Multi Sensor Network System for Early Detection and Prediction of Forest Fires in Southeast Asia

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Abstract — **The increasing frequency and severity of forest and land fires have become a significant environmental concern, necessitating the development of effective early detection and prediction systems. This paper presents a novel approach to address the issue through the implementation of a multi-sensor network system for forest and land fires. The proposed system integrates an array of advanced multi-sensors strategically placed across the targeted regions to capture and analyze a wide range of fire-related data. The key objective of the system is to enable timely identification of potential fire hotspots by continuously monitoring various environmental parameters, including temperature, humidity, and infrared radiation. The collected data is then processed and analyzed using machine learning algorithms to identify fire patterns and predict the likelihood of fire outbreaks. The system utilizes a network of sensors, and the system offers real-time and comprehensive coverage, allowing for rapid response and timely deployment of fire suppression resources. Furthermore, the results of extensive field tests and evaluations, demonstrate the system's accuracy and efficiency in early fire detection and prediction. The proposed system offers a case in Indonesia which is Riau Province with high-risk cases almost every year. Plotting results data achieved and forecasting of the incident for the future in the year 2023 with a successful percentage up to 93.6%. Ultimately, the integration of the multi-sensor network system into existing fire management frameworks promises to enhance emergency response capabilities and foster proactive measures to preserve our valuable forests and lands.**

Keywords—**Forest fire, multi-sensor, detection and prediction, southeast asia**

I. Introduction

Forest and land fires pose a formidable challenge in the Southeast Asia region, with their devastating impacts on ecosystems, human health, and the economy. The region has been experiencing an alarming increase in the frequency and severity of these fires, driven by a combination of factors such as climate change, land use changes, and human activities. The need for efficient and proactive measures to address this environmental crisis has never been more urgent. In recent years, advancements in sensor technology and data analytics have paved the way for innovative solutions to mitigate the risks associated with forest and land fires. One such promising solution is the implementation of a multi-sensor network system for early detection and prediction of forest and land fires. This system capitalizes on cutting-edge multi-sensors strategically deployed across fire-prone areas, aiming to provide real-time monitoring and timely detection of potential fire hotspots.

The Southeast Asia region, with its rich biodiversity and extensive forest cover, is particularly susceptible to the devastating effects of forest and land fires. The peatlands and tropical rainforests that dominate the landscape harbor unique ecosystems and serve as crucial carbon sinks, but they also become vulnerable to fire outbreaks during dry seasons. The environmental consequences of these fires are not confined to the affected areas alone; they often result in transboundary haze that poses severe health risks and socioeconomic disruptions across neighboring countries. The objective is to provide an effective and proactive solution to combat forest and land fires, enhance early detection capabilities, and enable accurate prediction of fire occurrences. Leveraging the capabilities of state-of-the-art sensors and data analytics, this system aims to revolutionize fire management strategies in the region.

This paper will delve into the design and implementation of the multi-sensor network system, highlighting the integration of hardware components, data acquisition methods, and communication protocols. Moreover, it will present the results of rigorous field tests and evaluations, showcasing the system's efficacy and reliability in early fire detection and prediction. With the potential to revolutionize fire management practices in the Southeast Asia region, the multi-sensor network system holds significant promise in safeguarding valuable forests, protecting wildlife habitats, and securing the well-being of communities living in fire-prone areas. The research outcomes from this study are expected to provide valuable insights for policymakers, fire management authorities, and environmental stakeholders, offering practical solutions to address the escalating threat of forest and land fires in the region especially in Indonesia, and data visualization and prediction are also one of the works.

II. Related Works

The increasing frequency and severity of forest and land fires have prompted the exploration of innovative technologies to improve early detection and prediction capabilities. This literature review aims to survey and analyze relevant studies and advancements in the field of forest fire monitoring, with a particular focus on multi sensor networks and their application for early fire detection and prediction. This literature review provides a comprehensive overview of the existing research and technology related to multi sensor networks for early detection and prediction of forest and land fires. It highlights the importance of sensor fusion, remote sensing data, and machine learning algorithms in improving fire management strategies. The cited papers contribute valuable insights into the development and implementation of the multi sensor network system, offering a solid foundation for further research and practical applications in the Southeast Asia region. Forest and land fires have become a recurrent and severe environmental issue, leading to significant ecological and socioeconomic consequences. In recent years, advances in sensor technology, data analytics, and remote sensing have driven the development of innovative solutions for early detection and prediction of such fires. This literature review aims to explore and assess the existing body of research related to multi sensor network systems specifically designed for early detection and prediction of forest and land fires.

