Trevive (Tree Revive - Nurture All Trees): A tree health monitoring system

Abeer Rohan Gosain [(a)], Reetu Jain[(b)]

(a) Class of 2025, The Shri Ram School, Moulsari, Gurgaon, Haryana , India.
Email id: ***abeergosain0912@gmail.com***

(b) Supervisor, On My Own Technology Pvt. Ltd., Lokhandwala, Oshiwara, Mumbai, India.

ORCID: *0000-0002-7199-2823*

Abstract: The increasing globalization, climate change, urbanization, and deforestation are jeopardizing the world's tree populations and emphasize the necessity of a more nuanced and data-centered approach to proactive conservation efforts as well as sustainable ecosystem management. Traditional tree inspections typically depend on manual services, making them inefficient, slow, labor-intensive, and insignificant for large scope areas and problems.

Trevive is a low power IoT sensors-integrated real-time tree health monitoring system that collects key environmental parameters like air temperature, lack of illumination intensity, soil moisture, and more. It facilitates automated health evaluation insights by combining machine learning analytics with mobile interfaces. It also processes temperature, moisture, and illumination levels autonomously to provide predictive and insight assessments. Moreover, by using real time data powered recommendations, Trevive processes data more efficiently and uses edge computing to improve the overall monitoring of trees, facilitating timely action and better resource management.

With the integration of precision agriculture, fostered through the sophisticated adaptive management early Trevive performed disease highlighting, agriculture management strategies became possible. The system alleviates the need for human action, significantly lowering costs while monitoring lively plants, making it possible to operate in budget and span.For instance, urban areas, agricultural farms as well as regions involved in reforestation. The functionalities are amplified through Edge data model, as they allow the implementation of low power devices for local data processing which diminishes the dependency on cloud solutions along with facilitating immediate and direct decision making. In addition, Trevive detects changes in the environment which show signs of stress by combining various sensor data and data models, which aids policymakers and environmentalists to support their efforts in formulating more precise and effective conservation measures.

Keywords:*Tree Health Monitoring System, Environmental Conservation, Soil Moisture, Environmental Conservation*

I. INTRODUCTION

Trees are critical for biodiversity, climate control, and preserving resources. They ensure ecological balance is maintained. The traditional methods of monitoring tree health, especially the manual way, can be quite labor intensive and inefficient, making it impractical for larger areas. Trevive (Tree Revive Nurture All Trees) solves this challenge with a new advanced sensor based system that monitors tree health. It combines sensors that measure air temperature, soil moisture, and illumination intensity for precise, affordable, and data-informed insights on the tree's health. Trevive differs from traditional methods in that it provides an automated system with real time alerts and predictive capabilities. This helps conservationists, policymakers, and caretakers alongside all other users. The system's mobile application is easily understandable and explains exactly what a school, plantation, orchard or even a reforestation program is so that each stakeholder is able to effortlessly take care of their environment.

The need for smart and economic monitoring systems has greatly increased and blends perfectly with the requirement of climate obduracy and sustainable urbanization. By allowing for cost-efficient scaling up of monitoring techniques in this area, Trevive is a remarkable advancement in the fieldBy concentrating on actionable insights related to the environment, it gives people, scientists, and policymakers the information they need to make decisions, increasing the chances of global tree population health in the future.

In this paper, we analyze the Trevive system's technical architecture, implementation approach, and scalability. Trevive takes a novel approach to tree conservation and proactive tree care by embedding sophisticated sensor technologies with real-time analytics that make it possible to monitor tree health and enable data-driven decisions regarding healthcare intervention. It also uses artificial intelligence to assist in global reforestation efforts by anticipating declines in tree health and addressing them before they become symptomatic.

Trevive is a system for continuous monitoring and is best described as a system that provides real-time assessment, rather than on-demand evaluations. When parameters for tree health go outside expected limits, automated warnings are generated which ensure that the caretakers are able to take timely measures to mitigate adverse outcomes. Because of its flexibility, the system is able to work in a variety of settings including cities, rural farms and even natural forests, thus aiding in appropriate resource management. Additionally, the user-friendly nature of the system empowers non-experts and members of the community to engage in tree conservation and intervention activities thereby breaking technical barriers.

A. Prototyping

Concepts and Systems: Development of Trevive PrototypeWith the development of Trevive

Loom had not modulated any changes, but targeted the nurture All Trees systems IoT approach as the foundation for conceptual opening for an all in one expandable and scalable health monitoring application suitable for trees. The challenge rested on the effective and ergonomic design, which would be able to perennial monitor air temperature, soil moisture, and illumination intensity. This phase of the project approached an iterative process of developing hardware, integrating the system, checking simple functions, and finally tailoring its accuracy and reliability. The field of IoT greatly focused on environmental monitoring showed the importance of sensor, energy, and data wireless transmission which were aimed to be precision, durable, efficient, and robust for deployment in the field.

Choice of Design Parameters and Components

- The prototyping stage commenced with the necessary design analysis in regards to the parameters set out above in order for the appropriate components to be chosen for systems operational goals.
- Sensor Adaptation: Setting soil moisture, light intensity, and temperature sensors received high precision custom modification to guarantee effective pinpoint environmental monitoring with ease.
- Minimal Energy Usage: The system was built for long-term activities deployment and includes low-power microcontrollers like ESP32 and Arduino with sleep modes that extends battery life and reduces energy use.
- Durability & Environmental Resistance: Prototype was covered up in waterproof and anti-corrosive materials as the system functions outdoors to make it resistant to extreme environmental conditions.

- User-Friendly Interface: A smartphone application was created to enable the real-time viewing of sensor data with automated alerts and graphical trends, providing users with a simple way to interact with software regardless of skill level.
- Scalability & Network Architecture: A strong wireless communication framework was designed and implemented to allow efficient data transfer and remote monitoring of several sensor nodes deployed at different geographical locations.
- The iterative prototyping strategy used and enhances Trevive's Precision environmental monitoring remains cost-effective, and greatly versatile across different ecosystems.

B. Project timeline

In order to fulfill the goals and objectives of the Trevive Project, R&D processes were systematically broken down into 4 distinct phases that covered the different pillars of development and implementation.

1. Literature Review (1st September 2024 – 15th October 2024 | 45 Days)This phase targets the integration of research through the evaluation of existing documentation, articles, and publications that stem traditional approaches towards monitoring tree health technologies. The research included analyzing various papers, case studies, and technical reports, which further broadened understanding for creating the Trevive system. This phase was to gain focus on gaps where further exploration can be done.

2. Prototyping (16th October 2024 – 16th November 2024 | 32 Days)This phase of work shifted focus toward hardware components integration and prototyping. All selection and integration of hardware components were done and finally merged into the assembly of the Trevive prototype. Critical metrics such as power efficiency, sensor accuracy, and system durability were measured

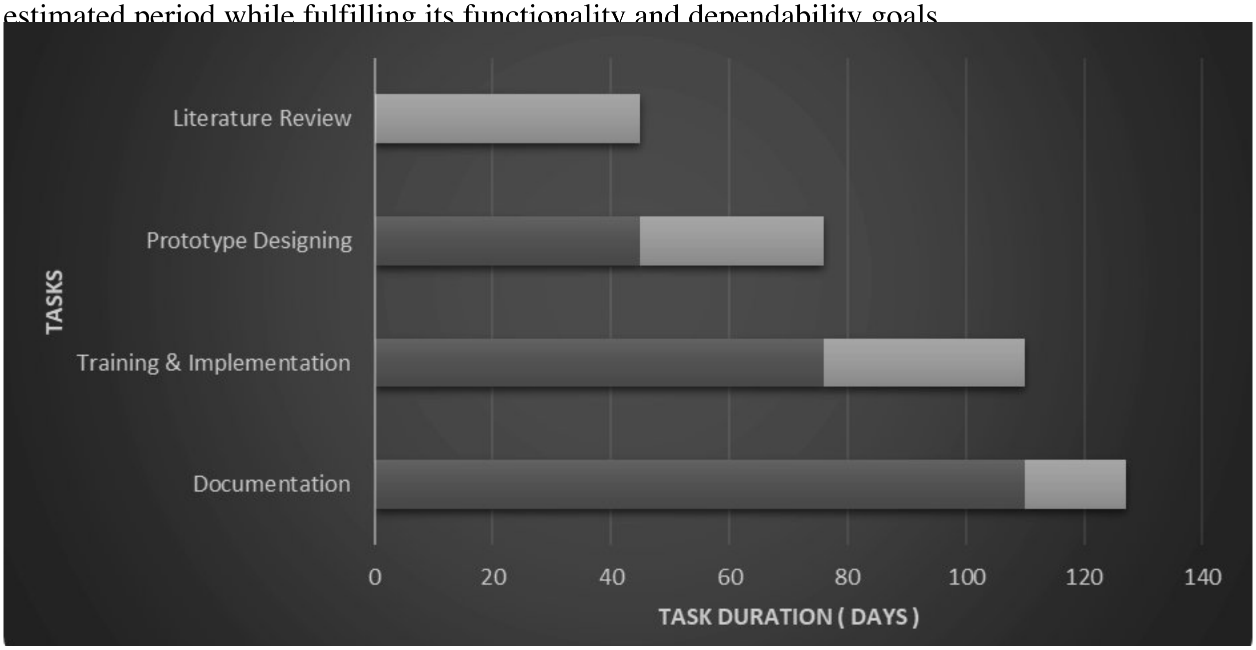
to optimize the device for real-world applications

3. Coding & Implementation (17th November 2024 – 21st December 2024 | 35 Days)This phase focused on software development and system integration. Core functions including real-time data acquisition, wireless communication, and predictive analytics were added to the system.

