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Automated Fire Fighting Robot Using HAAR Cascade Algorithm

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Abstract—

Traditional firefighting techniques rely heavily on human involvement, making it a very dangerous occupation. By combining the Internet of Things (IoT) with the HAAR Cascade Classifier Algorithm, this article introduces a novel prototype of a firefighting robot that uses human intervention as little as possible. The robot's automatic movement and fire extinguishing are controlled by an Arduino Nano, while the fire detection and real-time video feed are processed by a Raspberry Pi 4 using OpenCV. The Pi Camera 2 allows the robot to transmit footage in real-time via Wi-Fi. The robot can stop what it's doing and start putting out fires when it senses the presence of a flame, thanks to an integrated flame sensor. The findings demonstrate that HAAR cascade outperforms conventional approaches, such as relying just on flame sensors for fire detection, and it works better in both well-lit and poorly-lit environments.

Keywords— HAAR-Cascade, Image Processing, IoT, Fire, Firefighting robot, Raspberry Pi, Arduino Nano

BACKGROUND

Due to a long history of risk and a lack of technical advancement, firefighting has long been considered one of the most hazardous occupations.[1] Even with all the training that firefighters get, the methods that are now used are not very effective since they depend too much on human involvement.[2] in Robots have recently gained a lot of interest due to their increased reliability, adaptability to restricted areas, and ability to capture live video, which may be used as evidence in investigations [3]. Internet of Things (IoT) development over the last decade has also shown promise for building complex robots with state-of-the-art electronic components to aid firemen in fire detection and control, therefore lowering the chance of casualties. The Internet of Things (IoT) makes previously dumb things smarter by attaching sensors to them [4].

MOTIVATION

Compared to conventional Internet of Things (IoT) robots, there are several benefits of combining IoT with vision-based fire detection methods (image processing). Conventional sensor-based systems for detecting fires depend on smoke, heat, and temperature; however, these systems have drawbacks such as expensive prices, lengthy reaction times, and reduced effectiveness in outdoor settings owing to environmental conditions like sunshine and wind pressure. On the other hand, vision-based systems can detect light more accurately and respond more quickly.These methods make use of the flame's properties, such as its color, shape, and motion [5]. Convolution Neural Networks (CNNs), You Only Look Once (YOLO) algorithms, HAAR cascade, and other image processing methods are available for use in vision-based systems. Because of its speed and relative simplicity compared to CNN, the HAAR Cascade method was employed to construct the robot in this case. Because YOLO has problems detecting and localizing tiny items in clusters, HAAR Cascade is the method of choice for this article. With its superior frame rate and detection capabilities, HAAR Cascade

OBJECTIVE

Using the Internet of Things (IoT) and image processing, namely the HAAR Cascade algorithm, the major goal of this research is to build and create an autonomous robot. Pi camera 2 and Raspberry Pi 4 are used to process the images. An Arduino mini automates the robot. The use of the Internet of Things lessens the potential danger to firefighters. Verifiable testing confirms that the HAAR Cascade method is effective. In addition, the research compares the outcomes of systems that rely on vision with those that rely on sensors.

LITERATURE REVIEW

One example is a robot that uses embedded systems to find its way about and identify fires with the use of sensors. When things are calm, the robot can direct traffic, but when danger strikes, it may activate its fire suppression system. Firefighters are able to keep their distance from dangerous fires thanks to an AI-powered firefighting robot [2]. The robot can effectively put out fires and navigate with pinpoint accuracy thanks to operator instruction and automation based on sensors. Using three temperature sensors, the suggested approach [3] can only identify individual flames up to a certain distance. An Arduino Uno microcontroller is used for the realization of the prototype that was produced here. Internet of Things (IoT) and sensor-based technologies were used in the creation of a firefighting robot prototype [4]. Following its successful construction and testing, the prototype proved that the Internet of Things (IoT)-based system could effectively track, command, and direct the robot's nozzle spray towards the fire's origin.

