A Rain Sensing Scheme Based on the Structural Properties of the Vehicle Rooftop

A Project Report

submitted by

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THESIS CERTIFICATE

This is to certify that the thesis titled **A Rain Sensing Scheme Based on the Structural Properties of the Vehicle Rooftop**, submitted by **Akhil Nath C.K.**, to the Indian Institute of Technology, Madras, for the award of the degree of **Master of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: Rainfall; Acoustics; Microphone; Sound Analysis; Automobile; Wiper control.

Smart and intelligent devices are the most salient features that have been evolving in automobile industry in these recent years, to enhance the customer comfort and safety. One such application is windshield wiper control. Due to inefficient sensing and cost constraints, most of the vehicles still utilizes the traditional manual wiper control system. During rainy season, it requires constant attention of the driver to adjust the wiper speed based on rain intensity. So an automated and smart wiper control system is a good solution, so that the driver can be at comfort and can pay full attention on to road while driving in such environments.

This project discusses about the analysis of sound generated by the rainfall on the roof of the vehicle, for the detection of rain. It uses a microphone and/or sound analyzer to capture the sound generated by the rain drops falling on the metallic body of the automobiles and further analyze the audio data for rain detection. Experiments are carried out in laboratory to analyze the impact of an impulse force acting on the vehicle rooftop. Also a comparison study is done by analyzing the impact of rain drops falling on rooftop. Envelop of the frequency response of audio samples from various experiments are studied to detect the presence of rainfall on vehicle.

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ABBREVIATIONS

LabVIEW	Laboratory Virtual Instrument Engineering Workbench
DAQ	Data Acquisition
USB	Universal Serial Bus
PC	Personal Computer
ADC	Analog to Digital Converter
DFT	Discrete Fourier Transform
FFT	Fast Fourier Transform
STFT	Short Time Fourier Transform

CHAPTER 1

INTRODUCTION

1.1 General

Automobile industry is one of the most dynamic industries in the world in terms of technology. In recent years, researchers in this field are trying hard to develop technologies to enhance customer satisfaction and safety. Also while purchasing any vehicle, customers are more interested to have the latest technologies including voice command recognition, smart air conditioning, automatic headlamps etc., so that drivers attention from the road is not distracted. Also, we believe that driver-less vehicle's are the future of this industry. In these fast changing technology era, utmost care must be taken while designing the systems, as any malfunction of some of these devices can cost lives of many. One such application which involves distraction of driver off the road and needs technology improvements is the windshield wiper system.

Figure 1.1: Tranditional manual wiper control system

In tropical countries like India, people experience prolonged and heavy rainy season. Driving vehicles in such environments is itself a difficult task as the vision may not be very clear. So, with the traditional wiper control systems as shown in Fig. 1.1, driver constantly needs to adjust the wiper motor speed manually based on the rain intensity and this can cause distraction off the road. Such distractions can end up in devastating accidents. To eliminate such situations, several technologies have been developed over the years for smart sensing of rain in automobiles.

1.2 Background

Researchers have constantly put efforts in developing rain sensing techniques for Automobiles in the past. However each of such configurations developed has its own limitations when it comes to practical situations. Commonly used technologies for rain sensing in Automobile industry are:

- **Resistive type**: Fig. 1.2 shows one of these resistive type of sensors. Sensor geometry is such that lower edge restricts the water flow across the sensor and forms water films, which in turn changes the resistance of the sensor. However, these sensors are not very effective as the sensitivity is very low (small change in resistance detected). Also since these sensors are in direct contact with outside environment, it is prone to noise and is not robust.

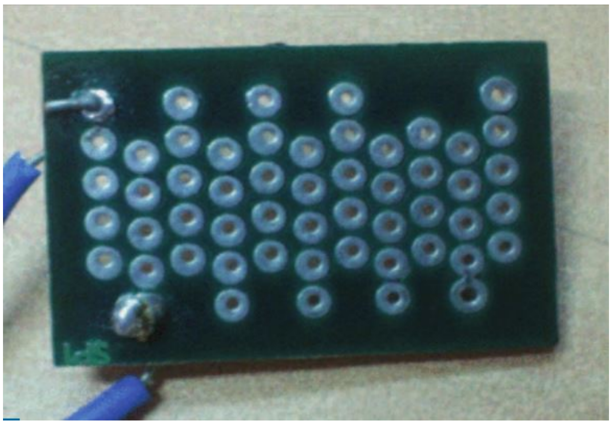


Figure 1.2: Resistive type rain sensor (Joshi *et al.*, 2013)

- **Capacitive type**: Capacitive rain sensors utilizes the property of high dielectric constant of the water molecules to measure the change in capacitance. These kind of sensors suffers from the malfunctioning caused by moisture layer formation and also on the dependency of dielectric constant on temperature.

- **Optical type**: This is the most common and widely used technique in the industry. It uses the property of total internal reflection caused by the water particles. It is generally found at the back side of rear view mirror, facing towards the windshield. Fig. 1.3 shows optical type rain sensor. Major drawback of this type of sensors is the limited sensing area and also dust particles settling in the sensing area causes malfunctioning.

- **Image processing based**: As the name suggests, it uses image processing technique, captured using a high resolution camera. These sensors are primarily found in high end vehicles as it requires improved technology and equipment's and hence becomes quite expensive.

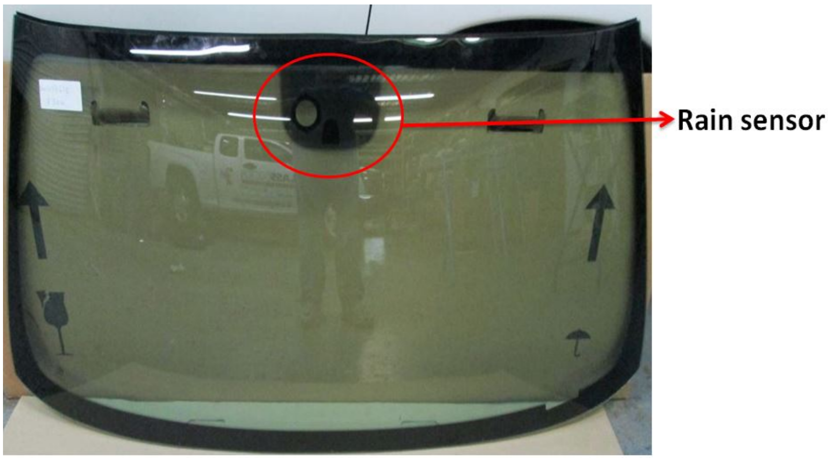


Figure 1.3: Optical type rain sensor on windshield

1.3 Objective and scope of the project

Humans are able to sense rain with the help of just vision or audio. Anyone who has traveled in car during rainy seasons might have noticed that the sound generated by rainfall on the car roofs dominates any other surrounding sounds. Hence, the motive behind this project is to utilize the sounds thus generated to detect the rainfall.

The main objective of this project is to detect the rainfall on automobiles (cars) by analyzing the sound generated, by the raindrops falling on the metallic body, captured with the help of a sound recorder or microphone.

1.4 Organisation of the thesis

Chapter 1 gives an introduction to the need of smart and intelligent technologies in the automobile industry, especially the smart windshield with an automatic wiper control. It explains the various existing technologies in the field and its drawbacks. It also provides the primary objective of this project.

Chapter 2 discusses the researches and studies happened in this field. Also it deals with the simulation done to test the effect of rainfall on the car rooftop, its settings and results obtained.

Chapter 3 describes various properties of microphone to be considered while selecting for a particular application. Also, it briefly describes the features of microphone used in this project.

Chapter 4 explains the experimental setup made in laboratory and its testing and discusses the results obtained. It also covers the results obtained during real time rainfall and a comparison study of results obtained during experimental study and real time situation.

Chapter 5 provides a summary of the results observed and the conclusion of the work carried out. It also includes the future scope of the project.

CHAPTER 2

SIMULATION STUDY

2.1 Rain drops and its impact

To detect the intensity of rainfall based on sound generated and to design the automation of wiper control, it is necessary to understand the effect of rainfall on car body. It is the rain drops falling that makes rain. Therefore in order to understand effect of rain in overall, it is important to perceive the effect of a single drop on car rooftop.

Also, to analyze the sound generated by some object, it is very much required to understand the basic principle behind the sound generation. Sound is generated when an object vibrates. This vibrating object causes the near by medium to vibrate and the longitudinal waves thus generated in the medium hits the ear drum of our ears and we can hear the sound. So, the sound generated by rainfall inside the car can be reckoned to be the result of the vibrations of car body caused by the force exerted by rain drops.

Experiments were carried out in past to study the rain load induced on surfaces. Fu and Li (2018) in their paper calculated the rain load based on single raindrop impinging experiment. In their experiment, force exerted by water drops falling from various heights was measured with the help of a piezoelectric transducer. Fig. 2.1 shows the results obtained in the experiment. From the results, it is very much evident that the force exerted by water drops is similar to that of a impulse force of small duration. Even though the amplitude of force varies, its shape and duration is almost the same when released from different heights.

So studying the sound generated by rainfall hitting the car body can be understood better by simulating the vibration caused by the force induced by falling rain drops (impulse vibration response).

