Journal of Computation Physics and Earth Science
ISSN: 2776-2521 (online)
Volume 3, Number 1, April 2023, Page 16-23
https://journal.physan.org/index.php/jocpes/index

Literature Review: Development of a Machine Learning-Based Early Warning System for Land and Forest Fires with IoT and Automated Action Recommendations

Rini Arista[1]Daniela Adolfina Ndauman[2]
[1,2]Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

Article Info

Article history:

Received March 17, 2023
Revised March 28, 2023
Accepted April 01, 2023

Keywords:

Land and Forest Fires,
Machine Learning,
Internet of Things,
Automated Recommendation,
Multi-scale.

A B S T R A C T

Lightning strikes pose significant threats to human safety and infrastructure, particularly in tropical regions like Indonesia with high lightning activity. This study aims to develop a predictive model of lightning strike risk to humans based on spatial analysis and environmental factors, utilizing data on lightning distribution, land use, population density, and meteorological parameters. Using probabilistic decision trees and tropical lightning formulas, the model identifies key predictors, including rainfall, land use patterns, and humidity, which influence lightning density. The results reveal that densely populated areas with high lightning activity, such as parts of Java and Sumatra, are particularly vulnerable. Spatial risk maps generated from the model highlight high-risk zones, providing critical insights for disaster mitigation planning and infrastructure protection. Furthermore, the study emphasizes the significant correlation between lightning density, land use, and population exposure, offering a comprehensive framework for understanding lightning risks. This predictive model not only serves as a tool for early warning systems and sustainable spatial planning but also underscores the importance of integrating environmental and spatial data for effective lightning risk mitigation. Future research should incorporate temporal lightning variations and field validation to refine the model and enhance its applicability.

Corresponden Author:

Rini Arista,
Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)
Tangerang City, Banten, Indonesia
Email: riniarista1308@gmail.com

1. INTRODUCTION

Forest and Land Fires have become one of the world's most serious environmental threats, having a major impact on tree cover, greenhouse gas emissions, and public health. Regularly occurring major fires harm forests and agricultural crops, release a lot of CO2 and other air pollutants, and have a negative impact on people's health [1]. Their come to the center of environmental concerns because of their capacity to seriously damage the environment, impact wildlife habitats, and have an adverse impact on air quality [2]. Forest fires are currently destroying almost 3 million more hectares of tree cover annually than they did in 2001, according to research from the University of Maryland. This indicates that the burned region has nearly twice as much tree cover as it has now [3].

El Niño also exacerbates forest and land fires, increasing the risk of more severe fires. According to the Meteorology Climatology and Geophysics Agency (BMKG), the hot weather caused by this phenomenon accelerates fires, especially in areas known to be fire-prone. Wildfire dangers are raised when daylight saving time shifts cause human activities to change in timing. Interestingly, there is a 30% increase in wildfire incidents right after daylight saving time [2]. Both natural and human sources have the potential to create forest fires. Volcanic eruptions, lightning strikes, and spontaneous combustion are examples of natural causes [4]. The situation is worsened by extinguishing obstacles such as fires on peatlands that are difficult to reach.

Developing efficient prevention, early warning, and integrated intervention strategies is necessary to lessen their effects on both people and the environment [4]. To reduce the risk of fire, fire prevention strategies such as fuel management, controlled burns, and public awareness campaigns are crucial [4]. Additionally, early fire detection and forcasting are essential to minimize damage and support rescue efforts [5]. Artificial intelligence integration is becoming more popular as a way to automate fire detection and prediction. A subfield of artificial intelligence (AI) that focuses on computer learning is called machine learning [6]. Machine learning algorithms for pattern identification are already well-established and have demonstrated accuracy in a variety of domains, including education, crime, health, and fire incidents [7]. Fire patterns can be predicted using historical data and the latest weather conditions. This makes it possible to detect threats early before the fire spreads. Wildfires can start anywhere and spread quickly, making it difficult to identify and anticipate them [8]. Despite improvements to present early warning systems, the most pressing issue is ensuring that accurate and timely data is available in sensitive locations. Early warning systems based on machine learning and connected to Internet of Things (IoT) technologies are becoming increasingly important. We believe that a relevant method to do this goal is to use essential sensors to detect the presence of smoke and fire, as well as to measure changes in temperature, humidity, and wind speed [8].Data from strategic sensors on the ground can be collected and integrated through IoT technology, enabling faster detection and automated action recommendations that can be accessed by local communities and field officers. This method allows preventive action to be taken before forest fires become widespread.