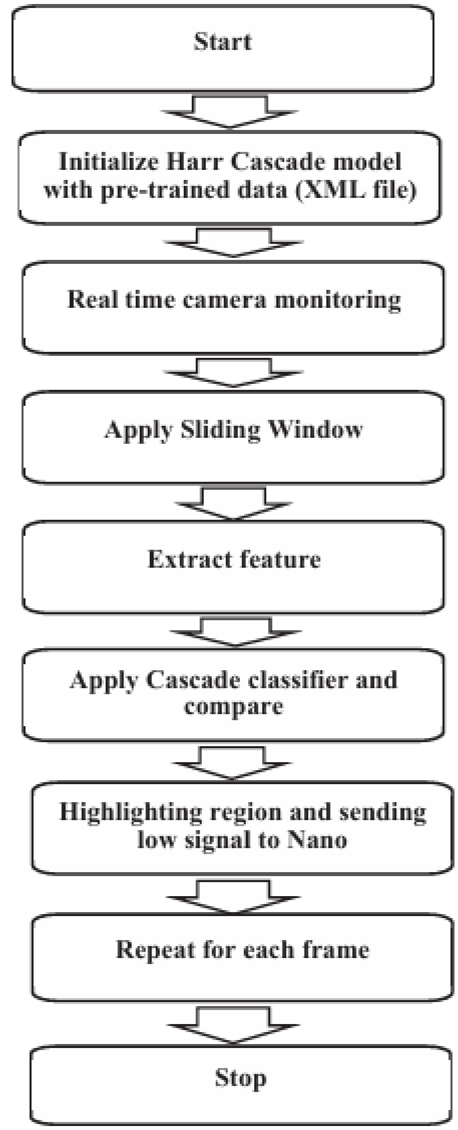

Fig. 1. Proposed Method

METHODS

A fire detection signal is sent to the Arduino Nano from the Raspberry Pi camera, which uses the HAAR Cascade Algorithm to detect fire. In response to commands sent by the Raspberry Pi, the extinguishing process is managed by the Arduino Nano. When it comes to detecting faces, the HAAR cascade classifier is often used [7]. The ease and speed of this approach make it useful for identifying faces as well as automobiles, buildings, fruits, and more. For faster feature evaluation at the bottom, it employs HAAR features and the Integral Image

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method; to train the classifier, it employs the Adaboost algorithm; to compute features in each region, it slides a subwindow over the image window to be detected; and to filter out features, it applies the cascade. The suggested technique is shown in Fig. 1 and explained in full below. Collection of Data (A) Using Google's "Batch Image Downloader," we were able to extract both the positive and negative photos from ckdataset. (B) Open the XML file containing the HAAR Cascade Model. Put the positive and negative picture folders into the Cascade Trainer GUI in different locations. Choose the number of steps, the feature type (HAAR), the size of the object detection window, and the total number of positive and negative photos to be utilized for training.

The XML file containing the feature/pattern information needed to detect fire is created when the training is finished. C. Continuous Tracking With the help of VNC viewer, we can see live footage captured by the pi camera. D. Making the present frame white on white The detecting method is made simpler and quicker by converting images to grayscale. Algorithms focus on variations in brightness and intensity rather than colors to identify patterns and forms. Section E. Characteristics; Assessment and Extraction In order to find characteristics that match the one in the XML file, the algorithm scans the picture in tiny portions, like a sliding window. In order to identify objects of varying sizes, it starts by covering smaller areas and then gradually expands the size of the scanning window. Estimate the intensity variations within the window using HAAR-like characteristics (such as edge, line, and rectangle patterns). Selecting the most relevant characteristics for classification becomes much easier with the aid of AdaBoost. In the case of fire detection, for instance, the model may seek for bright, asymmetrically shaped spots bordered by darker ones. To refine and narrow down the likely areas of fire, F. Cascade Classifier passes the characteristics through a series of classifiers. At each step, it verifies that the picture area corresponds to the attributes in the XML file. G. Nano-based area highlighting and poor signal transmission A bounding box is used to emphasize the area of existence of the item after it has been detected. Nano receives a low signal when a fire is detected. Classifier for H. Cascade Keep doing this for every frame of the live video.
By painting a box around places affected by fire, for example, we can identify which parts have passed all phases in the picture or video. Fire suppression and mobility are controlled by an Arduino Nano microcontroller, which is linked with the Raspberry Pi. Optimizing performance while preventing the Raspberry Pi from being overwhelmed is achieved by dividing work between the Nano and the Pi. Since the bot runs on batteries, the former helps with energy conservation since it uses far less power than the latter. Upon fire detection, the Nano immediately sounds an alarm via a buzzer and, with the help of two DC motors controlled by a motor driver, moves the robot forward. At its core, the robot is a flame detector that, when activated, will halt its movement when it detects an open flame and, using a battery-operated pump, will put out the fire automatically. Water is used as an extinguisher. After the fire has been put out, the robot will take five seconds to back up before starting the detecting process all over again. Chapter One: HAAR Cascade Classifiers Figure 2 shows the first stage of the HAAR features, which are two or three rectangles formed by comparing the bright and dark areas of positive and negative pictures during the learning phase [8]. In its never-ending quest to find the target feature, the HAAR function traverses the photos from top to bottom, pixel by pixel.

