

LB/TH/33/2025  
TH5913

**TINY ML BASED EARLY WILDFIRE DETECTION**

Gampalage Isara Subasana Pathmendra Fonseka

208525F

Degree of Master of Science in Artificial Intelligence

Departments of Computational Mathematics

Faculty of Information Technology

University of Moratuwa

Sri Lanka

April 2025

# **TINY ML BASED EARLY WILDFIRE DETECTION**

Gampalage Isara Subasana Pathmendra Fonseka

208525F

Dissertation submitted in partial fulfillment of the requirements for the degree  
Master of Science in Artificial Intelligence

Departments of Computational Mathematics

Faculty of Information Technology

University of Moratuwa

Sri Lanka

April 2025

## DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date: 26.06.2025

The above candidate has carried out research for the Masters dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Prof. Thushari Silva

Signature of the Supervisor:

Date: 26/06/2025

## **DEDICATION**

This thesis is dedicated to my parents who support and encourage me all the time. Without their sacrifices, I wouldn't be able to come this far in my academic journey. To my mentors and friends who always stood by my side through every challenge I faced during this master's study, thank you for believing in me and encouraging me when I doubt myself. Research in this field is limited. Therefore, I dedicate this research to the whole world.

## **ACKNOWLEDGEMENT**

To my supervisor Prof. Thushari Silva, thank you for your continuous support and advice. It was fortunate to have a supportive and knowledgeable supervisor like you. I would like to mention the help and guidance given by my friends in preparing the research process. Our shared experiences made this journey both enriching and enjoyable. And of course, I could not forget to thank all my friends from Sipearl GmbH for reminding me all the time about the thesis and encouraging me. Finally, I am grateful to my family and my partner for their unconditional love, prayers, and encouragement. Your faith in me has been my greatest strength.

## ABSTRACT

Wildfire is an enormous and increasing threat to the global ecosystems, human settlements, and climatic conditions. Traditional methods for wildfire detection such as satellite imaging and ground-based monitoring methods are not providing timely and spatially focused warnings, especially in remote forest regions. This research introduces a novel Tiny Machine Learning (TinyML) based Wireless Sensor Network (WSN) model to meet the critical demand for a strong, real-time, and energy-efficient early wildfire warning system. The proposed TinyML Wildfire Detection System (TWDS) integrates low-power sensors with on-device machine learning to detect environmental abnormalities typical of fire occurrences, such as temperature spikes, humidity declines, and particulate matter or gas detection, such as Total Volatile Organic Compound (TVOC) and Carbon Dioxide (CO<sub>2</sub>).

Decentralized processing is emphasized in the system design, where sensor nodes process information locally using a lightweight Deep Neural Network (DNN) trained on historical wildfire datasets. This method reduces latency and power consumption by reducing reliance on continuous data streaming to a central server. Hardware implementation of the sensor node uses an Arduino Nano 33 BLE Sense Lite, DHT22 temperature and humidity sensors, and SPG30 gas sensors. The model training was done by using TensorFlow and converting them using TensorFlow Lite and TensorFlow Lite Micro for deployment in TinyML devices. Evaluation metrics such as accuracy, precision, recall, F1-score, and Area Under Curve (AUC) establish the system to be reliable in detecting fire conditions and non-fire conditions. The results validate the system's performance in early wildfire detection with improved responsiveness and scalability, making it a viable candidate for deployment in resource-constrained forest environments. TWDS offers an advanced approach for wildfire prevention through the use of energy efficiency, low-latency, and scalability by combining WSN and TinyML technologies.

**Keywords:** Wildfire Detection, TinyML, WSN, On-device Processing

# TABLE OF CONTENTS

Declaration .....	i
Dedication .....	ii
Acknowledgement.....	iii
Abstract .....	iv
Table of Contents .....	v
List of Figures .....	ix
List of Tables.....	xi
List of Abbreviations.....	xii
List of Appendices .....	xiv
Chapter 1 .....	1
Introduction.....	1
1.1 Prolegomena.....	1
1.2 Aim and Objectives .....	2
1.3 Background and Motivation .....	2
1.4 Problem Definition .....	4
1.5 TinyML Wildfire Detection System.....	4
1.6 System Requirements .....	5
1.7 Structure of the Thesis.....	5
1.8 Summary .....	6
Chapter 2 .....	7
Literature Review of Wildfire Detection .....	7
2.1 Introduction .....	7
2.2 Wildfire Stages .....	7
2.3 Wildfire Detection Technologies .....	9

2.3.1	Camera based technologies .....	9
2.3.2	Satellite based monitoring.....	10
2.3.3	Unmanned aerial vehicles .....	12
2.3.4	Wireless sensor network .....	12
2.4	Machine Learning Approaches in Wildfire Detection .....	16
2.5	The Emergence and Relevance of Tiny Machine Learning .....	17
2.5.1	TensorFlow lite and lite micro as a framework for TinyML .....	18
2.6	WSN and TinyML Approach .....	19
2.7	Summary .....	20
Chapter 3 .....		21
Technology Adapted – TinyML Based WSN.....		21
3.1	Introduction .....	21
3.2	Wireless Sensor Network .....	21
3.2.1	Real time and continuous monitoring .....	22
3.2.2	Local and Precise Detection.....	22
3.2.3	Energy Efficiency and Sustainability.....	22
3.2.4	Robustness and Scalability.....	22
3.3	Issue in Current Wireless Sensor Network for Wildfire Detection.....	23
3.4	Tiny Machine Learning .....	24
3.4.1	On-Device Real-Time Decision Making .....	25
3.4.2	Reduced Power Consumption.....	25
3.4.3	Lightweight Computational Requirements .....	25
3.4.4	Scalability and Adaptability.....	25
3.5	TinyML Approach for Wildfire Detection Model.....	26
3.6	Summary .....	26
Chapter 4.....		28

