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Internet of Things Enabled Fire Resilient Building Automation System Using Artificial Intelligence Approaches

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Abstract: In recent years, fire accidents mainly in buildings are considerably increasing around the world. The reasons being due to overheating of pots and pan, improper way of keeping portable heaters, smoking in bedrooms, electrical equipment, candles near to explosive or flammable materials, faulty wiring, congested construction of the building and even due to increasing the number of population as well as improper light fittings. Fire outbreak is the third biggest risk to smart cities in India. According to the Indian Risk Survey (IRS) in 2018, 7.24% of accidents occur due to fire outbreaks [1]. So the demand of automation system to detect fire and take appropriate actions such as giving alerts as well as taking immediate action to reduce the intensity of fire has become obvious. In this zest, mainly two approaches are experimented and explored here. Primarily fire detection using machine learning approaches is achieved and also rule-based approach is employed with other relevant parameters. Different machine learning approaches like Deep Learning Neural Network (DNN), AlexNet, VGG-16, LeNet-5, and ResNet-50 experimented for classification of images and detection of fire based on image dataset. Also for rule-based system input from context-aware sensor system were taken and adjudged the intensity of fire according to different rules so as to initiate appropriate actions.

***Index Terms* - Machine Learning, Deep Learning, Internet of Things, Rule-based System, fire reorganization, context aware, fire disaster management, Building Automation System.**

I. INTRODUCTION

The Internet of Things plays a vital role in the development of nations because it provided with a unique identity to every object which helps to take proper actions without human interaction. In real-world of automation it is the most important technology. Depends upon data given by various sensors and context, it automatically takes action in real-time. The varied potential domains are mainly healthcare, transportation logistics, automated vehicles monitoring, smart payment systems such as banking, smart space, agriculture, wearable computing, construction, real estate and smart home [2] .

Smart building process aims to automatically control building operations. Instrumented sensors are enabled with IoT technologies to communicate and analyze data used to optimize building management systems. In the same zest, Smart home is the premier ranked application in Internet of Things by all channels. Smart home is basically aimed to help concerned people in their everyday activities. The different types of smart home application are Smart electricity meters, Smart home apps, and Smart parking in society buildings, automatic control of electrical appliances such as fans and lights, smart locks, recycling systems in home, security and protection in home [3].

Context-aware system is promising technological path of innovation which is integral part of Ubiquitous computing. It helps IoT to increase parameters and makes system more meaningful. According to system there are different contexts are present such as time, location, id, temperature, humidity, smoke and many more. A key objective of Context-awareness has significantly simplified in Human Computer Interaction (HCI) by deploying all possibilities of IoT devices such as sensors and actuators.

Machine learning is the subset of the Artificial Intelligence. It is a mathematical science that focuses on analyzing as well as interpreting of the patterns which are used for learning, dynamic decision making, reasoning outside of human interaction. ML is also used in various domains such as online fraud detection, product recommendation, social media services, video surveillance, predictions, classifications, object detection as well as Virtual Personal Assistants.

Recently, across the globe, fire accidents in buildings have become larger because lack of real time fire detection on the correct time and hence it has become necessary to build efficient fire management system in the design of smart cities. In the traditional systems, according to the intensity of fire, taking of appropriate actions dynamically is not available. Smart fire management system is important to minimize damage of life and property. Accurate and precise diagnosis of the intensity of fire has been a significant challenge.

The Machine learning object detection algorithm benefits to detect fire faster and in accurate manner. For detection of fire, the Deep Neural Network is promising which is an extension of the Convolution Neural Network. DNN mainly used for two purposes, first is for image classification and second is for object detection [4]. Rule based approach is mainly used to store and utilize knowledge or information to expand information in a useful and systematic way. Rule-based system is better in systems involving human-crafted and it provides automatic problem solving tools for capturing the human expertise along with capability of decision making.

