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An IoT-Based Fire Image Recognition for Home/Industry Security Using Machine Learning

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ABSTRACT - This paper presents the development of Internet of Things (IoT) based fire image recognition for home/industry security using Machine learning. Fireoutbreaks have ravaged homes, industries, banks, hospitals, organizations etc., and kept a lot of people homeless. Government agencies, security agencies, and even private organizations seek to make their assets safe and to restrictaccess to areas that could pose dangers. In the same vein, individuals have also sought reliable ways to keep their homes safe and alert themselves of any impending danger. Hence, this work is aimed to address the challenges posed by fire outbreaks using IoT-based Machine learning techniques. The IoT system comprises both hardware and software. Raspberry Pi and other components were selected to handle the detecting and capturing part of the fire images. For fire image recognition,Raspberry Pi sends captures the fire imagesand sends them to the Google Cloud Vision APIwhich calls a pre-trained model to recognize any hazard in the image. The pre-trained model predicts with high percentage confidence and sendsto the mobile phone of the homeowner/personnel on duty for necessary action.
Keywords— Home Security,IoT, Machine Learning, Raspberry PI, Google cloud, Image Recognition

I. INTRODUCTION

Fire outbreak is a common issue happening everywhere and the damage caused by this type of incidence is tremendous [1]. Homes, Industries, Organizations, Hospitals, Banks etc. have been experiencing fire outbreak times without numbers. Many researchers are involved in early warning systems, which considerably minimize the consequences of fire damage [2]. It is important for fire detectors to operate quickly in the event of a fire, but existing conventional fire detectors sometimes do not work properly or there are problems where non-fire or false reporting occurs frequently [3]. Machine Learning, a subset ofArtificial Intelligence (AI)has tremendously improved on the intelligence of smart security systems in recent times [4].Most of the security problems that require machines are now solved easily by applying IoT and machine learning together. Security has become the talk of the day in every field of life. People have been recruited to monitor and raise alarm but to no avail. Most companies have also used fire detectors which basically detects the presence of carbon II oxide or increase in temperature and send an alert when set limits are exceeded.

II. REVIEW OF RELATED WORKS

The authors in [5], presented a computer vision-based fire detection algorithm. Fire colourmodelling and motion detection were used for thefire detection algorithm.TheFire colour model was tested with ten diverse video sequences including different types of fire. The experimental results showed correct classification of fire pixels according to colour information only.In [6, 7],Convolutional Neural Networks Based Fire Detection in Surveillance Videos was implemented. They deployed Google Net and fine-tuned it according to the targeted problem with fire data. Experimental results revealed the effectiveness of the chosen framework and its suitability for fire detection in CCTV surveillance systems.

A wireless sensor network using multiple sensors for early detection of house fires wasdesigned and simulated by the authors in [8]. They used Global System for Mobile Communications (GSM) to alert personnel on duty to avoid false alarms. Fire Dynamics Simulator was used to simulate the fire in a smart home to test the results. The simulation results showed that the system is able to detect early fire, even when a sensor is not working while keeping the energy consumption of the sensors at an acceptable level

The work in [9], is on a dependable Fire Detection System with Multifunctional Artificial

Intelligence Framework. The framework includes a set of multiple machine learning algorithms and an adaptive fuzzy algorithm. They introduced Direct-MQTT based on SDN to solve the traffic concentration problems of the traditional MQTT. The system performance on fire detection accuracy and delay time was over 95%. The transfer and decision delays between devices were reduced by an average of 72%.In [10], a machine learning techniques method for Multimedia Surveillance during fire emergencies was proposed. They used a hybrid model made of Adaboost and many Multi-layer perceptron (MLP) neural networks in their work. The hybrid Adaboost-MLP model was used to predict fire efficiently. This model used different sensors data like smoke, heat, and gas for training. After predicting the fire, the CNN model was called to detect the fire immediately. The test results show that the trained model has near 91% fire detection accuracy while false-positive results were quite low.

