

DESIGN AND IMPLEMENTATION OF A RECONFIGURABLE AUTOMATIC RAIN SENSITIVE WINDSHIELD WIPER

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ABSTRACT

In today's automotive industry, the issue of driver safety and comfort is of great importance. An automatic windshield wiper system is of great aid in such cases. It betters the driving experience and improves the safety factor of a vehicle by converting the manual windshield wiper system into an automatic system. By taking care of the attentions drivers would have to devote to control a manual system, an automatic wiper system helps them to concentrate more on driving safely. Although, few automated windshield wiper systems are available in the automotive market, they are very costly and not very effective. This paper presents a cost effective and high performance automatic windshield wiper system developed using an Arduino Uno microcontroller and a rain intensity detection sensor. The system was programmed to use fuzzy logic to manipulate the analog data collected from the sensor, and the microcontroller controlled the wiper motor using pulse width modulation (PWM). The use of fuzzy logic allows the system to be easily reconfigurable. Such feature can be utilized to design different wiper system for different vehicles and weather conditions without any hardware modification. It was successfully connected to a commercial vehicle (Mazda Protégé) and tested for different rain conditions. The sensor data was collected using artificial rain conditions to mimic real world raining conditions and the resultant windshield wiper movement strongly resembled manual control of the wipers. In a nutshell, the developed system was not only cost effective but also highly performing.

KEYWORDS: Automatic windshield wiper, microcontroller, rain sensor, PWM, fuzzy-logic

I. INTRODUCTION

Rapid advancement in the automotive industry and in transportation systems has resulted in quicker means of travel. Owing to this faster moving traffic, drivers now cannot afford to pay much attention in controlling several additional independent systems manually. Such a system is the windshield wiper system, which clears the windshield during rain or snow to provide better visibility to the drivers. Controlling a wiper system manually can be very problematic in some situations. For instance, heavy-duty vehicle drivers have to control their vehicle's transmission manually. In foul weather conditions, controlling both ABC (Acceleration, Brake and Clutch) and the windshield wiper system is troublesome and can lead to severe accidents [1]. In such a case, automatic windshield wiper systems can greatly aid driver safety and provide a better driving experience. Application of automatic windshield wiper systems can also be seen in motorsport, where the racers have to pay full attention in driving as a small fraction of inattention can lead to failure in competition and harsh accidents. To get rid of controlling the windshield wiper, the racers keep the system on for whole racing time regardless of weather conditions. An automatic windshield wiper system can be used to ensure a clear visibility without racer's involvement.

Many attempts have been made at constructing an effective, reliable, and cheap rain detection and wiper control system for vehicles. Despite this, automatic rain-sensing wiper systems are relatively uncommon in modern vehicles for a number of reasons. They are often too expensive [2, 3], too

unsightly, or too unreliable to be desired in new automobiles [4]. While a number of different design approaches have been undertaken into consideration to improve upon these issues, none of them have been successful enough technically and financially to become widely adapted in new vehicles. In this paper, Section 2 and 3 discusses related work and existing rain sensors technologies, respectively. Section 4 describes the hardware feature of the developed smart wiper system and section 5 discusses development of the fuzzy logic control. After that, section 6 describes the system design implementation. Section 7 elaborates on the research results and discussions. Then, section 8 concludes the paper and section 9 details the possible future works related to this field of research.

II. RELATED WORK

For about twenty years, a significant amount of researches have been conducted to automatize the windshield wiper systems. Primitive ideas of using ultrasonic vibrations to remove the raindrops from the windshield or using special coating that prevent raindrops to form in the windshield has been proven ineffective as drivers found those systems annoying and disturbing. Among other considered ideas, the idea of using optical rain sensor has proven to be somewhat effective. For this wiper system, an optical rain sensor was used, which detected the change in the reflection of light projected by another source to determine the presence of water in the windshield. This system has been produced by TRW Inc. and has been used in recent Cadillac cars manufactured by General Motors (GM) [4]. However the method has also been proven less effective for certain circumstances. The next section addresses the disadvantages of this system along with other considered systems. Although many automobile companies didn't have automatic windshield wipers available for their marketed vehicles before, many companies are currently manufacturing vehicles with automatic windshield wiper system. Renowned automotive companies such as Toyota Motor Corporation and Honda Motor Companies have launched their new vehicles equipped with rain-sensing wipers [2, 3]. Additionally, other companies, for example Ford Motor Company and Volkswagen AG, are also bringing in rain-sensing wipers into the market [5, 6]. Specific information about the wiper system of those vehicles is not available, as those vehicles are not available in the market yet.