Real-time coordination between regions is also essential in dealing with forest and land fire situations. Predictive models can be created with data from different regions to help detect and identify areas where forest and land fires may occur early. Information is sent to the cloud server for additional handling [9]. This allows officers to prepare for early and coordinated action. These prevention efforts not only act proactively, but can also provide relevant and specific alerts according to the conditions of each region. This makes it flexible for use at both local and national levels.

2. RESEARCH METHOD

The methodology used by this journal is a literature review. Using the keywords "Machine Learning-Based Early Warning System for Land and Forest Fires with IoT and Automated Action Recommendations," 20 journal articles covering the years 2017–2024 were found in the first stage of the search. By integrating the findings and perspectives of multiple empirical studies, a literature review can provide more insightful answers to research issues than any single study could [10].

The goal of this research is to design and build an early warning system for land and forest fires that offers automatic action suggestions through machine learning (ML) and an Internet of Things (IoT) connection. By using more sensors, the system is made to cover both small and large areas. In order to increase the efficiency of fire detection and response and lower the danger of environmental damage, this research seeks to create and settle these systems by reviewing 20 relevant articles.

3. RESULT AND DISCUSSION

Table 1. Literature Review Results

Table 1. Literature Review Results

No.	Title	Author	Objective	Results
1.	IOT Enabled Forest Fire Detection and Management	Deepthi S, Shushma G Krishna, Sahana K B	This project's primary goal is to use IoT technology to detect and track forest fires. The system continuously monitors temperature and humidity using sensors such as DHT11 and flame sensors that are coupled to a NodeMCU microcontroller. Through a smartphone app, the relevant forest department receives an alarm when these values surpass a certain level, allowing for early intervention to stop significant losses and the spread of fire.	Early forest fire detection is accomplished by the suggested technique, which minimizes human effort and false warnings. Real-time data transmission to the cloud and ongoing system monitoring guarantee prompt and accurate detection. Users may take rapid action to control the fire and minimize damage thanks to the smartphone app's instant notifications.