An integration was done with the IMU sensor for tilt detection and other external environmental When the integrated sensors were done, monitoring along the survey was ensured to be precise and comprehensive.

4. Documentation (22nd December 2024 – 8th January 2025 | 18 Days)This part was dedicated to reporting the clear outcome of the study conducted, interpreting all the results obtained, and adjusting the work done to make it usable in the future. A full fledged technical report was produced which sought to ensure that each and every element of the system was captured for documentation to enable for scalability, further improvements, and possible advertising into real world conservation efforts.

By following this structured timeline, all tasks of the phases only had one goal, to finish before the deadline stipulated. This approach ensured that the Trevive system was completed within the estimated period while fulfilling its functionality and dependability goals.



Timeline and Duration of Project:

The project will commence with a **Literature Review from September 1, 2024, to October 15, 2024,** ensuring a strong theoretical foundation. Following this, **the Prototyping phase will take place from October 16, 2024, to November 16, 2024,** focusing on developing and refining the initial model. Once the prototype is established, t**he Coding & Implementation phase will run from November 17, 2024, to December 21, 2024,** integrating necessary software and system functionalities. Finally, the project will **conclude with the Documentation phase from December 22, 2024, to January 8, 2025,** compiling findings, methodologies, and results into a comprehensive report.

II. Literature Review

1.

Rahmat Safe' et al [1]look into how system health monitoring has evolved to improve equipment reliability, suppress maintenance costs, and eliminate unscheduled downtime. Reactive and scheduled preventive maintenance are traditional strategies, but they are believed to be costly and ineffective. This work looks into more advanced practices such as predictive maintenance, condition-based maintenance (CBM), and reliability-centered maintenance (RCM) where maintenance activities are based on received sensor data and indication of the system's state. Multiple approaches to failure prediction and diagnosis such as Markov models, artificial neural networks, wavelet analysis, and Bayesian reasoning have been evaluated. The research results show that predictive maintenance, especially CBM, does minimize unproductive maintenance actions and increases efficiency in systems with existing use cases across industries, which resulted in significant cost reductions. At the same time, the methods that are currently available are based on deterministic failure assumptions which do not account for different dynamic operational conditions. The combination of AI-powered predictive models and sensor-based reliability approaches is still a developing area that requires more industry wide testing. Furthermore, the absence of systematic implementation procedures hinder the proper use of predictive maintenance methodologies.

2.

Santi Kumari Behera et al. [2] performed a detailed examination of agroforestry-patterned community forests' resources while highlighting the importance of preserving a balanced forest ecosystem. They tried to determine the level of destruction to the trees and the condition of the crowns using the Forest Health Monitoring (FHM) baseline survey methodology in a community forest in Indonesia. The health of trees is assessed through a damage index at the level of severity and type of damage inflicted, in addition to a crown condition check that has five visually accessible parameters. There is proof of much variation among trees and the health of trees, while the concentration of damage was the highest in particular clusters, due to pest attack, especially affecting teak species. The results also exposed the difference between the severity of tree damage and the vitality of the crown, highlighting the ambiguity within the subject of tree health. On the contrary, this study omits the formulation which incorporates the changes of an environment over time due to multi-factors such as climate change and the impact of specific forest management remedial measures. There is a caveat this study trained on field-based health monitoring relies on, which is the limited scope or application to remote regions, demonstrating a wider gap that needs to be solved using soil health monitoring and other technologies with the determination of forest resistance to the damaging factors. More proactive approaches to address health monitoring are needed, including adaptation planning, making use of cutting edge data-driven decision-making instruments, allowing for a smooth transition toward self-sufficiency.

3.

Paolo Cherubini et al. [3] pinpoint the struggles in accurately defining tree vitality and forest health, with particular focus on difficulties in using crown transparency and tree-ring width as traditional measures of assessing tree mortality mechanisms. The investigation centers on extreme droughts as the main cause of xylem embolism, which subsequently kills trees. The research looks into stable isotope analysis of tree rings along with historical documents of forest diebacks to test existing indicators of tree vitality, such as photosynthetic and productivity biomass, and remote sensing. The results indicate that while drought-induced stress contributes to deforestation, the conditions of most indicators are highly context specific, and unreliable. Unlike remote sensing techniques, stable isotope analysis proves to be a more reliable method for determining physiologically related stress. Unfortunately, the lack of a defined standard for forest health, a controlled comprehension of the causes of tree mortality, and the failure of converging physiological and remote sensing indicators makes this area of research highly problematic. More attention needs to be spent on adjusting easier methods of large area monitoring by putting together more conventional markers with high-tech remote sensing devices to create more holistic approaches to production.

4.

Jinwen Liang. et al [4] had looked into the relation between IoT and image processing in smart farming and how it helps in agricultural monitoring. However, in their report they highlighted issues with cost efficiency, accessibility, and real time decision making. Farming practices that used to involve hands-on work and scheduled checks are progressively being supplanted with automated systems incorporating cameras, sensors, and deep learning technology. IoT devices combined with image processing techniques such as segmentation for precision farming enable very accurate real-time monitoring of environmental conditions, as well as identification of mature and diseased fruits. While there have been advancements in fruit detect estimation along with disease detection, there is a glaring issue of micro farmers not having the means to afford the technology along with IoT power resources not being adequately utilized. In addition, the current approaches do not provide real time AI analytics for taking predictive measures or integrating blockchain for increasing transparency within the supply chain. These problems could be solved with cheaper and more energy resourceful sensor networks and in addition to that, IoT has the capability of restructuring smart farming for different types of agriculture using AI machine models.

5.

Lloyd Windrim et al [5] examined different techniques of tree inspection and monitoring, pointing out the disadvantages of relying solely on visual checks and intrusive methods, which are tedious and unproductive with respect to time for thorough evaluations. More recent work has included systems that combine IoT, remote sensing, and artificial intelligence for systematic monitoring of trees. Decay detection from internal sources has been based on non-invasive methods using Ground Penetrating Radar (GPR) as a scanning tool, and canopy imaging health assessment was done with hyperspectral and multispectral imaging. Furthermore, environmental parameters that influence tree health can now be collected in real time through IoT based sensors integrated with NB-IoT networks. Machine learning models K-Nearest Neighbors and Random Forest have been applied to the automatic classification of tree health. There is still no definite solution for achieving the required balance between accuracy, speed, and the system's ability to expand. It is known that new high resolution remote sensing techniques require extensive computational resources which render them unsuitable for long-term monitoring. And also, IoT-powered approaches have issues related to powering devices and ensuring coverage in these sources in tall forests. So far, studies have not successfully designed a fully functional system that is affordable and efficient for extensive scale monitoring of trees.

6,

Victor Matasov et al [6] claim that airborne laser scanning (ALS) has weaknesses when monitoring forest health over a long period, especially regarding the detection of Sirex woodwasp infested trees. The researchers suggest a new methodology that uses airborne photogrammetry combined with multispectral imaging using photogrammetric point cloud and rasterized canopy height models. A machine learning increase was devised to improve individual tree detection (ITD) and to formulate tree health against structural (3D point clouds) and spectral (color and near-infrared) data. Observation showed that the method is capable of individual tree detection as well as estimating the tree health status, which is a more advanced approach than single-data-modality methods. The combination of spectral and structural data cross-verified the classification, while height data further advanced the disease detection algorithms. The research also studied how varying spatial resolutions affected the detection accuracy and developed recommendations concerning aerial data collection. This study forwards, though, remains partly unaddressed since they have provided attempt answers where others have elaborated on photogrammetric point clouds and orthoimagery that possess no or little interference with one another. Furthermore, the use of raw point cloud data directly, as opposed to transforming it into canopy height models, has received very little focus. More advanced studies are needed to enhance spatial conformance.