III. CURRENT RAIN SENSOR TECHNOLOGIES

A rain sensor is used to detect the intensity of the rain and to provide different signals for different rain intensities to the controller. The ADC in the controller detects the sensor input and gives the signal to the driver circuit. The motor driver actuates the motor to run at high speed or low speed based on the amount of the rain intensity detected, and thus, the speed of the wiper is controlled. Currently, there are many types of rain sensors are proposed for use in automotive industry. To illustrate the predominance of these sensors, some types are described briefly below:

3.1. Image array sensor

An image array sensor, a CMOS active pixel sensor, is used to detect the intensity of the rain in patent [7]. When a raindrop is present in pixels of the sensor, the voltage of those pixels creates an illumination level, which is converted to grey scale values and stored in memory. Then, the frequency pattern of those grey scale values is analysed to determine the amount of rain present. The problem with such a sensor is that once the pixels are wet, they become less sensitive to the next raindrop, for the previous raindrop layer hinders the direct contact between the pixels and the new raindrops. Besides, the optical sensor covers only a partial section of the windshield. Thus, it does not provide results based on the overall condition. Moreover, the sensor fails to differentiate any unwanted objects, such as dusts or leaves, from raindrops, and thus can be very ineffective at times [8].

3.2. Audio Sensor

The condition of rain can be detected using a microphone by listening to the sound created by falling raindrops on a metallic panel such as the roof of the vehicle. However, this system will require the use of a frequency selective filter to eliminate ambient noises [9].

3.3. Capacitive Sensor

In [8] and patent [10] a film of capacitive sensors are embedded within the laminated layer of the front windscreen, and the sensors detects the intensity of the rain based on the fluctuation of the capacitive signals and resistance due to the connection of the electrodes of the sensor via raindrops. The manufacturing procedure is a limitation to implementing this system, as many car windows are not laminated. Plus, the electrodes of the sensors require electric connections, which is difficult and costly [11]. Plus, once the sensing electrodes are wet, they become less sensitive to the next raindrop [12].

3.4. Optical rain sensor

The optical rain sensor is built on the theory of reflection of light. Infrared light is projected on the windshield from a source, which is collected by a photo detector. And, based on the change in the amount of deflection of light, the system recognizes the presence of raindrop in the windshield and moves wiper automatically [1, 4]. However, unwanted objects like darts and leaves lying on the windshield can easily disrupt the reflection path of the light. Besides, the sensor becomes sensitive to external lights such as underground parking lights, lights inside tunnels, and starts to move the wiper regardless of clean weather condition [4]. Also, due to using infrared lights, the sensor suffers from small sensing area.

3.5. Omni-directional rain sensor

In this method, similar approach as the optical sensor is used. However, instead of throwing lights at a certain angle like traditional methods, this system scatters the inputted light source in many directions. Then, the photodiode receives the scattered light reflected by the raindrop and calculates mathematically the intensity of the received light. This approach helps to use bigger surface area of the windscreen [12]. However, this system is still not efficient in cases of differentiating the unwanted objects from raindrops.

As described above, all of the proposed methods are somewhat costly and ineffective. This paper discusses a cost effective and highly performing windshield wiper system. A rain intensity detection sensor is used to receive an analog data about the intensity of the rain. Different weather conditions are assigned to different sets of data using fuzzy logic. A control device transmits the data from the sensor to the wiper motor. Then based on different weather conditions detected by analysing the transmitted data, the windshield wiper rotates automatically.