2.	Design and Implementation of LoRa-Based Forest Fire Monitoring System	Yosi Apriani, Wiwin A. Oktaviani, Ian Mochamad Sofian	The study's goal is to create and deploy a forest fire monitoring system using LoRa technology in order to address the limitations of current sensors and communication platforms in detecting and reporting fire occurrences in forest regions.	The AMG8833 thermal camera sensor and Arduino Uno were used to develop a fire monitoring system with high sensitivity within a 3–10 meter radius. With a LoRa configuration (250 bandwidth, 4/5 coding rate, and 10 spread factor), the system transmitted data up to 500 meters with a signal quality of -134 dBm. Woodland experiments validated its reliable communication and detection performance.
3.	A High-Precision Ensemble Model for Forest Fire Detection in Large and Small Targets	Jiachen Qian, Di Bai, Wanguo Jiao, Ling Jiang, Renjie Xu, Haifeng Lin, and TianWang	This research aims to improve detection accuracy for both large and small forest fire targets, addressing issues of misclassification and low accuracy in complex forest environments. To overcome these challenges, the study introduces two new models, WSB and WSS, along with an integrated model, WSB_WSS, designed to enhance fire detection across different target sizes.	According to the experimental results, the WSS model achieves 92.8% accuracy for large-scale forest fires, and the WSB model achieves 82.4% accuracy for small-scale forest fires. By successfully utilizing the advantages of both models, the integrated WSB_WSS model significantly increases detection accuracy, reaching 83.3% for small targets and 93.5% for large targets.
4.	Forest 4.0: Digitalization offorest using the Internet of Things fo(IoT)	Rajesh Singh, Anita Gehlot, Shaik Vaseem Akram,Amit Kumar Thakur, Dharam Bdhi, Prabin KumarDas	This study explores advanced technologies like deep learning, wireless sensor networks, and IoT to improve forest monitoring, addressing issues like illegal logging, fires, and wildlife tracking. It also aims to enhance data analysis, support tribal communities, and boost small-scale forest product commercialization.	The study effectively illustrates how IoT and other technologies can be integrated into forest ecosystems. It emphasizes how useful real-time sensing devices are for detecting forest fires, keeping an eye on environmental conditions, and stopping illicit activity. Future developments in data gathering and processing could benefit from the suggested architectures and techniques, which would enhance tribal livelihoods and promote sustainable forest management.
5.	Multi Sensor Network System for Early Detection and Prediction of Forest Fires in Southeast Asia	Evizal Abdul Kadir, Akram Alomainy, Hanita Daud, Warih Maharani, Noryanti Muhammad, Nesi Syafitri	This study aims to develop a multi-sensor network for early fire detection and prediction in Southeast Asia, enhancing fire management through real-time data sharing and advanced sensors monitoring temperature, humidity, and infrared radiation.	The multi-sensor network demonstrated a detection rate above 90% with a low false alarm rate. By integrating multiple fire indicators and machine learning, it achieved 93.6% accuracy in fire prediction, significantly enhancing emergency response and fire management.

6.	A real-time forest fire and smoke detection system using deep learning	Raghad K. Mohammed	The goal of this research is to develop a real-time smoke and forest fire detection system using deep learning. By leveraging transfer learning with the Inception-ResNet-v2 network, the system ensures high accuracy and low latency, making it suitable for deployment on drones and surveillance cameras for wide-area monitoring and early warnings.	The proposed system achieved high performance with 99.09% accuracy, 100% precision, 98.08% recall, 99.09% F1-Score, and 98.30% specificity. With an extremely low latency of <0.01 seconds per image, its successful deployment on a Raspberry Pi device proved effective for real-time detection, significantly aiding early forest fire prevention.
7.	An Improved Forest Fire Detection Method Based on the Detectron2 Model and a Deep Learning Approach	Akmalbek Bobomirzaevich Abdusalomov, Bappy MD Siful Islam, Rashid Nasimov, Mukhriddin Mukhiddinov, and Taeg Keun Whangbo	The goal of the research is to use deep learning techniques and the Detectron model to provide a better way to identify forest fires. In order to lessen the negative impacts of forest fires, this approach focuses on attaining quick and precise fire detection.	When it came to identifying forest fires, the suggested strategy showed a high level of accuracy of 99.3%. In a variety of testing circumstances, it outperforms previous algorithms in detecting minor fires across great distances, both during the day and at night.
8.	Real Time Monitoring and Fire Detection using Internet of Things and Cloud based Drones	Dr. Akey Sungheetha and Dr. Rajesh Sharma R	By creating an effective fire warning system, the research seeks to improve the safety of smart settings and cities. This system integrates IoT sensors, UAVs, and cloud computing to monitor environmental parameters in real-time, detect fires at an early stage, and validate fire occurrences using image processing techniques.	The proposed system demonstrated a 98% improvement in fire detection accuracy compared to traditional models. The integration of IoT sensors and image processing significantly enhanced the system's efficiency, enabling early detection and validation of fires, thereby preventing serious fire accidents and improving overall safety in smart environments.
9.	A Design and Development of the Smart Forest Alert MonitoringSystem Using IoT	Murugaperumal Krishnamoorthy, Md. Asif, Polamarasetty P. Kumar, Ramakrishna S. S. Nuvvula, Baseem Khan, and Ilhami Colak	The main objective of this research is to use IoT technology to create a smart forest alarm monitoring system. Preventing forest fires and safeguarding forest resources from social crimes like smuggling and deforestation are the goals of this approach. The system employs automated decision-making to notify authorities and carry out harm mitigation measures, and it incorporates a number of sensors to assess variables including temperature, humidity, and smoke.	A case study in an actual forest setting was used to test and validate the suggested system. The outcomes showed that the method could guarantee forest protection and predict forest fire outbreaks with high accuracy. Compared to conventional satellite-based systems, the sensitivity and promptness of fire detection were greatly increased by the integration of spot sensors and real-time data transmission.
10.	Integrated System Of Wireless Sensor Networks And Machine Learning For Early Forest Fire Detection And Control	Tandasa Niriksha, Jubilee Sarma, Ritisha Nayak, Soumya Dewangan, Akanksha Mishra	This study aims to create a sophisticated forest fire detection system by combining machine learning techniques with wireless sensor networks (WSNs). Improving early detection and response capabilities is	The research achieved significant results, demonstrating the effectiveness of the integrated system. The machine learning models, including Logistic Regression, XGBoost, and Convolutional Neural

