STRUCTURAL HEALTH MONITORING USING SIGNAL PROCESSING AND DEEP LEARNING

Project report submitted in partial fulfillment of there requirement for the degreeof

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

By

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UNDER THE GUIDANCE OF

Dr. Sunil Datt Sharma

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY,WAKNAGHAT

May 2020

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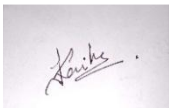
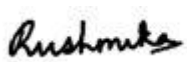
DECLARATION

We hereby declare that the work reported in the B.Tech Project Report entitled **“Structural Health Monitoring using Signal Processing and Deep Learning”** submitted at **Jaypee University of Information Technology,Waknaghat,India**is an authentic record of our work carried out under the supervisionof**Dr. Sunil DattSharma.**We have not submitted this work elsewhere for any other degree or diploma.





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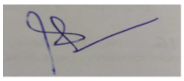
This is to certify that the above statement made by the candidates is correct to the best of my knowledge.



Dr. Sunil Datt Sharma

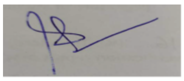
Project Coordinator

CERTIFICATE

This is to certify that the work which is being presented in this project report titled **"Structural Health Monitoring using Signal Processing and Deep Learning"** for partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Electronics and Communication Engineering and submitted to the department of Electronics and Communication Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Kanika Choudhary (161017) and Rushmika Singh (161070)** during a period of July 2019 – May 2020 under the supervision of **Dr. Sunil Datt Sharma** (Assistant Professor (Senior Grade), Departement of Electronics and Communication Engineering), Jaypee University of Information Technology, Waknaghat .

The above statement is made correct to the best of our knowledge.

Date



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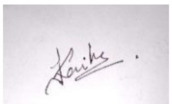
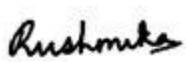
We would like to thank our parents for their continuous support and motivation. Finally we would like to thank those who directly or indirectly helped us in completing this project.





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LIST OF ACRONYMS AND ABBREVIATIONS

SHM	Structural Health Monitoring
CNN	Convolution Neural Network
STFT	Short Time Fourier Transform
FT	Fourier Transform
WT	Wavelet Transform
MUSIC	Multiple Signal Classification
TS	Time Series
FFT	Fast Fourier Transform
HHT	Hilbert-Huang Transform
MSLL	Maximum side-lobe level
MLW	Main Lobe Width
ReLU	Rectified Linear Unit
1D	1- Dimension
2D	2-Dimension

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ABSTRACT

The goal of this project is to use signal processing to bring out, minute changes in the vibration signal in order to ascertain, discover and compute the damage and its austerity in the structure using Deep Learning. The Civil underlying framework may be impaired because of an assortment of causes such as earthquakes, whirlwinds, cyclones, high winds and repeated element vibrations. A system proficient for supervising and determining the structural performance fundamentally is profoundly desirable to find the damage at the earliest and take corrective actions.

CHAPTER 1
INTRODUCTION

1.1General

In present era where technology is booming at its peak, at present all the data can be saved at a single platform and can be used for different techniques. By analyzing that data we can solve many present era problems. Various new enterprise application and social networking sites are available and with it the amount of data generated is enormous and is increasing tremendously in the coming year. To extract useful information from the data is necessary for enhancing market value and for human kind benefit.

Deep learning is a class of machine learning that processes through several layers to extract higher level features from the raw input.By using Signal Processing (that is the analyzing, modifying and synthesizing signals) and Deep Learning, we would be processing the seismic vibrations of a structure to identify the threat beforehand and act accordingly.

Structures often collapse in hilly regions, bridges and other such structures often get damaged with time due to different factors like earthquake, rusting, humidity, wind speed etc. With time these factors reduce the reliability of the structure. Many previous works have been done in this field to detect structure health beforehand only so that future loss can be saved. It's also done to monitor the health of historic structures or bridges so that proper maintenance is kept of all these structures. Other than it, authorities can be alert beforehand if a building is about to collapse so that it can be evacuated and loss can be reduced.

1.2Need of Study

The environment conditions at present aren't as natural and healthy as they used to be before, due to many different factors the environment has become toxic and is affecting our civil structures as well. Being in Himachal, landslide is very common here as it is a part of the Himalayan mountain system. As we have seen in past that all the above-mentioned calamities leadto a lot of damage, compensatory as well as psychologically, it also slows down the development of the state. Identification of these types of threat before the calamity is not very easy. If we could inform beforehand about the calamity that's going to happen then we can save lots of lives as we would be able to inform them and be able to evacuate the prone area in advance.

Other than it, regular structure health monitoring of historic buildings and bridges can be done as they do get damaged with time due to many factors like wind speed, humidity, earth quake, rusting, rainfall, traffic crossing etc. These are some of the many factors due to which any structure core or the outer part also damages but it can't be pointed out from outside or just looking at the structure. A proper monitoring of structure health is required to notify the maintenance authorities about the damage.

Our study is based on this only to make a system that will send an early notification to the management about the threat if it detects any change in the audio vibrations then it will notify the management, if the damage is severe then it will notify to evacuate and if there are minor changes then it will notify the management accordingly so that they can do the maintenance of the building.

1.3Objectives

Vibration signals of every structure can discriminate significantly that whether the signal is normal or abnormalities are present in it. With detection of these abnormalities we can identify the threat.

- Currently if there is occurrence of any such threat its impossible to evacuate the area as the abnormalities in the vibration are detected with a very little time difference.
- The work which has been done in this field includes a complicated technical ways which is difficult for a person without technical background to operate.
- We are trying to develop a system using such techniques so that it is easily operable.
- The goal is to make a system which is practically possible at low cost and less number of human labor needed.
- This system is also to secure the historic buildings by early detection of the damage and alerting maintenance for it.

- This system will also notify if any damage is there in bridges, roads, runways etc. which cant be repaired by stopping the way.
- With our study, we would be able to identify these abnormalities with a significant amount of time difference so that we can avoid the collateral damage.
- With enhancing techniques many methods to detect the threat are been introduced, we are also trying to add on our effort, our objectives are:-
    - Signal processing using – Short Time Fourier Transform.
    - Classification of the threat using - Deep Learning Technique that is Convolutional Neural Network

CHAPTER 2
LITERATURE OVERVIEW

2.1 A bone-fracture based algorithm for healthy and unhealthy sound wave detection

Zakira Qadir, Muhammad Ali and Tayfun Nosimoglu came up with a low-cost technique using a microphone and stethoscope, to test sound vibrations such that the any change in shape depends on the amplitude, with results which say that the amplitude of healthy sound waves is higher as compared to unhealthy waves. The results were analyzed using the Matlab software. [2]

2.2 Signal Processing algorithms for Structural Health Monitoring Techniques

Juan Pablo Amezquita-Sanchez and HojjatAdeli suggested various signal processing algorithms that could be used for SHM namely Fast Fourier Transform (FFT), Short-time Fourier transform(STFT), Statistical Time Series model (TS), Wavelet Transform(WT), MUSIC-algorithm and HHT. [1]

2.3 Comparative Study on STFT, FFT and WT for signal Processing

The literature proposes that instead of using FFT, STFT and WT analysis should be used for non-stationary signals. As FFT does not provide time-frequency analysis simultaneously, STFT which determines both frequency and time analysis simultaneously and WT which shows changes in amplitude and distribution.[3]

2.4 A deep-learning method for diagnosis based on Time-frequency image

The literature provides with an improved algorithm of the Alexnet Neural Network algorithm for the classification process of the time - frequency image based on the various signal processing techniques namely FFT, STFT, WT(CWT and DWT), HHT etc. [5]

2.5 Detection of Sputum by using Image Processing Techniques

JinglongNiu, Yan Shi, Maolin Cai and Zhixincao provided deep understanding for the usage of signal processing to detect abnormality in sputum detection, by interpreting the images by signal processing and feature extraction. Multiple audio signals were taken and then preprocessed using STFT to result in spectrograms for feature extraction process.[8]

2.6 Deep output Learning method for structural diagnosis

Wentao Mao, Wushi Feng, Xihui Liang [17] proposed a novel method for deep learning which was different from the conventional and established method of neural networks for classification, they suggested methods for shared diagnosis of multiple bearing faults, which was not possible in the older method [17]

2.7 Real- time structural damage detection using convolutional neural networks

Osama Abdelijaber, OnurAvci, Serkan Kiranyaz, MoncefGabbouj and Daniel J. Inman wrote that the damage detection system works majorly based on the features desired and the classifier used to achieve the same. Alot of speculations might arise as amodel trained for feature extraction for a particular dataset may fail to provide the desired results on another model with slightly different parameters which could ultimately prove to be fatal for 'Real-time structural damage detection'.[11]

This research paper, provides with a more novel method that is 1D CNN for better and enhanced performance, with higher accuracy and efficiency.[11]

CHAPTER 3

PROPOSED HYPOTHESIS

A lot of work has been done in this field in past also, what makes this project different is the hypothesis proposed. The main difference in hypothesis from the previous work done in this field is that this hypothesis is based on Deep Learning concept.

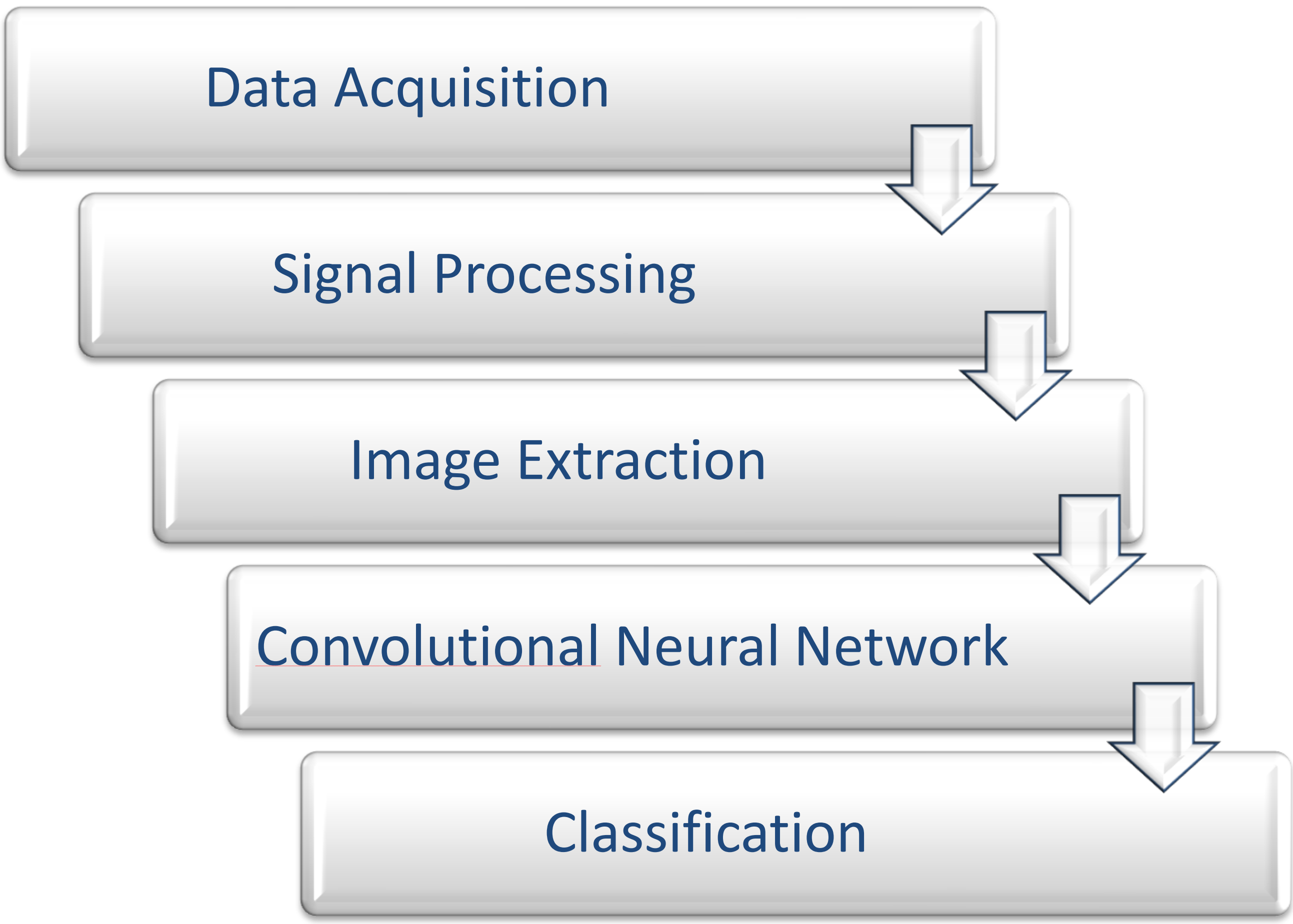

Figure3.1: Flow Chart for the proposed Algorithm

3.1Data Acquisition

Data Acquisition can be defined as the measurement of electrical or physical phenomenon such as current, voltage, temperature, pressure or a sound with the help of a computer. A DAQ system consist of various elements such as sensors, DAQ measurement hardware and a computer with programmable software.

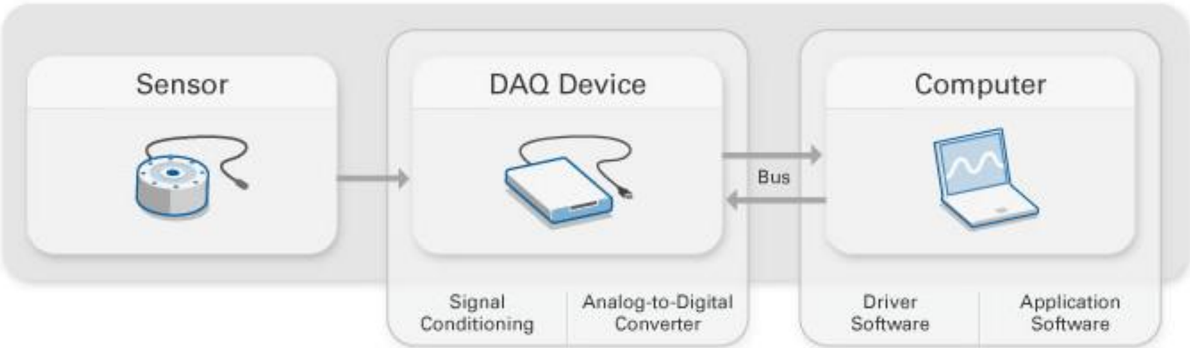

Figure3.2: Parts of a DAQ system.

The goal of this project is to make project practically possible so that it can be used in daily life and is practically possible for everyone to operate it even they are not technically capable. The goal is to make a system which will collect the data and will process and directly give the result. For project to be practically available a small prototype of hardware is built so that we can collect the data at small level, obviously with time a prototype will be needed or we can use the same prototype in a large number on different joints. Here we used a pressure sensor SW-420 which collects the data with the help of Arduino and give the audio vibration frequency which can be processed further.

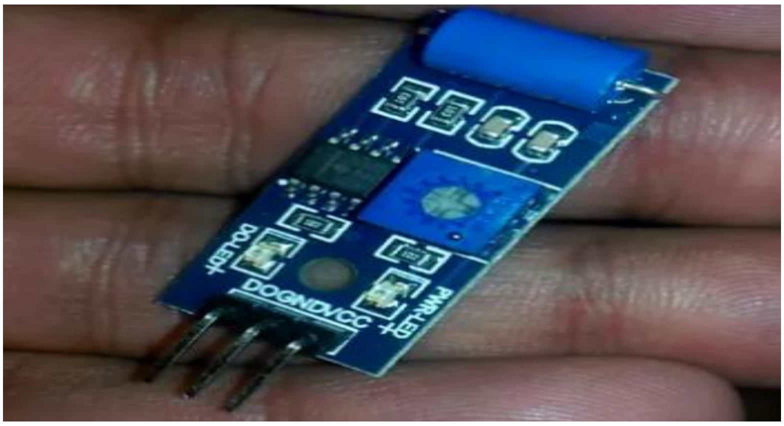

Fig. 3.3: Sensor SW-420

Figure3.4: Arduino

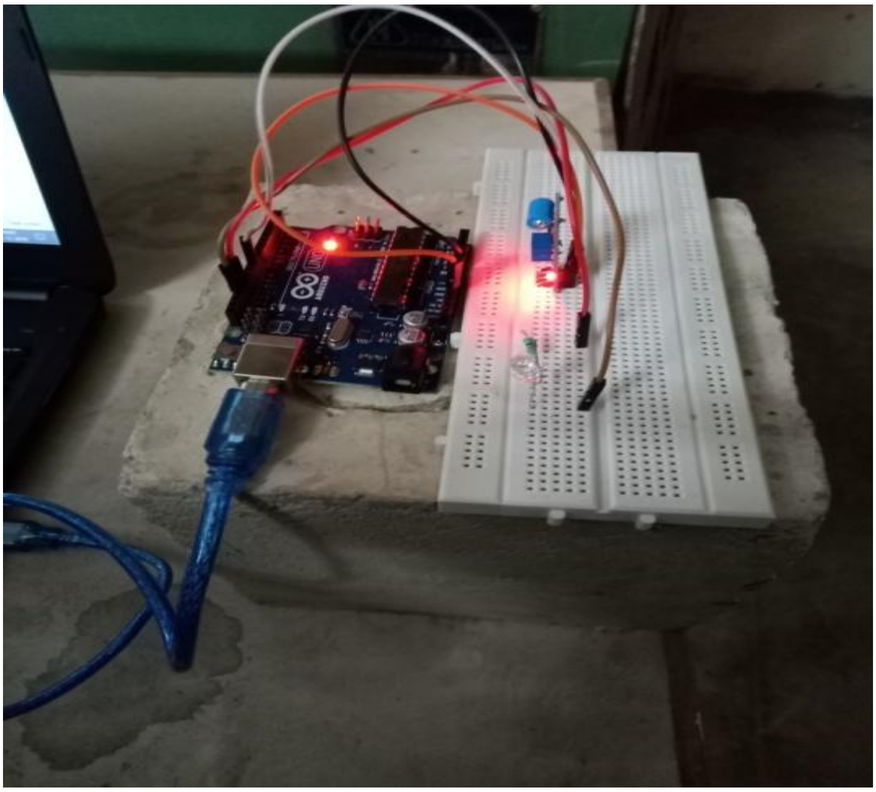

Figure3.5: Hardware setup

Though for further processing we need a large amount of data because we can get the accuracy of the system if we train it with enough data then only it will give us accurate results. As mentioned earlier the hardware we setup is for small scale so to achieve the accuracy we searched for the dataset which has been tested earlier, whoever worked earlier in this field must have large dataset so that they can get the desired results. We search for such datasets to prove our hypothesis. Therefore the next method of Data Acquisition is the online source.