IV. SYSTEM HARDWARE DESCRIPTION

The system hardware consists of a control device, a rain intensity detection sensor, a power supply module, windshield wiper system and the wiper motor. Description on each component is provided below:

4.1. Control device

A microcontroller was used rather than using a footprint mini-computer like Raspberry pi as the control device between the sensor and the wiper motor. The microcontroller used was Arduino Uno, a microcontroller board built based on the ATmega328. Figure 1 shows the Arduino Uno board. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, and a 16 MHz ceramic resonator [13]. Arduino Uno is preferred to Raspberry pi because higher functionality, security, expandability and cost effective features. As the developed system requires a better hardware support base, rather than computer-like features, Arduino is a better choice in terms of functionality. Besides, the hardware nodes of an Arduino Uno is more secured than that of Raspberry pi, as in order to change any functionality of the nodes an intruder needs to know the software codes, whereas for Raspberry pi he only need an external SD card. Moreover, Arduino Uno is open source whereas Raspberry pi is closed source. That's why, an Arduino compatible board is less expensive. Moreover, Arduino Uno supports a greater range of modules, thus a wide choice of sensors can be used [14].

4.2. Rain intensity detection sensor

A sensor is an electronic device, which senses and real world phenomena, such as lights, water vapour, humidity etc. In this system a sensor that measures the intensity of raining is used. The sensor

used was an analog sensor, which generated a voltage range mimicking the differences in the pressure created by raindrops [13]. Arduino Uno then converted this voltage range to digits. The sensor had small holes in the printed copper tracks, which will cause the tested raindrops to pass down so that pressures of new raindrops can be gathered. Figure 2 shows the rain sensor that used in our system.



Figure 1: Arduino Uno

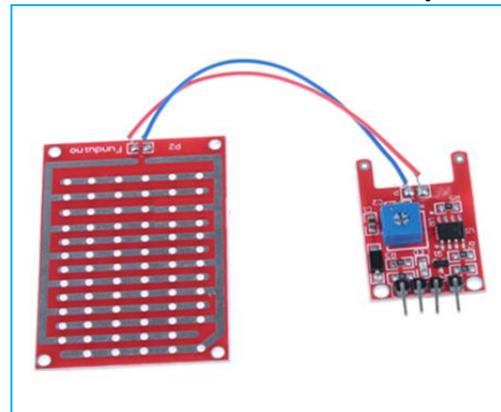


Figure 2: Rain sensor used

One of the very important aspects of the system was placing the sensor in a right place so that raindrop pressure can be gathered to the best accuracy and preciseness. Studies of vehicle aerodynamics using different methods such as computational fluid dynamics (CFD), wind tunnel system and LS-DYNA R7 [15, 16, 17] shown that, the curl vortex region of a car (see Figure 9) is the best suited place to place the sensor. However, this region confronts very high vorticity. The vorticity vector is used in the fields of fluid mechanics and aerodynamics to describe the rotational characteristic of a fluid flow in a region. As the vorticity vector value is very high in the curl vortex region, the sensor has to be connected strongly with the external part of the curl vortex to avoid any damage to it due to high rotational speed.

Additionally, the volumetric flow rate is highest around this region. If a rain sensor case is placed in this place to help the sensor sustain high vorticity, the airflow will move very quickly passing the case. Therefore, it won't greatly affect the vehicle aerodynamics. Moreover, different aerodynamically friendly case models can be developed to address this issue. In spite of the facing problems like high volumetric flow rate and vorticity, the curl vortex is the best place to mount the sensor, as this is the only place where the pressure applied is positive.

4.3. Power supply module

The voltage range of automotive vehicles range from 11 Volts to 13.5 Volts [9], and the Arduino can be powered using 3.3 Volts, 5 Volts or 9 Volts. Therefore, a power supply module was used to convert the vehicle voltage to Arduino Uno compatible voltage. The module used was DSN2596. It can take in 3.2V-40V and convert it into 1.25V-35V. The module has a built-in potentiometer to control the output voltage. For this system, 3.3V output voltage was used. This module is very accurate and cost effective (\$0.90). The power supply module is shown in Figure 3 below.