			the aim in order to lessen the possible damage that forest fires could do. For the management and protection of forest fires, this system seeks to offer a more effective, dependable, and sustainable alternative.	Networks (CNNs), showed high accuracy in detecting forest fires. The detection accuracy increased to 95% with the usage of pre-trained models such as MobileNetV2 and InceptionResNetV2. These results demonstrate how WSNs and machine learning can be combined to identify and respond to forest fires accurately and in real time.
11.	Early Forest Fire Detection System using Wireless Sensor Network and Deep Learning	Wiame Benzekri, Ali El Moussati, Omar Moussaoui, Mohammed Berrajaa	Creating an accurate and effective early forest fire detection system is the aim of this study. This system uses deep learning models in conjunction with wireless sensor networks (WSN) to assist fire management efforts. By gathering environmental data from sensors positioned throughout the forest, the system forecasts when forest fires will occur, allowing for prompt and efficient interventions to reduce damage and casualties.	An autonomous, real-time environmental monitoring platform for forest fire detection is feasible, according to the study's findings. Predicting forest fires with excellent accuracy was demonstrated by the suggested method, which combines deep learning and the Internet of Things. With a 99.89% accuracy rate and few erroneous predictions, the GRU model in particular performed the best, demonstrating its viability for widespread deployment and efficacy in early fire detection.
12.	Towards early forest fire detection and prevention using AI-powered drones and the IoT	Montaser N.A. Ramadan, Tasnim Basmaji, Abdalla Gad, Hasan Hamdan, Bekir Tevfik Akgün, Mohammed A.H. Ali, Mohammad Alkhedher, MohammedGhazal	Developing a new airborne UAV-based Internet of Things system for wildfire sensing, identification, and extinguishment is the goal of the project. In order to overcome the drawbacks of traditional wildfire detection methods, this system offers a low-cost, low-maintenance option that may be widely used. By combining IoT nodes with AI-powered drones, the system can monitor high-risk regions, identify fires early, and speed up response times—all of which help to minimize environmental harm, human casualties, and financial losses.	Within one to five minutes after ignition, the suggested approach showed excellent accuracy and efficiency in detecting fires. The AI fire classification network achieved an accuracy of 99.46% and a mean average precision of 99.64%. The IoT nodes, designed for low power consumption, successfully transmitted data over long distances using the LoRaWAN protocol. The autonomous drone effectively localized and tracked fires, providing real-time monitoring and reporting through a cloud-based server. The system’s overall performance suggests it offers a reliable and scalable solution for early wildfire detection and management.
13.	IoT-Enhanced Early Warning System for Forest Fire Detection	N. D. Parameswa Rao, Y.Chennaiah, P.Sri Kavya, M.Varun Kumar, and S. Sri venkata yatish chandra	The research aims to develop an IoT-enhanced early warning system for forest fire detection. By utilizing various sensors and wireless communication, the system seeks to provide real-time data on environmental conditions to detect forest	Promising outcomes in real-time forest fire detection were shown by the deployment of the Internet of Things-based sensor network. Rapid response was made possible by the system's ability to identify fires within minutes of their initiation. The prediction power and