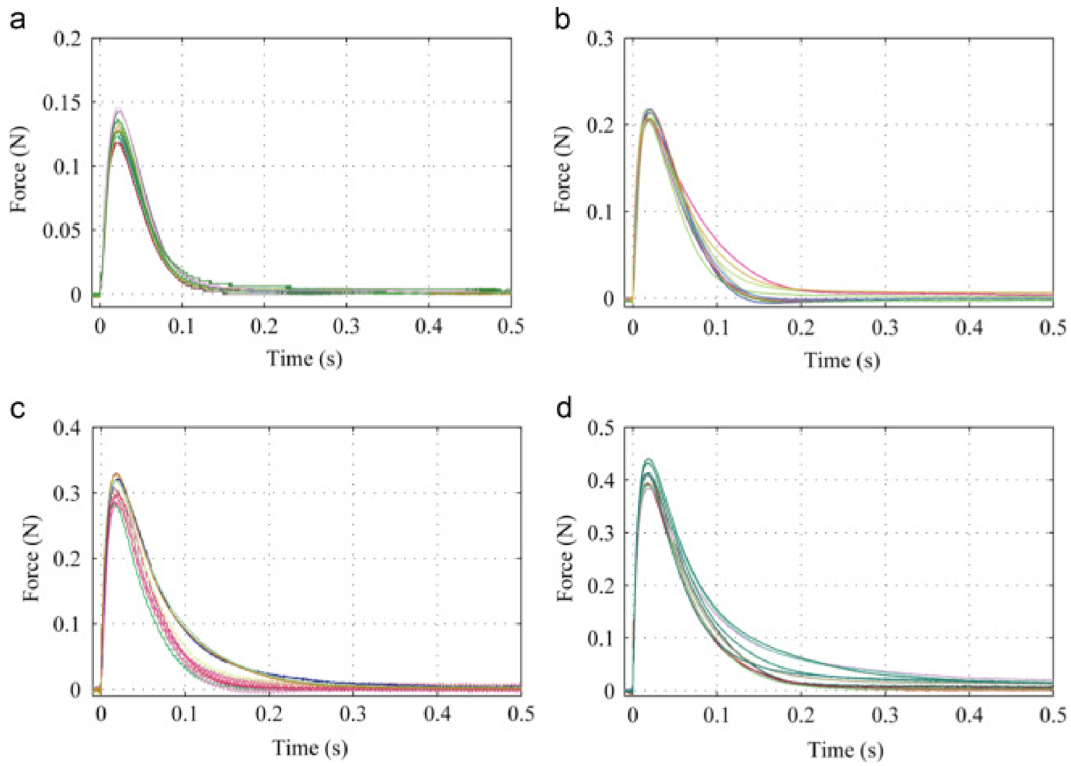


Figure 2.1: Impact force results observed for different release heights: (a) H = 1 m, (b) H = 2 m, (c) H = 3 m, and (d) H = 4 m (Fu and Li, 2018)

2.2 Simulation Settings

Simulations to study the vibration of car rooftop due to rain drops is done using Ansys Software. Ansys helps in simulating and solving engineering and/or multiphysics problems with the help of finite element analysis. In this simulation, we used Harmonic Response module of this software to do a vibration analysis due to impulse force.

Simulation involved building a geometry similar to that of car rooftop. Reference car model used is the Hyundai i10. In automobile industry, most commonly used material for car rooftops is a steel composite (Dual phase Steel), however other materials like aluminium alloy and carbon fibers are rarely used by some manufacturer's. Also, the thickness of the rooftop material generally falls in the range of 0.8 mm to 1 mm. For the simulation purpose, we assumed the material to be mild steel and thickness to be 0.8mm. Table. 2.1 shows the basic properties of metal sheet used in simulation.

To simulate the same effect as on the car roof, fixed constraints are applied on 4 side faces of the sheet and an impulse force of 0.004N magnitude is applied at the center as shown in the Fig. 2.2.

Table 2.1: Properties of metal sheet used in Simulation

Material used	Mild steel
Density	7870 kg/m^3
Dimension	1.5m x 1.2m x 0.8mm
Young's Modulus of elasticity	2.05 x 10^{11} Pa
Poisson's ratio	0.29
Car model approximation	Hyundai i10

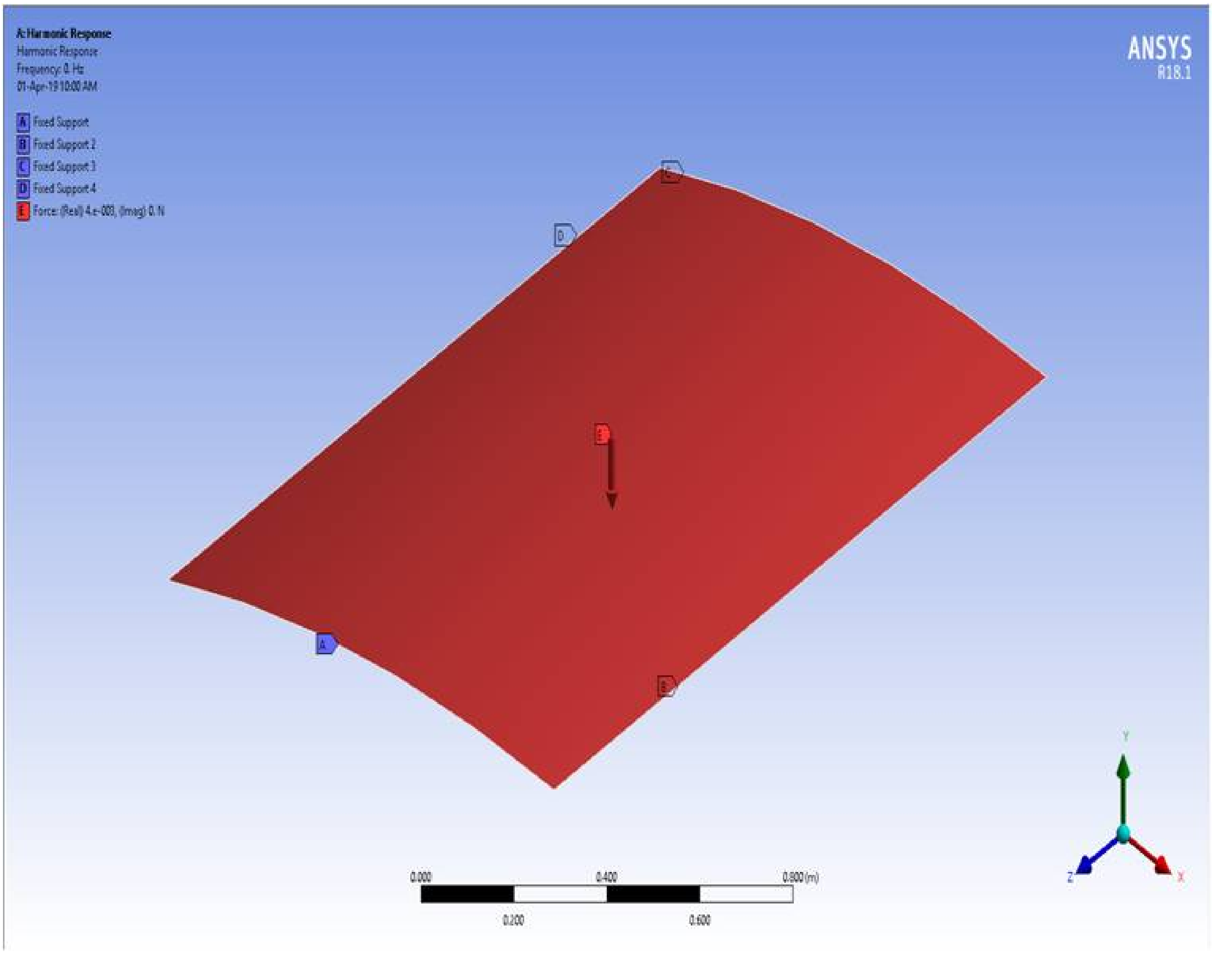


Figure 2.2: Simulation setup in Ansys software

2.3 Simulation Results

Simulation results showed a peak at around 276 Hz when the frequency sweep was done from 0 Hz to 1000 Hz. To have a closer look at the peak, frequency sweep was done from 275 Hz to 278 Hz. Simulation result obtained from Ansys software is shown in Fig. 2.3. Plot gives the magnitude response of vibration caused by the impulse force acting on the metal sheet. As observed from the plot, there is a peak in the response obtained at approximately 276.4 Hz. Also, a phase change of 180 degrees is observed at the same frequency where the peak occurred in magnitude plot, which in turn is a clear indication that the system is vibrating at its resonant frequency.

Resonance is a phenomenon that occurs when a periodic force is applied on a system at a frequency that is equal or nearly equal to one of the natural frequencies of the system itself. This causes the system to oscillate with larger amplitude than when the force is applied at other frequencies. Cantilever structures are generally treated as second order systems. The system under study can also be considered as a beam supported on all four side faces and hence can be approximated as second order.

Order of the system is defined by the number of independent energy storage elements in the system, and intuitively by the highest order of the linear differential equation that describes the system. A system whose input-output relation is defined by a second order differential equation is called a Second Order System. Differential equation describing a typical second order system (mass-spring-damper system) is given by Eqn. 2.1 and the generalized transfer function of such systems in Laplace domain is given by Eqn. 2.2.

$$M\ddot{x} + C\dot{x} + Kx = f \tag{2.1}$$

where,
$\ddot{x}$ is acceleration,
$\dot{x}$ is velocity,
x is displacement,
M is mass of the system,
C is damping coefficient,

