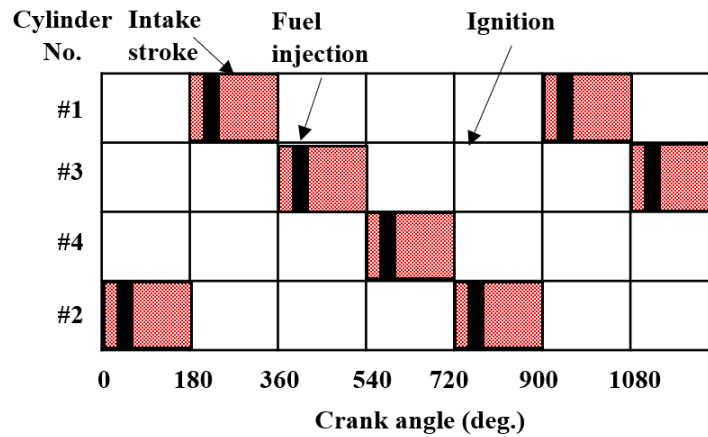
**Figure 4.** Example of air-fuel ratio (AFR) function of engine speed and torque [20]

**Table 2.** Target intake efficiency based on throttle position and speed of the engine

Throttle position (%)	Air intake efficiency (%)	on the speed of the engine			
		1000 RPM	2500 RPM	4000 RPM	5500 RPM
7.0	60	1.00	1.35	1.23	1.23
14.0	61	1.00	1.12	1.14	1.14
21.0	62	1.00	1.00	1.07	1.01
28.0	63	1.00	1.00	1.00	0.90
35.0	64	1.00	1.00	1.00	0.88
42.0	68	1.00	1.00	1.00	0.86
49.0	70	1.00	1.00	1.00	0.83
56.0	72	0.97	1.00	1.00	0.81
63.0	74	0.91	0.97	0.93	0.78
70.0	76	0.91	0.91	0.82	0.76
77.0	80	0.91	0.89	0.80	0.73
84.0	81	0.91	0.88	0.79	0.71
91.0	83	0.91	0.88	0.79	0.71
100.0	85	0.91	0.88	0.79	0.71

**2.2.4. Calculation of the amount of injected fuel and the time of opening the injector for one cycle**

In this study, the authors used an engine with a displacement of 1.4 liters, consisting of four cylinders, four strokes, and four fuel injectors, and an operating cycle described in Figure 5.



**Figure 5.** Fuel injection cycle of the engine

Cylinder intake volume in one charge (liters):

$$V_{Intake\_cylinder} = \frac{C_{Engine}}{n_{Cylinder}} = \frac{1.4}{4} = 0.35 \quad (3)$$

In Equation 3,  $V_{Intake\_cylinder}$  is the intake air volume of the cylinder in one intake,  $C_{Engine}$  is the capacity of the engine, and  $n_{Cylinder}$  is the number of cylinders of the engine.

Calculate the volume of air intake for a real cycle (mg):

$$m_{ai\_actual} = \frac{V_{Intake\_cylinder} * aie * m_a}{14.7} \quad (4)$$

In Equation 4,  $m_{ai\_actual}$  which is the mass of air loaded for an actual cycle,  $m_a$  which is the specific mass of air (1,130.5 mg/liter),  $aie$  is the air intake efficiency rate of the engine.

The volume of air loaded into a cylinder in one minute (liter):

$$V_{ai\_actual} = V_{Intake\_cylinder} * aie * \frac{N_e}{2} \quad (5)$$

In Equation 5,  $V_{ai\_actual}$  is the volume of air loaded into a cylinder for one minute,  $N_e$  which is the speed of the engine surveyed in rounds per minute (RPM).

The mass of air loaded into the cylinder in one minute (mg):

$$m_{ai\_actual1m} = V_{ai\_actual} * m_a \quad (6)$$

The mass of fuel sprayed for a cylinder for one minute (mg):

$$m_{f\_actual1m} = \frac{m_{ai\_actual1m}}{(14.7 *)} \quad (7)$$

The mass of fuel sprayed for a cycle (X [mg]):

$$X = \frac{m_{f\_actual1m}}{N_e/2} \quad (8)$$

Opening time for a cycle (Y [ms]):

$$Y = (0.33 * X) - 0.57 \quad (9)$$

### 2.2.5. Development of fuel injection control program

In this study, we used LabVIEW software to perform automated program building that calculates and controls the injectors in operation. The advantage of LabVIEW software is that it allows for building intuitive human-machine interaction interfaces. LabVIEW also allows programming in many different languages, such as G-code and C programming. The collection of data and control of different hardware is also relatively convenient due to the support from the software. Therefore, we used the Arduino Mega 2560 module, which is cheap but meets all the requirements to allow the program to be built, making it suitable for students to equip themselves and do their homework at home. The calculation from Equation 1 to Equation 9 is set, and the Arduino output control is shown in Figure 6. The control and monitoring interface of the program is depicted in Figure 7.