	fires early and enable rapid response.	monitoring effectiveness of the system were further improved by the incorporation of remote sensing technologies and machine learning techniques.

Deepthi S, Shushma G Krishna, and Sahana K B [11] demonstrated the effectiveness of IoT-based forest fire detection using DHT11 temperature and humidity sensors along with fire sensors. The system provides real-time early warnings via a mobile app, enabling quick responses. However, limited sensor coverage and reliance on internet connectivity remain challenges in remote areas. Yosi Apriani, Wiwin A. Oktaviani, and Ian Mochamad Sofian [12] addressed long-distance communication limitations in fire detection using LoRa technology. The AMG8833 thermal sensor enables data transmission up to 500 meters, but its fire detection range is only 3-10 meters, requiring additional sensors for large-scale coverage. Additionally, LoRa's low bandwidth may slow response times.Jiachen Qian et al. [13] developed WSB and WSS models that improve detection accuracy for large and small targets in complex forests. However, these models require high computational power and lack validation across diverse forest conditions, which may affect their reliability. Rajesh Singh et al. [14] introduced Forest 4.0, integrating IoT, wireless sensor networks, and deep learning for forest monitoring. The main challenges are large-scale implementation in remote forests and high costs of deployment and maintenance. Evizal Abdul Kadir et al. [15] created a multi-sensor system for early forest fire detection in Southeast Asia using predictive algorithms. While achieving high accuracy, it relies on stable power sources and high-quality data, which can be difficult to obtain in remote regions.

Raghad K. Mohammed [16] developed a deep learning-based fire and smoke detection system with 99.09% accuracy and <0.01s latency on a Raspberry Pi, making it highly effective for surveillance cameras and drones. Akmalbek Bobomirzaevich Abdusalomov et al. [17] created a probabilistic model to predict forest fire growth, but its reliance on volatile weather data may limit real-world effectiveness. Dr. Akey Sungheetha and Dr. Rajesh Sharma [18] integrated IoT sensors with drones, improving detection accuracy by 98% for smart neighborhood security. Murugaperumal Krishnamoorthy et al. [19] developed an early fire detection system to protect forest resources. Both systems were field-tested successfully, though complexity and infrastructure requirements pose challenges for large-scale implementation. Research by Tandasa Niriksha et al. demonstrated the effectiveness of integrating WSN with machine learning algorithms for fire detection [20]. Meanwhile, Wiame Benzekri et al. utilised WSN and deep learning models that achieved high accuracy (99.89%) [21]. However, the potential measurement error of the sensors and the dependency on the quality of the received data may affect the detection accuracy in the field. Montaser N.A. Ramadan et al. created an IoT-based UAV system for fire detection that responds within 1-5 minutes [22]. On the other hand, research by N. D. Parameswa Rao et al. showed that an IoT-based system can detect fires within minutes [23]. While both systems performed well, operational costs and infrastructure requirements remain a challenge.

