Fire Simulation and Modelling for Data Centers

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***Abstract*—Data in our modern world is the most important currency. The whole world works on various kinds of data. It is crucial that this data is safely stored and not lost. Servers come to mind when large data storage is required. Many servers are needed, so server racks are grouped together in buildings - called data centers. Though data centers are typically safe, at anytime disaster can strike. Fires often break out of data centers which are difficult to control. All data in the racks are destroyed. As such, fire modelling in data centers are essential to stop fires from destroying servers. Details of cloud servers, sources of fires, causes of fires and fire detection software is discussed in the background. Fire detection in data center is elaborated in details, with prior systems and modern systems in place today. Fire suppression is then discussed again with prior and modern systems. A machine learning based approach is utilized with the K Nearest Neighbor (KNN), Support Vector Machine (SVM) and Random Forest Classifier (RFC) algorithms. The model is simulated and results recorded. Findings are concluded and plans for future research are discussed.**

***Index Terms*—Data, data centers, fire detection, fire suppression, machine learning based approach, K Nearest Neighbor, Support Vector Machine and Random Forest Classifier, model simulation.**

I. Introduction

The digital era is rapidly evolving and data has emerged as the cornerstone of technological progress, functioning as the most valuable currency. The intricate web of global society relies heavily on various forms of data, making its secure storage and preservation a paramount concern. Data centers are the nerve center of any organization or country. The modern world relies more on data centres for power. The requirement for enormous data storage and processing capacity is driving the skyrocketing demand for data centres as technologies like artificial intelligence (AI), the Internet of Things (IoT), and cloud computing become more popular with consumers and companies. Heavy investments in new digital infrastructure to support this expansion are required. Securing the infrastructure with data centre fire protection is absolute [1]. At the forefront of this challenge are data centers, where vast quantities of information are housed within server racks. While these centers are designed to be secure, the specter of unforeseen disasters, particularly fires, looms ominously. Protecting the vital data and computer resources kept in data centres requires effective fire protection. Servers may sustain irreversible damage from fire, which could result in disastrous data losses involving banking transactions, medical records, intellectual property, etc. Well-planned security against constant fires must be created, taking into account the context in which it will be executed, in order to prevent incidents of this kind. This plan calls for preventive actions that include site management and public instructions, in addition to passive and active protection measures [2]. In light of this, mapping and understanding the statistical information on fires- like their types, number of incidences per year, and confirmed fatalities- is crucial [3]. It is also critical to examine scientific and technological studies on fire safety in order to spot patterns and gather relevant data that can help advance and enhance fire safety [2]. In the pursuit of fortifying data centers against the looming threats of various types of fires, this endeavor aims to refine and expand upon a machine learning based approach. Rigorous simulations across diverse scenarios will serve as a testing ground, ensuring adaptability and robustness. For the future, it will take a leap into practical implementation, the method will undergo validation alongside state-of-the-art fire-fighting droids, specifically tailored for data center environments. Furthermore, the scalability and efficacy of the approach will be tested in multi-floor data centers, marking a significant stride towards ensuring its effectiveness in the complex, multi-dimensional landscapes of contemporary data storage facilities. Will encourage more research into using machine learning based solutions particularly more video and audio based.

II. Background

A. Cloud Servers

In the data center, there are often racks of servers. The servers contain all data - which is considered the cloud. According to Ahmed, Khadhim and Kadhim, ownership of cloud infrastructures are shared over the internet. Additionally, services provided by the cloud is superior, reliable and easy to utilize. Three models of cloud computing are very common - Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) [4]. Figure 1 details the differences below.

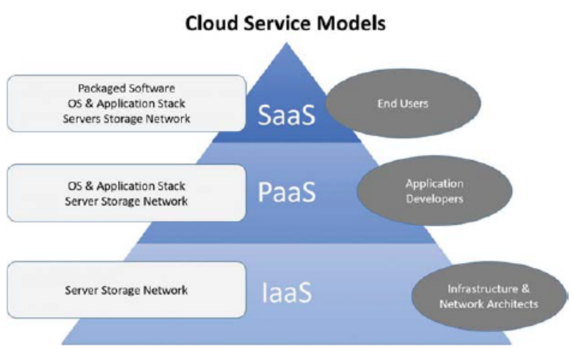

Fig. 1. Types of Cloud Computing

According to Nasri, rack servers are major energy mis-spending factors. Servers that consume less energy are important for continuous evolution of the data centers. There is a linear relation between CPU utilization and power consumption in the server. Almost as much as 40% of electricity is consumed via data centers and its devices [5]. Figure 2 shows a statistical representation of energy usage of different data center components.

