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A Fire Detection Algorithm Using Convolutional Neural Network

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Abstract. Fire destroys everything on its way. It is the most dangerous hazard that causes disasters. It can be started from a small ignition which could lead to a big loss or unwanted disaster. People lose their lives from fires. According to National Fire Protection Association (NFPA), the reported fire cases were nearly 1,400,000 in 2020 while those cases caused almost 3,500 civilian deaths. In addition, the number of civilians injured from fires is around 15,000 and the estimated properties damage is around 21 billion US Dollars. Thus, the detection of fire has become a very important topic especially due to the rapid and evolving of technology. This paper proposes a simple, fast, and accurate method of fire detection using a deep learning approach. This method is developed based on image processing techniques and a Convolutional Neural Network (CNN) tool. This tool is AlexNet which is a type of convolutional neural network and utilizes the deep learning method. If the fire is not detected early, then the Oxygen level decreases which leads to suffocation. So, this method can help us by detecting fires at an early stage. This approach filters an image into pixels based on thresholds according to features such as colors, immobility source, and flame texture with its reflection. MATLAB is used as a simulation tool to conduct several experiments to verify the effectiveness of the proposed method. A dataset utilized in this research was downloaded from the Kaggle website and is divided into three categories. The obtained results show that the accuracy was over 97% when applied to more than 700 images for training and testing purposes. Lastly, a comparison evaluation between the proposed algorithm and some literature works is provided. This evaluation indicates that the proposed algorithm herein outperforms other works in terms of accuracy, precision, and recall.

Keywords: fire detection; image processing; segmentation; feature extraction; deep learning; artificial intelligence.

1. Introduction

Fire can be a reason for huge and heavy damage to nature including human resources and infrastructure [1], [2]. Furthermore, fire leads to a high rate of civilian deaths according to NFPA [1], [12]. Climate change causes a major effect on the environment such as heatwaves, droughts, and dust storms [2]. The first factor, which is the heat waves, can lead to huge fires that have extreme consequences on human resources, the local, and global economy [1], [2]. Thus, fire detection has become increasingly important for people to protect their lives and resources as well [2].

Recently, some forest fires are detected by a simple method which is human observations [2]. This method required high towers to be utilized for this purpose. However, it is ineffective and uneconomical since it is susceptible to human errors which may cause a fatigue disaster.

.On terms of the economical side, fires cause damage to properties such as buildings and increase death rates. On the other hand, a huge number of sensors to

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detect smoke, flame, and heat are required since their ranges are quite small [2]. Thus, these sensors are costly and need to be effectively placed and installed to cover huge areas adequately.

Recently, researchers from academic and industrial fields focus their attention on the benefits of using deep learning approaches to real problems. These methods automatically extract required features and have capabilities to learn about new complex feature interpretations [2, 5], [7]-[10]. Thus, deep learning methods are the most rapidly evolving technologies that are widely used, utilized, and employed on numerous Computer Vision (CV) applications.

Due to evolving technologies, including Machine Learning (ML) and Computer Vision (CV), the detection of fire has acquired researchers' attention. To detect fires, two categories need to be identified: flame and smoke [3]. In general, smoke is visible before flames, hence, this feature helps us detect early fire and reduces the damage cost [1]-[3]. However, smoke detection is not possible at night without using lights [3]. Fire detection systems should be placed almost everywhere to minimize the risk of fire and its impact on nature and human properties [4]-[6].

Convolutional Neural Network (CNN) is an approach of deep learning to manage information that has various features which are represented in either 2D or 3D model. This approach takes its inputs through an image or a sequence of images which can be in colors or in grayscale modes. Fig. 1 illustrates a typical and general CNN structure, and it was downloaded [15].