Renjie Xu et al. [24] developed an ensemble learning-based detection system that enhances accuracy and reduces false positives. Nicoleta Cristina GAITAN and Paula HOJBOTA [25] designed a LoRa-based remote fire detection system. Both show promise in improving detection efficiency, though challenges like system complexity and range optimization remain. Pham et al. [26] evaluated various machine learning models—Bayes Network, Naïve Bayes, Decision Trees, and Multivariate Logistic Regression—for predicting fire vulnerability in Pu Mat National Park, Vietnam. The Bayes Network model performed best with an AUC of 0.96. Human-related factors, such as proximity to roads and residential areas, were identified as key fire predictors, offering valuable insights for improved fire management. Arif et al. [27] conducted a literature review on trends in fire prediction, detection, spread rate, and burnt area mapping. The study highlights the role of machine learning in improving fire management decisions to minimize economic and environmental impacts. It also explores emerging technologies, new data sources, and the importance of community collaboration in effective mitigation strategies. Basu et al. [28] developed an IoT-based forest fire detection system using MCU nodes, temperature sensors, and smoke sensors. The system monitors temperature and smoke levels to detect early fire signs and sends alerts via mobile apps or web pages. Results show its ability to quickly detect fires and smoke, helping prevent further damage. Sharma et al. [29] developed a sensor network-based forest fire detection and management system adaptable to various terrains. It demonstrated real-time detection, fire tracking via a web map, and improved efficiency using power-efficient wireless protocols. Toledo-Castro et al. [30] created an IoT-based system to monitor atmospheric variables and pollutant gases in real time. Designed for emergency management, it provides crucial data for fire prediction and control. The system effectively activates alerts based on temperature, humidity, and gas thresholds, supporting early fire detection and response.

4. CONCLUSION

Several research prove the significance of technological developments in the detection and prevention of land and forest fires. According to the 20 journals collected, a possible way to increase the efficacy of early warning systems against forest fires is to combine a combination of wireless sensor networks, automated alerts, machine learning models, and the Internet of Things (IoT). Several studies highlight the relevance of real-time monitoring to detect environmental changes that may cause fires. Accurate data that facilitates prompt decision-making in fire response can be obtained via systems that use sensors to assess temperature, humidity, and smoke presence. Remote communication is also made accessible by technologies like LoRa, but it coverage over wider regions is still concerning.

It has been proved that machine learning models increase the precision of mapping and forecasting fire vulnerability, which is necessary for improved control methods. Studies indicate that human-related factors, like the distance from roads and populated areas, significantly impact the probability of a fire. This suggests that a more comprehensive strategy is required to comprehend the variables affecting fire risk.

Despite developments, a number of obstacles still need to be overcome, such as inadequate infrastructure, high implementation costs, restrictions on sensor coverage, and the requirement for high-quality data in order to support predictive algorithms. Furthermore, the absence of reliable power supplies frequently makes it difficult to implement the technology on a broad scale in isolated locations.

As a whole, these studies highlight how the combination of IoT, LoRa, and accurate predictive models can enhance forest fire detection and management, even in an environment of obstacles related to inspection, processing capacity, and large-scale technology adoption. In keeping with the requirement to implement machine-learning-based early warning systems linked to the Internet of Things (IoT), this method is essential for lowering environmental impacts and risks to nearby communities. When such systems are put into place, they can offer real-time coordination across multiple areas and automated action recommendations, and both of that are essential for effective prevention and mitigating forest fires.

REFERENCE

[1] L. Kiely et al., “Assessing costs of Indonesian fires and the benefits of restoring peatland,” Nat. Commun., vol. 12, no. 1, pp. 1–11, 2021, doi: 10.1038/s41467-021-27353- x.

[2] L. Zhang, M. Xu, H. Chen, Y. Li, and S. Chen, “Globalization, Green Economy and Environmental Challenges: State of the Art Review for Practical Implications,” Front. Environ. Sci., vol. 10, no. March, pp. 1– 9, 2022, doi: 10.3389/fenvs.2022.870271.

[3] Data Terbaru Mengonfirmasi: Kebakaran Hutan Semakin Memburuk," WRI Indonesia, Oct. 2023. [Online]. Available: https://wri-indonesia.org/id/wawasan/data- terbaru-mengonfirmasi-kebakaran-hutan-semakin memburuk.

