EFFICIENT ROUTING AND DATA FUSION IN IOT-WSNS FOR RESILIENT FOREST FIRE MONITORING

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ABSTRACT

The routing protocol is a crucial technology for data transmission in UAV-WSNs. In this study, we propose an efficient routing protocol for UAV-WSNs data collection to address the high energy consumption and premature death of some sensor nodes (SNs) caused by existing routing protocols. Forest fires have become a major threat around the world, causing many negative impacts on human habitats and forest ecosystems. Climatic changes and the greenhouse effect are some of the consequences of such destruction. Interestingly, a higher percentage of forest fires occur due to human activities. Therefore, to minimize the destruction caused by forest fires, there is a need to detect forest fires at their initial stage. This research proposes a system and methodology that can be used to detect forest fires at the initial stage using a wireless sensor network. Furthermore, to acquire more accurate fire detection, a machine learning regression model is proposed. Because of the primary power supply provided by rechargeable batteries with a secondary solar power supply, a solution is readily implementable as a standalone system for prolonged periods. Numerous trials conducted in real tropical forest sites found that the proposed system is effective in alerting forest fires with lower latency than the existing systems.

Keywords: *Forest fires, wireless sensor network, Numerous trials, UAV-WSNs data collection, high energy consumption, human habitats.*

INTRODUCTION

"Wireless Sensor Networks (WSNs) represent an emerging category of wireless communication systems that are rapidly gaining traction due to their broad range of applications in both commercial and military fields. A WSN consists of a collection of spatially distributed, self-operating sensor devices designed to detect and monitor physical or environmental conditions. These networks are made up of numerous compact sensor nodes that are interconnected and capable of sharing information with each other." The temperature, the pressure, the humidity, and pollutants are among the environmental data that these nodes collect and send to a base station. The latter either sends the data to a physical network or starts an action or alarm, depending on the type and quantity of data being watched. Common uses include tracking the movement of people and animals in woods and along borders, monitoring the weather and forests, monitoring the battlefield, and physically measuring environmental parameters including pressure, temperature, vibration, and pollution. The primary distinction is that sensors have a relatively tiny energy source (often a battery) that runs out quickly, in contrast to devices taking part in local area networks. Therefore, it becomes necessary to create new energy-aware MAC protocols. Given that a WSN has less resources than a typical WLAN, there is obviously some distinction between the two. Forest fires are calamities that seriously harm the environment, economy, and ecology of the whole planet. The causes of these fires may be either natural (high temperatures can cause dry fuels like sawdust, leaves, lightning, etc. to spontaneously ignite) or man-made (unextinguished campfires, arson, improperly burnt garbage, etc.).

LITERATURE REVIEW

Lu, Luling (2025) Forest fires significantly endanger human health and ecosystems, and their rising occurrence contributes to the worsening of global warming. This article presents a novel approach to smoke and forest fire detection by combining an improved Capsule Neural Network (CNN) with an Adapted Golden Search Optimizer (AGSO). The technique successfully identifies intricate patterns connected to wildfires by using cutting-edge deep learning and optimisation techniques. Tested on images of wildfire smoke and the BowFire dataset, the proposed method outperformed traditional choice of features and classification methods. Rapid reaction and mitigation efforts were made easier by the combination of the updated CNN and AGSO, which improved the precision and reliability of forest fire detection. This study emphasises how crucial sophisticated computational methods are to lowering risks, guaranteeing security, and advancing automated forest fire warning systems. Capsule neural networks and the golden search optimiser together demonstrate how cutting-edge technology may be used to effectively address complex environmental problems.

Imdadul Alam (2025) In terms of dependability, effectiveness, and interpretability, this work introduces FireNet-CNN, a sophisticated deep learning model specifically created for forest fire detection that far outperforms current techniques. "FireNet-CNN demonstrates superior performance across key evaluation metrics, surpassing widely recognized pre-trained models such as VGG16, VGG19, and Inception V3. It achieves an accuracy of 99.05%, precision of 99.41%, and recall of 98.28%. The model was evaluated using two enhanced datasets—Dataset A and Dataset B—comprising fire and non-fire images sourced from diverse video and image repositories. FireNet-CNN's architecture is specifically optimized for fire detection tasks, featuring 2.75 million parameters and a compact footprint of just 10.58 MB. This design enables an inference time of only 0.95 seconds per image, making it highly suitable for real-time deployment on resource-limited platforms such as drones, embedded sensors, and other field devices in forested areas.