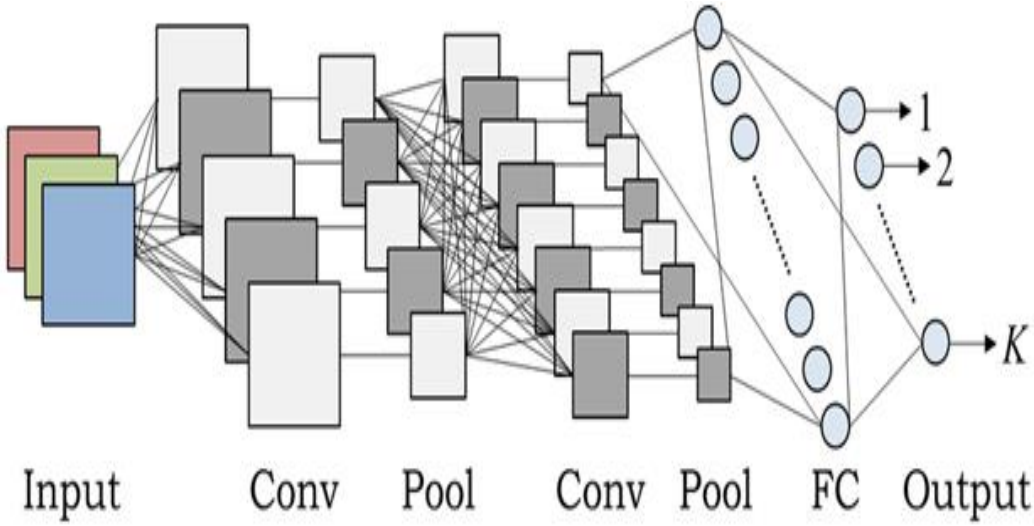

Fig. 1: Typical CNN structure

The convolutional neural network is composed of a series of components which are named layers. These layers form Kernels components which are utilized to learn and extract required features. In general, the convolutional neural network has five layers as depicted in Fig. 2 from [16]. Every layer is differentiated in a unique color except the first and the last layers. However, the last layer is considered one of the five layers.

Fig. 2: General CNN layers

AlexNet was developed and implemented in 2012 by a group of three developers. It is a type of convolutional neural network tool that employs the deep learning technique. Typically, AlexNet contains eight layers as illustrated in Fig. 3 from [17]. These layers are classified into two classes which are five convolutional layers and three fully connected layers. The convolutional layers are denoted by convx in Fig. 3 where x refers to the assigned number for each layer which starts from 1 to 5 while the fully connected layers are represented by FCx in the same Fig. x refers to the given number for every layer and it starts from 6 to 8.

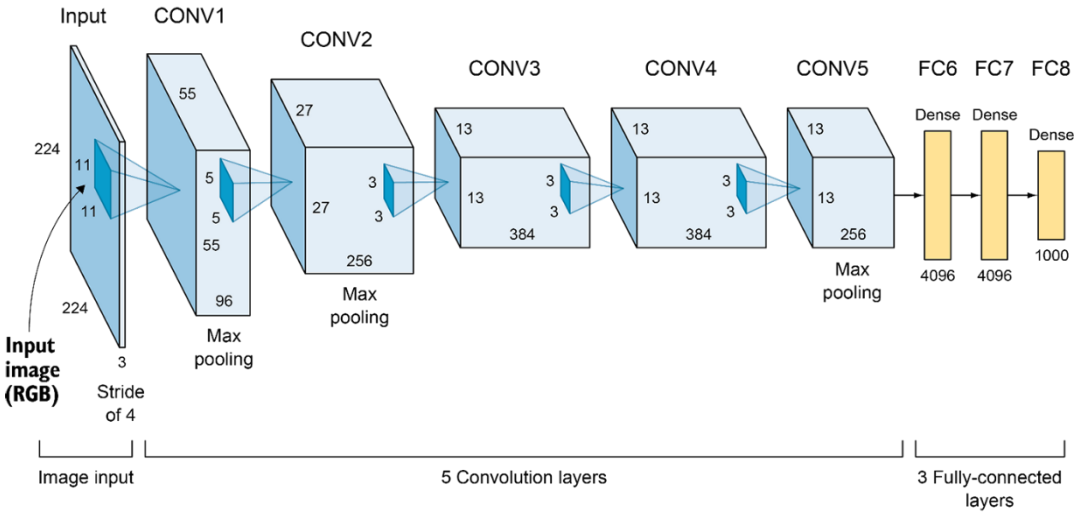

Fig. 3: AlexNet structures

The presented algorithm herein uses image segmentation techniques and CNN to form intelligent and deep learning method to detect fires. Numerous examples are conducted and illustrated in MATLAB to validate and verify how the proposed approach works and demonstrate its correctness and effectiveness as well.

In this paper, the contribution is done by proposing the fast and accurate algorithm to detect smoke and fire early to save lives and properties. This algorithm uses colors to identify smoke and flames along with their reflections. The rest of the paper is organized as follows: a literature review is covered in section 2 while section 3 provides details about the proposing approach. Discussion and results are presented in section 4 and the conclusion is provided in section 5.

2. Related Work

N. Ya'acob et al. in [1] proposed a method for forest fire detection based on image processing using an infrared camera. Their motivation was to capture fire during nighttime since other methods lacked that. Their infrared camera was treated as a satellite to capture from above. Their method used RGB and YCbCr colors to

distinguish the pixels that contain the fire and then take them out from the background. After that, the images were filtered using MATLAB. Lastly, Wavelet analyzer 5.0 was used to perform some calculations on the fire image after generating 15 parts from that image which implies that it requires a heavy computation. Herein, the proposed approach uses the RGB technique to find the fires if exist by performing several computations, more information is presented in the next section. This method gives accurate results, and the accuracy is over 97%. In addition, this approach is light as it just requires a few computations.