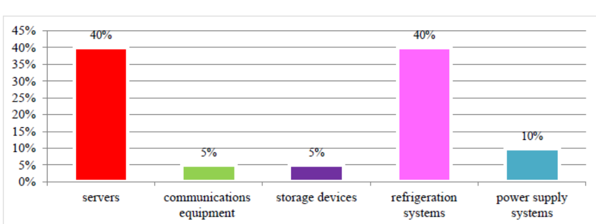

Fig. 2. Energy Utilized by Different Components

B. Sources of Fires in Data Center

Fire is a combination of four elements - heat, fuel, oxygen and a chain reaction process - combustion. Fires in data center are different when compared to typical house fires. Most often these are electrical fires. According to Zhang, in data center a variety of materials can be considered as combustibles. They are given as -

- Electronics - routers, power switches, servers, power supplies, batteries and wire insulation.
- Structure Materials - cabinets, cabling, material of floors and ceiling and backboards.
- Furnishing and Storage - documents, desks, chairs, cardboard boxes and other items.

Above covers the fuels of fire, now for the heat. Sources of heat are-

- Power Density - powerful servers packed in smaller spaces increases temperatures to higher levels, too high levels will act as a dangerous heat source. Amazon web services use AI and ML to reduce workload, which reduces temperature.
- Warm section containment - encapsulating warm exhausting air from server fans ensures cooler temperatures, else it would rise to dangerous levels.

The final component that is oxygen. In most data centers there is ample supply of oxygen present. Fires will keep on raging till all the oxygen is used up. Combustion of electrical equipment produces chain chemical reactions that produce different gases. Corrosive ones like hydrogen cyanide (HCN) and hydrogen chloride (HCL) are very common. All information above are according to Zhang [6].

C. Causes of Fires in Data Center

Again according to Zhang, there are many causes of fires in data centers. The causes and details are given below.

1) Electrical failures - Often the most common type of occurrence of fires in data centers. Often components overheat or short circuit and it results in a raging blaze. Among them two are most notorious -
   - Electrical Surges - When components a sudden burst of high voltage increases which leads to circuit overload. Uninterrupted Power Supplies (UPS) are not designed to withstand high voltages, chances of sparks are inevitable.
   - Arc Flashes - electrical leaks due to low impedance connections within systems. Can cause sparks which can cause a fire outbreak. Can quickly spread via data center materials.
2) Lithium-ion Batteries - In some data centers, separate storage facilities exist just to house the batteries. If batteries are exposed to air via leaks or become too hot, catching fire is the only result. Fire from this source spreads quickly and difficult to extinguish due to the hazardous combustibles.
3) Improper Maintenance - Dirty components, dust, debris and maintaining components often lead to disaster. Dust is conductive and can cause static electricity build up and later causes fires due to electrical surges.
4) Human error - Many conditions, perfect for fires to break out can come from simple human errors, such

as handling dangerous objects without care, improper connections or ignoring safety codes.

All given information is according to Zhang [6]. Next section discusses fire detection in data centers.

D. Fire Detection Software

Many popular fire detection software is often utilized in conjunction with many fire suppression systems to effectively fight against fires. Many popular ones are available online and also many are open-source. Some are commercial as extra services are provided. Some examples FireGFX, OWL fire management, Eocortex fire video software.

III. Data Center Fire Detection

To ensure such disasters do not become uncontrollable many data centers often have various fire detection systems. According to Zheng, prompt identification of fires and responding with countermeasures as soon as possible. Many systems also prioritize safety and warns any people within the premise so the casualties can be avoided. Upon fire detection, the fire alarm is raised warning people in the vicinity to leave. Below are different types of fire detection systems-

- Smoke detectors - photoelectric spot-types and ionization types are very popular due to being affordable, reliable and comes with sensitivity regulation. Although, not too good in detecting electrical fires within components.
- Heat detectors - an effective alternate, good in areas where smoke detection is not practical. Good in areas with dusty or cooler environments.
- Air sampling systems - highly effective for fire detection. Drawing in air and analyzing the combustion particles continuously, can provide early warnings. One of three is often utilized - standard fire detection (SFD), early warning fire detection (EWFD), and very early warning fire detection (VEWFD). Usually EWFD and VEWFD are preferred.
- Gas detectors - detects ionizing gases in the air, which could be a potential fire starter like - hydrogen. Hydrogen detection adds more safety.
- Video detection - utilizing advanced video analysis can see earliest fire signs, visible by smoke or fire colours. Can enhanced detection via object detection algorithms.