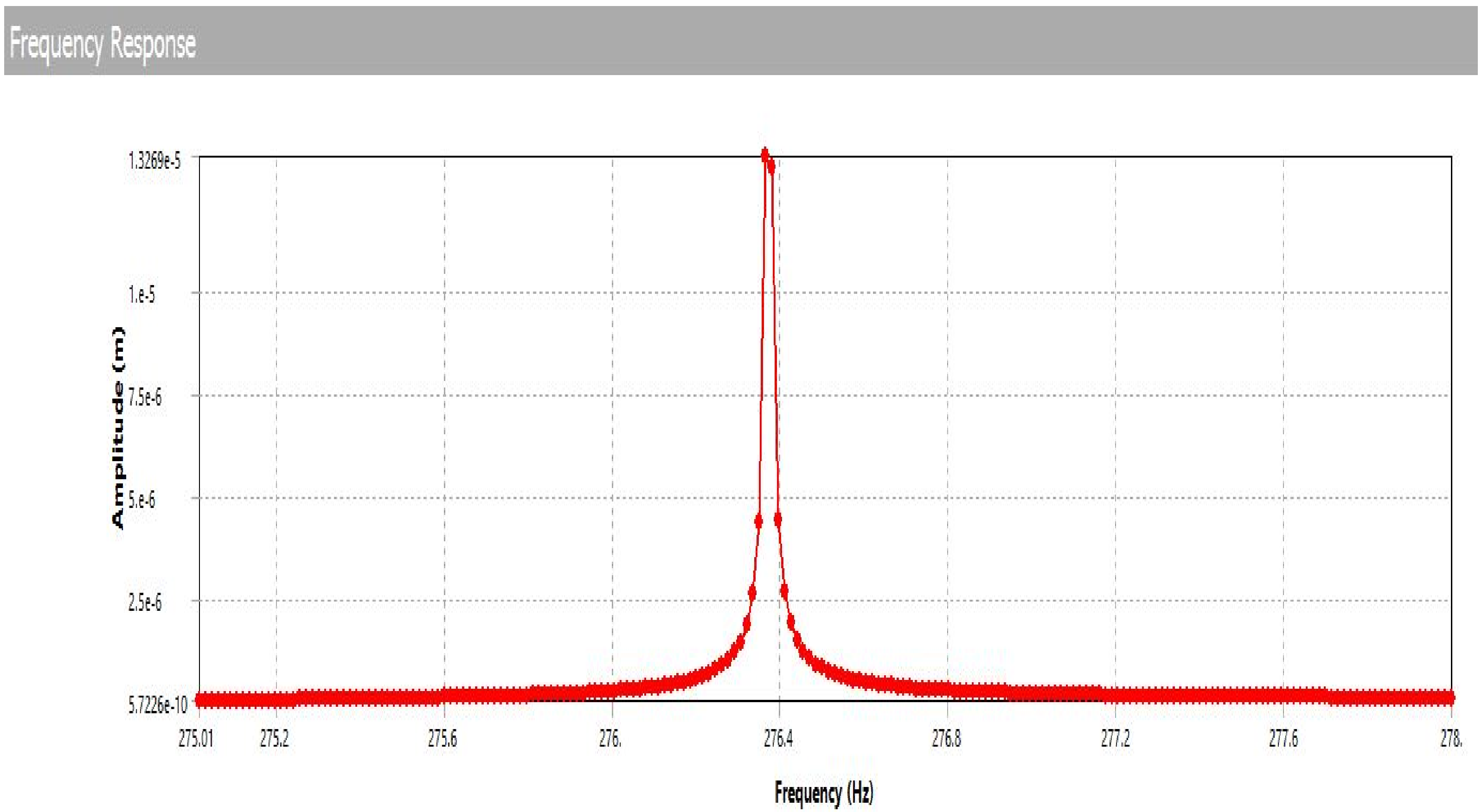


Figure 2.3: Magnitude response of vibration obtained in simulation

K is spring constant, and

f is external or excitation force.

$$\frac{X(s)}{F(s)} = \frac{A\omega_n^2}{s^2 + 2\zeta\omega_n + \omega_n^2} \tag{2.2}$$

where,

A is system gain,

ω_n is natural frequency of the system, and

ζ is damping ratio ($0<\zeta<1$ for underdamped systems).

Comparing the Eqn. 2.1 and Eqn. 2.2, we get the relation shown in Eqn. 2.3 and it clearly indicates that the natural frequency is inversely proportional to the square root of mass of the system.

$$\omega_n = \sqrt{\frac{K}{M}} \tag{2.3}$$

Typical time response of a underdamped second order system excited by an impulse force is shown in Fig. 2.4 and the corresponding magnitude spectrum is shown in Fig. 2.5

From the magnitude spectrum, it can be clearly noted that when a second order system is excited by an impulse input, its response is maximum at its natural resonant frequency and is similar to the magnitude response obtained in simulation.

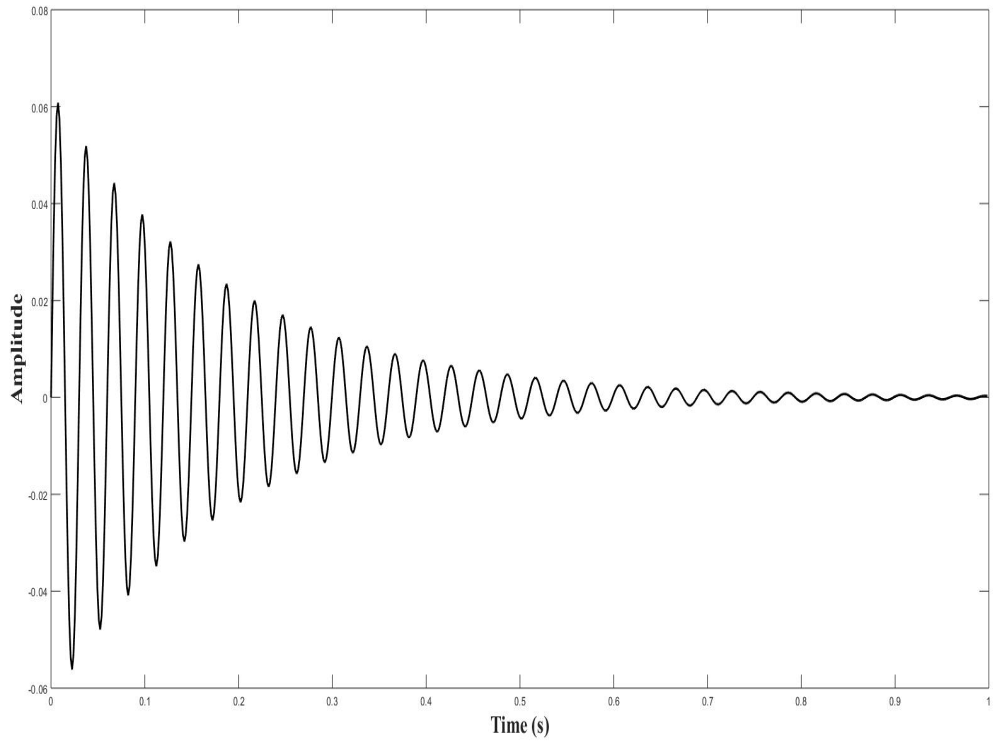


Figure 2.4: Time domain impulse response of a second order underdamped system

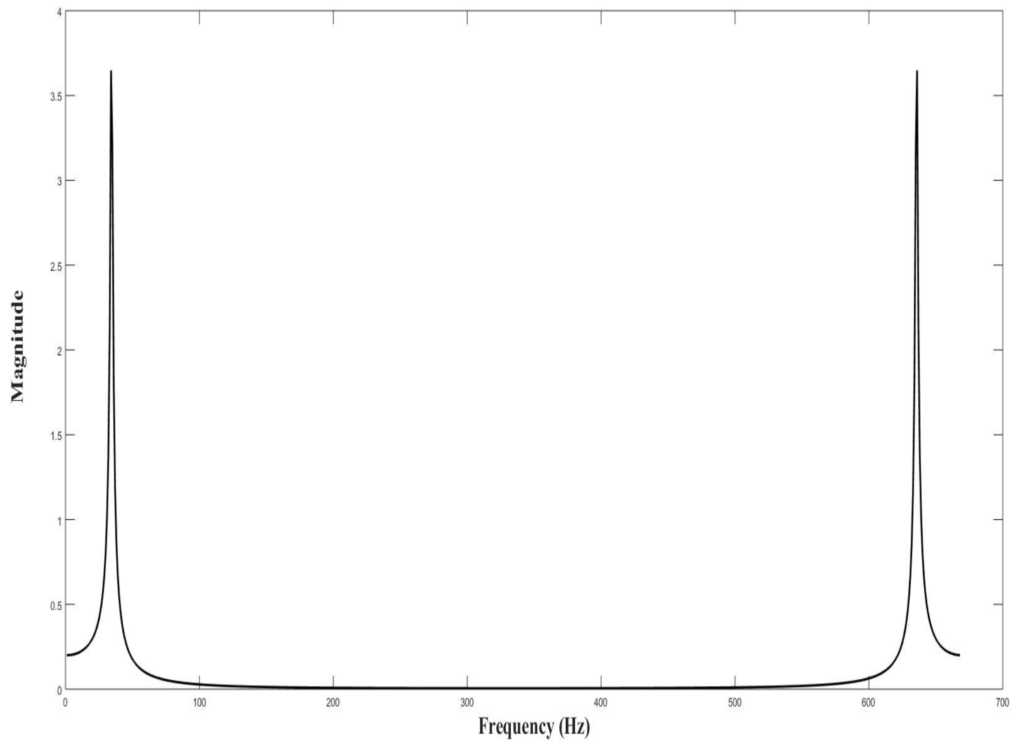


Figure 2.5: Impulse magnitude spectrum of a second order underdamped system

CHAPTER 3

MICROPHONE BASED SOUND ANALYZER

An experiment involving sound or audio data acquisition requires a well designed microphone to serve the purpose. Selecting the suitable microphone is done based on some of the characteristics discussed below.

3.1 Polar patterns

Polar patterns describe the positions of the microphone which the diaphragms listen to and those positions to which they are blocked. Understanding these patterns helps in selecting the right mics that captures the sound we need and blocks unwanted noises. Most commonly found polar patterns are Cardioid type, Super/Hyper Cardioid type, Bi-directional type, Omnidirectional type and Shotgun microphone. Fig. 3.1 shows the polar patterns of different microphones.

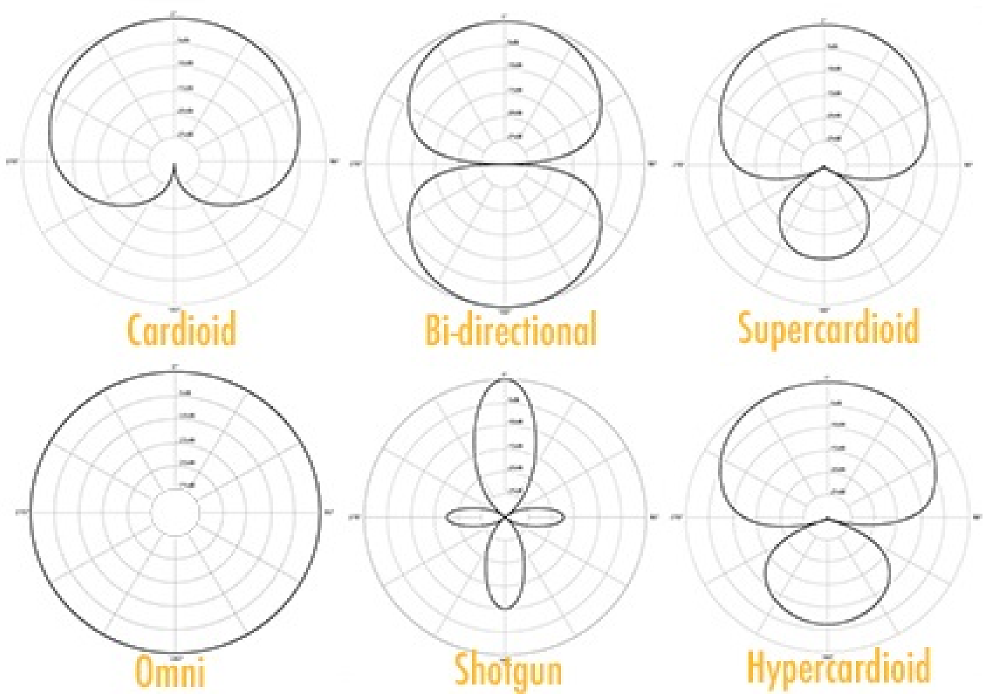


Figure 3.1: Polar patterns of microphones (Briones, 2015)

Cardioid mics are unidirectional and captures only the sound from its front facing side and blocks everything else. It helps in isolating a particular sound source from its other surrounding noises. Also these are the most popular type of mics used. Compared to cardioid type mics, Super/Hyper cardioid mics have their capture area in front side slightly narrower, however its sensitivity to noise from the back side makes it slightly prone to external noises while capturing the audio from a focused source. On the other side, bi-directional mics as the name indicates, is sensitive to both front and back faces, but blocks the sides. Bi-directional ones are used when recording of two different instruments or sound sources are required. Omnidirectional mics captures the signal from all directions. They have non-directional design and hence zero rejection. Shotgun mics has a tube like structure that makes the polar pattern even more narrower and directional than Super/Hyper cardioid mics in their front side. Its tighter pattern makes it suitable for long range pickup.