P. Barmpoutis et al. in [2] presented a general overview of fire detection based on optical remote sensing. They provided deep details about the algorithms that were used to detect flame and smoke. The authors identified three systems that were named terrestrial, airborne, and spaceborne respectively. Lastly, a discussion of the strengths and weaknesses of each system was performed by showing a comparison between numerous factors such as accuracy, the volume of works and minimum fire size to be detected. Interested readers can refer to [2] for more information.

In [3], T. W. Hsu et al. proposed a general framework to detect fire based on filtering images to blocks. This process is performed according to predefined thresholds for different features. These features referred to the temporal and the spatial of the images. The process started by dividing an image into blocks, then, the flames were isolated and analyzed to identify several features such as the flickering of the flames, their colors, and immobility source. Furthermore, additional analyzing procedures were done on the surrounding blocks to extract the texture and reflections of the flames. The authors claimed that their approach was consistent with the real evidence, more information is found in [3]. In this paper, the proposed method is fast and accurate as its success rate exceeds 95% of all test scenarios.

R. Sandhiya et al. in [4] developed a method that used color and motion information that were obtained from video sequences for fire detection. It worked indoors and outdoors, and it had the capability to detect fires at the starting phase of the scorching process. This approach worked based on the segmentation of the growing region of fires to identify colors on pixels. After that, identifying moving pixels were extracted according to a ratio of their height and width. Readers can get more information in [4].

In [5]. L. S. Ravi et al. utilized shading location, movement identification, and region scattering to create a joint methodology for fire detection from information that was captured by a video. It used handling methods of a picture to detect fires. YCbCr has a powerful feature to isolate luminance from chrominance, so it was used along with the RGB shading method for fire detection.

C. Shrimantrao et al. in [6] developed a novel approach to detect fires from an image sequence that was captured by a camera. The authors used a method to identify fires based on finding the foreground moving object by using the adaptive background subtraction approach. Then, the identified objects were verified according to a color-based method to detect fires. Lastly, the authors conducted several experiments to verify their approach on two groups of videos that contained fires. These groups were fire-colored objects and non-fire color objects. However, it did not consider detecting the smoke and this lacking is a sign of weakness since the smoke can refer to an early fire warning. In addition, this method lacks detection of fires if they are not clearly noticeable to the camera.

Z. Jing et al. in [13] presented a power grid GIS-based analysis and application for forest fire surveillance and prewarning. The developed system worked based on performing several operations as it started with querying of basic information and ended with forest fire thematic map and its

management. Lastly, the authors proposed a solution based on the power grid. Herein, the proposed approach detects fires at the early stage. In addition, detection only smoke is provided too.

D. Wu et al. in [14] developed a Graph Neural Network (GNN) method to detect forest fire based on the feature similarity method. Extracting features similarities was performed by establishing the correlations features of nodes between multi-view images and their libraries. After that, detecting forest fire was performed by setting a threshold in the HSV method. Interested readers can refer to [14] for more information.

3. THE PROPOSED ALGORITHM

The main goal of this method is to detect fires at an early stage so that saving lives, resources, and properties from damage is possible before the fires grow and cause disaster. Hence, the proposed algorithm is developed using the deep learning approach based on the convolutional neural network tool which is AlexNet. Fig.4 depicts the proposed system. The algorithm starts by reading the images either from a file or a video by extracting them into a simulation tool. Herein, MATLAB is used as the simulation tool. Then, the algorithm detects the needed colors which are Red, Green, and Blue. After that, the images are converted to gray ones, Fig.5 shows an example of an image while Fig.6 displays that image after being converted to the gray image by the proposed approach. Fig.7 displays the original image after the algorithm converts it to an equivalent HSV where H stands for Hue, S represents Saturation and V refers to Value.

Image segmentation is a technique used in image processing and it is performed by detecting edges as illustrated in Fig.8. This process is used in the proposed algorithm to identify the illumination and intensity in the images. it aims to find the discontinuity of regions in the images being tested to observe a major and considerable change in the gray color. In this paper, the Gradient technique for edge detection is sued. Three operators are used and these operators namely: Sobel, Prewitt, and Robert