Figure 3. Power supply module

4.4. Windshield Wiper Motor

For this system, the built-in electric wiper motor with permanent magnet of the tested car was used. The built-in motor had four inputs: one for the highest speed movement of the motor (colored blue and red), one for the lowest speed (colored blue and white) and two other inputs for intermediate speeds to provide the speed variations. Detailed schematic of the motor system is presented in Figure 6.

4.5. Windshield wiper system

This motor is then connected with the wiper body through several linkages, such as wiper-actuating rod, wiper stroke, crank lever, crank pin and eccentric shaft. The wiper body, which is the only visible component other than the sensor, has various components, such as wiper arm, wiper blade, and wiper stroke. [19] The overall conventional windshield wiper system is shown in Figure 4.

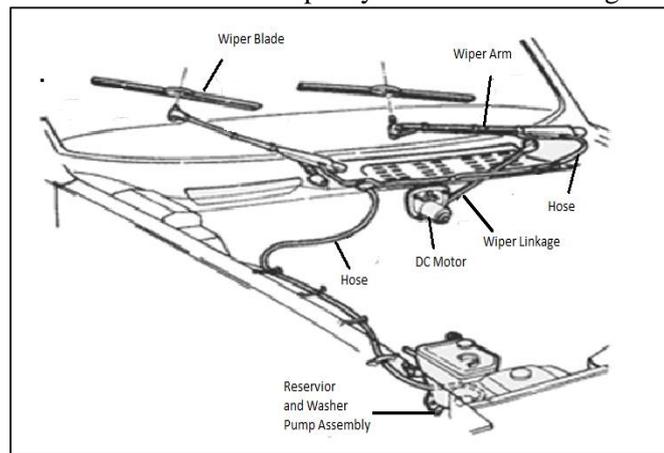


Figure 4. Conventional Windshield Wiper System [19]

V. DEVELOPMENT OF FUZZY LOGIC BASED-CONTROL

The rain sensor used for this system is an analog sensor. Therefore, the data collected through the sensor was analog. The Fuzzy logic is used to assign different weather conditions to different ranges of the analog data. The advantage of using fuzzy logic is that, it is very much similar to way human interpret weather pattern [9]. Therefore, use of fuzzy-logic makes the software design easier and efficient. To interpret the analog data using fuzzy-logic, certain weather conditions were assigned to certain ranges of data. As described earlier, the wiper motor had four inputs, two of which were used for the highest and the lowest speeds. In the automatic system, these two inputs were used to manipulate the motor speed, while other two inputs for intermediate speed variations were taken out. To serve the purpose of providing speed variation with two inputs, the Pulse Width Modulation (PWM) feature of the microcontroller was used [20]. Using this feature, different duty cycle was used for different conditions. Following table describes the use of PWM duty cycles and choice of inputs for different weather conditions and Figure 5 shows the flowchart of the system algorithm.

Table 1. Different assigned weather conditions using fuzzy-logic

| Assigned Condition | Input used | Duty cycle % |
|--------------------|-------------|--------------|
| Slow Rain | B/R colored | Low |
| Lower Medium Rain | B/R colored | High |
| Upper Medium Rain | B/W colored | Low |
| Heavy Rain | B/W colored | High |