3.2 Types of microphones

Based on the working principle, microphones are mainly of 3 types: Dynamic, Condenser and Ribbon microphones. Characteristics of each are described below.

3.2.1 Dynamic microphones

Basic working principle of Dynamic mic is electro magnetic induction. It uses a moving coil magnetic diaphragm. When the sound waves hits the diaphragm, it starts vibrating along with the coil attached to it. The coil that is vibrating in the magnetic field, creates a current which in turn is converted into electric signals. These electric signals are used to operate amplifiers. These types of mics are generally used to capture loud surroundings as it can handle high pressures. Fig. 3.2 shows a typical dynamic microphone and its working principle.

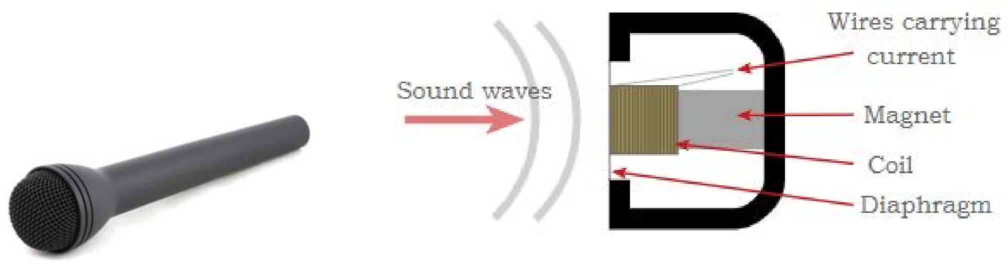


Figure 3.2: Dynamic microphone and its working (Poole, 2016)

3.2.2 Condenser microphones

Condenser mics work based on the change in capacitance caused by diaphragm movement. It contains a diaphragm and a back plate that are kept together to work like a capacitor and when the sound waves hits the diaphragm, it vibrates to produce a change in capacitance which is sensed to produce audio signals. They have improved sound quality due to the technology used and hence are used for precision sound recording. Fig. 3.3 shows the working of a condenser microphone.

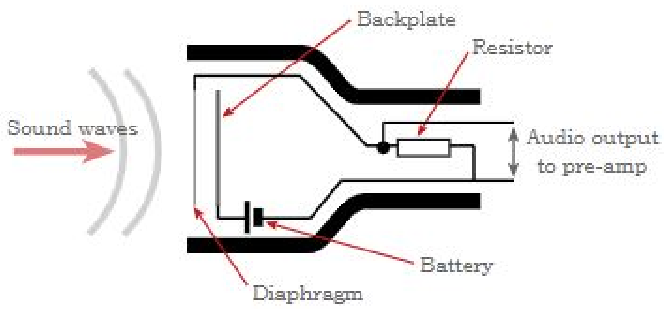


Figure 3.3: Working of a condenser microphone (Poole, 2016)

3.2.3 Ribbon microphones

Ribbon mics uses a metal ribbon which is made of a material called duraluminium. This ribbon is placed in between two poles of magnets to produce voltages and picks up the velocity of air, and hence are suitable for higher frequency audio signals. Due to their high sensitivity, the high end gets rolled off when the sound source is very near to microphone. These type of mics are not commonly used in present day situations.

Fig. 3.4 shows the working of a ribbon microphone.

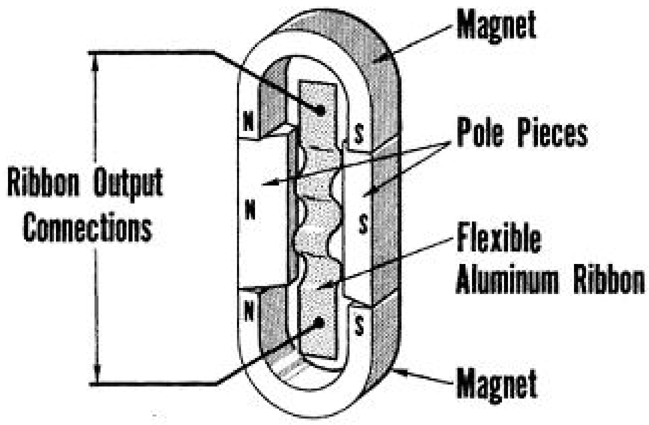


Figure 3.4: Working of a ribbon microphone (Poole, 2016)

3.3 ZOOM H1 recorder

Microphone used in this project is Zoom H1 digital recorder, which is appropriate for all types of live recordings. It has a unidirectional condenser microphone which uses X/Y technique which can cover a wide area, however gives precedence to the sound sources in the center and gives them better clarity and definition.

Figure 3.5: Zoom H1 digital recorder

Some of the important characteristics of this microphone are listed in Table. 3.1.

Table 3.1: Technical specification of Zoom H1 recorder

Built in stereo mic	Unidirectional Condenser microphone
Recording format	WAV/MP3 format
Sampling frequency	44.1/48/96kHz
Quantization	16/24bit
Signal processing	32bit
A/D Conversion	24bit, 128times oversampling
D/A Conversion	24bit, 128times oversampling
USB Interface	Mini-B type (USB2.0 High Speed compatible)
Power requirements	LR6 or Ni-MH AA battery x 1, or AC adapter

Another important feature that makes Zoom H1 suitable for this experiment is that it can be easily interfaced with a PC and software like LabVIEW, using Mini-B USB cable for live capturing or recording of the sound signals without the help of any other external/internal equipment.

CHAPTER 4

EXPERIMENTS & RESULTS

4.1 LabVIEW data acquisition

Data acquisition (DAQ) is the process of sampling the electrical or real world physical signals and converting the samples into a digital equivalent that can be analyzed using a PC. Primary components of DAQ system are the sensors, signal conditioning circuit and an ADC. LabVIEW is a system design software which uses a visual programming language commonly used for data acquisition and Industrial automation.

Microphone Zoom H1, which is used in this project as the primary sound sensor or recorder, is interfaced with PC (i.e. LabVIEW) using mini-B USB cable. It allows us to analyze the surrounding sounds in real time with the help of LabVIEW software.

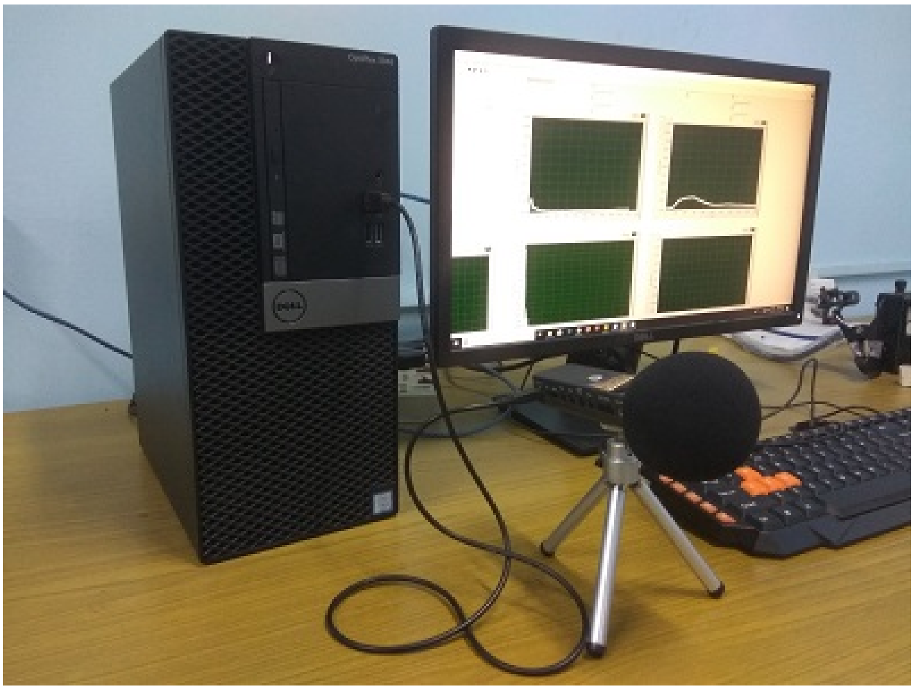
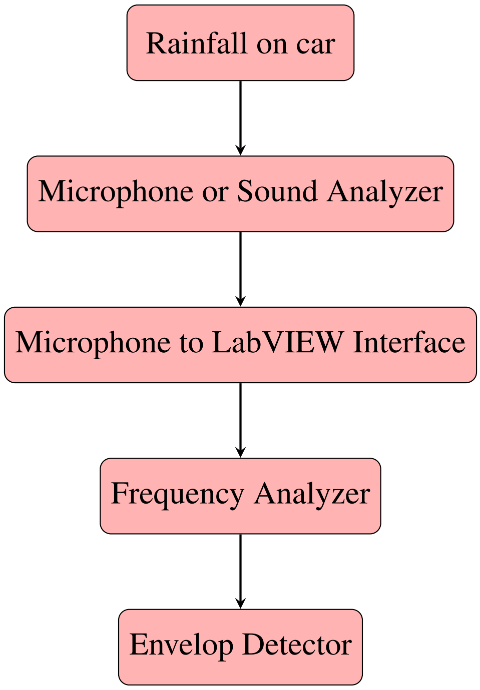


Figure 4.1: Microphone interfaced with PC and data acquisition

4.1.1 Virtual Instrument

Methodology used to detect the rainfall using sound analysis is as below.