3.2 Signal Processing

Signal processing is basically transmission of the signals using different techniques of signal processing. Transducer converts physical signals into electronic form be it voltage or the waveform which are further sent to processing. Signal processing is an electrical building subfield that centers around breaking down, altering, and blending signs, for example, sound, pictures, and logical estimations. Signal processing methods can be utilized to improve transmission, stockpiling effectiveness and emotional quality and to likewise accentuate or identify parts of interest for a deliberate signal.

There are various Signal Processing Techniques:
Signal processing involves various techniques which will increase our understanding of the information which we are getting in graphical form. Most of the signals are more explainable in time domain, they are more logical to understand in that way but when we want a signal in frequency domain then it shows how much of a signal energy is the function of frequency.
Signal processing helps us in understanding the meaning of the data which we are getting from different sensors or other ways, without it acquisition of data is worthless. There are many techniques present for signal processing.

Statistical TS models: -Statistical time series modelsisamathematical model based on set of input-output measurement. These are of two types:
Linear and Non-Linear statistical TS model. They are sensitive to noise as it cannot adapt to nonlinear variations.
A statistical model is a numerical model that typifies a lot of measurable suspicions concerning the age of test information (and comparative information from a bigger populace). A measurable model speaks to, frequently in extensively admired structure, the information creating process.

factors and other non-arbitrary factors. All things considered, a factual model is "a proper portrayal of a hypothesis"
Casually, a statistical model can be taken as aset of factual presumptionswith a specific property: that suspicion permits us to ascertain the likelihood of any occasion. For example, consider number of six-sided dice. We will examine 2 diverse measurable suspicions about the bones.

The principal factual supposition that is this: for every one of the bones, the likelihood of each face (1, 2, 3, 4, 5, and 6) coming up is

1/ 6

. From that supposition, we can ascertain the likelihood of both bones coming up 5:

$1 / 6 \times 1/ 6 = 1 / 36$

. More for the most part, we can figure the likelihood of any occasion: for example (1 and 2) or (3 and 3) or (5 and 6).

The option factual supposition that is this: for every one of the bones, the likelihood of the face 5 coming up is

$1 / 8$

(since the bones are weighted). From that presumption, we can figure the likelihood of both bones coming up 5:

$1 / 8 \times 1 / 8 = 1 / 64$

. We can't, be that as it may, ascertain the likelihood of some other nontrivial occasion, as the probabilities of different countenances are obscure.

The principal factual presumption establishes a measurable model: in light of the fact that with the supposition alone, we can figure the likelihood of any occasion. The option measurable supposition doesn't comprise a factual model: in light of the fact that with the presumption alone, we can't figure the likelihood of each occasion.

FFT: -Fast Fourier Transform (FFT) is one of the most exercised and bygone method for signal processing in Structural Health Monitoring. FFT converts distinct samples of a continual signal time domain into a frequency domain signal. FFT has a notable drawback, that is FFT cannot be used in the surveillance of the buildingswhich are exposed to dynamic factors because nonlinear and non-stationary properties can't be modelled by FFT adequately.
FFT is thealgorithmthat processes the discrete Fourier change (DFT)or its inverse (IDFT) of a sequence. Fourier transform of any sequence changes the sign from its original range that can be time or space. The DFT of any signal is sustained by the decomposition of any signal into different range offrequencies.. A FFT quickly registers such changes by factorizing the DFT framework into a result of scanty (generally zero) factors.[2] subsequently, it solve the issue of how to decrease the motley nature of processing the DFT from {\displaystyle

O\left(N^{2}\right)}{\displaystyleO\left(N^{2}\right)}, to {\displaystyle O(N\log N)}O(N\log N), where {\displaystyle N}N is the information size. The difference in speed could be huge, mainly for large informational indexes where N might be in the thousands or millions. Within the sight of adjust mistake, numerous FFT calculations are substantially more exact than assessing the DFT definition straightforwardly or in a roundabout way. There is a huge range of FFT calculations dependent on a wide scope of distributed supposition, from basic complex number-crunching to different theories.

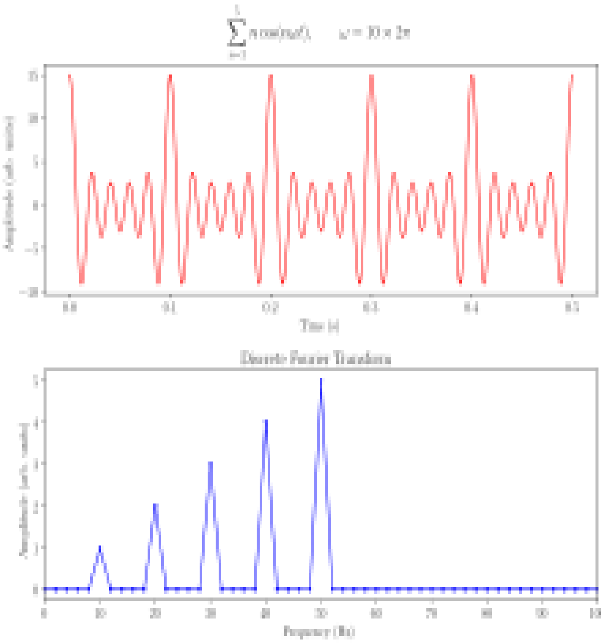

Figure 3.6: FFT of a signal

STFT: - The short time Fourier transform is an extension of Fast Fourier Transform suited for examining nonstationary signals. It can show the abnormality of the frequency details of a signal as and when the signal varies with time by isolating the signal into limited time windows, where each window is probed using Fast Fourier Transform.

The Short-time Fourier changes, is a Fourier-linked transition used to elect the sinusoidal repetition of neighborhood segments of a signal as it shifts over time. By and by, the procedure for processing STFTs means partitioning into a greater drawn out time signal into smaller remnants of equal length, afterward register the Fourier change separately on individual lessened portion. This divulges the Fourier range on every smaller section. At that point ordinarily plots the changing spectra as a component of time, known as a spectrogram or cascade plot.

The width of the windowing capacity identifies with how the sign is spoken to. It decides if there is acceptable recurrence goals (recurrence parts near one another can be isolated) or acceptable time goals (the time at which frequencies change). A wide window gives better recurrence goals however poor time goals. A smaller window gives great time goals however poor recurrence goals. These are called narrowband and wideband changes, separately.

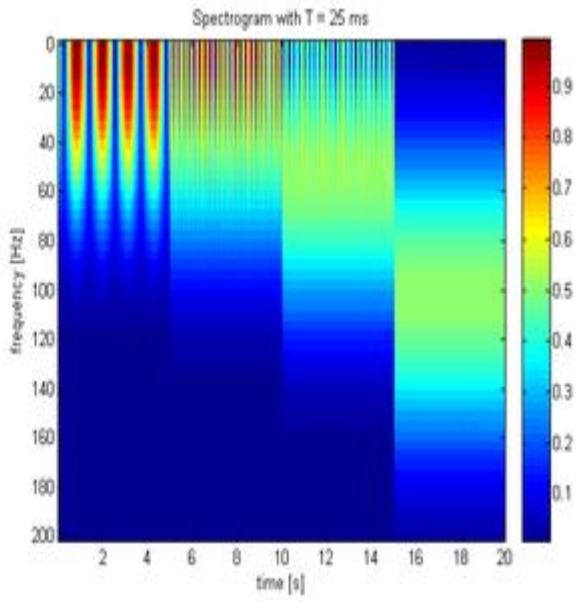

Figure 3.7: STFT (Spectrogram of a signal)

WT: -Wavelet Transform is comparatively recent signal processing technique, it gives a time-frequency delineation of the signal via time and scale window functions. Main benefits of WT has the qualities like"computational efficiency, data compression, and noise elimination". It'sdisadvantage is that it suffers spectral leakage.

The wavelet transform (WT) is amapping from $\mathbf{L}^2(\mathbf{R}) \rightarrow \mathbf{L}^2(\mathbf{R}^2)$.

WT is a mathematical tool that is mainly for data analysis in both time and frequency domain. Wavelets are utilised mainly for non linear SID with a specificform, here the distinct time variable can be defined as a linear combination of various (wavelet) functions.

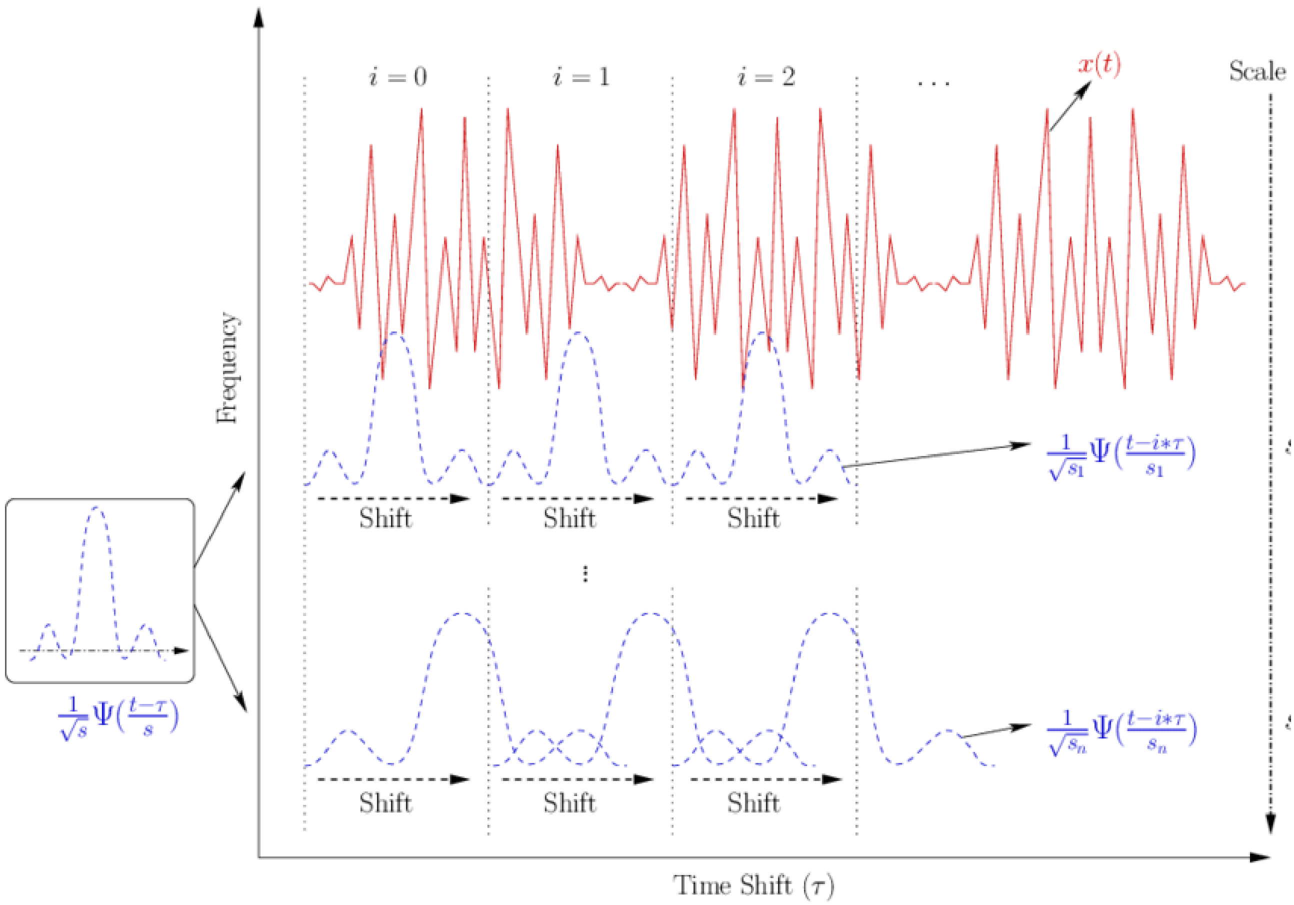

Figure3.8: Wavelet Transform

S-Transform: - ST merges proposals from Wavelet Transform and a operating and scaleable limiting Gaussian window to permit alterationof the time resolution dependent over frequency details of signal. The ST is obtained by shifting the window down the signal in time across a range of frequencies selected.

The Fourier transform of the complete time series accommodates details of the spectral contents in time series, it cannot determine time dispensation of enumerate frequencies, as a result for sizeable class of pragmatic implementations, the Fourier transform is not satisfactory. So, the time-frequency evaluation is suggested and practiced in somesituations those aren't typical. Mostly STFT is used in all signal processing. The STFT can't trail the signal passage congruously for non-stationary signals on account of the constraints of riveted window width. The WT is adequate at unsheathing data from time and frequency domains. Even so, the WT is susceptible to noise. Properties of the S transform are that it has a frequency relying resolution of time-frequency dominion and fully cite to limited phase knowledge. For example, in the outset of a seismic activity, the spectral peripherals of the P wave certainly have a substantial dependence on time.

Thereforegeneralization of the S- transform to accentuate the time resolution at the onset time & the frequency resolution at a later onset time.

MUSIC algorithm: -The multiple signal classification algorithm [1] , a power density spectrum method [1] , can distinguish various frequencies having low SNR.

It gives us the frequency representation of a signal, but here time information is not there.

It is basically used for frequency estimation and radio direction finding. MUSIC beats basic strategies, for example, picking pinnacles of DFT spectra within the sight of commotion, when the quantity of segments is known ahead of time, since it misuses information on this number to overlook the clamor in its last report.

Dissimilar to DFT, it can appraise frequencies with exactness higher than one example, since its estimation capacity can be assessed for any recurrence, not only those of DFT containers. This is a type of superresolution.

Its main disservice is that it requires the quantity of parts to be known ahead of time, so the first strategy can't be utilized in increasingly broad cases. Strategies exist for evaluating the quantity of source segments absolutely from factual properties of the autocorrelation grid. It couldn't be any more obvious, for example [5] what's more, MUSIC accept concurrent sources to be uncorrelated, which confines its commonsense applications.

Ongoing iterative semi-parametric strategies offer strong superresolution in spite of exceptionally corresponded sources, e.g., SAMV

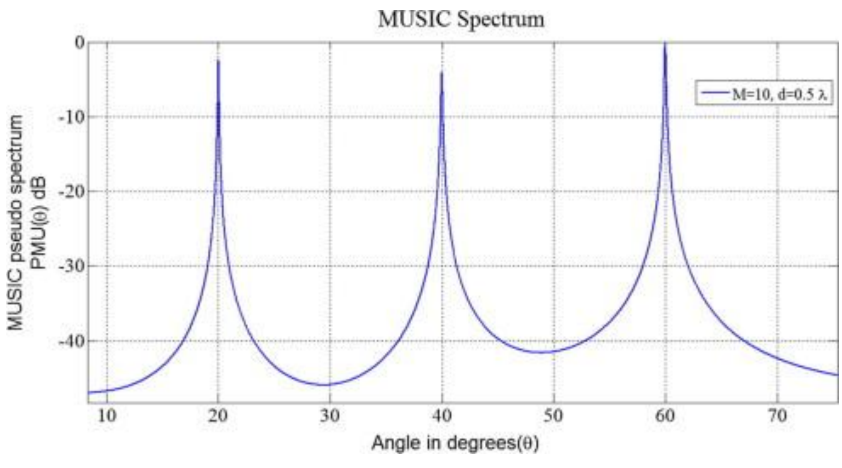

Figure 3.9:MUSIC Algorithm.

We would be using STFT signal processing technique in this project

Why we are using STFT ?

The most common and popular method of signal generation used is FT to measure frequency elements of the signal. Butthe FT has a major drawback that during the process its time information may be lost while transforming into the frequency domain, i.e. when we would look at the FT of a signal, we wouldnot have an idea of where the event has taken place.