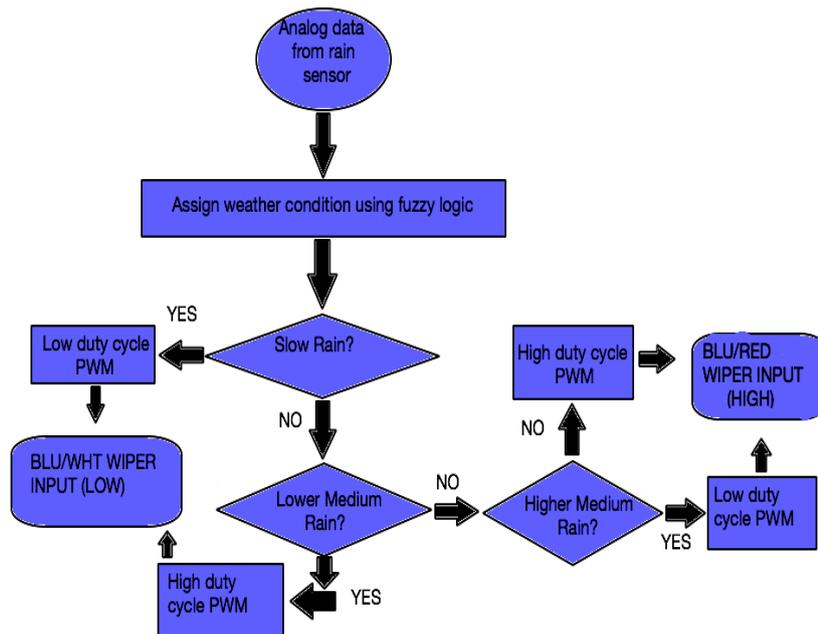


Figure 5. Flowchart of the rain detection algorithm

VI. SYSTEM DESIGN IMPLEMENTATION

The built in design of the windshield system contains two high or low inputs colored blue/ red and blue/ white respectively as shown in Figure 6 below. Also, the system has two other inputs, colored blue/ yellow and blue, which are connected to the intermittent wiper relay.

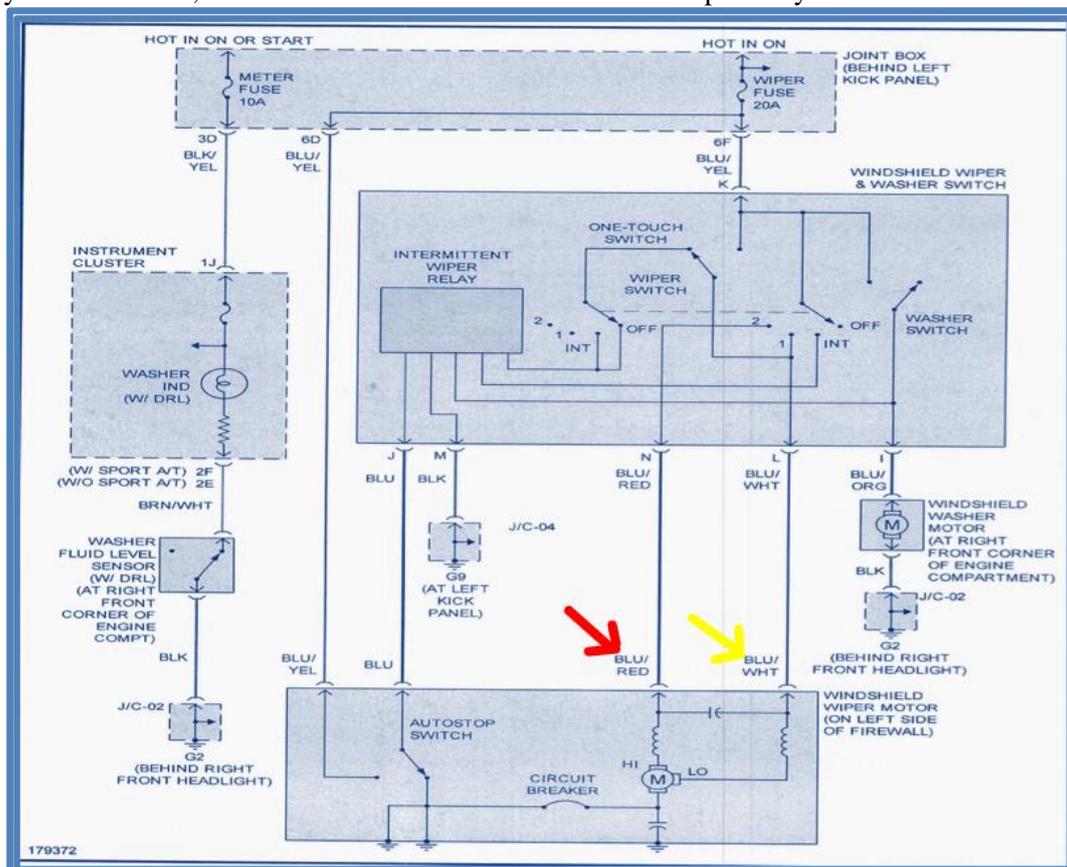


Figure 6. The schematic of the built-in windshield wiper system

These two inputs were used for intermediate wiper speed, while the first two provided the highest and lowest speeds. For this system, the system was improvised by disconnecting the intermittent relay connected inputs and by connecting the other two inputs with the PWM output pins of the microcontroller. Using this feature, different duty cycles were used for different conditions, as shown in Table 1.