Public protection is a key priority and building should be safe from man-made accidents such as fires. The International Association of Fire and Rescue Services reported some 16,190 fire-related fatalities in the United States, 2012-2016. The ratio of casualties of fire accidents is very high compared to other reasons. Figure 1 represents the statistical data of casualty of fire for the United States from 2012 to 2016. The main reason is lack of early fire sensing technologies and control systems [4].

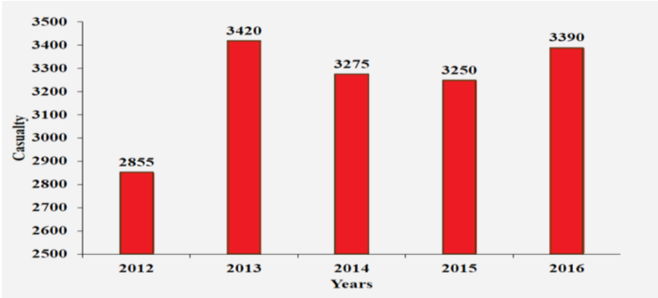

Fig 1: Statistical Data of Fire Casualty [4].

Fire resilient building automation system is emergent value addition to a smart city. Detection of fire is important to take appropriate action. Fire Resilient building automation systems are designed to detect fire using IoT devices or machine learning object detection algorithms and take appropriate actions so as to automatically deliver alerts. It is opt fully essential to minimize the damage of life and property as well. Fire alarm system is important to safely evacuate the premises when a fire is arising. The whole echo system noted as building automation system (BAS) which shown in Figure 2.

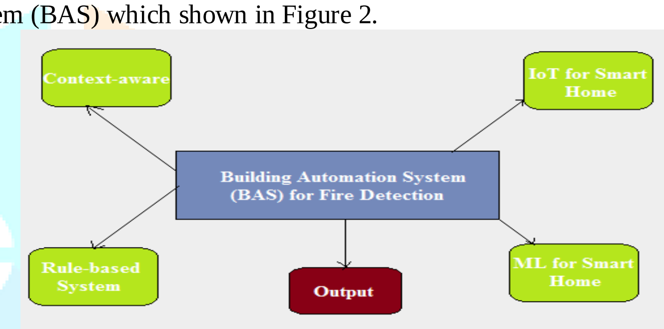

Fig 2: Building Automation System

II. RELATED WORK

The paper authored by A. Kumar et al. differentiated the different hardware components used to detect fire. It also mentioned the information related to how to reduce the false-positive values in the system with various test cases. This addresses the requirements of fire protection in industrial and residential buildings and different fire sensing technologies. Author compares many hardware components with each other in terms of limitations, benefits, and disadvantages. [7].

D. H. Kang et al. proposed one system using IoT and MQTT to send IoT sensors values to the AWS cloud and after analyzing it send messages using MQTT publish/ subscribe message transfer protocol. The broker MQTT has used as a network for the provision of Things (IoT), Internet applications for tracking and regulating room temperatures, and sensing, warning, and fire suppression. Rather than using the GSM network or the other technology, the MQTT formula is enforced to create the system that is possible, modular, scalar, and cost-effective, allowing information to flow simultaneously between sensors and servers. It addresses two major issues those are the system having less safe and cannot cover large areas [8].

O. Giandi and R. Sarno presented prototype of fire symptom detection system. It detects fire using a fuzzy system. This system mainly accomplished fire prevention and fire detection using gas sensors. The fire indicator clearly shows the concentration of the gas leakage and generates a warning bell. The concept of fuzzification and defuzzification used in this research along with various IoT sensors [9].

B. Sarwar, I. S. Bajwa, S. Ramzan, B. Ramzan, and M. Kausar proposes a smart and intelligent fire detection system based on multi-sensor based on fuzzy logic and sends warning to the fire control network. This paper is composed of knowledge on the nature of fuzzy logic, various applications of fuzzy logic on GSM technology and simulation on matlab [10] .

A. Surve provided information related to context aware computing. To make system meaningful context plays vital role. Context aware system mainly deals with relevant information with services. Context means any information which will help us to characterize the situation of an entity. Context information generated through the processing of raw data from various sensors. Context is the user-specific function and can differ between user and device. It is used primarily for data acquisition, and provides appropriate action [11]. This research work gives the idea of smart homes with low-power context-awareness [12].

