A SUSTAINABLE IOT-ENABLED WSN FRAMEWORK FOR PROACTIVE FOREST FIRE DETECTION AND MITIGATION

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ABSTRACT

Recently, Internet of Things (IoT) technologies are developing technology with a variety of applications. The Internet of Things (IoTs) is defined as a network of ordinary objects such as Internet TVs, smartphones, actuators and sensors that are smartly connected together to enable new types of communication between people and things as well as between things themselves. Wireless sensor networks (WSNs) play an important part in Internet of Things (IoT) technology. A contribution to wireless sensor networks and IoT applications is wireless sensor nodes' construction with high-speed CPUs and low-power radio links. The IoT-based wireless Sensor network (WSN) is a game-changing smart monitoring solution. ZigBee standard is an important wireless sensor network (WSN) and Internet of Things (IoT) communication protocol in order to facilitate low-power, low-cost IoT applications and to handle numerous network topologies. This research presented a review on the energy efficient and routing topologies of ZigBee WSN, applications of IoT enabled Wireless Sensor Network as well IoT WSN security challenges.

Keywords: *Internet of Things (IoT) technologies, Wireless Sensor Network, low-power radio links, Internet TVs, smartphones, actuators.*

INTRODUCTION

Thanks to advancements in processing capabilities, connectivity, and the energy efficiency of embedded systems, Wireless Sensor Networks (WSNs) have become a widely adopted solution in both industrial and commercial sectors. Numerous environmental characteristics, including temperature, humidity, pressure, place of residence, vibration, & sound, are monitored by nodes in these networks. These nodes support a wide range of real-time functions, including intelligent detection, node discovery, data collection and processing, storage, target tracking, monitoring and control, synchronization, localization, and efficient communication with the base station. WSNs are evolving in their structure and functionality. With the integration of WSNs into the Internet, it's plausible to foresee a globally secure and interconnected environment within the next decade or two. This convergence signifies a transformation of the Internet into a tangible network infrastructure. The technology is particularly compelling due to its versatility across numerous domains such as healthcare, environmental monitoring, transportation, defense, entertainment, homeland security, emergency management, and intelligent spaces. A WSN typically consists of numerous compact, low-power devices—known as sensor nodes or motes—that function autonomously and collaboratively. These battery-powered, embedded systems are deployed in large numbers to meticulously gather, process, and transmit data to operators. Despite their limited computational and processing capabilities, these nodes effectively form a cohesive network.

LITERATURE REVIEW

Jiajun Hu (2025) Ecosystems and economic growth are seriously threatened by forest fires. Because of their great mobility, affordability, and real-time observation capabilities, in recent years, unmanned aerial vehicles (UAVs) have become a vital tool for forest fire monitoring. Three main areas are examined in this paper's comprehensive evaluation of research advancements in UAV-based forest fire monitoring: multi-sensor data fusion technologies, hardware design, and improved fire detection algorithms. In order to increase flight stability and environmental adaptability, it first lists optimisation techniques for UAV hardware, such as sensor combinations, wing designs, and power supply upgrades. Second, it examines how developments in fire detection techniques, namely the lightweight modifications and performance enhancements of deep learning models, may be used in high-noise conditions. Finally, by integrating temperature, smoke, and image data, it explores the potential for improving fire detection accuracy using multi-sensor data fusion approaches.

Lingxia (2025) The utilization of aircraft platforms for fire detection is a crucial piece of technology for forest monitoring. The ability to identify in real time is still a challenging problem, however. "This study presents a real-time forest fire detection approach based on edge computing, utilizing unmanned aerial vehicles (UAVs). The aim is to enhance response speed and improve the accuracy of detecting small fires at an early stage." The onboard cameras' colour and thermal pictures are combined with the proper proportions and registered to the same scale. The fire detection network model is trained using these dual-modal, previously processed pictures as input. This model is compressed and accelerated to decrease size and improve efficiency before being deployed on the resource-constrained UAV edge computing device. To verify the accuracy and speed of the suggested approach, experiments are carried out using publicly available datasets taken from actual forest ecosystems and self-made UAV dual-modal photos of simulated fire situations. According to experimental findings, the ground computer's inference speed achieves 34.6 FPS on the self-made dataset, and the mAP is 93.76%.

