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FINAL REPORT

Embedded Tuning Device for EFI Engine with Carbon Monoxide

Adjusting Potentiometer

By

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Abstract

Engine tuning was always a major concern for cars manufacturers and cars users and many researches have been performed to make the engine tuning cope up with the modern world requirements for controlled pollution laws, economic fuel usage and to make the engine in a good condition for longer time. A transition state between carburetors which have no mechanical ability to correct lean or rich fuel mixtures until the 1980s and the current Air to fuel (A/F) ratio control method using oxygen sensors implemented in the car exhaust was the carbon monoxide potentiometer which was used to keep the A/F ratio at a certain level using a potentiometer to achieve an ideal fuel consumption and engine performance, but this method requires a frequent check by the car user and a mechanic assistant which makes the engine tuning for these cars (old cars which normally require tuning more frequent than the new cars) a difficult process and has a limited flexibility for the car user to make his own choice on the car performance as well. By using microcontrollers which can work perfectly with the engine control unit (ECU), this potentiometer can be replaced and can allow the user to do the tuning through different buttons which will make the tuning process simpler, more accurate and more flexible with more tuning options for the car driver, beside some more functions that will enhance the engine performance and fuel consumption in general and the ability to change any time from the old system (CO potentiometer) to the new embedded tuning device.

ACKNOWLEDGEMENT

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

_____
KHALED RAOUF TAWFIK MOHAMED

CERTIFICATION OF APPROVAL

Embedded tuning device for EFI cars using CO potentiometers

By

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Approved by,

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CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

The petrol-based fuel injected vehicles have several ways of adjusting the Air/Fuel Ratio (A/F) such as using the Carbon Monoxide potentiometers (CO pot), this exists in the cars which were produced from the late 1980s till 2005 as before that time cars used to have carburetors and the new cars from 2005 till now use Oxygen sensors to do the tuning [1].

The tuning of the A/F ratio is performed to control the gases emissions from the vehicle, control the engine performance and adjust the combustion level which results in fuel consumption control based on the A/F ratio provided to the engine. In this report only the CO potentiometers for A/F ratio control will be discussed for the car models which were produced between late 1980s and 2005; where tuning must be carried out more frequent than the new cars and the tuning procedure is more complicated to be performed by the user himself. The CO potentiometer is an adjustable variable resistor that can be adjusted manually by changing the resistance values of the CO potentiometer, that will adjust the voltage values fed to the engine control unit (ECU) which in return will decide the amount of the fuel (A/F ratio) to be injected to the engine.

A 5V reference voltage will be supplied by the ECU to the CO potentiometer which can be adjusted by a technician or by the user (if he is well familiar with the tuning procedure in order not to cause any damage to the engine if a short circuit happens while the engine is working) by tuning a small screw on the CO potentiometer [2]. By adjusting the voltage, the ECU will adjust the pulse width of the fuel injectors which directly dictates the air/fuel ratio in order to provide different ratios of air/fuel mixtures influencing the combustion level which then controls engine performance and carbon monoxide emissions [3].

This system of tuning is used in a lot of cars nowadays and the CO potentiometer can be adjusted to one value (equivalent to a certain voltage value in a scale from 0 V to 3 V in most cars) that will be assumed to provide the best engine performance and fuel consumption known as the stoichiometric value (almost 1.25 V).

1.2. PROBLEM STATEMENT

A CO potentiometer adjustment for the A/F ratio control can only be done manually when the front hood of the car is opened and when the car is not moving; beside the tedious procedure of tuning if the user is not familiar with this tuning which normally require a technician assist, this will limit the flexibility of fine tuning by the user at a desired time if he decides to make sure that the A/F ratio is at the ideal condition (14.7 :1) or to adjust the Air/Fuel ratio in order to suit his driving requirement –relax (economic) - or spirited (fast speeds) driving modes before the intended trip which makes him get a powerful performance in case of long journeys or a less fuel consumption and gases emissions in case of stopping in traffic lights or crowded queues .

1.3. OBJECTIVES

- To design, develop and implement a tuning device to be installed inside the car to replace the Co potentiometer that will give various voltage level to the engine control unit in order to adjust the Air/Fuel ratio accordingly and can be controlled by the driver using particular push buttons and thus will provide the flexibility for the driver to configure the required driving mode instantly while sitting in his chair.
- To give the option for the car driver to switch between the traditional tuning technique using the CO potentiometer of the car or to do it using the electronic system of tuning that will be newly introduced to the car based on his own preference.

1.4. SCOPE OF STUDY

The project starts by collecting information about how the engine control unit (ECU) works together with a CO potentiometer in the car to provide the desired A/F ratio based on the resistance value set for the CO pot and the effect of that on the engine performance and the CO emissions. Then a model for a fine tuning device will be designed in order to replace the CO pot and provide a variable DC voltage source to the ECU using push buttons according to the chosen mode of driving using simulation for the used controller and electronic components. Later on a prototype for this device will be implemented using Arduino controller, electronic components (Op amp and inverters), push buttons and LCD to be installed in the car and be tested by drivers and further implementation might be introduced according to the time scale.

CHAPTER2

LITERATURE REVIEW

Many researches have been conducted on engine tuning for the A/F ratio adjustment using different techniques in order to achieve acceptable fuel consumption with the increasing fuel prices and to reduce the car emissions which contribute much in the environmental pollution and that is why many European countries applied what is called EU emission standards for passenger cars which set limits to the percentages of each gas emitted from cars as shown in Table 1, so that makes fine tuning for car engines more important to satisfy these conditions and for better satisfaction of the car user. In order to understand how CO potentiometer tuning that will be changed by the new microcontroller tuning device work, a description of the engine related parts that work together with the CO potentiometer will be reviewed.

Table 1: EU emission standards for passenger cars

Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
		g/km					#/km
Compression Ignition (Diesel)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)	-
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08	-
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10	-
Euro 3	2000.01	0.64	-	0.56	0.50	0.05	-
Euro 4	2005.01	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009.09[b]	0.50	-	0.23	0.18	0.005[f]	-
Euro 5b	2011.09[c]	0.50	-	0.23	0.18	0.005[f]	6.0×10^{11}
Euro 6	2014.09	0.50	-	0.17	0.08	0.005[f]	6.0×10^{11}
Positive Ignition (Gasoline)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-	-
Euro 2	1996.01	2.2	-	0.5	-	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-	-
Euro 4	2005.01	1.0	0.10	-	0.08	-	-
Euro 5	2009.09[b]	1.0	0.10[d]	-	0.06	0.005[e,f]	-
Euro 6	2014.09	1.0	0.10[d]	-	0.06	0.005[e,f]	6.0×10^{11} [e,g]

2.1. ELECTRONI FIEL INJECTION (EFI) MECHANISM

Starting from the late 1980s, almost all manufactured cars used to have the newly introduced electronic injection system controlled by electronic control unit (ECU) which were more complicated than the older system of supplying fuel to the engine using carburetors but were much efficient in terms of fuel injection control and engine performance [4]. The electronic injection system consists of three major sub systems: air induction, fuel delivery and electronic control unit systems.

Electronic control unit (ECU) is considered to be the brain of the car used to optimize the performance of the engine so that it can control some actuators in the engine using sensors. The ECU performs mainly four major tasks:
- Fuel mixture control
- Idle speed control
- Ignition timing control
- Valve timing control

ECU determines the exact amount of fuel needs to be delivered to the engine by the injectors based on its several sensors and its operation is as following [5, 6]:

- Air induction system will let the air enters the engine (at constant level) after it is measured by the air flow meter and as the air keep flowing inside the engine, it will be mixed with the fuel by the fuel injector (electrical solenoid controlled by the ECU).
- The injector is pulsed by the ECU which switches the injector ground circuit off and on.
- When the injector is turned on, fuel will be pumped as spray in the intake airstream, it mixes with the flowing air and then vaporized due to the low pressure in the intake.
- The ECU pulse the injector to deliver the accurate enough amount of fuel to reach the ideal air/fuel ratio of 14.7/1 [6] which is also referred to as stoichiometry providing the best efficiency for the engine.

The Air/Fuel ratio still can be changed to be leaner or richer [7] in terms of less or more fuel injected, so in case of leaner mixtures than the stoichiometric value, this will improve the fuel economy but increase the nitric oxide (NO) amount so much and if the mixture is too lean the engine might fail to start which might cause misfire and increase the emissions of unburned hydrocarbons (HC), finally lean mixtures burn hotter which might burn some engine valves or the catalytic converter.

The mixtures which are richer than the stoichiometric value leads to greater peak power of the engine and this increases the oxygen density intake which results in more combusted fuel and more generated power but on the opposite side richer mixtures increase both the fuel consumption and the CO emissions.

To make it clearer, a lower A/F ratio number contains less air than the 14.7:1 stoichiometric ratio; therefore it is a richer mixture. On the other hand, a higher A/F ratio number contains more air and therefore it is a leaner mixture (e.g. 15.0:1 = Lean, 14.7:1 = Stoichiometric, 13.0:1 = Rich) [8].