The authors in [11] presented forest fire image recognition based on convolutional neural networks. An adaptive pooling approach was introduced in their work. Experiments show that the convolutional neural network method based on the adaptive pooling method has better performance and has higher recognition rate.In [12,13], an Integrated Fire Detection System using IoT and Image Processing Technique for Smart Cities was designed. Their system combined wireless sensor technologies, UAVs, and cloud computing to achieve its aim. Some image processing techniques and rules were integrated into the fire detection system to identify the fire event with better results. The simulation results of the fire detection system were compared with several existing methods and observed a higher fire detection rate from 95 to 98 percent.

Image fire detection algorithms based on Convolution neural network was developed using four advanced object detection CNN models (Faster-RCNN, R–FCN, SSD, and YOLO v3) [14-16]. YOLO v3 achieved 83.7% accuracy which outperformed other models when compared. The authors in [17-19] worked on the extraction and classification of image features for fire recognition based on a convolutional neural network (CNN). A Gaussian mixture model was used to extract features from the fire smoke movement areas to improve the efficiency of image analysis. Experiments results proved that the system was feasible and effective. The works, [20-23], were on real-time video-based fire and smoke detection using CNN YOLO v2 in anti-fire surveillance systems. The training stage was processed off-line with indoor and outdoor fire and smoke image sets in different indoor and outdoor. The trained model was deployed in a low-cost embedded device (Jetson Nano). The experimental results showed that the model is suitable for creating a smart and real-time video-surveillance system for fire/smoke detection. Deep –Learning (YOLOv4) Based Approach was developed for Smart City Environment in [24, 25]. The method successfully detected and notified the incidence of disastrous fires with a high speed and accuracy in different weather environments—sunny or cloudy, day or night. Experimental results revealed that the method can be used successfully for the protection of smart cities and in monitoring fires in urban areas.

III. SYSTEM DESIGN METHODOLOGY

The system is made up of hardware and software. The design method adopted for hardware is prototyping while agile methodology for software designs.

A. IoT Hardware

The IoT hardware comprises of Raspberry Pi 3, IP camera, Wireless Router, Speaker, +5v power supply, Wi-Fi adapter, OTG cable, memory SD card and 5V DC infrared lightas shown in figure 1.

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Figure 1: IoT Hardware components of the system

IP camera is used for fire image capturing. The wireless Router provides the internet connectivity and Wi-Fi adapter used to connect the raspberry pi to the wireless router for internet access. SD card is used to store the captured fire images. The speaker is used to alert the user before sendinga message to the user's mobile phone. 5V DC power adapter provides 5V Dc voltage to the system to function. The block diagram of the IoT system is shown in figure 2.

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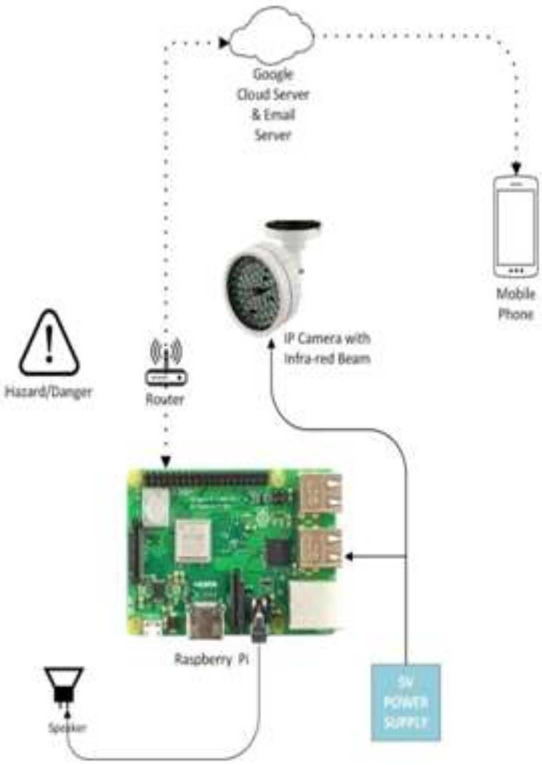

