

# **Design and Development of Electronic Tree Surveillance System for Detection of Illegal Wood Cutting**

A Dissertation submitted in fulfillment of the requirements for the Degree of

## **MASTER OF ENGINEERING** *in* **Electronic Instrumentation & Control Engineering**

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**June 2016**

# DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled “**Design and Development of Electronic Tree Surveillance System for Detection of Illegal Wood Cutting**” by Mr. J. Sai Praveen Kumar (Roll No. 801451012) in partial fulfilment of requirements for the award of degree of Masters of Engineering in Electronic Instrumentation and Control Engineering submitted in the Department of Electrical and Instrumentation Engineering at THAPAR UNIVERSITY, PATIALA is an authentic record of my own work carried out under the supervision of Dr. Ravinder Agarwal, (Professor, EIED). In case of any plagiarism or copyright violation, I will be solely responsible for it.

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Certified that the dissertation entitled, “**Design and Development of Electronic Tree Surveillance System for Detection of Illegal Wood Cutting**”, which is being submitted by **Mr. J. Sai Praveen Kumar** in fulfilment of the requirements for the award of **Masters in Engineering (M.E.) in Electronic Instrumentation & Control Engineering** to **Thapar University, Patiala**, is a bona-fide record of the candidate’s own work carried out by him under my supervision and guidance. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other university or institute for award of any degree.

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## ABSTRACT

Unauthorized cutting of trees is a prevailing global socio-economic problem. In the past few years, number of cases of illegally felled trees has been reported nationally and globally. Encroachments and illegal wood smuggling has resulted in severe downfall of Indian as well as global economy. Despite implementation and enforcements of various legislative and regulatory measures, globally, this is still an existing problem. It is necessary to curb illegal exploitation of precious plantations and an objective oriented research can provide a robust and effective solution. Current research work 'Electronic Tree Surveillance System' is a new initiative for developing an effective, robust and simple approach to detect and classify malicious logging activity. 'Electronic Tree Surveillance System' (ETS System) is a multi-disciplinary project designed to provide a feasible and reliable model for eradication of illegal wood logging by strictly considering all the hardware development constraints like low cost components, effective, robust, easy availability of components, easy replicability of components, cheap installation and maintenance costs throughout the design and development of the system. Also, prototype system is developed to be reliable, realizable and feasible as per the existing scenario. An effective combination of fields like sensor technology and wireless sensor networks *etc.* are implemented and several signal processing approaches namely thresholding approach and machine learning approach have been implemented which can provide a solution for current problem. ETS system majorly operates on the tree vibrations considering a fact that forced vibrations are imparted on the tree trunk during a wood cutting process. Various traditional wood cutting techniques like axe cutting, handsaw cutting and machine cutting are employed and the research study was conducted on the trees existed in the university campus. This system consists of accelerometer sensory nodes for event identification and whenever there is an unauthorised or malicious activity identified, an alert will be generated at the Local Control Station (LCS) through the proposed system network. In a nutshell, a working prototype of feasible and realizable 'Electronic Tree Surveillance System' is designed and developed for eradication of illegal wood cutting by considering all possible parameters. This research has a huge social and economic impact and will provide the roadmap for further research work.

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# LIST OF ABBREVIATIONS

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<b>Abbreviations</b>	<b>Details</b>
ETSS	Electronic Tree Surveillance System
SN	Sensory Node
SS	Sensor Station
RCS	Remote Control Station
LCS	Local Control Station
RAU	Receiver and Analysis Unit
SVM	Support Vector Machine
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	united nations environment programme
INTERPOL	international police organization
LEAF	Law Enforcement Assistance for Forests
ICCWC	International Consortium on Combating Wildlife Crime
CITES	Convention on International Trade in Endangered Species
UNODC	United Nations Office on Drugs and Crime
WCO	World Customs Organization
REDD	Reducing Emissions from Deforestation and Forest Degradation
CAMPA	Compensatory Afforestation Fund Management and Planning Authority
KELTRON	Kerala State Electronics Development Corporation Limited
MOEF	Ministry of Environment and Forests
GPS	Geographical Positioning System

PSD	Power Spectrum Density
FV	Feature Vector
RMS	Root Mean Square
KNN	K-means Neural Networks
ANN	Artificial Neural Networks
FFT	Fast Fourier Transform
DAQ	Data Acquisition
GUI	Graphical User Interface
RAU-PC	Receiver and Analysis Unit -Personal Computer
RAU-Rx	Receiver and Analysis Unit – Receiver
HP	Hewlett Packard
RxU	Receiver Unit
MATLAB	Matrix Laboratory
LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench
PCB	Printed Circuit Board
WSN	Wireless Sensor Network
RTOS	Real Time Operating System
LED	Light Emitting Diode
GPIO	General Purpose Input Output
MEMS	Micro Electro Mechanical Systems
CWT	Continuous Wavelet Transform
RFID	Radio Frequency Identification
GSM	Global System for Mobile
BT	Bluetooth

# CHAPTER 1

## INTRODUCTION

### 1.1. Illegal Wood Logging: A Global & National Problem

Forests are considered as the ‘Green Gold’ and they play an important role in the human ecosystem. Forests serve mankind with various natural resources and mankind depends on forests to meet their major needs. One of the main natural resource of forests is wood. Till date people keep depending on the forest for various products like timber, paper, medicine, fuelwood and fodder. Apart from these, forests also provide essential products like cane, fibre, bamboo, grasses, floss and essential oils. The costliest wood species like sandalwood, red ivory, Black wood, agar wood, Lignum vitae, Bocote, purple heart wood are also the products of international forests [1]. The recent statistics for global forest cover and the India’s forest cover is shown in Figure 1.1 and Figure 1.2 respectively. India is a major exporter of Sandalwood species to various countries like U.S., China, Japan, and Middle East. [2]

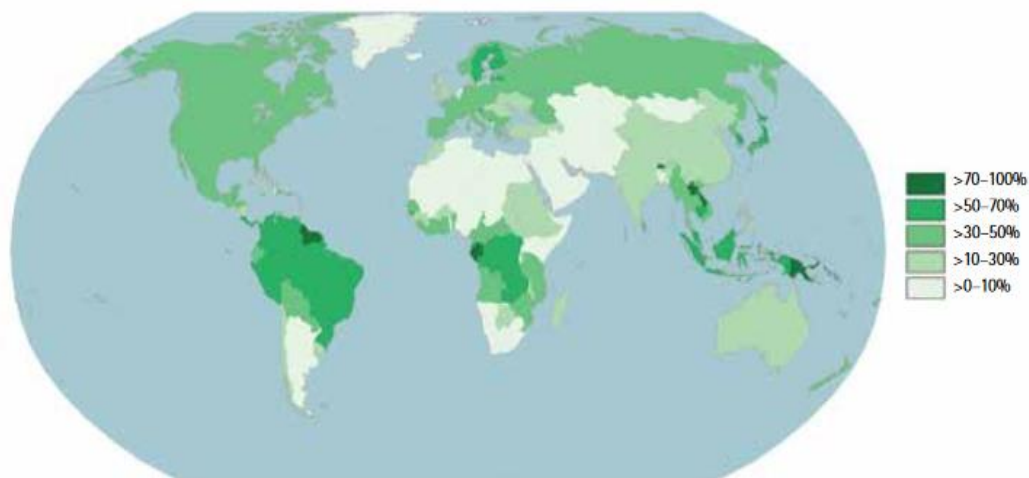


Figure 1.1: Forest cover estimate as percentage of total land area in year 2015

These wood species can be used for manufacturing various wooden products and have high international demand. Increase of demand of these woods in international markets and several other factors led to a vast increase in smuggling and illegal wood logging [2].

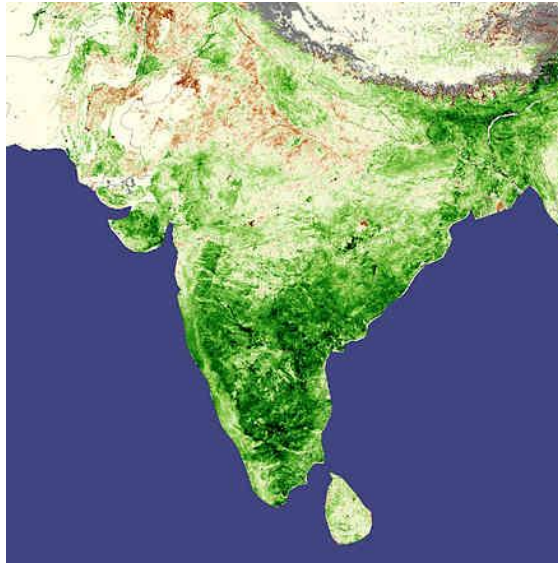


Figure 1.2: Forest cover in India, photo captured by NASA

Most of the forest lands and trees are already under the control of government organizations and removal is prohibited whether on private or public lands. This was not sufficient for the poachers from cutting trees down during the authority's blind eye situations [3].

**1.1.1. Effects on Forest Area Reduction:** In 1990, the forests accommodate 4,128 million hectare of forest in the world; by the year 2015 this forest area has reduced to 3,999 million hectares. This change results from 31.6 % of global land area in 1990 to 30.6 % land area in 2015 [2]. Wood cutting or Deforestation, illegal wood logging, is more complicated than that. Global gain or loss of forests occur frequently and constantly and are highly difficult to monitor even by high resolution satellite imagery. Forest area variation can be described as a process of expansion and reduction due to various factors.

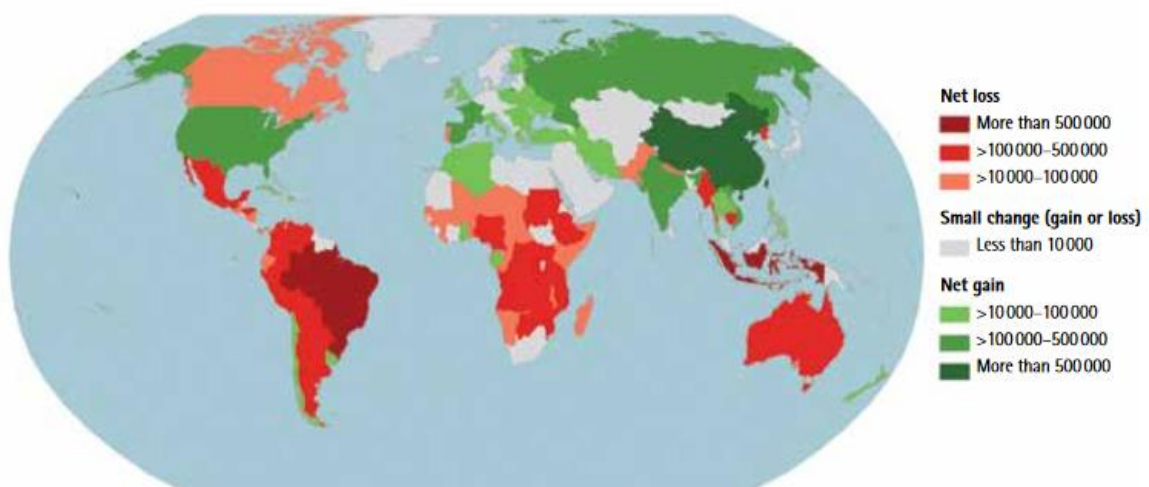


Figure 1.3: County wise net annual forest change (gain/loss in hectare 1990 - 2015)

There was an approximate loss of 129 million hectare of forest land including natural and planted from 1990 to 2015. This represents an annual rate of 0.13 % reduction and this total area is equated to that of the size of South Africa [4]. During the years 2010 and 2015 there was an annual reduction of 7.6 million hectares and an annual gain of 4.3 million hectares/year, resulting in a net current annual reduction in forest area of about 3.3 million hectares/year [4]. In India, rise in prices of sandalwood species is partly due to a decline in the available supplies. During the years 1930's through the 1950's, the country's overall production was roughly constituted about 4,000 tons of heartwood/year; now it is estimated only up to 2,000 tons [2]. Figure 1.3 describes the annual net gain/ loss of forests by country during the years 1990 to 2015. Some statistics of illegal teak and non-teak tree cut down in last few years is shown in Table.1.1 as mentioned in [2].

TABLE 1.1 Statistics of illegal teak and non-teak tree cut down

Year	Total Trees cut	Teak Trees	Non Teak trees
2007	over 1.86 Lakh	88,640	97,578
2008	over 1.86 Lakh	87,720	98,469
2009	over 2.00 Lakh	10,00446	10,0698
2010	over 1.66 Lakh	81,445	84,914
2011	over 1.39 Lakh	64,618	75,249

**1.1.1. Effects on Climate Changes:** Apart from the forest reduction problems, deforestation and illegal wood logging also resulted in drastic climatic changes. Deforestation and other factors estimate for nearly about 20% of global greenhouse carbon emissions. The first place in these emmissions is by the entire global transportation sector and the second place is occupied by the energy sector. According to UN Framework Convention on Climate Change (UNFCCC), it is estimated that illegal ood logging or deforestation accounts between 1/6 and 1/4 of global carbon emissions [4].

**1.1.2. Effects on Social and Global Economy:** Smuggling and illegal wood logging has created socio-economic and law and order problems both globally and nationally [2]. According to joint survey conducted by UNEP and INTERPOL on wide effects of unauthorized wood logging and trade, illegal wood cutting accounted for around 50–90 % of the over all forestry volume of tropical countries and 15–30 % globally. Meanwhile, the economic estimate of global illegal deforestation is estimated between 30 and 100 billion US dollars, which constitutes 10–30 % of global wood trade [5]. Figure 1.3 and Figure 1.4 shows

the annual net forest gain/ loss statistics from 1990 – 2015 as per various surveys. Data regarding the illegal timber wood market which is collected from various environmental protection agencies, wildlife charities and other criminal justice information estimates that the economic impact of illegal logging is around 30 Billion US Dollors and illegal wood logging trade in East Asia and the Pacific alone stands 17 Billion US Dollors[5].