Referring to Figure1 we can see that different air to fuel ratio have different effects on the engine power, the economic level of fuel consumption and also on the amount of several gases emissions as Nitrogen oxide (NO), carbon monoxide (CO) (which should remain around 3.5% according to law in most countries and can go maximum to 5% of the total gases emitted) and hydrocarbons (HC) and to make the A/F ratio leaner or richer depends on the users preferable outputs wither higher engine performance with higher speed but more fuel consumption and gases emissions or more economic in fuel consumption but lower engine performance and less emissions but the value of the CO pot responsible for the user choice of A/F mixture will be constant until the CO pot value will be adjusted manually resulting in different A/F mixture. So this project will aim at giving the user the flexibility of choosing the mode of driving thus changing the CO Pot value and A/F ratio accordingly using push buttons and a continuous feedback will be sent to the controller to keep changing the A/F mixture until it reaches exactly the value that was set for the desired mode.
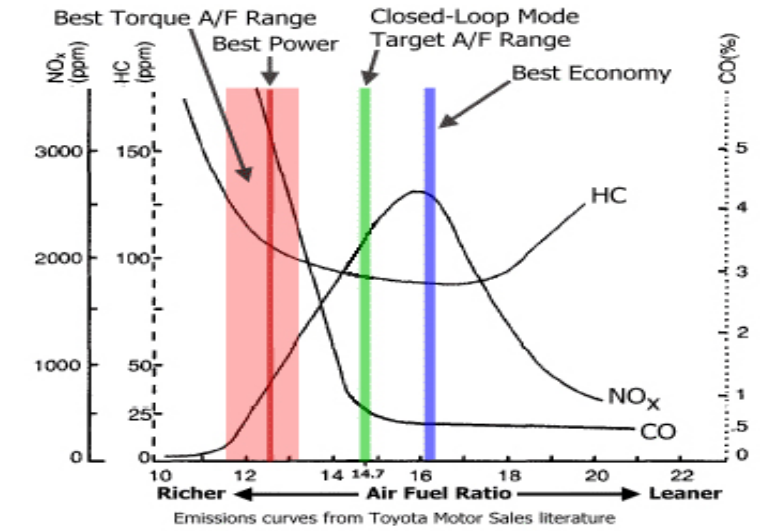
Figure 1: Air to fuel relation with the engine parameters and gases emissions

2.2.   CARBON MONOXIDE (CO) POTENTIOMENTER

Adjusting the A/F ratio can be done using the CO potentiometer which is a variable resistor that influence this ratio and can be modified manually [9] to suit the user needs and the reason it is adjustable is to reduce the amount of CO in the exhaust stream in order to meet emissions requirements as well. The CO potentiometer can provide several resistance values based on the ohm's law (V=RI) where the relation between the voltage and the resistance is directly proportional providing constant current, so by adjusting the screw of the CO pot this will adjust the voltage values fed to the engine control unit (ECU) which in return will decide the amount of the fuel (A/F ratio) to be injected to the engine. A 5V reference voltage [10] will be supplied by the ECU to the CO potentiometer by tuning a small screw as shown in Figure 2 on the CO potentiometer to go from the Stoichiometric value to either lean or rich as represented in the potentiometer model shown in Figure 3. By adjusting the voltage, the ECU will adjust the pulse width of the fuel injectors which directly affects the air/fuel ratio in order to provide different air/fuel mixtures.

Figure 2: Carbon monoxide potentiometer inside the car
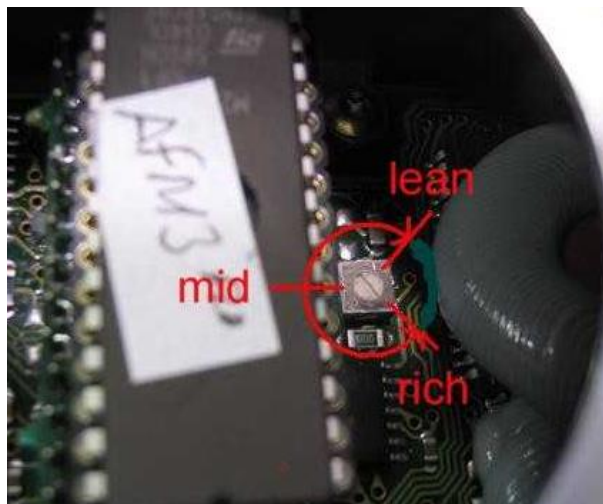
Figure 3: CO potentiometer model connected to the controller acting as ECU

2.3 PULSE WIDTH MODULATION PROJECT RELATED THEORY

PWM is a way of encoding a voltage onto a fixed frequency carrier wave, similar in concept to FM (frequency modulation) or AM (amplitude modulation) in what it achieves. Instead of varying the modulation frequency with voltage, an output is merely switched on and off at a fixed frequency. The percentage of the on-time is in proportion to the signal voltage. To see better what this means, let's examine what a PWM signal looks like for various levels. As shown in Figure 4, the duty cycle is the (which is the percentage of signal one period active mode or the time signals takes to complete and on- off) output value from the PWM pin of an Arduino divided by 255
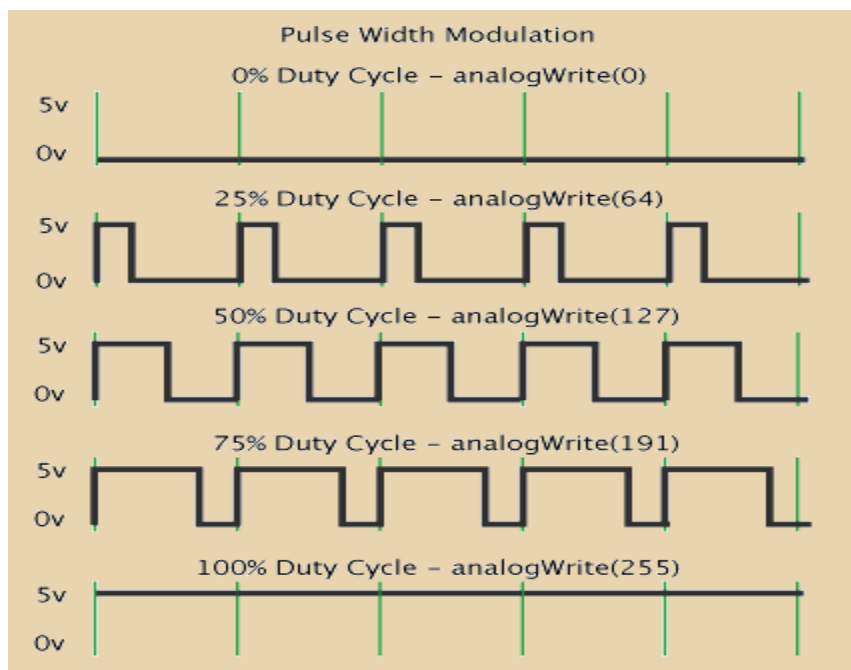
Figure 4: PWM Arduino output

This method will be used to transform the digital output of the Arduino board into analogue representation within the desired range of voltage required (0.5V- 2.25V) and its implementation will be explained in the methodology section

2.4 VOLTAGE FOLLOWER CONCEPT

Having the output voltage of embedded tuning device connected directly with the high impedance of the ECU and the same cable that is providing 5 V power supplied to the existing CO pot to be dropped by its resistance to the desired voltage value fed back to the ECU will cause a disturbance to the output voltage due to the different currents and voltages of the 2 voltages sources according to Thevenin's theorem and the desired voltages supplied by the device will not be the required one when connected to the real car system.

In order to avoid this the voltage follower shown in figure 5 concept is used which will ideally make the input to the op amp (which is the Arduino filtered voltage output) equals the op amp output V out = V in; this application is so useful in this case because the op amp input impedance is very high giving enough isolation of the output from the signal source and from the second voltage source avoiding loading effects on the system and thus it can neglect the second voltage source coming from the car battery as it will be explained later in the methodology section
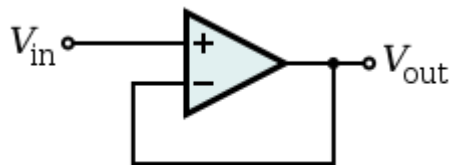
Figure 5: Voltage follower circuit using Op amp

CHAPTER3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

Figure 4 below shows the overview flow of the research methodology for the FYP1 and FYP 2, each step will be described in the project activities in the next section

```
┌─────────────────────────────┐
│     Preliminary research     │
└─────────────────────────────┘
              ↓
┌─────────────────────────────┐
│      Finalizing proposal     │
└─────────────────────────────┘
              ↓
┌─────────────────────────────┐
│    Experimental application  │
└─────────────────────────────┘
              ↓
┌─────────────────────────────┐
│          Simulation          │
└─────────────────────────────┘
              ↓
┌─────────────────────────────┐
│      Design improvement      │
└─────────────────────────────┘
              ↓
┌─────────────────────────────┐
│      Analysis of results     │
└─────────────────────────────┘
              ↓
┌─────────────────────────────┐
│    Discussion on result and  │
│          conclusion          │
└─────────────────────────────┘
              ↓
┌─────────────────────────────┐
│        Recommendations       │
└─────────────────────────────┘
```
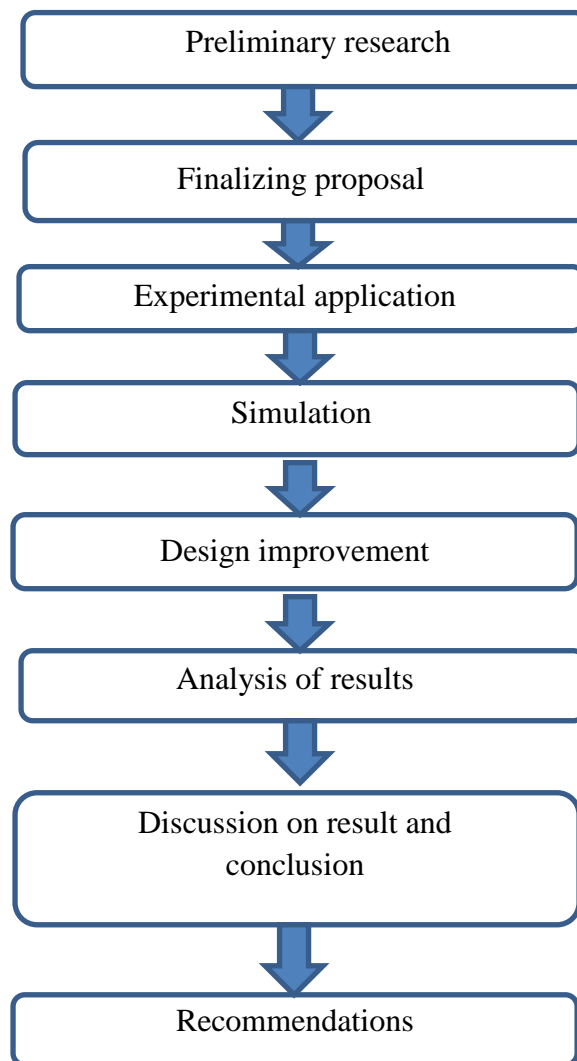
Figure 6: Research methodology for FYP 1and FYP 2

3.2 PROJECT ACTIVITIES

Advanced research

After getting familiar with the project aspects in FYP 1, some further research was required about the internal parts of the car regarding the volatage, resistance, current and frequency needed or supplied by different parts and also how to provide realistic values from the prototype to the car.