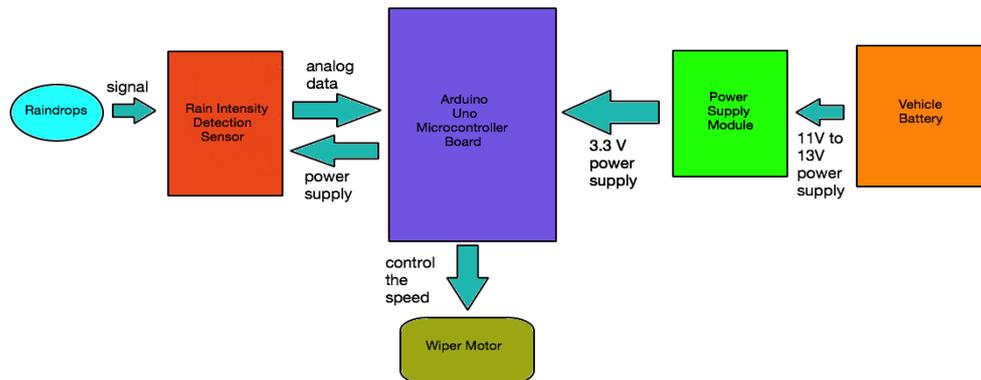


Figure 7. Block diagram of the windshield wiper system

The rain sensor was connected with the analog pin. Besides that, the using the potentiometer of the power supply module, the output value of the module was converted to 3.3 V. Then, the input pins of the module were connected with the positive and negative pins of the vehicle battery, and the output pin was connected with the 3.3V and GND pins of the microcontroller. The power supplied by the vehicle battery ranges from 11V to 13.5V [9].