Y.-L. Liu, Y.-T. Liao, Y.-Y. Lin, and Y.-Y. Chuang explains video frame interpolation algorithms predict intermediate frames to produce videos with higher frame rate and smooth view transitions, due to two consecutive frames as inputs. This research, synthesized frames are more reliable as they used to reproduce the input frames of high quality [13].

V. Subedha, G. Akash, N. Lokesh, and P. Sasikumar explained surveillance videos and the importance of dynamic decisions when processing with surveillance videos. Cognitive decisions can be made using machine learning. It also explains the surveillance video's drawbacks, i.e. it generated a large amount of data and it is in the form of images so the space needed to save information is more, showing how to retrieve frames from surveillance video to detect fire that requires less space. This work conducted with various classification algorithms i.e. AlexNet, VGG-16, and GoogleNet for fire detection [14].

K. Muhammad, J. Ahmad, I. Mehmood, S. Rho, and gave an idea to use a deep convolution neural network algorithm to detect the fire and avoid property damages. It consists of a convolution layer with four layers, max pooling, and ReLU. Rectified Linear Unit (ReLU) layer is used to improve the accuracy as it removes only positive values and excludes all negative values from the matrix based on activation function. Max pooling is another primary concept discussed in this research which is primarily used to achieve maximum values for every part of the function map. The system's main goal is to reduce the computation time, but it only works with binary classes if the system has more than two classes it cannot function efficiently. It's the challenge to increase model accuracy by proper feature selection for accurate prediction. It provides detailed information about CNN architecture and the various activation functions used in convolution neural network. [15].

T. S. Issues, S. Instances, F. Workshops, and T. Keynotes explained how to properly classify a dataset. Classification of a highly unbalanced dataset is very difficult because there are fewer real-world fire occurrences, so that a number of fire images are less than number of non-fire images in the dataset. To boost the accuracy a fully connected layer was added by the ResNet-50 and VGG-16. It increases the amount of time spent doing training work. Therefore, the time it takes to the classification of images to detect fire is high and it causes the machine to become inefficient. Through this study, the researcher reveals the discrepancy between CNN and DCNN. It explains in depth the benefits and demerits of the different algorithms, and how to balance the dataset [16].

III. SYSTEM ARCHITECTURE

The majority of the researches over the last decade have concentrated on traditional methods of flame detection using feature extraction techniques. The key issues with these approaches are it is time consuming process of designing features. It shows low performance in flame detection. Due to this it generates a large number of false alarms especially in varying lighting, and fire-colored objects. Motivated by recent developments proposed system investigated several DCNNs to improve flame detection accuracy and reduce the false alarm rate. The overview of the system is shown in Figure 3.

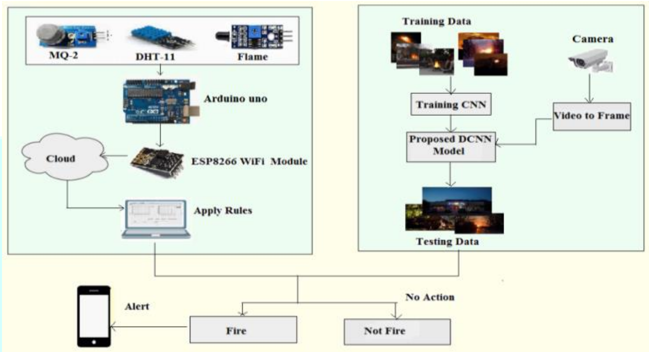

Fig 3: System Architecture of BAS.

IoT and Context Aware System

Early fire detection is important to prevent the mass hazard of fire as it saves money as well as lives. In BAS, MQ-2 sensor is used to detect inflammable gases and smoke while DHT11 sensor performs two actions at a time. It measures temperature and humidity, while the MQ-2 sensor is used to detect inflammable gases and smoke. Flame sensor is used to detect flames. GSM modem used to send text messages to the mobile when fire is detected and there is caution of fire. These all sensors are instrumented to microcontroller as per IoT ecosystem needs.