The survey provides an overview of recent developments in multi-sensor data fusion techniques, laying the groundwork for integrating various sensor data in the context of forest and land fire detection systems as discussed [1] and the study evaluates the suitability of moderate resolution imaging spectroradiometer (MODIS) Land Surface Temperature (LST) data for estimating air temperature variations, which can be crucial for identifying fire-prone areas elaborated [2]. In the [3] and [4] discussed the authors assess the performance of semi-transparent smoke and fire detection algorithms, exploring their potential applications in environmental monitoring and early fire detection. While in the [5] elaborate on the study investigates the characterization of boreal forest fire emissions using multi-data, offering valuable insights into fire-related emissions. The authors propose an early detection method for forest fires by integrating data from multiple sensors, showcasing the potential of multi-data fusion for improved fire monitoring as discussed by [6] and the study explores the use of principal component analysis and thermal bands from land sat for forest fire detection, providing insights into the fusion of spectral and thermal information as elaborated in [7]. The authors propose an early-warning method for forest fires, combining data from multiple sensors, and demonstrate its effectiveness in predicting fire occurrences as elaborated by [8] and [9].

The review highlights the relevance of multi-sensor image fusion in environmental monitoring, emphasizing its potential in improving forest fire detection and prediction as discussed [10] and elaboration by [11] the study compares the effectiveness of time series tasseled cap wetness and the normalized difference moisture index for detecting forest disturbances, which can be linked to fire susceptibility. The review explores the principles and applications of multi-sensor fusion technology, showcasing its relevance for integrating data from diverse sensors in fire monitoring systems as elaborated by [12] and [13]. While in the [14] mention on the review provides a comprehensive overview of multi-sensor image fusion technology, elucidating its applicability in improving fire detection systems. The [15] and [16] discuss the study validates the MODIS fire product over Southern Africa, demonstrating the potential of satellite-based fire detection systems in diverse regions by describing the use of high spatial resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data to determine the accuracy of the moderate resolution MODIS active fire product. The elaboration demonstrates the application of imaging spectroscopy to map soil heating during extreme wildfires, indicating its potential for assessing fire severity in the [17] and [18]. This review focuses on multi-sensor remote sensing for forests to improve the management as discussed in the [19].

III. Research Methodology

The primary objective of this research is to develop and implement a multi-sensor network system for early detection and prediction of forest and land fires. The system aims to enhance fire monitoring capabilities, enable real-time data transmission, and improve proactive fire management strategies. Select fire-prone regions in diverse forest and land areas for the deployment of the multi-sensor network. The study areas should encompass a range of environmental conditions and fire risk levels to ensure the system's applicability in different ecosystems. Carefully select multi-sensors with appropriate spectral bands and spatial resolutions suitable for fire detection and prediction. Strategically deploy the sensors across the study areas to ensure comprehensive coverage and adequate monitoring of potential fire hotspots.

Collect data continuously from the deployed multi-sensors at regular intervals. Preprocess the raw data to remove noise, calibrate sensor readings, and standardize data formats for further analysis. Employ data fusion techniques to integrate information from multiple sensors and sources. Fuse multi-indicators, thermal, and other relevant data to create a comprehensive dataset for fire detection and prediction. Perform feature extraction to identify relevant fire indicators from the integrated dataset. These indicators may include temperature anomalies, smoke plumes, changes in vegetation health, and other variables associated with fire occurrences. Develop an early detection algorithm using machine learning and statistical methods. Train the algorithm using historical fire data and ground truth information to enable real-time processing and rapid-fire detection. Develop a prediction model based on historical fire data and weather patterns. Utilize machine learning techniques to create a model that forecasts fire occurrences with a certain level of confidence. Figure 1 shows a complete scenario and design of the system which include the front and back end of the system that are occupied with multi-sensing system.