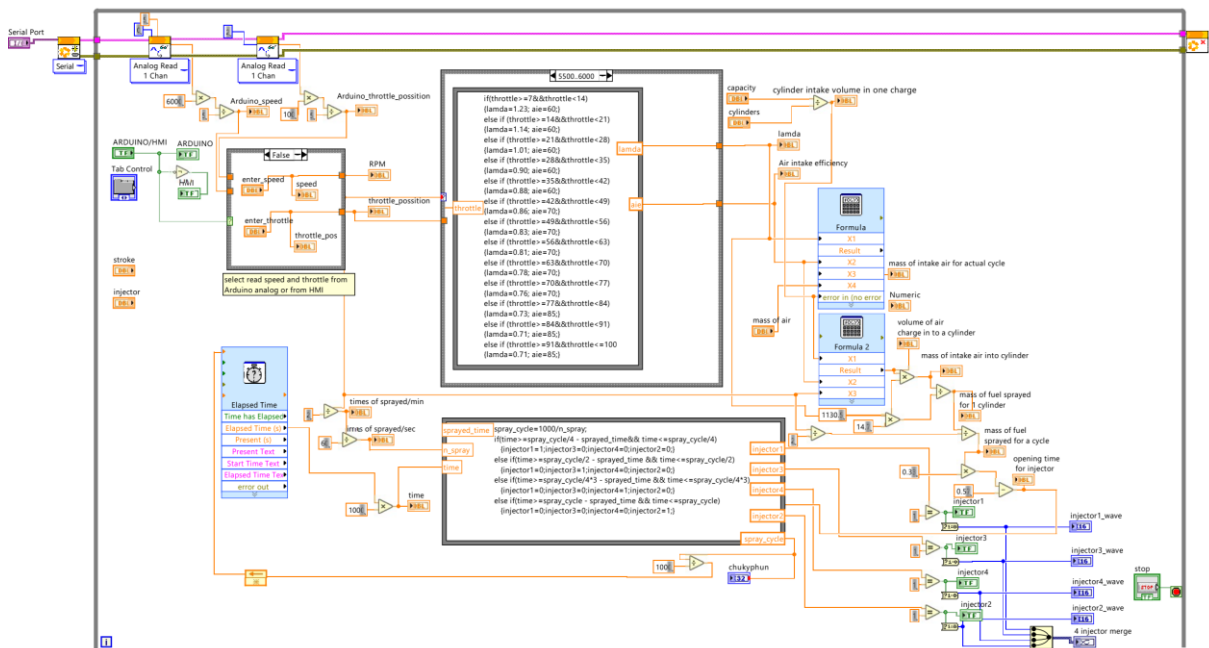


Figure 6. Programming program on LabVIEW software



Figure 7. Control and monitoring interface on LabVIEW software

### 3. Results and Discussion

#### 3.1. Calculate fuel injector opening time.

The input parameters for calculating the fuel injection time and checking the characteristics of the injectors are presented in Table 3. These inputs are entered from the console, and monitoring is depicted in Figure 7. Other input parameters, such as exhaust sensor and intake efficiency, have been pre-set in the programming, and a program to achieve target charging efficiency percentage indicators has been formulated in Table 2.

Table 3. Input variables for fuel injector calculations.

No	Parameters	Input value	No	Parameters	Input value
1	Engine speed	2500 RPM	5	Engine displacement	1.4 liters
2	Throttle valve position	85%	6	Number of injectors	4
3	Number of cylinders of the engine	4	7	Air mass	1130.5 mg/liter
4	Stroke number of the engine	4			

From the input values of Table 3, the interface of Figure 7 was created, and the results of calculating the values related to the volume of fuel injected and the injection time are presented in Table 4. The result of calculating the fuel injection time of each injector is presented in Figure 8.