Figure 1.4: Some of state – of – art wood cutting and transportation technique

Afore mentioned survey report conducted by UNEP and INTERPOL, it is observed that illegal traders are combining the older techniques with the sophisticated methods in all levels of global illegal wood trade. Axe, Chain Saw and other tree cutting tools are considered as the traditional tree cutting tools and the poachers fell trees in no time using these wood cutting techniques [3, 5]. Figure 1.4 show of the state of art illegal wood cutting and wood transportation techniques. Figure 1.4 also shows the adverse situations created for the environment by illegal wood logging and vast deforestations.

## 1.2. Preventive Measures: Global & National Level

Several legislative and regulatory measures were taken by global and national legislative bodies to eradicate illegal wood dwelling in all possible ways.

### 1.2.1. Global Measures

- Project LEAF: LEAF stands for ‘Law Enforcement Assistance for Forests’ [7] is a climate initiative consortium for countering illegal wood cutting and deforestation

globally. Organized forest crime of this project is led by the United Nations Environment Programme's (UNEP) centre in Norway, UNEP GRID Arendal and the INTERPOL Environmental Crime Programme.

- ICCWC: ICCWC stands for 'International Consortium on Combating Wildlife Crime' [8] is the collaborative initiative by five inter-governmental organizations. ICCWC comprises the INTERPOL, CITES Secretariat, the World Bank, the United Nations Office on Drugs and Crime (UNODC) and the World Customs Organization (WCO).
- LACEY ACT: Lacey Act [9] is a landmark conservation law passed in the year 1900 and amended in 2008 by the US in countering illegal deforestation problem. According to this Act, the importers of wood products have to take steps to ensure the legality of their product sourcing and violation of the act by the importers face huge fines or imprisonment.
- REDD: REDD stands for 'Reducing Emissions from Deforestation and Forest Degradation'. This is a United Nations initiative with the objective of eliminating climate change by reducing net greenhouse gas emissions through sophisticated forest management in developing countries. REDD is a mechanism that has been under negotiation by the UNFCCC (United Nations Framework Convention on Climate Change) since 2005 to achieve the intended objectives successfully [10, 11].

### **1.2.2. National Measures**

Apart from the international legislative measures, Indian Ministry of Forest, Environment and Climate Change has also enforced various regulatory measures for eradication and prevention of illegal logging.

- CAMPA: CAMPA stands for 'Compensatory Afforestation Fund Management and Planning Authority' [12] focus on improvement of natural resources and eradication of illegal wood logging in the nation.
- COUNTER FORCES: Indian State has also considered various other steps to eradicate illegal wood smuggling by increasing the combing operations of forces in the forests to counter the poachers [13].
- KELTRON CHIPS: Kerala state government recently proposed for implementation of electronic chip in trees for eradication of wood logging and the contract has been provided to KELTRON, an autonomous organization under Govt. of Kerala. R Raja Raja Varma, Principal Chief Conservator of Forests, Wildlife. However, a press

report confessed that the proposed project will be implacable if found feasible since Keltron has never undertook such a research in its past [14, 15].

### **1.3. Chapter Summary**

Despite all these efforts and measures globally and nationally, cases of illegal wood logging are constantly being reported. Illegal wood logging is a major socio – economical issue causing severe threat not only to the economy but also the ecosystem by its adverse effects. Number of international and national certification schemes and programmes which enforced aiming at protection and preservation of the environment, illegal wood logging is still a serious threat causing the measures ineffective and not an option in bringing down the illegal wood logging and trade. A novel solution for the current problem is demanded in addition to the legislative and regulatory measures. There is a necessity of Electronic Threat Detection (ETD) System to detect illegal wood logging activities and effectively eradicate the malicious activities.

## CHAPTER 2

### LITERATURE SURVEY

#### 2.1. Forests, Trees and their significance

Forest is a large land area covered by trees or other woody and green vegetation. They provide various ecosystem services to humans and serve as a tourist attraction in many regions. Forests are considered as the dominant terrestrial ecosystem of earth. About 75% of the gross primary productivity of the earth's biosphere accounts to forests and containing 80% of the earth's plant biomass [16]. They serve mankind with various products. Some of the tree species like sandalwood, redwood *etc.* are costly species and has high demand in international markets. India has been the global leader of sandalwood oil production for pharmaceuticals and perfumery for more than 5000 years [17]. They also generate water supplies, pharmaceuticals, biodiversity, recycled nutrients for agriculture and flood prevention and are stand epicentre to the transition towards a Green Economy in the context of sustainable development and poverty eradication [5].

#### 2.2. Previous Reports: Illegal Wood Logging

Forests represents one of the most important pillars in countering climate change and delivering sustainable development. About 17% of all man-made emissions is because of deforestation, largely of tropical rainforests, and this constitutes to 50 % more than that from ships, aviation and land transport combined. Today only 1/10 of primary forest cover remains on the globe [5]. Illegal logging is on a whole is the harvest, transportation, trade of wood in violation of legislated laws. The harvesting procedure itself may be illegal, including using corrupt means to gain access to forests which can also include the cutting of protected plantations, extraction of species from a protected area without permission, or the extraction of wood in excess amounts than that of agreed quantity. A joint study by the UNEP and INTERPOL [18] states that the global illegal logging is estimated to be 30% of the global logging trade and contributes to more than 50% of tropical deforestation in Central Africa, the Amazon Basin and South East Asia [5]. This illegal wood logging in key countries is estimated between 50% and 90% by the organised criminal entities. [18]

According to another survey conducted by the TED team [2], it was observed that there is a great inclination in sandalwood tree smuggling from the forests of countries like India, Africa

and Australia. The Indian sandalwood tree has become an endangered species in recent years. This sandalwood tree is already a government controlled and removal is prohibited whether on private or temple grounds until the tree is thirty years old. Attempts to encounter its possible extinction by the Indian government led to the limitation of the exportation of sandalwood. This has not stopped many poachers from cutting trees down as soon as authorities are blind eyed. Smuggling of this species has created socio-economic and law and order problems in areas bordering several south Indian states.

### **2.3. Previous Efforts: Legislative and Regulatory Measures**

Number of certification schemes and programs have evolved to reduce illegal logging. Some of the International schemes are voluntary trade agreements including the International Consortium on Combating Wildlife Crime (ICCWC), EU Forest Law Enforcement, Governance and Trade (FLEGT) Voluntary Partnership Agreements (VPAs), or Forest Stewardship Council (FSC) certification, have been successful in bringing stakeholders together and generating incentives for legal exports and more sustainable forestry [5].

In India, several legislative and regulatory measures which have been developed aim at preservation, conservation and protection of the environment. Some important legal instruments are: Wildlife (Protection) Act, 1972, Forest Conservation Act, 1980, Environment (Protection) Act, 1986, National Environment Tribunal Act, 1995, National Environment Appellate Authority Act, 1997 and National Conservation Strategy and Policy Statement on Environment and Development, 1992 [19].

Apart from these, Ministry of Environment, Forests and Climate Change has taken several measures for conservation and protection of Forests and wildlife by releasing a project named “CAMPA - Compensatory Afforestation Fund Management and Planning Authority” in 2009 for the increase in quality and quantity of sandalwood plantations and to preserve the natural resources and wildlife of forests [20]. It also mentioned to improve the protective measures by deploying the police personnel in the forest regions on combing operations for combating the illegal wood smugglers.

In June 2013, N. Kiran Kumar Reddy, Chief Minister, AP has taken various counter operation steps by constituting special Task force with Forest and Police personnel to have an effective monitoring and to eradicate the smuggling of Red sanders in various districts of the state [21].

State governments of India had proposed a bill named ‘All India Policy for Controlling Sandalwood/ Red Sanders Smuggling’ has been proposed to Govt. of India in a letter which proposed that the forestry is a concurrent subject and the Govt. of India in consultation with States could enact an Act similar to the FCA-1980 in the interest of the protection and preservation of Sandalwood species and regulation of Sandalwood trade in the country [22].

Kerala Government has proposed a project to prevent the illegal smuggling by introducing electronic chips in sandalwood trees in collaboration with “KELTRON” in 2012 [3] [14-15] [23-24]. However, the sample units were being imported by KELTRON as the company has not done such thing earlier. Hence, the agencies from abroad were give work and also this project will be implemented if found feasible. The current status related to this proposal is unknown. After all these measures no effective mechanism has been implemented to curb the encroachments as still cases regarding sandalwood and other precious wood smuggling from remote forests are being reported till date.

#### **2.4. Previous Works: Technological Aspects**

S. Srinivasan *et al.* [25] has proposed a monitoring system for sandalwood trees based on RFID sensor networks using ZigBee and mobile networks. The main objective of this work was to monitor each tree by deploying RFID Tags in trees and track them using RFID Readers. If there is any tree cut down by unauthorised person, sensors will trigger the transceiver and alert signal to the control room will be generated. This system is prone to false alert signals due to various environmental factors.

D. Paturkar *et al.* [26] proposed a wireless system for disaster prevention. This work discusses the prevention of illegal or unauthorized woodcutting of trees the wireless system is designed, in this sensor network are coupled with wireless technology. Sensor network in the system comprises of accelerometer which monitors the illegal woodcutting of trees in farms and the camera will take a snapshot. This work is proposed to design and implement a wireless system based on Arm 7. The exact location of illegal activity in the form of latitude and longitude is obtained from Global positioning system (GPS), this information is send using Global System for Mobile (GSM) technology at the gateway. This enables the maintenance department authority to have automated technique for the supervision under the enforcement of law. Real time implementation and feasibility related issues are not discussed in detail.

Salma Assuboid *et al.* [27] designed a Tree RFID Tracking System where RFID tags are placed in the trees and hand held readers are used for tracking the activity. This work has been tested in real time locations for validating the feasibility of the developed system. This RFID based approach provides a unique tree identity however this cannot be applicable for online remote applications as the reader has to be present in the range of the deployed tags for accessing the data.

Chetan K. P. *et al.* [28] designed a wireless system for event detection. The objective of this work was to monitor the tree theft using WSN. In this work, it was noted that in forest monitoring application, event occurrence is rare, so apart from the threat detection power harvesting and power management are also given major importance by implementation of sleep mode for the sensory nodes. However, issues like false alert generations due to environmental parameters are not addressed satisfactorily.

A.K. Jain *et al.* [29] proposed a framework for forest fire detection and monitoring as an application area of wireless sensor networks. The proposed systems address the speed sensory data transfer from the sensory nodes to the control center effectively across a WSN network. This system also discussed the concepts of energy harvesting and power management briefly by implementing sleep mode similar to that of [28].

Xiaochuan Jiang *et al.* [30] proposed a Forest Environment Monitoring system based on WSN and the tests in real world forest environment are performed for validating the feasibility of the developed system by deploying the system in Purple Mountain Area for 20 long days.

Yingli Zhu *et al.* [31], proposed a forest fire monitoring system based on wireless sensor network and GPRS network. This system generates alerts during the forest fire situations which can be effectively alert the authorities to take forest fire situations under control.

M. Aboelaze *et al.* [32] discussed in detail regarding the trends of sensor networks and presented some of the challenges in designing wireless sensor networks including design Factors, power consumption, communication aspects, processor and data aggregation related issues. The state-of- the-art and future direction in wireless sensor networks was also briefly discussed in this work.

H. Tao *et al.* [33] illustrated a forest monitoring system using a ZigBee based WSN in order to improve the insufficiency of the existing monitoring ways.

The above papers [25 - 33] mentions the importance of Forest alert systems for various applications and discuss various design and development aspects including hardware, power consumption and environmental constraints.

Alessandro Leone *et al.* [34] conducted a study for improving the olive fruit output. Since Olive fruits are extracted from the tree traditionally by trunk shakers, the identification of vibration frequency and duration for efficient olive harvesting using a trunk shaker is performed. The vibration analysis on a tree has been performed using accelerometers and signal conditioners. In this study vibration imparted from the shaker to the trunk is considered as the primary parameter and the weight of the fruit removed was determined accordingly.

Kimio Oguchi *et al.* [35] proposed a simple security system for orchards. The system reliability and feasibility of this developed system are validated by conducting experiments in the trees available in the campus and considering a hanging ball on tree branch as a substitute for the fruit. Tree and branch vibrations during a fruit pluck are considered as the primary factor for the threat detection and frequency domain thresholding is implemented effectively for identification of the threat scenario.

These papers [34 – 35] show the importance of tree vibrational frequency for activity recognition related applications for better accuracy and threat detection. Especially [35], mentions a frequency thresholding approach to identify the threat scenario based on the tree/branch vibration frequencies mentioning the variation of vibration frequency with variation in the branch size.

Edmond Mitchell *et al.* [36] presented a biomedical activity recognition system which can distinguish between symmetric and asymmetric running of the persons using wearable inertial sensor framework and machine learning approach. The accelerometer sensors, Short time Fourier transforms and feature extraction are employed for achieving the objective. The system was effective in identifying the activity with accuracy of up to 94% using 3D accelerometer. K Fold validation is implemented in this work for validating the classifier accuracy.

Swathy. L *et al.* [37] developed a machine conditioning system for the Spacecraft application. The vibrations emerged in the aircrafts are considered as a severe threat for damaging the internal machinery. So vibration monitoring system was designed using ADXL345

accelerometer sensor interfaced with a ATMEGA microcontroller. The data acquisition system in this work was developed in LabVIEW software.