All of the above are according to Zheng [6]. Those are some detection systems used in data centers. Some other more advanced systems are there as well.

According to Spearpoint, humans feel heat near fires, heat detection systems have been around for a long time. Principles of heat transfer - conduction and convection processes are involved. The first system was built in the 1860s. In sprinkler systems activation temperatures can range from 57 to 2000° Celsius. In some it is 68° Celsius. In the technological modern world flames can also be seen via videos or heard via noise detectors. Solid-state or ionisable gas-filled tube elements or photovoltaic cells can be used to see different radiation waves. Although, systems must have visible line of sight. Flames have a 5 to 30 Hz flame frequency range, some IR detectors utilize this. New technology based on hearing fire are being researched. Figure 3 shows a sprinkler bulb while Figures - 4, 5 and 6 show diagrams of various smoke detectors [7].

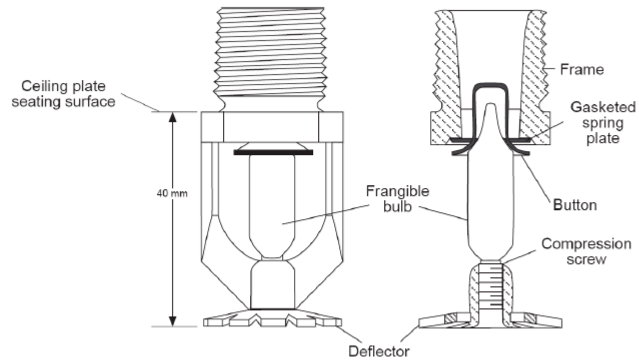

Fig. 3. Frangible bulb sprinkler head

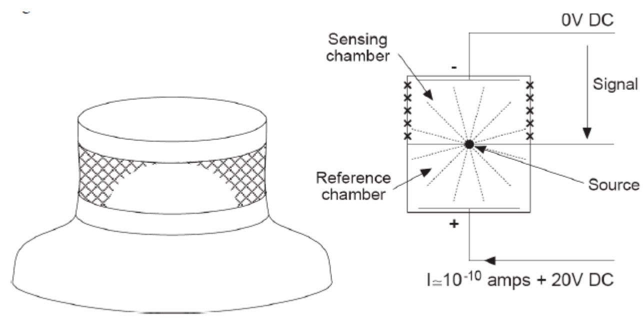

Fig. 4. Ionisation chamber smoke detector

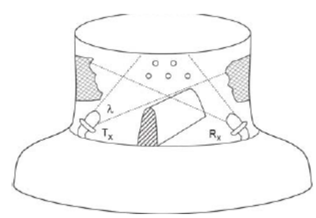

Fig. 5. Photoelectric smoke detector

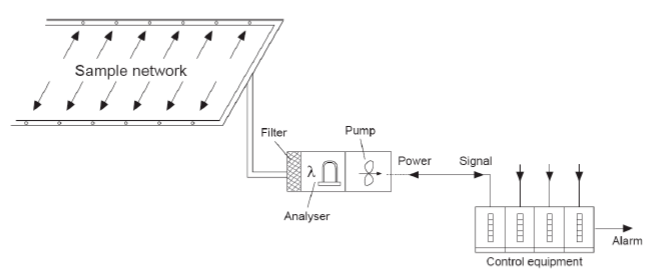

Fig. 6. Aspirating smoke detector

IV. Fire Suppression Systems

In data centers, fire suppression systems are often utilized to put a stop to any raging blaze that can come about. There are many types of fire suppression systems, many with extinguishing different types of fires. Some types use water, others inert gases. Simple systems like sprinklers spray fine mists to douse flames, where as other systems can use inert gases, like nitrogen. Fire suppression systems for data centers have become a forefront for good research.