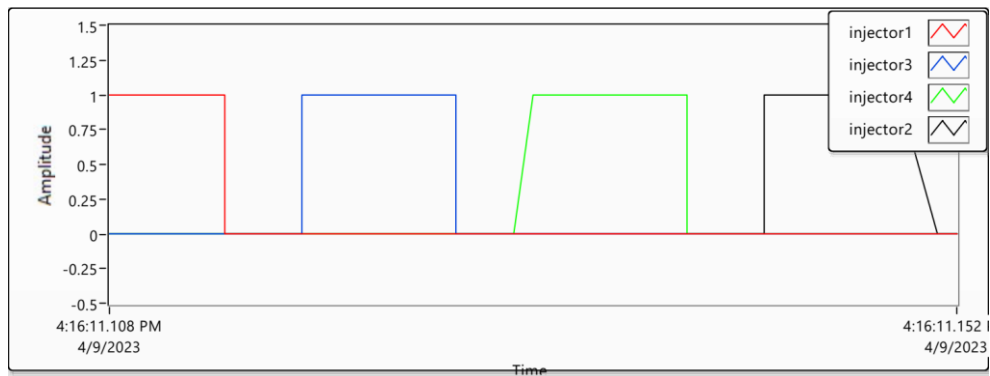
Table 4. The result of calculating the volume of fuel and the time of opening the fuel injectors

No	Parameters to calculate	Result	No	Parameters to calculate	Result
1	Lambda	0.88	7	Mass of fuel sprayed for 1 cylinder in 1 minute	32498.8mg
2	Air intake efficiency	85%	8	Mass of fuel sprayed for a cycle	25.9991mg
3	Cylinder intake volume in one charge	0.35 liters	9	Opening time of injector for a cycle	8.0096ms
4	Mass of intake air for actual cycle	20.1337mg	10	Number of times open injector in 1 minute	1250 times

5	The volume of air charged into a cylinder in 1 minute	371.875ml	11	Number of times open injector in 1 second	20.8333 times
6	Mass of intake air into the cylinder in 1 minute	420405mg			

Figure 8 depicts the opening times of injectors 1, 2, 3, and 4. These injectors will operate according to the cycle depicted in Figure 5. These injectors are open and out of phase with each other by 180°. Through Figure 8, the injector opening time works properly according to the calculation results from the results in Table 4. The injectors are opened in turn and the time allocated to each injector achieves good results.

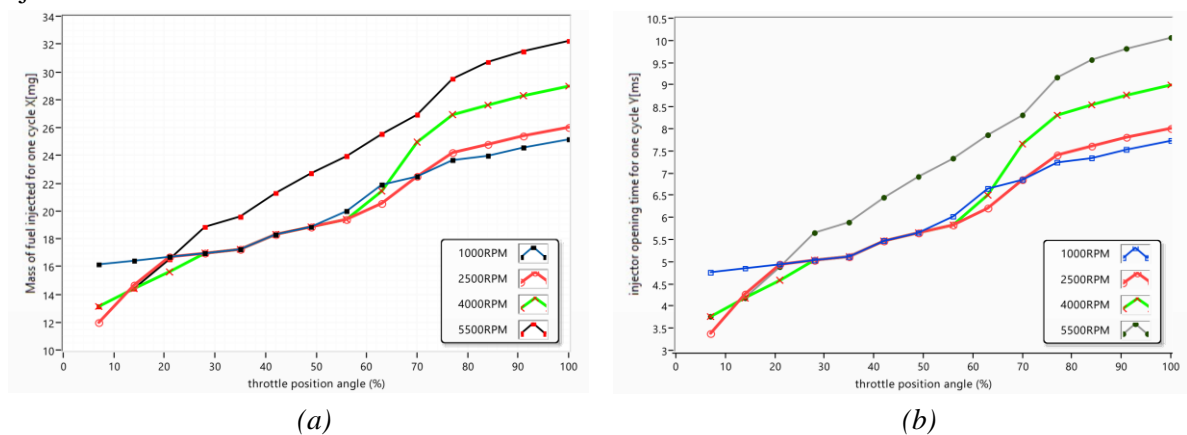
The outputs of the Arduino are pulsed to control the output and open the timed active injectors that are automatically set in the program. However, the output of the Arduino pins has a maximum voltage of only 5 VDC, but the injectors operate with a power supply of 24 VDC, so 4 MOSFET DC modules must be used as intermediate switches between the Arduino outputs to control the injectors' operation.