Salih Taze (2024) There are several causes of fire forests, and the spread of fire may lead to the partial or total burning of forests over a wide region. If the fire did not control in the first 15 to 20 minutes, it might be harmful. To protect the forest from the effects of fire, early identification is necessary. Because of this, fires that are detected early may be put out far more quickly and with less damage. Because forests cover enormous regions and are far from residential areas, it may be difficult to notice fires in these locations. Delays in discovery make it more difficult to contain the fire and sometimes may be the cause of extensive damage. With the use of machine learning and data from sensors positioned throughout the woodlands, this research sought to ascertain if a fire was occurring in the area. Material and Method: The following procedures were followed in order to complete the project: Several models for fire detection were developed in the research using artificial intelligence methods and sensor data.

Juvanhol (2024) In regions with natural forests and replanting, forest fires are a persistent issue that lead to the destruction of vast tracts of vegetation, it is detrimental to both the economy and the environment. Prevention, detection, and combat must be the cornerstones of any firefighting strategy, with quick detection being a key component. In order to maximise the geographical coverage of traditional observation towers in forest fire-prone regions, this study aims to propose an integrated method using geographic information system (GIS) technology and operational research. The Vale Nature Reserve (VNR), which is situated in the northern region of Espírito Santo, Brazil, is the research area. After defining the forest fire risk (FFR) areas that were fed into the mathematical programming model, visibility assessments were carried out by altering the fire towers' heights in eight different scenarios.

Winkler (2023) Wireless sensor networks (WSNs) hold significant potential for military applications, including force protection and monitoring insurgent movements in remote locations. When equipped with suitable sensors, these networks are capable of detecting enemy personnel, tracking their trajectories, and assessing their progress. This article emphasizes the critical need for adaptable WSNs tailored to military operations. To offer a clearer understanding of how these networks are expected to function in the near to mid-term future (spanning the next three to eight years), the article presents insights into specific military requirements, informed by core networking attributes and operational scenarios. Additionally, the article outlines three distinct generations of sensor technologies and their respective capabilities, providing a structured perspective on the evolution of military sensor network development.

Software Components of Wireless Networks

Some necessary software programs on our PCs enable us to connect to wireless networks. We are all aware that web browsers and other software are necessary in order to access the Internet. But there are alternative programs: System and protocol stacks for network operations.

Operating system for networks (NOS): An operating system that facilitates network functioning is called a NOS. A NOS, as opposed to an OS, may be found on network servers, switches, and personal PCs. In reality, it is a unique operating system that primarily manages hardware, applications, protocols, and system resources. It also has the ability to link nodes to a local area network (LAN). Among its other features are security protection, print sharing management, and more. (Rouse)

Additionally, we learnt about DHCP (Dynamic Host Configuration Protocol), which is capable of automatically allocating IP addresses to various users. It will guarantee that every individual has a distinct IP address. Security software and firewall software are also available for data protection and management. Additionally, service set identification (SSID) is utilised to differentiate across various WLANs.

Wireless Sensor Networks

The capabilities of (WSNs) include distributed computation, sensing, and communication. They are defined as fault-tolerant, infrastructure-less, and self-organising networks that provide low-cost, simple-to-implement, quick, and adaptable installs in a different setting for various objectives.

The wireless sensor & sensor node architecture is shown in the image below.

Characteristics of WSN

The following are the attributes of WSN:

Resource limitations: WSN nodes are smaller and rely on batteries for power. It explains why the nodes' capacity to deliver services like communication and processing is severely constrained.

The data-centric aspect of WSN describes its data-centric nature and supports the restriction of communication to nodes. This is the communication paradigm.

Application-specific design: WSNs are application-specific, meaning that their architecture is determined by its use.

Node failure and poor communication – Typical WSN nodes are prone to errors due to a number of issues, including unpredictability, nodal mobility, environmental interferences, and severe operating conditions that cause instability.

Scalability and density: In a variety of applications, WSNs may have a large and densely deployed number of nodes.

Dynamic Topologies – In some applications, nodes are allowed to move at irregular rates and occasionally may not function, add, or replace nodes. Thus, several network topologies may exist.

