Tree Health Monitoring and Management System

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ABSTRACT: This paper explores innovative approaches to environmental and tree health monitoring using IoT, machine learning, and advanced communication systems. A LoRaWAN-based sensor system for urban trees collects real-time data on soil moisture, temperature, and humidity, improving tree management. Another study focuses on an IoT system for coconut trees, enhancing remote agricultural decision-making. A heterogeneous neural network (HNN) predicts the Urban Tree Health Index (UTHI) with high accuracy, automating tree assessments. Lastly, a hybrid edge computing and LoRa architecture enables real- time forest monitoring, addressing challenges like deforestation and climate change. Together, these technologies promote sustainable forestry and tree health management.

1. INTRODUCTION

The collection of research papers explores innovative approaches to environmental monitoring and tree health assessment using advanced technologies such as the Internet of Things (IoT), LoRaWAN, and machine learning.

1. A LoRaWAN-Based Environmental Sensor System for Urban Tree Health Monitoring discusses the development of a low- power, wireless sensor system designed to monitor various environmental parameters affecting urban trees. The study highlights the integration of soil temperature, moisture sensors, and air temperature/humidity sensors to assess tree health, demonstrating the effectiveness of LoRa technology in urban settings.
2. IoT Based Smart Coconut Tree Health Monitoring System for Sustainable Agriculture in India presents a novel wireless sensor network that enables continuous monitoring of coconut tree health. This system leverages IoT technology to provide real-time data on soil moisture and other critical parameters, aiming to enhance agricultural practices and sustainability in coconut farming.
3. Urban Tree Health Assessment using Heterogeneous Neural Network: A Novel Approach introduces an Urban Tree Health Index (UTHI) developed through a heterogeneous neural network model. This model utilizes both dynamic and static features to evaluate tree health, offering a more efficient and automated assessment method compared to traditional manual inspections.
4. LoED: LoRa and Edge Computing based System Architecture for Sustainable Forest Monitoring proposes a hybrid architecture that combines LoRa technology and edge computing for real-time forest monitoring. The architecture aims to address challenges such as population growth and environmental degradation by monitoring soil, water quality, and climate conditions to support sustainable forest management.

2. TECHNICAL SURVEY

Various advanced technologies have been deployed to monitor and improve the health of trees and agricultural systems. LoRaWAN (Long Range Wide Area Network) was used in combination with soil temperature and moisture sensors, air temperature and humidity sensors, and point dendrometers to measure tree trunk growth. This system demonstrated low power consumption and effective long-range communication, accurately monitoring tree growth rates at approximately 20.53 μm/day over a 9-day period. Similarly, IoT and Wireless Sensor Networks (WSN) have been utilized to enhance real-time decision-making in coconut farming, addressing challenges such as disease management and resource optimization by continuously monitoring environmental parameters. Additionally, a Heterogeneous Neural Network (HNN) model was developed for urban tree health assessments, integrating dynamic features (e.g., temperature, humidity) and static features (e.g., tree species, age) to create an Urban Tree Health Index (UTHI). This model achieved high accuracy with an error rate of less than 5%, improving efficiency over traditional methods. Furthermore, the use of LoRa and edge computing in forest monitoring systems enabled real-time data collection and visualization through sensor motes and cloud servers, facilitating efficient and reliable data transmission and enhancing forest health management.

3. TECHNICAL CHALLENGES IN SYSTEM DESIGN

1. Network Coverage: Ensuring reliable communication over the entire monitoring area can be challenging, especially in urban environments with potential signal interference.
2. Data Accuracy and Calibration: Maintaining the accuracy of sensors and calibrating them for different environmental conditions is crucial for reliable data collection.
3. Power Management: Designing low- power systems that can operate for extended periods without frequent battery replacements is essential for sustainability.
4. Interoperability: Integrating various sensors and devices from different manufacturers can lead to compatibility issues, complicating system design.
5. Data Security and Privacy: Protecting sensitive agricultural data from unauthorized access and ensuring secure data transmission is a significant concern.
6. Scalability: Designing a system that can easily scale to accommodate more sensors or additional features without significant redesign is a challenge.
7. Data Quality and Availability: The effectiveness of machine learning models depends on the quality and quantity of data available for training, which can be difficult to obtain.
8. Complexity of Algorithms: Implementing advanced algorithms like heterogeneous neural networks requires expertise and can lead to increased computational demands.
9. Feature Selection: Identifying the most relevant features for tree health assessment from a large dataset can be challenging and may require extensive analysis.
10. Latency in Data Processing: While edge computing reduces latency, ensuring real- time processing of data from multiple sensors can still be a challenge.
11. Integration of Technologies: Combining LoRa communication with edge computing and cloud services requires careful design to ensure seamless data flow and processing.
12. Environmental Variability: Designing systems that can adapt to varying environmental conditions and still provide accurate monitoring is a significant challenge.