Nishkam Ravi *et al.* [38] performed the human activity recognition using the accelerometer data in conjunction with effective machine learning classifier. Activity recognition is performed by extracting several features from the acquired acceleration data during various human activities and by implementing a machine learning classifier. The results show that machine learning techniques can produce high system accuracy provided with effective features.

Mitja Luštrek *et al.* [39] had proposed a machine learning approach for activity recognition in the confidence project. This work uses effective use of SVM classifier in activity recognition and position of the sensory nodes is considered as a major parameter effecting the activity recognition. Eight machine learning algorithms were compared in this study and the highest classification accuracy of over 95 % is achieved by Support Vector Machine classifier.

Andrea Mannini and Angelo Maria Sabatini [40] described the human physical activity classified using on-body accelerometers, with a major emphasis devoted to the computational algorithms employed for this purpose. In particular, this current work used classifiers based on Hidden Markov Models (HMMs). An example is illustrated and discussed by analysing a dataset of accelerometer time series and 99.1% accuracy has been achieved.

Jiang Zhi-qiang *et al.* [41] proposed a fault diagnosis approach for rolling bearings using SVM based classifier. Vibration signals of bearing were acquired directly without pre-processing of extracting features. A comparative analysis was performed between ANN and SVM classifier in identifying the bearing faults where SVM was proved better in bearing fault identification.

P. Konar *et al.* [42] performed frame vibrations by using SVM in combination with Continuous Wavelet Transform (CWT). The encouraging results obtained from this work analysis is hoped to set up a base for condition monitoring technique of induction motor which will be simple, fast and overcome the limitations of traditional data-based models/techniques using machine learning SVM classifier.

Chauhan *et al.* [43] proposed a forest fire monitoring system by implementing wireless sensor network in combination with Machine learning approach for threat scenario detection. This proposed framework describes that the data collection from designed data acquisition system

is performed by BT module and then implemented SVM classifier for classification of collected data. Effects of various kernel functions of SVM technique on system accuracy are discussed.

These papers [36 - 43] gives the importance of accelerometers for activity classification in conjunction with the machine learning techniques. Also, from these paper one can conclude that the utilization of supervised learning machine learning models like SVM in combination with clean accelerometer or raw vibration data can be implemented to achieve the accurate activity recognition for various applications.

## **2.5. Chapter Summary**

It is observed that forests are important to human ecosystem and illegal wood trade is causing a serious threat to global economy and environment. Despite regular law enforcement and regulatory measures, illegal wood logging is still prevailing and several cases were reported regularly. There is a necessity to introduce electronic sensor technology for solving this problem. Accelerometers are proved to detect the vibrations and physical actions effectively. Effective implementation of accelerometers can provide the solution for the wood cutting activity detection. Tree vibrational frequency can be used as a feature for threat detection. By frequency domain thresholding, wood cutting activity recognition can be achieved. Also by combining, accelerometers with machine learning techniques can be implemented for accurate activity recognition and activity classification. Combination of accelerometer with wireless sensor networks one can realize accurate and feasible solution for forest monitoring application.

## **2.6. Objectives**

1. Provide possible forest monitoring solutions for eradication of illegal wood cutting
2. Design and develop prototype of Electronic Tree Surveillance System
3. Study and identify the tree vibration frequencies and factors affecting the tree vibrations
4. Realize possible feasible approaches for realizing ETSS to detect the threat scenario effectively and accurately

## CHAPTER 3

### MATERIALS AND METHODS

#### 3.1. Project Integration Schematic

ETS system is designed to provide a feasible and reliable prototype model for eradication of illegal wood logging. Figure 3.1 show the three layered network topology implemented in the project where star topology of wireless sensor networks was considered in the prototype model development. The first layer involves the Sensory Nodes (SN) and Sensory Station (SS) followed by the second or intermediate layer covering the Remote Control Station (RCS) and the final or user end layer covering Local Control Station (LCS) of ETSS. The low cost accelerometer sensory nodes are deployed in trees and the data acquisition will be performed at the respective Sensory Stations (SS) as shown in the Figure 3.1. All the Sensory Stations (SS) of the surveillance zone are connected to a Remote Control Station (RCS) and the user level communication will be performed at LCS. It consists of the database and analysis units which are helpful for identification of threat scenarios. If any abnormal or malicious activity is identified in the sensory node, the alert will be transferred to respective Sensory Station and later to the Remote Control Station. Finally, alert signal of the activity will be delivered to LCS and authorities in charge will be notified with the activity and the necessary counter measures will be taken effectively.

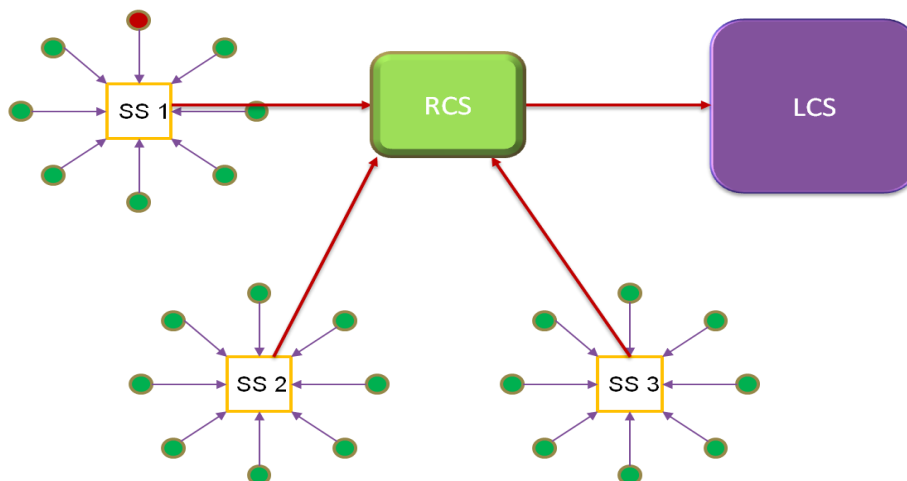


Figure 3.1. Integration Schematic of Electronic Tree Surveillance System

### 3.2. Research Phases in the Project development

The research was carried out in several phases in which primarily a vast literature survey is done to provide a feasible solution for the problem. The later phases involve designing and development of project hardware, implementation of threat detection methodologies followed by system testing and validation. The research phases implemented in this research study are given in Table 3.1.

TABLE 3.1: Research phases in ETSS

Research Phase No.	Research Phase	Work performed during the phase
1	Preliminary Research Phase	Thorough literature survey on environmental and technological aspects to provide appropriate solution for existing problem
2	Design and Development Phase	Design and development of Sensory Nodes (SN), Receiver and Analysis Unit (RAU) for data acquisition and data logging
3	Data Acquisition Phase	Acquire vibration data of employed wood cutting techniques on all selected subject trees
4	Thresholding Approach	Extraction of tree vibration frequencies and application of frequency domain thresholding in addition to time domain thresholding for threat detection
5	Machine Learning Approach	Implementation of machine learning techniques like using SVM classifier for wood cutting activity recognition
6	Testing and Validation Phase	The developed solutions or approaches are tested individually to validate the effectiveness in feasibility, reliability and accuracy in illegal wood logging activity detection

### 3.3. Hardware Design & Development

All the components employed are considered to be cost effective, efficient and application oriented. Strict considerations on parameters like cost, robustness, feasibility, reliability and availability are taken into account. Along with afore mentioned parameters easy maintenance and simple implementation protocol are considered at all levels of design and development.

#### 3.3.1. Realizing Sensory Node

Sensory Node (SN) of an ETS System is used for sensing of the physical malicious event happening at the remote end. This Node consists of accelerometer sensors for vibration acquisition, microcontroller for processing and wireless transmitter for transmitting the data or occurrence of event depending on the application requirement. The following sections in 3.3.1 explain about the hardware electronic components involved in designing and development of the SN along with the designed and developed Sensory Nodes. Figure 3.2 depicts the block diagram of the SN.

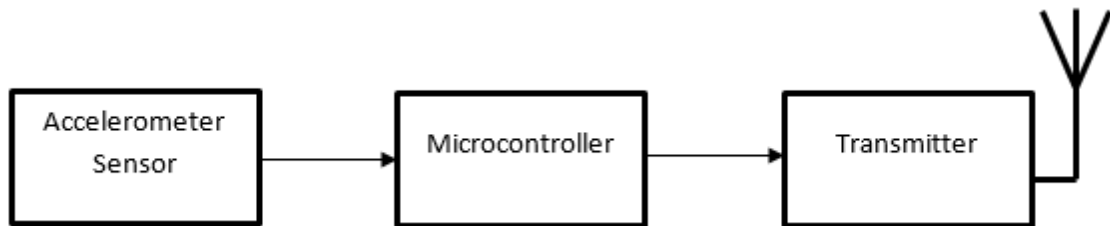


Figure 3.2. Block diagram of sensory node

##### 3.3.1.1. Electronics Employed

In Figure 3.2, SN in ETS System consists of an accelerometer sensor for sensing the event, a microcontroller for processing applications and a wireless transmitter for transmitting the sensed data or event to the respective further layers in the network.

###### *a. Accelerometer*

Accelerometer sensors are the instruments used for measuring the acceleration or vibration of any object. An accelerometer sensor measures the physical acceleration experienced by any object due to inertial forces or mechanical excitation. It is a measure of speed changes, having both magnitude and direction. An ability of an accelerometer to sense acceleration is

used to measure vibration, rotation, tilt, gravity, collision, *etc.* Acceleration of an accelerometer is measured in terms of ‘g’ where ‘g’ is acceleration measurement for gravity ( $1g = 9.81m/s^2$ ). Simply accelerometers are those transducers which convert mechanical motion into electrical signals. Figure 3.3 represents the operation of the accelerometer sensor in three axes namely X, Y and Z [44]. Common types of accelerometers are piezoelectric, piezoresistive and capacitive, which convert the respective mechanical vibration action to electrical signals. Nowadays, Micro Electro-Mechanical System (MEMS) accelerometers is widely used because of reliability and cost effectiveness. These MEMS accelerometers consists of a cantilever beam along with a seismic mass which deflects due to an applied acceleration [45].

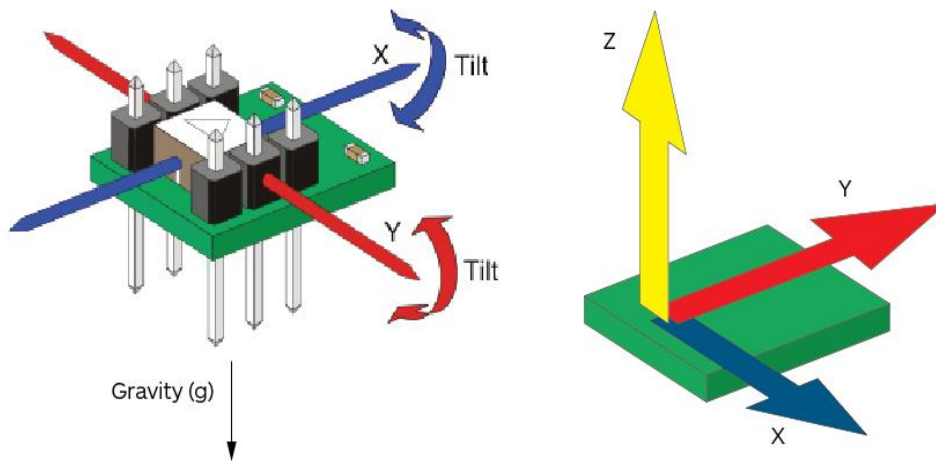


Figure 3.3: Basic operational of 3 axis accelerometer

In this case analog systems make ADXL335, which is a 3 axis MEMS based accelerometer sensor, is employed for sensing the malicious vibration activity as shown in Figure 3.4 (a). ADXL335 has the performance ability to operate for dynamic acceleration applications like shock, vibration *etc.* and also for the static applications like gravity, tilt *etc.* This also has the ability to withstand 10,000 g shock force with application selective bandwidths ranging 0.5 Hz to 1600 Hz for the X and Y axes, and a range of 0.5 Hz to 550 Hz for the Z axis [46]. The functional Block diagram of ADXL335 is shown in Figure 3.4 (b).



When it is configured to the output state, GPIO pins drive external devices such as LEDs or motors, often indirectly, through external power electronics [47].

In this prototype system, Atmel made ATMEGA328p microcontroller [48] is employed in the form of the developed Arduino Nano development board for performing the necessary sensing operations in the prototype model. Arduino is a simple and application effective RTOS which has minimal and non-complex software programming and maximum application oriented functions and compatible with the Nano development hardware board as shown in Figure 3.5. This microcontroller is selected to meet the minimum requirements like size, cost and minimum required operational performance.

### c. *Wireless Transmitter*

A wireless sensor network (WSN) is a network containing sensory nodes and performs data transfer from node to node or node to base station. These WSN are used in various applications such as remote monitoring and target tracking etc. These WSN are effective in acquiring the data from huge number of nodes and its implementation in real time is simple because of the availability of sensors that are smaller, cheaper and intelligent. Sensors with wireless interface forms a network which enables the communication in the network. Factors such as the application’s design objectives, cost, hardware and system constraints, environmental constraints are to be considered in WSN [49]. There are various types of wireless sensor network topologies as shown in the Figure 3.6.