Once the microphone is interfaced with PC through a mini-USB cable, its configuration has to be done in the LabVIEW program to read the sampled data. LabVIEW program designed to configure data acquisition and signal condition the acquired audio signal is shown in Fig. 4.2. To acquire the data from microphone, two steps are followed: Input device configuration and then reading data. LabVIEW has its inbuilt module ’Sound Input Configure’ to interface microphone with LabVIEW environment and ’Sound Input read’ module to read the samples from microphone at user specified sampling rate. Data thus obtained is passed through signal conditioning and/or manipulating circuits.

Signal conditioning involves finding the frequency response of time domain audio signal. It is done using FFT analyzer module. FFT(Fast Fourier Transform) is a faster algorithm used to compute the DFT (Discrete Fourier Transform) of a time domain signal. DFT is a signal processing tool used to get the frequency spectrum of finite duration signal. Since we are considering the raw audio signal to get the frequency response, the response is in a crude form. To get a clear picture of the frequency response, an envelop detector circuit is utilized.

Envelop detector used in this project is a variant of the typical moving average filter, instead that to preserve the peak amplitudes a peak detector is also included.

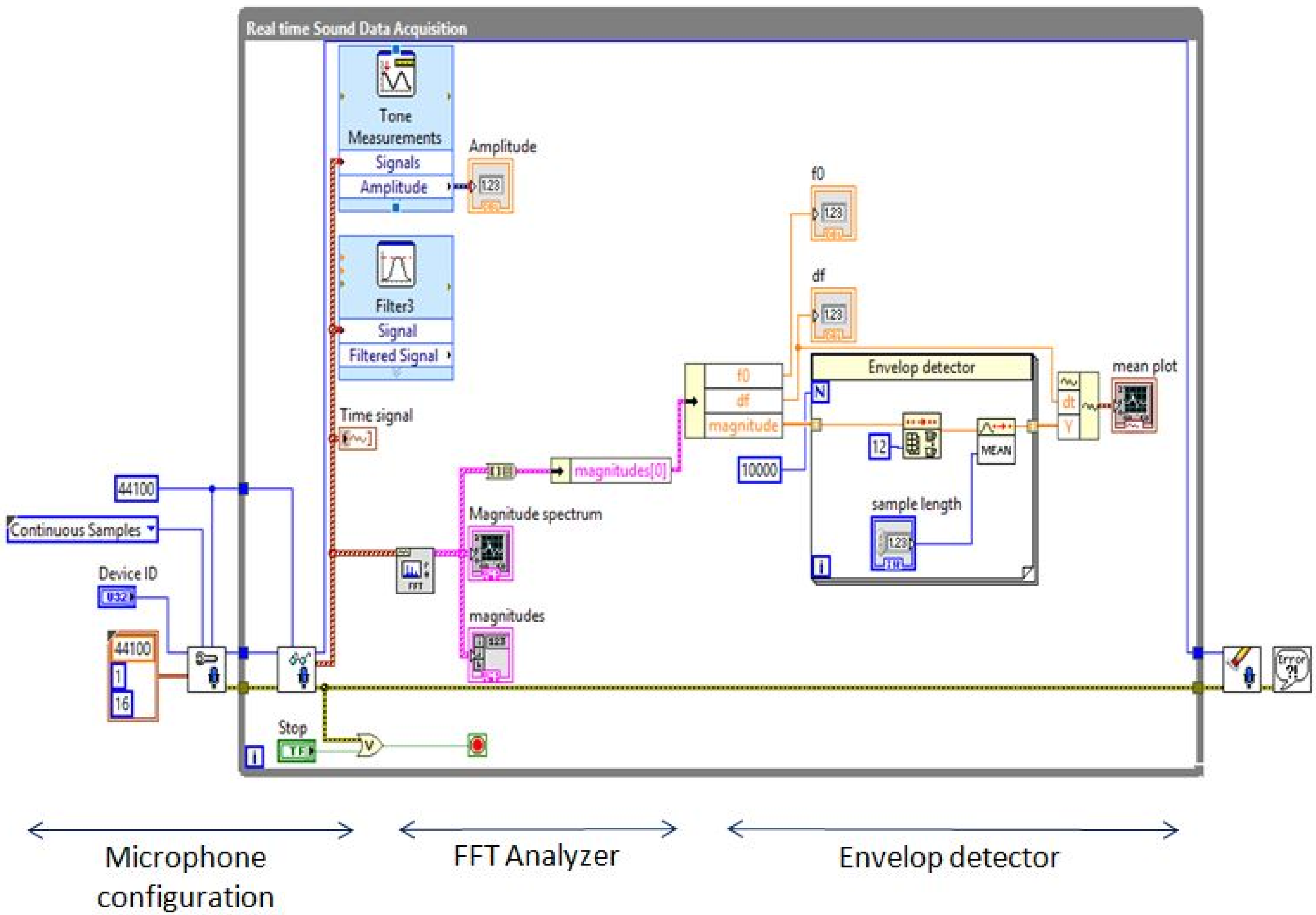


Figure 4.2: Signal conditioning circuitry in LabVIEW

The envelop detector designed as shown in Fig. 4.2, consists of a peak detector and a mean calculator. Frequency spectrum array that is fed into this detector is considered as a group of samples whose length is user defined. Peak detector collects the peak value from each group of samples and the mean calculator further calculates the mean of sample groups, output by peak detector, and thereby giving the envelop of input frequency response graph.

4.2 Knocking experiment

Knocking experiment is done to check the impact of an impulse force on car rooftop and also to verify the simulation results obtained . It involves giving a knock on the rooftop (equivalent to impulse force of short duration) and analyzing the frequency response of the sound generated. Fig. 4.3 shows the time domain response obtained from the knocking experiment.

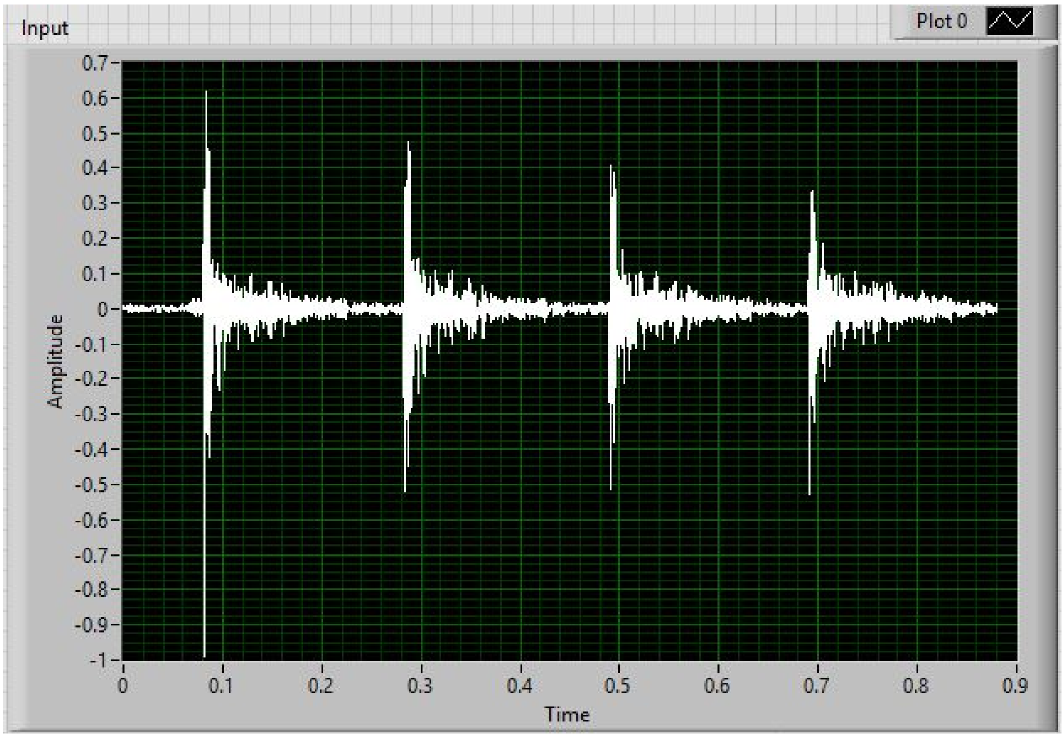


Figure 4.3: Response of test input used to check the impulse response of car rooftop

Fig. 4.4 shows a zoomed version of a single knock on the rooftop. It can be clearly noted that the response looks similar to that of a second order system excited with impulse input (Impulse response of second order system) as shown in Fig. 2.4