Daniyar Kaliyev (2024) In many parts of the globe, forest and urban fires remain a major problem. There are many ways to fight forest fires. Through early detection and prevention, these devices seek to lessen the harm caused by fire. This research presents a novel approach to fire detection and management using modern technologies. We suggest patrolling fire-prone regions using unmanned aerial vehicles (UAVs) outfitted with a convolutional neural network-based fire detection system. By training using datasets, you may get high-accuracy fire image detection that's consistent with fire detection. In this work, we provide a fire detection system based on (CNNs). This enables the use of still images or drone camera footage to detect smoke or fire. A collection of video frames involving fire is used in this study. CNN then uses the preprocessed data to create a fire detection model. The training dataset comprises

1650 scaled and reshaped photographs, whereas the testing dataset comprises 1310 resized and reformed images. We use the max pooling strategy, activation functions, and convolution to train the model.

Al Shehri (2024) Advances in electronics and wireless communication have enabled large-scale (WSNs). Security is essential for numerous applications of wireless sensor networks, as it ensures data integrity, confidentiality, and system reliability. A lack of infrastructure, limited processing power, little memory, inadequate power resources, and susceptibility to physical capture are some of the drawbacks of WSNs, which lead to unique security issues and inspire innovative solutions. This study summarizes security issues in WSNs, discusses the state in the art in sensors network security research, and identifies some possible directions for further investigation.

Luo et al. (2021) Hangzhou East Railway Station has been outfitted with a Wireless Structural Sensor Network (WSSN). Four different sensor types are included into the measuring units of this specially constructed academic WSN system, including a vibrating cable node intended to track temperature, wind gusts, acceleration, and strain. Each specialized multi-type sensing module ensures seamless coordination and operation among the various sensors distributed throughout the station's network. The system features 323 interconnected sensors arranged in a dynamic, tree-structured topology. It is utilized to assess various structural components during both the construction phase and the building's operational lifespan. To get a better understanding of the structure's complicated states and internal force redistribution, data is gathered throughout the course of its whole life cycle.

Wireless Sensor Networks and IoT

The Internet of Things (IoT) is one of the most fascinating technologies of our day. It is having an impact on how we engage with technology and with one other. But other technologies connected to sensor networks are also becoming more and more well-liked. "A wireless sensor network represents a fundamental technological element within the Internet of Things. Implementing IoT solutions relies heavily on wireless sensor networks. While the Internet of Things connects the physical environment to the web, wireless sensor networks are primarily concerned with integrating IoT devices on a local scale. The sections that follow outline key aspects of both systems."

Wireless Sensor Network

"Wireless Sensor Networks (WSNs) are self-governing collections of devices that create ad hoc networks to collect information from their surrounding physical environment. Their ecosystem includes various network types such as sensor networks, mesh networks, field area networks (FANs), narrowband IoT (NB-IoT), and body area networks (BANs)." These devices use certain communication protocols to transmit data and have minimal power consumption. Each of these independently connected devices has data that is gathered and analysed by IoT systems. Storage and applications are offered by public cloud providers, whereas private cloud providers only provide these services to a select few clients. "A wireless sensor network (WSN) example is a system of sensors mounted on a ship's hull to detect water infiltration." In this instance, every sensor operates independently of the others and has a distinct ID. Usually battery-operated, each sensor transmits data to a central gateway using an ultralow-power protocol. "The gateway processes aggregate all sensor data before transmitting it to the IoT platform." A network of nodes used for infrastructure management is an additional illustration of a WSN. They have improved the efficiency and convenience of people's lives.

Wireless Sensor Network Architecture

"A typical Wireless Sensor Network (WSN) comprises numerous nodes, each tasked with gathering environmental data and transmitting it to a central server. These nodes can be organized in a mesh topology or linked directly to a central hub. Additionally, they may connect to the internet to upload data to a cloud-based platform. While various WSN architectures exist, the most commonly used include:"

Star topology – "In a star architecture, each node connects directly to a central node, which then relays the data to a main server, simplifying the data collection process. However, as the number of nodes grows, this setup becomes less efficient and lacks scalability." This topology's primary benefit is its ease of deployment and node synchronisation.