WSNs use a variety of communication paradigms, including distributed, hierarchical, flat, homogeneous, and heterogeneous WSNs.

Operating Environment

Because of their resilience to severe environmental conditions, WSNs are mostly used for unattended operations in isolated and dangerous areas.

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Requirements of WSN

The following explains the WSN requirements:

Flexibility: WSN's architecture is not set in stone. Instead, it differs depending on the application, which supports the self-organization properties of the algorithms and protocols.

Fault tolerance – WSN nodes are able to continue operating in the network even when faced with extreme environmental conditions, low battery power, external interference, and node failure rates.

Lifetime - The two primary factors that must be considered are load balance and energy conservation. The WSN architecture's lifespan may be extended as much as feasible by these two elements.

Scalability: A WSN network may have a huge number of nodes. WSN protocols and architecture should be developed accordingly.

Real-time – WSNs must meet stringent time limitations since their sensing, processing, or communication capabilities are applied to a range of real-world problems.

Security - For instance, WSN networks provide sensitive, private data in the fields of health care and the military. Thus, such structures are clearly secure.

Production cost – Since nodes in a WSN network must be replaced by newer nodes when their energy runs out, their cost must be minimal.

Deployment: In large-scale (WSNs), nodes that are nearly impossible to maintain and replace are deployed at random. Therefore, re-configuration and re-programming are absolutely necessary.

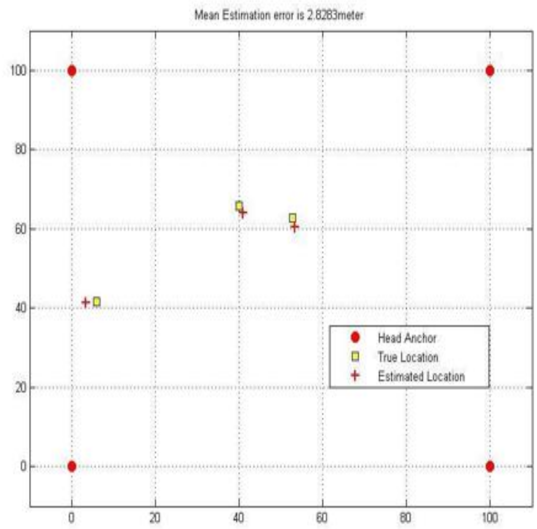
Dependability – WSN is dependable due to its strong architectural design, which ensures safe data collecting and lossless transport.

RESEARCH METHODOLOGY

Forest fires are disasters that have a major negative impact on the planet's ecology, economics, and environment. These fires might have either natural or man-made sources. Numerous techniques, Forest fires may currently be detected using a variety of methods, such as satellite image processing, optical sensors, digital camera-based methods, and watchtowers. Wireless sensor networks (WSNs) are autonomous, infrastructure-free wireless communication networks that assist in monitoring environmental or physical parameters and transmit data to a specified location or sink for examination and monitoring. A wireless sensor network's efficacy and low power consumption are its primary advantages. Using power components, a transceiver module, or a microcontroller, the proposed detection system deploys wireless sensor nodes that follow cellular design to track temperature, CO levels, relative humidity, and light intensity over the whole area. The sensor node is primarily powered by batteries, with solar panels serving as a backup. These spherically shaped nodes for sensing are made especially to withstand environmental and animal damage. Only when the ratios above the predetermined threshold ratio does the sensor node transmit them to the base stations for further analytical processing. Either a predetermined threshold ratio or a ratio that is continually computed in real time inside the node for each parameter has been compared to the sensor data.