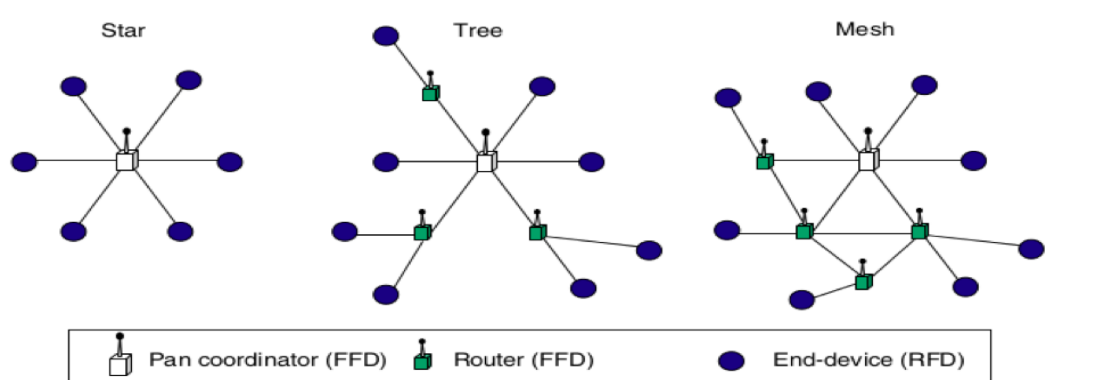


Figure 3.6: Wireless sensor network topologies

For development of wireless communication for data acquisition for the research and analysis of vibration signals in this specific application, HC-05 Bluetooth [50] based sensor network has been employed in the prototype research work as shown in Figure 3.7.

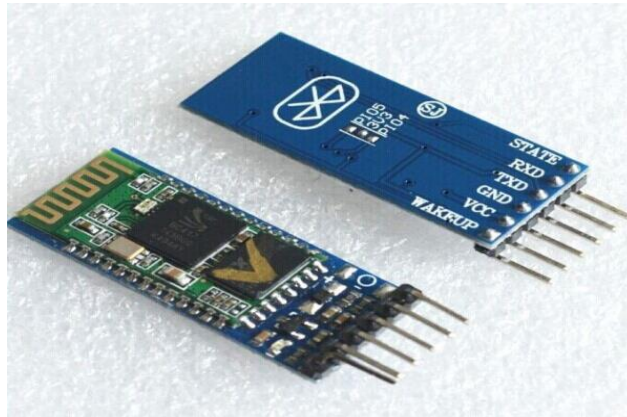


Figure 3.7: Wireless transmitter module in ETS system prototype model

### 3.3.1.2. Design and Development of Sensory Node (SN)

The SN was initially designed and developed on a general purpose PCB. After found operational, the single side copper cladded PCB layout was designed for end use prototype. EAGLE 7.5.0 design software was used to design the schematic and PCB layout of the SN. The designed circuit schematic diagram of the SN is shown in Figure 3.8. PCB layout of the SN is shown in Figure 3.9 which is designed in EAGLE design suite. Figure 3.10 (a, b) shows the assembled SN meanwhile Figure 3.10 (c) shows the developed SN along with packaging as per the end user application. These developed SN prototypes are used in data acquisition and threat detection during all the research work.

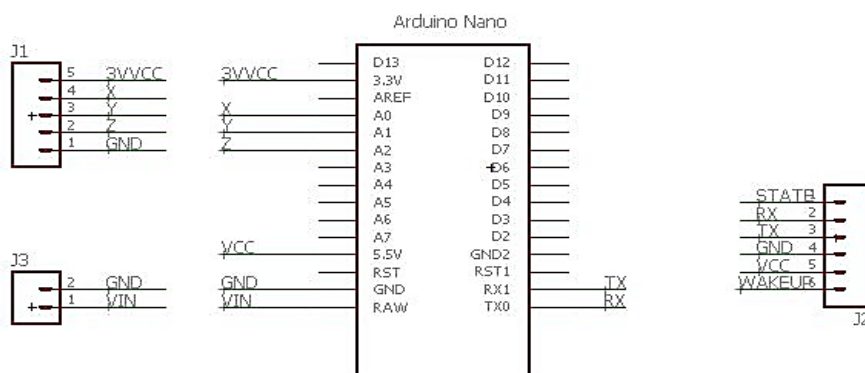


Figure 3.8. Designed EAGLE schematic diagram of ETSS sensory node

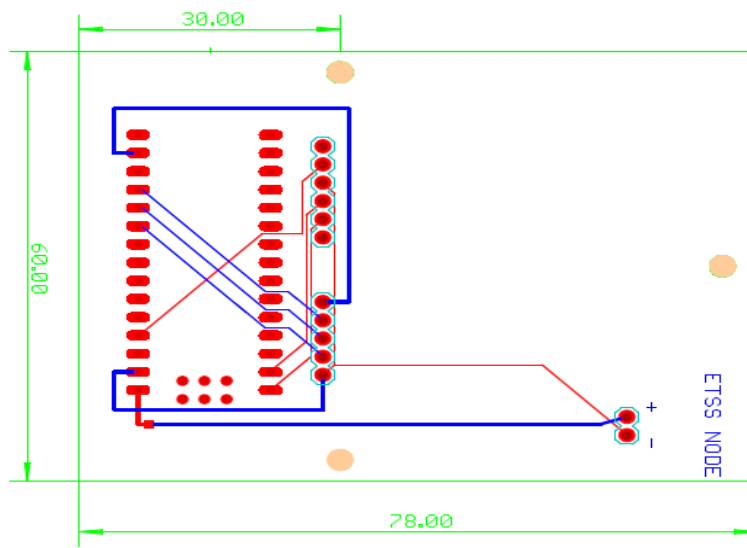
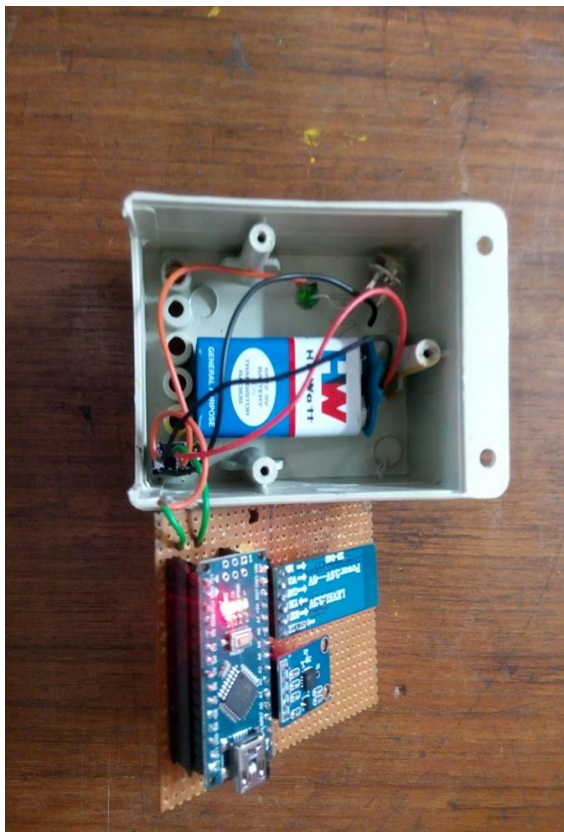
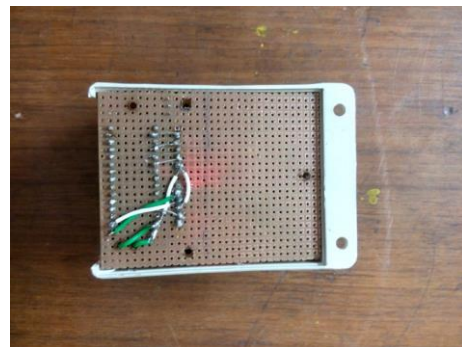


Figure 3.9. Designed PCB board layout of ETSS sensory node in EAGLE



(a)



(b)



(c)

Figure 3.10. Developed initial prototype of ETSS sensory node with casing

### 3.3.2. Design and Development of Receiver and Analysis Unit (RAU)

Receiver and Analysis unit (RAU) is present in the Local Control Station (LCS) of Figure 3.1. This unit is essentially required for acquiring the sensory signals from SN or sensory stations respectively and process the acquired information to detect any malicious activity at the remote end. Further, section discusses the hardware electronic components required for the design and development of the RAU along with the software's designed.

#### 3.3.2.1. Electronics Employed

Receiver and Analysis Unit (RAU) are also termed as the database and analysis Unit during data acquisition and data logging phases. The vibration data from the SN is transmitted by the wireless transmitter on the transmitter side. This transmitted sensory data will be received by the receiver module present in RAU and later logs the data to the data base for further research and analysis. The RAU in this prototype consists of two hardware units namely a HP made Laptop PC (RAU-PC) which constitutes for the Database and Analysis Unit (DAU) and a Bluetooth receiver dongle (RAU-Rx) which constitutes for a Receiver Unit (RxU) as shown in the Figure 3.11. The RAU-PC station used in this prototype research is an advanced PC with up to date specifications having a high capable 4GB RAM and 1 TB Hard disk facilities. The RAU-PC works on a 64-bit operating system with Intel(R) Core(TM) i5 CPU @2.40 GHz which has high fast processing speeds providing better Analysis performance. The data communication between RAU-PC and RxU will be using wired or physical serial communication interface protocol through USB 2.0. The combination of RAU-PC and RAU-RxU is called as the Receiver and Analysis Unit (RAU) or Receiver and Analysis Unit (RAU) and this RAU will be located in the Local Control Station (LCS) as in Figure 3.1.

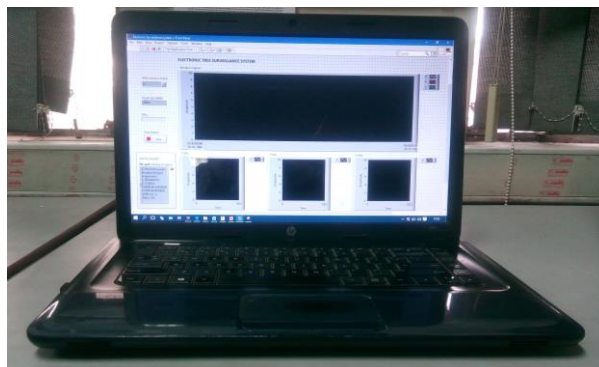
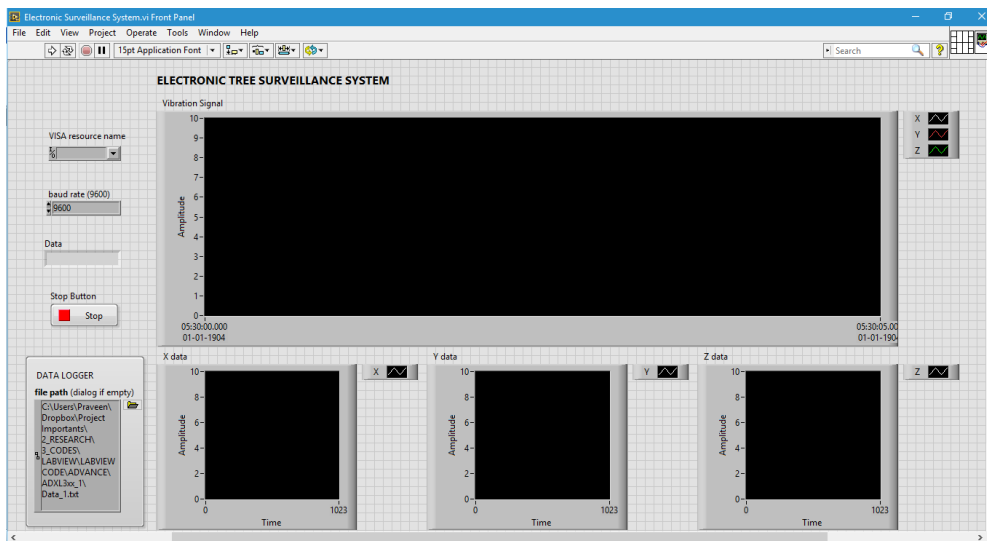


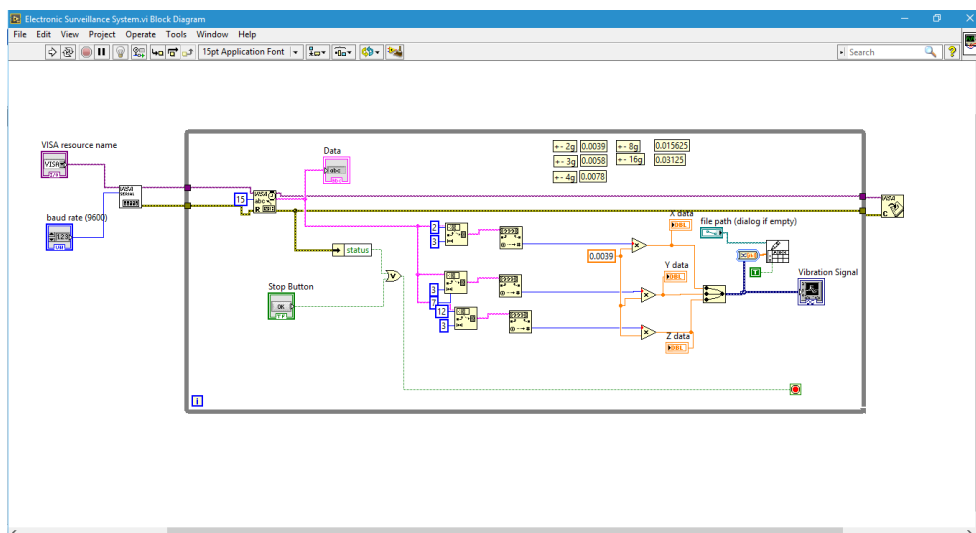
Figure 3.11. Receiver and analysis unit of ETSS prototype along with receiver dongle

### 3.3.2.2. Design and Development of Receiver and Analysis Unit Software

The Data Acquisition from the sensors during real time operation is a key function directing the project to achieve the objective. Labview Software is employed in designing the interactive Data acquisition since Labview is well renowned for its vast range of high speed data acquisition applications. The designed Data Acquisition Graphical user Interface (DAQ GUI) is presented in Figure 3.12 which consists of a vibration analysis chart and a data logger.