Hub topology – "A hub-and-spoke WSN consists of a central hub connected to multiple nodes via wired or wireless links. Data gathered by the nodes is transmitted to a core server through either a wired or wireless network. The data can either remain within the local network or be forwarded to an online platform." The nodes are positioned in certain areas to keep an eye on various environmental variables. The sensors might be mounted on tiny robots or moving automobiles. The environment determines how many nodes are needed.

Numerous industries, including healthcare, the military, agriculture, manufacturing, and retail, may benefit from WSNs.

IoT Architecture

"The Internet of Things (IoT) refers to a network of interconnected devices capable of communicating with each other and with the internet. These devices can range from everyday household items to smartphones." The gadgets may transmit and receive data since they are online. The data may then be used to provide user information or operate the devices.

"The architecture of the Internet of Things (IoT) consists of sensors, actuators, and internet connectivity integrated with physical objects. The real-time data generated by IoT devices can be analyzed for various purposes, including equipment control and operational decision-making." IoT devices are used in industrial, healthcare, agriculture, and home automation systems. IoT hardware comes in two varieties: industrial and consumer. "The consumer sector encompasses wearables such as smartwatches and smart glasses, along with remote monitoring and automation devices like smart thermostats."

RESEARCH METHODOLOGY

The fire may be discovered in its early stages because to this process's minimal delay design, which also allows the responsible parties to respond more quickly to minimise damage. Over the last ten years, a lot of academics have focused on forest fire detection because of the rise in forest fire case reports worldwide, which have caused significant harm to both the environment and civilisation. Numerous techniques, including camera-based systems, WSN-based systems, and machine learning application-based systems, have been suggested to identify forest fires. To improve detection accuracy, the analytical approach included threshold ratio analysis and a machine intel regression procedure. Data from fire & non-fire scenarios in various locations and climates were gathered in order to train and assess the model. Temperature, relative humidity, the amount of light, and CO level at a certain moment were all included in the 7000 data samples that were gathered throughout the data collecting procedure. Eighty percent of the collected data was chosen at random to train the model, while twenty percent was used as test data. A text message will be created and sent to the authorized officers' mobile phones in the appropriate units if the predictive model's output shows a fire in a certain location. In addition to identifying performance measurements, each approach offers pros and cons. WSNs have a more promising future and are the preferred technology in many fields since they employ a variety of sensor sources and place nodes that collect data in places that are concealed from satellites.

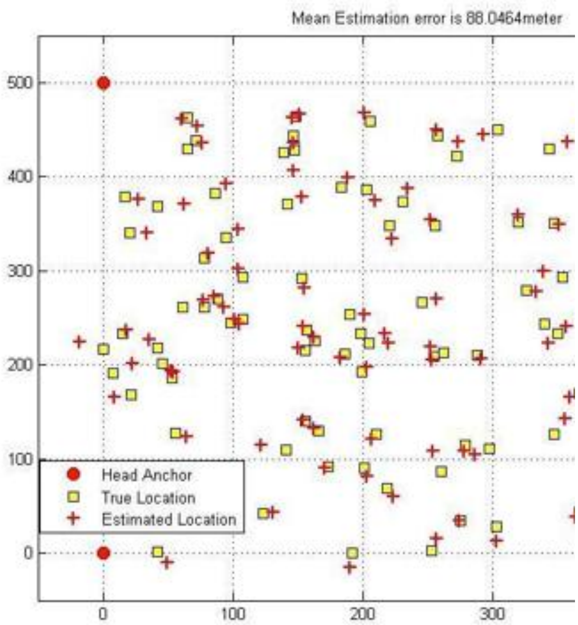
RESULTS AND DISCUSSIONS

The head anchor nodes help other regular nodes determine where they are. The estimate accuracy of regular nodes is higher in experimental scenario 2, where the grid size and anchor ratio are increased, than in case 1, when fewer sensors are placed. For scenario 2, the mean estimate error is found to be 35.89 meters.