Lab experiments and car measurements

After getting all the data needed, a first prototype was built and the written code for Arduino was tested to assure that the basic requirements were met and measurements were done on a car to obtain all the required results for the prototype to replace the existing CO potentiometer inside the car

Simulation

Stimulation for the PWM signal using LTspice software was done and the right filter parameters and isolation mechanisms were chosen to obtain the best outcome.

Design improvement

The prototype should be transformed from the bread board design into a Vero board or PCB in order to be implemented into the car and test its performance so that the final results must be the ability of the user to choose a different driving modes and each mode will supply different voltages to the ECU equivalent to various the A/F ratios and try keeping this ratio constant using closed loop feedback until another mode is chosen by the driver

Figure 7: Project achievements for FYP 2

3.3 KEY MILESTONE

Table 2: key milestone of FYP 1

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	FYP title selection and allocation by the responsible supervisor		■												
2	Extended proposal submission						■								
3	Proposal defense									■					
4	Interim draft report submission													■	
5	Interim final report submission														■

Table 3: key milestone for FYP 2

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Progress report submission								■							
2	Electrex										■					
3	Draft final report submission													■		
4	Final report submission														■	
5	Oral presentation/Viva															■

3.4 GANTT CHART

Table 4: Gantt chart of FYP1

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection and confirmation of project title	■	■												
2	Early research on the proposed topic and proposal finalization			■	■	■	■								
3	Lab experiment and proposal defense preparation							■	■						
4	Proposal defense									■					
5	Preparing interim draft report and doing simulations of the project										■	■	■		
6	Submission of the interim draft report and interim final report submission													■	
7	Submission of the interim final report														■

Table 5: Gantt chart of FYP2

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Further research on the electronics and the car parts	■	■	■												
2	Building a primary prototype and testing methodology				■	■	■									
3	Testing on a car and obtaining real components values							■								
4	Progress report submission								■							
5	Finalizing the design and building the PCB board for the prototype									■	■					
6	Electrex											■	■			
7	Draft preparation and Final report submission													■	■	
8	Oral presentation															■

3.5 TOOLS

3.5.1 SOFTWARE

- <u>Arduino IDE</u>: To do the coding for the whole system and upload it to the Arduino board.
- <u>MATBLAB</u>: Will be used in case of any graphical relation needed.
- <u>LTspice</u>: To perform simulations of the electronic circuits needed before finalizing the hardware circuit design and analyze the output signals.

3.5.2 HARDWARE

- Arduino Uno board microcontroller.
- LCD (16 x 2) display.
- Electronic components: Resistors, push buttons, capacitors, op amp IC MAX 232.

Component	Quantity	Function
4 leg push buttons	4	Mode selection buttons
10 KΩ resistors	4	Pull up resistors
IC LM 358P	1	Op amp for voltage follower circuit
IC Max 232	1	Charge pump to supply negative voltage to the op amp
5 KΩ resistor	1	Resistor of the RC filter
33 uF capacitor	1	Capacitor of the RC circuit
47000 pF	4	Capacitors for the MAX 232
47 uF Capacitor	1	Capacitor for the MAX 232
25 KΩ potentiometer	1	Adjusting the brightness of the LCD

- Vero board.
- Electronic components equivalent to those on the Arduino board to build an external ATMEGA circuit for the final prototype to be placed inside the car.

3.6 FIRST PROTOTYPE IMPLEMENTATION

The first prototype as shown in Figure 8 includes the circuitry that will replace the CO potentiometer inside the car built on a bread board using:

1. Push buttons: To assist the user increase or decrease the A/F ratio giving corresponding voltage values that will be supplied to the ECU which will in return control the injector and also to allow him reach the extreme values for the A/F ratio -rich mode = race mode = more fuel- or - lean mode = economic mode = less fuel and less CO emissions - as shown in Figure 1.

2. LCD (16x2): To provide the user with a readable interface of his adjustment, current operation mode and also the A/F ratio value corresponding to the current mode.

3. Arduino board (ATMEGA 328P): To perform the required calculation for the voltage output that will be supplied to the ECU representing the A/F ratio and the mode of operation and also to provide the corresponding display on the LCD for each mode.

4. RC filter circuit: To convert the PWM voltage output signal from the square form to a DC analogue voltage signal with the lease ripple.

5. Voltage follower: To make sure the voltage output from the system will not be interfered by the ECU impedance and it will neglect the 5 V voltage source coming from the battery as well so that the circuit will be the only voltage source supplying to the ECU.
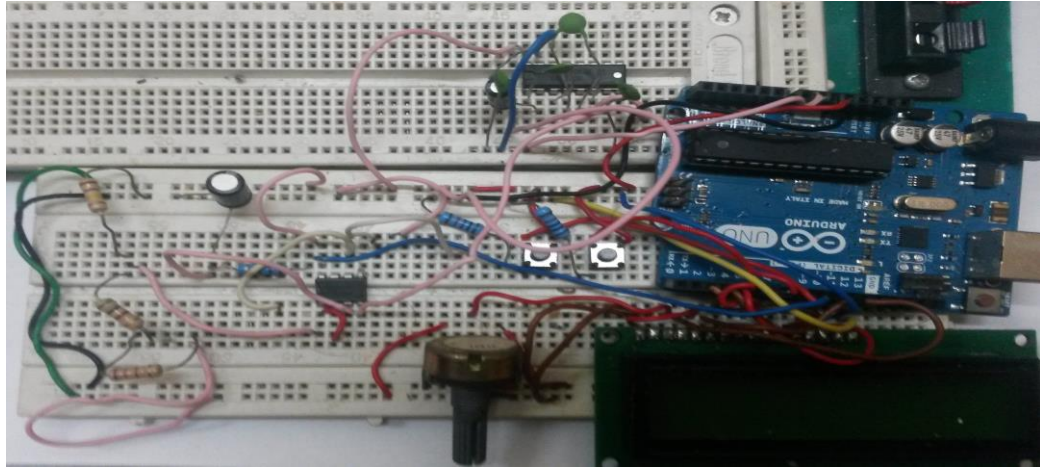
Figure 8: Project prototype layout

3.6.1 ARDUINO OUTPUT

The Arduino board is used for 2 purposes:

1. Performs the required calculation for the output voltage according to Table 6 so that each A/F ratio value is corresponding to one of the driving modes (Rich- Ideal- Lean) and allows the increment and the decrement throughout the range of A/F ratio values using the push buttons (+ and -) which will allow the user to set the desired value before driving or even through the journey according to his requirements. The output of the Arduino will be taken from pin 6 which is a PWM digital pin and the required output to be connected to the ECU should be in DC analogue form in a range from (0.5 V to 2.25 V) so a mapping for the digital PWM output was done using the following formula to obtain for example the 1.25 V

   if (value == 14.7)

   { volt = 1.25;

   val = 255 * (volt / 5);

   analogWrite(pwmPin, val); }

Table 6: Driving modes and their corresponding A/F ratio and Output voltages

Driving mode	A/F ratio value	Output voltage (V)
Rich Max	12.3	Almost 0
Rich	12.9	0.25
Rich	13.5	0.5
Rich	14.1	0.75
Ideal	14.7	1
Lean	15.3	1.25
Lean	15.9	1.5
Lean	16.5	1.75
Lean Max	17.1	2

Note:

1. According to Figure 1, 12.5 is considered the best power A/F ratio which means the highest speed power with the highest fuel consumption and the highest CO emissions.

On the other hand, 16.3 is considered the best economic A/F ratio which means the least fuel consumption with the least CO emissions

While 14.7 is considered the Ideal value between the 2 extremes values which provides average fuel consumption and average CO emissions, that's why the chosen A/F ratio range used in the prototype goes from 12.3 until 17.1 passing by the 14.7 which represents the Ideal mode as shown in Figure 9.

2. For safety matter, If the user tried to exceed 17.1 (Rich Max mode) or go below 12.3 (Lean Max mode), the A/F ratio will return automatically to 14.7 (Ideal mode) as a warning for the driver and to keep the A/F ratio within the desired safety range only.
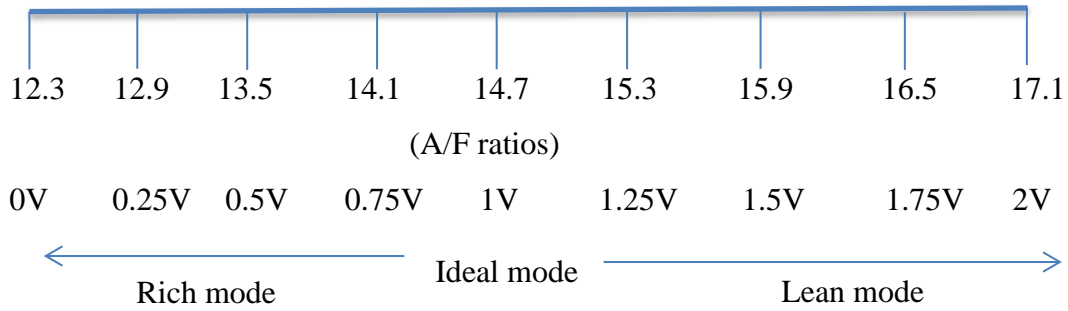
| 12.3 | 12.9 | 13.5 | 14.1 | 14.7 | 15.3 | 15.9 | 16.5 | 17.1 |

(A/F ratios)

| 0V | 0.25V | 0.5V | 0.75V | 1V | 1.25V | 1.5V | 1.75V | 2V |

Rich mode   Ideal mode   Lean mode

Figure 9: A/F ratio and their equivalent voltages range used in the prototype

2. Controls the LCD displayed messages which indicate both the current driving mode (first row) and the corresponding A/F ratio (second row) as the driver's indication. At the starting of the engine the A/F ratio will be set to the Ideal mode and the user can adjust it any time he desires.

3.6.2 OUTPUT VOLTAGE SIMULATION

The Pulse Width Modulation (PWM) Arduino output is just a simulation for the analogue voltage which is based on switching rapidly between on and off states, so they are similar to the analogue DC signals but actually they are a form of AC signal (square waveform). In many cases it is acceptable to use the PWM output directly but in our case as we are dealing with a car so a true analogue voltage output must be used. In order to obtain this, the PWM signal must be modified or smoothed using a filter (RC circuit) which will convert the PWM signal into an average output voltage of the PWM and it will be DC analogue voltage that can be connected to the ECU.