Context is important because it provides additional information regarding to a situation that will be helpful to find a meaningful prediction though IoT- based sensing. Different contextual associated information is used such as Home_Id, Date, Time, Location and Class. Class is being the most important context parameter. According to intensity of fire, system gives output as Normal, Caution, Smoked or Fire. The comprehensive information regarding to context are shown in Table 1.

Table 1: Context Elements and Context Values

Context	Context Values
Home_Id	Unique Id to identify particular home
Date	In the form of day, month and year i.e. dd-mm-yyyy
Time	AM or PM
Location	Address of home
Class	Fire, Smoke, Caution, Normal

Deep Learning / Machine Learning

Dataset

The experimental dataset comprises of total 3350 images. It consists of two classes Fire and Neutral. In this dataset images are divided into two sections, which are training and testing. The overall distribution of images is shown in the Table 2:

Table 2: Distribution of Images in the dataset

Classes	Training	Testing
Fire	1328	332
Normal	1352	338
Total	2680	670

There are 80 % of data is assigned for training and 20 % data is assigned for testing.

Pre-processing

Pre-processing is required mainly used to reduce complexity and increase the accuracy of the model. According to requirement different types of pre-processing is applied. In this proposed system, all images in the dataset are resized by width=200 and height=200 so as to increase the accuracy of DNN algorithm and avoid over fitting and misclassification issue. For more accuracy large number of dataset is required so data augmentation is also used.

Video to frame generator

When the camera starts, system captures the video. So the input to the proposed system is by means of video. First step is to create frames from the video which is to be categorized using CNN architecture. OpenCV is used for the generation of frames from source input.

Classification

By applying different DCNN algorithms, program classifies the fire is 'present' or is fire 'not present'. The DCNN classifications done by using calculate probability of each class. The class having highest probability is assigned as a result to that image.

Send Text Messages to the Mobile

For messaging sms4india is incorporated in the system. It can directly plug into the system because it is readymade API which is used for send text messages all over India.

IV. METHODOLOGY

Building automation system for indoor fire detection mainly uses two approaches. The first approach is using IoT sensors and context parameters to build a rule-based approach. The second approach is the machine learning approach. It is worked for image datasets. There are some classifications algorithms are used to detect fire on image dataset.

System Workflow for IoT and Rule based approach

IoT and Rule based approach mainly works on real-time text values. In Rule-based approach is achieved using fuzzy logic. For calculate the intensity of fire Temperature, Smoke and flame values plays most important role. The flow chart of the BAS using IoT and rule - based approach are as follow i.e. Figure 4:

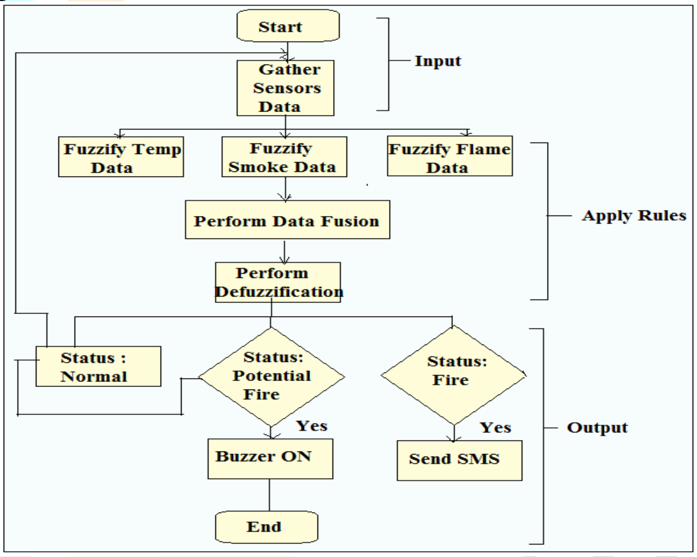

Fig 4: Flow Chart for Rule-Based Approach.