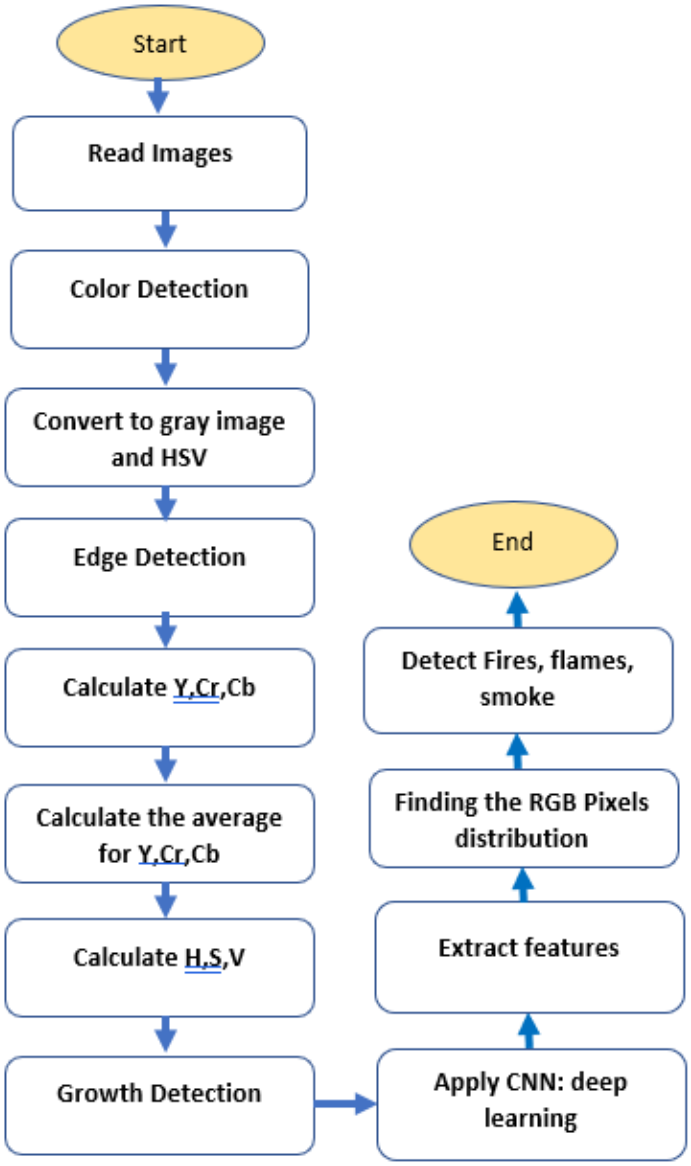

Fig. 4: Flowchart of the proposed approach

Fig. 5: The original image

Fig. 6: The gray image

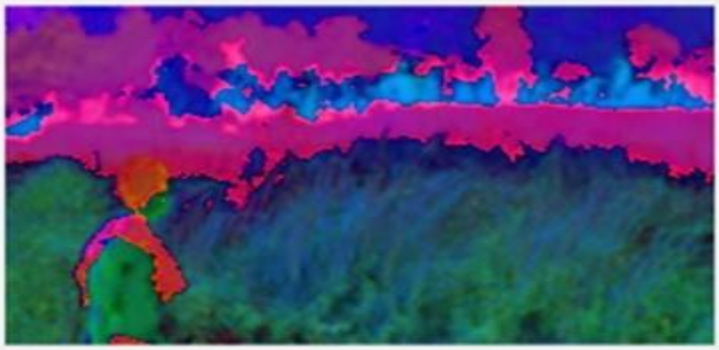

Fig. 7: The resultant HSV image

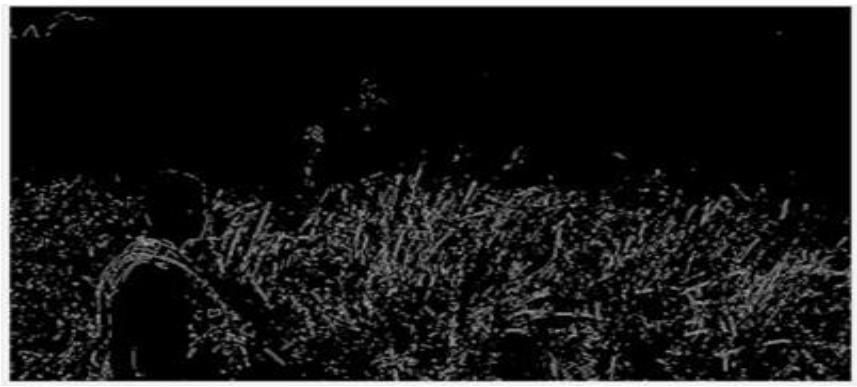

Fig. 8: Edge detection image

The next step of the proposed algorithm is to compute Y, Cr and, Cb for the considered image or images. YCrCb is another color space that is used in digital media to describe colors. Y is referred to the brightness component of colors which the human eyes are very sensitive to it while Cr and Cb are represented the red and blue components relative to the green component. This procedure is performed by a built-in function inside the simulation tool. After that, the algorithm computes the values of HSV using the built-in function.

Removing the connected objects that have values less than a predefined threshold is determined by the proposed algorithm from the binary images. This process is performed by using the built-in functions inside the simulation.

AlexNet is used to perform the deep learning technique to extract required features such as color intensity and mean. Furthermore, eight features are extracted in this algorithm.