(a)



(b)

Figure 3.12. Labview based (a) Front Panel GUI of data acquisition of ETSS, (b) Block diagram of data acquisition of ETSS

This GUI has the capability to access the available COM ports of the RAU-PC in order to acquire the serial data from the RxU and has the provision to set the baud rate of the acquisition. The instant acceleration or vibration values can be visualized in a numeric display and as a continuous waveform in a waveform chart as shown in Figure 3.12. This designed DAQ GUI also has the ability to log the acquired data continuously into a CSV file which can be essential for further research and analysis of the acquired signal patterns.

### 3.4. Real Time Data Acquisition Protocol:

The prototype data acquisition schematic from the sensor level to the Local Control Station (LCS) is shown in the Figure 3.13. Figure 3.13 significantly shows the operation of one Sensory Station (SS) and this figures shows the sensory nodes consists of an accelerometer sensor, microcontroller and a transmitter which are used for sensing, initial processing and transmission of the data respectively. The transmitted data for respective nodes will be received by the Acquisition System and will be transferred to the Receiver and Analysis Unit (DAU) present in the LCS, where the received data is continuously logged and analysed for detection of malicious wood logging activity.

According to [3, 5], these days, various state of art machinery is used by the poachers to cut done the tree in no time. The traditionally followed state of art wood cutting techniques as mentioned in Table 3.2 are employed.

TABLE 3.2: Employed wood cutting techniques

Activity Number	Type of Wood Cutting
1	No Cutting
2	Axe Cutting
3	Hand Saw Cutting
4	Machine Cutting

Vibration signal from the subject trees during all the employed wood cutting technique is sensed by the deployed SN and is logged into the RAU present in local control station for further research study and analysis. Preliminary research study was conducted on the trees available in the campus site. The trees are selected based on their property matching with that of the Indian sandalwood trees.

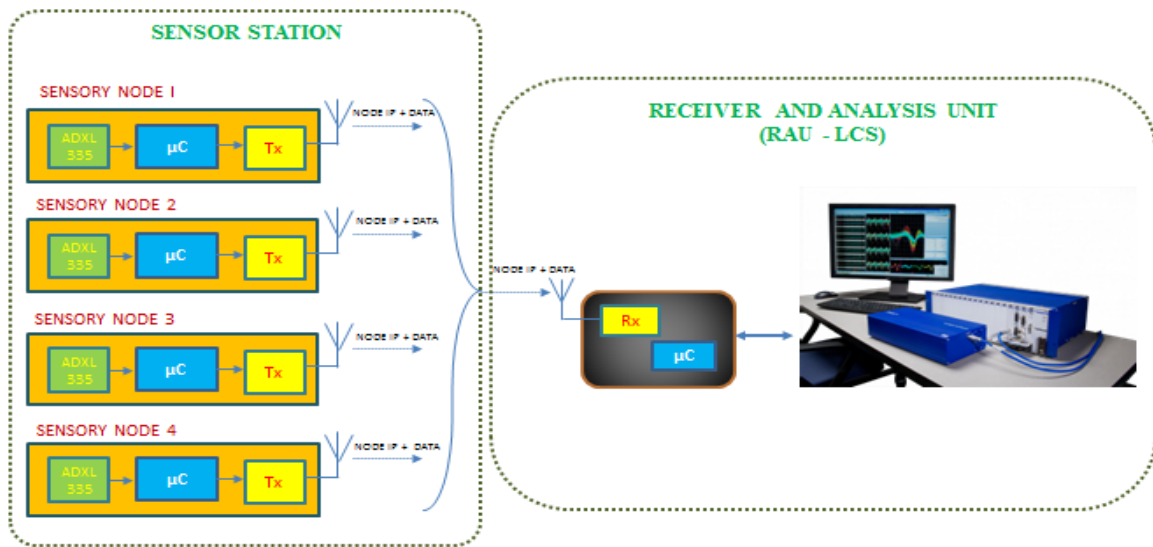
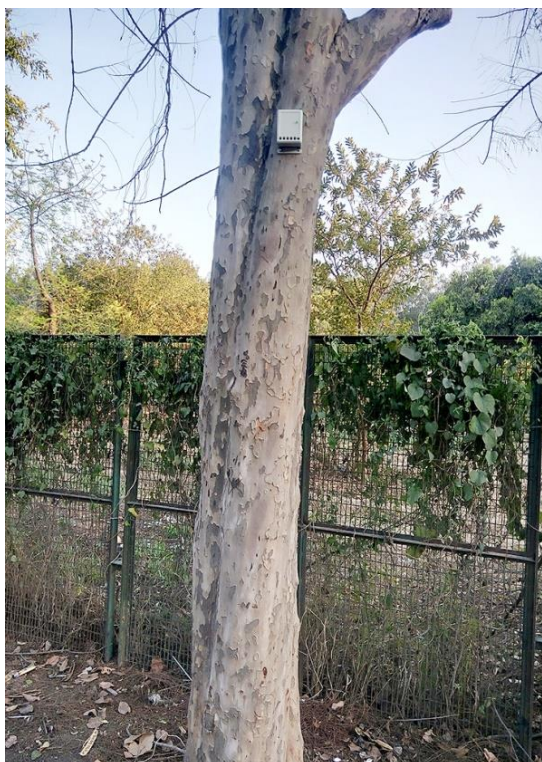


Figure 3.13. Data acquisition schematic of ETS system

The SN deployment for the real time data acquisition is as shown in Figure 3.14. The SN placement and positioning on the tree are considered after initial research study.



(a)



(b)



(c)

Figure 3.14. ETSS sensory node deployment for real time data acquisition

### **3.5. Phase for Threat detection methodologies**

The main objective of the design and development of ETS System is to eradicate illegal wood logging and accurate detection of threat scenario. In this research study, all possible feasible and realizable approaches and methodologies are implemented by considering various real time hardware parameters and environmental constraints in threat detection. Two main realizable threat detection methodologies found feasible and realizable after a thorough research. Experiments were carried out to check the feasibility, reliability, robustness and accuracy in accurately detecting the threat scenario. The two methodologies implemented are as follows

1. Threat detection using Thresholding Technique
2. Threat detection using Machine Learning Technique

#### **3.5.1. Threat Detection using Thresholding Technique**

Vibration frequency is considered as a primary feature since forced vibrations are imparted on to the tree trunk during the malicious woodcutting activity. The flow chart of the thresholding methodology is mentioned in Figure 3.15. In the research and analysis all afore mentioned wood cutting techniques are employed and corresponding vibration data is acquired from the SN. To reduce the channels of acceleration, RMS acceleration of the sensor is performed [35]. The tri-axial vibration data is further processed to extract the RMS acceleration using the formula mentioned in eq. (3.1).

$$R(t) = (A_x(t)^2 + A_y(t)^2 + A_z(t)^2)^{1/2} \quad (3.1)$$

where R is the RMS acceleration and  $A_x$ ,  $A_y$ ,  $A_z$  are the acquired acceleration data along X, Y and Z axis, respectively. After acquiring RMS acceleration, dominant frequency components of employed wood cutting activities were extracted by performing Fast Fourier Transform (FFT) and by performing short time windowing of the signal [35]. Finally, after extraction of dominant frequencies, a frequency domain thresholding was performed in addition to the amplitude thresholding [35] on a real time signal to detect and recognize the employed wood cutting activity.

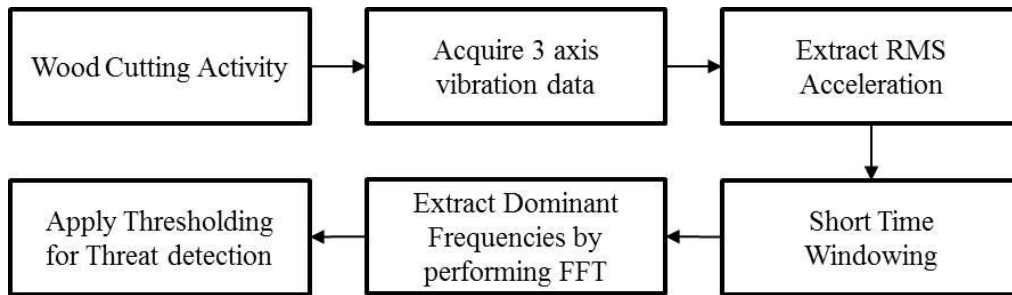


Figure 3.15. Flow process of threat detection using thresholding technique

### 3.5.2. Threat Detection methodology using Machine Learning

Machine learning is a subfield of computer science that evolved from the study of pattern recognition and computational learning theory in artificial intelligence. Various machine learning techniques are proposed till date to study the pattern recognition and for signal classification [36-43]. Vast research has been carried out proposing various machine learning techniques to accurately detect the activity or an event. SVM, KNN, ANN *etc.* and many more evolutionary algorithms are proposed till date which can be used as machine learning based classifiers for activity recognition based applications to achieve high accuracy in less computational time. Basically machine learning classifier requires ample training dataset to train the machine and the trained machine can accurately detect the event or activity basing on the training provided. The computational time and memory consumption for training the classifier depends on the amount of training data provided to the classifier. For optimum computational time and memory usage, training data for accurate classification has to be optimum as per the application.

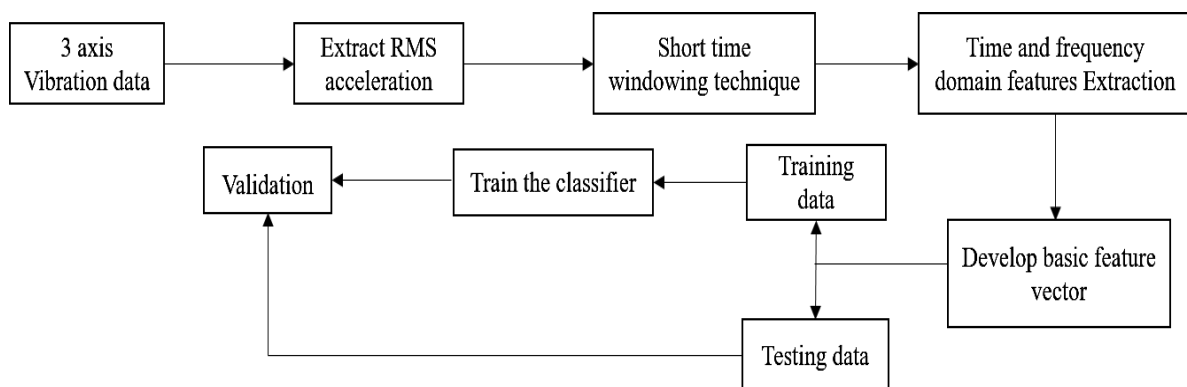


Figure 3.16. Flow process of threat detection using machine learning technique

In the threat detection approach using machine learning technique, a supervised learning SVM classifier was implemented for performing the activity recognition or classification [37 - 42]. In machine learning, SVM are supervised learning models with associated learning algorithms that analyse data used for classification and regression analysis [51]. SVM is a non-probabilistic binary linear classifier. Based on the provided set of training data, the SVM Classifier classifies the data into two classes. In addition to performing linear classification, SVMs can efficiently perform a non-linear classification using kernel tricks. The clustering algorithm which provides an improvement to the SVM is called support vector clustering [52] and is often used in industrial applications either when data is not labelled or when only some data is labelled as a pre-processing for a classification pass. The SVM classifier with linear kernel is used in the experiments. The flow process of threat detection using machine learning technique is shown in Figure 3.16.

TABLE 3.3: Time and frequency domain features

Feature No.	Features
1.	Mean
2.	Median
3.	Standard Deviation
4.	Kurtosis
5.	Skewness
6.	Correlation Coefficients
7.	RMS Magnitude
8.	Peak to peak
9.	Peak to RMS
10.	Peak Frequency
11.	Min Frequency
12.	Mean Frequency
13.	Median Frequency
14.	Power Bandwidth
15.	Total Band Power
16.	Occupied bandwidth
17.	Signal to Noise Ratio
18.	Equivalent Noise Bandwidth

In Figure 3.16, tri-axial acceleration data is acquired from the SN during all the employed wood cutting techniques and the RMS acceleration is extracted in the first step using eq. (3.1). Various time domain and frequency domain features are extracted from the acquired signals using short time windowing technique to develop a basic Feature Vector (FV) for classification [Table 3.3]. From the basic Feature Vector (FV), the training and testing data are extracted by using K Fold validation technique [39]. The SVM classifier is trained using the extracted training data and the testing data was used to test the trained SVM classifier and measure the accuracy of activity recognition.

In the research and analysis during this phase, initially, accuracy of activity recognition by individual feature is extracted [36, 38-39]. Efforts were made to optimize the real time hardware constraints like computational time and memory usage of the system. Number of features affect the memory usage and amount of training data affect the computational time of classifier, a detailed analysis on the effects of amount of training data and number of features for developing a FV on accuracy are analysed and optimum acceptable amount of training data and Features are proposed. K fold validation of the results is performed [38 - 39].

### **3.6. Testing and Validation Phase**

Feasibility and reliability of the developed system and methods were tested during various environment and robust scenarios. After performing all possible tests on the developed system, the feasibility, reliability, robustness, effectiveness, accuracy of threat detection are validated.