We have used STFT instead of FT, as it is time dependent and it can simultaneously provide us with frequency and time domain analysis. The procedure to find STFT is that we divide the protracted time signal towards shorter divisions of equivalent portion, then the FT for every section. FT of the sections provides us with spectral information of that particular section, with simultaneous time and frequency information.

3.3Image Extraction

Short Time Fourier Transform is appropriated as result of signal processing. This STFT signal is passed through a power spectral density function also known as spectrogram function in MATLAB. The STFT signals after signal processing which involve use of appropriate window size and type for the desired output which is further crossed through a spectrogram function, here we take care of the length of data and frequency value and then we will get our desired spectrogram. Here, the audio vibration data has been converted into a image which can be further used for CNN.

This results in giving us a dominant frequency feature.

Dominant Frequency: - Dominant frequency customarily implied to the one that bears additional energy with reference to gross frequencies in the deliberated spectrum. This frequency component is picked hardly because it comprises of max power spectral densityof the signal or that it consists of greater energy with regards to the total number of frequencies available in the spectrogram.

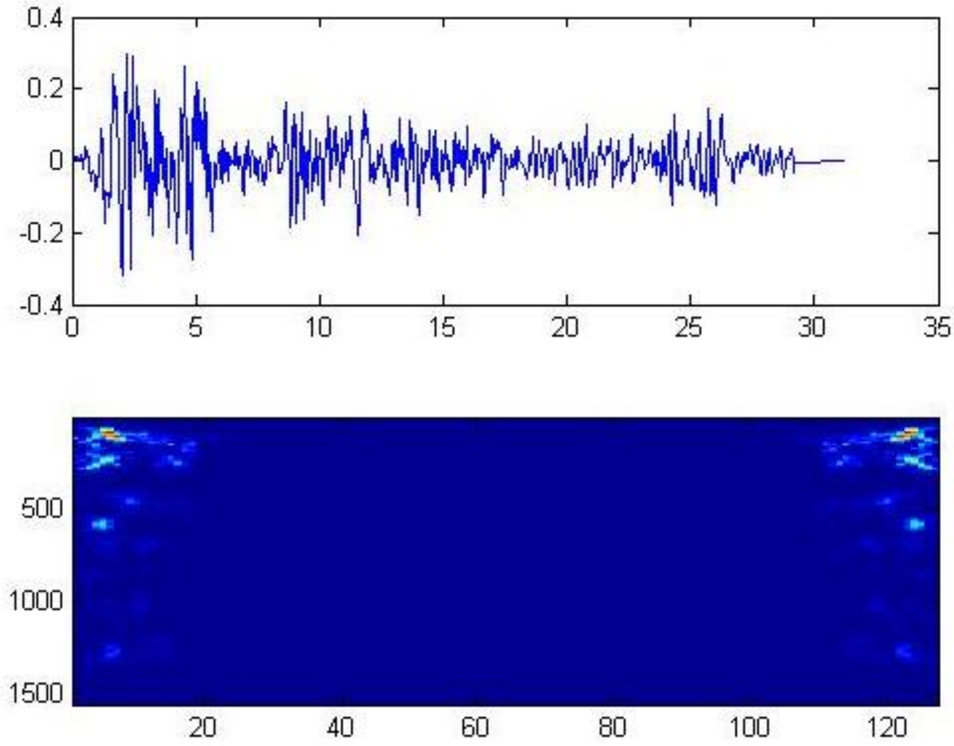

Figure 3.10: Image extraction from the STFT signal.

3.4 Convolutional Neural Network (CNN)

The evolution of deep learning can excerpt attributes from aggregate points without preceding information and simply needs to regulate the numerous amounts of neurons in the product layer. Convolutional Neural Network is a special deep feed – forward neural network, which is predominantly built by input layer, convolution, pooling , fully connected and classification layers.

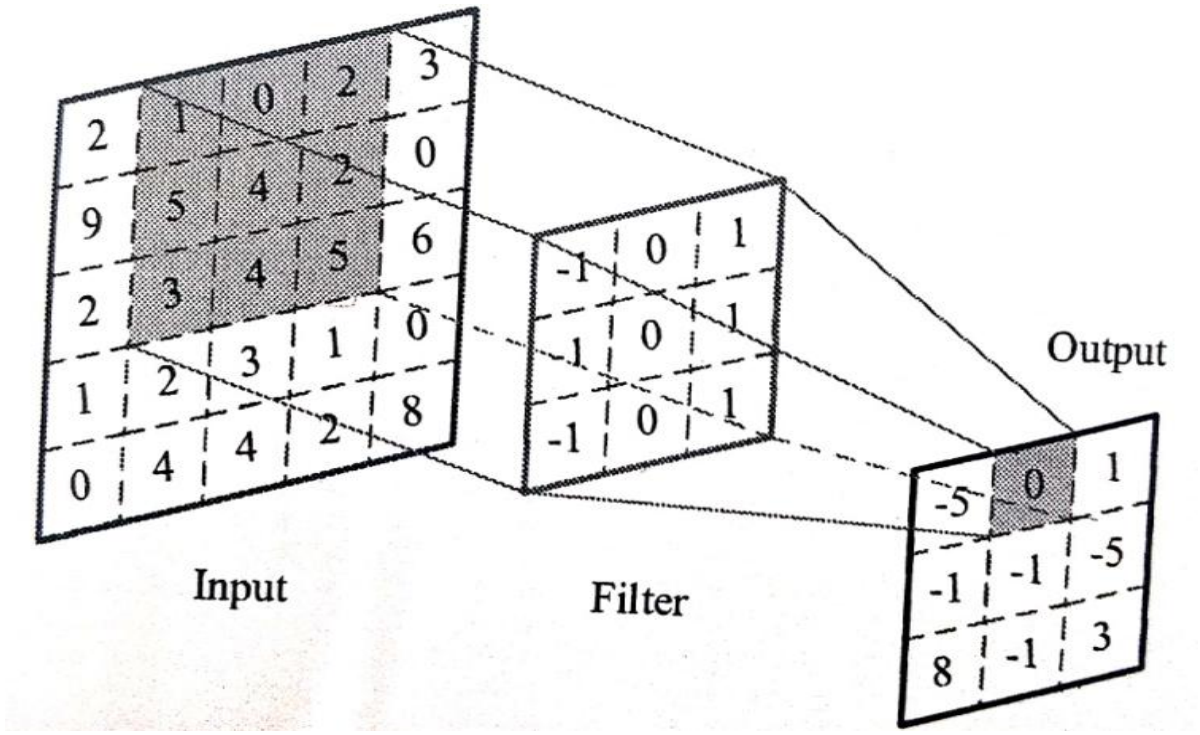

Figure 3.11: Processing through multiple layers in CNN

A convolutional neural network comprises of an input and an output layer, also accommodating multiple layers. The undisclosed layers of a CNN ordinarily subsist of a course of convolutional layers that convolute using dot product. Anactivation functionis common called ReLU, finally succeeded by supplementary layers such as pooling layer, fully connected layer and normalization layer, indicated as hidden layers owing to their inputs and outputs are covered by activation function and final convolution. The results of the last layer often necessitate back propagation for unerring weight of the final resultant.

Even so the layers are vernacularly attributed as convolutions, by convention. Mathematically, elucidatedas asliding dot product, connotation for indicators in the interior of matrix, wherein the weight is regulated at particular index destination.

Neural network’s first layer should subsist these attributes as their programming is computed:

- Inputted image a “tensor” tabulating shape, justified as (total images)x(width of the input)x(heightof image)x(image intensity).

- Filters in convolutional layer must have equivalent hyper- parameters as that of the inputted image by user. Earliest layer in the model, it convolves the input and passes the outcome to the next layerin order. A similarity is uncovered with that of the feedback of neuron in the cortex of the human brain.

Processing of data, by individual neurons is solitarily for responsive field. Usage of the previously mentioned technique , for validation of images is not evaluated as favorable in fully-connected neural networks. Enormous amounts of neurons required for a miniature model architecture, the weights on the images may end up as a large amount making the model complicated and complex.

An example of small-scale image of size 100x100 is weighted approximately 10,000 weights on every neuron in the following layer, the first layer operates to reduce this factor by a considerable amount, decreasing the large amounts of extra parameters, leaving the available network tabulating the fewer parameters only.

Considering for an image size, convolution over 5x5 window size is assessed, the resultant requires fewer parameters to train itself, limiting to 25 only.

The training for multi-layer neural networks is benefitted as the free parameters are removed and the model remains less complex with higher learning abilities.

Time Domain :- It is the analysis of various characteristics with respect to time, like mathematical functions, physical signals or sequence of any environmental data. It is the plot between time and amplitude. It shows how a signal changes with time.

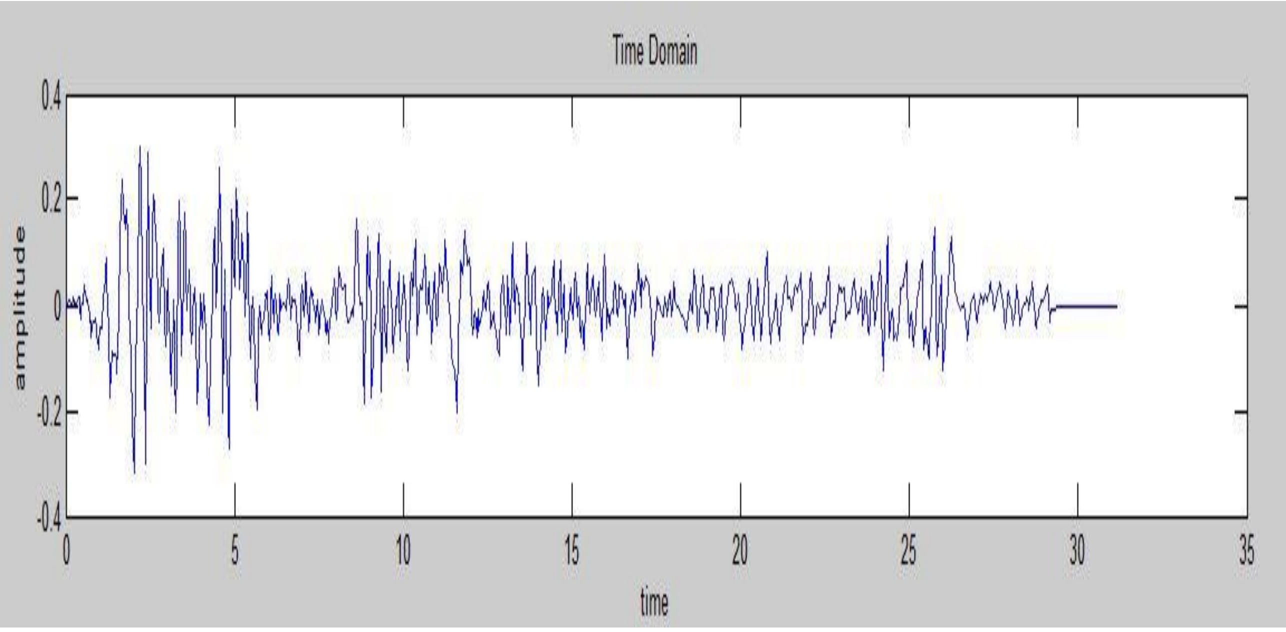

Figure 3.12: Time domain signal

Frequency Domain : It is the analysis of various characteristics with respect to time, like mathematical functions, physical signals or sequence of any environmental data rather than time. It is the plot between frequency and magnitude. It shows how much of the signal lies within each given frequency band over the range of frequencies.

In the fig 3.6 we are using Short Time Fourier Transform operation on a non-stationary time domain signal.

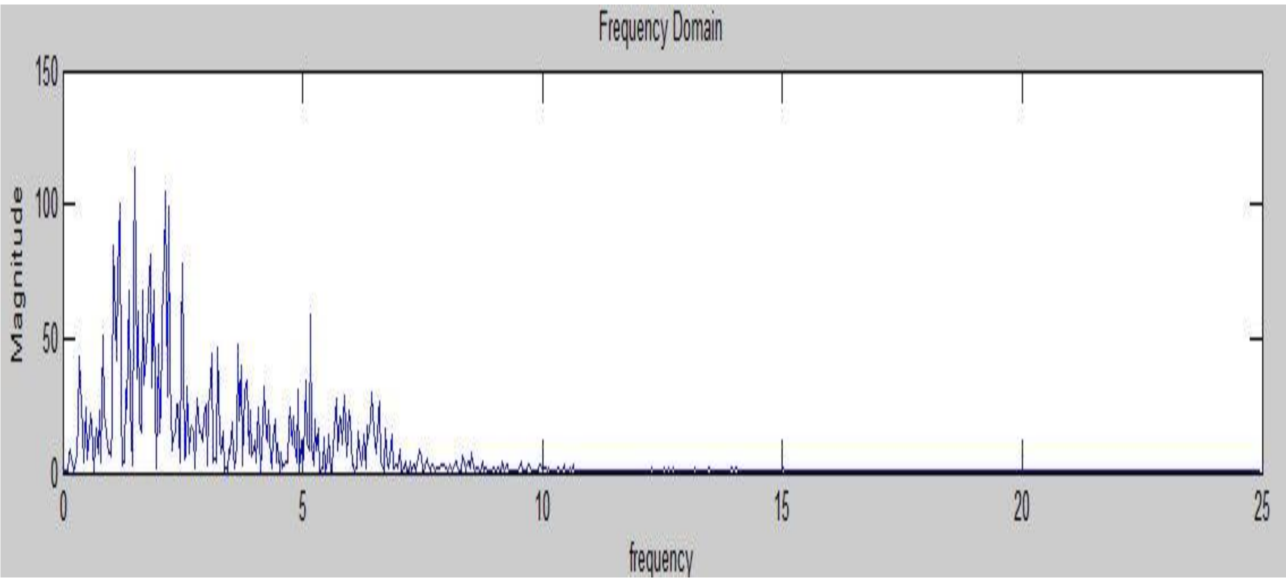

Figure 3.13: Frequency domain signal

Spectrogram : -Spectrogram are time- frequency analysis representation of signals. They are the representation of the intensity of the frequency of the signal with the progression of time.
It's a heat map which means it shows different color at different intensities.
In fig 3.7 we are using spectrogram analysis on an STFT signal.

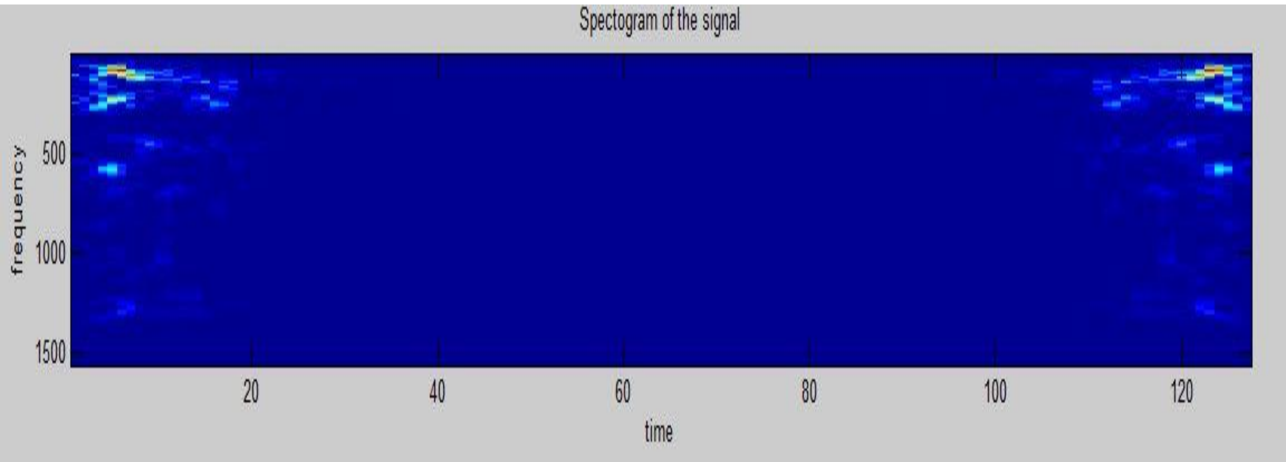

Figure 3.14: Spectrogram

3.5. CLASSIFIACTION: Our classification will be in two categories:

1. Damaged
2. Undamaged

Using CNN we will give above classification, in itwe would be training the system for damaged structure vibration signal as well as undamaged. So, at present we will be giving the classification as damaged and undamaged.

In future it's the goal to achieve the classification of

1. Evacuation
2. Maintenance Required.

CHAPTER -4

MATERIAL AND METHODS

4.1 STFT (Short Time Fourier Transform)

Short Time Fourier Transform (STFT) is a method used to find the Fouriertransform using a window, to find the frequency and phase content of a signal as the signal changes with time.

The difference between STFT and Fourier Transform(FT), is that FT is used to find frequency information over the entire signal while STFT divides a signal into smaller sections of same length and the computation of the FT distinctly over every section.