According to Novozhilov, architectural complexity followed by a slow introduction to performance based fire systems has put the focus on fire science. Fire suppression is a very complex physico-chemical process, which is poorly understood. Over the last decade much progress has been made but more research needs to be done. Computational fluid dynamics are give much attention for prediction of sprinkler spray dynamics. Two regular systems are - sprinklers systems and water-mist systems.

1) Sprinklers systems - A long historical tool for fire suppression. The first was introduced in New Zealand for textile mill fires. Experimental testing has forced the sprinkler to evolve with time, FMRC-developed "spray" sprinkler replaced the old one. Still, CFD models remained scarce. Factory Mutual research program contributed many great systems in upcoming years.
2) Water-mist systems - Received good attention as an alternative to the sprinkler system. Water Mist Fire Suppression Systems (WMFSS) are a very popular part of active fire proofing design of modern architectures. Buildings, transport and other systems use WMFSS. Water mist has shown phenomenal performance in extinguishing fires of various sizes with a fixed amount of water. Although, factors like obstacles and unreachable spaces. To achieve volumetric uniform distribution, some design enhancements must be made. Mist cannot protect against low flash flammable liquids. In large open spaces, due to quicker evaporation and cooling mist is not adequate enough.

All the above are according to Novozhilov [8].

According to Kim, other types of fire suppressing agents have been utilized for a long time. Firstly, halogens were utilized in the 1940's, though halogens were amazing suppressants, halogens led to ozone layer depletion. As such, different alternatives had to be utilized. Secondly, other gaseous systems came to function. These systems are of two types halo-carbon agent based - which showed prominent performance, but exposure to halo-carbons by humans can cause cardiac arrhythmia. Also, release of other toxic chemicals during suppression prompted researches to find new alternatives. Inert gases were the next logical step. Inert gases have shown excellent performance in fire suppression. In the current market 3 are available, Argonite (IG-55), Inergen (IG-541), Argon (IG-01) - the first two are mixes of different volumes of nitrogen, argon and small carbon, the last one is only argon. Issues with these is the need to store in high pressure cylinders - weight and space complexities. Fourthly, water suppression systems - the very common one. Fine water mist is capable of handling fires of any size anywhere. The industry in some cases refuse to utilize this due to fear of water damage to electronic equipment. Water mist systems often also use up water during discharge from sprinkler thus the amount required to fight fire is often reduced. Also cannot reach fire in challenging locations like vents or empty spaces. Fifthly, compressed air foam has often been utilized to douse flames. Compressed air foam is formed by injecting pressured air into foam solution and mix is later released in a high pressure from the nozzle. There are issues that the nozzle can get jammed and the foam can also get contaminated. Two other issues are - traditional sprinkler nozzles cannot distribute the foam without collapse and foam degenerates in the fixed pipes. Recently, NRC has solved these issues. Currently compressed air foam is very popular. Lastly, aerosol and gas generators. Commercial aerosol contains solid rocket fuel, when electrically or thermally lit, aerosol-forming composition produces dry chemical particles and gas products. Aerosol must remain suspended for a long time for it to be effective and the volume must adequate to counter the flames. Gas generators have been developed for fire suppression applications based on car air bag technology. Conventional gas generators contain propellant and electrical initiator. Gases generate are typically very hot and new variations have been made. These are the current systems utilized for fire suppression. Over the past decades these systems have been updated, revamped and improved, all according to Kim [9].

According to Mihalache et al., smoke can damage electronic tools seriously, thus INERGEN gas systems are extremely effective is extinguishing fires in data centers. The system is however very noisy. INERGEN gas contains three gases - argon, carbon dioxide and nitrogen. The INERGEN gas is stored in pressured containers. Table I shows the INERGEN gas composition.

TABLE I
INERGEN Gas Composition

Gas-Percentage	Proportion	Proportion range as per ISO14520-15
Argon	40%	37.2% to 42.8%
Carbon Dioxide	8%	7.6% to 8.4%
Nitrogen	52%	48.8% to 55.2%

INERGEN decreases the oxygen present from 20.9% to 12.5% and increases carbon dioxide from 0.03% to 3.0%. INERGEN agent is stored as gas and discharges as an invisible gas, permitting bystanders to safely leave the place without obscuring sight. INERGEN gas is released from a nozzle in a pressurised form. The INERGEN gas fights blazes by reducing the amount of oxygen present in the room. Upon fire detection the system is activated and gas is released. The gas is effective in fighting almost any type of fire. Figure 7 shows the position of the INERGEN gas system in the data center.