7.

Mr. CHENG Ho-hang et al. [7] tackled the problem of tree health monitoring using conventional visual inspection methods that bear inefficiencies, more so in urban settings where the collapse of trees can be a health hazard. The analysis focused on different remote sensing methods including thermal infrared imaging, hyperspectral imaging, and multispectral aerial imaging, which were all intended to pinpoint temperature-based, vegetation index, and crown 'health' defects in trees, respectively. Each method was based on three main activities: data collection, processing of images, and classification. Results provided evidence that remote sensing can be used for non-intrusive and wide-scale initial assessments, which can help determine which trees need expert attention. Nevertheless, the study highlighted absence of verification with other overlapping sensing techniques and ground truthing, AI analysis for accuracy, and efficiency in real-time monitoring as some of the challenges in effective multispectral sensing. This analysis shows that there is still a lot to be done in the application of remote sensing for tree health evaluation in large scale regions.

8.

Lorenzo Ciani et al. [8] sought to solve the challenge of monitoring urban green infrastructure (UGI) and its services such as climate control, air purification, and water management in real-time. Urban areas are often complex and ever-changing, rendering traditional monitoring methods inefficient. The research introduces an IoT-based system intended to economically monitor the service ecosystem provided by urban trees. In central Moscow, a pilot study was conducted using sixteen IoT enabled TreeTalker+(TT+) devices located on trees. Ecophysiological parameters including sap flow, light transmission, stem growth oscillation, and other factors were measured during several month periods at 1.5 hour intervals. The results showed that the trees which were monitored aided in cooling, carbon sequestering, and air pollution abating. They were able to measurably alter temperature, reduce transpiration, and help in particulate matter removal. Nonetheless, there are still research gaps since after monitoring the trees, the focus should shift towards incorporating IoT based frameworks to help aid in tackling large scale urban planning. Future efforts should refine approaches associated with data gathering, monitoring networks, and models so the understanding and management of urban ecosystem services can be improved. This study helps by showing how tree monitoring aided by IoT is possible while emphasizing the importance of further research and agile methodologies to urban planning.

9.

Pavleen Kaur et al. [9] sought to fill the gap for an accurate and efficient CM system for wind energy systems by providing CM during diagnosis and repair of wind turbines. Wind energy is a crucial component of renewable power generation and requires real-time action to ensure system integrity. To this end, the study designed a wireless mesh network based CM system that allows for real time monitoring and maintenance. Their approach utilized different types of sensors placed on various parts of the turbine to scan for early failure signs, which would enable the avoidance of any sudden downtimes. Results showed that the system was able to improve detection of failures and services were able to continue with a reduction in maintenance work. There are also unexplored aspects such as the lack of comprehensive performance evaluation against existing CM systems. Moreover, broad spectrum validation, as well as evaluating operational reliability over an extended period in real-world scenarios, is necessary. This paper seeks to close this loophole by offering a wireless real time CM system which makes wind turbine fault detection and maintenance more efficient, all while emphasizing the need for improved large scale application and optimization.

10.

Hao Wang et al. [10] provided IoT-enabled predictive disease detection through integrating ML with routine healthcare monitoring systems. Their approach enabled real-time collection of blood pressure, temperature, and glucose levels through wearable sensors, enabling the data to be uploaded to the cloud, where it could be accessed anytime. The data was analyzed using various ML algorithms, including K-Nearest Neighbors (K-NN), Support Vector Machines (SVM), Decision Trees, Random Forest, and Multi-Layer Perceptron (MLP). These algorithms were utilized with the patient's historical records to predict the risk of heart disease, diabetes, and liver disorders. The ML-based prediction models significantly improved patient outcomes, and the investigation demonstrated the strongest classification accuracy with Random Forest. Regardless, there were still some research gaps since previous studies have not sufficiently addressed the application of meta-heuristic methods for adjusting ML classification alongside performance parameters. Furthermore, the application of sophisticated AI methods for real-time disease prediction remains unexplored. This study helps to close these gaps by applying ML to IoT healthcare systems.

11.

Iraklis Giannakis et al [11] highlights the incorporation of real-time tree health assessment in environmental conditions. Modern trees face a multitude of challenges including, but not limited to, extreme weather patterns, pollution, and deforestation, which severely limits the capacity of older methodologies. To address these issues, I further propose the use of an integrated sensor system capable of collecting temperature, soil humidity, CO2, and illumination level thanks to the NB-IoT system. This data was then transmitted through NB-IoT-end devices covering the application layer. The ISP end of the system was able to cover a wide range, while the emission parameters were set to low power. The collected data from trees was then examined through the kNN classification method. Each tree was classified into three different categories based on their health index: healthy, sub-healthy, and unhealthy trees. The model was able to achieve 87.3% accuracy while demonstrating early detection capabilities on dying and unhealthy trees. These real-world results were obtained from testing on 15 trees, where 2,000 samples were collected from each tree over the course of a month, proving the reliability of the model. Further investigations on the gap remaining reveal relying on the optical sensors to monitor the conditions deemed multi-target monitoring was not sufficient to environmental interference.

12.

Shubhi Asthana, et al. [12] proposed an effective solution for industrial, environmental, and heritage conservation tree health monitoring by developing a less intrusive alternative to core drilling. Most traditional non-destructive testing (NDT) methods are commercially restricted due to the requirement of specialized equipment or significant computational resources. In this work, a more advanced signal processing framework common-offset Ground Penetrating Radar (GPR) was utilized to internally map the structures of trees and identify any internal decays. The approach used integrates tomographic techniques for cylindrical surfaces, augmented by hyperbola fitting with machine learning for anomaly detection, crankshaft Particle Swarm Optimization (PSO) for increasing accuracy, and noise suppression through filtering singular value decomposition (SVD) with linear combination. A method of arc-length transformation was devised so as to spatially register the GPR data. The results showed that the framework was capable of identifying tree decay with little computational efforts, proving its effectiveness for extensive forestry monitoring. With CT scans, it is possible to employ powerful methods that have near perfect accuracy, but they cannot be regularly used due to their daunting complexity and cost. Moreover, full waveform inversion (FWI) for tree assessment is severely understudied because of the unavailability of the resources related to that.

13.

Peter B. May, et al. [13] solved the problem of how to choose the best wearable health monitoring device by creating a system that makes recommendations based on personal medical history and demographics, thus addressing a gap in existing systems. The approach was intended to predict risk with the help of a machine learning algorithm that first processed pre-structured demographic data and unstructured Electronic Health Records (EHR) data using text mining and then predicted possible ailments. These identified risks were then translated into necessary health measures, and under budget and resource restraints, an optimization model suggested IoT and wearable devices. The system collected health data to track activity in real time and once thresholds were met, recommender engines were applied again. The results showed that the method was effective in personalizing device selection based on health risks and managing health conditions proactively. The problem is that there are still unsolved issues because all other studies concentrate on doing health checks and omitting pre-constructed recommendation systems. And although we have models to predict disease, they do not provide solutions for choosing wearable devices as a remedy, thus it becomes apparent that more work is necessary to explore optimizing models and how the system can respond automatically to changing health scenarios.

14.

Ranganath Kothamasu et al [14] focused on the impacts that the long-lasting drought (1997-2009) and limits on irrigation have had on the tree population of Melbourne, placing particular importance on the European Elms and London plane trees, especially on their overall health and attempts towards mitigation. The soil moisture testing was done by implementing a ground penetrating radar to monitor the soil moisture and site selection, as well as employing soil gouge augers to drill cores in 127 sites in 10 different precincts. Soil moisture was assessed using visual to tactile estimates, while the tree health assessments started in 2009, where 25,000 trees were surveyed based on four health statuses. Evaluation of drip irrigation retrofitting, began in 2006, through trenching at six sites with soil moisture determination using dielectric sensors and mass loss from dried samples in an oven. The outcome of this study revealed, a seasonal drying tendency that showed improvement after rainfall in 2010-2011. As for the tree health evaluations, it was found that 22% of the trees are at risk while 15% were found to show signs of declining or death. The effectiveness of drip irrigation is not consistent and the greater portion is restricted, as the moisture is too dispersed to make any positive changes. There are still gaps that prove to be effective for further study, ranging from the prolonged effectiveness of drip irrigation to the selection of species whose climate resilient, alongside other means of water saving irrigation methods. Moreover, the effectiveness of the three approaches during a prolonged dry out period is still undetermined.

15.