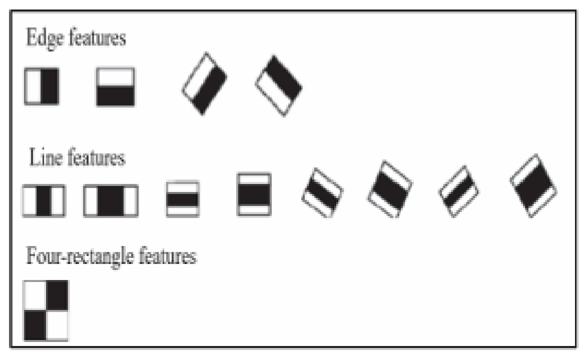

Fig. 2. HAAR Cascade features

Using the first set of characteristics, called edge features, one may locate edges in a vertical, horizontal, or diagonal orientation. The second group of characteristics is used to ascertain if a brighter region is encircled by darker regions or vice versa. To find the variation in pixel intensity across the diagonals, the third set of features consists of four rectangles. If you add up all the pixels in a rectangle and then subtract all the pixels in a black rectangle, you get the feature value. A more effective feature template to differentiate the object (fire) is produced by a larger value difference between features in positive and negative pictures. One hundred and eighty thousand features are produced for a 24x24

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window sample. Second Stage: An integral image is a method for rapidly calculating the total pixel value in a rectangular area of a picture. The feature extraction procedure is made faster and there is less need for unnecessary computations in areas that are used again. All the pixels on each side of it add up to one pixel.

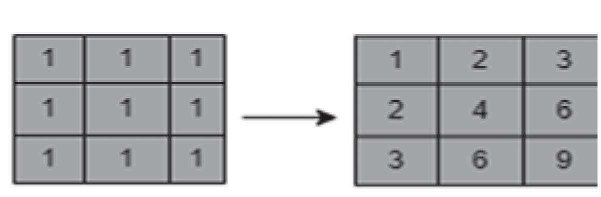

Fig. 3. Integral Image Representation

In the third stage, a robust classifier is constructed using the Adaboost algorithm to differentiate between the target item (fire) and all other non-fire objects. Selecting the most relevant characteristics for classification becomes much easier with the aid of AdaBoost. It prioritizes the data samples that are more challenging to accurately categorize by giving weights to both the decision-makers (the classifiers) and the samples. This is how AdaBoost fine-tunes its feature selection to maximize accuracy. Then, to improve prediction accuracy, it merges several weak classifiers into a single strong classifier. The AdaBoost classifier reduced the original set of 180,000 features to 6,000 in the 24x24 window sample. To determine whether a fire has occurred, the training photos will be processed once again using a subset of all 6,000 characteristics. Each training cycle yields weak classifiers until either the maximum number of iterations is reached or a low error rate is achieved. [9] It becomes more challenging for a face candidate to accomplish each successive level of the cascade classifier process, as seen in Figure 3. Candidates may exit the cascade in two ways: first, if they succeed in every stage; and second, if they fail in even one step. When all the necessary processes are taken, a face is discovered [10]. When training a classifier, it is necessary to have both good and bad photos of the item, with consistent sizes across the board. Following training, the classifier may be used to fresh photos, with "1" labels applied to areas resembling the item and "0" labels applied to other portions of the image. In order to find areas with characteristics comparable to those it learnt during training, the classifier searches the whole picture.

