Forest Fire Detection

Saurabh Nair
Institute WEST
University of Koblenz
Koblenz, Germany
saurabhnair1999@uni-koblenz.de

***Abstract*—Forest fire is one of the deadliest threats to the world. Due to this lot of human habitants have come to the verge of extension, and it is mainly caused due to human activities such as leaving campfires unattended, leaving burning cigarettes and many more. So it is always better to detect forest fires quickly and get a way out of them. In this technological era, wireless sensors can be very useful in detecting forest fires rather than depending on old techniques or satellite-based detection approaches. This paper focuses on collecting data from wireless sensors in the forest, analyzing the Machine learning models which are built on top of it and possible future updates it need.**

***Index Terms*—Machine Learning, Forest fire, wireless sensors**

I. INTRODUCTION

Forest is one of the most important resources on the earth. It helps in various ways such as ecological and economical aspects.[1] Even it provides shelter to the animals and provides to all other living creatures for survival. Forest fires are disasters that cause severe damage to the wild and human beings. It doesn't just destroy the forest but also destroys human infrastructure in the urban areas which are close to it[2]. There are several reasons which cause it such as increasing temperature that can easily burn the sawdust, dry leaves, and wood. In addition, human activities such as leaving burning campfires or cigarettes in the forest are a good sources to generate fire. Out of all this 90% of the time it is human being's fault that create this huge destruction to the entire world.[1] The ashes from the forest burn might sometimes even lead to soil erosion or flood.

All of this has led, to find the forest fire quickly before it destroys everything. Previously, Watch towers were used to keep track of fire in the forest. But this work is also being done by human beings and where human beings are present there human errors were also possible. It was not always possible to find the fire quickly using this method. Later on, satellite images, optical sensors, and digital camera-based methods were used.[1] power consumption, latency, and accuracy were the major drawbacks that they had.[1] So in this paper, we have discussed how wireless sensors can be useful in this field along with a tie-up of machine learning algorithms.

Wireless sensors networks are dedicated sensors that can be useful in monitoring and recording the weather condition data of an environment such as temperature, sound, pollution, etc.[3] They have been developed a lot in the past few years. The power supply to the sensors was provided using batteries or solar panels which result in low power consumption[3]. Currently, satellite thermal images were used to de the forest fire, but as discussed earlier it has some drawbacks in that It takes a lot of time to scan the whole area. In addition to this, it is also tough to use satellite technology to know about forest fire in the early stages.

This paper analysis new methods and algorithms that can be helpful in creating a new real time based systems that can predict the forest fire in the early stages using wireless sensors so that forest fires can be detected quickly, accurately. Hence all this can lead us to minimize the loss incurred due to that to the humans, wild animals and environment. This powered up sensors can pick up the data and send it to cluster. Then various different neural network architecture or machine learning algorithms can use it as their input along with various other factors for predicting the output. All this can be the used to predict will it cause the forest fire or not.

II. RELATED WORK

A. Forest Fire Detection

In the beginning, when technological development was not at its boom, watchtowers were installed in the forest for the detection of forest fires. This was managed manually by the guards who used to keep watch on the forest if there is a fire or not.[4][5] They were usually located on the top of the mountain or at a height so they can get a bird's eye view of that area.[5] In addition to this, they are located in an area where there is a high risk.[4] They were equipped with maps, weather reports, and binoculars. Later with the development of technology, satellite-based forest fire detection came into the picture. Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MORIS) were the high-resolution camera-based satellites that were launched in the years 1978 and 1999 respectively. [6][7][8]. One of the biggest issues with this technology was that it takes almost 2 to 3 days to cover the entire earth. Along with that, the quality of those images was also not that great. Furthermore, they are miles away from the earth's surface so it becomes hard to predict forest fire in its early stage itself and these satellites were not designed in such a way that they have some special antennas or sensors that can quickly detect the smoke in the forest which can be very helpful in determining the forest fire. They were designed with the intention to give support to other technological development such as telecommunication, signals, etc. [6] But this technology gave the very definite idea that high-resolution cameras and wireless sensors can be used in the development for detecting forest fire by integrating them with Machine learning and deep learning techniques [8][9][10]. This can result in lower communication and computation costs.