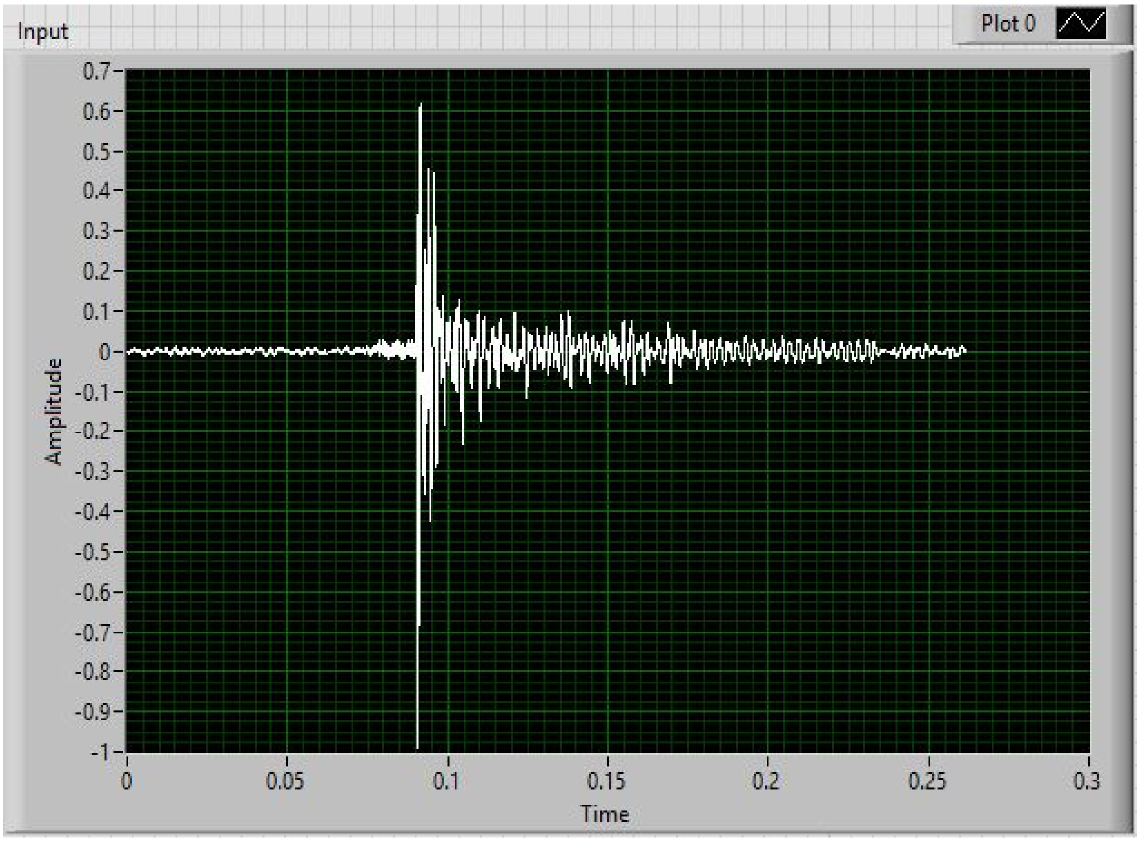


Figure 4.4: Time domain response of a single knock on the rooftop

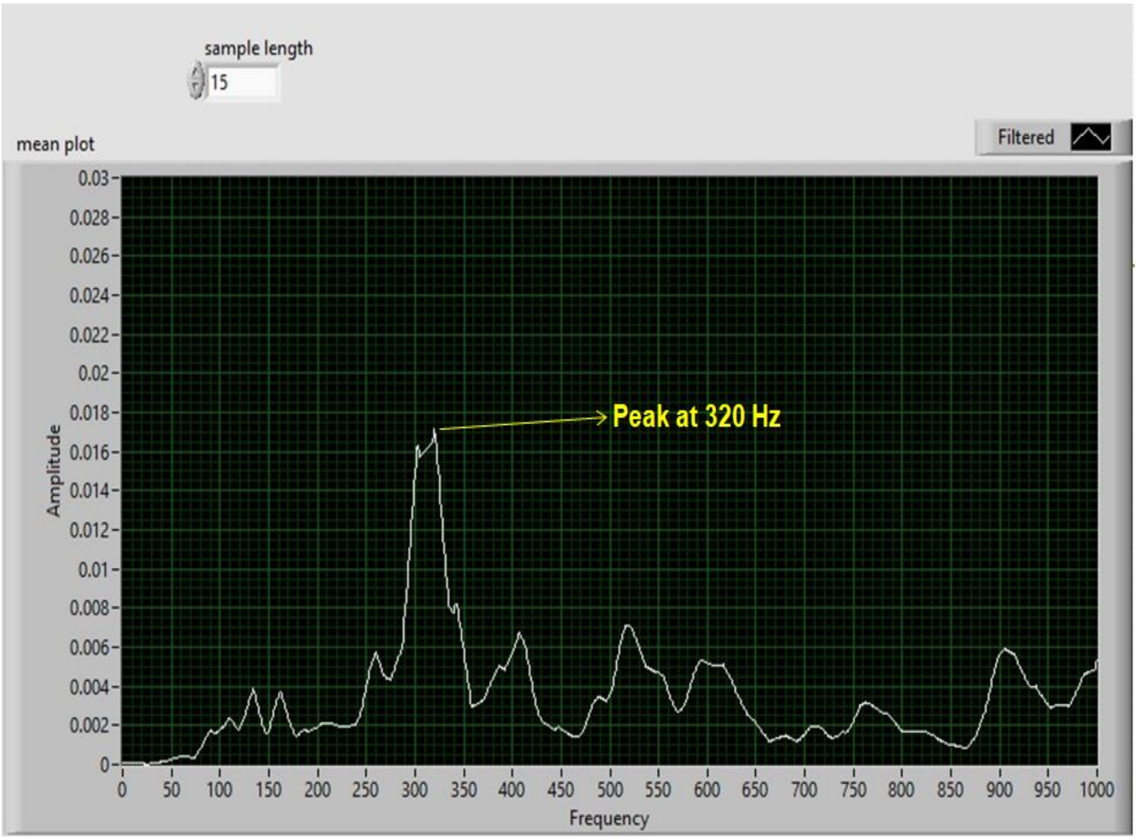


Figure 4.5: Envelop of magnitude response of the waveform in Fig. 4.3

Fig. 4.5 shows the envelop of frequency response of the audio signal obtained using knocking experiment. On analyzing the frequency spectrum of the obtained signal, we could clearly observe a peak in the response similar to that observed in simulation results in Fig. 2.3, except that now the peak frequency has slightly shifted to approximately 320 Hz compared to 276.4 Hz in simulation.

4.3 Laboratory experiments

4.3.1 Initial experimental setup

To test the impact of water drops on metal sheets, a setup was made in the laboratory. It consisted of a glass tank of size 2 ft x 2 ft x 3 ft filled with water upto a height of 10 cm. A mild steel sheet was kept inside the tank floating in the air with the help of 4 clamps attached to the tank. The sheet was kept in a slightly slanting position so that the water drops falling on the sheet will flow down along the sides of tank and won't make any unnecessary sounds by falling directly into the water in the tank below. A shower head of size 10 cm x 10 cm was fixed at a height of 3 ft from the ground level and an submersible type motor was kept in the water in tank, to pump the water through the shower head onto the metal sheet. Fig. 4.6 shows the experimental setup.

Primary objective of the experiment was to study the impact of water drops on a metal sheet. However, due to the small height of the shower head from the sheet, water hitting on the sheet was mostly in a continuous manner rather than hitting as drop by drop. Later in the lab, the height of shower head from ground was increased to 6 ft. Even in this case, with the minimum speed of the motor, it was not possible to analyze the effect of water drops. Also there was heavy noise generated by the water falling inside the tank. So it was finally decided to conduct the experiments outside the laboratory environment.

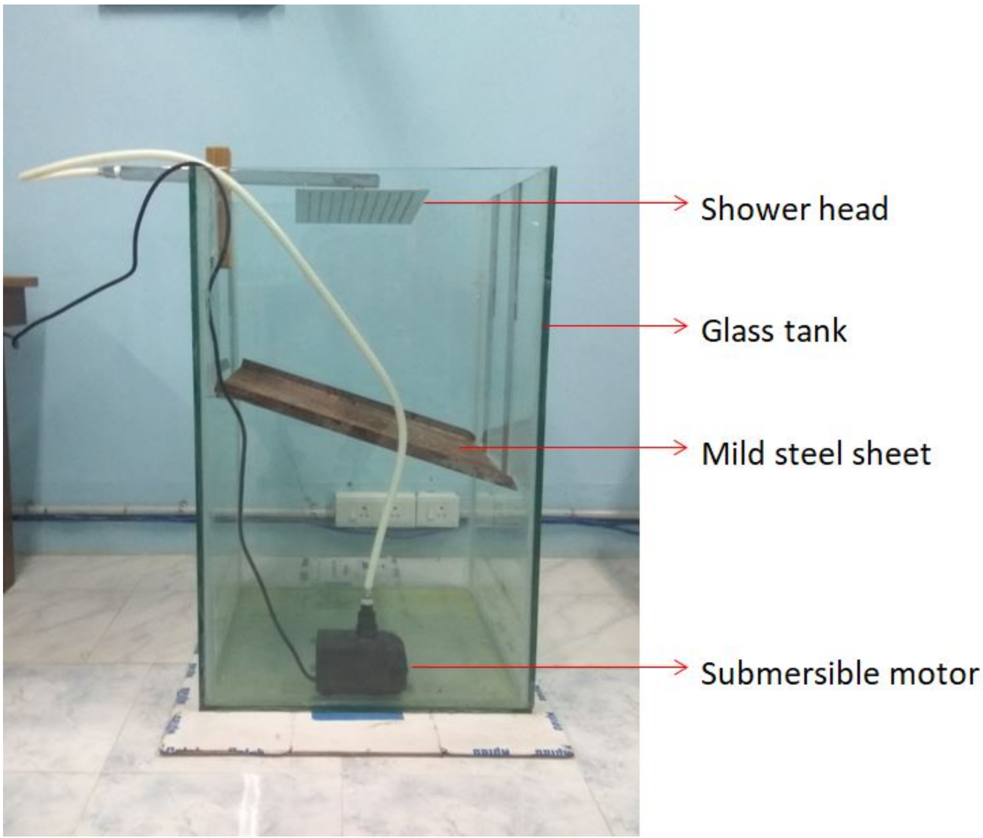


Figure 4.6: Initial experimental setup made in Laboratory

4.3.2 Rain drop experiment

After knocking experiment, it was necessary to further investigate the effect of water drops on the metal sheet. So a setup was made to observe the effect of water drops falling on the model car itself. The setup involved a shower head kept at approximately 8 m height, and the water drops coming out of the shower was made to fall on the model car (Hyundai i10) parked right below the shower head. Also, since the water drops are released from a larger height, the impact velocity of the drops hitting on the car rooftop can approach towards that of a real time rain drop which typically lies in the range of 8 m/s to 10 m/s. Fig. 4.7 shows the experimental setup made to test water drop impact analysis.

Audio signals were recorded and analyzed for the frequency response. From the envelop of frequency response obtained shown in Fig. 4.8, a peak is observed at a frequency of approximately 310 Hz, which in turn matches with the result obtained during knocking experiment. It confirms the assumption that the water drop falling on the car rooftop act as an impulse force of small duration.