STFT of a signal f(t) is defined as:-

$$\mathrm{F}(\omega,t)=\int_{-\infty}^{+\infty} f(\tau)h(\tau-t)e^{-j\omega\tau}d\tau$$

Here h(t) is the hamming window, w is the frequency, t is the time and f(t) is the input signal for which we have to calculate the STFT.

4.2 Calculation of STFT

- Firstly we define a window function of finite length.
- Further we place the window on the top of the signal at t=0.
- Then we truncate the signal using the window.
- After truncation we compute the FT of that section.
- We slide the window gradually towards the right.
- We go back to stage 3, until the window reaches the end of the signal.

4.3 Choosing the window

For our project we decided to take the hamming window for reasons primarily because of low ripples, that is the Maximum side-lobe level (MSLL) as well as the Main lobe width (HMLW) has lower values. Because of this it has finer resolution and higher rate of decay (SFLOR).

4.4 Choosing the Window size

- The window size should be tapered for the port of the signal which fit inside the window is stable.
- But choosing a very narrow sized window is not the best idea as it does not provide good position in the frequency domain.
- A not so narrow but wide window is preferable, as it helps to provide bad time resolution and good frequency resolution.

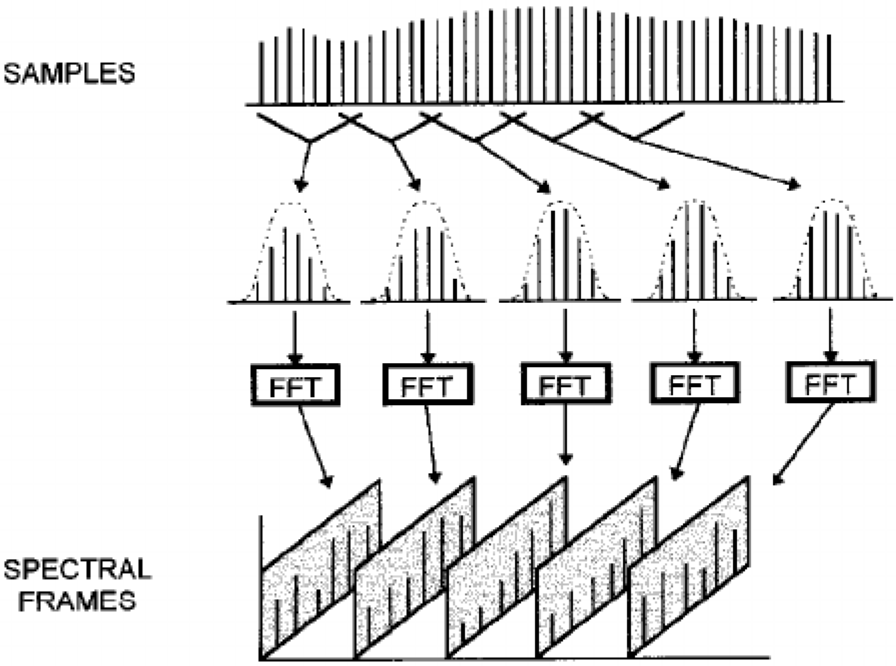

Figure 4.:1 General representation of STFT

4.5 Stationary vs Non- Stationary Signals

We define Stationary Signals as the signals whose frequency componentsdoesnot change with time, an e.g. is a sine wave, its frequency components do not change with the change in time.

While Non-Stationary signals are the signals whose frequency components changes as time changes, an e.g. would be speech or audio signal.

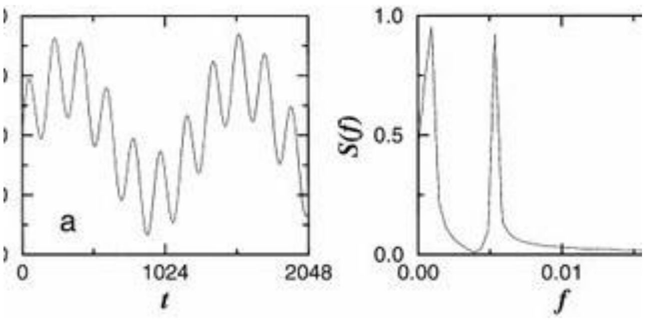

Figure 4.2: Stationary signal and its FT

For the above Stationary signals with continuous frequency components there will be only less number of frequency components.

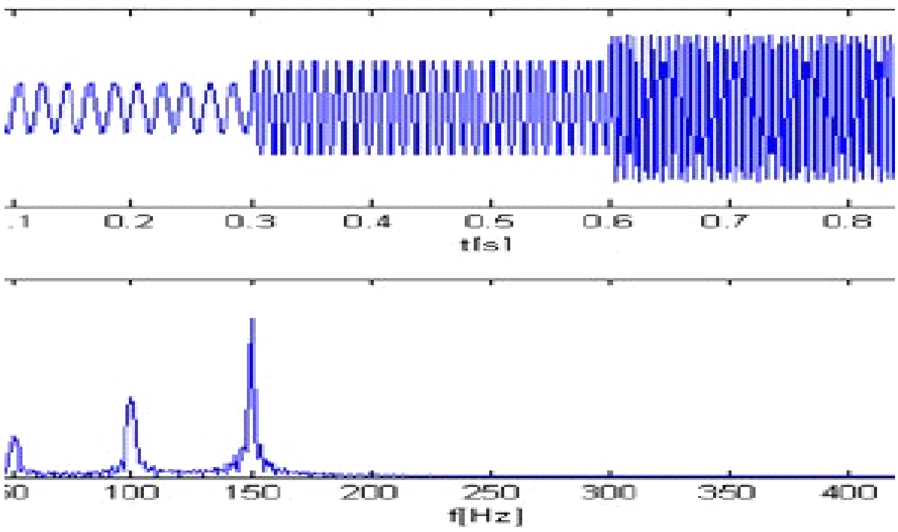

Figure 4.3: Non-Stationary signal and its FT

For the above image we already know which frequencies will be present in the signal, but we do not have any knowledge about the location of the frequencies.

4.6 Why we are using STFT

The most common and popular method of signal generation used is FT to measure frequency elements of the signal. But the FT has a major drawback that during the process its time information may be lost while transforming into the frequency domain, i.e. when we would look at the FT of a signal, we would not have an idea of where the event has taken place.

We have used STFT instead of FT, as it is time dependent and it can simultaneously provide us with frequency and time domain analysis. The procedure to find STFT is that we divide a signal inlarge into equal small parts, then we find the FT of every section. The FT of the sections provides us with spectral information of that particular section, with simultaneous information about time and frequency.

4.7 Limitations of Fourier Transform

- The drawback of using FT is that it doesnot provide us with time and frequency representation at same time.
- The second major drawback of the FT is that we cannot use this method for non-stationary signals.

4.8 Feature Extraction

Feature Extraction is a process which is majorly used in pattern recognition systems, it captures the required characteristics of high-dimensional patterns into lower dimensional patterns.

We will draw out the features of the structural vibration signals using Time- Frequency Method, that is we will be using STFT.

The steps for feature extraction used are: -

- We take the STFT of the data acquired using MATLAB.
- Then we plot the spectrogram of the signal, and we extract its characteristics by adding all the power spectral densities at a frequency and then plot its normalized graph.

•	The tabular dataset downloaded, is converted into spectrograms that is processing of a signal from the acquired data. This is evaluated by using MATLAB®, a code for the same describing the amplitude v/s time and another plotting the STFT which is a important requirement for signal processing.

Spectrograms:

These may be 1-dimensional, 2-dimensional and 3-dimensional representation of a spread of frequencies over varying time period. In this report, a 2-dimensional(2D) demonstration of spectrogram is taken.

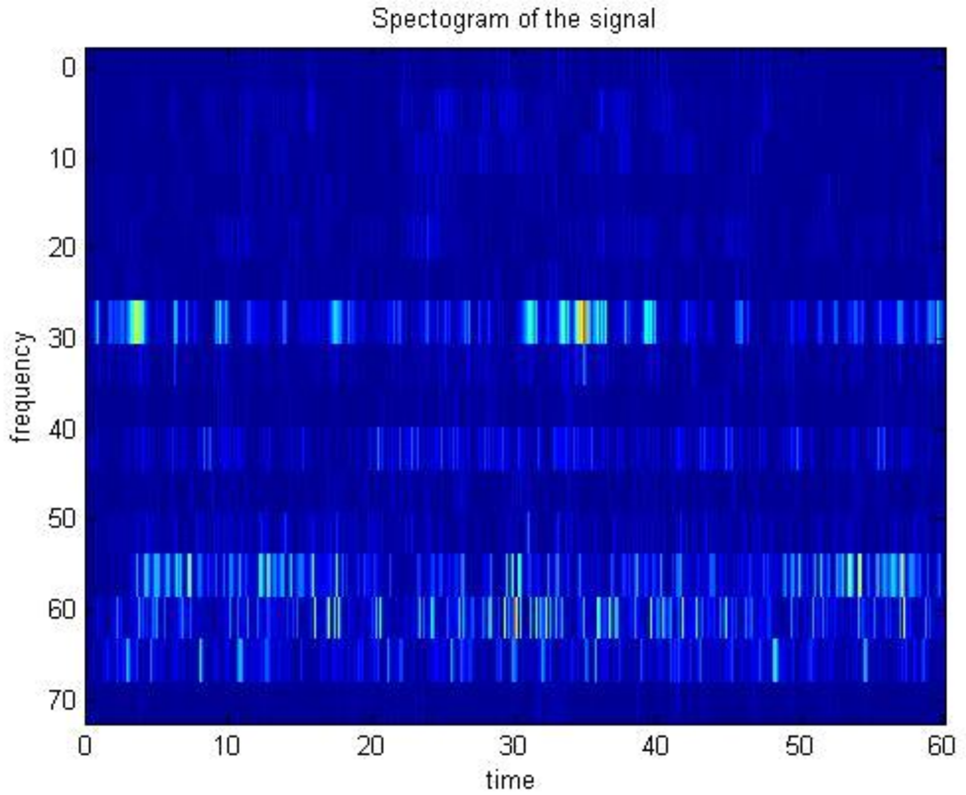

Figure 4.4: Spectrogram representation

The format of a spectrogram as seen in the above figure, is with varying time in the x-axis while the frequency can be seen on the y-axis, this can also be flipped and is not necessarily the fixed demonstration of a spectrogram.

Generation of these 2D spectrograms can be made by various techniques, most commonly used is Fourier transform while others can be, WT, STFT, FFT etc.

Some of the major applications of spectrograms include signal processing and analysis, music, radars, diagnostic usage in medicine etc.

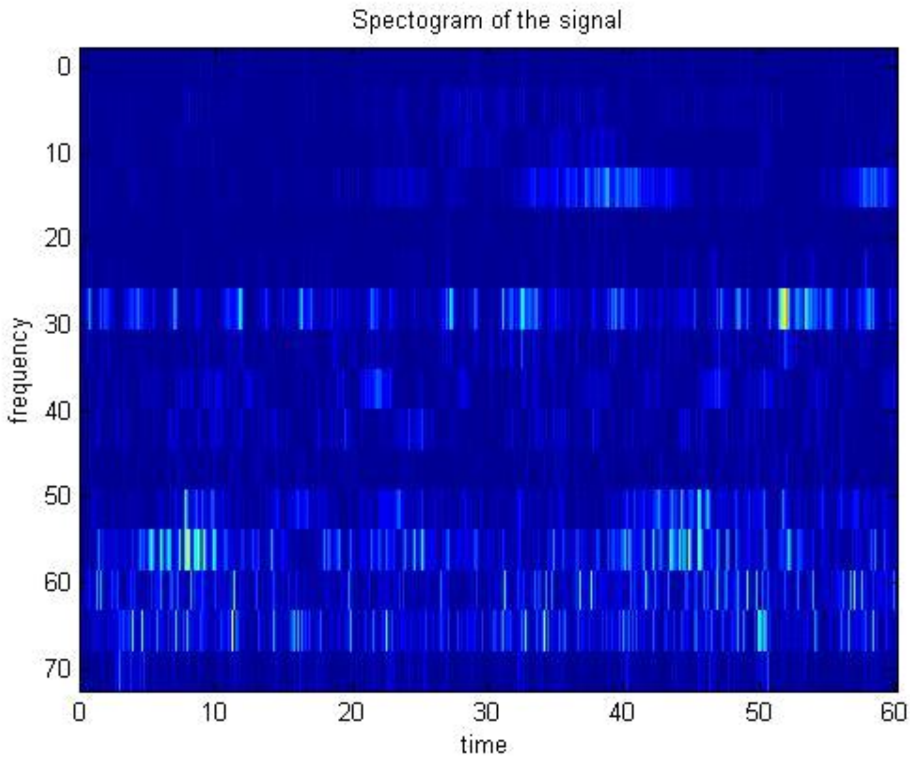

Figure4.5: Spectrogram for a undamaged signal

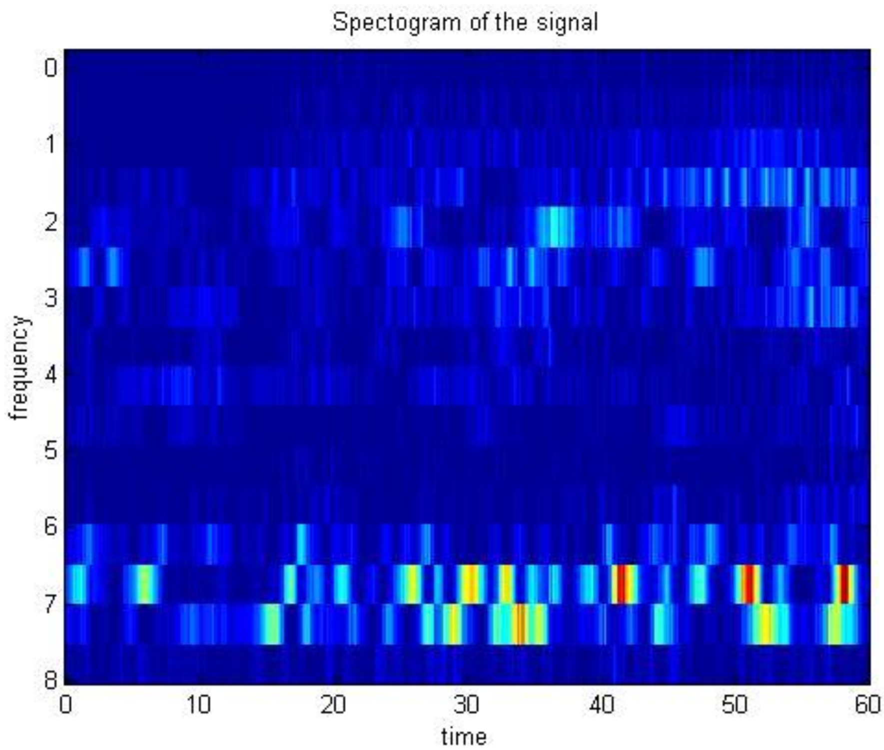

Figure 4.6: Spectrogram for damaged signal

As in the above figures, it is clear that one can distinguish between a undamaged and a damaged vibration signal from these plots but, the fallback of a spectrogram, which could be clearly seen upon inspection was that the location of the exact phase of any damage in a damaged signal could not be specified, as a result of which classification between the damaged and undamaged structures was not possible. Therefore another approach was drawn to perform the same, that is Convolutional Neural Network(CNN).

4.9 Classification

4.9.1 Introduction to Neural Network

After the process of feature extraction, we will be classifying the structural vibrations as healthy and unhealthy vibrations, for that we use Neural Networks.

Neural networks were initially a replication of the working of the human brain, to make the working of things more easier and intelligent.

Neural networks is basically set of computing devices which represents the neuron system of our brain. The main goal of the Neural network is that it would make the computational task faster and easier than the technical way which is being used so far. These tasks mainly include the analysis of data and using it for optimization, characteristic finding, classification, data clustering etc.

Artificial Neural Network

Artificial neural network is basically asystem whose concept is just like human neural system. It’s also known as “parallel distributed processing system” or “connectionist system”. In it there are large numbers of small units just like in human neural system. They are also known as nodes or neurons just like our human brain. Similarly to the human brain these units are connected parallel to each other. These parallel connections are made through connection link. Each of these connection link bears a weight that contains the knowledge of the signal to be initiated. This information is very important for any network or neuron of network to solve the problem. As this is the information which would excite or restrain the signal that is being send or communicated through. There is an internal state known as an activation signal. Output signals are created through the combination of input signals and different activation rules which are then sent to the other unit.

Figure 4.7:A brain neural network connection

Above figure shows the neurons of the brain, see the connection between them. How they are parallelly connected to each other if a flow diagram be made of these brain neurons, it would be something like this.

Figure 4.8: Flow diagram of the neuron connection inside the brain.

The above image shows how the neurons in brain are interconnected to each other, similar to this structure our artificial neural network is also made.The artificial neural network model is based on the interconnection of the neurons.