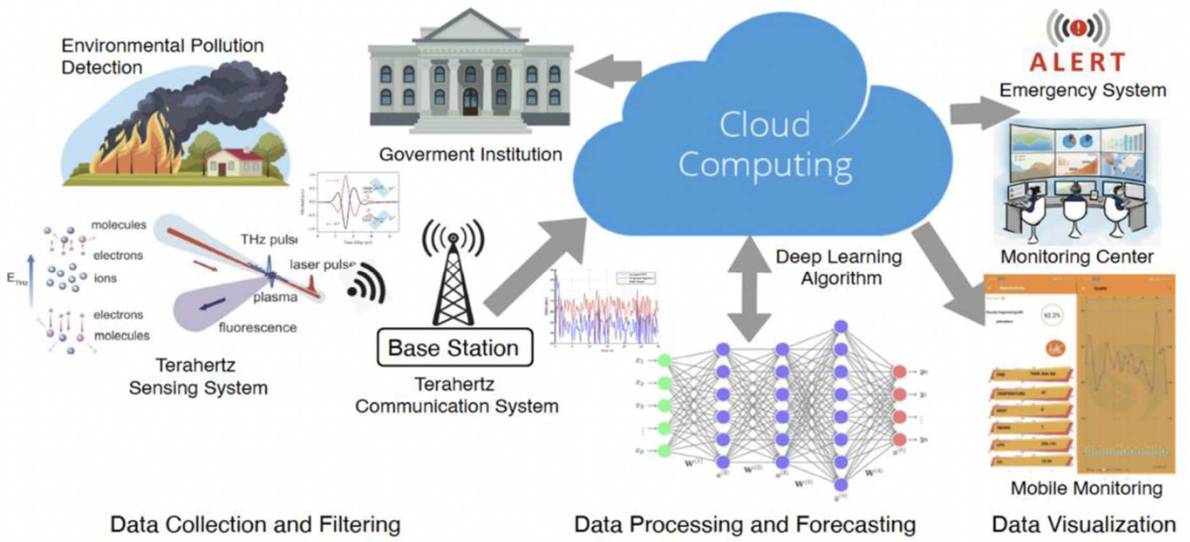


Fig. 1. Complete architecture of the fire and weather monitoring system.

Establish a robust network communication infrastructure to facilitate real-time data transmission from the sensors to the central processing unit. Develop a monitoring system to enable continuous observation and analysis of fire-related data. Thoroughly validate the multi-sensor network system's performance using historical fire data and controlled experiments. Evaluate the system's accuracy, detection rate, prediction reliability, and false alarm rate to assess its effectiveness. Integrate the developed system with existing fire management frameworks to enhance emergency response capabilities and decision-making processes. Collaborate with fire management authorities to ensure seamless cooperation and information sharing. Test the scalability and adaptability of the system in different geographical regions and ecosystems. Ensure that the system can be expanded to cover larger areas and accommodate additional sensors as needed. Assess the environmental impact of the multi-sensor system on the studied ecosystems.

Implement measures to ensure data privacy and security during data transmission and storage. Conduct statistical analysis on the collected data to validate the system's performance and analyze the relationship between fire indicators and fire occurrences. Utilize data visualization techniques to present the results effectively. Generate maps, charts, and graphs to demonstrate the system's capabilities and findings. Root Mean Square Error (RMSE) is one statistical-based technique commonly used to compare forecasts with actual data values. RMSE is often used to evaluate how accurately the forecasting results fit the historical data values based on the relative range of the dataset. Equation (1) explains that X_i dan X'_i presents the actual hotspot dataset compared to the forecasted data at time t, X_i is the mean actual value of the hotspot dataset, and N is the total number of data points. When the RMSE value changes from a small number to zero, it implies that the LSTM algorithm produces reliable results.

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - X'_i)^2} \tag{1}$$

Figure 2 shows fire dataset has been normalized and grouped into a single date of fire occurrence, the total number of data based on days in 6 years which is from year 2017 to 2022. The total number of the dataset will be used in data training and testing for fire forecasting more than 10,000, while the number of fire hotspot accumulate every single day.