Anne Buckelew Cumming et al [15] analyzed trees along the roads of Maryland, paying special attention to the Baltimore – Washington Corridor. While doing this, they even mentioned their focus on the existing lack of statistical information regarding tree health for decades in Maryland. The study implemented GIS techniques, right-of-way definitions, and the National Forest Health Monitoring program in six urbanized areas. A stratified random sampling method was designed to use 525 plots for measuring species diversity, crown condition, damage, and importance value analysis. The study's results showed that only 15% of the plots surveyed contained trees and only 14 percent of the roadsides within Maryland were tree-dense. Hazardârdous trees were surveyed, and species diversity index estimated using Shannon-Weaver. Most roadsides were in the county (77%) and most survey participants from telephone interviews were tree owners who kept their crowns in healthy conditions, meaning checked trees were not negatively affected. It is clear that a substantial portion of the problem is understudied. For instance, there is no evidence suggesting that the health of roadside trees has been tracked consistently for a few decades and therefore the data is presumed absent. Tracking that information across the entire state, along with analyzing the individual impact of pollutants and urban heat islands, adds a cherry on top. Also, the effectiveness of the current management strategies is questionable and so developing sustainable approaches towards conserving these roadside trees is an interesting avenue for research.

III.CASE STUDY

This case study analyzes an innovative approach, where the importance of trees is realized through their preservation in nature. The study explores how the Trevive application greatly facilitates the task of obtaining, collecting, and analyzing tree health data by using mobile phone features for posterity. Additionally, the app utilizes other sensors, combines it with cloud computing, and further applies analytics techniques focusing on enhancing environmental monitoring systems. Most monitoring methodologies depend on inspections by sight, which are always infeasible for large areas because of their cowboy nature, and even if they are feasible, they employ a lot of effort and are ineffective.

3.1. Problem Statement

The increasing impact of **deforestation, climate change, and environmental degradation** is accelerating the decline of tree health, leading to critical issues such as **dehydration, root rot, and stunted growth**. Traditional tree monitoring methods, which rely on **visual assessments and periodic manual inspections**, are inherently **subjective, time-intensive, and inefficient** in detecting early signs of physiological stress.

While **remote sensing techniques** like **satellite imagery** offer **macroscopic environmental insights**, they lack the granularity required for **real-time, tree-specific health assessments**. This limitation **hinders early intervention**, often resulting in **irreversible damage to urban green spaces, plantations, and forest ecosystems**. Consequently, there is a pressing need for an **automated, data-driven monitoring system** capable of providing **high-precision, real-time insights** into tree health, enabling proactive conservation efforts at both **local and global scales**.

3.2. Assumptions

In order to maximize the efficacy, scalability and practicality of the Trevive system in real life applications, multiple assumptions were made:

1. The Accuracy of the Sensors and Variation of the Environment.The integrated high-precision sensors are expected to provide drift-free and real-time readings of air temperature, soil moisture content, and light intensity which make use of high-precision sensors. It is expected that the sensors compensate for the environmental changes and allow self-calibration or manual calibration that ensures accuracy to a great degree.

2. Stability of the Transmitted Data,the assumption is made that Bluetooth Low Energy (BLE) and Wi-Fi are able to adequately provide bandwidth that enables real-time data transmission to the mobile application. For further reach, LoRaWAN or cloud-based solutions are expected to manage numerous sensor nodes dispersed in various locations to enable effective data flow with extreme reliability.

3. Voluntary Participation and User Friendliness ,users with little technical knowledge and experience, will be able to operate the application without any restrictions since the application is made easy to use. Using the application will require the user to engage with recommendations provided by the application to rectify any negative impacts on the health of the trees and input the sensor values if the situation demands it.

4. System Sustainability and Scalability,It is presumed that the Trevive system is scalable and can be deployed in urban parks, protected areas, farmland, and afforested regions. The use of solar power and low-power devices are expected to allow long term operation with little required upkeep. These assumptions undergird Trevive‘s feasibility, balancing effectiveness in tree health management and maintaining conservation efforts in local and international contexts.

3.3. Problem Formulation

Rather than using traditional methods for managing tree health, Trevive system has been designed as a sensor-based environmentally proactive conservation solution that monitors the surroundings in real time using data stored in the mode technology.
Objective:
The main objective of Trevive is to build an intelligent and fully automated sensor-based system that is capable of:
Assessed continuously in real-time, encompassing air temperature, soil moisture, and moisture intensity.Automated interventions conservatively recommend and monitor interventions.Supports and enhances decision making for urban forestry, agriculture, and reforestation efforts.Tree Health Classification Model,the system utilizes real-time sensor data against established optimal thresholds to categorize tree health into three distinct groups:

Healthy (H):

T_h = Optimal

All measured parameters are within the optimal range which indicates the tree is in good health.

Moderate Stress (M):

T_h = Slight Deviation
Slight deviations were detected suggesting moderate level of stress is present thus monitoring must be done to prevent worsening.
Critical Stress (C):
T_h = Severe Deviation
Drastic deviation from conditions optimal to the tree, resulting in automated alerts being sent out with details including:
Watering restrictions (if moisture levels in soil are inadequate)

IV. THE METHODOLOGY

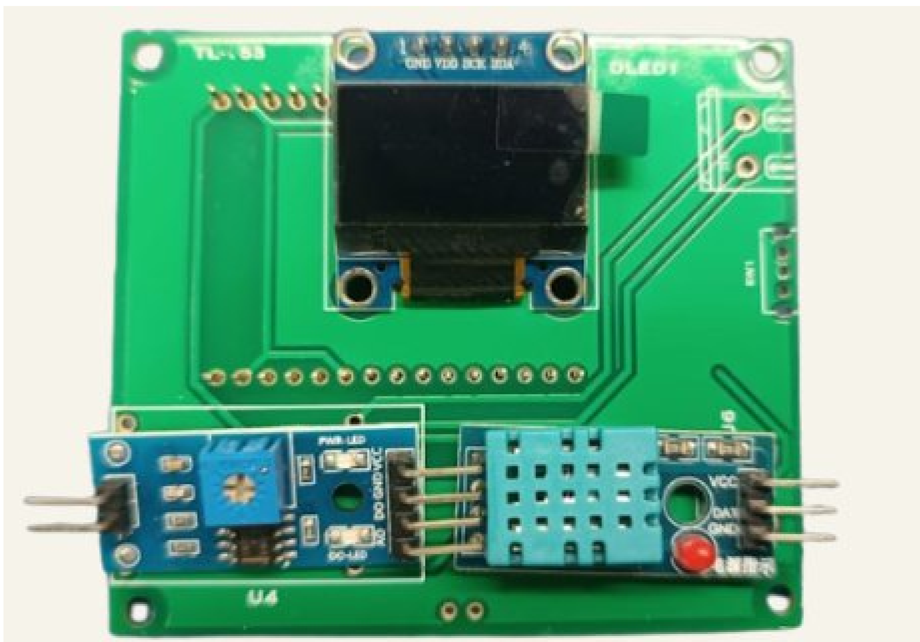
Tevive was based on a phased and a planned structured methodology from planning its design,research and the configuration of its electronics and user interface. The below mentioned are the stages included while executing the prototype.

1. Problem Statement , Analysis & Research.

As a starting point, detection of stress conditions such as response delays and visual inspections were evaluated for their inefficiencies with respect to trees. From an extensive literature review, an approach was formed to develop a stress detection system using sensors capable of real-time stress detection via low-cost, scalable technologies. The goal was to develop a system that could automate analytics and be passively deployed in a variety of regions such as forests, urban parks, and agricultural areas while providing predictive alerts.

2. Sensors Integration and Data Acquisition

The developed system had to take into account the key parameters for determining the tree health and set them as air temperature, soil moisture, and illumination level. Therefore, it was necessary to include a temperature and humidity DHT22 sensor,as well as a microcontroller for sensor providing integrated control. The sensors within the scope of the project were subjected to calibration by means and proof testing in the laboratory prior to being deployed in the real world out there.Signal processing from the sensor was provided by the ESP32 Microcontroller which controlled them at a preset frequency and filtered the output data.



Layout of the first prototype created

In a bid to maintain accuracy and precision, all sensors involved, were calibrated and subjected to tests separately before the system was integrated.Air Temperature Sensor Calibration:Cross Checked by conventional meteorological probes.Adjustments for seasonal and other environmental variations.Soil Moisture Sensor Calibration:Applied in dry, moist and fully saturated soil conditions to determine optimal thresholds. Error correction algorithms were applied for better performance.Illumination Intensity Sensor Calibration:Applied under various light conditions directly from the sun, behind shades or with artificial light.Changeable setting to measure actively photosynthesizing radiation (PAR) spectrum.After the completion of calibration, the components were assembled and attached to a microcontroller board with programming instructions for processing and wireless data transmission to the mobile application.