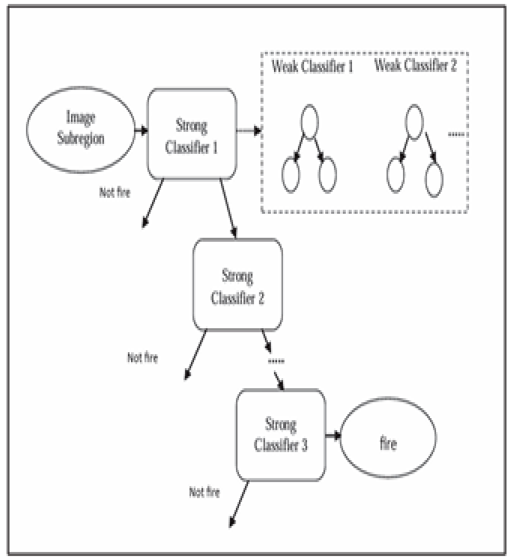

Fig. 4. HAAR Cascade Classifier

To increase detection speed and accuracy, the classifier dynamically modifies the scanning window size. By guiding the algorithm's attention to the most important parts of the picture, the adaptive method speeds up the detection process. To further refine the detection process, the classifier finds the ideal rectangles that match the items in the window as part of the classification. The OpenCV library for computer vision is freely available to the public. The library is compatible with Linux, Windows, and Mac OS X, and it is developed in C and C++. A heavy emphasis on real-time applications informed its design for computational efficiency. Only programmers and computer scientists well-versed in computer vision utilize it. The process of computer vision involves converting input from images or videos into a new representation or decision [11]. Regardless of the platform you're using, VNC (Virtual Network Computing) is a platform-independent, basic display protocol-based compressed client solution. The Olivetti Research Laboratory in Cambridge, England, was responsible for its development. Without the need for any hardware, it is capable of doing mobile computing. By running a simple application on a different computer, we are able to access and manipulate data on one machine's desktop [12] [13].

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EXPERIMENTAL ANALYSIS AND RESULT

The tests in this study were conducted on a desktop computer with an Intel(R) Core ™ i5-8265U CPU @ 1.60GHz and 8 GB of internal RAM, and the environment was a Raspberry Pi 4 using modules from the newly released OpenCV 3.3.

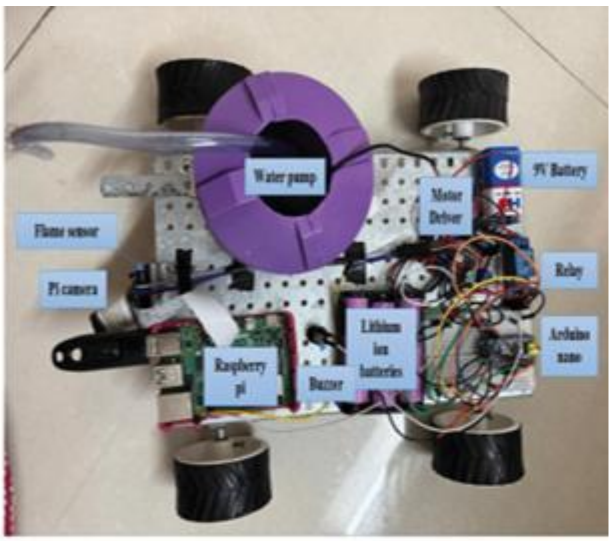

Fig. 5. Prototype of Fire Fighter Robot (Top View)

Figure 5 shows the schematic of the prototype with the parts labeled. Figure 6 shows the fire being put out automatically. In Fig. 7, we can see two images: one shows the pi camera's real-time picture, and the other shows the fire identified with a blue boundary box after the HAAR Cascade Algorithm was applied.

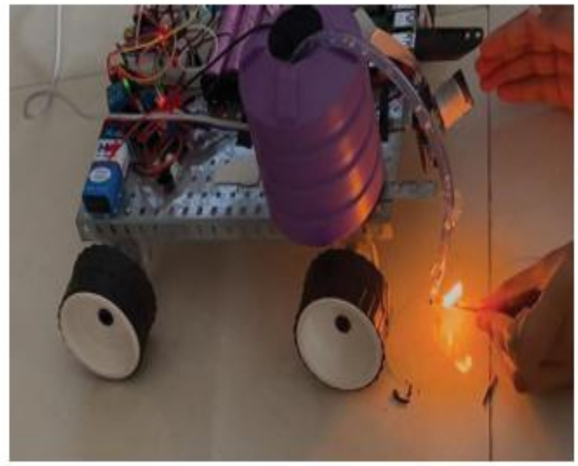

Fig. 6. Automated Fire Suppression

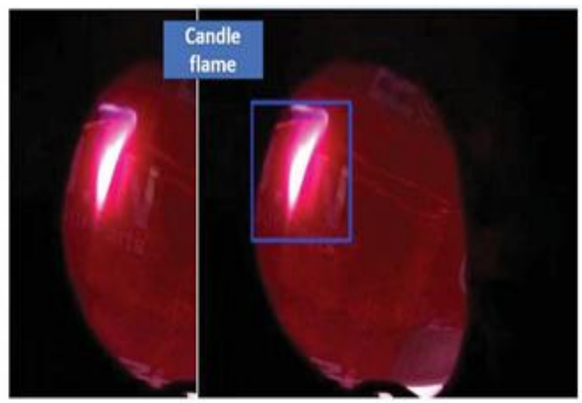

Fig. 7. Fire detected using HAAR Cascade

TABLE I. COMPARISON OF ACCURACY IN DIM LIGHT ROOM AND FULLY LIGHT ROOM OF THE PROTOTYPE

Distance (cm)	Accuracy in Fully Lit room	Accuracy in Dim Lit room
8	100	100
13	100	100
18	100	100
23	100	100
28	83	100
33	83	100
38	80	100
43	80	100
48	71.4	100
53	71.4	100
58	71.4	100
64	66.6	100
69	57.1	100
76	57.1	100
80	57.1	100