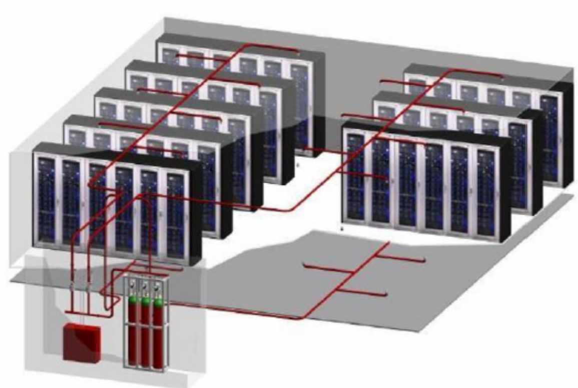

Fig. 7. INERGEN Gas System Position

The discharge nozzles are designed in a specific design. Nozzles are of 180 and 360 degrees types. Nozzles are made of steel head containing orifice plate. Figure 8 shows a diagram of the designs and a real picture.

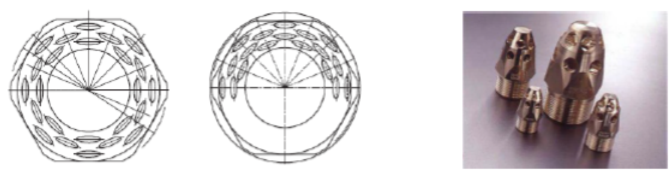

Fig. 8. 180 and 360 Nozzles and Real Pictures

Hard drives disks are often used in data centers to store huge amounts of data. Hard disks are very sound sensitive in data centers. Too much noise can cause damage to hard disks. To reduce the noise of the INERGEN gas system an acoustic nozzle is utilized. The function remains same but noise levels are reduced. Figure 9 shows the image of an acoustic nozzle.

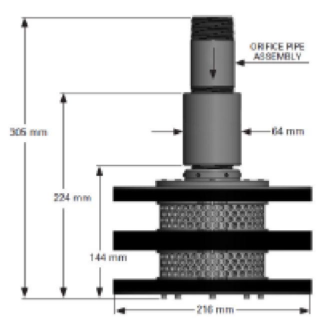

Fig. 9. Acoustic Nozzle

All above information are according to Mihalache et al. [10].

V. A Machine Learning Based Approach

Here, a machine learning based approach is utilized for finding fires, breaking out from server racks. The data set, after pre-processing, is passed through the algorithms of K Nearest Neighbour - KNN, Support Vector Machine - SVM and Random Forest Classifier - RFC. The data set and the algorithms are discussed in detail below.

A. Data Set Details

About 517 entries are present with 9 attributes. The following attributes are present - X, Y coordinates of the data racks, Months and Days denoting on which month and day the event occurred. Rack temperature, the temperature of the server racks at the given coordinates, Moisture of the rack surroundings, ISI - Initial Spread Index, how much fire spreads from rack is given along with room temperature and humidity during the events. Data set is pre-processed and fed into the given machine learning algorithm.

B. Machine Learning Algorithms

Many solutions utilize machine learning as a very good and stable approach to finding the best optimal solutions. The pre-processed data set is then fed into each algorithm and the results are recorded. Below the three algorithms are discussed in detail.

1) K-Nearest Neighbour - KNN: According to Srivastava, a popular machine learning technique, that handles regression and classification problems. In training, stores entire data set as a reference. Makes calculations by taking distance between input data points. Identifies k nearest neighbours to input data [11].

2) Support Vector Machine - SVM: As per Gandhi, objective of support vector machine is to find hyperplane in a Z-dimension space where Z denotes number of features, which classifies the data. The algorithm finds the plane which has maximum margin between both data. Support vectors are points closer to the hyperplane. Hyper-planes are decision boundaries. Utilizes the hinge loss function. Also has mis-classification gradient updates with regular ones [12].

3) Random Forest Classifier - RFC: According to Chaudhary, it uses supervised learning methods. Can be applied to classification and regression. Picks data points at random from the training set, creates decision trees for chosen points. Each tree gives result which is either averaged for final result or based on majority choices. RFC can handle over fitting well and produces fast results with a simple process [13].