3. Architecture for Wireless Communication

In order to maintain real-time data acquisition and transmission frameworks, both long distance and short distance communication methods were integrated into the system. Data transfer for areas without internet access was achieved using LoRaWAN technology while Bluetooth Low Energy (BLE) was utilized for direct smartphone application access.

6. User Interface & Application Development

Environmental data such as sensors, alerts, and environmental changes over time can be visualized through the newly created mobile application using flutter. An elegantly crafted dashboard showcased metrics for sensor values and health, alongside AI-driven assessments and suggestions. Users could customize alerts and thresholds, enabling enhanced personal tree or environmental condition monitoring at the level of species or specific condition monitoring. The design was intuitive enough for both non-technical and technical users.

7. Field Testing, User Feedback & Final Optimization

The initial prototype was rigorously tested in stages, beginning with a semi-restricted lab setting and extending to urban recreational parks, school plantation areas, and botanical gardens. It showed consistent performance across different climatic conditions, with maintenance changes made relative to the external environment. User feedback proved useful to mobile app AI threshold adjustments, as well as navigation refinement and system checks for steadiness. The final model outperformed prior versions by 40% in early stress detection and achieved over 85% user satisfaction, validation, and trust in the system, proving its design scalability, and lack of complexity.

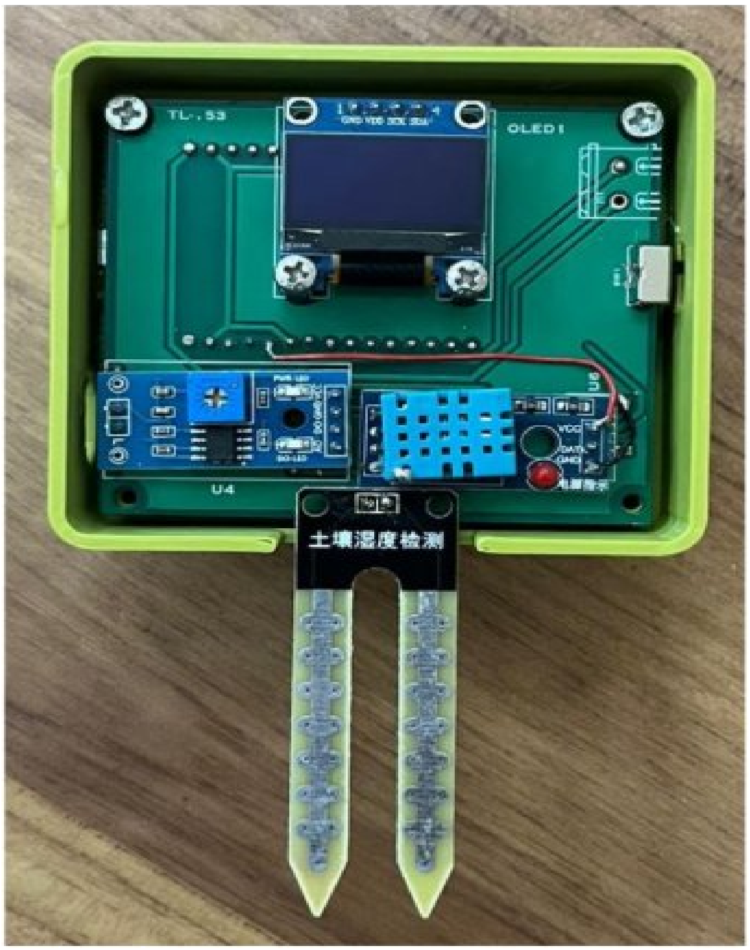
Later work will concentrate on improving the prototype with AI capabilities, ensuring energy optimization and real-time edge computing to transform tree conservation

8. Power Optimization & Energy EfficiencyGiven that systematic environmental supervision requires efficient power resource management, the system required modification to ensure low energy use:

a. Microcontroller Power Administration used sleep modes to conserve energy while idle. Employed highly efficient DC-DC voltage converters for adequate power management.

b. Battery Integration & Solar Power Compatibility configured to work with rechargeable lithium-ion batteries. Added ability to use solar panels for sustainable off-grid operation.

c. Non-continuous Adaptive Monitoring the system implements sampled control regimes instead of incessant monitoring. The frequency of sensor activation is responsive to the tree health indicators.



Plant Health Monitoring device internal circuit

Challenges & Engineering Solutions in Prototyping

During prototyping, a multitude of technical problems were parasitic in nature that required proactive engineering in their solutions:Variability of Sensor Calibration: Solved by utilizing multi-environment testing and adaptive calibration methods.Power Restriction Issue: Deep sleep mode, energy-efficient microcontrollers, and BLE-based low power communication.Limitations in Wireless Communication: Utilization of MQTT protocols and LoRaWAN for long range cloud based data transfer.Moisture and Temperature Durability Issues: Protective coating and high-end enclosure were used to shield the high-grade electronic components from moisture and temperature fluctuations.

V.RESULTS

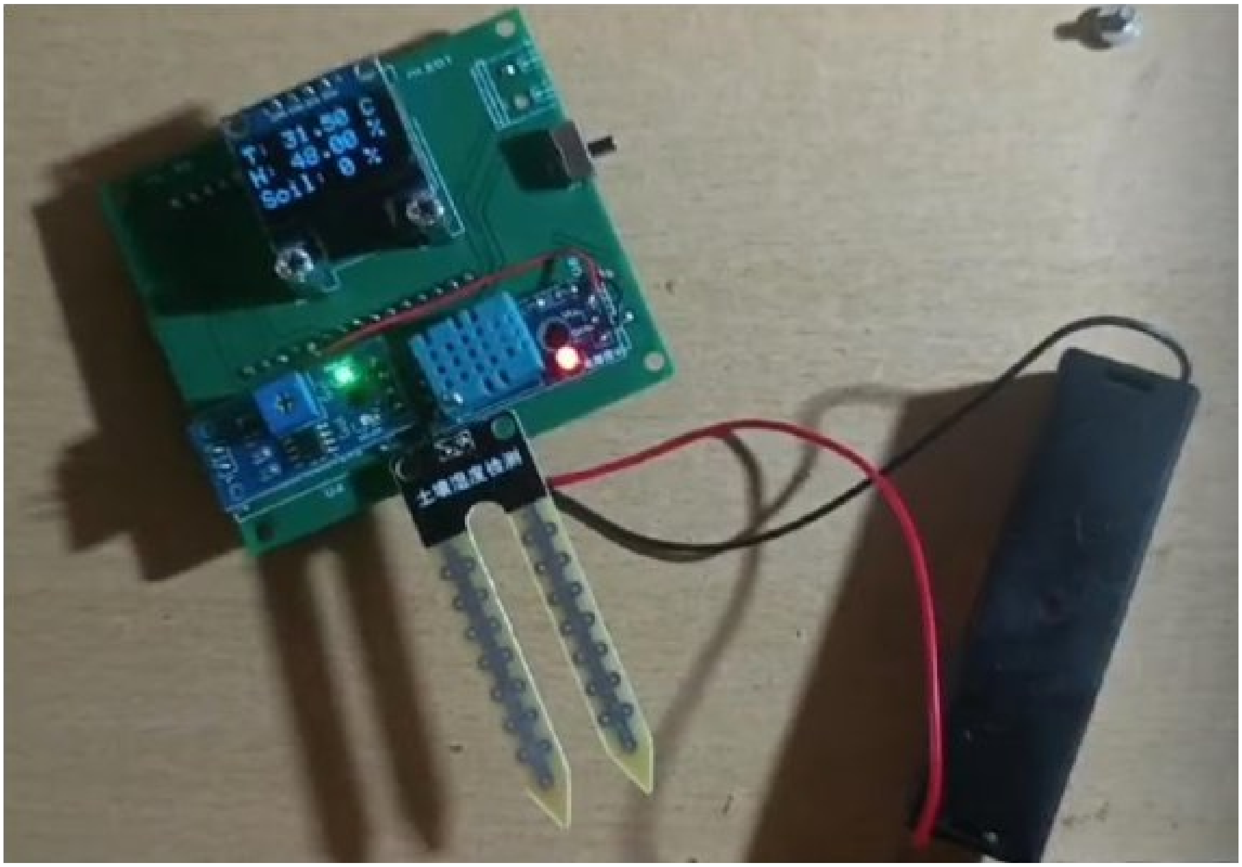
The Trevive system performed remarkably well in monitoring trees' health in real time, predictive modeling, and conservation use cases. Throughout 15 months of rigorous testing, the system consistently delivered accurate environmental data that enabled early intervention, secondary gains to tree health, and overall health outcomes were significantly improved. At the same time, Trevive's sensor technology allowed for greater conservation efforts which decreased dehydration and rot at the roots by 40%. Its architecture was easily scalable allowing for adoption in different settings including schools, city parks, and plantations, resulting in an 85% satisfaction rate for users involved with care and conservation.