The last step of the algorithm is to detect fires. It is determined by removing all objects, also known as components, except the pixels that have values larger than the threshold as shown in Fig.8. Fig.9 illustrates the resultant image where pixels that contain fires are isolated and displayed.

Fig. 9: The resultant image with fire detection

Keep in mind that all calculations are determined using an image processing toolbox that is already built-in inside MATLAB and this is the main reason that this simulation tool is picked and utilized.

Various performance parameters are computed and evaluated in the developed and proposed algorithm. These parameters are as follows:

1- True Positive (TP): this parameter measures a number of correctly identified images in the given dataset during the testing stage.

2- False Positive (FP): it measures a number of predicted types of images incorrectly.

3- True Negative (TN): it gives an indication about a figure of the negative images that are correctly identified by the proposed approach.

4- False Negative (FN): it measures a number of negative samples that are identified incorrectly.

5- Precision (PREC): it shows the ratio of the truly identified samples over the summation of the classes that were identified incorrectly plus the true samples that were correctly classified as shown in the following equation

$$PREC = TP / (TP + FP) \quad \textbf{(1)}$$

6- Recall (REC): it gives the ratio of the truly identified sample over the summation of the true samples plus the number of negative samples that were classified incorrectly as depicted in equation (2).

$$REC = TP / (TP + FN) \quad \textbf{(2)}$$

7- Accuracy: this parameter shows the percentage of the summation of the true samples and the negative ones that were classified correctly by the proposed method over the summation of all metrics that were mentioned from 1 to 4 earlier as depicted in equation (3).

$$Accuracy=(TP+TN)/(TP+TN+FN+FP) \quad \textbf{(3)}$$

4. SIMULATION EXPERIMENTS

MATLAB has a powerful tool for the purpose of imaging processing, visualization, and analysis. This tool is called Image Processing Toolbox and it helps users and developers to perform numerous operations. Those operations include but are not limited to: noise removal, segmentation, enhancement, and geometric transformation. This toolbox supports 2D and 3D images. Due to those features, MATLAB was selected to conduct several experiments to prove the correctness and effectiveness of the proposed method. The dataset was collected from the Kaggle website and it was

uploaded by a team in 2018 for NASA Space Applications Challenge. This dataset contains 999 images in total and among them 244 are fire-free. The following figures illustrate the resultant images from the proposed approach for several scenarios. Fig.11 depicts HSV image of the original one after converting it by the proposed method. Fig.12 illustrates the detected fires from the presented algorithm

Scenario 1: an image with huge fires.

Fig.10: The original image

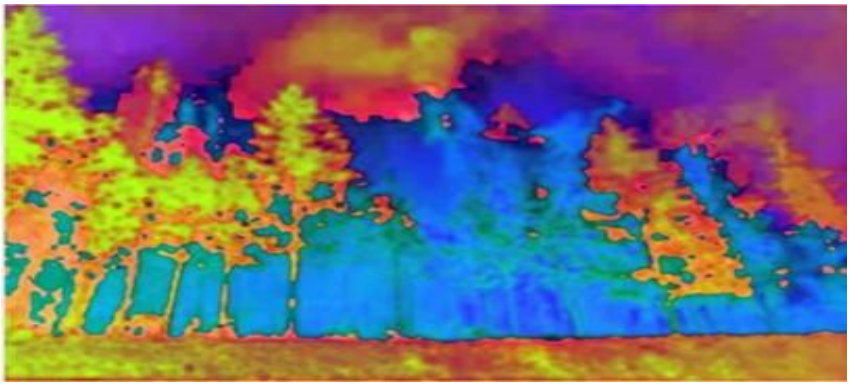

Fig. 11: HSV image

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Fig. 12: Detecting fires image

Scenario 2: an image with fire-free.

Fig. 13: Fire-free image

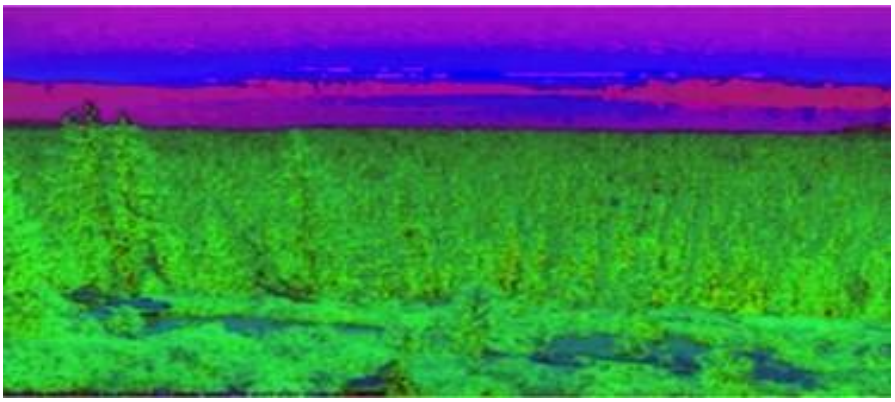

Fig. 14: HSV image

Fig. 15: No fire is detected

Scenario 3: an image with a small fire.