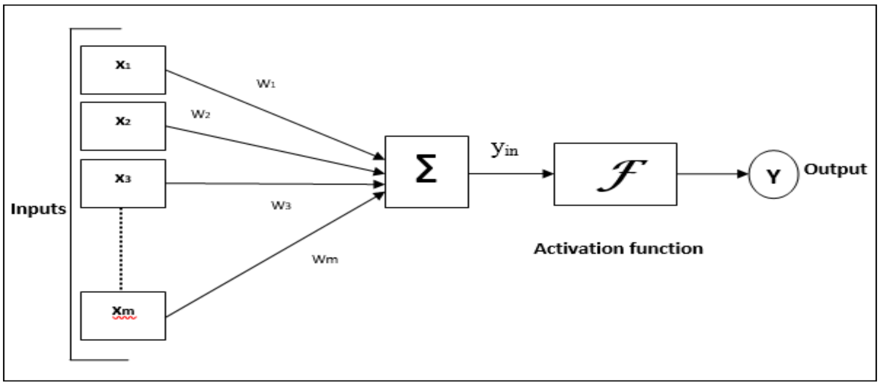

Figure 4.9: Modelof artificial neural network.

the net input can be calculated as follows −

yin=x1.w1+x2.w2+x3.w3…xm.wm

where,

x1,x2………..xm are the input signals and w1,w2…………..wm are the different window functions which we would be using.

Therefore, yin=∑mixi

The output can be calculated by applying the activation function over the net input.

Y=F(yin)Y=F(yin)

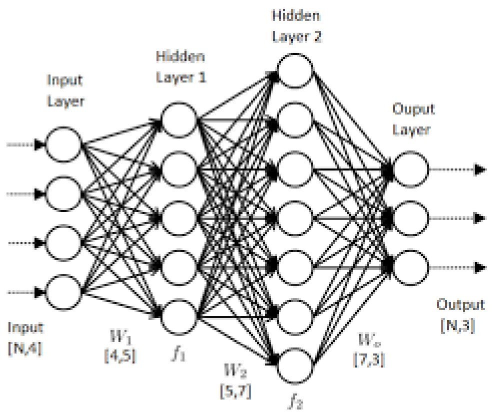

Figure 4.10: Artificial neural network

Above figure shows a prototype of an artificial neural network. Now, a similarity can be seen with Figure 4.8 which is replicating the neural connections in brain. Both the figure shows same neural connection be it brain or the neural network.

4.9.2 Definition of Neural Network

Neural Network is the computational replica of human brain neuron system to make a system which is faster than the traditional one. A computer, does not read an image as buildings, colorful skylines but as described by 3-colour channels namely, RGB, that is Red, Green and Blue. These three colors further play an integral role in mapping the pixels of the image and then defining the size of the image. While for a black-white image the color-channel used is only one, but involves the same procedure as stated above.

4.9.3 Processing of Neural Network

There are majorly three building structures for the further processing in the artificial neural network:

- **Network Topology:**
  It's the geometrical representation of a network with nodes and the connecting links.
- **Adjustment of Weights or Learning:**
  Adjustment of weight is very important in neural network and it's the basic learning of the ANN.
- **Activation Function:**
  Activation function is applied over the input. Integrated function is used when there are more than one input functions. Activation function is used to get the desired output.

4.9.4 Convolutional Neural Network (CNN)

With its resemblance and working similar to that of neural networks, convolutional neural networks consist of neurons with an interesting property called, "learnable weights and biases". The entire process is simple and involves the neuron attaining several inputs, taking their weighted sum and then passing these through a activation function to get an output.
For better understanding, an example can be taken:-

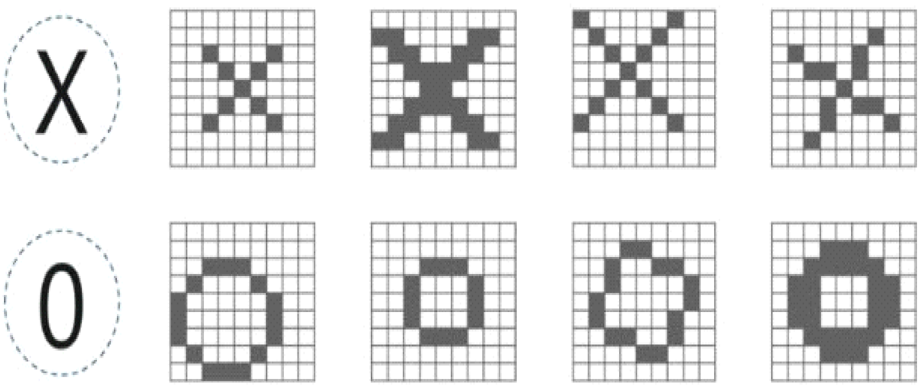

Figure 4.11: Example for CNN depicted by X and O's

In the above image there are a couple of interpretations of X's and O's. For the computer to

recognize and categorize them as there counterparts, is not an easy task, for the same a classification using CNN might be convenient.
The computer will allocate the whiter pixels with -1 and the black pixels with a +1 and the image is converted into matrix form consisting of reusable weights, this is done for simple understanding only.
There are 'Four' layering processes involved namely:-

- Convolution
- Activation
- Pooling
- Classification (Fully Connected Layer)

Convolution of the input image

This is the first step where the input image as matrix undergoes convolution by using kernels or filters, this process play key role in determining the features important for classification and thus the model learns to categorize the features for better reference.
This has been formulated into four simple steps:

- Firstly, place the kernel and the image together.
- Multiplication of the image pixel with its corresponding kernel pixel, resulting in storage of the products into another matrix.

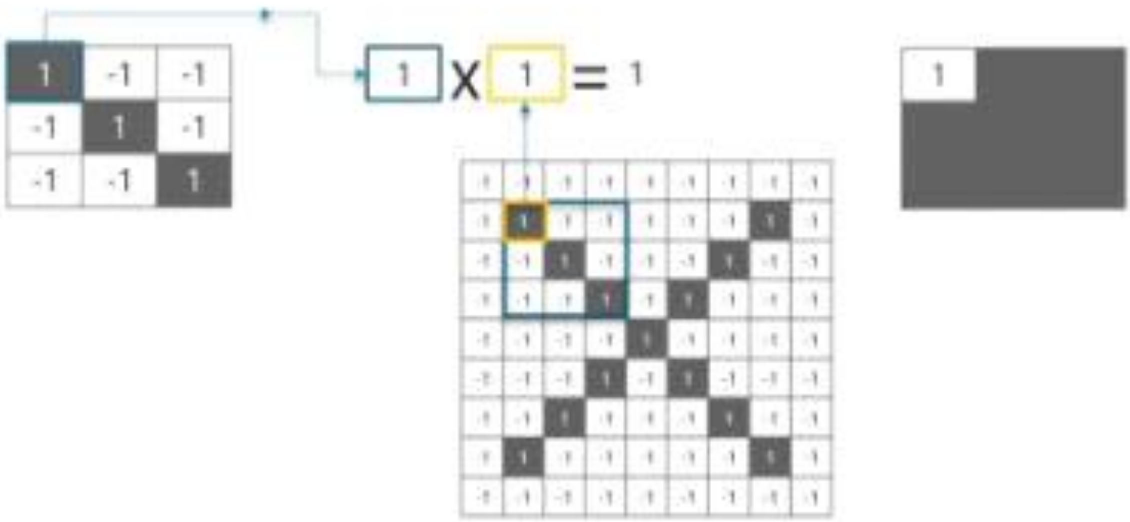

Figure 4.12: Multiplication of kernel and image

- Then, addition of all the values of that matrix is done.
- Finally the division of the addition of values by the total number of pixels in the kernel is done. After the result is obtained it placed at the centre of newly filtered image.

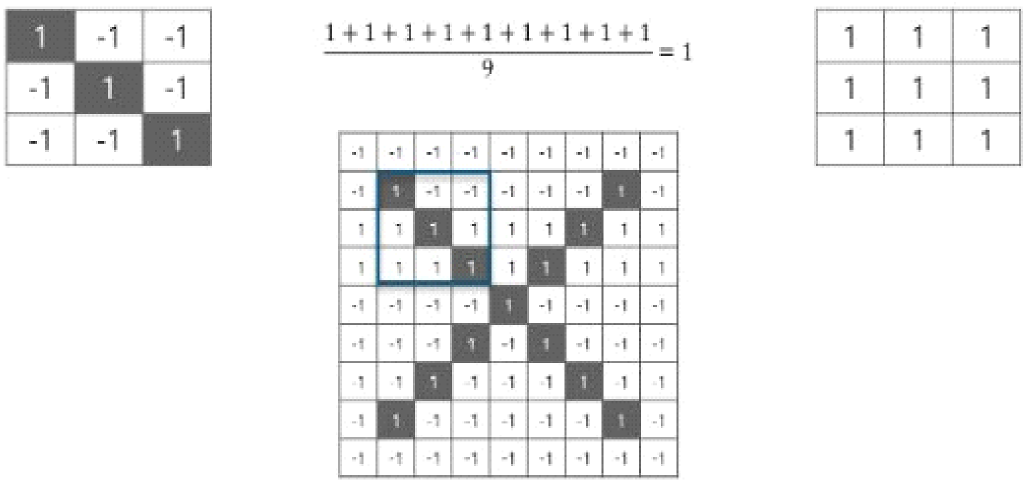

Figure 4.13: Addition and multiplication of resultant

Similarly, this process is applied with the kernel moved to each and every position in the image, an a convoluted image is obtained.

0.77	-0.11	0.11	0.33	0.55	-0.11	0.33
-0.11	1.0	-0.11	0.33	-0.11	0.11	-0.11
0.11	-0.11	1.0	-0.33	0.11	-0.11	0.55
0.33	0.33	-0.33	0.55	-0.33	0.33	0.33
0.55	-0.11	0.11	-0.33	1.00	-0.11	0.11
-0.11	0.11	-0.11	0.33	-0.11	1.00	-0.11
0.33	-0.11	0.55	0.33	0.11	-0.11	0.77

Figure 4.14: Final convoluted image

Activation Function

Most prominently used activation function is **ReLU** (Rectified Linear Unit). An activation function is a transform function which comes into being, only when its value exceeds above a particular level or quantity.

Need for an Activation Function:-

It provides for removal of all the possible negative values that might have been obtained during the convolution of the image, by giving every negative value equivalent to a '0'. As a result of this process, there is smoothening of the image to reduce the noise.

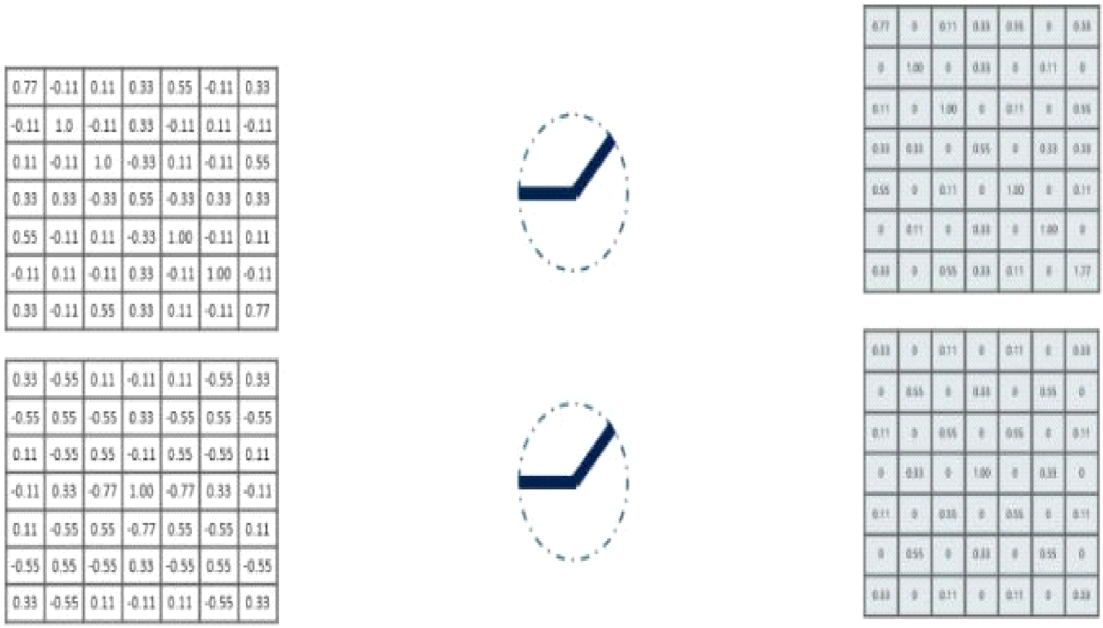

Figure 4.15: Activation function on convoluted image

Pooling Layer

The main purpose of this layer is to reduce or shrink the size of the convolved image, after it has passed through the activation layer.

This process consists of four steps:

- Pick a window size preferably of 2 or 3.
- Select a segment of the filtered image which should be of the same size as the window size.
- The window then slides across the filtered images.
- As the window moves across the image, the maximum value can be taken.

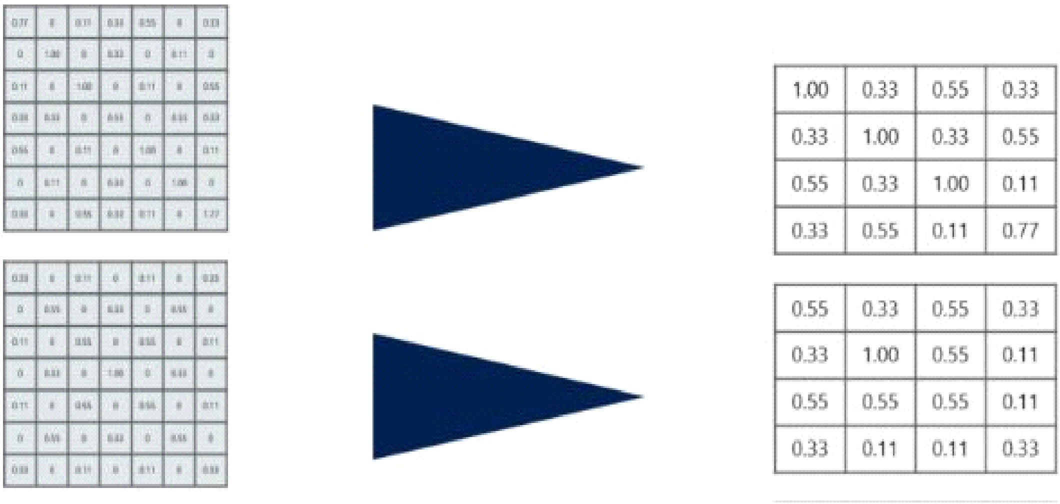

Figure 4.16: Image across Pooling layer

Stacking the above layers together.

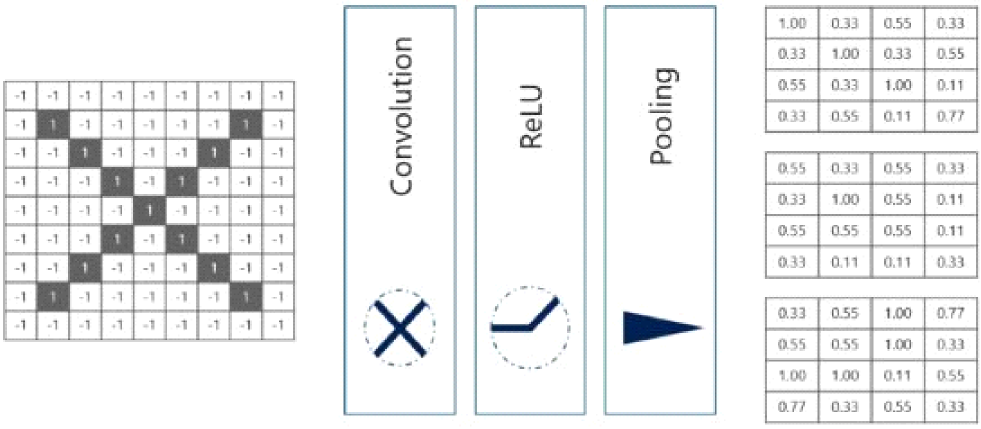

Figure 4.17: Stacked layers

Further the image matrix can be minimized by performing the above steps again over the processed image matrices, or reiteration.

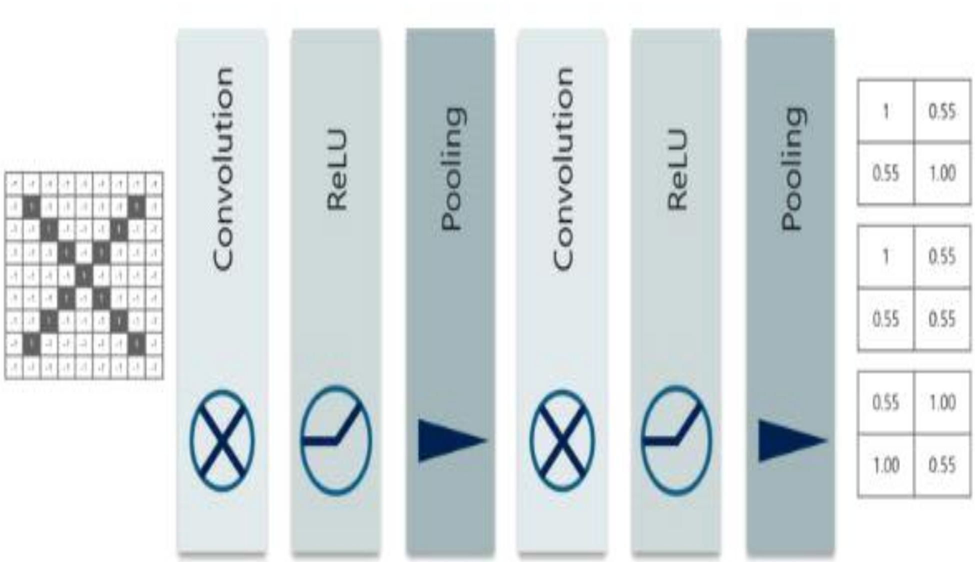

Figure 4.18: Iteration on the processed images

Classification Layer:

The images, filtered undergo classification in the fully connected layer. The matrices are forwarded into a single list and the higher values are examined, which would be referring to a particular image. This ends the training process of the input images.