The overall system classified into three parts. In the first part gather information from sensors and generate context. In this partial system required temperature, flame, and smoke values. Once information is gathered it sends to the cloud and stares into it called data acquisition. After data acquisition applies designed rule for appropriate prediction. To design the rules fuzzy membership sets play the most important role. The designed membership sets for Temperature, Flame, Smoke, and Output shown in Figure 5. In the last part, according to the rule get an output as fire, potential-fire, and normal. According to the predicted output if the fire is detected, then send a message. If the potential fire is detected, then buzzer is ON [12][6].

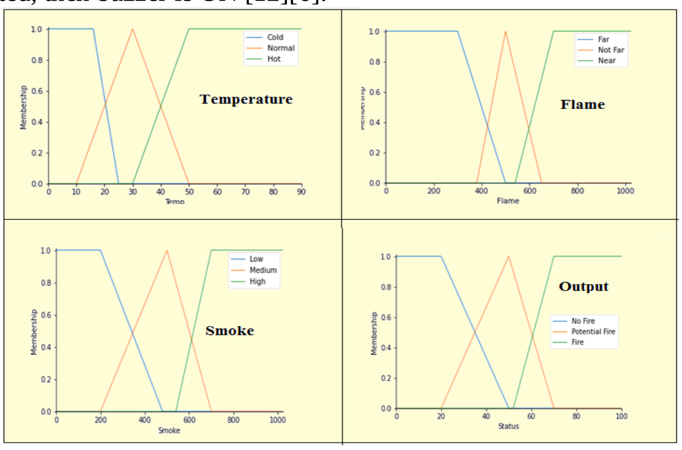

Fig 5: Fuzzy Membership Sets

The designed rules for rule-based system are as shown in Table 3:

Table 3: Rules for Fire detection using Rule-based approach

Temperature	Smoke	Flame	Output
Cold	Low	Far	Normal
Cold	Low	Not Far	Normal
Cold	Low	Near	Potential Fire
Normal	Low	Far	Normal
Normal	Low	Not Far	Normal
Normal	Low	Near	Fire
Hot	Low	Far	Potential Fire
Hot	Low	Not Far	Fire
Hot	Low	Near	Fire
Cold	Medium	Far	Normal
Cold	Medium	Not Far	Fire
Cold	Medium	Near	Fire
Normal	Medium	Far	Potential Fire
Normal	Medium	Not Far	Fire
Normal	Medium	Near	Fire
Hot	Medium	Far	Potential Fire
Hot	Medium	Not Far	Fire
Hot	Medium	Near	Fire
Cold	High	Far	Potential Fire
Cold	High	Not Far	Potential Fire
Cold	High	Near	Fire
Normal	High	Far	Potential Fire
Normal	High	Not Far	Potential Fire
Normal	High	Near	Fire
Hot	High	Far	Fire
Hot	High	Not Far	Fire
Hot	High	Near	Fire

System Workflow for Machine learning / Deep learning Approach

For classification and comparatively study, proposed system is implemented using four architectures. Those are namely AlexNet, VGG-16, ReNet-50, LeNet-5.

A. AlexNet
It has 60M parameters and 8 layers. From that 5 are convolution layers and 3 are fully-connected layers. AlexNet just added a few more layers onto LeNet-5. It is one of the largest CNN architecture but subset of GoogleNet.

B. VGG-16
VGG-16 has 13 convolutional and 3 fully-connected layers, carrying with them with some activation function. It consists of 138M parameters and takes up about 500MB of storage space.

C. LeNet-5
It is one of the famous and simple architecture. It has 2 convolution and 3 fully-connected layers. The average-pooling layer is known as sub-sampling layer and it had trainable which is not present in other DCNNs architectures. So, it gives more accuracy as compare to other algorithms. This architecture has near about 60,000 parameters.