**Figure 8.** Characteristics of 4 injectors

### 3.2. Simulation of the volume of injected fuel and the time of opening the injectors

In this study, we performed experiments that controlled fuel injectors one after another at different speeds and different throttle valve angle positions. We have made speed changes at values of 1000 RPM, 2500 RPM, 4000 RPM, and 5500 RPM, respectively, with throttle valve angle values from 7% to 100%, corresponding to Table 2. The results obtained will be compared with the actual fuel consumption; these values will serve as the basis for us to evaluate the injector characteristics and thereby make reasonable adjustments.



**Figure 9.** The relationship between speed, throttle position, the volume of fuel injected, and injector opening time is as follows: (a) fuel volume to be injected per cycle; (b) injector opening time per cycle.

The results of the program's calculations on the correlation between speed, throttle valve angle position, and the volume of fuel injected for a specific cycle are shown in Figure 9a. We can see that if

we alter the speed while maintaining the same throttle valve angle, the injectors will need to inject more gasoline. The correlation between engine speed, throttle valve angle position, and injector opening time is shown in Figure 9b. We notice that if we retain the same position of the throttle valve angle and gradually raise the engine speed, the time to open the injectors will also rise, just like the amount of gasoline that needs to be injected. We discovered that the use of LabVIEW software and an Arduino module to develop experiments linked to automatic control systems in cars has produced positive results through the programming of computational algorithms, automatic control, and data gathering. We can easily observe the results thanks to the user-friendly interface without the use of numerous additional external measuring tools. Students have access to new, affordable control theories for Arduino modules when they utilize them to replace exclusive and secure ECUs. This is advantageous since it enables them to outfit and construct research models at home.

#### 4. Conclusions

The primary source of emissions and the greatest environmental polluter are vehicles. Because of this, finding ways to lower car emissions is a major problem. In the world and Vietnam, there is a significant development tendency toward learning, investigating, and developing automatic fuel injection control systems for intelligent electronic application engines. The goal of these studies is to find ways to run cars more effectively. Additionally, there are numerous advantages to the study and research done to enhance the performance of modern fuel injection systems. These advantages are supported using inexpensive open-source microcontroller technology platforms and user-friendly programming tools. In this study, using a low-cost, open-source programmable microcontroller called the Arduino Mega 2560 and LabVIEW software, the authors developed a program to calculate and control fuel injection for engines. The author developed a calculating approach to help students in understanding the basic workings of an electric fuel injection system. This calculation method is based on references from actual measured values and the link between lambda values, air-fuel ratio, and emissions. The findings of this research show that the fuel injection system functions effectively and produces positive results. Charts on the LabVIEW program are used to visually depict the injectors' characteristics. However, this research only relates to the fields of learning and research and is not meant to take the role of an actual ECU. The results of the research suggest that LabVIEW and Arduino's microcontrollers are practical learning tools that let students' study independently on a budget. Through this study, the authors also give students a computational method and a tool so that students can more easily complete projects, repeat experiments, and develop themselves according to them.