B. Image Processing

With the advancement in the field of AI now it is possible to train machine learning models with training inputs such as images and it will help them to learn by themselves. Image processing is used in various fields such as medical, scanning a document and many more. [11][12] All this have led to the image processing in the field of forest fire too. Many different papers have approached this idea with different methods they have used by installing high resolution cameras to detect forest fire in their early stage.[13][14][15]

C. Wireless Sensors

S. Taruna, Kusum Jain, and G.N. Purohit state that wireless sensors are small sensing devices that communicate with each other in a collaborative manner and transfer the data over a wireless medium. They are highly robust, self-organized and energy saving which makes them helpful in monitoring different things.[16] They are being used in many different sectors such as health, landslide detection, agriculture, etc.[16][17][18] Srivastava et al. state that because of advancements in technology, the use of wireless sensor networks is possible in the data collection of a patient and this can be helpful in understanding the psychological and physical issues that patients in facing.[17]. Using wireless sensors agricultural domain has also received a lot of advancement. Using this technology it became very useful for the farmers to understand what kind of fertilizers or pesticides they need to cultivate the vegetables. [18] All results show how useful will wireless sensors be in the field of forest fire in real time so that forest fire can be detected.

III. Methodology

A. Real-time Forest Fire Detection with Wireless Sensor Networks

Machine learning is sub-topic of Artificial intelligence that enables the system to train itself from the previous data and predict the future forecast. There are many machine learning models such as Random Forest, Decision Tree, XG boost, etc. Deep learning uses various different neuron architectures to mimic itself as a human brain. It is mostly used for processing unstructured data such as images. Convolutional Neural Networks (CNN), Artificial Neural Networks (ANN), Long Short Term Memory Networks (LSTM), etc. are the different kinds of deep learning techniques. Wireless sensors are a dedicated device which are embedded into the system to get a relevant information from it. Many researcher have found that combining both Machine learning or Deep Learning with Wireless sensors can be helpful in detecting the forest fire in the real time scenario and prevent it from vast amount of destruction.

Wireless sensors will collect all the required data which can be preprocessed and use it to detect forest fire by constructing neural networks.[9] the neural network take this data as an input and try to find out the weather index . All this result will be eventually sent to the manager node which will then determine the level of danger. The neural network is used to preprocess the data in the cluster itself. Data preprocessing becomes easy by using simple neural network architecture. It extract only required data from the vast amount of raw data which can be further used to make decisions.

Firstly the routing protocol was chosen which was the clustering algorithm. Using this routing algorithm the sensors and cluster header was opted as an input for the neural networks followed by te hidden layers. The each packet generated by the sensor nodes are then forwarded to the manager node by labelling it as Regular report(RR), Query Response(QR), or Emergency Report (ER) [9]. Each sequentially generated data is tagged as RR and sent it to the destination. If it receives query packet then it is directly sent to the sink for further reports. If any of the node detect unusual data such as smoke then it immediately sends an ER to the cluster head.

Now the question will be how this data is being preprocessed in the cluster header. So the pre-processing is done on the basis of the tag that has been given to the packet from the sensor nodes. There are different methods to preprocess each of this tags.[9]

Once the cluster head receives an ER packet it will immediately forward it to the next node. ER packet has the highest priority so once the next node receives the ER packet it will forward it immediately to the further node keeping other packets aside. [9]

If the cluster header receives the QR packet it will perform the aggregation function upon that and will process it. When the header receives RR packet it will include the preprocessing using neural network. All this RR packets will be taken as an input by the neural network and predict the weather index which will be later on forwarded to the sink by labelling it as Processed report (PR).[9]