D. ResNet-50
ResNet is one of the early adopters of batch normalization. It has near about 26M parameters.
Important concepts of DCNN are pooling layer, flatten layer, convolution layer, fully connected layer, activation functions and stride. These layers are present in all architectures of DCNNs. The overall working of the system using ML approach is as shown in the Figure 6:

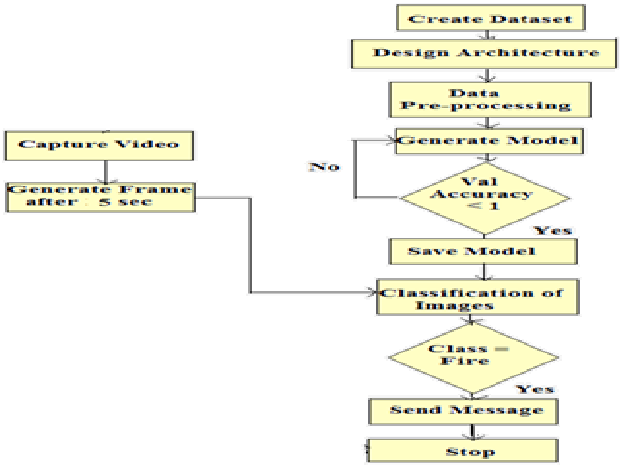

Fig 6: Flow Chart Using ML/DL Approach

V. COMPARATIVE ANALYSIS

Various DCNN algorithms are used for the classification of images. Python language used to implement all DCNN architectures on platform Anaconda. The same results are obtained on the online tool Colab. The following results are obtained using the various DCNN architectures. They are shown in Table 4 and Figure 7.

Table 4: DCNN Algorithm with Accuracy

Sr. No.	Algorithm	Accuracy(%)
1	AlexNet	78.33
2	VGG-16	83.75
3	ResNet-50	81.06
4	LeNet-5	92

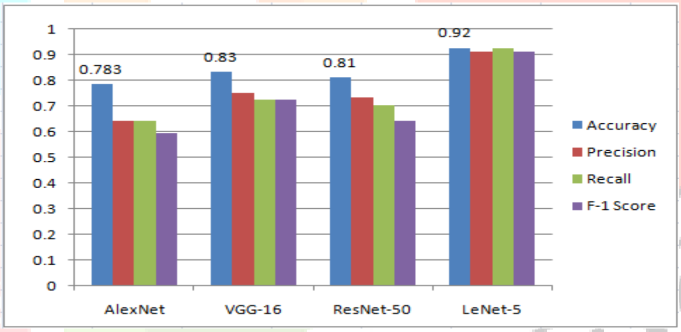

Fig 7: Performance Evaluation for Different Algorithms.

These are the results for the different architectures of DNN. LeNet-5 having the highest accuracy as compared with the other experiments. So the proposed system uses LeNet5 for integration in the entire project. Accuracy, precision, recall, F1-score are the important metrics to evaluate the system performance. The detail information with mathematical expressions is as follows:

Accuracy:
Accuracy represents number of correctly predicted values out of the total values.

Precision:
It is called as positive predicted values. It is defined as true positive values divided by true positive plus false negative.
Precision = True Positive/ (True Positive +False Negative)

Recall:
Recall gives percentage of total relevant results correctly classified by algorithm
Recall = True Positives / (True Positives + False Negatives)

F-1 Score:
It measures test's accuracy.
F-1 Score = 2*((precision*recall)/(precision + recall))

VI RESULTS AND DISCUSSION

Results Using Rule-Based Approach

The context-aware IoT enabled experimental prototype setup is realised using sensors used for BAS to detect fire. DHT-11 is used for detect temperature as well as humidity. MQ-2 sensors are used for smoke detection. Flame sensor is used for detect flame. For sending data to the cloud WiFi module is used. According to rule-based algorithm when fire is detected system gives alert by using buzzer and led is ON.

The output of the rule-based system after prediction is shown in Figure 8. In this X-axis represents the intensity of the fire and Y-axis represents the membership function. As shown in Figure 8. 80% of fire is detected. So, it belongs to Fire class.