RESULTS AND DISCUSSIONS

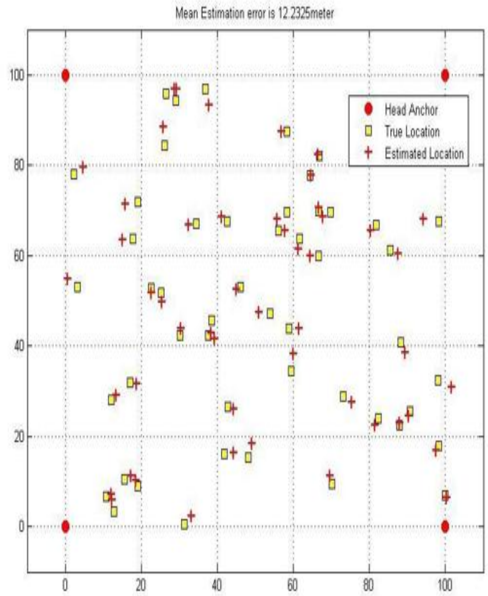
We placed three unknown regular nodes—represented by a yellow square sign—at the coordinates (6, 42), (40, 66), and (52, 63) in order to assess the algorithm's effectiveness for location estimation. The positive (+) symbol in red in Graph 1indicates that the nodes are roughly situated at coordinates (4, 42), (41, 64), and (53, 61) according to the location estimation technique.



Graph 1: Test phase deployment of 3 regular nodes and their location estimation

The red point in the image above indicates that the final position estimate from the proposed technique is somewhat closer to the real location of the standard sensors. We have placed a number of common sensor nodes at various points across the 100 × 100 m2 grid to evaluate the effectiveness of the suggested approach.

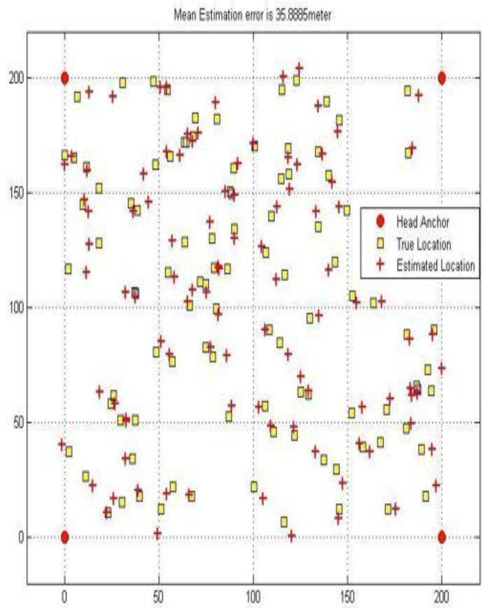
The mobile node deployment throughout the region is shown in Graph 2. Assuming a network size of 100 x 100 m2, case 1 uses 50 regular nodes and 4 head anchors. Head anchor locations are shown by red circles in the picture below, regular sensor nodes' actual locations are shown by a yellow square, and regular nodes' estimated locations are shown by a red positive (+) sign.



Graph 2: 50 standard sensor nodes with four head anchors are deployed in a 100 × 100 m2 grid.

Keeping the head anchor node 4 fixed, Case 1 shows 50 regular nodes spread throughout a network size of 100.

This graphic shows the actual position of regular sensor nodes as a yellow square, the estimated Regular node sites are shown as red positive (+) signs, while head anchor positions are shown as red circles.



Graph 3: 100 standard sensor nodes with four head anchors are deployed in a 200 × 200 m2 grid.

Keeping the head anchor node 4 constant, 100 regular nodes are shown throughout the 200 m network size for scenario 2.

CONCLUSIONS

The governing authorities become quite concerned about the fires that are common in smart city (or forest) regions. It was shown that the suggested approach of identifying forest fires using and machine learning is efficient and yields more precise findings. The analysis is done at the base station as well as within the sensor node to provide a greater degree of precision with the least amount of delay. A threshold ratio is included into the analysis all over the sensor node to allow the system to adapt to any conditions, climate, or location. Based on specialized built-in network infrastructure, the transceiver module it can be deployed anywhere in the forest, even without a preloaded network connection. Rechargeable batteries serve as the main power source, and a backup renewable energy source makes it easier to implement a stand-alone system solution for extended periods of time. During several test trials carried out in actual tropical forest environments, the suggested system and its communication infrastructure informed the appropriate authorities more quickly than the current methods. According to this research, WSN technology is a viable and environmentally responsible choice for more precise and efficient forest fire detection nationwide. When compared to other algorithms, a real-world field experiment conducted throughout the summer further illustrates the efficiency and mathematical simplicity of the suggested method for determining the fire danger rate.

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