In this case, a low pass filter (RC) is used and the chosen value for the resistor was 5kΩ while that of the capacitor was 33uF, the reason behind choosing these values are the time constant which is equal to RC (the time required to reach 63% of the output final value) and the ripple associated with the output signal, so in order to reduce the ripple, bigger capacitor value (in terms of micro) should be used and also by trial and error technique 5 kΩ resistor together with the 33uF capacitor obtained the least ripple output with an acceptable time constant of 0.165 s.

By simulation only, the output will appear as a constant DC voltage but if applied to the car directly it will be influenced by the internal circuitry and the car power supply so it is necessary to check by simulation also what will be the output at the ECU if the circuit is directly connected to it, so in case of error in the resultant voltage supply from the prototype to the ECU extra circuitry will be needed (in this case a voltage follower was introduced) and the simulation was done again having the 5 V supply from the battery of the car and the 750 Ω internal resistance of the cable and also a high impedance resistor representing the ECU to confirm the prototype is working as required before real connections with the car.

3.7 SECOND PROTOTYPE IMPLEMTATION

The second prototype will be the finalized product after all the testing using Arduino and bread board based circuit has met the required output which will be building the same first prototype circuit but on a Vero board and using an ATEMAGA 328P with its related electronics components to replace the Arduino board so it will include 2 parts:

1. The controlling circuit: which will include the ATMEGA circuit, the filtering circuit and the negative voltage supply from the IC MAX 232 charge pump and will be considered the main circuit (to be placed in the front hood of the car).

2. The driver interface circuit: which will include the 16x2 LCD display and 5 push buttons (big size) which will allow the driver to do the tuning while sitting inside the car and screen it using the LCD and which will be connected by means of cables to the main circuit.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 CAR TESTING AND MEASUREMENTS

The CO potentiometer which has a 1k Ω resistance is located in the front hood of the car connected through cable that gains voltage supply from the battery of the car and can be adjusted using a screw drive that will change the resistance of the CO pot and in return will change the voltage supplied to the ECU which will give order to the injector about the A/F ratio (by changing the fuel amount as the air ratio is always constant) to be supplied based on this voltage value.

The CO pot has three terminals as shown in Figure 10, one is connected to the VCC and the other two are grounded to provide a voltage divider with two resistor values

Resistance adjustment using a screw drive

Terminal 2

Grounded

Terminal 2

Grounded

Terminal 3

5V

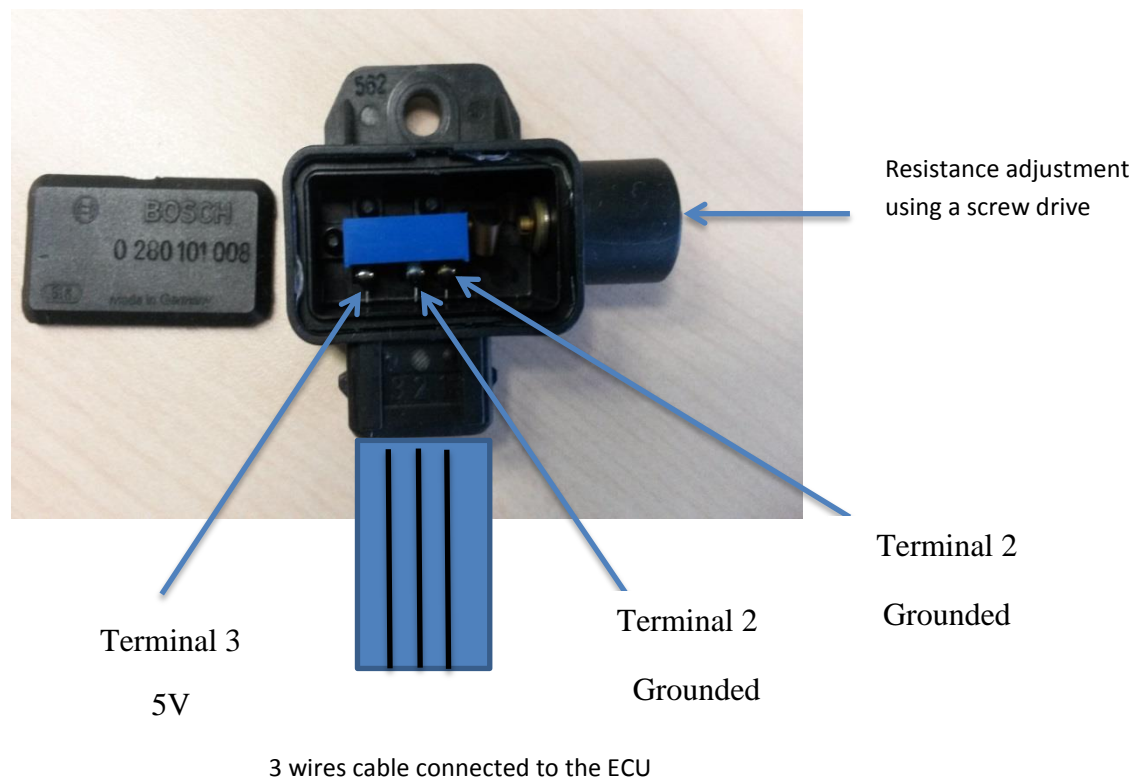3 wires cable connected to the ECU

Figure 10: CO potentiometer layout

Testing was done on the car (Mercedes E280, W124) to get some information about the range of the voltage output from the CO potentiometer that is supplied to the ECU by changing the resistance value beside checking the effect of that on the car performance in the steady state and also finding out the internal resistance of the cabling that is connected to the CO pot.

Several adjustments for the potentiometer were done and the results of voltage output and the resistor values for the 2 CO pot divisions are shown in Table 7.

Table 7: Measured resistance and voltage values from the car CO pot while the engine is running

Cases	Resistance between terminal 3 and 1 (Ω)	Resistance between terminal 2 and 1 (Ω)	Output voltage (V)
Case 1	219.8	782	1.134
Case 2	84.4	917	0.507
Case 3	189.5	813	0.999
Case 4	511.7	490.8	2.03
Case 5	747	254.7	2.496
Case 6	998	2	2.857

We can see from the table and from Figure 11 that the maximum output voltage that the CO pot can supply in our case is 2.860 V (can vary in other cars), so we have adjusted the output voltage range to be of maximum 2 V as shown in Table 6 to be suitable for other cars and to stay within a safety range but still be able to get a recognizable effect on the car performance.

Figure 11: Maximum output voltage from the CO potentiometer while the engine is running

So through testing the cable seems to have an internal resistance, and in order to know its value some circuit theory calculations were done as shown in Figure 11.
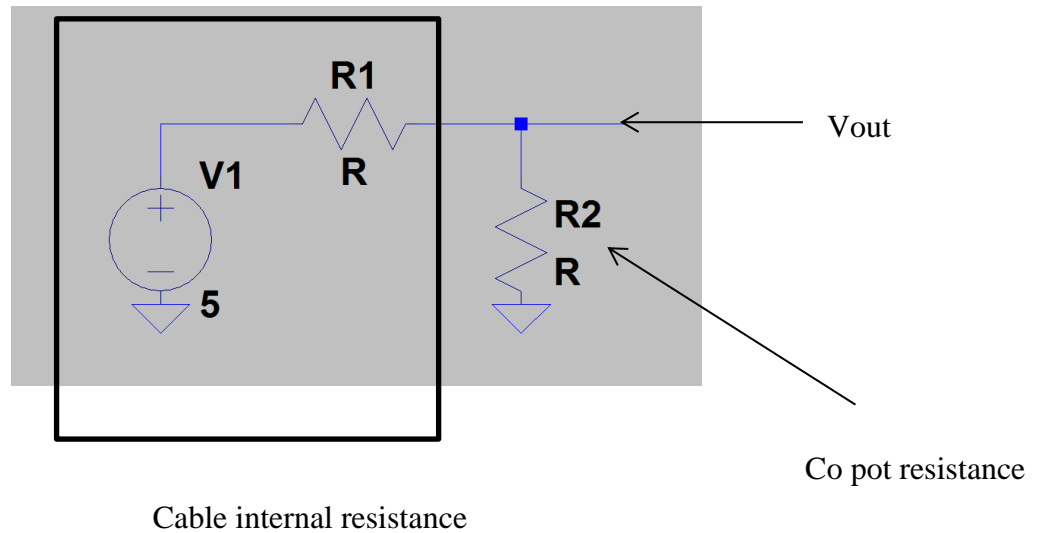

Cable internal resistance

Figure 12: Simple representation of the cabling and potentiometer resistances

Case 1: From Table 7, at resistance between terminal 3 and 1 (which is corresponding to R2 in Figure 11) equals 219.8, Vout is equal 1.134 V and voltage division rule can be applied to obtain R1 value

$$\text{Vout} = \frac{V\ source\ x\ R2}{R1+R2}$$

Vout x (R1+R2) = Vsource x R2

Vout x R1+Vout x R2 = Vsource x R2

Vout x R1 = Vsource x R2 - Vout x R2

$$R1 = \frac{R2\ (Vsource-Vout)}{Vout}$$

$$R1 = \frac{219.8\ x\ (5-1.134)}{1.134}$$

R1 = 749 .335 Ω   eq (1)

Case 2: From Table 7, at resistance between terminal 3 and 1 (which is corresponding to R2 in Figure 11) equals 84.4, Vout is equal 0.507 V and voltage division rule can be applied to obtain R1 value

$$R1 = \frac{R2\ (Vsource-Vout)}{Vout}$$

$$R1 = \frac{84.4\ x\ (5-0.507)}{0.507}$$

R1 = 747.947 Ω   eq (2)

From equations 1 and 2 we can see that the internal resistance of the cable and circuitry is around 748 Ω which is needed in case of designing the prototype and implementing it inside the car as this internal resistance might affect the prototype circuit calculation so it will be taken in consideration.

4.2 PROTOTYPE TESTING

After the design and the building of the prototype is done some measurements were obtained to make sure it is functioning well and the PWM output voltage was giving the desired value at each selected A/ F ratio.