# CHAPTER 4

## RESULTS AND DISCUSSION

### 4.1. Chapter Overview

This chapter deals with phase wise results and observations mentioned initially and discussions related to acquired vibration data regarding the results obtained by extraction of tree vibration frequencies. The effects of trunk girth on vibration frequency are also keenly discussed. Thereafter, the results and observations regarding the accuracy of the threat detection using machine learning technique are discussed in detail. Finally, the key findings of the research study implementation.

#### 4.1.1. Phase wise Results and Observations

The phase wise research achievements are indicated in the Table 4.1.

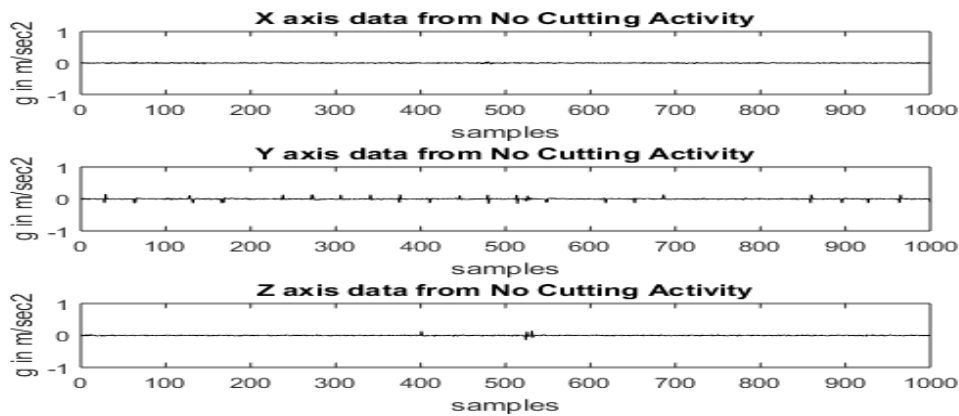
TABLE 4.1: Phases wise observations of ETS system

Research Phase No.	Research Phase	Results achieved after phase completion
1	Preliminary Research Phase	<ul style="list-style-type: none"><li>• Motivation for the existing problem along with knowledge related to solution oriented previous research works</li><li>• Decided objective as goals of the thesis</li></ul>
2	Design and Development Phase	<ul style="list-style-type: none"><li>• Successfully realized the system hardware</li><li>• Designed and developed prototype SN and RAU for preliminary research study</li><li>• Knowledge on significance of wireless system including its advantage and limitations</li></ul>
3	Data Acquisition Phase	<ul style="list-style-type: none"><li>• Acquired vibration data from subject trees successfully using the developed hardware</li><li>• Observed hardships during data acquisition using wired prototype and implemented wireless data acquisition protocol as per section 3.4</li></ul>
4	Thresholding Approach	<ul style="list-style-type: none"><li>• Extraction of tree vibration frequencies from acquired vibration signals</li><li>• Effects of variation in trunk girth on tree vibration frequency</li><li>• Successful application of frequency domain thresholding for threat detection as mentioned in section 3.5.1.</li></ul>
5	Machine Learning Approach	<ul style="list-style-type: none"><li>• Successful implementation of machine learning techniques like using SVM classifier for wood cutting activity recognition.</li><li>• Extraction of accuracy in threat detection by individual</li></ul>

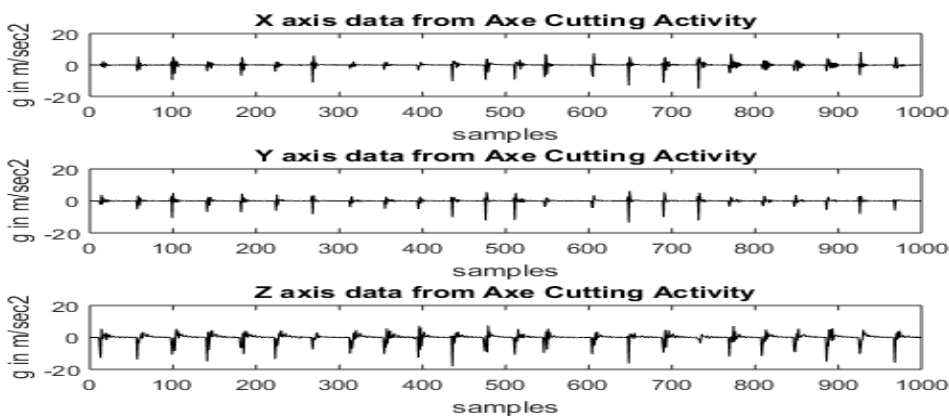
		feature from Table 3.3 in Section 3.5.2.
		<ul style="list-style-type: none"> <li>Performed detailed analysis of variation in amount of training data on system accuracy successfully and obtained optimum values of amount of training data and number of features required to optimize real time hardware computational constraints like computational time and memory usage without compromising system accuracy</li> </ul>
6	Testing and Validation Phase	<ul style="list-style-type: none"> <li>The developed solutions or approaches are tested individually and validated the effectiveness in feasibility, reliability and accuracy in illegal wood logging activity detection successfully</li> </ul>

#### 4.2. Acquired Vibration Data during employed Traditional Tree cutting techniques

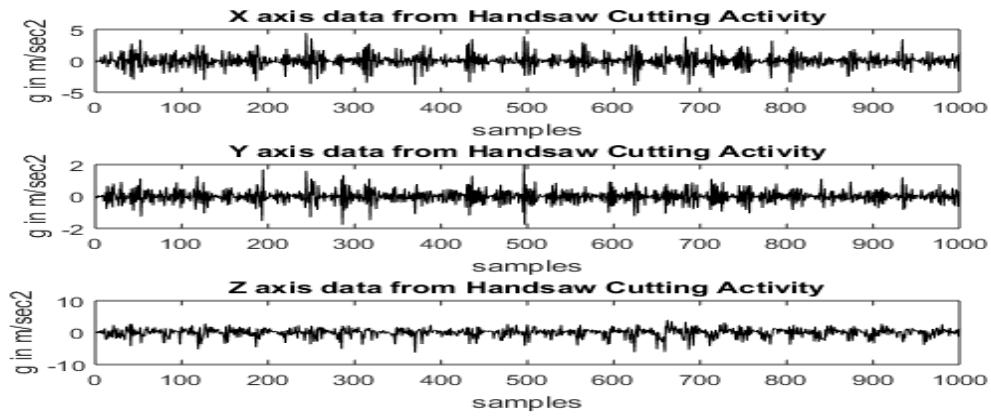
Figure 4.1 shows the acquired vibration data from the tree trunk during various traditional wood cutting techniques mentioned in Table 3.2. Figure 4.1(a) shows the tri axial vibration data during no wood cutting scenario where as Figure 4.1 (b, c & d) represents the acquired tree vibration data during axe, handsaw and machine wood cutting techniques, respectively.



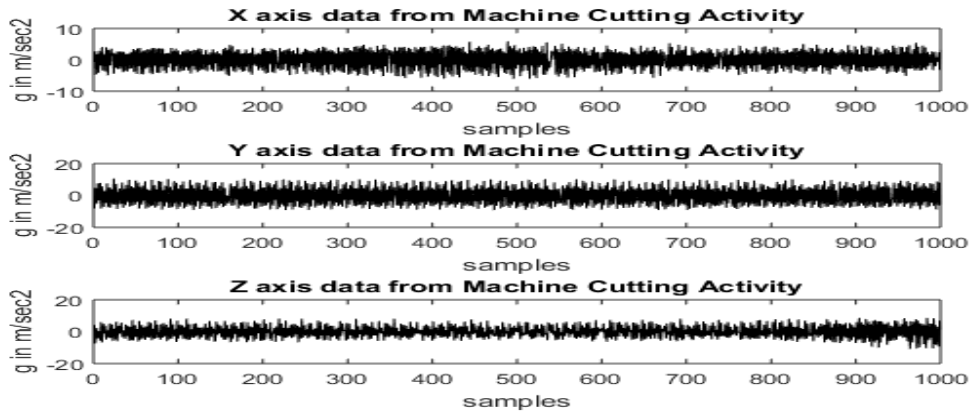
(a)



(b)



(c)



(d)

Figure 4.1: Vibration data of X, Y, Z-axis of the accelerometer during wood cutting activity.

(a) No cutting (b) Axe cutting, (c) Handsaw cutting, (d) Machine cutting

### 4.3. Normalized tri-axial vibration data

Eq. (3.1) in section 3.5.1, Figure 4.2 shows the normalized tri-axial vibration data or resultant acceleration. Figure 4.2 clearly indicates that every employed wood cutting activity has distinct pattern and periodic in nature. When there is no wood cutting performed, the acquired vibrations on the tree trunk are almost equal to zero with some negligible noise content as shown in Figure 4.2 (a). For a handsaw wood cutting and acquired signal pattern is almost periodic as in Figure 4.2 (b), because poacher pushes and pulls the handsaw across the trunk in a continuous pattern with respect to time. During a wood cutting activity by Axe as shown in Figure 4.2 (c), the poacher strikes the tree trunk with ample force of impact and perform this in continuous intervals. While performing a machine wood cutting, the poacher cuts the trunk with high speed rotating electric machine cutter which indeed generates a peculiar

pattern on the tree trunk as mentioned in Figure 4.2(d). Both Axe wood cutting activity and handsaw wood cutting activity are observed to be a low frequency wood cutting techniques where as a machine cutting activity is observed to possess comparatively high frequency components. The impact of vibration acceleration on the tree trunk is observed to be comparatively high during electric machine cutting followed by axe cutting and handsaw cutting respectively since the impact of electrical machine is higher on the tree trunk compared to other human involved wood cutting techniques. The impact of striking during the axe wood cutting will be more compared to that of handsaw wood cutting, so axe wood cutting amplitude is observed to be higher than that of the handsaw wood cutting activity in Figure 4.2.

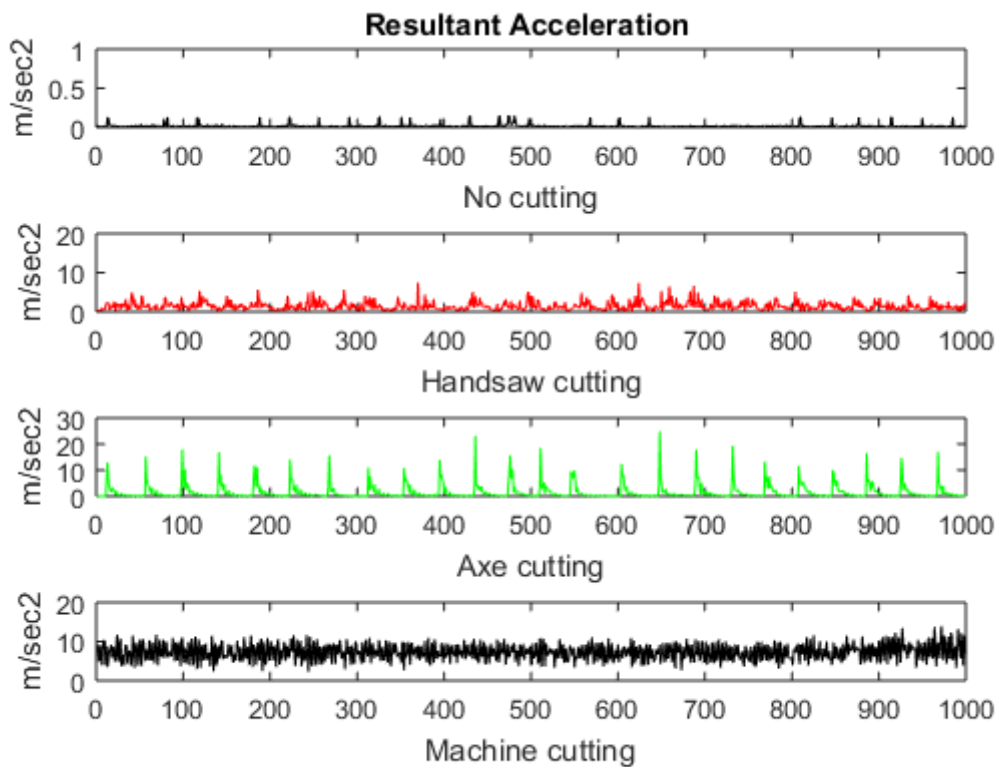


Figure 4.2: Normalized/resultant acceleration of the acquired data for all the four activities

#### 4.4. Observations of Frequency Domain Thresholding Approach for Threat detection

The frequency components of the normalized signal are acquired by performing Fast Fourier Transform operation (section 3.5.1). Figure 4.3 shows the power spectrum density (PSD) of each employed wood cutting technique with respect to Figure 4.2, respectively. The

frequency observed without wood cutting is observed to be zero as shown in Figure 4.3 (a). Figure 4.3 (b) and Figure 4.3 (c) shows the PSD observed for handsaw wood cutting and axe wood cutting activities respectively. As indicated in section 4.3, both handsaw cutting and axe cutting frequencies are observed to be low frequency wood cutting techniques with major frequency components accommodating below 5 Hz frequency. These two wood cutting activities possess low and similar frequencies, the activities can be distinguished by amplitude thresholding in addition to that of the frequency thresholding since the amplitude of axe cutting is observed to be comparatively higher than that of hand saw wood cutting in Figures 4.3 (b & c). Figure 4.3 (d) shows the PSD of the machine wood cutting where the frequency components are observed to lie on the higher side in a range of 25 to 30 Hz. It is observed that all the employed wood logging activities can be distinguished in real time by applying the respective frequency domain thresholding and amplitude thresholding,