Fig. 16: The original image

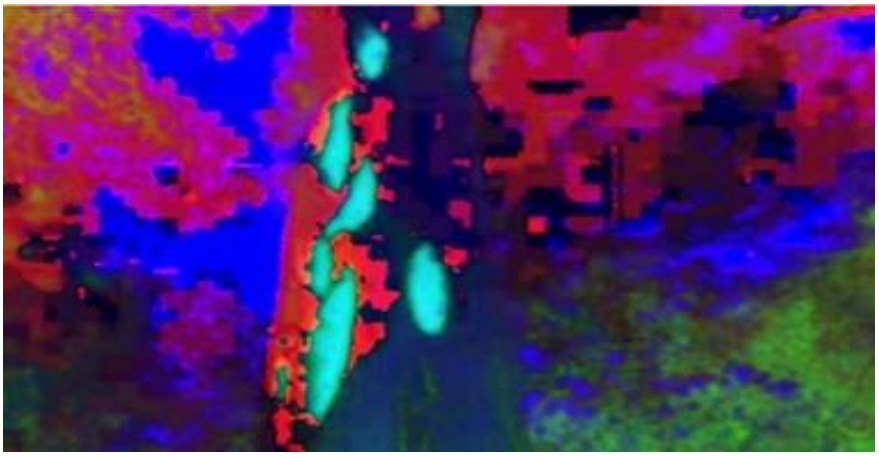

Fig. 17: HSV image

Fig. 18: Detecting fire image

Scenario 4: an image with a huge cloud of smoke only.

Fig. 19: The original image

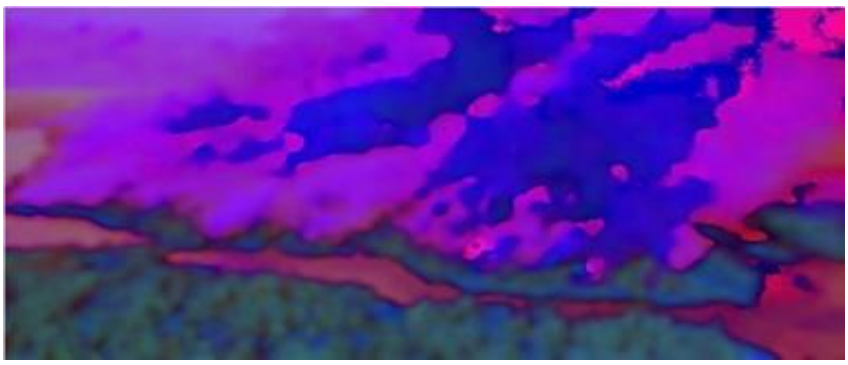

Fig. 20: HSV image

Fig. 21: Smoke detecting image

Scenario 5: an image with a small smoke only.