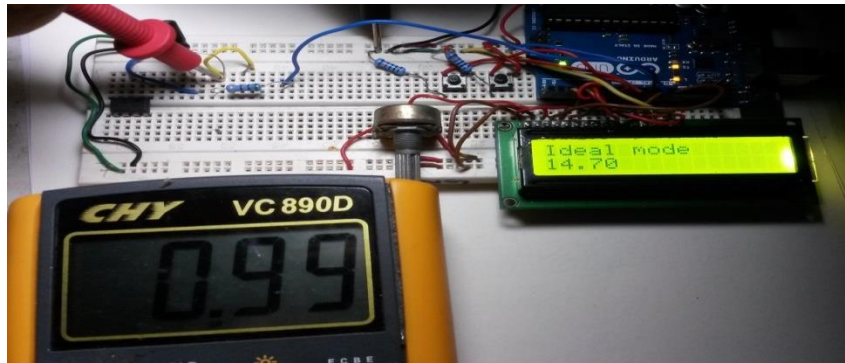1. Ideal mode: A/F ratio is 14.7 and the output voltage is 1 V as shown in Figure 13

Figure 13**:** Vout of Ideal mode and its corresponding A/F ratio

2. Rich mode : A/F ratios are 14.1, 13.5,12.9 and 12.3 is the Max rich mode value and the output voltage are 0.75 V, 0.5 V, 0.25 V and almost 0 V respectively as shown in Figures 14, 15, 16 and 17
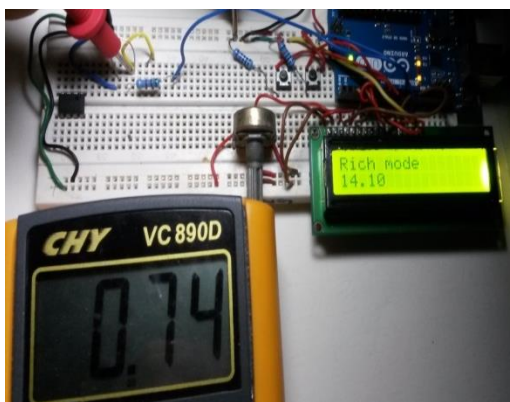
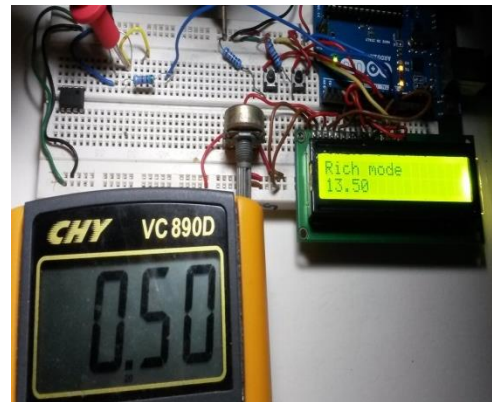Figure 14: Vout of Rich mode 1   Figure 15: Vout of Rich mode 2
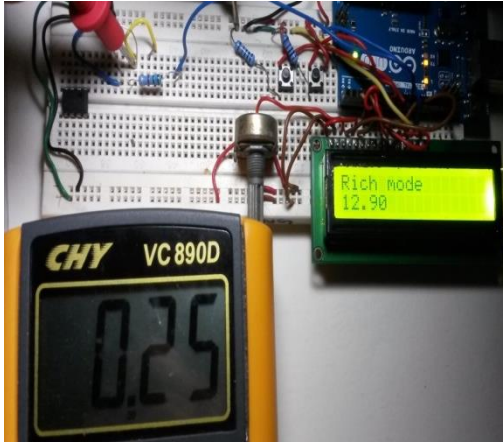
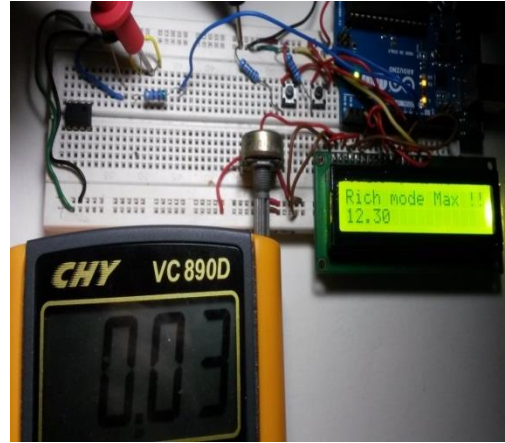Figure 16: Vout of Rich mode 3   Figure 17: Vout of Rich mode Max

3. Lean mode : A/F ratios are 15.3, 15.9, 16.5 and 17.1 is the Max Lean mode value and the output voltage are 1.25 V, 1.5 V, 1.75 V and 2 V respectively as shown in Figures 18 ,19 and 20, 21
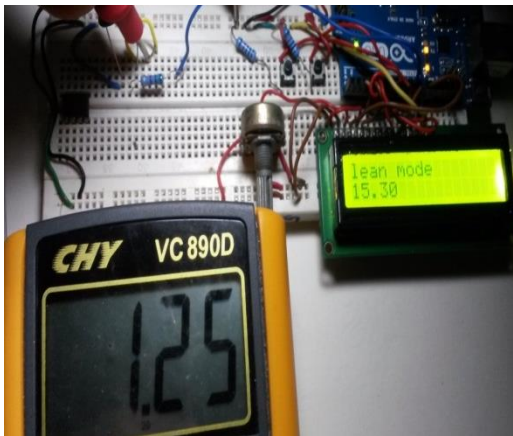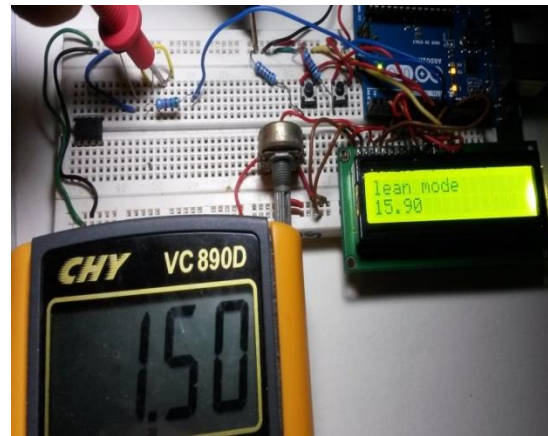

Figure 18: Vout of Lean mode 1   Figure 19: Vout of Lean mode 2
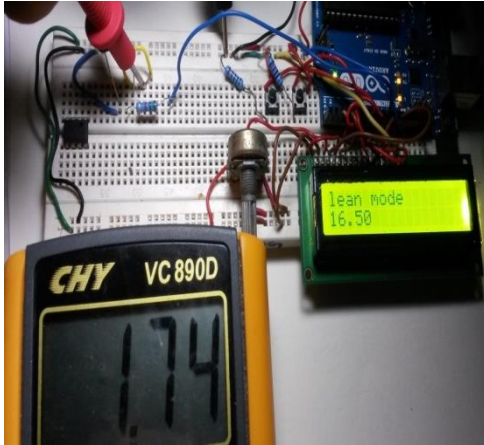
Figure 20: Vout of Lean mode 3   Figure 5: Vout of Lean mode Max

4.3 RC FILTERING FOR THE PWM OUTPUT VOLTAGE

The PWM output voltages obtained are correct and as desired for our application but the multi meter cannot detect the fast changes in the output state as it goes from on to off state (square wave) which is the behavior of the PWM signal due it its high frequency so the reading is just an average representation of the output voltage but it is not a DC analogue voltage that can be supplied to the ECU directly.

That's why an RC circuit was built based on the chosen values mentioned in section 3.6.2 in the methodology to filter the PWM output voltage and make it a DC signal that can be properly used inside the car.

The simulation for the filter circuit and the resulting output are shown in Figures 21 and 22
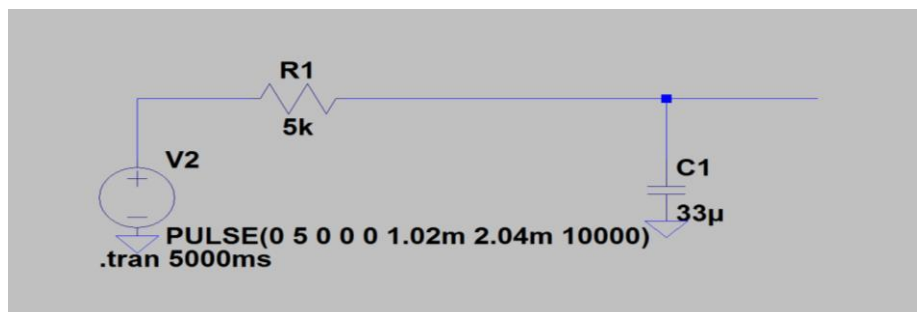

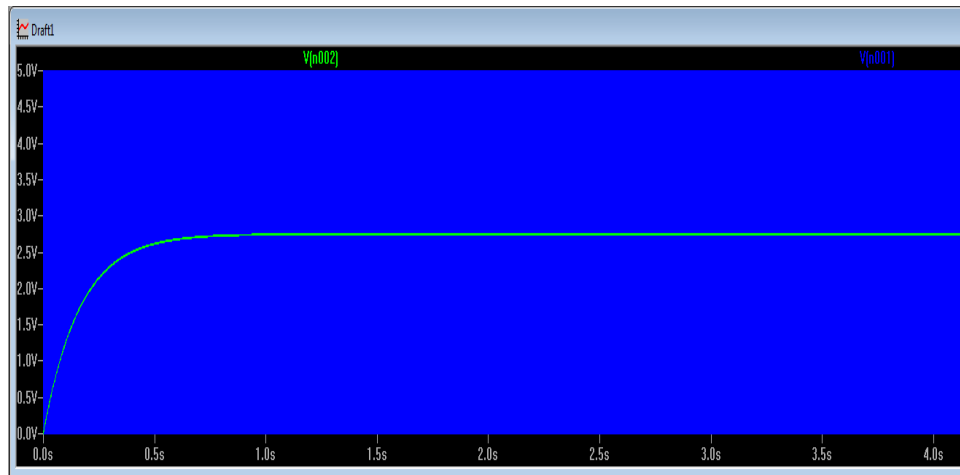Figure 6: RC filtering circuit for the PWM output voltage

Figure 7: The PWM output voltage and the filtered DC output voltage from the RC circuit

After making sure that the RC filter design is working well, testing was done in the laboratory using an oscilloscope to see the difference between the output signal before and after the filtering and the results are shown as below.