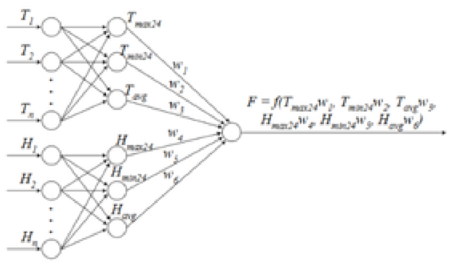

Figure 1: Pre-processing RR packets with Neural Network[9]

Figure 1 shows the structure of a neural network used for pre-processing the data. The cluster header has several n number of cluster member. Each of this cluster member N_i $1 \leq i \leq$ n sends the data to the cluster header with the tag RR. Each of this cluster member send temperature and humidity which are denoted $T_i and\ H_i$ respectively. Cluster header also computes $T_{max24}, H_{max24}, T_{min24}, H_{min24}, H_{avg}, T_{avg}.H_{min24}, H_{max24}$, and H_{avg} are minimum humidity in last 24 hrs, maximum humidity in last 24 hrs and average humidity in last 24 hours whereas $T_{max24}, T_{min24}, T_{avg}$ are maximum, minimum and average temperature in last 24 hours.[9] After passing all this input to the neural network it can generate the weather index.

After predicting the weather index using the neural network, it is encapsulated in the PR and then forwarded to the master node. Master node have set a certain threshold, which make the decision that the data must be send to the sink or not i.e. if the weather index is greater than the threshold then it will send the data to the sink otherwise not.

The parameter w_i is the key parameter for the Neural network and it can be optimized using another algorithms. The manager node will manage the learning algorithm, later it will spread the data across all the cluster head. By doing so it is always possible that cluster header get exhausted so it becomes very important to manage that balance.[9] In this scenario new cluster header will be selected which sends an announcement message. Later the older cluster node send all the previous parameter to it. If new header receive old parameter from several old cluster head then it can select only one which has lowest Euclidean distance.

Evaluation of this technique is done through in-network processing using neural network methods. Every simulation works for 200 seconds where each sensor node generate one RR packet in every 2 seconds. Along with this they are averaged over three different networks.[9]

The evaluation of this techniques was done using comparing one way implementing it without Neural network and one with it. The comparison was done on the basis of the communication cost. In the given Figure 2 the different number of nodes and different scale size is denoted on y-axis, and x-axis denoted the Average communication load which is N_t/N_{RR} where N_t denoted the single transmission from cluster header to sink and N_{RR} denotes the total number of RR packets sent by all the nodes. As it can be clearly observed that communication load decreases as neural network is used and secondly, as the scale increases the communication load is still stable and doesn't vary too much which can be seen in the below Figure 2.[9]

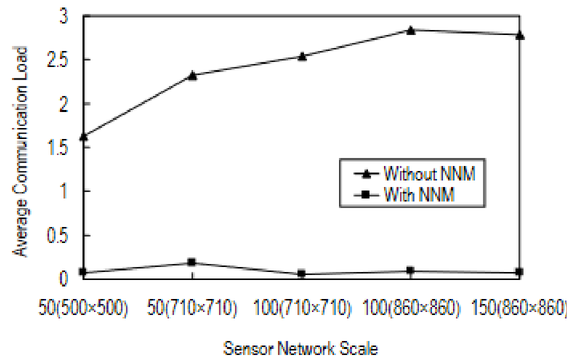

Figure 2: Average communication load with different network scale.[9]

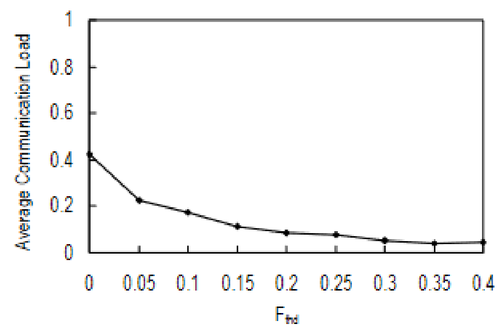

Figure 3: Average communication load with different threshold.[9]