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The following table compares the accuracy of a 2.5cm (1 inch) flame in well-lit and poorly-lit environments. In order to determine the accuracy, 5 trials were conducted at each distance. For any value of TP (True Positive), TN (True Negative), and FP (False Positive), the corresponding accuracy may be calculated using the following formula: The term "false positive" (FN) refers to the detection of a fire when none exists. Detection of fire when none exists; this is known as a false negative. The sensitivity factor or recall That is, 88.37% of real fires up to 80 cm in diameter were identified. For all detections, the percentage of accurate firing directions is 69.09%, as measured by Precision(Positive Predictive Value - PPV) (plus) Even at 80 cm, our prototype can detect a 2.5 cm (1 inch) flame. The prototype's range increases as the flame lengthens. As an example, a flame sensor can only detect flames that are 2.5 cm (1 inch) in diameter from a distance of 5 cm. With a 20-centimeter flame, the range may reach 40 centimeters. So, compared to the conventional flame sensor, our prototype has a much better range and efficiency.

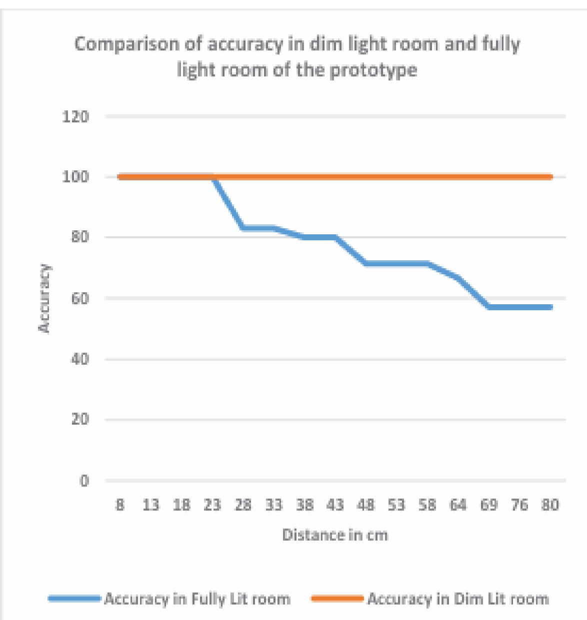

Fig. 8. Accuracy vs Distance graph for dim and fully lit rooms

DISCUSSION

"Fire Detection and Direction Control of Fire Fighting Robot" and "Firefighting Robot Based on IoT and Ban Levels Technique" describe a robot that uses infrared smoke and flame sensors, which have a limited range, to detect and control the fire. The prototype described in this research, on the other hand, can detect heat and smoke from a distance and act quickly. The present prototype is more advanced because to the linked publications' suggestions for future upgrades, such as the integration of live camera feed.

CONCLUSION

A new automated firefighting robot has been created that uses the HAAR Cascade Algorithm in conjunction with the Internet of Things to identify fires.The accuracy of the system was boosted by combining the HAAR cascade classifier with image processing methods and OpenCV. Unlike traditional smoke and flame detectors, the robot can detect fires from a large distance. Because Wi-Fi has a longer range and faster data transmission speed than Bluetooth, it is preferred for live camera feed monitoring. Firefighters might save lives if autonomous robots could detect fires early and put them out.

FUTURE RESEARCH DIRECTION

Camera quality and environmental factors impact the planned prototype's accuracy, which in turn highlights opportunities for development. The first step in improving the cascade's fire detection accuracy, precision, and reaction speed is to train it using several pictures. Second, by using real-time video frames to train the classifier, the system may adapt to its surroundings and improve its fire detection efficiency and accuracy via fine-tuning its identification skills. Finally, several types of fire extinguishers, such as chemical, wet chemical, carbon dioxide foam, dry powder, etc., may be integrated into the prototype to suppress fires caused by various sources.

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