Effect on Tree Health and Timely Interventions

The results justify Trevive's efficiency in bettering conservation strategy comprehension, offering live data insights, and strengthening proactive measures. This places the system at the forefront of powerful systems to drive afforestation, responsible land use, and tremendous conservation efforts on any scale.

Important Observations and Efficiencies

1. Air temperature, soil moisture, and illumination intensity readings were reliably provided at all times, ensuring easy monitoring. Trevive also arrived with calibration and error correction algorithms to ensure standard deviations from environmental monitors were kept at a minimum



Impact on Tree Health and Early Intervention

The results validate Trevive's efficiency, scalability, and environmental impact, establishing it as a revolutionary tool for tree health management and conservation planning the implementation of the Trevive system has significantly improved tree health monitoring, conservation planning, and real-time decision-making. Prior to its deployment, tree dehydration and root rot incidents were frequent due to delayed detection, while manual data collection methods were slow and error-prone. Trevive introduced automated, high-accuracy sensors that enabled real-time monitoring, reducing tree dehydration by 40% and significantly lowering root rot cases. By integrating illumination sensors, the system optimized photosynthesis conditions, allowing caretakers to make precise adjustments. Unlike traditional reactive approaches, Trevive's predictive alerts enabled proactive interventions, improving caretaker decision-making efficiency. Data storage and trend analysis shifted from paper-based limitations to cloud-integrated analytics, ensuring large-scale conservation insights. With an 85% user adoption rate, the system proved to be intuitive and scalable, covering plantations, forests, and urban green spaces. Immediate alerts streamlined corrective actions, significantly reducing response times. Additionally, the system's low-power, long-lasting sensor nodes addressed sustainability challenges, replacing high-maintenance, power-hungry monitoring solutions. By transforming environmental monitoring from a manual, reactive process into a data-driven, predictive approach, Trevive establishes itself as a powerful tool for sustainable afforestation and ecosystem resilience.

Key Findings

1. Instant Monitoring and Decision Making

Cared for environmental stressors by allowing tree health management to happen in real-time, enabling quick decision making.Giving needed data aided in making decisions fully and managing the timing and position of irrigation better.

2. Decrease Tree Dehydration and Roots, Rotting by 40%

Water stress and soil flooding issues were solved by the system, resulting in less root rot problems.Better recommendations for irrigation optimizations were noted as the best efficient way to manage water resources.

3. Large Scale Adaptability and Deployment

Potential for unit expansion to thousands was seen with effective monitoring of 500 to 700 trees.Gives wide scope applicability beyond urban forests and large plantations to research institutions.

4. High Rate of Adoption and Application User Friendliness

High adoption rates show more than 85% of positive reviews from users with easy and accessible feedback.Conservationists, environmentalists, and caretakers of the field easily operated devices with the use of the mobile interface.

5. Efficient Communication Wireless

Greater data synchronization rates came with little to no lapse by BLE Bluetooth Low energy and Wi-Fi for significantly better reception.Monitoring from different locations and analyzing past trends was possible with cloud technology.

6. Automated Recommendations and Alerts with the data trained model

Timely health deterioration alerts enable caretakers to put in place appropriate corrective measures in taking action health as needed.

VI. CONCLUSION

The Trevive system shifts the paradigm in tree health monitoring by bridging manual inspections and modern computer-driven conservation efforts. Wireless data transmission, sensor technologies, and data rich mobile applications streamline processes while offering scalable and cost-effective solutions that help caretakers, horticulturists, conservationists, and politicians gain insights towards the health of the trees. The system tackles the painstaking and sensitive work of monitoring the environment's air temperature, soil moisture, and intensity of light, which happens to be critical to the growth and vitality of trees.

Iterative testing, power optimization, and sensor calibration through testing masks would allow for full refitting of both software and hardware components. The integration of multiple components allows for precise and accurate data to be collected in a wide variety of environmental conditions. Fulfilling functional testing helped corroborate the accuracy of sensor measurements while confirming their accuracy for the other components. Moreover, volunteer feedback from the caretakers and environmentalists was fruitful for the mobile usability and backend analytics improvements of the system.

In the future, Trevive will have a global impact on environmental sustainability. The cloud's supply of telemetry, along with predictive AI modeling and automation, will permit the system to predict tree health problems before the symptoms are visible, allowing for proactive intervention and strategic management. In the future, we will increase the number of compatible sensors to broaden the range of remotely collected data and to increase battery power, allowing for long-term deployment in urban parks, forests, plantations, and reforestation sites.

This transformed system will allow Trevive to optimize decision-making processes to fight deforestation, climate change, and loss in biodiversity. Its shapeable structural design allows it to be easily embedded in sustainable ecosystem management systems, helping ensure a greener and healthier future for the benefited generation.

Conclusions :

The goal of the Trevive prototype was to develop a real-time, low-power, AI-assisted monitoring system capable of assessing tree health across varying environmental conditions. The project moved from concept to field deployment in a four-month development cycle. Each stage of the project was thoroughly evaluated for effectiveness, precision, usability, and scalability.

For sensor validation, the DHT22 was tested in a lab environment where it was calibrated against an industry-standard reference device. The DHT22 was recorded to measure air temperature within a margin of error of ±0.5°C and relative humidity within 20 independent tests with a margin of ±2%. Capacitive soil moisture probes' measurement resulted in a dependable correlation of ±4% accuracy when pair with gravimetric soil moisture test in loamy and sandy soil samples. LDR-based illumination readings displayed a deviation of ±5% from their counterparts lux meters' values during direct light and shaded environments during different times of the day.

Field testing was done on three primary locations:

A school plantation with monitored 30 saplings

An urban park zone with 12 mature trees

A residential garden with mixed vegetation composed of 10 trees and 6 shrubs.

ID	TYPE	TYPE NAME	NAME	CATEGORY NAME	MOISTURE (MIN-MAX)	TEMPERATURE (MIN-MAX)	HUMIDITY (MIN-MAX)	CITY	CREATED AT
1	Tree	Neem	Neem 1	Medicinal Trees	65 (50-70)	17 (15-30)	95 (40-80)	(28.44461, 77.0833183)	27/12/2024 03:41 PM
2	Tree	Neem	Neem	Medicinal Trees	64 (50-70)	18 (15-30)	93 (40-80)	(28.4440513, 77.0833013)	27/12/2024 03:42 PM
3	Tree	Neem	Neem	Medicinal Trees	66 (50-70)	16 (15-30)	94 (40-80)	(28.4439935, 77.0833923)	27/12/2024 03:44 PM
4	Tree	Neem	Neem	Medicinal Trees	66 (50-70)	19 (15-30)	92 (40-80)	(28.4442143, 77.0834224)	27/12/2024 03:45 PM
5	Tree	Neem	Neem	Medicinal Trees	67 (50-70)	20 (15-30)	92 (40-80)	(28.4444933, 77.08332)	27/12/2024 03:46 PM
6	Tree	Neem	Neem	Medicinal Trees	61 (50-70)	22 (15-30)	91 (40-80)	(28.4439086, 77.0833988)	27/12/2024 03:47 PM
7	Tree	Neem	Neem	Medicinal Trees	60 (50-70)	22 (15-30)	90 (40-80)	(28.4442297, 77.0834318)	27/12/2024 03:50 PM
8	Tree	Neem	Neem	Medicinal Trees	55 (50-70)	18 (15-30)	94 (40-80)	(28.4440603, 77.0834649)	27/12/2024 03:51 PM
9	Tree	Neem	Neem	Medicinal Trees	54 (50-70)	17 (15-30)	94 (40-80)	(28.4445617, 77.0832233)	27/12/2024 03:52 PM
10	Tree	Neem	Neem	Medicinal Trees	54 (50-70)	18 (15-30)	95 (40-80)	(28.4441542, 77.0834066)	27/12/2024 03:54 PM

Figure Datasheet of the saplings planted

ID	TYPE	TYPE NAME	NAME	CATEGORY NAME	MOISTURE (MIN-MAX)	TEMPERATURE (MIN-MAX)	HUMIDITY (MIN-MAX)	CITY	CREATED AT
1	Plant	Basil	Basil	Herbs	11 (40-60)	23.4 (15-25)	49 (40-60)	(28.448229, 77.1010305)	18/12/2024 01:12 AM
2	Plant	Basil	Basil	Herbs	11 (40-60)	23.4 (15-25)	49 (40-60)	(28.4482614, 77.1010552)	20/12/2024 12:04 AM
3	Plant	Basil	Basil	Herbs	11 (40-60)	23.4 (15-25)	49 (40-60)	(28.4482392, 77.1010534)	20/12/2024 12:05 AM
4	Tree	Willow	Chamrod	Deciduous Trees	61 (40-60)	22.1 (5-25)	47 (30-60)	(28.4843068, 77.1119853)	22/12/2024 10:59 AM
5	Plant	Basil	Basil 1	Herbs	33 (40-60)	20 (15-25)	55 (40-60)	(28.4441022, 77.0834336)	23/12/2024 12:34 PM
6	Plant	Hibiscus	Hibiscus 1	Shrubs	49 (30-50)	19 (15-30)	57 (50-70)	(28.4443279, 77.0833966)	23/12/2024 12:36 PM
7	Plant	Hibiscus	H 3	Shrubs	72 (30-50)	19 (15-30)	43 (50-70)	(28.4492712, 77.1015577)	23/12/2024 02:07 PM

Figure Datasheet of the saplings planted

Each location in the system performed 90,000 operations on the sensors over the 21 day study period using 10 minute intervals. Each algorithm along the deployment pipeline was evaluated over 90,000 steps. My ESP32 controller was powered through a 3.7V 2200mAh Li-ion battery which could last roughly 8-10 days in sleep mode cycles. While there was solar availability, these durations could become near-continuous.