4. FEATURES AND TECHNICAL DETAILS OF PROPOSED SMART SYSTEM

Features:

1. LoRaWAN Technology: Utilizes low-power, long-range communication for data transmission.
2. Sensor Integration: Includes soil temperature, soil moisture, and air temperature/humidity sensors.
3. Dendrometer: Measures tree trunk growth with high precision.
4. Data Collection: Monitors environmental variables continuously and transmits data to a cloud platform.
5. Remote Monitoring: Allows farmers to monitor tree health via mobile devices.
6. Cloud-Based Server: Data is stored and analyzed on a cloud platform for accessibility.
7. Sensor Network: Integrates various sensors to monitor soil moisture and other environmental parameters.
8. Dynamic and Static Features: Combines dynamic features (e.g., temperature, humidity) with static features (e.g., tree species, age) for comprehensive analysis.
9. Automated Assessment: Facilitates automated tree health monitoring using machine learning.
10. Hybrid Architecture: Combines LoRa communication with edge computing for real- time monitoring.
11. Sensor Motes: Deployed at trees to monitor environmental parameters like soil moisture, temperature, and humidity.
12. Data Visualization: Integrates with cloud servers for real-time data visualization.

Technical Details:

1. Network Design: The system operates within a defined area (480m × 260m) with an average RSSI between -120.0 and -83.0 dBm.
2. Data Sampling: Sensors sample data every 10 minutes, while the dendrometer records hourly.
3. Power Supply: Powered by 2 × 1.5V AA batteries, ensuring low energy consumption.
4. Wireless Sensor Networks (WSN): Utilizes WSN for real-time data collection and transmission.
5. User Interface: Provides a mobile application for farmers to access real-time data and insights.
6. Data Analytics: Employs cloud computing for data analysis, enabling timely decision- making.

7. Heterogeneous Neural Network (HNN): Utilizes a combination of recurrent neural networks (RNN) and feedforward neural networks for data processing.
8. Model Performance: Achieves high accuracy with an error rate of less than 5%, indicating effective modeling of tree health.
9. Feature Extraction: Employs 14 indexing features, including 7 dynamic and 7 static features.
10. Data Acquisition Layer: Dedicated to continuous monitoring of environmental parameters.
11. Processing Layer: Uses edge computing devices to process data locally, reducing latency.
12. Communication Protocols: Employs 433 MHz LoRa for data transmission and Wi-Fi for cloud connectivity.

5. DESIGN CHALLENGES OF PROPOSED SYSTEM

1. Network Coverage: Ensuring reliable communication across the entire monitoring area can be challenging, especially in urban environments with potential signal interference.
2. Data Accuracy: Maintaining the accuracy of sensors and calibrating them for varying environmental conditions is crucial for reliable data collection.
3. Power Management: Designing low- power systems that can operate for extended periods without frequent battery replacements is essential for sustainability.
4. Interoperability: Integrating various sensors and devices from different manufacturers can lead to compatibility issues, complicating system design.
5. Data Security: Protecting sensitive agricultural data from unauthorized access and ensuring secure data transmission is a significant concern.
6. Scalability: Designing a system that can easily scale to accommodate more sensors or additional features without significant redesign is a challenge.
7. Data Quality and Availability: The effectiveness of machine learning models depends on the quality and quantity of data available for training, which can be difficult to obtain.
8. Complexity of Algorithms: Implementing advanced algorithms like heterogeneous neural networks requires expertise and can lead to increased computational demands.
9. Feature Selection: Identifying the most relevant features for tree health assessment from a large dataset can be challenging and may require extensive analysis.
10. Latency in Data Processing: While edge computing reduces latency, ensuring real- time processing of data from multiple sensors can still be a challenge.
11. Integration of Technologies: Combining LoRa communication with edge computing and cloud services requires careful design to ensure seamless data flow and processing.
12. Environmental Variability: Designing systems that can adapt to varying environmental conditions and still provide accurate monitoring is a significant challenge.