Figure 4.7: Experiment setup to study the impact of water drops

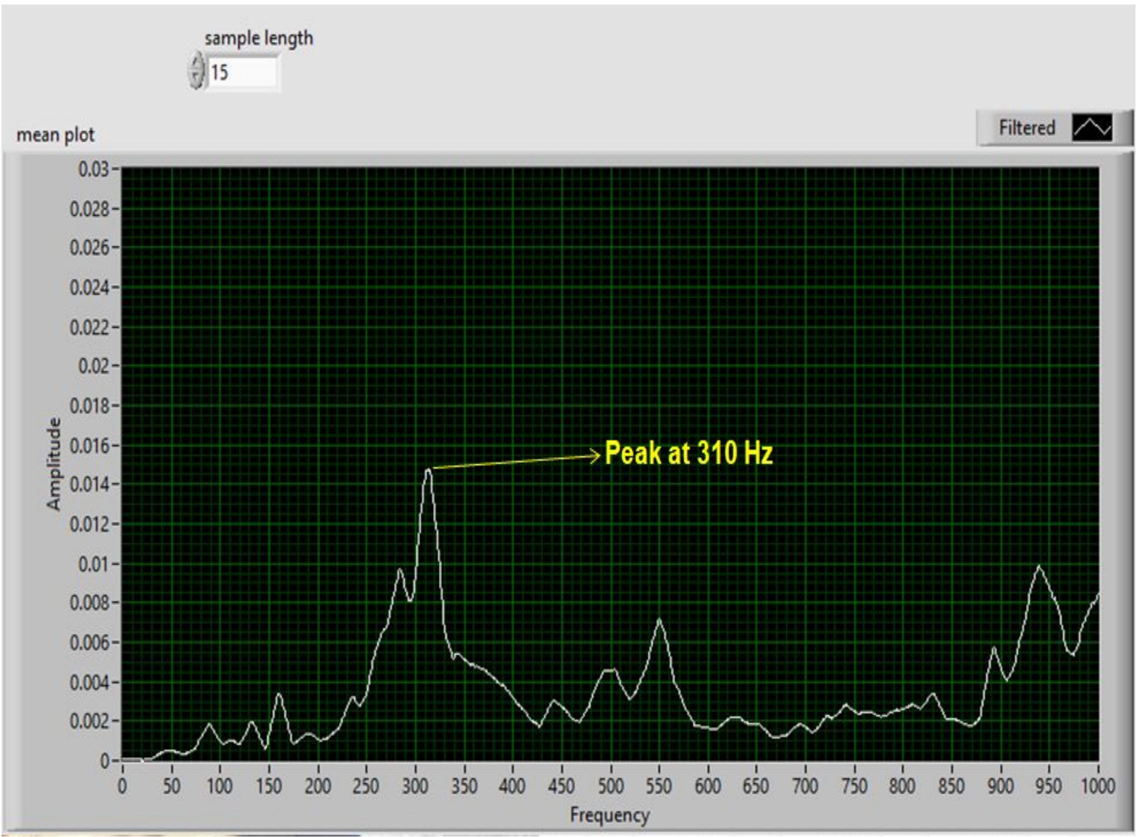


Figure 4.8: Envelop of magnitude response obtained from raindrop experiment

4.4 Real time rain data analysis

To study the effect of water drops during actual rainfall conditions, several samples of audio were collected. Samples were collected from inside the car during rainfall, while in parked situation and also while on running situation to compare and observe the impacts.

On observing the envelop of magnitude response obtained in those conditions as shown in Fig. 4.9, a peak in the response is obtained at a frequency of approximately 310Hz, which is matching with the response obtained during other experiments conducted in laboratory.

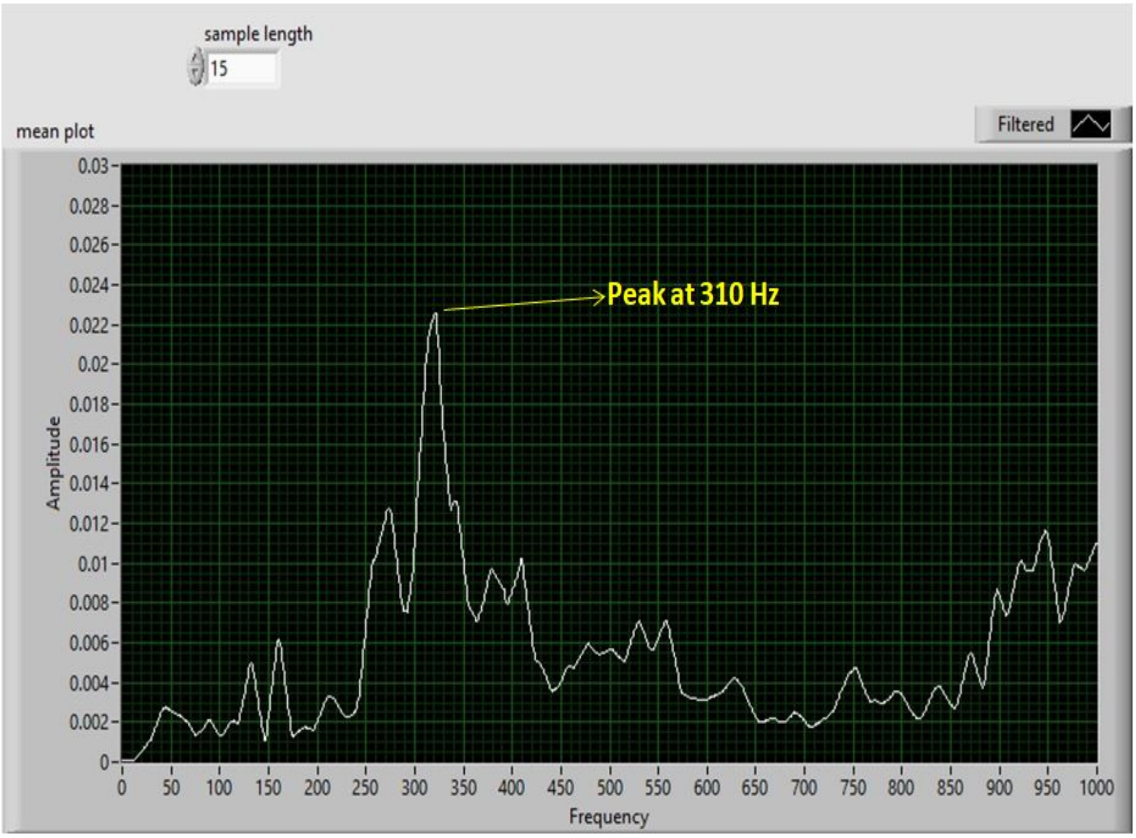
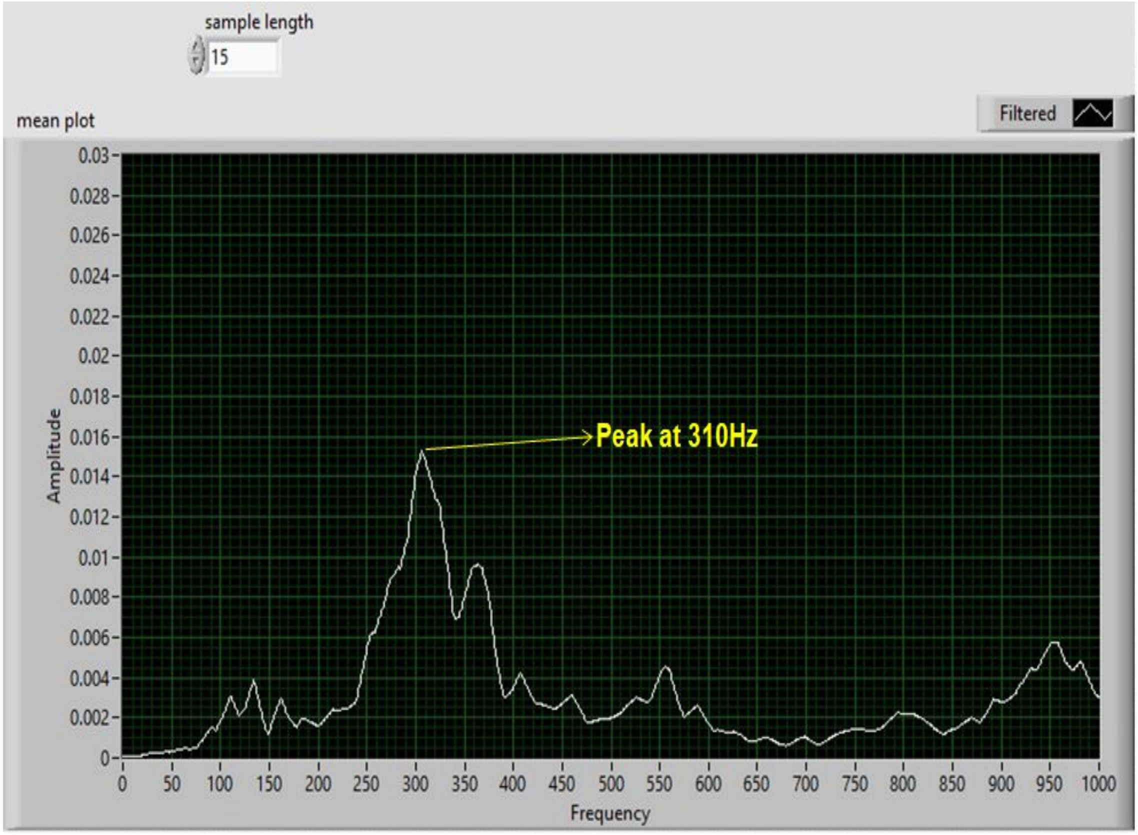


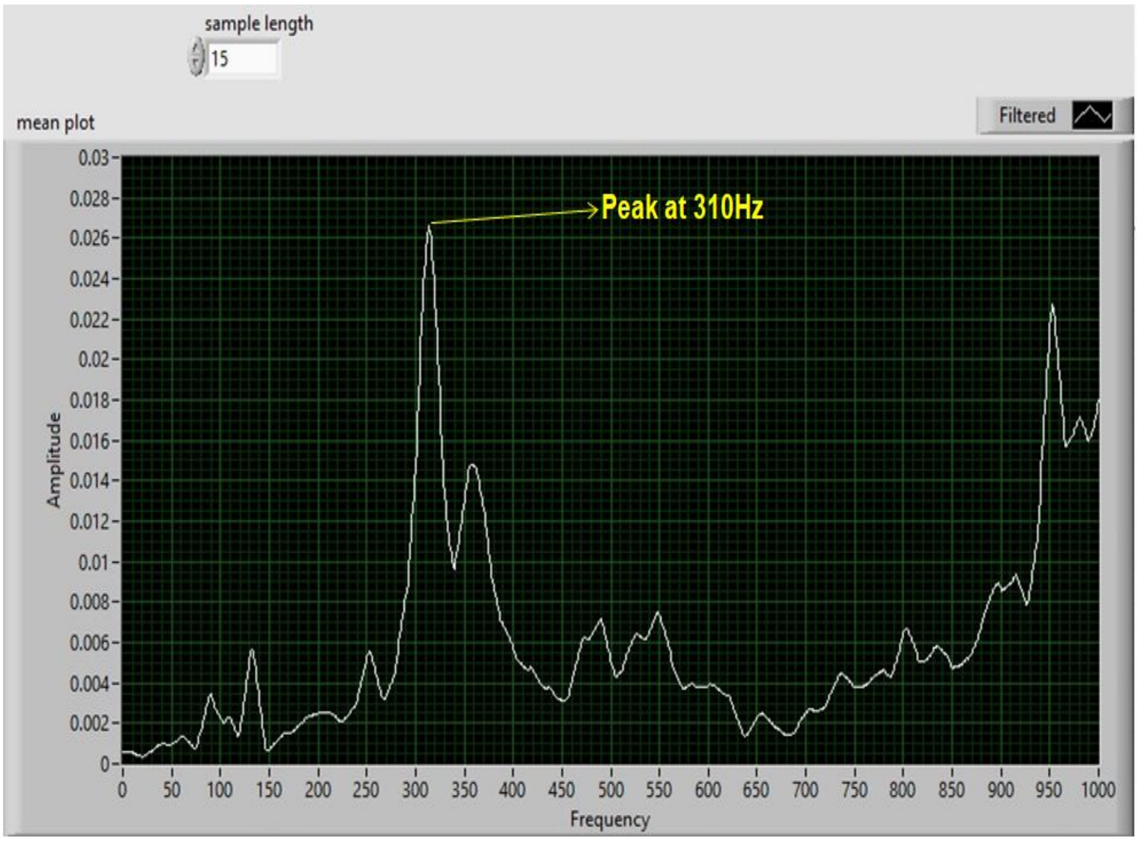
Figure 4.9: Envelop of magnitude response obtained from actual rainfall data