Fig. 22: The original image

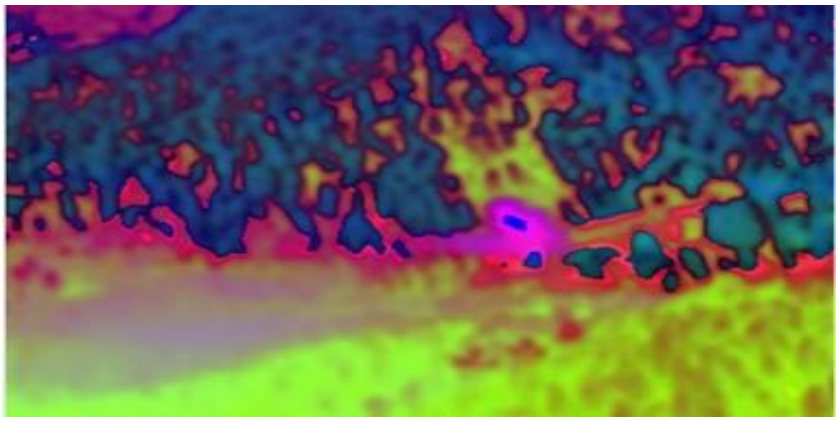

Fig. 23: HSV image

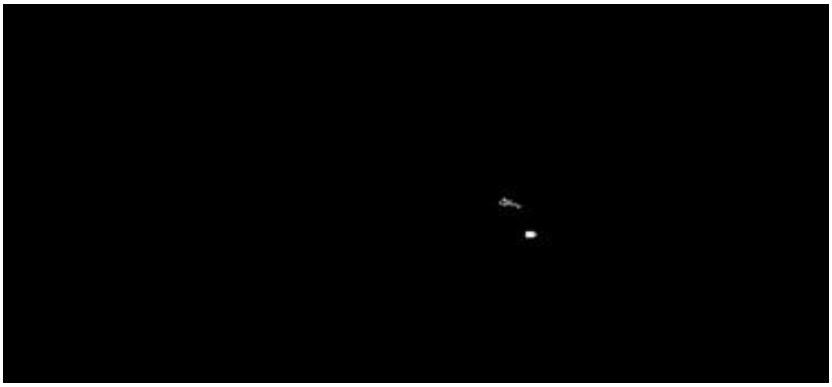

Fig. 24: Detected image

The proposed algorithm can detect fires whether they are small or big as shown in the previous Figures. In addition, it has the feature to detect and distinguish the smoke early as in Figs.23 and 24, or if the smoke forms a huge cloud as shown in Fig.21.

Table 1 lists values for all evaluated performance parameters by the proposed approach when applying it to a dataset that contains 1400 images. The dataset is divided into three parts. Part one is used for the training purpose and it has 980 images which are equal to 70% of the dataset. Part two contains 220 images which nearly represent 15% of the dataset and are used for the testing while the last part is used for validation. This dataset contains fires and fires-free images.

A comparison study between the proposed method and other approaches in the literature is conducted and illustrated in Table 2. This comparison focuses on three performance metrics which are precision, recall, and accuracy. However, many approaches that were developed earlier and mentioned in the literature did not consider the three performance parameters.

Table 1: Evaluated performance parameters

Performance parameter	Evaluated value
TP	186
FP	3
TN	29
FN	2
PREC	98.41%
REC	98.94%
Accuracy	97.73%

Table 2: The comparison study results

WORK CONDUCTED	PRECISION	RECALL	ACCURACY
L.S. RAVI ET AL. [5]	NOT MENTIONED	NOT MENTIONED	90%
K. POOBALAN AND S. C.LIEW [7]	NOT MENTIONED	NOT MENTIONED	93.61%
THE PROPOSED ALGORITHM	98.41%	98.94%	97.73%

The proposed algorithm is capable to detect fires and smoke correctly with an accuracy of over 97% as shown in Table 1. In addition, it has the ability to distinguish

between small and big smoke, however, the computation time is bigger than other approaches in the literature, thus, it needs to be minimized. The comparison results in Table 2 clearly show that the proposed method in this research outperforms other methods from the literature since it reaches over 97% of accuracy for fires and smoke detection.

5. CONCLUSION AND FUTURE WORK

Detection of fire at the early stage has become more crucial as people lose their lives, resources and properties because of the fire hazard. The proposed algorithm for fire detection in this paper provides excellent support to humans by detecting fires as its accuracy is over 97%. Several experiments were conducted using MATLAB to prove its accuracy and performance. Numerous images with fires ranging from small to huge, fire-free, and images with smoke only were tested. All obtained results from this approach show that it can detect fires properly.

The future work is to test it under severe and extreme environmental conditions such as dusty weather, foggy and high winds.

REFERENCES

[1] **N. Ya'acob, M.S.M. Najib, N. Tajudin, A.L. Yusof, M. Kassim,** "Image Processing Based Forest Fire Detecting Using Infrared Camera," Journal of Physics: Conference Series, vol. 1768, no. 1, pp. 1-14, 2021.

[2] **P. Barmpoitis, P. Papaioannou, K. Dimitropoulos, N. Grammalidis,** "A Review on Early For-est Fire Detection Systems Using Optical Remote Sensing," MDPI: Journal of Sensors, vol. 20, no. 6442, 2020.

[3] **T.W. Hsu, S. Pare, M.S. Meen, D.K. Jain, D.L. Li, A. Saxena, M. Prasad, C.T. Lin,** "An Early Flame Detection System Based on Image Block Threshold Selection Using Knowledge of Local and Global Feature Analysis," MDPI: Journal of Sustainability, vol. 12, no. 21, pp. 8899, 2020.

[4] **R. Sandhiya, S. Arulvallal, L. Shree, D. Dhina,** "Fire Recognition Based on Image Processing Using Raspberry Pi," International Journal of In-novative Technology and Exploring Engineering (IJITEE), vol. 9, no. 11, pp. 143-149, 2020.

[5] **L.S. Ravi, H.L. Harsha, C. Sushma, M. Swaroop, K. Thimme,** "Flame Detection Using Image Processing Techniques," International Journal of Engineering Research and Technology (IJERT), vol. 8, no. 13, pp. 115-117, 2020.

[6] **C. Shrimantrao, S.K. Mahesh, V.M. Bonal,** "Fire Detection System Using Matlab," International Journal for Research in Applied Science and Engineering Technology (IJRASET), vol. 5, no. 7, pp. 191-195, 2017.