6. OPERATIONAL PHENOMENA INVOLVED

1. Data Collection: Sensors continuously monitor environmental parameters such as soil moisture, temperature, and humidity, collecting data at specified intervals (e.g., every 10 minutes).
2. Wireless Communication: Utilizes LoRaWAN technology for long-range, low- power data transmission to a central gateway, which then relays the information to a cloud platform.
3. Data Analysis: The collected data is analyzed to assess tree health and growth, allowing for real-time monitoring and decision- making.
4. Remote Monitoring: The system enables farmers to monitor the health of coconut trees remotely through a mobile application, providing real-time insights into soil and environmental conditions.
5. Data Integration: Combines data from various sensors (e.g., soil moisture, temperature) and transmits it to a cloud-based server for analysis and visualization.
6. User Interaction: Farmers can interact with the system via a user-friendly interface, allowing them to make informed decisions based on the monitored data.
7. Feature Extraction: The system extracts both dynamic (e.g., temperature, humidity) and static features (e.g., tree species, age) to create a comprehensive model for assessing tree health.
8. Machine Learning: Employs a heterogeneous neural network (HNN) to analyze the extracted features and predict the Urban Tree Health Index (UTHI), facilitating automated health assessments.
9. Continuous Learning: The model can improve over time as more data is collected, enhancing its predictive accuracy and reliability.
10. Sensor Deployment: Sensors are deployed in

the forest to monitor various environmental parameters, including soil moisture, temperature, and humidity.

11. Edge Computing: Data processing occurs at the edge, reducing latency and allowing for real-time analysis of sensor data before it is sent to the cloud.

12. Data Visualization: The processed data is visualized on a cloud server, providing stakeholders with insights into forest health and enabling timely interventions.

7. EXPERIMENTAL ANALYSIS

1. Test Setup: The system was tested on a linden tree at Columbia University's Morningside Campus. Various sensors were installed to monitor soil moisture, temperature, and humidity.
2. Data Collection Period: Data was collected over a 9-day period, with measurements taken every 10 minutes. The analysis showed a negative correlation between air temperature and humidity (Pearson's $r = -0.65$). Soil and air temperatures were cross- correlated with a time lag of 390 minutes ($r = 0.33$). The tree trunk growth rate was approximately 20.53 µm/day.
3. System Testing: The system was tested in real agricultural settings to monitor coconut tree health. Various environmental parameters were measured, including soil moisture and temperature.
4. Data Analysis: The collected data was analysed to assess the health status of the coconut trees, providing insights into irrigation needs and overall tree health.
5. User Feedback: Farmers provided feedback on the usability of the system, which was used to refine the interface and functionality.
6. Model Development: The study developed a heterogeneous neural network (HNN) to model the Urban Tree Health Index (UTHI) using both dynamic and static features.
7. Performance Evaluation: The model was evaluated using a dataset that included various tree health indicators. The HNN achieved a low error rate of less than 5% and demonstrated high accuracy (RMSE of 0.217 and R^2 of 0.975). Comparison with Other Algorithms: The performance of the HNN was compared with other machine learning algorithms, showing significant improvements in accuracy (34% to 66% better than alternatives).
8. Real-Time Implementation: The system was deployed in Dehradun, India, to monitor environmental parameters such as soil moisture, temperature, and humidity.
9. Data Visualization: Sensor data was logged on the ThingSpeak server, allowing for real-time visualization of environmental conditions.
10. Node Mapping and Security: The sensor mote was equipped with features like node mapping to minimize data redundancy and symmetric encryption for secure data transmission.

8. CONCLUSION

The studies collectively highlight the significant advancements in environmental monitoring and tree health assessment through the integration of IoT technologies, machine learning, and wireless communication systems like LoRaWAN.

LoRaWAN-Based Environmental Monitoring: The implementation of a LoRaWAN-based sensor system for urban tree health monitoring demonstrates the effectiveness of low-power, long-range communication in collecting real- time data on critical environmental parameters. The findings indicate strong correlations between various factors affecting tree health, such as soil moisture, temperature, and humidity, which can inform better management practices.

Smart Coconut Tree Health Monitoring: The IoT-based system for coconut tree health monitoring showcases the potential for remote monitoring in agriculture. By providing farmers with real-time insights into soil and environmental conditions, the system enhances decision-making capabilities, ultimately leading to improved agricultural practices and sustainability.

Urban Tree Health Assessment Using Machine Learning: The development of a heterogeneous neural network (HNN) for assessing urban tree health introduces a novel approach to integrating dynamic and static features. The high accuracy of the HNN in predicting the Urban Tree Health Index (UTHI) emphasizes the role of machine learning in automating tree health assessments, which can significantly reduce management costs and improve urban forestry practices.

Edge Computing and LoRa for Forest Monitoring: The proposed architecture combining edge computing with LoRa technology for sustainable forest monitoring illustrates a comprehensive approach to real- time data collection and analysis. This system not only enhances the monitoring of environmental parameters but also facilitates timely interventions to address issues such as deforestation and climate change.

9. IMPLICATIONS

The integration of these technologies presents a transformative opportunity for urban and agricultural forestry management. By leveraging real-time data and advanced analytics, stakeholders can make informed decisions that promote sustainability, enhance tree health, and optimize resource use. The studies underscore the importance of continued research and development in this field to further refine these systems and expand their applications across different environments.

10. REFERENCES

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