**Conflicts of Interest:** The authors declare no conflict of interest.

#### REFERENCES

- [1] F. Arena, G. Pau, and A. Severino, "An Overview on the Current Status and Future Perspectives of Smart Cars," *Infrastructures*, vol. 5, no. 7, p. 53, 2020.
- [2] J. E. Duff, *Modern Automotive Technology Tenth Edition*, Tenth Edition ed. New York, NY, USA: GM Goodheart Willcox, 2020.
- [3] V. Dobromirov, S. Dotsenko, V. Verstov, and S. Volkov, "Methods of Examining Vehicle Electronic Systems in the Course of Automotive Forensic Expert Examinations," *Transportation Research Procedia*, vol. 20, pp. 143-150, 2017.
- [4] J. Á. Gumiel, J. Mabe, J. Jiménez, and J. Barruetaña, "Introducing the Electronic Knowledge Framework into the Traditional Automotive Suppliers' Industry: From Mechanical Engineering to Mechatronics," *Businesses*, vol. 2, no. 2, pp. 273-289, 2022.
- [5] Y. Jiao and B. M. Wilamowski, "Recent advances in in-vehicle embedded systems," in *IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society*, Melbourne, VIC, Australia, 2011, pp. 4623-4625.
- [6] C. Kathepuri, A. V. Nyayanit, J. Joglekar, and M. Kale, "Embedded system for automotive," in *2016 International Conference on Inventive Computation Technologies (ICICT)*, Coimbatore, India, 2016, vol. 3, pp. 1-3.
- [7] S. V. G. Kumar, M. Vadivel, U. Penchalaiah, P. Ganesan, and T. Somassoundaram, "Real Time Embedded System for Automobile Automation," in *2019 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN)*, Pondicherry, India, 2019, pp. 1-6.
- [8] R. R. I. Barwari, "Study of Air Pollutions Caused by Exhaust Gases Emitted from Gasoline Vehicles in Erbil City," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1105, no. 1, p. 012053, 2021.
- [9] L. Hou, Y. Wang, Y. Zheng, and A. Zhang, "The Impact of Vehicle Ownership on Carbon Emissions in the Transportation Sector," *Sustainability*, vol. 14, no. 19, p. 12657, 2022.
- [10] V. Lozhkin, O. Lozhkina, and V. Dobromirov, "A study of air pollution by exhaust gases from cars in well courtyards of Saint Petersburg," *Transportation Research Procedia*, vol. 36, pp. 453-458, 2018.
- [11] N. Hu, P. Zhou, and J. Yang, "Reducing emissions by optimising the fuel injector match with the combustion chamber geometry for a marine medium-speed diesel engine," *Transportation Research Part D: Transport and Environment*, vol. 53, pp. 1-16, 2017.
- [12] M. A. Fayad, "Effect of fuel injection strategy on combustion performance and NOx/smoke trade-off under a range of operating conditions for a heavy-duty DI diesel engine," *SN Applied Sciences*, vol. 1, no. 9, p. 1088, 2019.

- [13] S. Ilyas, U. Naveed, and J. Khalid, "Improving fuel consumption using Electronic Fuel Injection Technology for low-powered Motorbike Engine," in *2020 17th International Bhurban Conference on Applied Sciences and Technology (IBCAST)*, Islamabad, Pakistan, 2020, pp. 236-243.
- [14] Y. H. Teoh, H. G. How, C. G. Peh, T. D. Le, and H. T. Nguyen, "Implementation of Common Rail Direct Injection System and Optimization of Fuel Injector Parameters in an Experimental Single-Cylinder Diesel Engine," *Processes*, vol. 8, no. 9, p. 1122, 2020.
- [15] N. Shivakumar, G. A. C. Jayaseelan, Parthiban, Ahmed, and Akshay, "Ignition Timing and Fuel Injection Timing Control using Arduino and Control Drivers," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 993, no. 1, p. 012019, 2020.
- [16] L. M. Tien, P. Q. Thai, H. T. Tien, and V. A. Vu, "Design and Development of Gasoline Injector Test Bench," *The University of Danang - Journal of Science and Technology*, pp. 90-94, 2018.
- [17] N. Kim, L. K. Tan, and V. T. Tai, "Design and manufacturing deployment of diesel engine common rail electronic control system," *Journal of Technical Education Science*, no. 45, pp. 86-92, 2018.
- [18] D. V. Dung, H. Q. Viet, N. V. L. Giang, and T. T. Lien, "Application of LabVIEW to Communicating between PC and Training Model of Electronic Fuel Injected Engine," *Journal of Technical Education Science*, no. 12, pp. 8-13, 2010.
- [19] S. A. F. A. Arkawazi, "Analyzing and predicting the relation between air-fuel ratio (AFR), lambda ( $\lambda$ ) and the exhaust emissions percentages and values of gasoline-fueled vehicles using versatile and portable emissions measurement system tool," *SN Applied Sciences*, vol. 1, no. 11, p. 1370, 2019.
- [20] *Air fuel ratio*, x-engineer, Apr. 2020. [Online]. Available: <https://x-engineer.org/air-fuel-ratio/>
- [21] S. A. F. A. Arkawazi, "The gasoline fuel quality impact on fuel consumption, air-fuel ratio (AFR), lambda ( $\lambda$ ) and exhaust emissions of gasoline-fueled vehicles," *Cogent Engineering*, vol. 6, no. 1, p. 1616866, 2019.
- [22] L. Meng, X. Wang, C. Zeng, and J. Luo, "Adaptive Air-Fuel Ratio Regulation for Port-Injected Spark-Ignited Engines Based on a Generalized Predictive Control Method," *Energies*, vol. 12, no. 1, p. 173, 2019.



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