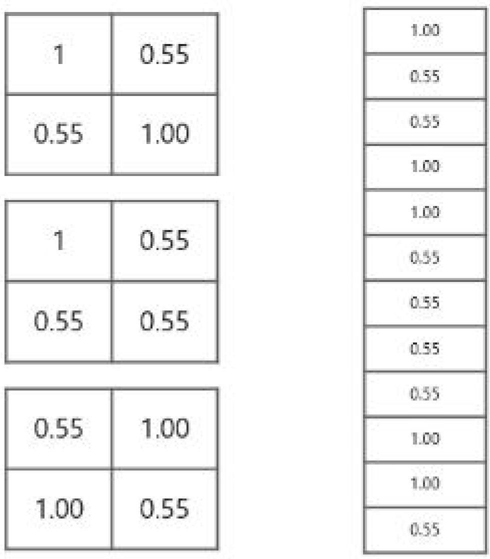

Figure 4.19: Matrices into a Single list Vector

Testing an image for prediction (At the fully connected layer):-

A set of images are inputted for making a prediction, to justify the classification. A similar single list of vectors is obtained for these images and they are compared with the trained values, a sum of all their values is done and collated.

Figure 4.13: Input image compared with X

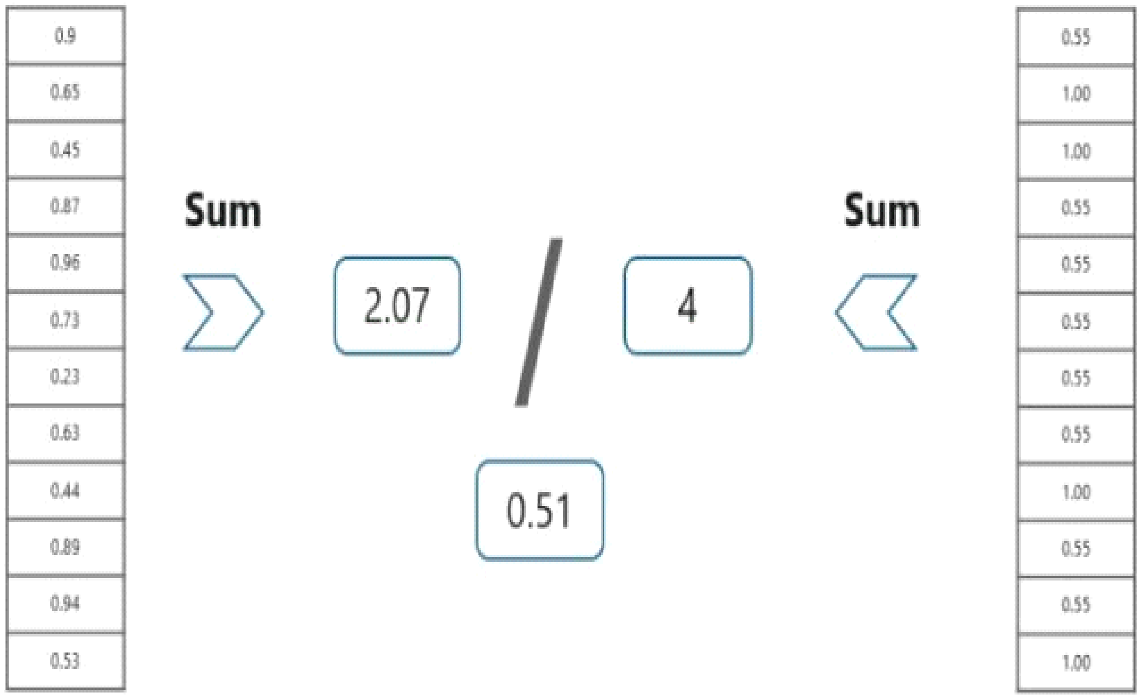

Figure 4.20: Input image compared with O

From the above figures, it is visible that the sum of the vectors is taken and further, division of input sum with the feature vector is done. A probability is achieved and on the comparison of these values a prediction can made.

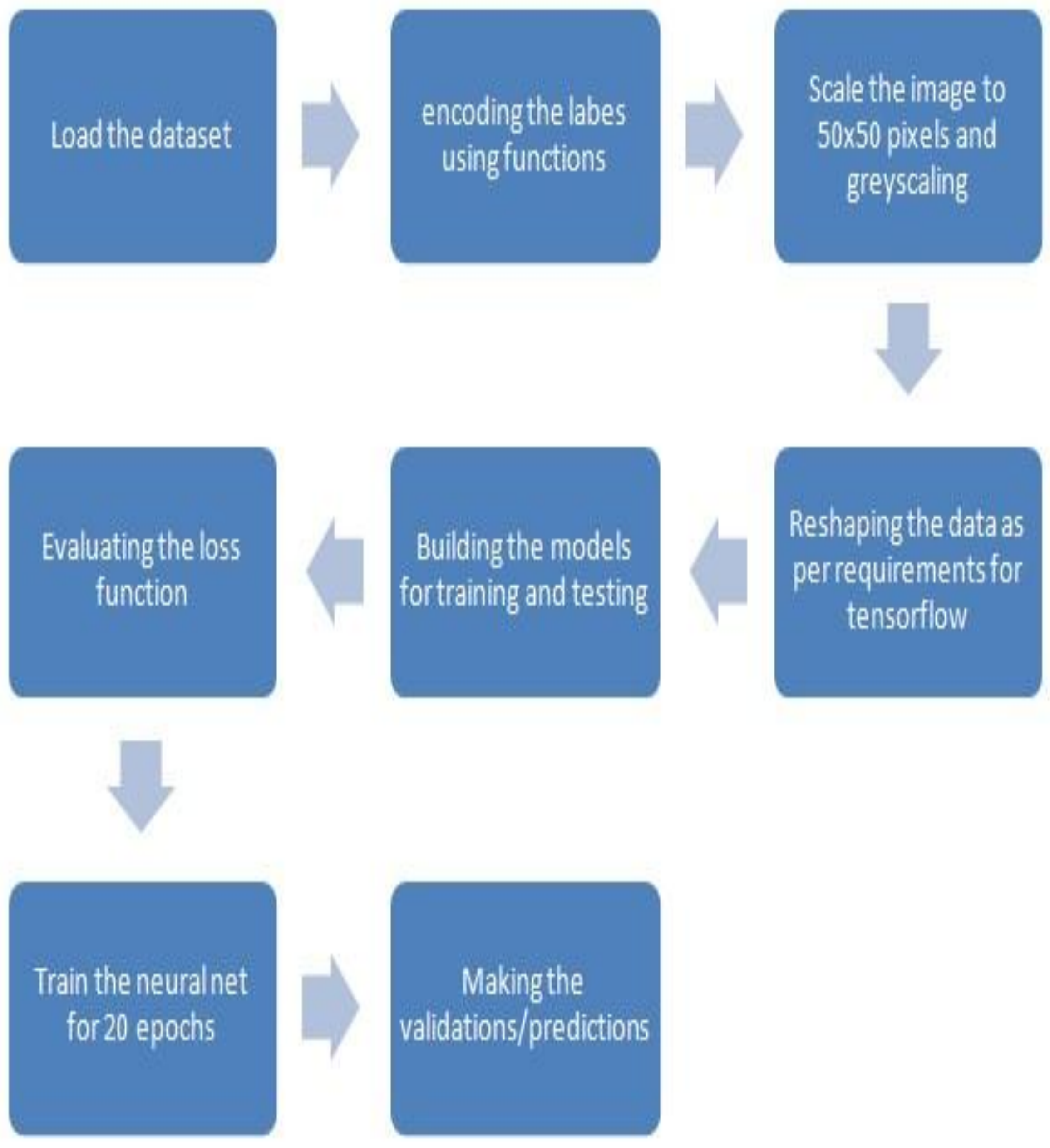

Figure 4.21: Use case implementation for CNN

- The spectrograms stacked together into a datasets is downloaded, and uploaded. The code follows the path (eg:- X:/dataset/train), provided by the user in the code to locate the dataset.
- Labeling of the image is done. Each label is the name of a particular idea, or class, that the

model will figure out how to perceive.

- Resizing of all the images to 50x50 pixels, for indistinguishable format of images and further greyscaling them to form matrices.
- Splitting of training and testing data is done, here 1000 images for training and xx images for testing are taken.
- The model that is to be made requires the following layers:

(i) **Convolution**- In the model prepared, 2D convolution is performed.
(ii) **Activation function**- ReLU
(iii) **MaxPooling**- 2D Pooling is done with maximum value chosen.
(iv) **Flatten**- Classification requires the matrices to be converted into single line vectors.

- Losses and accuracy is accorded for, using a categorical cross entropy, Adam as the optimizer helps to set the learning rate. Training of the entire neural network model is done for 20 epochs and then the validation is performed.

CHAPTER -5

DATA ACQUISITION

Data Acquisition can be defined as the measurement of electrical or physical phenomenon such as current, voltage, temperature, pressure or a sound with the help of a computer. Data Acquisition can be done by many ways. In this project, the main difference from the other work done in this field is the hypothesis which has been followed is different. In most of the previous work Machine Learning has been used to do the final classification of the data but in this case, the data would be converted into spectrograms that is 2D image form which we need for CNN(Convolutional Neural Network). The major difference between Machine Learning and Deep Learning is that in Machine Learning we have to train the machine with the lot of data that needs a lot of time but in case of Deep Learning, the machine train itself from the data we input in it. Deep Learning is basically a evolution of machine learning. But we need a lot of data to acquire the desired classification which we need. Neural network concept is being used in Deep Learning.

In this project two methods have been opted for the data acquisition process. Since this project long term goal is to have its practical application in real life so, a hardware is made to do it but it's also on a small level now so the amount of data needed for CNN, can't be obtained by the hardware. So, another option is to test the hypothesis on the datasheets available from the previous work done on the field.

5.1 Methods of data acquisition:

Data Acquisition is a major part of this project

- Hardware to collect data
- Take online data sheets.

5.1.1 Hardware to collect data:

To collect the audio signal vibration we take a sensor SW-420 attached with Arduino to collect the vibration data with respect to frequency.

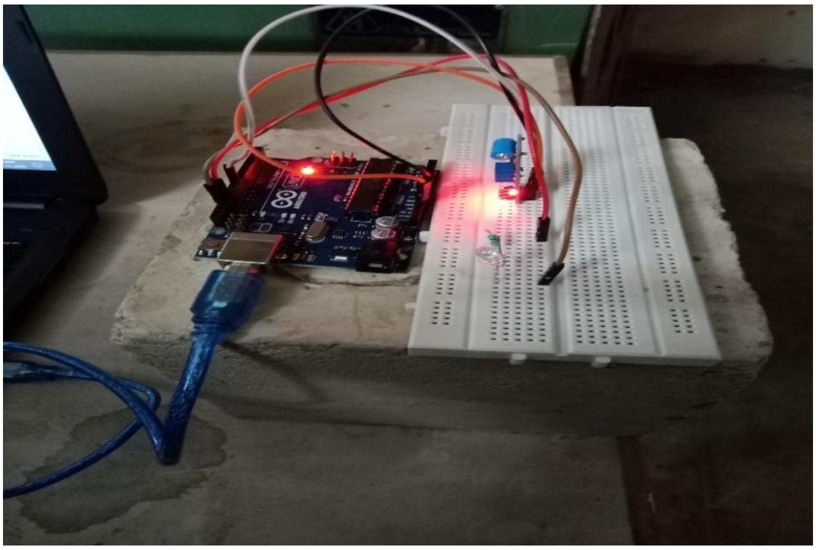

Figure5.1: Hardware to collect data.

Above shown figure is of the hardware which we used to collect the data, it’s SW-420 pressure sensor in circuit with resistance of value 220ohms, connected with Arduino through wires to the laptop.

Figure 5.2: Vibration Creation**.**

Now as shown in the above figure we used a heavy metal piece to create vibrations in the structure so that a prototype could be attained, we tried creating periodic vibrations for a fixed interval so, that it can be considered as a normal data when the structure isn't damaged or there is no change in vibrations after that we also tried with damaged structure and in both case we created periodic as well as aperiodic vibrations with different materials.

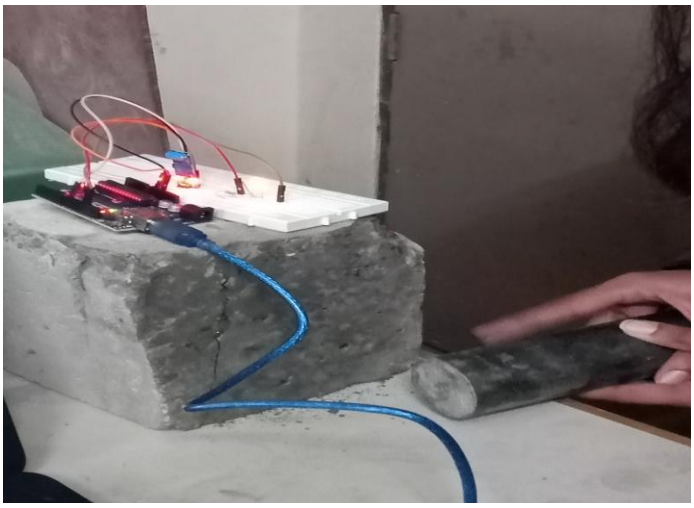

Figure 5.3: Concrete Block

First we used the hardware to collect the audio vibration data of a concrete block, firstly we used a completely perfect concrete block and created the vibration through the heavy metal piece periodically and then we created the vibrations not periodically. After that we performed the same procedure on a damaged concrete block with same periodic and then not periodic vibrations in the fixed interval of time so that we can get a fixed frequency at which we are working otherwise it will be a issue for the further process.

Many factors are responsible for the vibration change even the change in material can alter our results with great factors and a study has to be done by keeping all the factors in mind, therefore in next step we change the material how the change in density and other factors due to change in material are gonna effect the results.

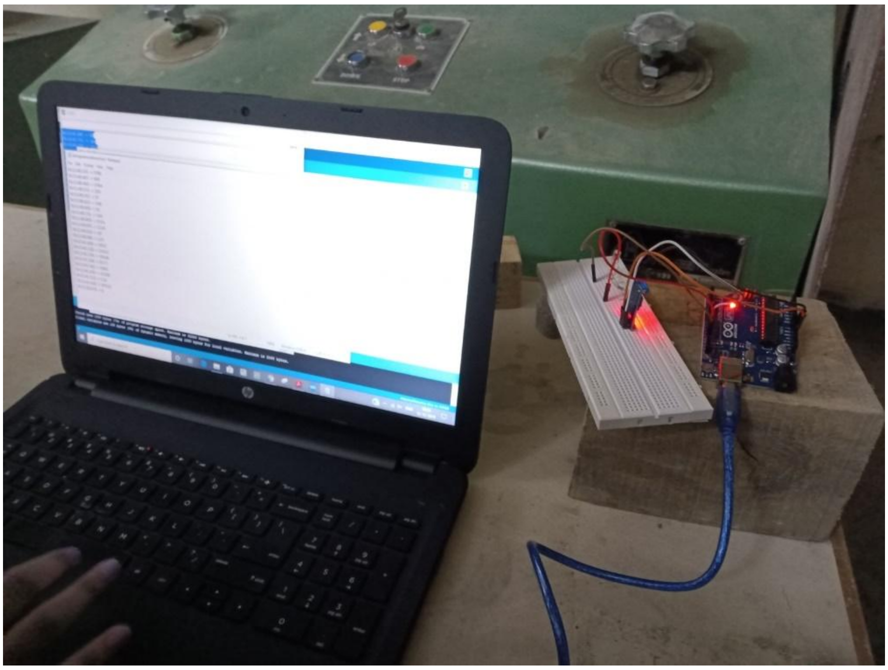

Figure 5.4: Wooden Block

Previously it was being discussed that all factors should be undertaken. Therefore after concrete block wooden block is taken following the same procedure firstly period and non periodic vibrations with undamaged wooden block then the same with damaged wooden block.