After evaluation it is always important to determine the threshold value of the weather index which decides whether the weather index must be sent to the sink or not. As shown in the Figure 3, the threshold value examined between 0 to 0.4 and it can be clearly noticed that communication load is getting decreased as the threshold increases. One should not choose 0 as the threshold because It can send all the index to the index and choosing a higher threshold shows that the accuracy of the pre-processed data is decreased and won't be even energy saving thus for this method the thresh hold value of 0.2 is better.[9]

B. Image Processing-Based Forest Fire Detection

This paper proposes a system that can detect forest fires using image processing. Many different systems were also developed to detect forest fires using image processing. This paper has proposed 7 color-based rules which can help in detecting fire. Figure 1 from appendix explains the architecture of the system. For the implementation RGB and YC_b C_r color space is used. A digital color based image can have the color space of 3 layers Red (R), Green (G), Blue(B).

Rule 1

It is very clear from the analysis that the density of Color Red is more than color Green and density of color Green is more than color Blue i.e. $R > G > B$ when there is a fire.[10] It will be vice versa if the image doesn't contain any fire. To make this idea very clear the segmentation was performed on the images, there were two sets if image one with fire and one without it and it proved that the analysis was right. Table 1 shown below indicates the pixels has more R value than G and B if it contains fire. Thus if this condition is satisfied then there is a fire.

TABLE I
MEAN VALUES OF R, G, AND B PLANES OF FIRE REGION.[10]

Row	Mean R	Mean G	Mean B
1	252.2	210.3	83.1
2	174.4	121.1	89.4
3	250.1	208.6	40.8

Rule 2

On the basis of the histogram being plotted which was created using manually segmenting the image certain threshold was being set. To determine this threshold the validation was performed on hundred images. As a result, using this threshold the below mentioned condition has been derived which will help in determining fire pixels.[10]

$$R_2(x,y) = \begin{cases} 1, \text{ if } R(x,y) > 190 \cap G(x,y) > 100 \cap \\ \quad B(x,y) < 140 \\ 0 \end{cases} \quad (1)$$

Rule 3 and 4

It becomes easy when the image is converted from RGB color space to YC_bC_r space. Because intensity and chrominance can be easily discriminated. This conversion from RGB to YC_bC_r is known as RGB-to-YC_bC_r where Y represents the luminance, C_r and C_b represent chrominance blue and chrominance red.[10][18][19]. Below mentioned are the formula to determine the mean of Y, C_b and C_r respectively. Where x, y are pixels and M,N are total pixels in the image. Using the value of mean Y, mean C_r and mean C_b the rule 3 and 4 were developed which states that[10]

$$R_3(x,y) = \begin{cases} 1, \text{ if } Y(x,y) \geq C_b(x,y) \\ 0 \end{cases} \quad (2)$$

$$R_4(x,y) = \begin{cases} 1, \text{ if } C_r(x,y) \geq C_b(x,y) \\ 0 \end{cases} \quad (3)$$

Rule 5

It is a general idea that a image which contains fire will have bright region. Along with analysis it can be found that the image which has fire which have Y value greater than Ymean. Additionally, the actual value of C_b is actually smaller C_b mean and C_r region with flames has higher value than C_r mean. Where R_5(x,y) indicated the fire pixels.[10]

$$R5(x,y) = \begin{cases} 1, \text{ if } Y(x,y) \geq Y_{mean}(x,y) \cap C_b(x,y) \leq \\ \quad C_{bmean}(x,y) \cap C_r(x,y) \geq C_{rmean}(x,y) \\ 0 \end{cases} \quad (4)$$

Rule 6

After converting the images from RGB space to space. It can be clearly seen that the fire pixels in C_b component has lower intensity, while it is reverse in the case of C_r component. Mathematically it can be written as

$$R_6(x,y) = \begin{cases} 1, \text{ if } \mid C_b(x,y) - C_r(x,y) \mid \geq Th \\ 0 \end{cases} \quad (5)$$