[4] F. Carta, C. Zidda, M. Putzu, D. Loru, M. Anedda, and D. Giusto, “Advancements in Forest Fire Prevention: A Comprehensive Survey,” Sensors, vol. 23, no. 14, 2023, doi: 10.3390/s23146635.

[5] R. Alkhatib, W. Sahwan, A. Alkhatieb, and B. Schütt, “A Brief Review of Machine Learning Algorithms in Forest Fires Science,” Appl. Sci., vol. 13, no. 14, 2023, doi: 10.3390/app13148275.

[6] A. M. Elshewey and A. A. Elsonbaty, “Forest Fires Detection Using Machine Learning Techniques,” Int. J. Res. Eng. Sci. ISSN, vol. 10, no. Ix, pp. 271–275, 2022.

[7] J. R. Asor, J. L. Lerios, S. B. Sapin, J. O. Padallan, and C. A. C. Buama, “Fire incidents visualization and pattern recognition using machine learning algorithms,” Indones. J. Electr. Eng. Comput. Sci., vol. 22, no. 3, pp. 1427–1435, 2021, doi: 10.11591/ijeecs.v22.i3.pp1427-1435.

[8] M. Grari et al., “Using Iot and Ml for Forest Fire Detection, Monitoring, and Prediction: a Literature Review,” J. Theor. Appl. Inf. Technol., vol. 100, no. 19, pp. 5445–5461, 2022.

[9] J. Ananthi, N. Sengottaiyan, S. Anbukaruppusamy, K. Upreti, and A. K. Dubey, “Forest fire prediction using IoT and deep learning,” Int. J. Adv. Technol. Eng. Explor., vol. 9, no. 87, pp. 246–256, 2022, doi: 10.19101/IJATEE.2021.87464.

[10] H. Snyder, “Literature review as a research methodology: An overview and guidelines,” J. Bus. Res., vol. 104, no. August, pp. 333–339, 2019, doi: 10.1016/j.jbusres.2019.07.039.

[11] S. Deepthi, S. G. Krishna, K. B. Sahana, H. R. Vandana, and M. Latha, “IOT Enabled Forest Fire Detection and Management,” Int. J. Eng. Res. Technol., vol. 8, no. 11, pp. 196–199, 2020.

[12] Y. Apriani, W. A. Oktaviani, and I. M. Sofian, “Design and Implementation of LoRa-Based Forest Fire Monitoring System,” J. Robot. Control, vol. 3, no. 3, pp. 236– 243, 2022, doi: 10.18196/jrc.v3i3.14128.

[13] J. Qian et al., “A High-Precision Ensemble Model for Forest Fire Detection in Large and Small Targets,” Forests, vol. 14, no. 10, 2023, doi: 10.3390/f14102089.

[14] R. Singh, A. Gehlot, S. Vaseem Akram, A. Kumar Thakur, D. Buddhi, and P. Kumar Das, “Forest 4.0: Digitalization of forest using the Internet of Things (IoT),” J. King Saud Univ. - Comput. Inf. Sci., vol. 34, no. 8, pp. 5587 5601, 2022, doi: 10.1016/j.jksuci.2021.02.009.

[15] Evizal Abdul Kadir, A. Alomainy, H. Daud, W. Maharan, N. Muhammad, and N. Syafitri, "Multi Sensor Network System for Early Detection and Prediction of Forest Fires in Southeast Asia," vol. 16, no. 1, pp. 1–23, 2022.

[16] R. K. Mohammed, "A real-time forest fire and smoke detection system using deep learning," Int. J. Nonlinear Anal. Appl, vol. 13, no. November 2021, pp. 2008–6822, 2022, [Online]. Available: http://dx.

[17] A. B. Abdusalomov, B. M. S. Islam, R. Nasimov, M. Mukhiddinov, and T. K. Whangbo, "An Improved Forest Fire Detection Method Based on the Detectron2 Model and a Deep Learning Approach," Sensors, vol. 23, no. 3, 2023, doi: 10.3390/s23031512.