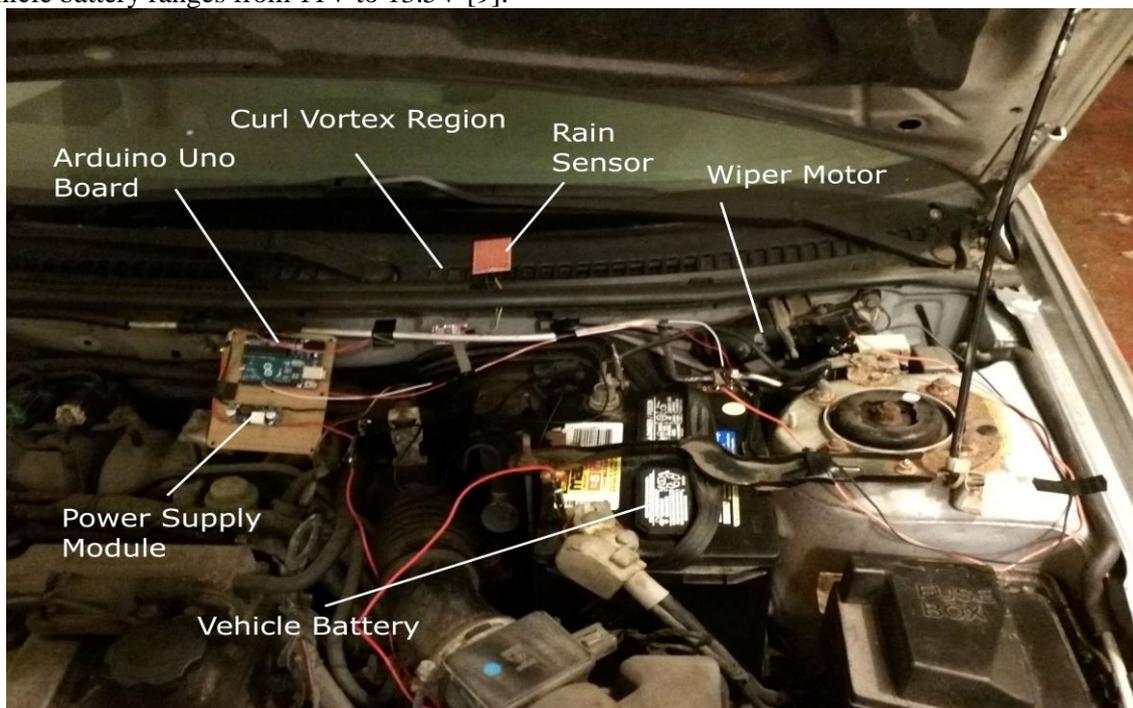


Figure 8. Hardware design of the system taken during test

The power supply module converted it from that range of voltage to 3.3V voltage and powered the microcontroller, which eventually powered the rain intensity. However, the windshield washer was not automatized, and thus left unchanged. The block diagram in Figure 7 shows the overall system design. Figure 8 shows the hardware design as tested in the vehicle.

The complete system was placed under the hood of the vehicle, except for the rain sensor. The rain sensor was placed in the curl vortex region. Following Figure shows the only visible part, the rain sensor, while the hood is closed.



Figure 9. The system while hood is off.

VII. RESULTS AND DISCUSSION

The integrated system has been tested by artificially dropping raindrops with different pressure to mimic different real-life rain conditions. The rotational speed variation of the windshield wiper was achieved by playing with the fuzzy logic ranges until it produced a practical speed. The following Figure shows results achieved during different trials, and is colored according to different rain conditions.

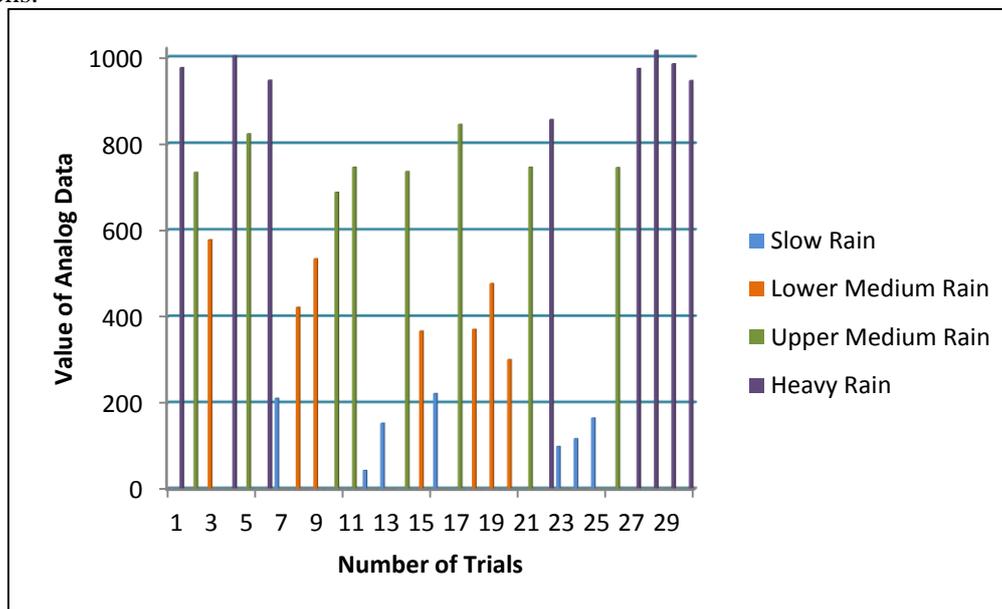


Figure 10. Test results with different weather conditions

Figure 10 represents different values of an analog data received by the rain intensity sensor during different trials while Figure 11 represents system's operates logically. The system generated four different wiper speeds for four different weather conditions by combining one of two considered PWM signals with one of the two available motor inputs. For instance, during slow rain, the lowest considered, the combination was lowest PWM signal and lowest input. Therefore, the resultant wiper speed was the lowest of the four resultant speeds. For superior control over the duty cycle range of the PWM, Arduino Uno can be connected and controlled through MATLAB-SIMULINK software [21].