[7] **K. Poobalan, S.C. Liew,** "Fire Detection Algorithm Using Image Processing Techniques," In Proceeding of the 3rd International Conference on Artificial Intelligence and Computer Science (AICS2015), pp. 160-168, 2017.

[8] **S. Gharge, S. Birla, S. Pandey, R. Dargad, R. Pandita,** "Smoke and Fire Detection," International Journal of Scientific and Research Publications, vol. 4, no. 7, pp. 498-502, 2014.

[9] **T. Hongda, L. Wanqing, W. Lei, O. Philip,** "Smoke Detection in Video: an Image Separation Approach," International Journal of Computer Vision, vol. 106, no. 2, pp.192-209, 2014.

[10] **B. He, X. Zhao, Z. Zhou, Z. Fan,** "Implementation of a Fire Detection Algorithm on TMS320DM642 DSP using MATLAB/Simulink," International Conference on Computer, Networks and Communication Engineering (ICCNCE2013), pp. 626-629, 2013.

[11] **K. Angayarkkani, N. Radhakrishnan,** "An Intelligent System for Effective Forest Fire Detection Using Spatial Data," International Journal of Computer Science and Information Security (IJC-SIS2010), vol. 7, no. 1, pp. 202-208, 2010.

[12] **M. Ahrens, B. Evarts,** "Fire Loss in the United States During 2020," NFPA Research, 2021.

[13] **J. Zhou, Y. Lou, Z. Li, C. Kang,** "Analysis of Forest Fire Surveillance and Prewarning Application System Based on Power Grid Gis," International Information and Engineering Technology Association, vol. 1, no. 1, pp. 23-28, 2014.

[14] **D. Wu, C. Zhang, L. Ji, R. Ran, H. Wu, Y. Xu,** "Forest Fire Recognition Based on Feature Ex-traction from Multi-View Images," International Information and Engineering Technology Association, vol. 38, no. 3, pp. 775-783, 2021.

[15] https://medium.datadriveninvestor.com/simple-speech-recognizer-using-tensorflow-1c63efa7cc7b, available online. Accessed on 27/6/2022.

[16] https://www.slideshare.net/GauravMittal68/convolutional-neural-networks-cnn, available online. Accessed on 27/6/2022.

[17] https://livebook.manning.com/book/grokking-deep-learning-for-computer-vision/chapter-5/v-3/34, available online. Accessed on 27/6/2022.

خوارزمية جديدة للكشف عن الحرائق باستخدام نهج التعلم العميق

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مستخلص. النار تدمر كل شيء في طريقها. إنه أكبر خطر يسبب الكوارث. يمكن أن تبدأ من اشتعال صغير ويمكن أن يؤدي إلى خسارة كبيرة أو كارثة غير مرغوب فيها. يفقد الناس حياتهم من الحرائق. وفقا للرابطة الوطنية للحماية من الحرائق(NFPA) ، بلغت حالات الحرائق المبلغ عنها حوالي ١٤٠٠٠٠٠ في عام ٢٠٢٠ بينما تسببت هذه الحالات في ما يقرب من ٣٥٠٠ حالة وفاة مدنية. بالإضافة إلى ذلك، فإن عدد المدنيين المصابين من الحرائق حوالي ١٥٠٠٠ وتبلغ الكلفة التقديرية للخسائر في العقارات حوالي ٢١ مليار دولار أمريكي. وبالتالي، أصبح الكشف عن الحرائق موضوعا مهما للغاية خاصة بسبب التكنولوجيا السريعة والمتوسطة.

في هذه الورقة، يتم اقتراح طريقة بسيطة وسريعة ودقيقة للكشف عن الحرائق باستخدام التعلم العميق. تم تطوير هذه الطريقة بناء على تقنيات معالجة الصور والشبكة العصبية. إذا لم يتم الكشف عن الحريق مبكرا، فإن مستوى الأكسجين ينخفض وقد يؤدي ذلك إلى الاختناق. لذلك، يمكن أن تساعدنا هذه الطريقة من خلال اكتشاف الحرائق في مرحلة مبكرة. يقوم هذا النهج بتقسيم الصور وترشيحها على شكل بكسل بناء على عدة شروط ومحددات ومميزات وخصائص لهذه الصور مثل الألوان وشدة سطوعها ووضوحها والملمس باللهب مع انعكاسها.

يستخدم MATLAB كأداة محاكاة لإجراء العديد من التجارب للتحقق من فعالية الطريقة المقترحة. تظهر النتائج التي تم الحصول عليها أن الدقة كانت أكثر من ٩٧٪ عند تطبيقها على أكثر من ٧٠٠ صورة لأغراض التدريب والاختبار. أخيراً تم توفير نتائج دراسة مقارنة مرجعية بين النهج المقترح وبعض الدراسات المقدمة سابقاً للكشف عن الحرائق.