TinyML Wildfire Detection System .....	28
4.1 Introduction .....	28
4.2 Hypothesis .....	28
4.3 Input.....	28
4.4 Output.....	29
4.5 Process.....	29
4.6 Features .....	29
4.7 Users.....	30
4.8 Summary .....	30
Chapter 5 .....	31
Design of TinyML Wildfire Detection System.....	31
5.1 Introduction .....	31
5.2 TWDS Architecture.....	31
5.3 Wireless Sensor Network Architecture .....	33
5.4 Wireless Sensor Node with TinyML Model .....	35
5.5 Summary .....	36
Chapter 6 .....	37
Implementation .....	37
6.1 Introduction .....	37
6.2 Datasets .....	37
6.2.1 Smoke Detection Dataset .....	37
6.2.2 Forest Fire - UCI Machine Learning Repository .....	38
6.3 Data Preprocessing .....	38
6.3.1 Features of Smoke Detection Dataset .....	38
6.3.2 Features of Forest Fire – UCI.....	39
6.4 Model Design .....	41

6.5	Training the Models .....	43
6.6	Convert the Models Using Tensor Flow Lite .....	44
6.7	Developing the prototype node .....	44
6.8	Summary .....	46
Chapter 7 .....		47
Evaluation .....		47
7.1	Introduction .....	47
7.2	Evaluation Setup.....	47
7.3	Evaluation Parameters .....	47
7.3.1	Confusion Matrix .....	48
7.3.2	Accuracy .....	48
7.3.3	Precision.....	48
7.3.4	Recall (Sensitivity).....	49
7.3.5	F1-Score .....	49
7.3.6	Area Under the ROC Curve (AUC).....	49
7.4	Results .....	50
7.5	Analysis .....	53
7.6	Summary .....	54
Chapter 8 .....		55
Conclusion and Future Work .....		55
8.1	Introduction .....	55
8.2	Conclusion.....	55
8.3	Further Work .....	56
8.4	Summary .....	57
References .....		58
Appendix A: Sensors Used .....		61

## LIST OF FIGURES

<b>Figure</b>	<b>Description</b>	<b>Page</b>
Figure 1:	Wildfire Stages .....	7
Figure 2:	Key words association for wildfire detection .....	8
Figure 3:	Camera based lookout tower wildfire detection architecture .....	10
Figure 4:	Current wildfire detection from Active Fire MODIS .....	11
Figure 5:	Satellite based wildfire detection architecture .....	11
Figure 6:	IoT architecture layers and the computing levels .....	17
Figure 7:	Architecture of General WSN .....	21
Figure 8:	Current WSN wildfire detection architecture .....	23
Figure 9:	Where does TinyML stand in overall technologies .....	24
Figure 10:	TinyML Development Flow .....	26
Figure 11:	TWDS Flow Diagram .....	32
Figure 12:	Architecture of TWDS .....	33
Figure 13:	Multi-hop LoRaWAN Relay-Device Architecture .....	34
Figure 14:	Routing paths of the LoRaWAN .....	34
Figure 15:	Sensor Node Design .....	35
Figure 16:	Training and Validation Accuracy .....	43
Figure 17:	Training and Validation Loss .....	44
Figure 18:	Schematic of the sensor node .....	45
Figure 19:	Breadboard design of the node using Fritzing Software .....	45
Figure 20:	Physical Prototype Design .....	46
Figure 21:	Output of the system with fire warning .....	46
Figure 22:	Confusion Matrix for each model .....	50

Figure 23: Confusion Matrix for each TinyML Model.....	51
Figure 24: ROC curve for each model .....	52

## LIST OF TABLES

<b>Table</b>	<b>Description</b>	<b>Page</b>
Table 1:	WSN based wildfire detection research.....	13
Table 2:	Usage of TinyML in environment spheres .....	18
Table 3:	Smoke Dataset Features .....	38
Table 4:	Features of Forest Fire-UCI data set.....	40
Table 5:	Summary of features used for each model.....	41
Table 6:	EON analyzer proposed DNN example .....	42
Table 7:	DNN architecture for each model .....	42
Table 8:	Parameter numbers used in each model.....	42
Table 9:	Confusion Matrix .....	48
Table 10:	Evaluation Parameters Results.....	52

## LIST OF ABBREVIATIONS

<b>Abbreviation</b>	<b>Description</b>
ANN	Artificial Neural Network
AVHRR	Advanced Very High-Resolution Radiometer
CNN	Convolutional Neural Networks
CO <sub>2</sub>	Carbon Dioxide
CO	Carbon Monoxide
DNN	Deep Neural Network
FWI	Fire Weather Index
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
LoRaWAN	Long Range Wide Area Network
ML	Machine Learning
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NN	Neural Network
RH	Relative Humidity
SNPP	Suomi National Polar-orbiting Partnership
TFL	TensorFlow Lite
TFLM	TensorFlow Lite Micro
TinyML	Tiny Machine Learning
TVOC	Total Volatile Organic Compounds
TWDS	TinyML Wildfire Detection System
UAV	Unmanned Aerial Vehicle

VIIRS	Visible Infrared Imaging Radiometer Suite
VWW	Visual Wake Words
WSN	Wireless Sensor Networks

## LIST OF APPENDICES

<b>Appendix</b>	<b>Description</b>	<b>Page</b>
Appendix A	Sensors Used	61