1. <u>Ideal mode:</u> Channel 2 of the oscilloscope was connected to the PWM output with 0.5 volt/ division scale and channel 1 was connected to the filtered output signal with 1 volt/ division so in Figure 24, the upper signal is the PWM signal with 2 volts and the lower signal is the filtered signal with 1 volt (for the ideal mode) which is half/ average of the PWM signal.
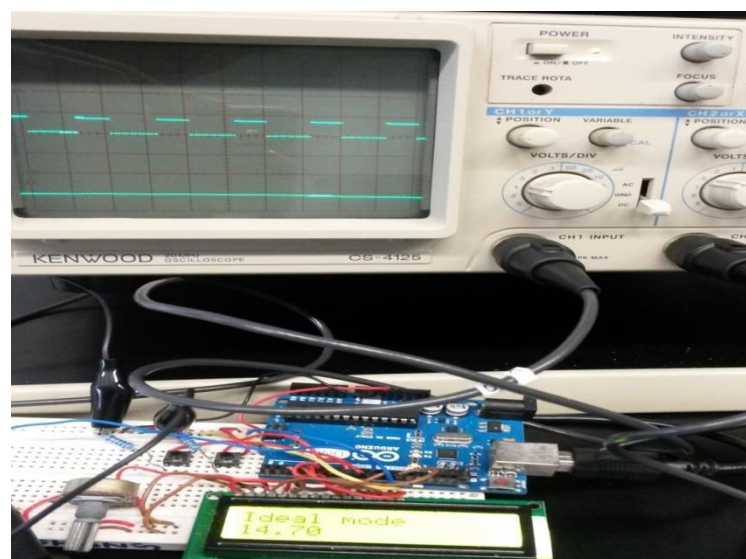

Figure 8: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Ideal mode using the oscilloscope

2. Rich mode: The filtered signals for the A/F ratios 14.1, 13.5,12.9 and 12.3 are 0.75 V, 0.5 V, 0.25 V and 0 Volt respectively as shown in Figures 25, , 26, 27 and 28.

Figure 25: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Rich mode1 using the oscilloscope

Figure 26: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Rich mode 2 using the oscilloscope

Figure 9: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Rich mode 3 using the oscilloscope

Figure 10: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Rich mode Max using the oscilloscope

3. Lean mode: The filtered signals for the A/F ratios 15.3, 15.9, 16.5 and 17.1 are 1.25 V, 1.5 V, 1.75 V and 2 Volts respectively as shown in Figures 29, 30, 31 and 32.
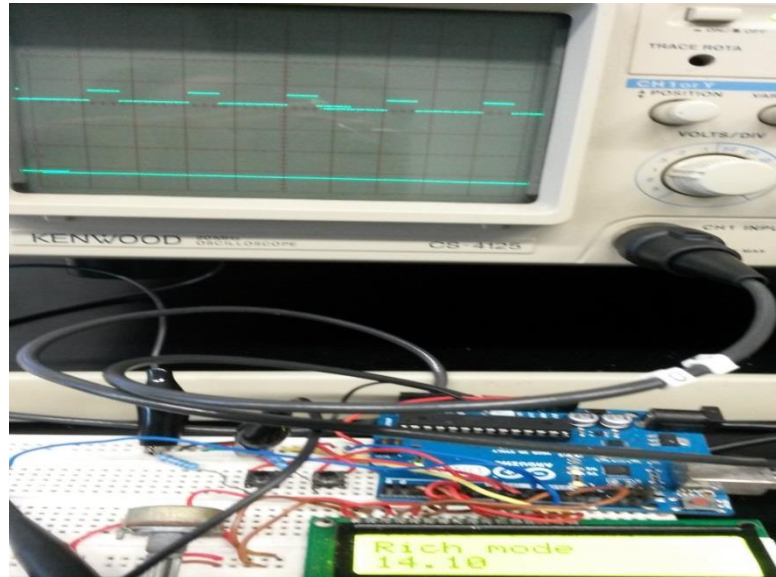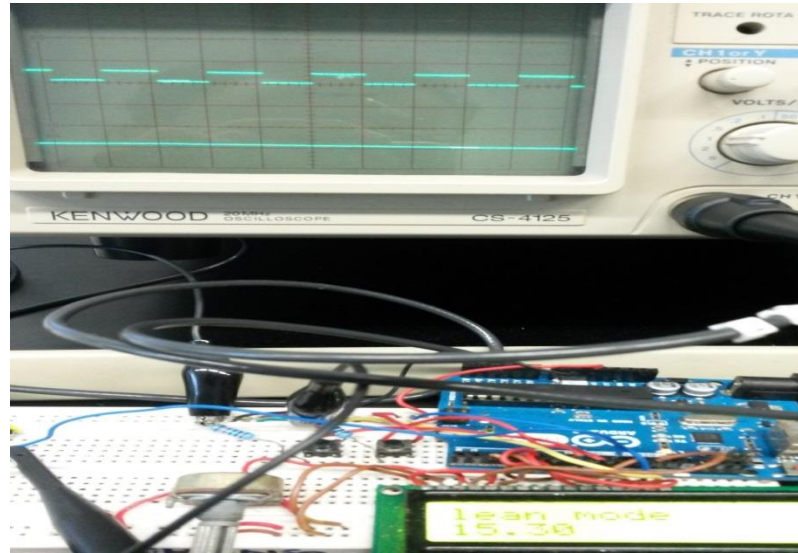

Figure 11: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Lean mode 1 using the oscilloscope
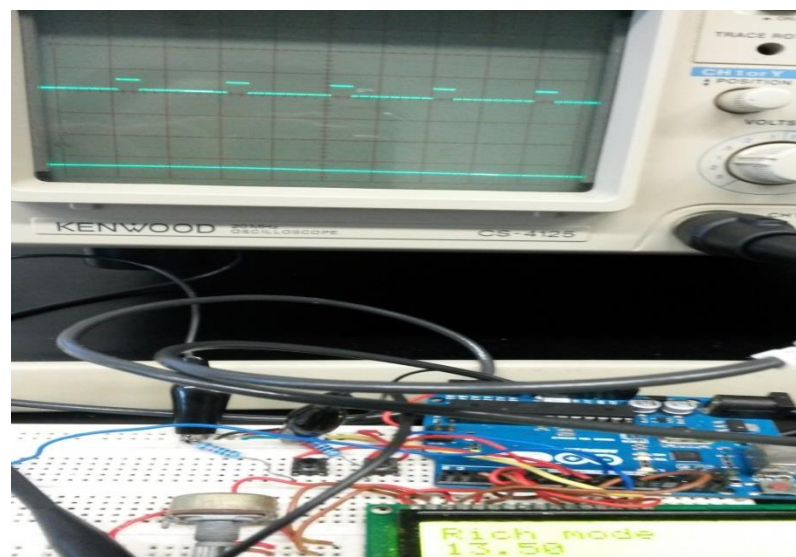

Figure 12: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Lean mode 2 using the oscilloscope
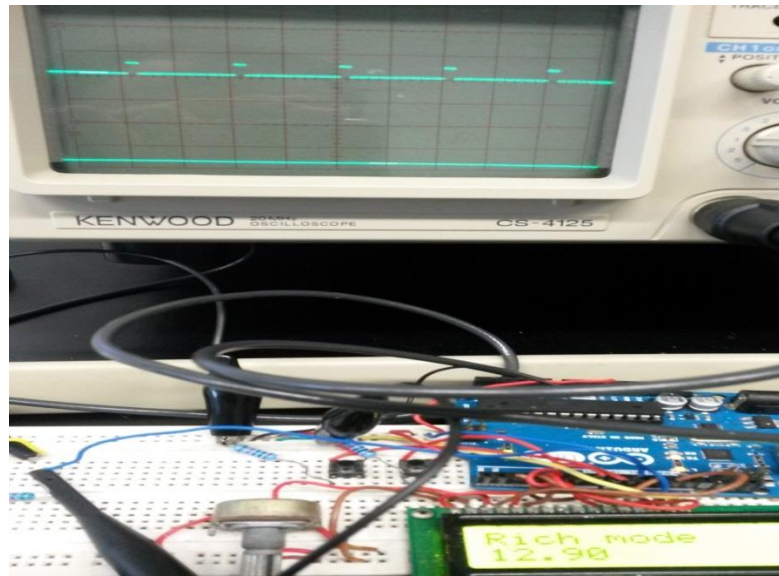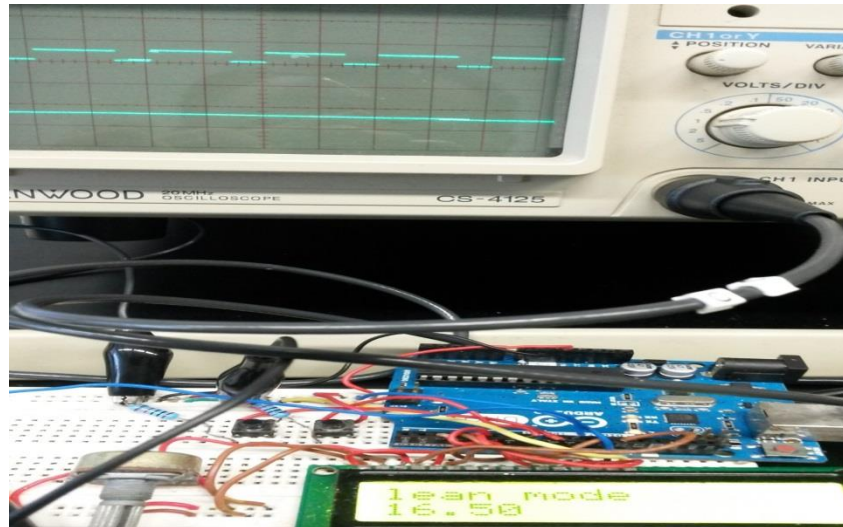
Figure 13: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Lean mode 3 using the oscilloscope
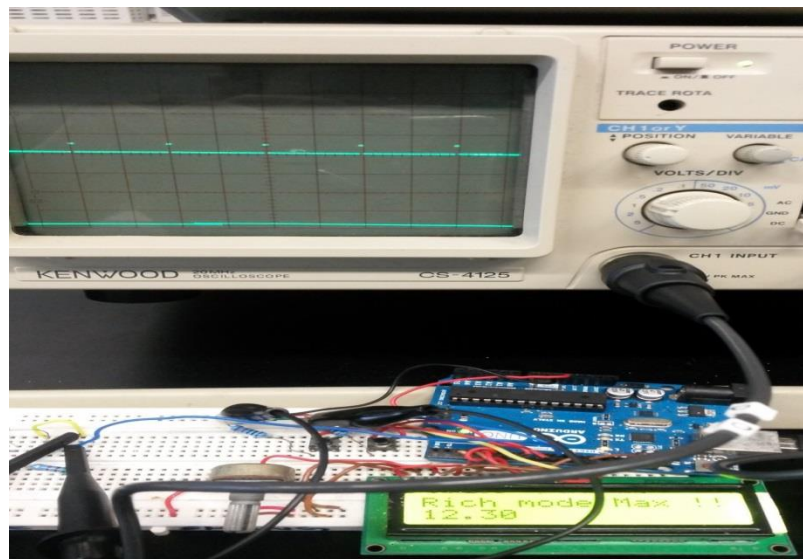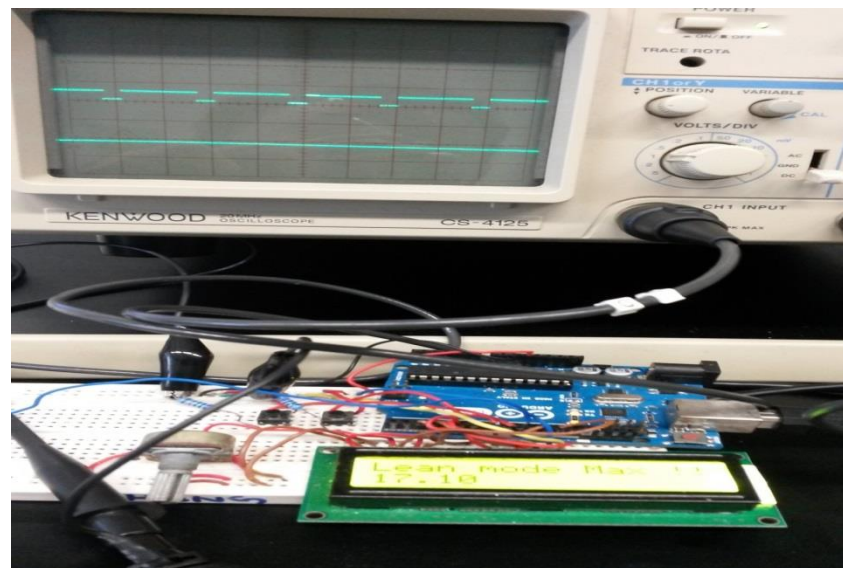