Figure 2: Block diagram of the IoT system for fire detection and capturing

B. System Implementation Tools Used

- **The Raspbian JessiePixel** is used to provide desktop view and command-line interface.
- **The SD Card Formatter** is used to format the microSD card on which the Raspbian image is mounted on.
- **Etcher software** is used to write the Raspbian image to the Raspberry Pi microSD card.
- **Putty** is a tool used to connect to the command-line interface (CLI) of the raspberry pi through a protocol known as SSH (Secure Shell).
- **VNC Viewer** is a Windows-based application used to provide system developer access for viewing the X windows of the raspberry pi
- **Google Cloud Vision API** is a Computer vision cloud-based machine learning resource provided by Google for machine learning activities. It was chosen because the model was trained using a very robust data set provided by Google with high accuracy.
- **BASH**is a shell scripting language used to automate tasks in the host computer. BASH script is used to actuate the Python program as soon as the Raspberry Pi boots up.
- **Python** is the main programming language used in this research work because of its rich libraries for image processing and machine language.
- **GPIO library**is an open-source Python based library used to address the GPIO (General Purpose Input Output) pins of the raspberry pi.

C. Algorithm and Flow Chart of Fire Image Recognition

The step-by-stepprocesses used to achieve the image recognition via the raspberry pi are written below and flow chart diagram shown in figure 3.

- Raspbian OS image isdownloaded from internet
- SD Card formatter is used to format the microSD Card in order to prepare it for the mounting of the Raspbian OS image.
- Etcher Software is used to burn the image file to the microSD Card
- After the image has been burnt into the microSD Card, it is then mounted into the Raspberry Pi and the Pi is powered up.
- All the peripherals are then attached to the USB hub
- After the raspberry pi zero is connected to a wireless network, the firmware is updated and upgraded.
- The Google Cloud Vision API is downloaded from gitHub.
- All the source files are built using the Cmake tool
- Thereafter, the training phase is launched. Here a user captures as many images as possible into a folder.

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- The folder is then used to train the controller and various parameters are assigned to a file that is generated. This file contains all the features of the images which have just been trained
- The enrolment phase is complete
- Finally, a python script is written to integrate the whole system and trigger the speaker when it recognizes a security-threatening image.