The value of Th is determined using the ROC curve [20][10]. ROC curve is True Positive Rate vs False Positive Rate. The value of Th is determined using 100 color images. True positive in this scenario is image contain fire and it is detected as fire, whereas False positive means the image doesn't contain fire pixels still detected as fire. Hence in other words it can be said that true positive means true alarm and false positive means false alarm. The system must have high True positive rate.[10]

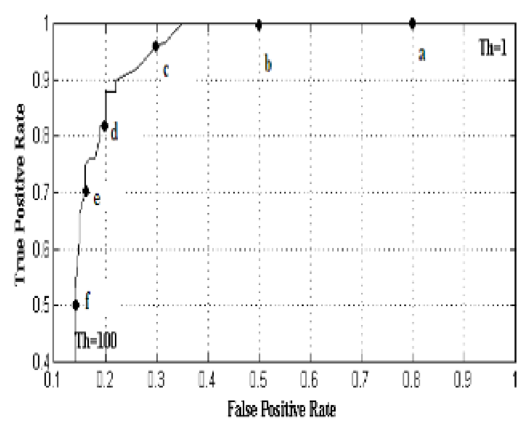

Figure 4: ROC curve to determine the value Th[10]

From the ROC graph in Figure 4, it can be clearly seen that the high True positive rate means high False positive rate. Hence because of tradeoff, the true positive rate of 95% was selected which is 30% false positive rate so the Th value is 70.[10]

Rule 7

From the observation of an histogram which is shown in Figure 5, it is developed on the basis of manual segmentation certain threshold value for C_b and C_r was defined. Y was not being considered because it is illumination.

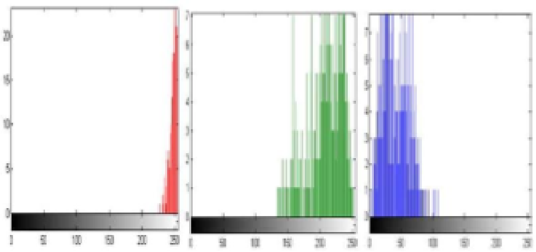

Figure 5: Histogram of manually segmented fire region of image R, G and B channel separately[10]

$$R7(x, y) = \begin{cases} 1, \text{ if } C_b(\text{x,y}) \leq 120 \cap C_b(\text{x,y}) \geq 150 \\ 0 \end{cases} \quad (6)$$

If the image satisfies all the above mentioned rules then it can be said that the fire is being caught in the forest and it need an immediate attention.

Evaluation

For making the evaluation the classification matrix was used.[21][22] The classification matrix in the Table 2 shows the result on the basis of the known images. It's diagonals shows the correct value i.e correctly predicted fire pixels and the opposite side shows the false alarm. i.e wrongly classified fire pixels. The algorithm used 200 images from the internet which has some fire pixels and rest of the images were nothing containing fire pixels but they were containing fire color such as sun, flower, etc. Even the kappa coefficient gives value of 0.85 which defines that classification model is good.[23][24][25]

TABLE II
CONFUSION MATRIX FOR DETECTING IMAGE.[10]

	Fire	No Fire
Fire	198(A)	28(B)
No Fire	2(C)	172(D)

IV. ISSUES

Today's world has become technological-centric, making innovation and the development of new technologies possible. All this has taken Information Technology into the new era of innovation. Due to all this development of automation, artificial intelligence, IoT devices, wireless sensors, etc. are all at its boom. So, from the above-mentioned methods, it can be clearly seen that all this technological development has also come into the picture for protecting the forest, human beings, and animals from the dreadful disaster of forest fire. Still, there are various loopholes in this system such as false alarms being generated due to the trigger of various unknown phenomena such as clouds and not proper night vision and so on.[8] Furthermore, it is very time-consuming to mask this kind of image, and this later results in high computational costs. In the forest, there will be various objects that will block the cameras like trees, mountains, etc. And this technique was developed with the intention to detect fire with less number of high-resolution cameras still it took a lot of time to detect the smoke and fire. Additionally, this technique was very expensive one watch tower equipped with a camera cost around 30,000$.[8] There are various further development that is needed. The basic comparison of all these methods by Ahmad Alkhatib [8] can be seen in Table 3