Figure 14: The PWM output voltage and the filtered DC output voltage from the RC circuit signals for Lean mode Max using the oscilloscope

After those stages, testing of the prototype will be conducted on the car to see if it preforms the required task, if it is the case then a Vero board will replace the bread board for the prototype to be presented in a more proper way, if not then further modification to the design must be done first before finalizing the prototype design (which was the case as the first testing gave different output than the intended one so the reason behind the error was examined and corrected in section 4.4).

4.4 CORRECTED CIRCUIT TO OVERCOME THE CAR VOLTAGE INFLUENCE

After testing on the car using the previous method the desired outcome was not as desired as the 5 V power supply from the battery which come through the same cable used to connect the prototype to the car's ECU which was connected before to the CO pot influence the voltage source presented by the prototype so the resultant Voltage that reach the ECU follows Thevenin's theorem for 2 voltage sources.

The problem was tackled by using a voltage follower circuit which was explain in the literature review section 2.4 and which will provide high impedance to isolate the prototype voltage source from the battery supply and make the input to the op amp represented by the filtered PWM signal always the same as the op amp output which will provide the desired voltages directly to the ECU.

The simulation for the final circuit and the final prototype is explained as below in figures 33 and 34.
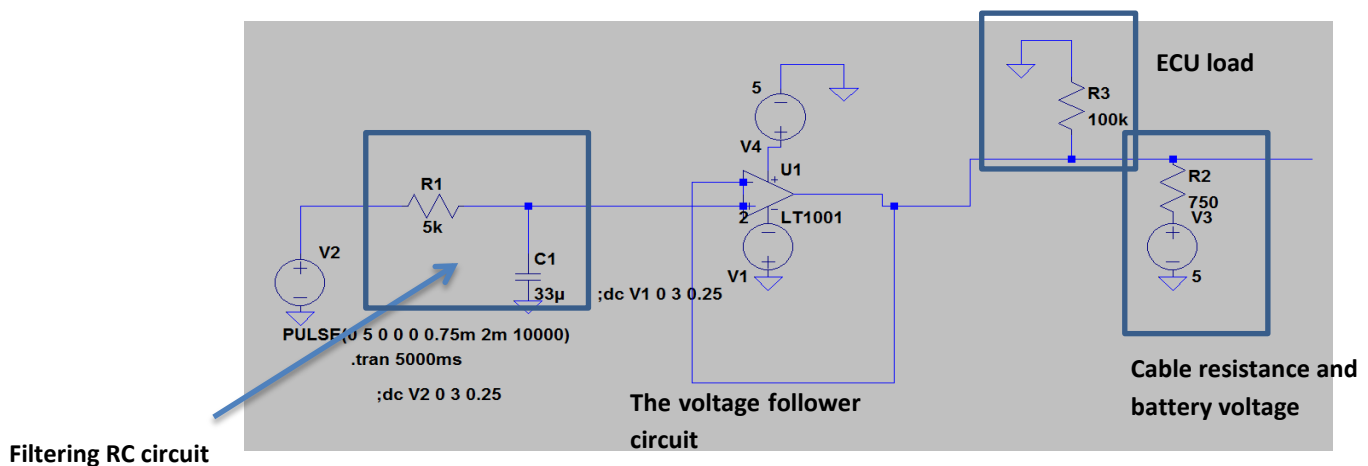

Figure 33: The final circuit design using the LTspice software
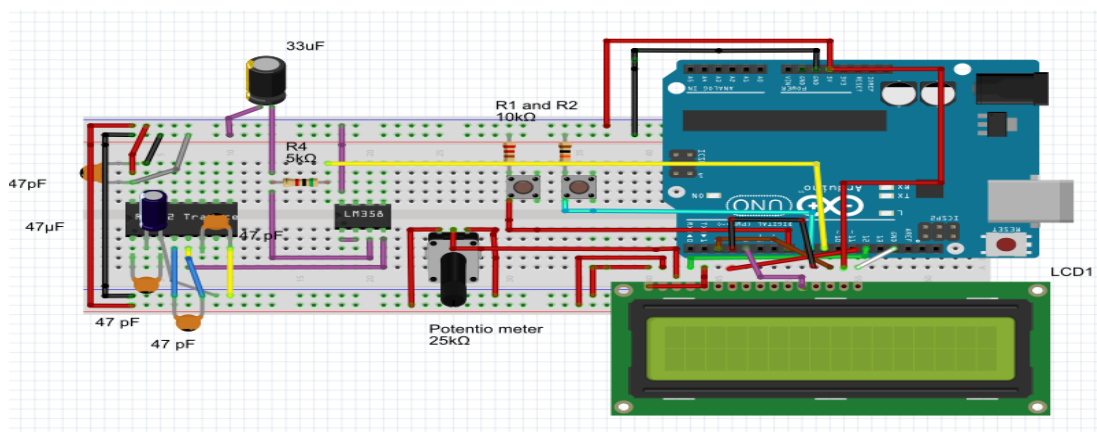
Figure 34: The prototype connections for the corrected design

The output of the op amp is equal to the Arduino filtered PWM voltage values which are the desired voltage levels to be supplied to the ECU and they will be always the same as the voltage at the ECU load as shown in the simulation curves of figure 35.
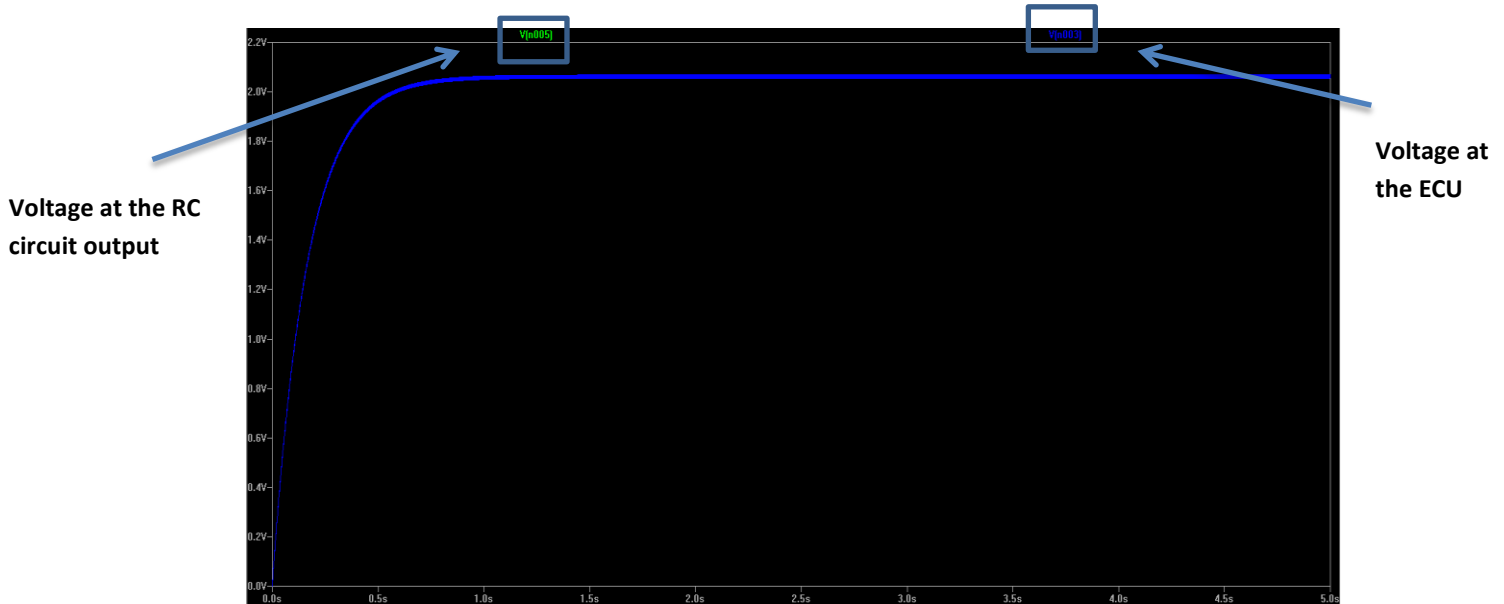
Figure 35: The Voltage output from the prototype equal to that on the ECU load

Note: The op amp –Vcc required a negative voltage from -1 to -5 V supply for the right operation (in case of connecting the –Vcc to ground will always have an input voltage offset) so there are 2 methods to obtain this negative voltage:

1. Make a voltage divider from the battery of the car after regulating it to 5V to provide a positive and negative voltage at its terminals
2. Use an IC MAX 232 charge pump which can provide a negative voltage output directly by supplying a 5 V from Arduino to the IC VCC

The second solution was used as it makes full use of the main circuit and requires less circuitry in the design compared to method one.