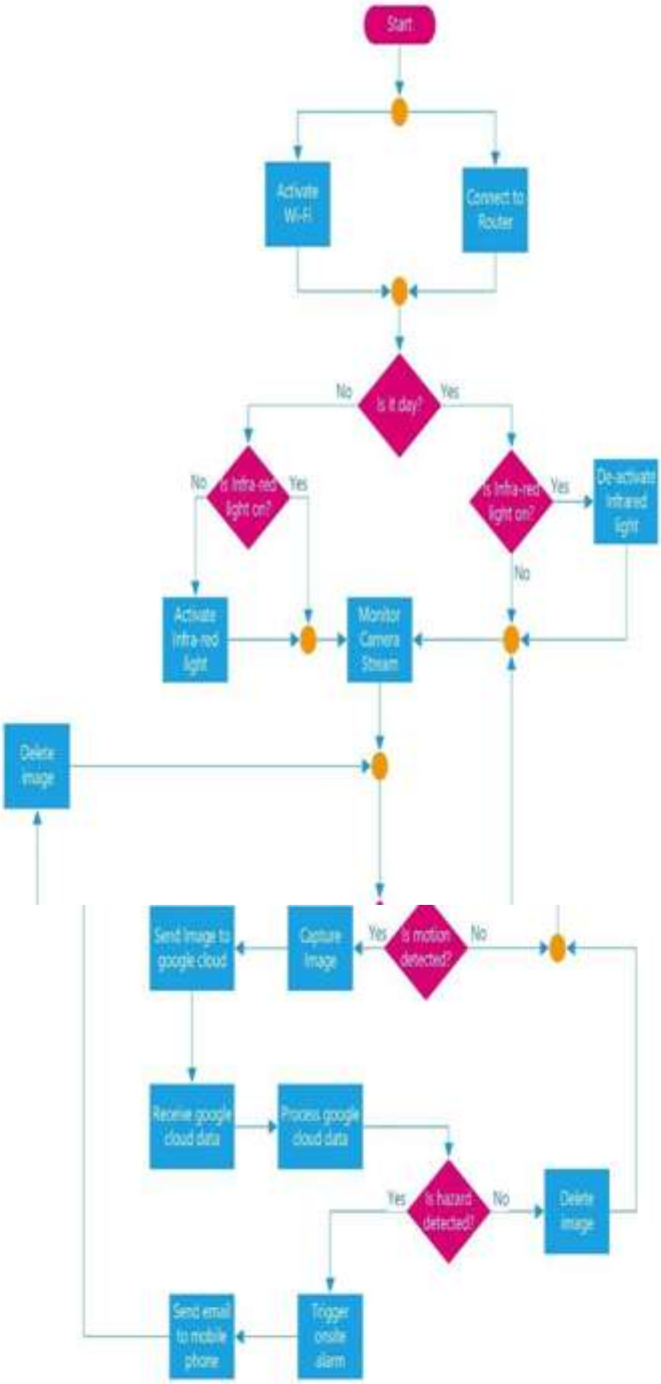

Figure 3: Fire Image Recognition flow chart

D. IoT System operations

The following steps are used by the system to detect the fire, capture the image and send it to the Google cloud server for recognition:

- The camera captures real-time video stream but does not saveit
- The infra-red light automatically gets activated on sensing low light

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- The python script processes the video frame by frame to determine if there is motion
- If motion is detected, the camera captures a frame and saves it as an image locally then sends this image to Google cloud servers for processing.
- The result is returned from the servers within seconds and the program parses this result to search for labels that have been pre-enrolled as threats.
- The program returns these labels with a degree of certainty expressed in percentage.
- If the returned percentage reaches the threshold percentage already set, the speaker is triggered to sound an alarm. An email is also sent to the registered email address on the system.
- The process repeats till the system is deactivated.

E. IoT System Test Conducted

The prototype of the image recognition system designed was first setup on a bread board. The microSDcard contains the Rasbian OS and all the necessary software for image recognition. A power bank was used to supply power to the raspberry pi and mobilehotspot configured to provides internet connectivity to the raspberry pi. The Raspberry Pi Camera was connected properly as an image input device. Before the system is powered up, all the connections were made and all the peripherals attached appropriately. The system powered up and tests carriedout as shown in the setup of figure 4.

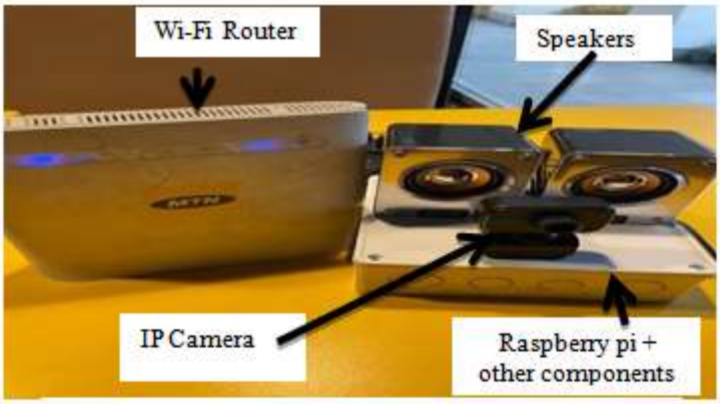

Figure 4: Setup Configuration of IoT system before

After system setup was successfully done, the following tests were conducted:

- **Hardware Tests**

V_{out} pin was tested to ensure that it supplies the power required; i.e., 5V for its functionality. The ground pin was tested to ensure that it is at zero potential.After the components were soldered to the Vero board, a meter was used to check for continuity to avoid a short circuit. The brightness and quality of the raspberry camera were tested in various rooms light conditions to ensure that itsfunction optimally for hazard detection. The results varied in different brightness levels and an infra-red was mounted on the system to improve on the brightness conditions of rooms that are poorly lighted.

- **Software Tests**

Image Detection Test: After the application was launched, the “activate” command was entered. This results in the system detecting an object in front of it and immediately startingthe required analysis.
Enrollment: The characteristics of the hazards captured by the system using the camera were saved in a folder. This was used to train the raspberry pi.
Recognition Test: The previously enrolled threats were simulated and observed to see if the system would recognize them. Other objects were also brought to the camera to see if the system would give false positives.