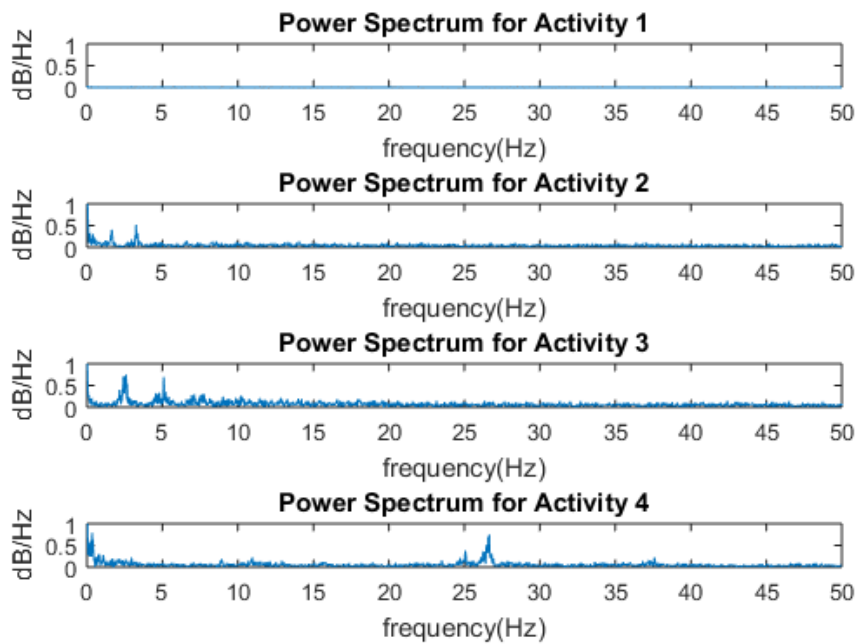


Figure 4.3: Frequency power spectrum density extracted for all employed woodcutting activities respectively

#### 4.4.1. Effects of Tree Trunk Girth on Tree Vibration Frequency

Efforts were made to analyse the variation of tree vibration frequency accordingly with the variation of trunk girth. Figure 4.4 indicated the observed tree vibration frequencies for all the

employed wood cutting techniques for all the selected sample trees. Figure 4.4 shows that the tree vibration frequency increases with decrease in tree trunk girth for all the employed woodcutting techniques. Lower the tree trunk, higher the tree vibration frequency has been observed from Figure 4.4.

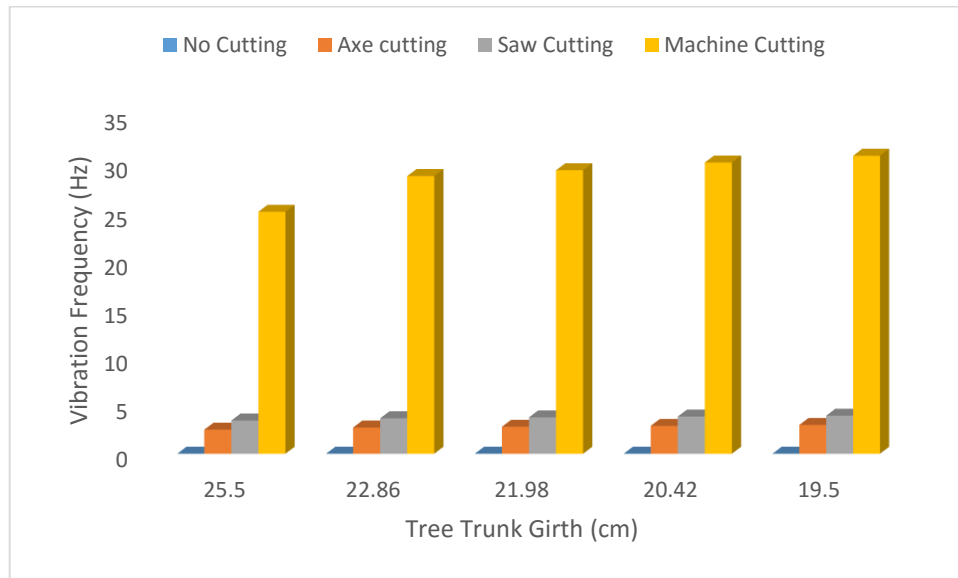


Figure 4.4: Vibration frequency during different wood cutting activities on different tree trunks

#### 4.5. Observations of Machine Learning Approach for Threat detection:

The procedure for the machine learning approach for threat activity classification is mentioned in section 3.5.2.

##### 4.5.1 Accuracy of individual feature for Threat activity recognition and Classification

The accuracy of the activity recognition of employed machine learning based SVM classifier by considering individual feature of Table 3.3 of section 3.5.2. as feature vector is shown in Figure 4.5. Individual feature is provided separately to train the classifier and accuracy of activity recognition has been observed. Figure 4.5 indicate that the features namely mean and standard deviation of time domain signal has high accuracy of 77.5% in activity classification compared to all other extracted features.

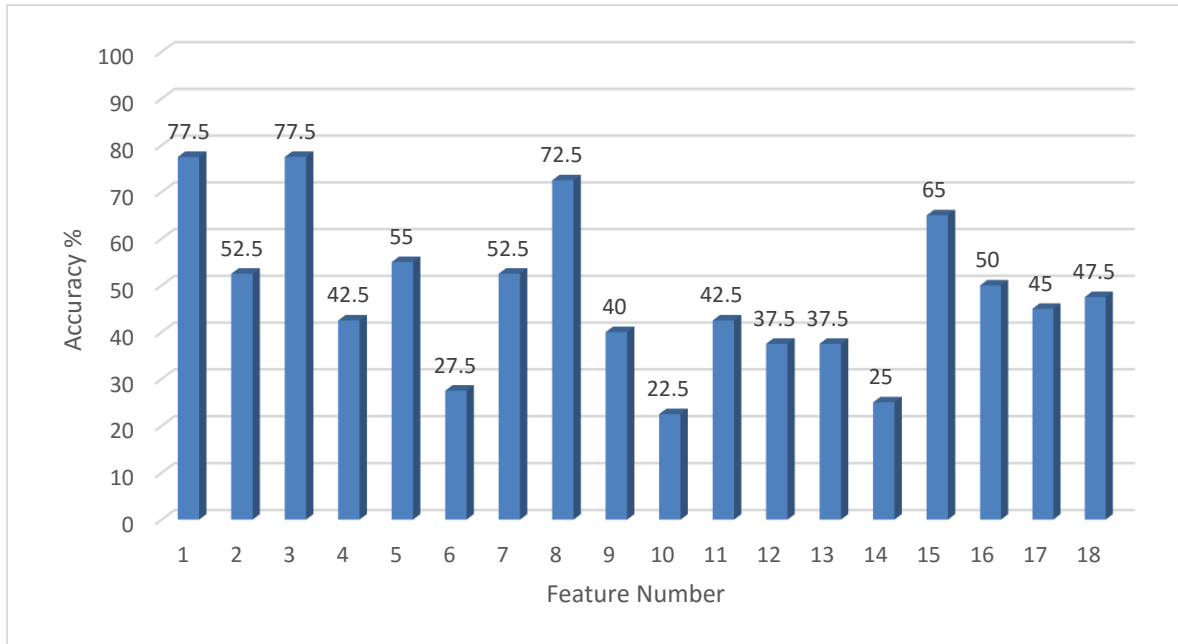


Figure 4.5: Accuracy of individual features for activity recognition

#### 4.5.2. Optimized Results of Real-time Constraints

All the 18 extracted features mentioned in Table 4.2 of section 3.5.2. were considered to form a basis feature vector for the employed machine learning based SVM classifier and by performing K-fold validation technique [38 - 39] along with increasing training data presents the overall accuracy of the system is calculated.

In order to optimize the memory usage, computation time and to verify the effect of number of features in feature vector on overall system accuracy, the number of features in the basic feature vector are reduced gradually by reducing to top 15, top 10 and top 5 accurate features from Figure 4.5 to form a new basis feature vector for activity classification. The overall system accuracy has been extracted with increasing training data present as shown in Figure 4.6 to Figure 4.9. Figure 4.10 represents the overall system accuracy during variable amount of Training data and No. of Features in a single visualization. It is observed that the accuracy of wood cutting activity recognition increases with increasing training data and is 100% for maximum training data for all except for 5 features classification. Also, it is observed that the minimum 10 number of top accurate features from Figure 4.5 with complete training data can effectively achieve 100% activity recognition as in Figure 4.6.

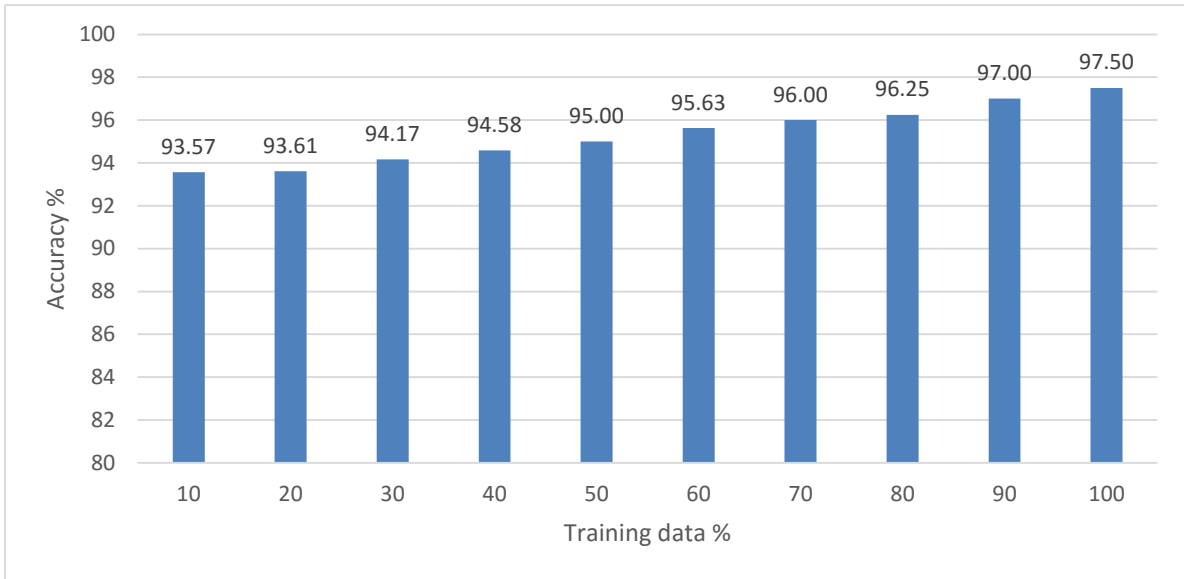


Figure 4.6: Overall system accuracy with no of top accurate features = 5 for basis feature vector development

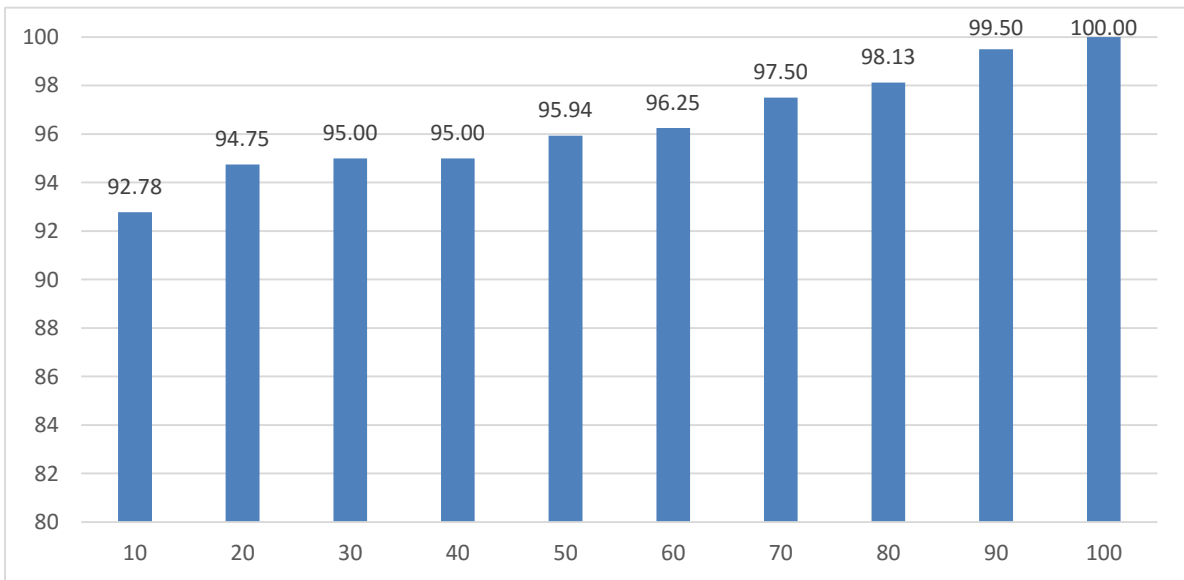


Figure 4.7: Overall system accuracy with no of top accurate features = 10 for basis feature vector development