The final design was tested on the car and it was working as intended and was recorded in case of demonstration if testing on the car will not be available and the circuit is transformed to the second prototype model (Vero board base) to be implemented inside the car.

The Voltage levels were changed to match the circuitry requirements as the minimum output from the op amp with IC MAX 232 negative supply is 0.5 and for

the safer condition of the ECU to avoid a short circuit on the long run in case of Lean mode Max with zero volt supply (short circuit), so the new voltage levels are stated in Table 8 and will be the final values to be applied in the car testing and operation later on.

Table 8: Latest Driving modes and their equivalent output voltages and A/F ratios

Driving mode	A/F ratio value	Output voltage (V)
Lean Max	12.9	0.5
Lean	13.5	0.75
Lean	14.1	1
Ideal	14.7	1.25
Rich	15.3	1.5
Rich	15.9	1.75
Rich	16.5	2
Rich Max	17.1	2.25

4.5 RECOMMENDATION FOR FUTURE WORK.

1. The voltage values steps between different modes can be changed by the designer to match his requirements. In this prototype the voltage step between modes is +/- 0.25 V but it can be changed to +/- 0.1 V for better accuracy and more options for tuning.

2. The RPM of the car is simply an indication for a voltage value from the motion sensor so this voltage value can be supplied to the ATMEGA in order to link the motion with the A/F ratio, so for example if the indicator shows deceleration when the speed reaches below 20 Km/h the equivalent voltage will tell the Arduino to change automatically to the Lean mode Max while saving the last chosen mode of driving to save fuel and reduce the emissions in the traffic lights and when the indicator show an increment in the RPM till it exceeds the 20 Km/h the A/F ratio will return automatically again to the last saved driving mode.

3. A Temperature sensor can also be linked to the Arduino in case of using a certain driving mode for longer time that leads to increasing the temperature of the engine so that the driver can get a warning to switch to the ideal mode

until the temperature is safe again then he will be allowed to choose this mode of driving.

CHAPTER 5

CONCLUSION

The Electric fuel injection system is the modern way of injecting the fuel to cars' engines controlled by the electronic control Unit (ECU) which is considered the brain of the car. The reading of the CO potentiometer will provide a certain voltage corresponding to the resistance set to it and this voltage will be fed to the engine which in return will adjust the pulse width of the fuel injectors resulting in a desired A/F ratio. The flexibility of changing the A/F value from the Stoichiometric value to be leaner or richer mixtures can be done manually and while the car is not moving, so the aim of this project is to give the flexibility for the driver to choose the desired A/F ratios corresponding to certain driving modes which will provide the best requirements for the driver wither economically wise or more power gain and higher speed. The different A/F ratio can be provided to the ECU simply by incrementing or decrementing the Ideal mode (A/F ratio = 14.7) which is the default A/F ratio when the car starts and a quick response in the voltage output changes is applied so that the best performance of the car beside the satisfaction of the driver can be met easily. The code used by the Arduino board can be easily adjusted to adapt to different cars models according to the required output voltage range and also to add mode modes of driving at any time in few minutes. The project represents an open research to be extended at any time which was a mile stone to prove that the concept of transforming the old car manual systems is possible using simple electronics circuitry which can provide a cheap alternatives with a lot of options for the car users and as stated in the recommendation part those can be the first simple ideas to be implemented in case the project will be extended in the future which will eventually lead to the satisfaction and the benefit for the car industry as well as the car users.

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The Arduino code for the prototype

```
// include the library code:

#include <LiquidCrystal.h>


// initialize the library with the numbers of the interface pins

LiquidCrystal lcd(12, 11, 5, 4, 3, 2);


// Button and Debouncing

int maxbutton = 13 ;

int minbutton = 6 ;

int incrementButton = 8;

int decrementButton = 7;

int pwmPin = 9; // output pin supporting PWM

//boolean plus = true;

double value = 14.7 ;

int incrementState = 0; //variable that will read the increment button (either HIGH or LOW)

int decrementState = 0; //variable that will read the decrement button (either HIGH or LOW)

int maxstate = 0 ;

int minstate = 0 ;

//int counter= 0; //variable that will store the count

int lastIncrementState = 0;

int lastDecrementState = 0;

int lastmaxstate = 0 ;
```

```
int lastminstate = 0 ;

double val  ;

double volt ;

void setup()

{

  // set up the LCD's number of columns and rows:

  delay(30);

  Serial.begin(9600);

  lcd.begin(16, 2);

  // Print a message to the LCD.

  lcd.print("Ideal mode ");

  lcd.setCursor(0,1);          // set cursor to column 0, row 1

  lcd.print(value);

  delay(5); //debounce delay


}

void loop()

{

  incrementState = digitalRead(incrementButton); //read the increment button state

  decrementState = digitalRead(decrementButton); //read the decrement button state

  maxstate = digitalRead(maxbutton); //read the Rich mode Max button state

  minstate = digitalRead(minbutton); //read the Lean mode Max button state

  delay(200);

  if(incrementState != lastIncrementState) //compare increment button state to its last
state

  {

      if(incrementState == LOW)//increment button is pressed
```

```
      {

       if (value < 17.1)

        {

          value = value + 0.3;

        }

      }

          lastIncrementState = incrementState;

       }

   else if(decrementState != lastDecrementState)

   {

     if(decrementState == LOW )//increment button is pressed

      {

        if (value > 12.0000000)

        {

          value = value - 0.3;

             }

        }

      lastDecrementState = decrementState;

   }

    else if(maxstate != lastmaxstate) //compare Rich mode Max button state to its last
state

    {

      if(maxstate == LOW)// Rich mode Max button is pressed

      {

        value = 17.10 ;

        lcd.setCursor(0,0);

          lcd.print("Sports mode    " ) ;
```

```
        lcd.setCursor(0,1);          // set cursor to column 0, row 1

        lcd.print(value);

    }

        lastmaxstate = maxstate  ;

    }

else if (minstate != lastminstate) //compare Lean mode Max button state to its last
state

  {

     if(minstate == LOW)// Lean mode Max button is pressed

     {

      value = 12.90 ;

      lcd.setCursor(0,0);

        lcd.print("Economic mode     " ) ;

        lcd.setCursor(0,1);          // set cursor to column 0, row 1

        lcd.print(value);

     }

        lastminstate = minstate  ;

     }


  if (value = = 14.7)

  {

  volt = 1.25;

  val = 255 * (volt / 5);

   Serial.println(val);

  analogWrite(pwmPin, val);

       lcd.setCursor(0,0);

       lcd.print("Ideal mode      " ) ;
```

```
        lcd.setCursor(0,1);          // set cursor to column 0, row 1
        lcd.print(value);

        }
else if (abs(value-12.90)<0.1)

 {

 volt = 0. 5 ;

 val = 255 * (volt / 5);

 Serial.println(val);

 analogWrite(pwmPin, val);

        lcd.setCursor(0,0);

        lcd.print("Rich mode Max !!" ) ;

        lcd.setCursor(0,1);          // set cursor to column 0, row 1

        lcd.print(value);

         }
else if (abs(value-17.10)<0.1)

 {

 volt = 2. 25 ;

 val = 255 * (volt / 5);

 Serial.println(val);

 Serial.println(val);

 analogWrite(pwmPin, val);

        lcd.setCursor(0,0);

        lcd.print("Lean mode Max !!" ) ;

        lcd.setCursor(0,1);          // set cursor to column 0, row 1

        lcd.print(value);

        }
```

```arduino
else if (value > 12.3 && value < 14.7)

{

     lcd.setCursor(0,0);

     lcd.print("Rich mode      " ) ;

     lcd.setCursor(0,1);          // set cursor to column 0, row 1

     lcd.print(value);

   else if (abs(value-13.50)<0.1)

     {

       Serial.println(value);

      volt = 0.75 ;

val = 255 * (volt / 5);

Serial.println(val);

analogWrite(pwmPin, (int)val);

     }

     else if ( abs(value-14.10)<0.1)

     {

       Serial.println(value);

      volt = 1.01;

val = 255 * (volt / 5);

Serial.println(val);

analogWrite(pwmPin, val);

     }

}

 else if (value > 14.7 && value < 17.1)

{

     lcd.setCursor(0,0);

     lcd.print("lean mode      " ) ;
```

```
        lcd.setCursor(0,1);          // set cursor to column 0, row 1

        lcd.print(value);

         if (value = = 15.30)

         {

 volt = 1.505 ;

val = 255 * (volt / 5);

Serial.println(val);

analogWrite(pwmPin, val);

        }

        else if ( abs(value-15.90)<0.1)

        {

        volt = 1.752 ;

val = 255 * (volt / 5);

Serial.println(val);

analogWrite(pwmPin, val);

        }

        else if ( value == 16.50)

        {

        volt = 2.05 ;

val = 255 * (volt / 5);

Serial.println(val);

analogWrite(pwmPin, val);

        }

}

else if ( value > 17.100000)

{

        value = 14.7;
```

```
        lcd.setCursor(0,0);

        lcd.print("Ideal mode      " ) ;

        lcd.setCursor(0,1);            // set cursor to column 0, row 1

        lcd.print(value);

}

else if ( value < 12.900000)

{

        value = 14.7;

        lcd.setCursor(0,0);

        lcd.print("Ideal mode      " ) ;

        lcd.setCursor(0,1);            // set cursor to column 0, row 1

        lcd.print(value);


}

}



        lcd.setCursor(0,0);
```