4.4.1 Rain intensity measurement

While implementing this technology of rain detection in automobiles for windshield wiper control, it is also important to identify the intensity of rain to control the speed of wiper motor during heavy and light rainfalls.



(a)



(b)

Figure 4.10: Envelop of magnitude response obtained during (a) Light rainfall and (b) Heavy rainfall

Audio samples recorded during actual rain situation included the signals during light and heavy rainfall as well and the obtained magnitude response is shown in Fig. 4.10a and Fig. 4.10b respectively. On analyzing the observed magnitude response envelopes, there is a peak in the response at a frequency of approximately 310 Hz in both the cases, however it is worth noting that the amplitude in both cases are giving a clear indication of the intensity of rainfall. As the intensity of the rainfall increases, a good change in the peak amplitude is observed and hence the amplitude can be used as a measure of the rainfall intensity.

CHAPTER 5

CONCLUSION & FUTURE SCOPE

5.1 Conclusion

From the Ansys simulation results, impulse force acting on a metal sheet structure (structure similar in geometry and properties of that of the rooftop of the model car) showed a peak in the magnitude of vibration at a frequency around 276.4 Hz. Comparing with the experimental results from knocking experiment, time domain signal obtained was similar to the response of a second order system to an impulse input and its magnitude response showed a peak at frequency around 320 Hz. Audio signals from the rain drop experiment and actual rainfall condition also gave a similar magnitude response with a peak at frequency around 310 Hz. The small variation in the peak frequency obtained in simulation and the real time experiments must be due to the assumptions made while selecting the physical properties of the metal sheet used in simulation. Also the actual rooftop geometry does not exactly resemble to that of a rectangle as simulated. And if we consider the system to be of second order, the resonant frequency is inversely proportional to the square root of mass of the object. So, even small changes in the geometry of metal sheet effects the mass of the sheet and hence have a direct influence on the resonant frequency. From these observations, it can be concluded that the raindrop hitting the metal body act as an impulse force and the sheet vibrates at its resonant frequency. Hence, by knowing the resonant frequency of the car rooftop and by sensing the presence of this frequency in the audio signal obtained, it can be used to detect the rainfall.

From the results obtained during heavy and light rainfalls, it can be observed that there is a significant change in the amplitude of the peak response in both cases, which in turn gives a direct measure of the rainfall intensity.

5.2 Future scope of the project

The future scope of this project is to convert the presence of the targeted frequency into an analog signal using a DAQ module and thereby controlling the wiper motor. Also, with proper calibration of the amplitude, the model can also be used for approximating the intensity of rainfall and hence to control the wiper speed based on rain intensity. This model can be experimented to be used as a general purpose rainfall detection system, with proper sound proofing techniques and a high sensitive diaphragm.

APPENDIX A

STFT ANALYSIS

Short Time Fourier Transform (STFT) is a commonly used signal processing tool which helps in analyzing the frequency response of small sections of a signal which changes over time. It divides a longer duration of signal into small sections of equal duration and then compute the fourier tranform of each smaller sections. STFT uses a window function of fixed length which moves over the actual signal to divide into small sections. Eqn A.1 shows the mathematical formulation to obtain STFT of a signal x[n].

$$X(m,\omega) = \sum_{n=-\infty}^{+\infty} x[n]w[n-m]e^{-j\omega n} \tag{A.1}$$

where, w[n] is the window function used.

STFT is used in this project to analyze the audio samples obtained during real time rainfall conditions. Program designed in LabVIEW to obtain the STFT spectrum is shown in Fig. A.1.

STFT plots the spectrum of frequency versus time and indicates amplitude with the help of different colour codes. On analyzing the results obtained in Fig. A.2, the peak in the magnitude is observed again at 310 Hz (indicated by the light blue line) while other frequencies are having minimal presence (indicated by black or dark blue), which again confirms the results previously obtained.

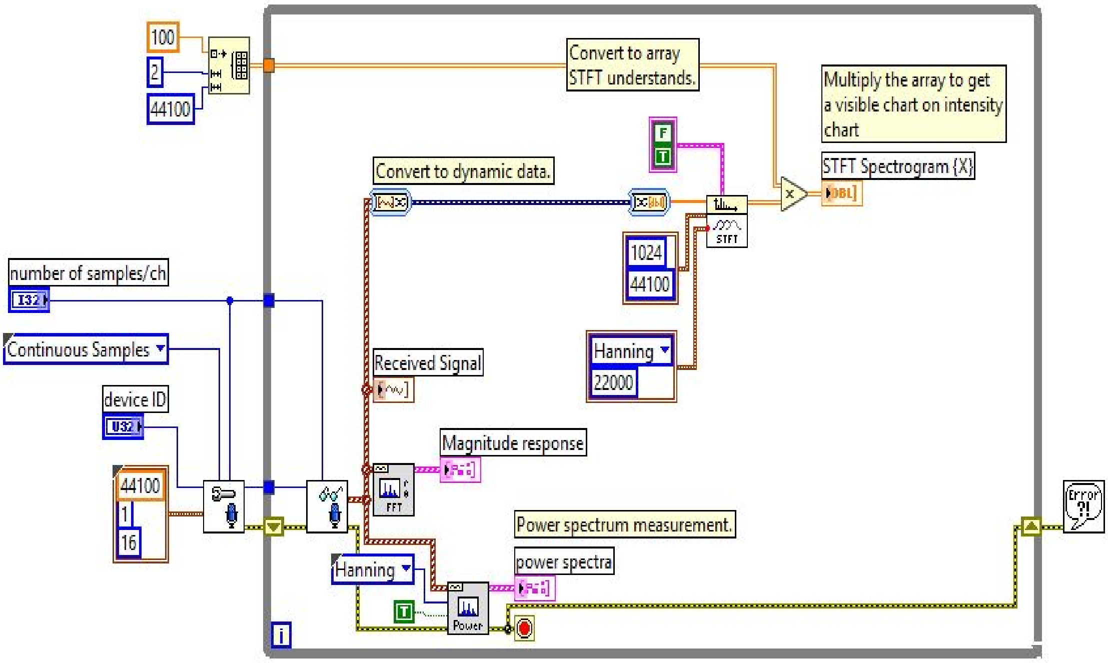


Figure A.1: LabVIEW program to obtain the STFT spectrum of audio signals

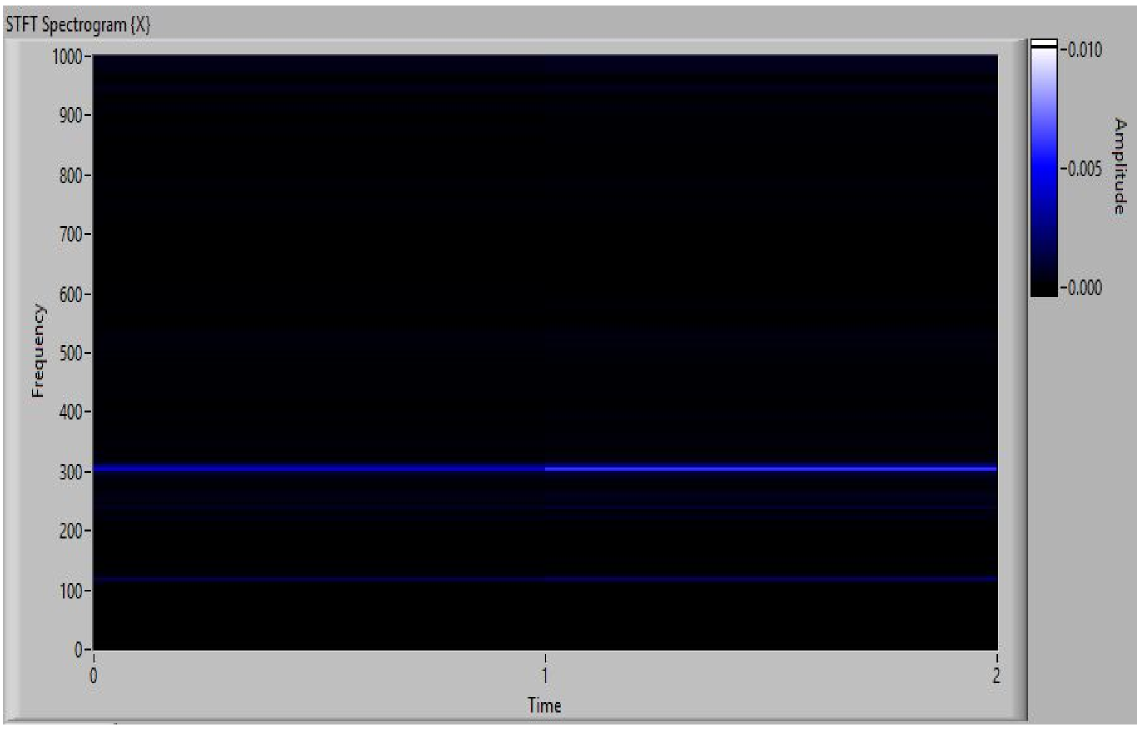


Figure A.2: STFT spectrum of the rainfall audio

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