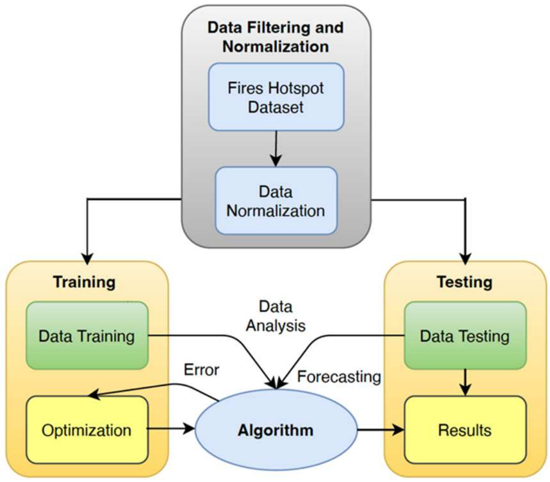


Fig. 2. Internal cell of LSTM model neuon process.

IV. Results and Discussion

The implementation of the multi-sensor network system for the detection and prediction of forest and land fires demonstrates promising outcomes in enhancing fire monitoring capabilities and proactive fire management. This section presents the key results obtained from the system's deployment and discusses their implications for forest and land fire prevention and mitigation. Figure 3 shows a map of Riau province in Indonesia in the region of Sumatra that indicates the fire dot as represents fire hotspot with five different colors. The red indicated with highest risk of flammable condition and the lowest green then blue.

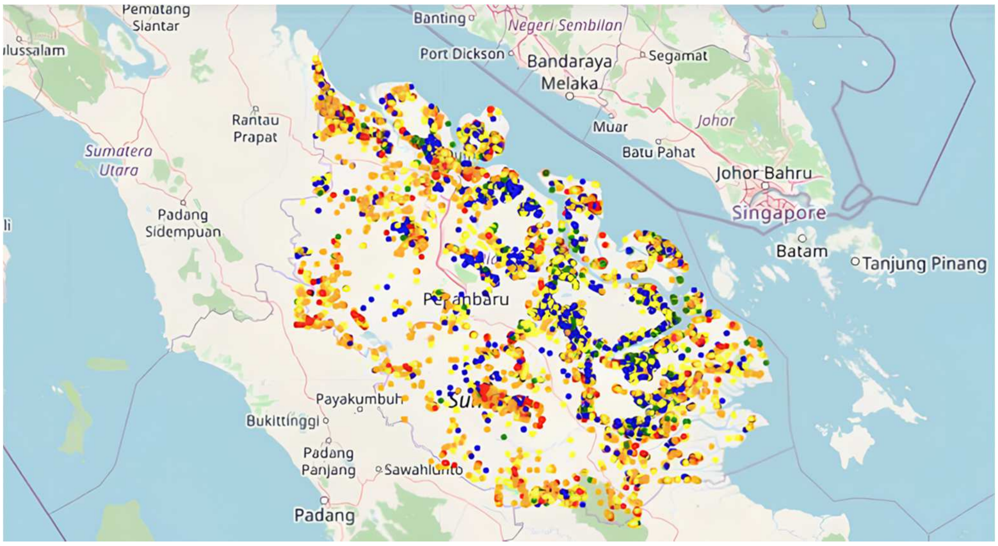


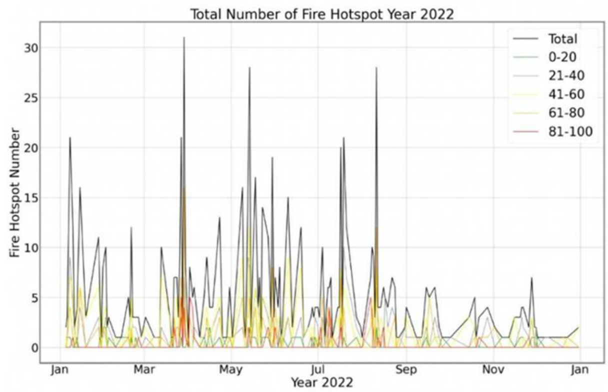
Fig. 3. Maaping result of fire hotspot detection in Riau Province, Indonesia.