V. CONCLUSION

To put it into a nutshell, it can be clearly seen that various methods are getting developed. These development are also being used for protecting the environment such are forest fires. Still, this technology needs more development but they are doing well in development and current infrastructure to detect fire. To overcome this situations or to upgrade this technologies in the near future video cameras must be installed as many of the different algorithms are available in the field of machine learning and deep learning where forest fires can be detected more quickly in the video in real-time. Furthermore, with the development of IoT devices, it is also possible to integrate both cameras and wireless sensors. Hence, it will be very useful to increase the precision of the detection.

VI. APPENDIX

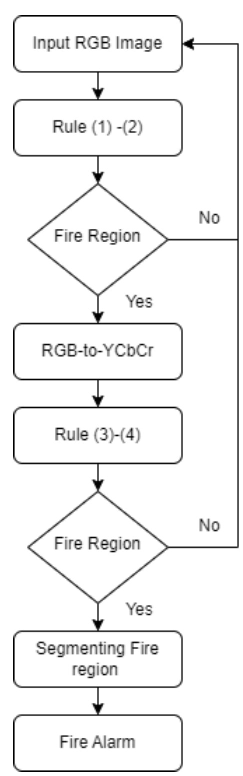

Figure 1: Image processing method workflow[10]

TABLE III
COMPARING VARIOUS TECHNIQUES

Comparision	Human Based Obeservation	Satellite based	Optical Cameras	Wireless sensors network
Cost	Low	Very high	High	Medium
Efficiency and practicality	Low	Low	Medium	High
Faulty alarms repetition	Low	Low	Medium	Medium
Fire localising accuracy	Low	Medium	Medium	High
Detection delay	Long	Very Long	Long	Small
Fire behaviour information	–	Yes	–	Yes
Can be used for other purposes	No	Yes	No	Yes

REFERENCES

[1] U. Dampage, L. Bandaranayake, R. Wanasinghe, K. Kottahachchi, and B. Jayasanka, "Forest fire detection system using wireless sensor networks and machine learning," Scientific Reports 2022 12:1, vol. 12, no. 1, pp. 1–11, Jan. 2022, doi: 10.1038/s41598-021-03882-9.

[2] M. Hefeeda and M. Bagheri, "Wireless Sensor Networks for Early Detection of Forest Fires," 2007, doi: 10.1109/MOBHOC.2007.4428702.

[3] "Wireless sensor network - Wikipedia."

[4] "What is the Forest Fire Lookouts system and how does it work? - SmokeD Operational Detection Systems: Forest Fire Lookout - SmokeD." https://smokedsystem.com/operational-detection-systems-forest-fire-lookout/ (accessed Jan. 21, 2023).

[5] "Fire lookout tower - Wikipedia."

[6] A. Taramelli, E. Valentini, and L. Cornacchia, "Remote Sensing Solutions to Monitor Biotic and Abiotic Dynamics in Coastal Ecosystems," Coastal Zones: Solutions for the 21st Century, pp. 125–138, Jun. 2015, doi: 10.1016/B978-0-12-802748-6.00008-5.

[7] "LP DAAC - MODIS Overview." https://lpdaac.usgs.gov/data/get-started-data/collection-overview/missions/modis-overview/: :text=The

[8] A. A. A. Alkhatib, "A Review on Forest Fire Detection Techniques," http://dx.doi.org/10.1155/2014/597368, vol. 2014, Mar. 2014, doi: 10.1155/2014/597368.

[9] L. Yu, N. Wang, and X. Meng, "Real-time forest fire detection with wireless sensor networks," Proceedings - 2005 International Conference on Wireless Communications, Networking and Mobile Computing, WCNM 2005, vol. 2, pp. 1214–1217, 2005, doi: 10.1109/WCNM.2005.1544272.