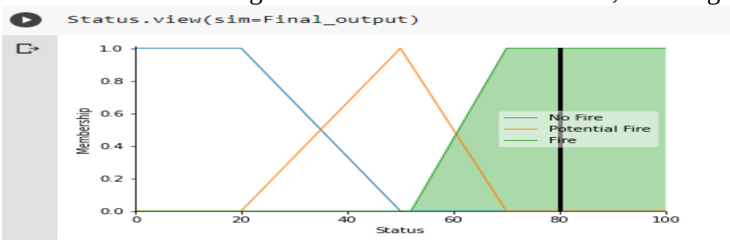

Fig 8: Screenshot of Fire Detection Using Rule-Based Approach

Results Using ML Approach

CNN is used to classify images. The first step of the system using ML approach is to take a single image as an input and classify it. The screenshot of the classification on the image is shown in Figure 9.

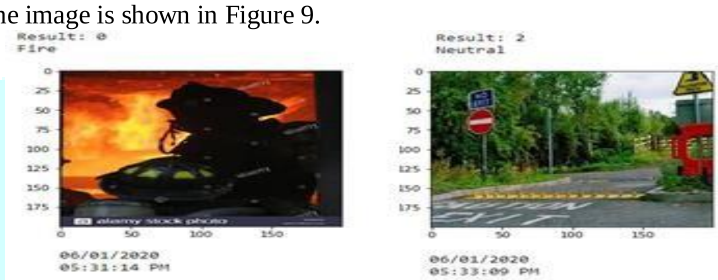

Fig 9: Screenshot of Single Image Classification

The second phase of the ML approach image is in detecting real-time fire. It takes real-time video as input and produces video frames then classifies it. Figure 10 demonstrates the Fire detection screenshot on the live dataset by taking input as a video:

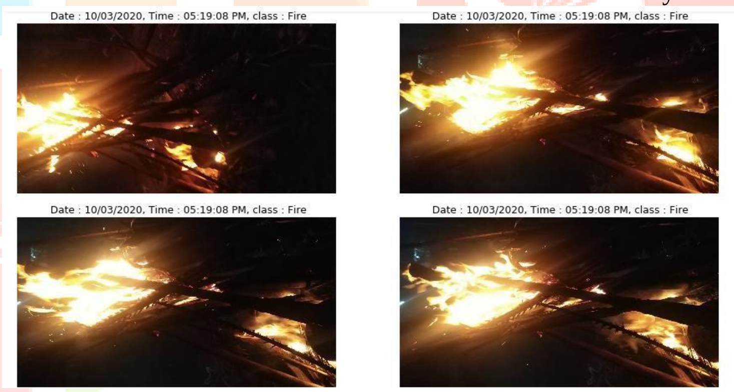

Fig 10: Result of Fire Detection on Live Dataset

When fire or smoke is detected system sends alert message to the user using sms4india. The screenshot after sending message when fire is detected is shown in Figure 11.

Fig 11: Screenshot of Sent Message using sms4india API.

VII CONCLUSION

To overcome the day-to-day life fire accidents which not only causes economic loss but they are harmful to live entities as well, this research attempt has been done using building automation system for indoor fire detection. Two approaches namely rule-based and machine learning exercised to provide desirable solution. Wherein different algorithms of CNN family were used to detect fire on image dataset using machine learning approach such as AlexNet, VGG-16, ResNet-50, and LeNet-5. It was found that LeNet-5 provides more accuracy hence the same was employed in the system for image classification. Also different sensors were deployed for the IoT enabled context-aware system to gather more parameters such as humidity (DHT-11), smoke (MQ-2), flame sensors which are related to fire. Further classification is used with rule-based approach so as to generate alert upon the fire is detected. The experimental system realized using these two approaches because of unavailability of real-time parameters and images data together. Creating combined multi-parameter real-time dataset i.e. text data as well as image data of fire and then applying appropriate machine learning algorithms on that for better accuracy, will be the future scope of this system.

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