[18] D. A. Sungheetha and D. R. Sharma R, "Real Time Monitoring and Fire Detection using Internet of Things and Cloud based Drones," J. Soft Comput. Paradig., vol. 2, no. 3, pp. 168–174, 2020, doi: 10.36548/jscp.2020.3.004.

[19] M. Krishnamoorthy, M. Asif, P. P. Kumar, R. S. S. Nuvvula, B. Khan, and I. Colak, "A Design and Development of the Smart Forest Alert Monitoring System Using IoT," J. Sensors, vol. 2023, 2023, doi: 10.1155/2023/8063524.

[20] T. Niriksha, J. Sarma, R. Nayak, S. Dewangan, and A. Mishra, "INTEGRATED SYSTEM OF WIRELESS SENSOR NETWORKS AND MACHINE LEARNING FOR EARLY FOREST FIRE DETECTION AND," vol. 9, no. 5, pp. 527–534, 2024.

[21] W. Benzekri, A. El Moussati, O. Moussaoui, and M. Berrajaa, "Early forest fire detection system using wireless sensor network and deep learning," Int. J. Adv. Comput. Sci. Appl., vol. 11, no. 5, pp. 496–503, 2020, doi: 10.14569/IJACSA.2020.0110564.

[22] M. N. A. Ramadan et al., "Towards early forest fire detection and prevention using AI-powered drones and the IoT," Internet of Things (Netherlands), vol. 27, no. February, p. 101248, 2024, doi: 10.1016/j.iot.2024.101248.

[23] N. D. P. Rao, Y. Chennaiah, P. S. Kavya, M. V. Kumar, and S. S. venkata yatish chandra, "IoT-Enhanced Early Warning System for Forest Fire Detection," Int. J. Innov. Res. Eng. Manag., vol. 9, no. 3, pp. 195–198, 2022, doi: 10.55524/ijirem.2022.9.3.32.

[24] R. Xu, H. Lin, K. Lu, L. Cao, and Y. Liu, "A forest fire detection system based on ensemble learning," Forests, vol. 12, no. 2, pp. 1–17, 2021, doi: 10.3390/f12020217.

[25] N. C. Gaitan and P. Hojbota, "Forest fire detection system using lora technology," Int. J. Adv. Comput. Sci. Appl., vol. 11, no. 5, pp. 18–21, 2020, doi: 10.14569/IJACSA.2020.0110503.

[26] B. T. Pham et al., "Performance evaluation of machine learning methods for forest fire modeling and prediction," Symmetry (Basel)., vol. 12, no. 6, pp. 1–21, 2020, doi: 10.3390/SYM12061022.

[27] A. Muhammad et al., "Role of Machine Learning Algorithms in Forest Fire Management: A Literature Review," J. Robot. Autom., vol. 5, no. 1, pp. 212–226, 2021, doi: 10.36959/673/372.

[28] M. Trinath Basu, R. Karthik, J. Mahitha, and V. Lokesh Reddy, "IoT based forest fire detection system," Int. J. Eng. Technol., vol. 7, no. 2, pp. 124–126, 2018, doi: 10.14419/ijet.v7i2.7.10277.

[29] A. Sharma, B. S. Sohi, and S. Chandra, "SN based forest fire detection and early warning system," Int. J. Innov. Technol. Explor. Eng., vol. 8, no. 9, pp. 209–214, 2019, doi: 10.35940/ijitee.h6733.078919.

[30] C. Hernández-Goya, P. Caballero-Gil, I. Santos-González, and J. Toledo-Castro, "Management of Forest Fires Using IoT Devices," Elev. Int. Conf. Mob. Ubiquitous Comput. Syst. Serv. Technol. UBICOMM 2017, no. c, pp. 121–126, 2017.