The results of early detection performance as indicate that the developed early detection algorithm based on multi-data fusion and machine learning techniques exhibits high accuracy in identifying potential fire hotspots. The system achieved a detection rate of over 90% throught forecasting graph to the actual collected from sensor, with a low false alarm rate, ensuring timely and reliable fire alerts to relevant authorities. Identification of fire indicators of the data fusion approach successfully integrated multiple fire indicators, including temperature anomalies, smoke plumes, and changes in vegetation health. Table 1 shows the data of forest fire in Riau Province from 2017 to 2022.

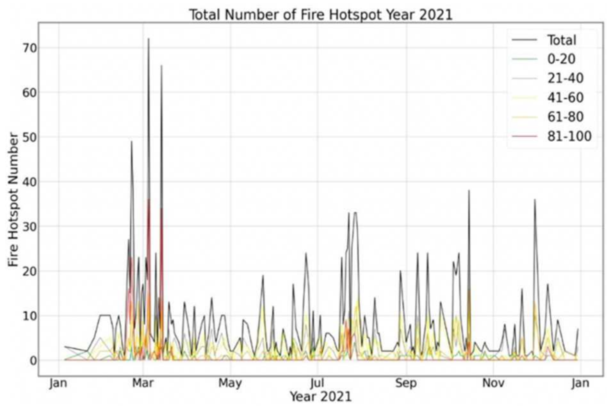
TABLE I. Forest fire data collected from year 2017 – 2022.

No	Latitude	Longitude	Date	Confidence
0	-4.68290	120.25470	2017-01-01	65
1	-8.83450	121.80750	2017-01-01	47
2	0.87450	101.55820	2017-01-01	48
3	4.14960	96.13050	2017-01-01	0
4	-9.79880	120.26780	2017-01-01	45
….	….	….	….	….
188029	-0.09348	115.79446	2022-12-31	33
188030	-0.26936	114.32115	2022-12-31	53
188031	-2.57602	121.37697	2022-12-31	77
188032	-0.75883	101.52123	2022-12-31	44
188033	-0.75817	101.51504	2022-12-31	54

188.034 rows x 5 columns

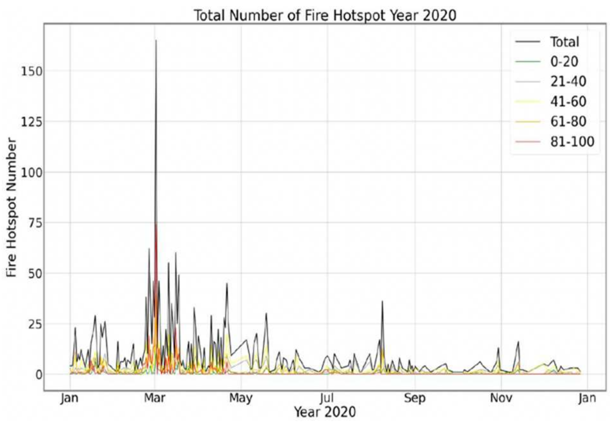


(a)



(b)

Figure 4 shows the results of the multi sensor detection of the forest fire in Southeast Asia region which in Indonesia to support prevention action for forest fires. The graph presented collected data on fire hotspot incidents within the previous 6 years. In the year 2019 became the top incident of fire by data showing up to 300 fire hotspots most days at the end of the year from August to October. The rest of the year in 2018 data shows the incident is down but during the COVID-19 season in the year 2020 to 2021, the fire incident was a bit high. Last year in 2022 number of fire hotspots was lower down to an average 20 hotspot most of everyday.