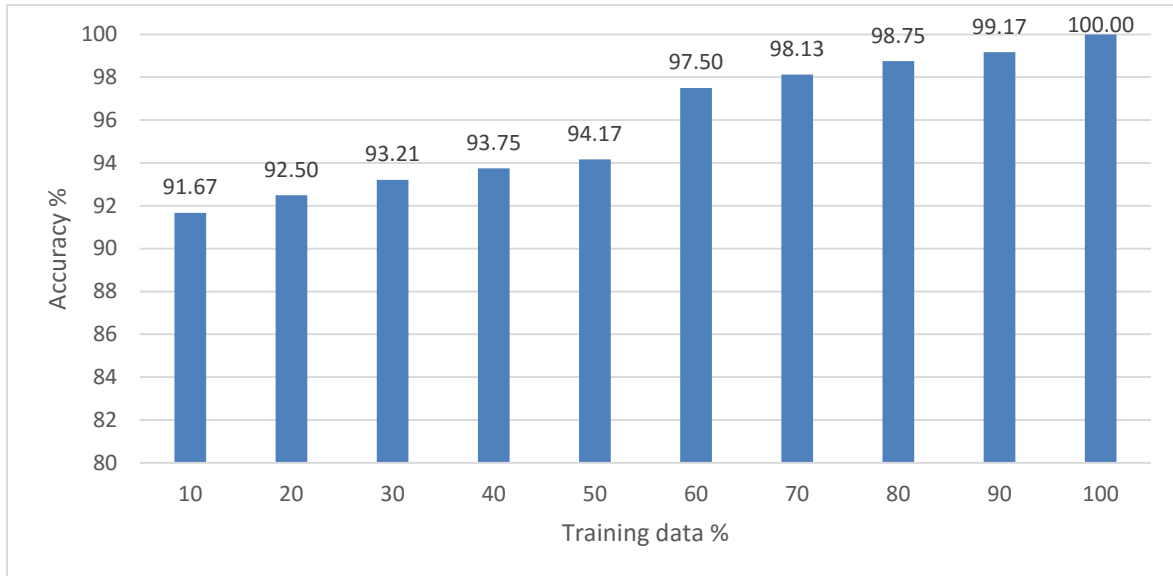


Figure 4.8: Overall system accuracy with no of top accurate features = 15 for basis feature vector development

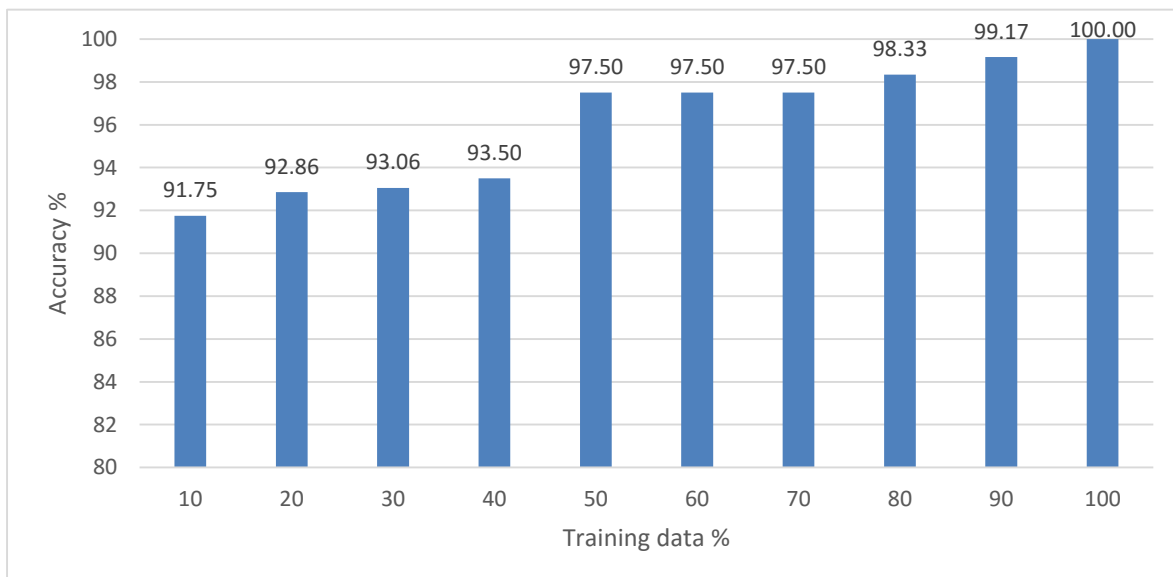


Figure 4.9: Overall system accuracy with no of top accurate features = 18 for basis feature vector development

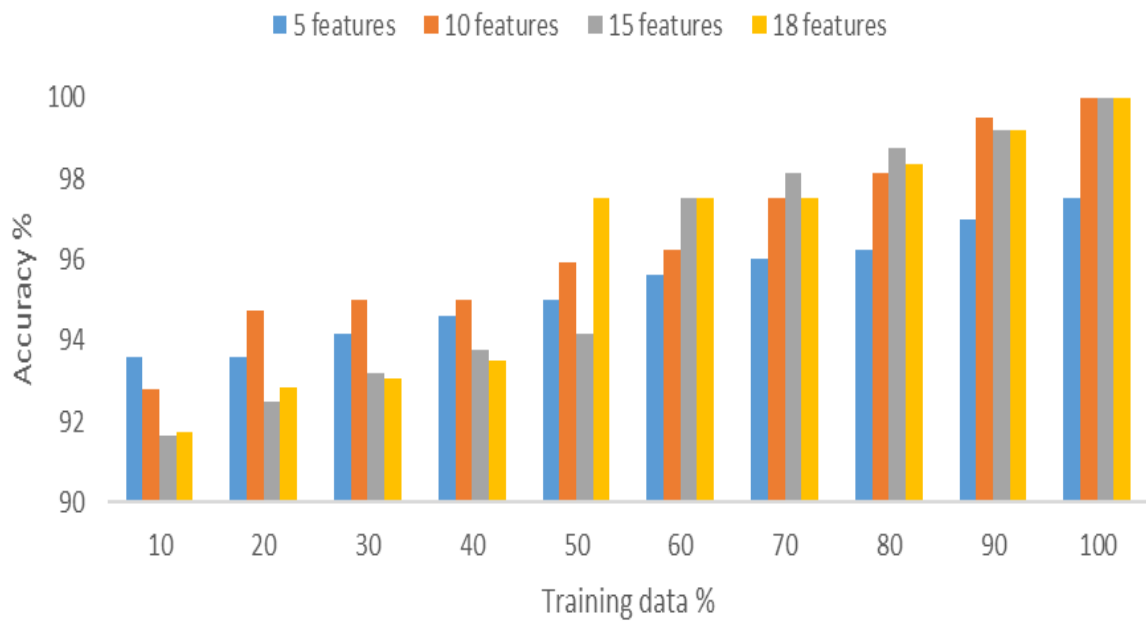


Figure 4.10: Overall system accuracy during variable amount of training data and number of features

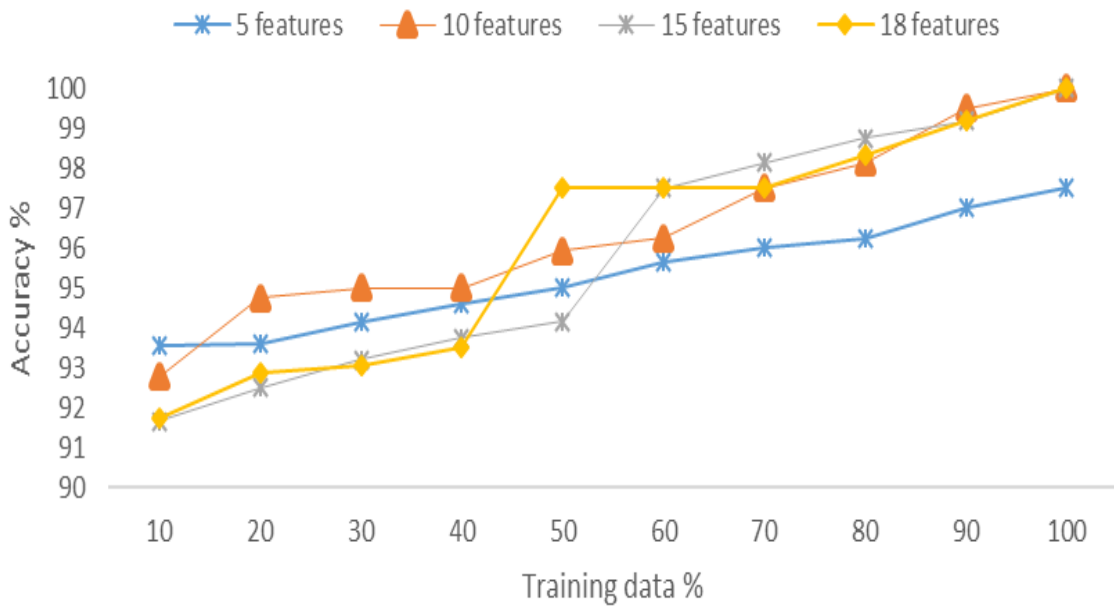


Figure 4.11: Trend lines of overall system accuracy

Figure 4.11 shows the accuracies based on variation of amount of training data and number of features, respectively. Figure 4.11 shows that the maximum accuracy of the system with maximum training data during a maximum number of features, as feature vector is observed to be 100% and minimum accuracy of the system with least training data during least features as feature vector is observed to be 91.67%. It is also observed that for 50 % training data, the basic feature vector containing all 18 features provide high accuracy of 97.50%. Also, it is observed that 97.50% accuracy has been achieved with only 50% training data by 18 features whereas it is obtained at 60%, 70% and 90% training data for 15, 10 and 5 featured feature vector, respectively. Moreover, from Figure 4.11, it is observed that with the increase in number of features, the slope of the output varies and accordingly the accuracy improves.

#### **4.6. Chapter Summary**

The proposed framework can accurately detect the employed woodcutting activities. It is found that the tree vibration frequencies on trees are different for different wood cutting activity. The vibration frequencies of tree selected tree trunks during axe wood cutting, handsaw woodcutting ranges between 0-5 Hz and machine woodcutting between 25 – 30 Hz, respectively. The overall accuracy of the proposed framework ranges from 91% to 100% depending on the percentage of training data considered for activity recognition. Also, the observations show that mean and standard deviation of the time domain signal can individually provide accuracy up to 77.5%. Top 10 featured feature vectors can provide 100% accuracy for unconstrained scenarios. For optimum computation time and memory usage, it is observed that 18 and 15 top featured feature vector with 50% and 60% training data respectively can provide 97.5% activity recognition accuracy.

## CHAPTER 5

### CONCLUSION AND FUTURE SCOPE

#### 5.1. Conclusion

The indigenously developed ETS system is useful for detection of illegal or unauthorized wood logging with effective use of advance technologies in sensors and vibration signal processing. This prototype framework was developed considering real time embedded implementation constraints and proposed feasible and realizable approaches that can be implemented in real time for accurate recognition of various malicious wood cutting activities. Both threat detection techniques implemented are found feasible for real time implementation. However, both techniques equally have pros and cons. Accuracy of threat detection is higher in case of machine learning approach whereas this technique has higher computational time and complex in real-time implementation. The thresholding technique is simple with comparatively less computation time and possesses fast threat detection capabilities. However, this threat detection method is prone to false alerts due to various environmental factors like sway winds, hurricane and animal interaction *etc.*, so accuracy of threat detection is comparatively lesser in the case of thresholding technique. The feasibility and reliability of this indigenously developed system are validated by conducting various sets of experiments. Also, the effects of amount of training data and number of features in feature set on system accuracy in the case of machine learning approach was discussed in detail. It is concluded that as the training data increases, the accuracy increases, however the computational time increases accordingly and as the number of features increases, the accuracy in activity recognition improves. However, consumes more storage in disk. Efforts were made to optimize the computational time and memory usage in machine learning approach. This piece of research work provides a feasible solution and if implemented in a large scale, this can eradicate the illegal wood logging problem for the global authorities.

#### 5.2. Future Scope

Present research work is the initial prototype and a novel approach intended to provide best feasible and realizable solutions for eradicate existing global illegal wood cutting problem. There is a vast scope of research in this field and many other feasible technologies can be applied to make the system even more feasible for real time ground implementation. Advance

wireless sensor networks like mesh networks or adhoc networks can be implemented to improve the system feasibility. This prototype system was designed on limited tree samples considering the protection of precious plantations of particular class. The work can be extended by implementing the proposed techniques on various tree samples and by employing more wood cutting techniques. Sample tree vibration data acquisition during tree cutting without harming a tree is a challenging task that has to be taken into consideration. There is also a possibility for development of secondary threat conformation system by using this proposed ETS system threat detection technique as primary threat detection with effective implementation of Drone technology in conjunction with GPS technology. After the threat detection by this proposed ETS system, the location of the alert originated can be identified using GPS and by feeding the GPS coordinated to employed drone, the online photographs or video footage can be acquired to confirm the threat existence. There is a vast scope for this particular research work ahead and an objective oriented research can provide more feasible and realizable system paving the path for eradication of illegal wood cutting.

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## APPENDIX – A

### RESEARCH PUBLICATION LIST

1. J. Sai Praveen Kumar, Ravinder Agarwal; “**Electronic Tree Surveillance System for Detection of Illegal Wood Logging**”, in *Instrumentation and Measurement IEEE Transaction*, (Communicated – June 2016)
2. J. Sai Praveen Kumar, Ravinder Agarwal; “**Machine Learning Based Electronic Tree Surveillance System for Detection of Illegal Wood Logging Activity**”, in *Engineering Applications of Artificial Intelligence - Elsevier*, (Communicated – June 2016)
3. J. Sai Praveen Kumar, Ravinder Agarwal; “**Vibration Analysis and Identification of Optimum Vibration Frequency on Tree Trunks**” in *9<sup>th</sup> International Conference on Advances in Metrology (AdMet – 2016)*, conducted by MSI, NPL and CSIR, 24 – 26 February, 2016. (Achieved Best Paper Award)