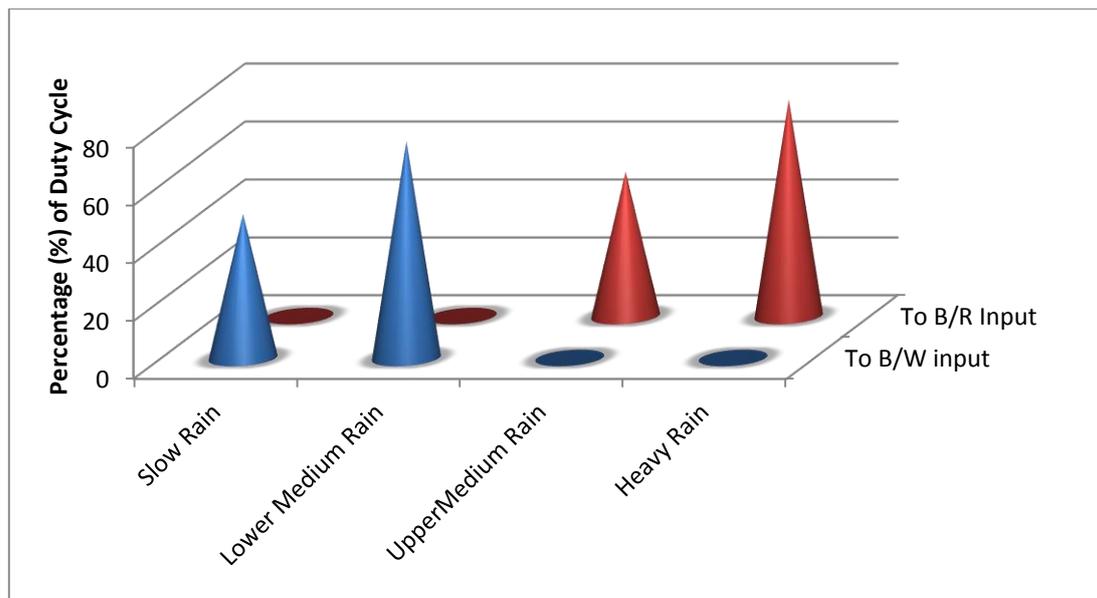


Figure 11. Representation of the system's logical operation strategy

VIII. CONCLUSIONS

We have developed an automatic wiper control system, which is an improvised version of an intermittent wiper system. This wiper system reduces cumbersome wiper operation and improves driver's level of comfort. Specially, it will give a new dimension of comfort to the drivers who work at night and in traffic prone areas where they have to concentrate on controlling the wiper system along with other important manual systems like brakes and clutch. Thus, introduction of this automatic system will provide them with much ease and help them concentrate on the basic ABC (accelerator, brake and clutch) of driving. Our system features high accuracy, high sensitivity, and non-contact measurement. This system is can be reconfigured very easily by creating more PWM duty cycle ranges. Such activities will provide more intermediate wiper speed, and thus will provide better wiper speed variations. The system is also highly configurable with all kinds of vehicles. Minimal changes are required to connect the system effectively due to its design simplicity. Additionally, this highly qualified system is relatively inexpensive. Comparing with all other approached system, this system uses a very inexpensive rain sensor, and all other components such as, the microcontroller and the power supply module are widely available and inexpensive.

IX. FUTURE WORK

Windshield of different type of vehicles, such as trucks, Sub-Urban Vehicles (SUVs), confronts different intensity of rain because of vehicle height, windshield area and windshield angle difference of different vehicles. Therefore, each type of vehicle consists of a somewhat unique windshield wiper system with a unique hardware design to tackle the applicable rain intensity. These different systems can be integrated into one system with a single hardware design by utilizing the reconfigurable feature of the windshield wiper system described in this paper. Through analysing each vehicle design requirements, suitable sets of motor speeds can be arranged for each vehicle using fuzzy logic-based operation. It will simplify the hardware design and aftermarket maintenance complexity and also reduce overall cost of the product. Besides, more automatic control features can be introduced in the vehicle by integrating multiple sensor nodes, each dedicated to sensing a specific condition, controlled by a single microcontroller. Moreover, future research can be conducted in automatizing the windshield washer system to provide more driver comfort.

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