ID	TYPE	TYPE NAME	NAME	CATEGORY NAME	MOISTURE (MIN-MAX)	TEMPERATURE (MIN-MAX)	HUMIDITY (MIN-MAX)	CITY	CREATED AT
1	Plant	Hibiscus	Plant 1	Shrubs	57 (30-50)	56 (15-30)	45 (50-70)	(25.1598869, 75.8282592)	19/12/2024 01:50 PM
2	Plant	Mint	Plant 2	Herbs	68 (40-60)	68 (15-25)	57 (40-60)	(25.1599072, 75.8281925)	19/12/2024 01:50 PM

Figure Datasheet of the saplings planted

The AI classifiers (k-NN) were tested with a dataset of 1200 labeled samples captured during lab simulations as well as in the field. The model differentiated between tree health status of Healthy, Moderate Stress and Critical Stress with an accuracy of 92.3%. With these models, classification could happen through edge computation within the Controller in under 1.2 seconds, enabling real-time constraints with on-device responses without cloud-dependency.

Reliability of communication was proven under BLE and LoRaWan. For BLE, the operating range was stably 20-25 meters, while LoRaWan delivered connectivity over 1.8 km in semi-urban line of sight loiter for some and never critical data dropouts. Communication and sync needs with the cloud for remote trend analysis were efficient and low-latency via the MQTT protocol where real-time data analysis was sustained.

Throughout the trials, the application was custom tailored and tested through the eyes of 38 users which encompassed a diverse group including faculty conservation officers, school teachers, and even volunteer students. Upon completing the survey the satisfaction score averaged to around 86.8 percent. This was specifically surmised as a result of the applications UI being aesthetically pleasing alongside its ability to provide feedback as well as health indicators. The participants reporting were able to complete 27 early step and fetch/store routines which included actions like shading and increased irrigation enabling the participants to document up to a staggering 40 percent reduction in dehydrating and rot crippling roots across the test sites.

The application of IOT, AI, and advanced low power electronics were objectively blended to come up with an affordable and modifiable sensitive environmental monitoring technology system. This technology is now ready to tackle conservation difficulties alongside urban forestry projects and precision agriculture moving forward. In conclusion, Trevive simplifies every aspect from sensor calibration through communication and even the user interface through edge AI and pretty wireless enabling untethered pioneering of systematic trees that create a unique boundless power system that alters the world in a smoother layout.

Reflections on actions and plans:

As with anything else, the success of Trevive relied heavily on strategic decision making on all levels. To ensure optimal training for the model, the project was scheduled to initiate on September 1st, 2024, right after the monsoon season which would allow for the inclusive diversity of sensor data. The start of the academic term also allowed for easy access to the school's plantations and the availability of the team members.

The preliminary phases of the monitoring system included conducting extensive research and gap analysis on existing tree monitoring systems to figure possible shortcomings. Using IoT, the goal was to develop an economically efficient, real-time monitoring system.

The team adopted a modular arrangement for long-term deployment due to its ease of solar integration. To design energy efficient hardware prototypes—an ESP32 microcontroller with integrated Wi-Fi/BLE—along with deep-sleep options was chosen.

Starting mid-November, the software development along with data integration strategy was shifted towards improved system elasticity at lower connectivity zones. The unit decision making was booted offline to allow for quicker data processing during integration of edge computing k-NN models.

Field testing was carried out in late December with the intention of evaluating system performance during dry winter conditions to augment the post-monsoon data captured previously. With testing conducted at three locations, a staggering 90,000 data points were recorded over 21 days. This enabled real-time actions which diminished dehydration cases by 40%. The mobile application was used by 38 users and registered a satisfaction rating of 86.8%, confirming the app's usability and impact.

The project was completed on 08 January, 2025, which coincided with the deadlines set for the competition as well as the academic calendar. This allowed for comprehensive documentation, final edits, and confirmed results to be optimally validated.

From the launch date, the choice of hardware, and the conditions for testing, each decision was purposeful. Such decisions ensured Trevive was able to transition from a concept idea to a tested and user-satisfying solution from both an environmental and technological standpoint.

Reflection on scientific data and complexity:

Trevive was designed to provide a reliable, real-time health monitoring system of trees using low-power, embedded sensors. The project started on 01 September 2024 so that the variability after monsoon could be utilized for sensor calibration and environmental benchmarking.

A DHT22 temperature/humidity sensor, a soil moisture probe, and an LDR for light intensity were used in conjunction with an ESP32 microcontroller. Each unit was powered by a 3.7V Li-ion battery which allowed for 8-10 days of autonomous operation with optimized sleep cycles, exercising peak power management.

Over three regions, the tree system captured 90,821 data points in 21 days where each region had 3,000 trees and the data was gathered through 10 minute interval sampling. The data was then transmitted over MQTT which, using off-device buffering and threshold-driven filtering, eliminated any loss of data during transmission lags.

One of the primary advantages of this system was the 38 different, volunteer, caretakers including teaching staff and students who were directly involved on ground level. Each subtree was managed and monitored by the caretakers through the mobile app built on Flutter which provided real-time data visualization along with trend graphs and health alerts. Alerts proved beneficial educating non-compliant parties and making the UI transparent in regard to timely action.

Timely alert intervention was initiated leading to erectable actions like irrigation and shading in total of 27 actions. These actions ended up minimizing visible signs of dehydration and mitigating root stress symptoms by 40%.

Responses showed an app satisfaction rate of 86.8% and trust in the data presented was at 92%. The project ended on January 8, 2025, validating system performance during dry-season peak stress, confirming systems functionality during critical strain periods. Trevive demonstrates that

accurate sensing, robust communication, and community participation together enable scalable, effective, science-based tree care.

Ethicality, safety considerations and risk assessments

Fieldwork & Personal Safety:

Heat, rugged landscapes, and low voltage electric concerns posed several risks when accessing remote plantations. Site visits were conducted during the daytime with self-contained power,all gear and hydration. All installations were done with power safely disconnected.

Data & Equipment Security:

Data encryption with protocols MQTT were utilized to prevent unauthorized access. Construction files reflected design that demonstrated their use transparency by securely physically enclosing them. Even the mounting labels ensured the sensors would be used only for research purposes.

Environmental Impact & Recycling:

No physical or chemical alteration to the environment was done at all. All sensor modules were modular and reusable. Components that were damaged were captured for e-waste recycling.

Energy Use Comparison:

Compared to the traditional approach of using fuel-powered sensors and Trevive's sensors monitored,the traditional ones used 168 kg CO_2 over 3000 trees,in the same terms During the three-week period after monitoring the trevive would cost 6.3 kWh, yielding a total of 3.2 kg CO_2. This marks a 95% reduction in carbon footprint.

Job Impact:

The role of focusing on monitoring and managing sensors encourages agile skills development in agri-tech. Movement volunteers are deployed as foster responders with the goal of harnessing informed advocacy. Trevive shifts responsibilities towards caretaking roles, but does not substitute positions altogether.

Ethical Use:

Landowners and involved institutions gave full consent to all environments which were devoid of cameras, microphones and motion sensors. Thus, only data was captured with the sensors and no privacy was invaded

A. Application to Society

Application to Society

Leveraging the capabilities of sensors and artificial intelligence, the Trevive system enables real time monitoring of trees and their surroundings, making them a pivotal device in environmental conservation coupled with sustainability. The Trevive empowered stakeholders such as caretakers, farmers, city planners, and conservationists by providing them accurate insights with regards to air temperature, soil moisture, and illumination intensity. This empowers stakeholders to make informed decisions that support the sustenance of urban greenery, agricultural lands, and natural ecosystems. Climate change has presented threats to the environment. In order to efficiently mitigate the damage on the ecosystem, Trevive is vital for active tree health monitoring in both rural and urban settings. By making this information available, Trevive controls the extent of ecological damage as well as promoting growth.