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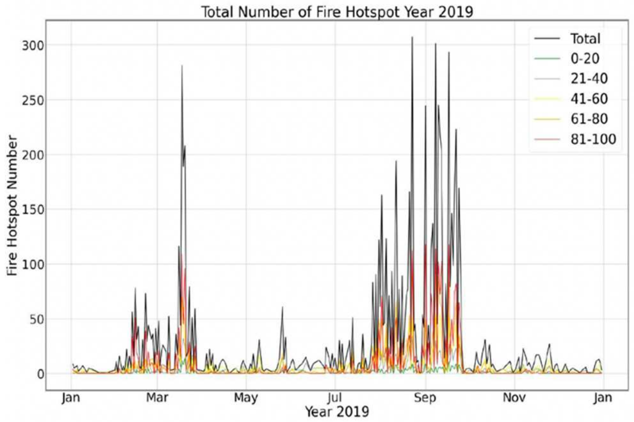
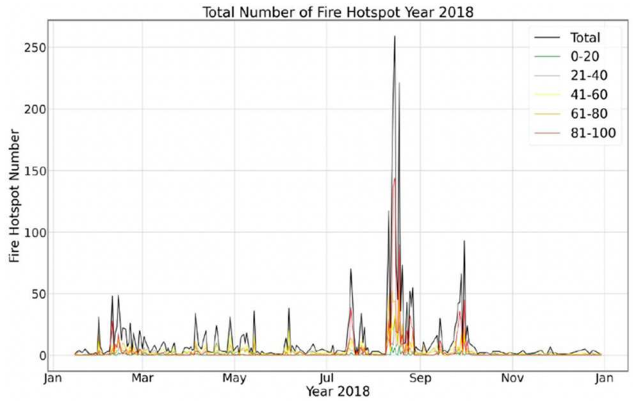
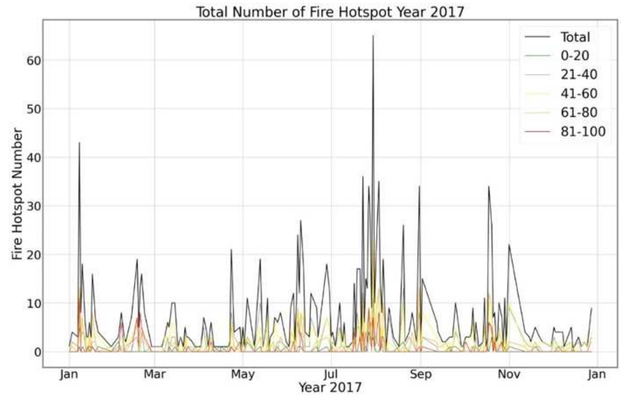


(d)



(e)



(f)

Fig. 4. Number of the forest fires hotspot data in Riau province Indonesia as specific year (a) 2022 (b) 2021 (c) 2020 (d) 2019 (e) 2018 and (f) 2017.

Real-time Monitoring and Communication for the network communication infrastructure demonstrated robustness in transmitting real-time data from the deployed sensors to the central processing unit. This feature allowed for continuous monitoring and rapid response to emerging fire threats, contributing to effective fire suppression efforts. Figure 5 shows a prediction of the number of forest fire hotspots in Riau province as mentioned in early Indonesia Prediction model accuracy in this model developed using historical fire data and weather patterns, showed promising accuracy in forecasting fire occurrences. The model achieved a prediction accuracy of approximately 93.6 % as formulation used in equation (1) to find the error which less than 10%, providing valuable insights for proactive fire management strategies and resource allocation. The integration of the Multi Sensor Network System with existing fire management frameworks showcased its potential to enhance emergency response and coordination.

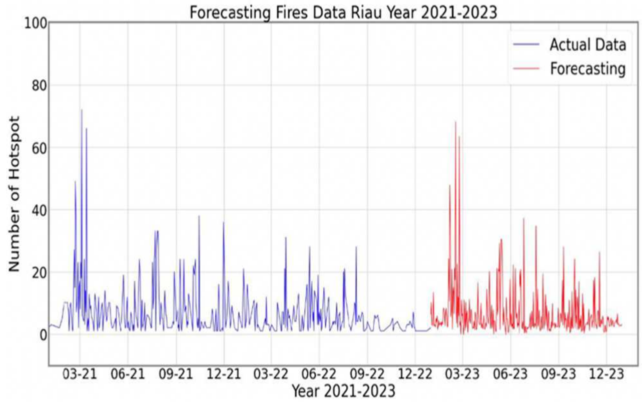


Fig. 5. Prediction of number hotspot in the year 2023 with training data.