Below images will show what were the results we got :

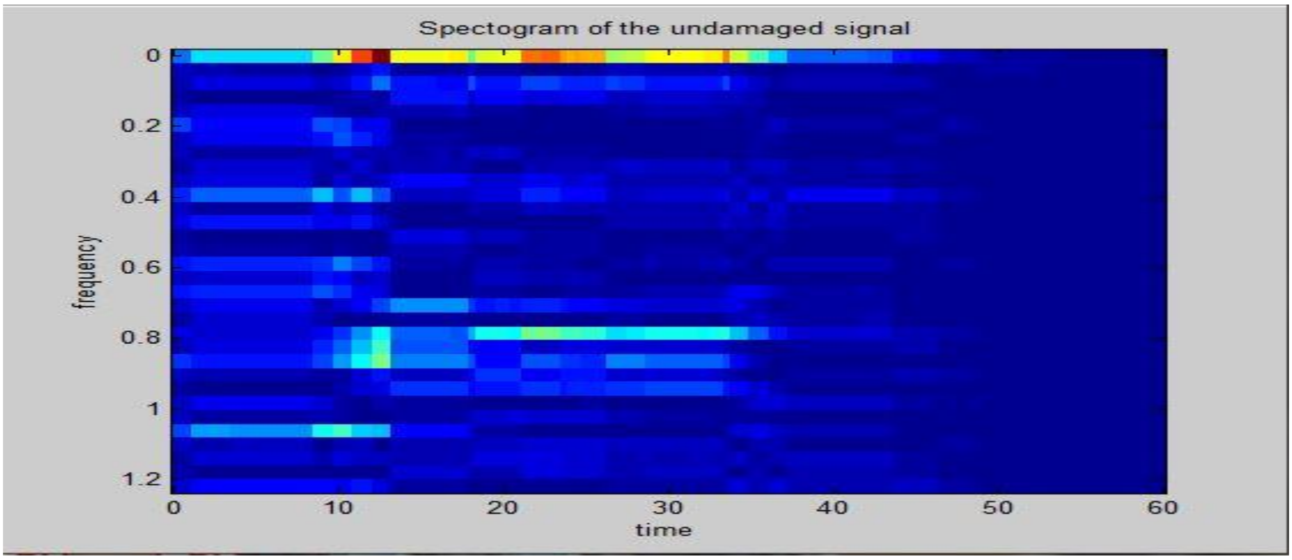

Figure 5.5: Spectrogram for undamaged concrete block

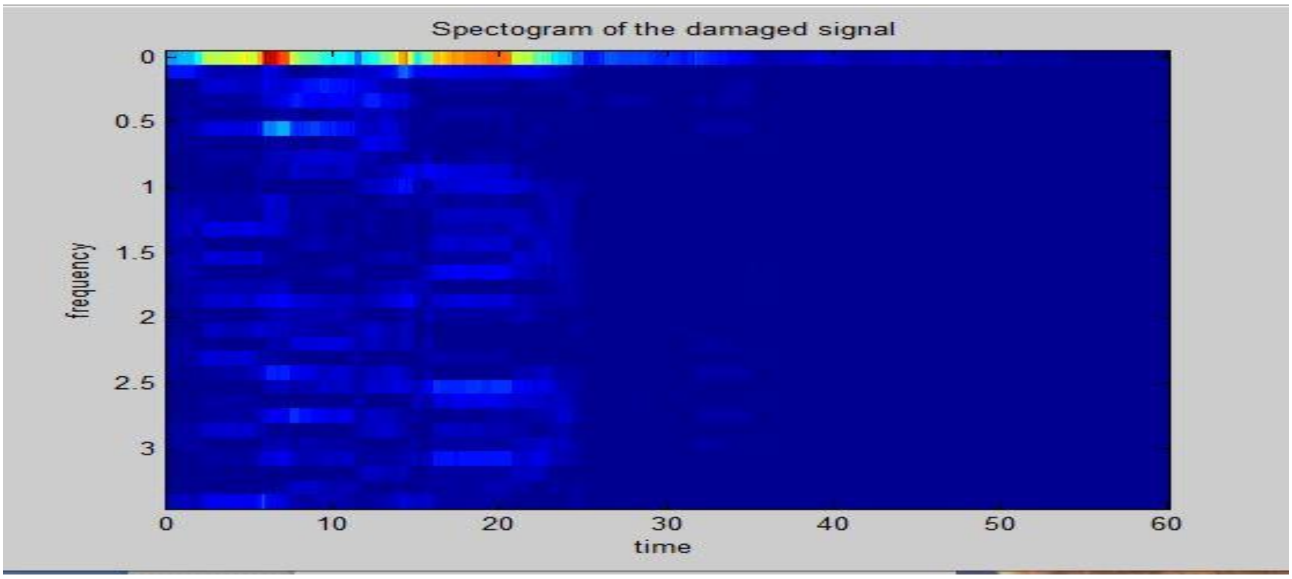

Figure 5.6: Spectrogram for damaged concrete block

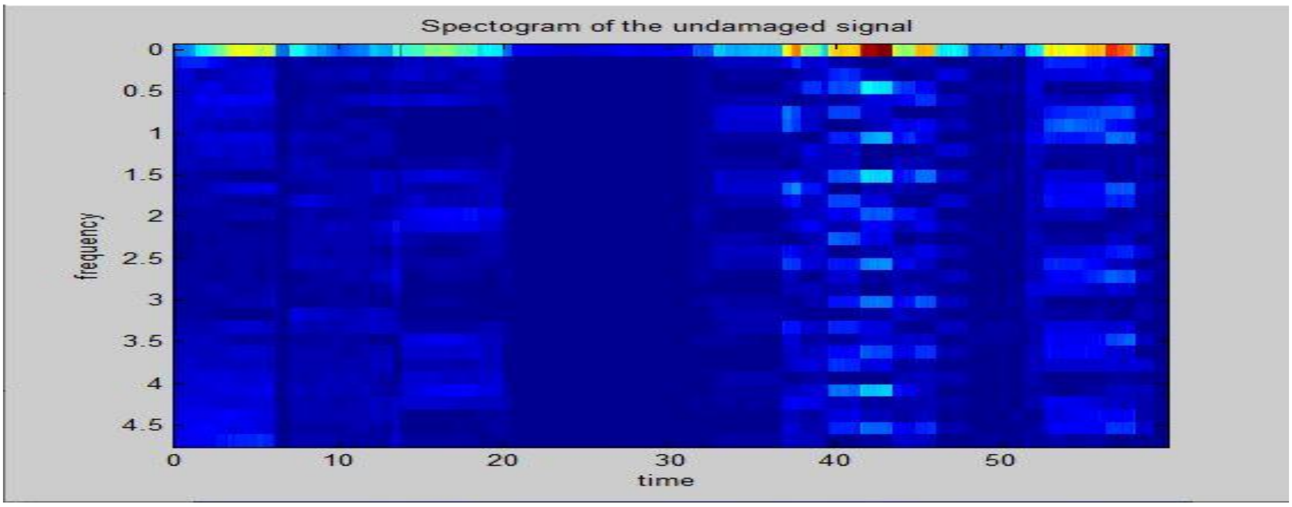

Figure 5.7: Spectrogram for undamaged wooden block.

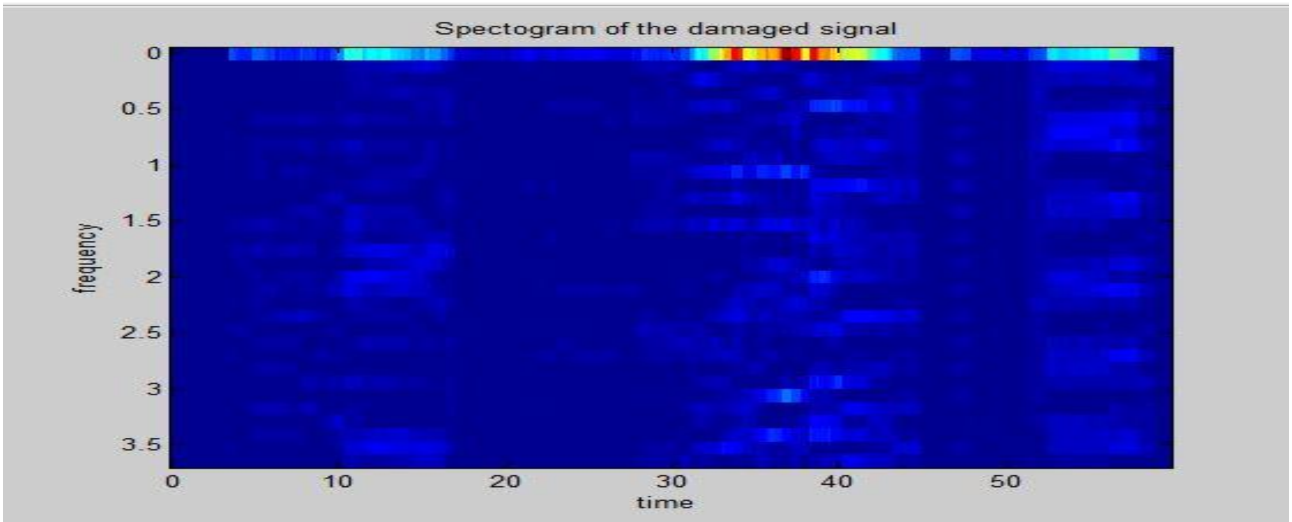

Figure 5.8: Spectrogram for damaged wooden block

As, it is clear from the above spectrograms that slight changes can be seen between the damaged and undamaged structure and if we see the material factor then between damaged and undamaged of same material there is no major thing to consider at present, In future we may consider this factor too. But, our goal isn't achieved from the data collected though thus is practical this we have proved that, if the same hardware is used at large scale or if the number of same hardware is used then it is practically applicable.

5.1.2 Take online data sheets

For our hypothesis that is using CNN we need a huge database so, we searched for the datasets online. Structural vibrations recorded at the Qatar University Structures Laboratory, regarding the disfigurement of structures to obtain large amounts of datasets.

The dataset is distributed here as another benchmark issue for vibration-based Structural Health Monitoring (SHM). We will likely furnish SHM specialists with another platform for verifying the recently evolved vibration-based damage identification in various structures.

We took their datasets so that we can prove our hypothesis that its working, therefore we implemented further processing of the project through their data.

CHAPTER 6
DATASETS AND RESOURCES

Structural vibrations recorded at the Qatar University Structures Laboratory, regarding the disfigurement of structures to obtain large amounts of datasets.
The dataset is distributed here as another benchmark issue for vibration-based Structural Health Monitoring (SHM). We will likely furnish SHM specialists with another platform for verifying the recently evolved vibration-based damage identification in various structures.

6.1 Structural Measures:

For the recording of the vibrations across the edifice the following criterias were met with.

- Steel frame with 30 junctions between major girders and 25 beams.

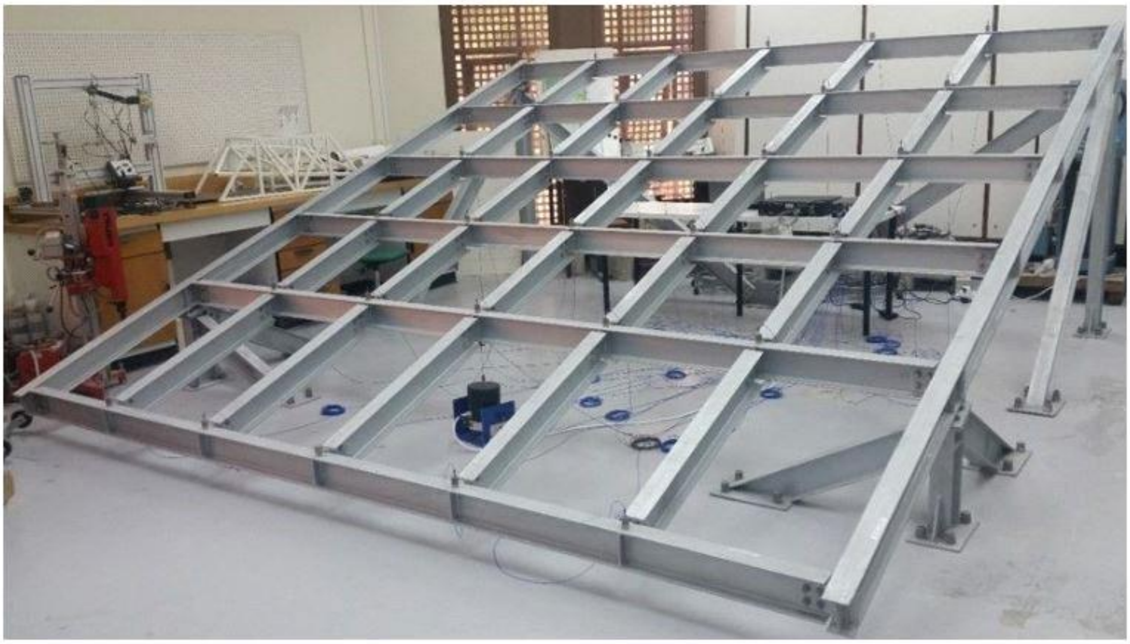

Figure 6.1: Qatar University Grandstand Simulator(QUGS)

- Accompanied by 30 accelerometers attached to those junctions.
- Accelerometers Used:- 27, PCB model 393B and 3, B&K model 8344

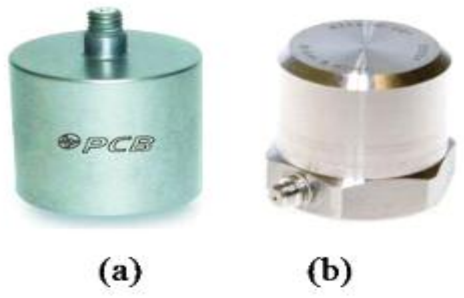

Figure 6.2: Accelerometer (a) PCB 393B04 (b)B&K 8344

- Accelerometer attached to steel frame using PCB model 080A121.
- For vibrations, modal shaker - model 2100E11 is used.[15]

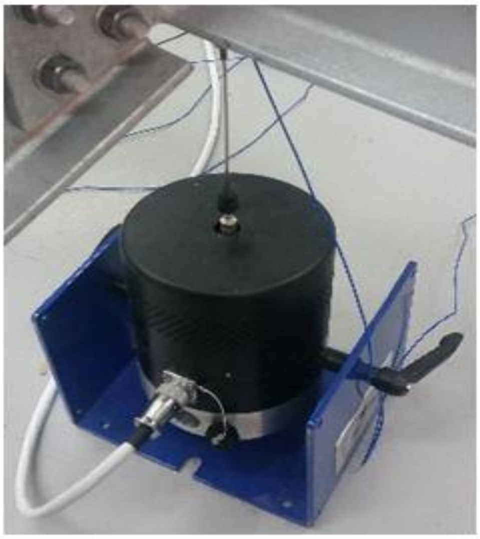

Figure 6.3: TMS 2100E11, attached to structure

- Collection of data inputs taken 2, 16-channel data acquisition devices.[15]

Figure 6.4: Data acquisition devices, modal shaker's amplifier

- For creating the damage vibrations, bolts were unbolted at beam-to girder joints.

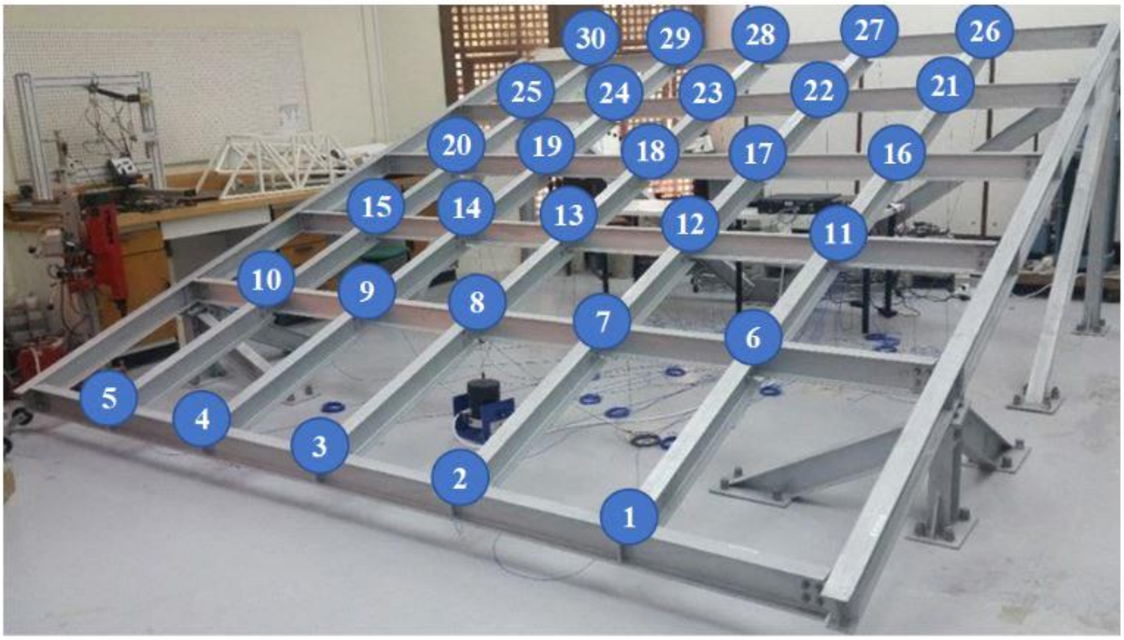

Figure 6.5: Positions of damaged junctions

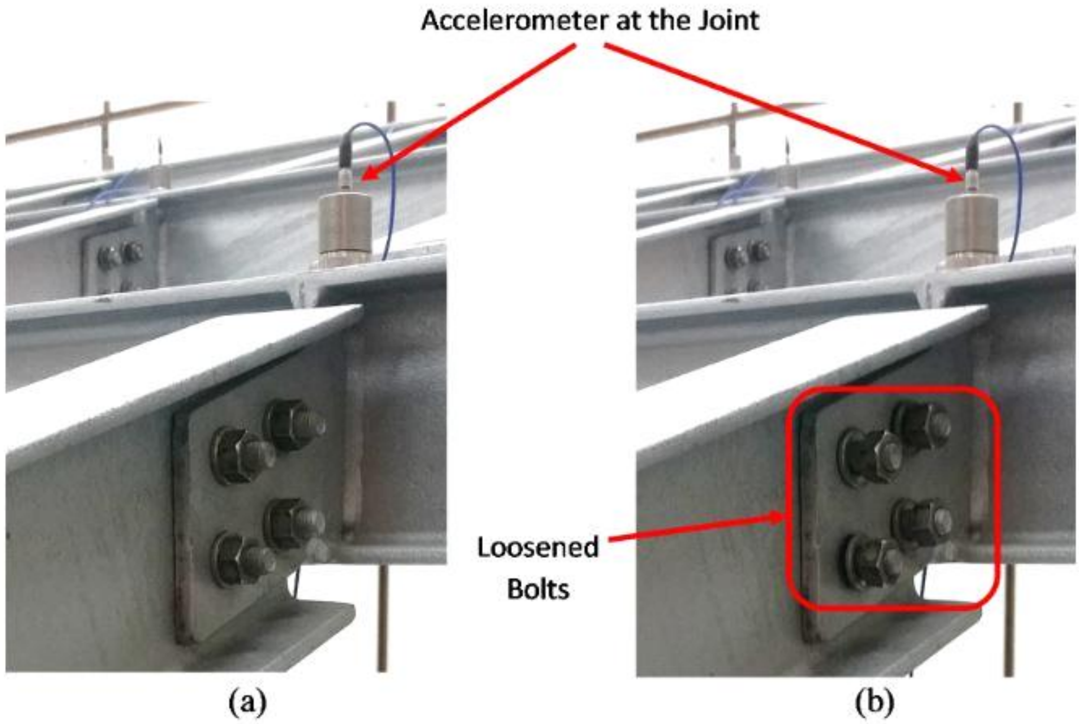

Figure 6.6: (a) Tightened bolts (b) Loose bolts

6.2 Dataset Elucidation:

Dataset was downloaded from, http://structuralvibration.com/benchmark/download/

Dataset consists of 31.TXT files, one file depicting the undamaged case and the others showcasing the vibrations at each joint. [16]