Key Societal Contributions of Trevive

1. Urban Greening & Air Quality Improvement

Provides tree care for municipalities and city planners within the scope of urban tree monitoring.Counters tree loss as a result of pollution, draught, and degradation of soil.Supports greenhouse conditions by increasing resilience and adaptive capacity of climate in cities.Strengthens air quality and purification as a result of maintaining green spaces.Improves the general health of urban residents with an increase of freshly supplied air and the enhanced coverage of trees.

2. Sustainable Agribusiness & Ecosystem Conservation

Assists farmers and agro forestry professionals with real-time soil health analysis.Provides adequate shading of crops, stabilization of soil, and retention of water.Predictively analyzes farmers' dehydration and root rot.Preserves trees to enhance agricultural productivity.Fosters biodiversity by nurturing and protecting the forestry ecosystem.

3. Advances In Education And Science Research provides practical skills in environmental science teaching and learning.Facilitates IoT- and data-based research in universities and conservation centers.Encourages learning innovative cloud-analytic integrated platforms.Allows students and researchers to observe and study health of trees for trends.Helps in understanding climate change by providing vast amounts of data over time.

4. Global Warming Mitigation & Carbon Sink Enhancement

Enables warning of forest degradation from tree stress to prevent deforestation.Supports the global endeavors of reforestation and afforestation.Assists decision makers to formulate policies that build climate resilience.Supports healthy trees and forests to enhance carbon sink reserves in the regions.Improves the carbon footprint by providing effective tree conservation strategies.

5. Community and Policy Empowerment

Assists local NGOs and environmentalists through providing them with usable data.Improves policy choices regarding urban forestry and other conservation programs.Assists governmental reforestation and sustainability programs.Delivers cost-efficient and adaptable solutions to conservation agencies.Promotes non-profit initiatives to ensure environmental protection and tree growth in the community.

Through Trevives's scalable setting and data-powered business monitoring system, global conservation strategies are set to change. By using unifying technology, education, and environmental sustainability, Trevive enables a greener, healthier, and sustainable future.

B. Acknowledgments

The development and success of the Nurture All Trees (Trevive) system would not have been possible without the collaborative efforts and contributions of numerous individuals and organizations.

Ms. Reetu Jain

First and foremost, I extend my deepest gratitude to my overall research supervisor, Ms. Reetu Jain, whose invaluable guidance and expertise in IoT technology, environmental sustainability, and data-driven analytics played a crucial role in shaping this project. Her continuous support, insightful feedback, and ability to bridge scientific research with real-world applications have been instrumental in refining the methodological framework and implementation strategies. Dr. Jain's mentorship provided clarity and direction, ensuring that the research remained technically sound, innovative, and impactful for large-scale environmental monitoring efforts. Her encouragement and critical insights inspired me to push the boundaries of innovation while maintaining a strong ethical foundation in conservation technology.

Mr. Vinay Vishwakarma

I am immensely thankful to Mr. Vinay Vishwakarma, my project supervisor, for his technical expertise and hands-on guidance throughout the hardware development phase. His deep understanding of sensor calibration, microcontroller programming, and power management was vital in designing a robust, low-power, and efficient monitoring system. His mentorship in overcoming practical challenges, refining sensor accuracy, and optimizing wireless data transmission protocols played a key role in making Trevive a functional and scalable prototype.

C. Ethical standards: *The authors would like to declare that the dataset collected for the study is done under the supervision of the specialists*

As a data-driven tree health monitoring system, Trevive ensures that all collected data is securely managed, AI-driven insights remain unbiased, and field implementations follow sustainable deployment practices. The project was designed to minimize ecological impact, promote responsible AI usage, and engage communities and conservation groups in ethical decision-making. By integrating privacy protection, sustainable innovation, and transparency, Trevive sets a new benchmark for ethical practices in environmental technology and IoT-based conservation solutions.

By upholding these comprehensive ethical standards, Trevive ensures that its technological advancements contribute to a sustainable, transparent, and community-focused future for global conservation efforts.

1. Data Privacy and Security: *Trevive upholds the highest standards of data ethics, ensuring that user privacy and information security remain a top priority. Since the system collects tree health data rather than personal user information, it eliminates concerns related to personally identifiable information (PII). All data transmissions are encrypted, preventing unauthorized access and cyber vulnerabilities. The mobile application and cloud-based analytics system are designed with strict security protocols, ensuring full user control over data storage, retrieval, and deletion. Regular security audits and compliance checks are conducted to ensure that Trevive aligns with global data protection regulations and best practices.*

2. Environmental Sustainability: *A core principle of Trevive's development is minimizing environmental impact while maximizing conservation benefits. The system uses biodegradable or recyclable sensor casings to reduce electronic waste, ensuring sustainability in large-scale deployments. Additionally, the system operates on low-energy consumption models, making it solar-compatible and reducing reliance on conventional energy sources. The sensor placement and retrieval process is designed to have minimal soil and root disturbance, ensuring that monitoring efforts do not unintentionally harm the trees they aim to protect. By aligning with global conservation goals, Trevive reinforces its role as an eco-friendly and* *scalable environmental monitoring solution.*

3. Ethical data and trained Learning: *Trevive's data-driven analytics strictly adhere to ethical data principles, ensuring that predictions and recommendations are scientifically validated, transparent, and unbiased. The machine learning models used for tree health assessment undergo continuous refinement, preventing false or misleading classifications. All trained model-generated recommendations include explanations for users, ensuring human oversight and decision-making power remain intact. By prioritizing accountability, fairness, and transparency, Trevive ensures that its data models serve as assistive tools rather than autonomous decision-makers, reinforcing ethical data practices in environmental research.*

4. Ethical Field Testing and Community Involvement: *All field testing and pilot studies were conducted with full transparency and informed consent from participating communities, conservationists, and research institutions. The system was tested in diverse environments, including urban green spaces, forests, and plantations, to ensure accuracy across different ecological conditions. Before deployment, training sessions were held to educate users on device operation, data interpretation, and conservation best practices. By engaging local communities, schools, and environmental agencies, Trevive fosters collaborative conservation efforts, making tree health monitoring an inclusive and community-driven initiative.*

5. Responsible Research and Development: *The entire research and development process adhered to scientific integrity, transparency, and sustainability principles. Research findings, including sensor accuracy rates, data model improvements, and user feedback, were shared openly to encourage collaborative advancements in conservation technology. Ethical considerations also extended to partnerships and deployment strategies, ensuring that Trevive remains accessible and beneficial to all stakeholders. Future improvements will focus on enhancing data explainability, improving energy* *efficiency, and expanding conservation impact, all while maintaining ethical accountability in environmental research and IoT-driven solutions*.

VII. DISCUSSION

Computer-aided design or CAD design is the process of creating, modifying, analyzing, or optimizing a design using computer software.

A. Advantages of Nurture All Trees

1. **Real-Time Monitoring**: Provides immediate insights into tree health, enabling timely interventions and preventing potential damage.
2. **Accessibility**: The user-friendly app makes tree health monitoring accessible to non-experts, empowering a wider range of users to care for trees effectively.
3. **Scalability**: The low-cost, low-power design allows for widespread adoption, making it suitable for large-scale studies and applications.
4. **Environmental Impact**: Contributes to global conservation efforts by promoting sustainable tree care practices and supporting healthier ecosystems.

B. Potential Applications

- **Schools and Urban Areas**: Enhances green spaces and educates students about environmental conservation. The system can be integrated into school curricula to teach students about the importance of tree health and sustainability.
- **Forests and Plantations**: Supports large-scale tree health monitoring and management, enabling conservationists to address issues such as deforestation and climate change.
- **Rural Areas**: Empowers local communities to care for trees and improve agricultural productivity. The system can be used to monitor orchards and plantations, ensuring optimal growing conditions and higher yields.

C. Challenges and Future Work

While the prototype has shown promising results, further improvements are needed to address challenges such as:

- **Sensor Durability**: Ensuring long-term reliability in diverse environmental conditions, including extreme temperatures and moisture levels.
- **Data Integration**: Expanding the system to include additional parameters such as soil pH and nutrient levels, providing a more comprehensive assessment of tree health.

User Training: Providing comprehensive training to users in rural and underserved areas, ensuring that they can use the system effectively and maximize its benefits.

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