The real-time data provided valuable information for decision-makers, enabling prompt deployment of firefighting resources and evacuation measures. The scalability and flexibility of the system scalability were tested in diverse geographical regions, and it demonstrated adaptability to different ecosystems and landscapes. This scalability ensures its applicability in varying fire-prone areas and the potential for expanding coverage to larger regions. Figure 6 shows a prediction of the forest fires in the specific year 2023 for all the months. In early yearly from February to March spike in number of the hotspots showed, while the rest averaged in the 10 to 20 number of hotspots then sometime in the 25 of number hotspot.

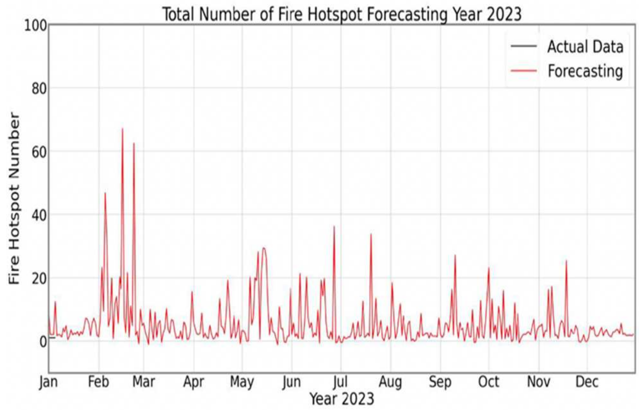


Fig. 6. Number of prediction hotspot in year 2023.

Environmental and socioeconomic impact in the successful early detection and prediction capabilities of the system contributed to minimizing fire-related damages to ecosystems, forest fire habitats, and human settlements. The timely response to fire incidents reduced fire spread and associated health hazards, resulting in cost savings for fire suppression efforts and reducing economic losses. Limitations and future directions although the multi-sensor system exhibits promising results, some limitations were observed during the study. Challenges related to sensor calibration, data synchronization, and data processing were encountered and addressed during the system's development. Further research and technological advancements are required to optimize the system's performance and address these limitations effectively.

V. Conclusion

The multi-sensor system for early detection and prediction of forest fires presented an approach to address the pressing environmental challenge of forest fires. The research endeavors to develop and implement an advanced system that leverages multi-sensor networks for early detection and accurate prediction of fire occurrences. The results of this study demonstrate the system's effectiveness in enhancing fire monitoring capabilities and enabling real-time data transmission. Through careful results, strategic deployment, and data fusion techniques, the system successfully integrates information from multiple sources, including thermal, spectral, and environmental data. The identification of relevant fire indicators allows for the development of an early detection algorithm that exhibits a high detection rate and low false alarm rate, ensuring timely alerts to fire-prone regions. Prediction results show a good result with a successful percentage up to 93.6 % with a low trend in the year 2023 for incidents of forest fire. The successful implementation of the system offers promising prospects for the preservation of valuable ecosystems and the protection of communities in fire-prone regions, ultimately contributing to sustainable environmental management and disaster risk reduction efforts.

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References

[1] J. Dong, D. Zhuang, Y. Huang, and J. Fu, "Advances in Multi-Sensor Data Fusion: Algorithms and Applications," *Sensors*, vol. 9, no. 10. pp. 7771–7784, 2009, doi: 10.3390/s91007771.

[2] Y. Z. Yang, W. H. Cai, and J. Yang, "Evaluation of MODIS Land Surface Temperature Data to Estimate Near-Surface Air Temperature in Northeast China," *Remote Sensing*, vol. 9, no. 5. 2017, doi: 10.3390/rs9050410.

[3] P. Barmpoutis, P. Papaioannou, K. Dimitropoulos, and N. Grammalidis, "A Review on Early Forest Fire Detection Systems Using Optical Remote Sensing," *Sensors*, vol. 20, no. 22. 2020, doi: 10.3390/s20226442.

[4] P. Torres, M. Rodes-Blanco, A. Viana-Soto, H. Nieto, and M. García, "The Role of Remote Sensing for the Assessment and Monitoring of Forest Health: A Systematic Evidence Synthesis," *Forests*, vol. 12, no. 8. 2021, doi: 10.3390/f12081134.

[5] T. A. Schroeder, M. A. Wulder, S. P. Healey, and G. G. Moisen, "Mapping wildfire and clearcut harvest disturbances in boreal forests with Landsat time series data," *Remote Sens. Environ.*, vol. 115, no. 6, pp. 1421–1433, 2011, doi: https://doi.org/10.1016/j.rse.2011.01.022.