Table 1: Position estimation of regular sensor nodes in the 200 × 200 m2 grid network

HEAD	**Regular Sensor Nodes**									
Anchors	1	2	3	4	5	6	7	8	9	10
1	268.3	6.81	184.3	168	212.9	225.9	105.2	233.1	169.6	141.9
2	189.8	198	246	88.47	136.6	206.3	98.23	137.5	97.38	63.82
3	190.2	193.5	38.45	196.8	179.9	121.5	208.6	198.7	189.1	226.3
4	14.50	276.8	167.4	135.4	75.23	79.37	205.2	63.96	128.4	187.4

Graph 1 shows the position estimate for 100 regular nodes with four head anchors. In this instance, the network size is chosen to be 500 x 500 m2, the regular nodes are regarded as 100, and the head anchors stay constant at 4. 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 1: 100 standard sensor nodes with four head anchors are deployed in a 500 × 500 m2 grid.

Keeping the head anchor node 4 fixed, 100 regular nodes are depicted throughout the 500 m network size for scenario 3. The location estimate of regular nodes in relation to head anchor nodes is shown in Table 2. Here, the regular node's location with the head anchor is calculated and shown in the table below. In a network, the head anchor nodes help other regular nodes locate themselves.

Table 2: Regular sensor node position estimate in the 500 × 500 m2 grid network

Head	Regular sensor nodes									
Anchors	1	2	3	4	5	6	7	8	9	10
1	309.7	458.4	390.9	440	339.2	437.8	312.7	462.8	382	474.7
2	455.0	528.4	112.4	469.8	580	646.3	287	284.2	297.7	95.89
3	262.8	197.3	615.1	253.3	164.5	67.21	427	452.7	411	621
4	424.4	328.6	488	302.2	498.4	480.1	408.5	267.5	334.1	411.6

The estimate accuracy of regular nodes is higher in experimental example, where the grid size through anchor ratio is increased, than in cases 1 and 2, where fewer sensors are placed. For scenario 3, the mean estimate error is found to be 80.05 m.

The suggested system is compared to the location estimating methods already in use. The strategy for a percentage increase in anchor ratio is compared to other current methods in Table 3.

Table 3: Comparative evaluation of location estimates Accuracy (%) Normalized error (%)

Anchor Ratio	DR LS	Grid Scan	Proposed	DR LS	Grid Scan	Proposed
0.05	25%	35%	62%	1.03	0.8	0.5
0.1	48%	50%	70%	0.78	0.654	0.4
0.15	57%	60%	74%	0.654	0.59	0.38
0.2	60%	65%	78%	0.624	0.563	0.31
0.25	64%	70%	80%	0.6	0.5	0.3
0.3	70%	73%	84%	0.594	0.4	0.22
0.35	72%	75%	85%	0.526	0.395	0.2
0.4	74%	73%	85%	0.468	0.38	0.2
0.45	72%	74%	86%	0.53	0.388	0.18

The research shows that the suggested approach produces a small change in average estimate error while the head anchor nodes remain constant and the anchor ratio increases. But the quantity of iterations needed to attain the worldwide optimum determines how well the suggested location estimate technique performs.

CONCLUSIONS

Additional methods to enhance the system include grouping nodes and using distributed sensing to determine the optimal channel of information for real-time communication. Lastly, using an AI algorithm might improve the system architecture even further. Early identification of forest fires is a topic of great interest to researchers. As awareness of the need to preserve biodiversity has grown in recent years, creative planning strategies for limiting forest fires have emerged. Creating a successful node deployment plan should be the main goal of real-time applications. Since a well-designed system will function better, this chapter examines effective data collection and real-time data processing. The main goal of this project is to monitor the forest ecosystem using WSNs. Thingspeak is an Internet of Things (IoT)-based analytical platform that controls the observed data from a nearby environment, such as moisture, temperature, light intensity, and atmospheric gasses. This chapter examines the steps involved in making judgements in the event of a fire, especially gathering, tracking, and analysing quantitative data in real time. Using sensors and the cloud-based Internet of Things platform ThingSpeak, the proposed system efficiently monitors forest fires. Temperature, humidity, light intensity, and gas sensor data are sent in real time to the ThingSpeak cloud.

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