Sampling frequency of 149.97Hz, 8999 samples over a time span of 87.7 seconds were taken.

CHAPTER 7

RESULTS

Epochs	Training Accuracy	Testing Accuracy
20	99.68%	70.39%
20	98.99%	72.72%
20	90.87%	70.87%
20	99.91%	72.57%

Table 7.1: Final Result

- 837 datasets were used for training of the model.
- 51 datasets were used for testing of the model.

CHAPTER -8

APPLICATIONS

Structural Health Monitoring can be implemented in variety of fields or we can say it can be applied on various structures. Such applications can be: -

8.1 Machine maintenance and Damage control

Various factories use heavy duty industrial machines for distinct tasks. These machines are automated and requires maintenance from time to time due to some damage caused to the machinery. These damages could be very expensive if not detected at initial stage. To avoid such conditions we can detect the health of the machinery at earlier stage using SHM techniques.

Figure 8.1: SHM Milk Equipment

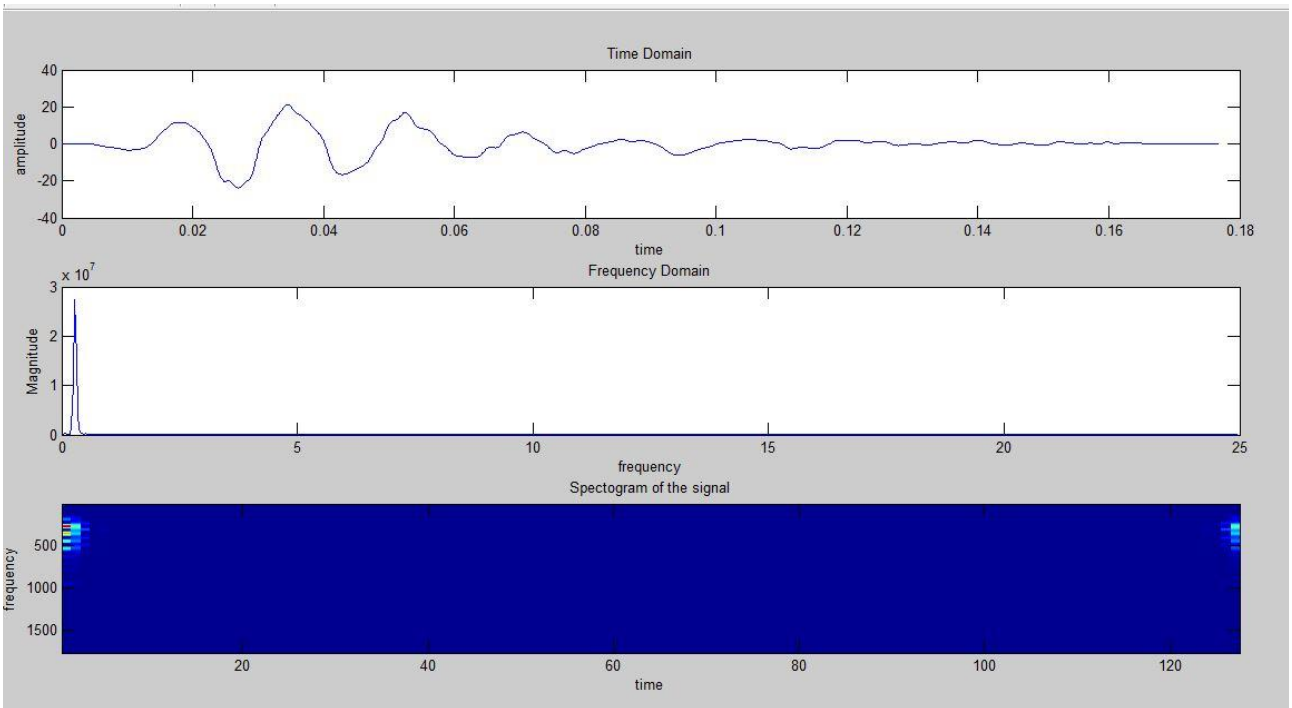

Figure 8.2: Ignition Motor Vibrations

8.2 Natural calamities Detection

Himachal Pradesh and places within Himalayan region are very prone to natural calamities mainly Earthquake and Landslides. These calamities usually led to actual as well as psychological damage.Currently if there is occurrence of any such threat its impossible to evacuate the area as the abnormalities in the vibration are detected with a very little time difference.

With our study, we would be able to identify these abnormalities with a significant amount of time difference so that we can avoid the collateral damage.

Figure 8.3: Damage caused by Landslide and Earthquake.

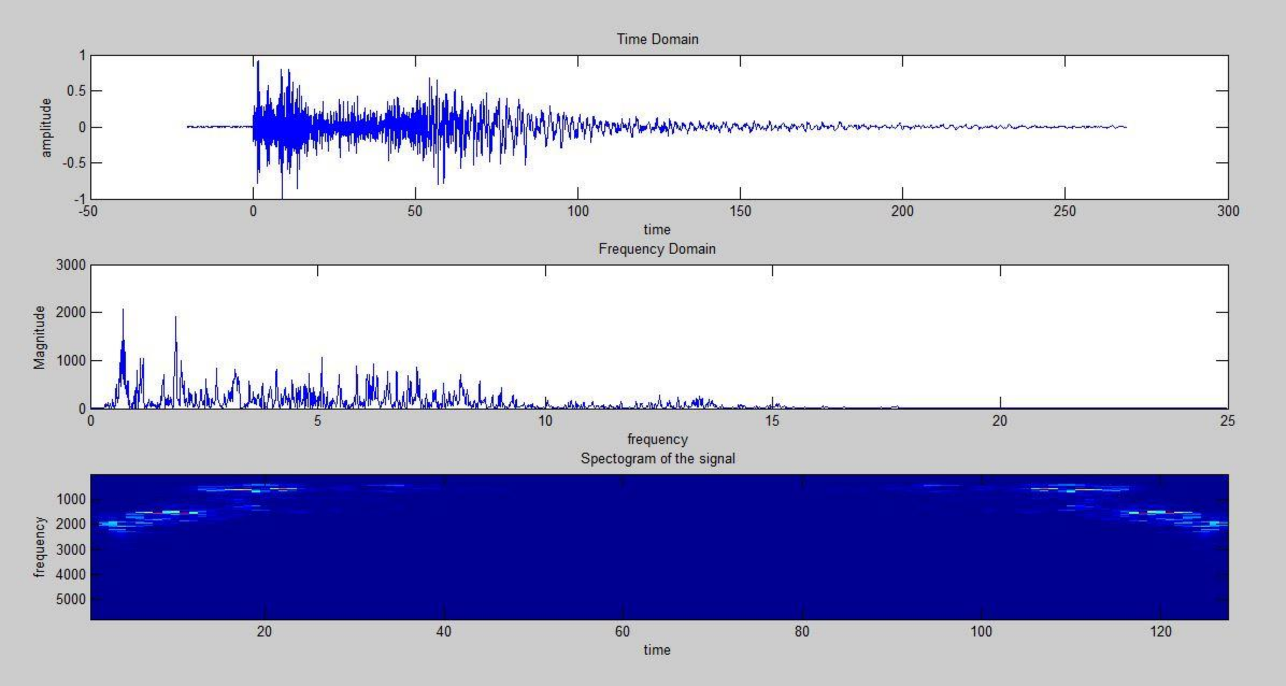

Figure 8.4: Korean Seismic Vibration

8.3 Architectural Structures

The architectural structures refer to majorly buildings, bridges, historical sites etc. Change in vibrations of such structure can be due to many reasons like high speed wind, material used, temperature, pressure, traffic, seismic vibrations, rusting etc. Due to these factors structural health degrades increasing the chances of collapsing of the structures such reasons cannot be controlled but we can monitor the vibration and inform the authorities regarding the damage or whether the structure is prone to collapse with the use of Structural Health Monitors.

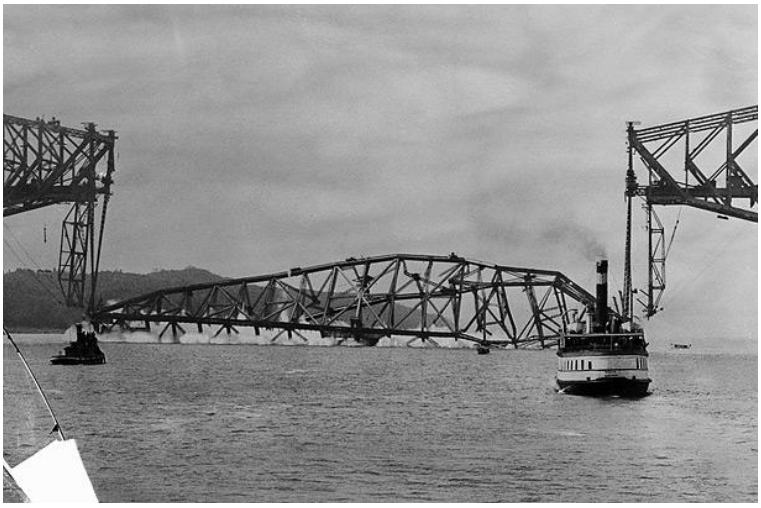

Figure 8.5: Bridge Collapse

8.4 Automobile Fault Diagnosis

Automobile is different machineries working together depending on each other. Failure of one machinery can lead to malfunctioning of the whole automobile which can lead to accidents causing death or lifetime injuries. Detection of these fault can not be diagnosed easily, as all the machineries are so complex. We can detect when it cause damage. Using SHM techniques we can diagnose these defects earlier and can rectify it.

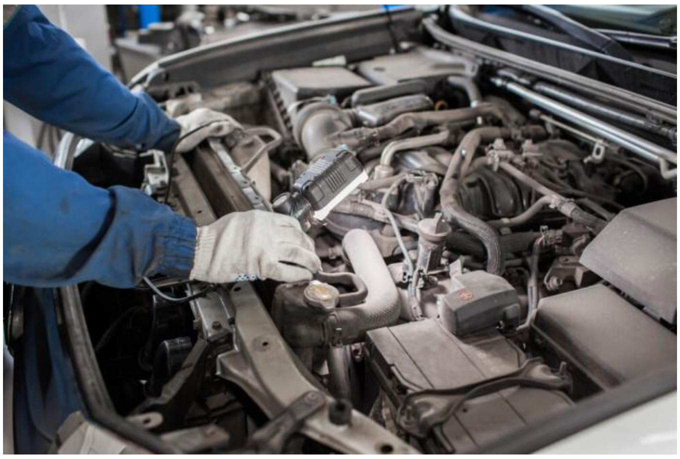

Figure 8.6: Car engine (Due to its complexity we can’t suspect the defect)

CONCLUSION

The project is based on the Deep Learning concept. The basic classification will be of damaged and undamaged structure and same characteristics has been used to train the CNN. The system performance has been tested on the damaged and undamaged structures and the accuracy of our system is **71.63%**. In future we desire to also classify between the structures which are needed to be evacuated or the maintenance is required during the sign of abnormal vibrational signals.

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[15] http://structuralvibration.com/benchmark/instrumentation/

[16] http://structuralvibration.com/benchmark/damage/

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APPENDIX

TABLE A.1: List of vibration data sources.

No.	Source Link
1	http://www.vibrationdata.com/tutorials_alt/synthesis.txt
2	http://vibrationdata.com/elcentro.htm
3	http://vibrationdata.com/data.htm
4	http://vibrationdata.com/QE.htm
5	http://structuralvibration.com/benchmark/download/

Codes Used:

For Signal Processing and Image Extraction:

```
clc;
clear all
close all;
fs=149.97;
t1=0:(1/fs):60;

%normal signal--------------------------------------------------
%z1
filename = '270.xlsx';
a = xlsread(filename);
a1=min(a);
a2=max(a);
z1=(a-a1)/(a2-a1);
z1=z1-mean(z1);
%z1 = xlsread(filename);
%plot(t1,z1);
% %z2
% subplot(4,1,2)
% z2=sin(2*pi*50*t2);
% plot(t2,z2);
% %z3
% subplot(4,1,3)
% z3=sin(2*pi*10*t3);
% plot(t3,z3);
% %z
% subplot(4,1,4)
% t=[t1 t2 t3];
% z=[z1 z2 z3];
% plot(t,z);
%ylabel('magnitude');
%xlabel('time');
%title('Time Domain')
```

```
%***************************************************
l_win=32;%64%242%220%82%50%80%50%50%30%351;%input('Enter the length of
window function:');M6514511
n=1:l_win;
w(n)=rectwin(l_win);

%zero Padding
MAz = [zeros(1,(l_win)/2) z1' zeros(1,(l_win)/2)];

s1=length(MAz);
        for i=1:s1-(l_win-1)
            M=MAz(i:i+(l_win-1));
            UA1=M.*w(n);
            %UA1=xcorr(UA1);
           % SAK=pburg(UA1,O_Ar,N);
            SAK=abs(fft(UA1));
            SAK2(i,:)=SAK.^2;
        end
        SAK3=SAK2';
        SAK4=SAK3(1:(l_win)/2,:);
       f4=((0:(((l_win)/2)-1)*fs)/l_win);
figure(2);
imagesc(t1,f4,abs((SAK4)))
ylabel('frequency');
xlabel('time');
title('Spectogram of the signal')
```

For CNN of the spectrograms:

```
import keras
from keras.models import Sequential
from keras.layers import Convolution2D
from keras.layers import MaxPooling2D
from keras.layers import Flatten
from keras.layers import Dense
classifier = Sequential()
classifier.add(Convolution2D(32,( 3, 3), input_shape = (64, 64, 3), activation = 'relu'))
classifier.add(MaxPooling2D(pool_size=(2,2)))

classifier.add(Convolution2D(32,(3,3), activation= 'relu'))
classifier.add(MaxPooling2D(pool_size=(2,2)))

classifier.add(Flatten())
```

```
classifier.add(Dense( activation= "relu",output_dim = 256))
classifier.add(Dense( activation= "sigmoid", output_dim = 1))
classifier.compile(optimizer= 'adam', loss = 'binary_crossentropy', metrics= ['accuracy'])
from keras.preprocessing.image import ImageDataGenerator



train_datagen = ImageDataGenerator(rescale=1./255,shear_range=0.2,zoom_range=0.2,horizontal_flip=True)

test_datagen = ImageDataGenerator(rescale=1./255)

training_set = train_datagen.flow_from_directory('/Train',target_size=(64, 64),batch_size=32,class_mode='binary')

testing_set = test_datagen.flow_from_directory('/Test',target_size=(64, 64),batch_size=32,class_mode='binary')

classifier.fit_generator(training_set,steps_per_epoch=837,epochs=20,validation_data=testing_set,validation_steps=51)
```

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