VI. Model Simulation

The model is simulated and the results are obtained. The data set is pre-processed and then is fed into the algorithms. The results are then plotted in graphical form. Table II shows training and testing accuracy.

TABLE II
ALGORITHM TRAINING AND TESTING ACCURACY

Algorithm	Training Accuracy (%)	Testing Accuracy (%)
KNN	67	44
SVM	100	96
RFC	100	92

In Table II, SVM has highest testing accuracy of about 96% followed by RFC which shows 92% testing accuracy. In both case training accuracy is 100% but it is practically close to 98%. KNN has low training accuracy of 67% followed by 44% of testing accuracy. The low accuracy of KNN is due to the randomness of the variables. Figure 10 shows the graphical representation of the data.

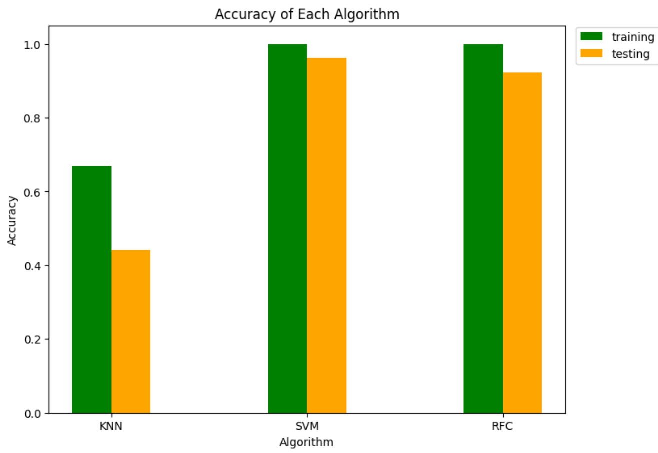

Fig. 10. Accuracy of Algorithms

In Figure 10, SVM has the highest accuracy followed by RFC then KNN. Finally, Figure 11 shows a correlation heat map to elaborate the different correlations between all attributes.

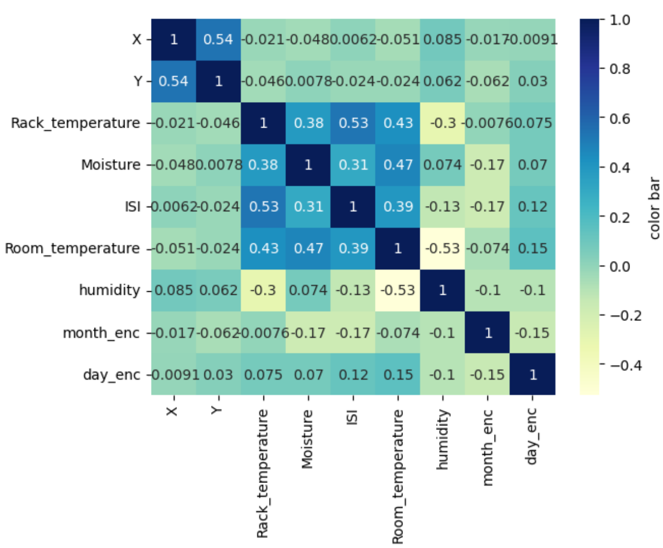

Fig. 11. Correlation of Attributes

In Figure 11 a relatively good correlation can be seen between rack temperature, moisture, ISI - initial spread index and room temperature. Other attributes have weak correlation. Therefore, these four elements affect the fires the most.

VII. Conclusion

In conclusion, fires in data centers are extremely dangerous. Once fires break out all data is damaged and lost. Losing important data can cause multitude of issues and if lost information cannot be retrieved, the loss will be monumental. A background study is conducted on cloud servers, sources and causes of fires in data centers. Then, various fire detection and fire suppression systems are discussed in detail followed by necessary diagrams and images. A machine learning based approach is utilized to find fires from breaking out. The data-set and the algorithms used are discussed. KNN, SVM and RFC machine learning algorithms are utilized and discussed in detail. The model is simulated and results are elaborated.

VIII. Future Work

The given machine learning based approach will be further refined to take more variables into account. More advanced algorithms will also be implemented in the design such as YOLOv8, CNN and RNN. Will also focus on audio or video capabilities as well. Will be simulated in different scenarios. The method will also be tested with fire fighting droids for data centers and on multi-floor data centers in the future. More detailed data sets will also be utilized.

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