IV. RESULTS OBTAINED

Various experiments were performed to test the robustness of the developed system in order to measure its accuracy. A paper was set on fire close to the IP camerato simulate a fire outbreak. Also, a lighter was used to ignite the fire to cause an outbreak. Here are various conditions by which the hazard detection system was tested:

- Recognition in a well-lit environment when the object is at a close distance (<100cm)
- Recognition in a well-lit environment when the object is at mid-distance (100cm<x<500cm)
- Recognition in a well-lit environment when the object is at a far distance (>500cm)
- Recognition in a dark environment when the object is at a close distance (<100cm)
- Recognition in a dark environment when object is at a mid-distance (100cm<x<500cm)
- Recognition in a dark environment when the object is at a far distance (>500cm)

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- False positives in a well-lit environment
- False positives in a dark environment

The results obtained are plotted as shown in figure 5.

A = Recognition in a well-lit environment when the object is at a close distance
B = Recognition in a well-lit environment when the object is at mid-distance
C = Recognition in a well-lit environment when the object is at a far distance
D = Recognition in a dark environment when the object is at a close distance
E = Recognition in a dark environment when the object is at a mid-distance
F = Recognition in a dark environment when the object is at a far distance
G = False positives in a well-lit environment H = False positives in a dark environment

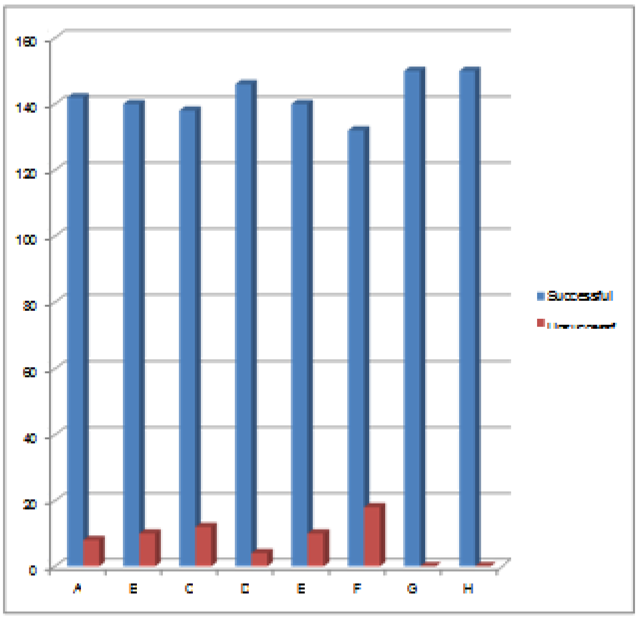

Figure 5: Result carried out under different conditions

Figure5 represents the results of how well the IoT system could perform on 150 test samples under different conditions. Table 1 shows the statistics of the success rate of hazard detection.

Table 1: Success Rate of Hazard Detection System

S/N	Test Condition	Fire		
		Accuracy	Failure	% Success
1	Recognitioninawell-litenvironment whenthe objectisataclosedistance	142	8	94.67
2	Mid-distance	140	10	93.33
3	Recognitioninawell-litenvironment whenthe objectisatafardistance	138	12	92.00
4	Recognitioninadarkenvironment whenthe objectisataclosedistance	146	4	97.33
5	Recognitioninadarkenvironment whenthe objectisatamid-distance	140	10	93.33
6	Recognitioninadarkenvironment whenthe objectisatafardistance	132	18	88.00

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7	False positives in a well-lit environment	150	0	100.00
8	False positives in a dark environment	150	0	100.00

V. CONCLUSION

IoT-based fire image recognition for home/industry security has been successfully implemented on the Raspberry Pi Single Board Computer. The IoT hardware has been implemented and Google Cloud Vision API set up. This system can be deployedin the home/industryas means of security to detect and classify situations that could pose a threat. From the tests carried out, it can be deduced that the image detection performedexcellently well following the conditions attached. It is also deduced that it has a higher accuracy of classifying slow motions as compared to rapid ones. The system has an improved response time and accuracy in message delivery

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