[10] V. Venugopal, W.: Www, and A. Professor, "Developing deep learning frameworks for diagnosis of skin cancer from macroscopic images View project International Journal of Emerging Technology and Advanced Engineering Image Processing Based Forest Fire Detection Vipin V," vol. 2, no. 2, 2012, Accessed: Jan. 21, 2023. [Online]. Available: https://www.researchgate.net/publication/362187130

[11] "document image processing — Encyclopedia.com."

[12] "What is Medical Image Processing — Synopsys."

[13] C. Yuan, Z. Liu, and Y. Zhang, "UAV-based forest fire detection and tracking using image processing techniques," 2015 International Conference on Unmanned Aircraft Systems, ICUAS 2015, pp. 639–643, Jul. 2015, doi: 10.1109/ICUAS.2015.7152345.

[14] K. Angayarkkani and N. Radhakrishnan, "Efficient Forest Fire Detection System: A Spatial Data Mining and Image Processing Based Approach," IJCSNS International Journal of Computer Science and Network Security, vol. 9, no. 3, p. 100, 2009.

[15] "(PDF) Application Domain of Wireless Sensor Network: - A Paradigm in Developed and Developing Countries."

[16] J. Ko, C. Lu, M. B. Srivastava, J. A. Stankovic, A. Terzis, and M. Welsh, "Wireless sensor networks for healthcare," Proceedings of the IEEE, vol. 98, no. 11, pp. 1947–1960, 2010, doi: 10.1109/JPROC.2010.2065210.

[17] Dr. K. Shinghal and N. Srivastava, "Wireless Sensor Networks in Agriculture: For Potato Farming." Sep. 22, 2017. Accessed: Jan. 21, 2023. [Online]. Available: https://papers.ssrn.com/abstract=3041375

[18] "YCbCr - Wikipedia." https://en.wikipedia.org/wiki/YCbCr (accessed Jan. 21, 2023).

[19] "RGB to YCbCr conversion." https://sistenix.com/rgb2ycbcr.html (accessed Jan. 21, 2023).

[20] "Classification: ROC Curve and AUC — Machine Learning — Google Developers." https://developers.google.com/machine-learning/crash-course/classification/roc-and-auc (accessed Jan. 21, 2023).

[21] A. Vanacore, M. S. Pellegrino, and A. Ciardiello, "Fair evaluation of classifier predictive performance based on binary confusion matrix," Comput Stat, pp. 1–21, Nov. 2022, doi: 10.1007/S00180-022-01301-9/TABLES/5.

[22] "Classification Matrix (Analysis Services - Data Mining) — Microsoft Learn." https://learn.microsoft.com/en-us/analysis-services/data-mining/classification-matrix-analysis-services-data-mining?view=asallproducts-allversions (accessed Jan. 21, 2023).

[23] G. M. Foody, "Explaining the unsuitability of the kappa coefficient in the assessment and comparison of the accuracy of thematic maps obtained by image classification," Remote Sens Environ, vol. 239, p. 111630, Mar. 2020, doi: 10.1016/J.RSE.2019.111630.

[24] M. A. Kalkhan, R. M. Reich, and R. L. Czaplewski, "Variance Estimates and Confidence Intervals for the Kappa Measure of Classification Accuracy," http://dx.doi.org/10.1080/07038992.1997.10855203, vol. 23, no. 3, pp. 210–216, 2014, doi: 10.1080/07038992.1997.10855203.

[25] E. A. Freeman and G. G. Moisen, "A comparison of the performance of threshold criteria for binary classification in terms of predicted prevalence and kappa," Ecol Modell, vol. 217, no. 1–2, pp. 48–58, Sep. 2008, doi: 10.1016/J.ECOLMODEL.2008.05.015.

[26] J. Fernndez-Berni, R. Carmona-Galn, J. F. Martnez-Carmona, and Á. Rodrguez-Vzquez, "Early forest fire detection by vision-enabled wireless sensor networks," Int J Wildland Fire, vol. 21, no. 8, pp. 938–949, 2012, doi: 10.1071/WF11168.