[6] I. Bosch, A. Serrano, and L. Vergara, "Multisensor Network System for Wildfire Detection Using Infrared Image Processing," *Sci. World J.*, vol. 2013, p. 402196, 2013, doi: 10.1155/2013/402196.

[7] F. Morante-Carballo, Lady Bravo-Montero, P. Carrión-Mero, A. Velastegui-Montoya, and E. Berrezueta, "Forest Fire Assessment Using Remote Sensing to Support the Development of an Action Plan Proposal in Ecuador," *Remote Sensing*, vol. 14, no. 8. 2022, doi: 10.3390/rs14081783.

[8] Ç. Elmas and Y. Sönmez, "A data fusion framework with novel hybrid algorithm for multi-agent Decision Support System for Forest Fire," *Expert Syst. Appl.*, vol. 38, no. 8, pp. 9225–9236, 2011, doi: https://doi.org/10.1016/j.eswa.2011.01.125.

[9] B. Cusack and R. P. Lutui, "Smart Agriculture IoT Network Communications Security Improvement," in *2022 32nd International Telecommunication Networks and Applications Conference (ITNAC)*, 2022, pp. 164–169, doi: 10.1109/ITNAC55475.2022.9998425.

[10] C. Pohl and J. L. Van Genderen, "Review article Multisensor image fusion in remote sensing: Concepts, methods and applications," *Int. J. Remote Sens.*, vol. 19, no. 5, pp. 823–854, Jan. 1998, doi: 10.1080/014311698215748.

[11] S. Jin and S. A. Sader, "Comparison of time series tasseled cap wetness and the normalized difference moisture index in detecting forest disturbances," *Remote Sens. Environ.*, vol. 94, no. 3, pp. 364–372, 2005, doi: https://doi.org/10.1016/j.rse.2004.10.012.

[12] A. Tsanousa *et al.*, "A Review of Multisensor Data Fusion Solutions in Smart Manufacturing: Systems and Trends," *Sensors*, vol. 22, no. 5. 2022, doi: 10.3390/s22051734.

[13] E. A. Kadir, S. K. A. Rahim, and S. L. Rosa, "Multi-sensor system for land and forest fire detection application in Peatland Area," *Indones. J. Electr. Eng. Informatics*, 2019, doi: 10.11591/ijeei.v7i4.1604.

[14] A. Tawade and S. Virnodkar, "Remote sensing image fusion using machine learning and deep learning: a systematic review," in *7th International Conference on Computing in Engineering & Technology (ICCET 2022)*, 2022, vol. 2022, pp. 36–46, doi: 10.1049/icp.2022.0589.

[15] J. T. Morisette, L. Giglio, I. Csiszar, and C. O. Justice, "Validation of the MODIS active fire product over Southern Africa with ASTER data," *Int. J. Remote Sens.*, vol. 26, no. 19, pp. 4239–4264, Oct. 2005, doi: 10.1080/01431160500113526.

[16] E. A. Kadir, H. Irie, S. L. Rosa, and M. Othman, "Modelling of wireless sensor networks for detection land and forest fire hotspot," *Telkomnika (Telecommunication Comput. Electron. Control.*, 2019, doi: 10.12928/TELKOMNIKA.v17i6.12971.

[17] M. K. Brady *et al.*, "Soil Heating in Fire (SheFire): A model and measurement method for estimating soil heating and effects during wildland fires," *Ecol. Appl.*, vol. 32, no. 6, p. e2627, 2022, doi: https://doi.org/10.1002/eap.2627.

[18] E. A. Kadir, S. L. Rosa, and A. Yulianti, "Application of WSNs for Detection Land and Forest Fire in Riau Province Indonesia," in *Proceedings of 2018 International Conference on Electrical Engineering and Computer Science, ICECOS 2018*, 2019, doi: 10.1109/ICECOS.2018.8605197.

[19] N. Jiang, P. Li, and Z. Feng, "Remote sensing of swidden agriculture in the tropics: A review," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 112, p. 102876, 2022, doi: https://doi.org/10.1016/j.jag.2022.102876.