Computer vision-based information system for landfill fire detection*

Miroslav Kvassay[1,†], Andrii Kuzmin[1,†,*], Mariia Kostiuk[1,†] , Oleksandr Khlevnoi[2,†] and Houda El Bouhissi[3,†]

[1] Zilina University, Univerzitná 8215, 010 26 Žilina, Slovakia
[2] Khmelnytskyi National University, Instytuts'ka str., 11, Khmelnytskyi, 29016, Ukraine

Abstract

Fires at municipal solid waste landfills pose a significant environmental and public health hazard. This study analyzes fire incidents in Ukraine over the past 20 years, identifying methane accumulation and spontaneous combustion as the most frequent causes, exacerbated by high temperatures and the presence of flammable substances. The consequences extend beyond air, soil, and water pollution, with several cases leading to human casualties. To mitigate these risks, modern information technologies, including the Internet of Things (IoT) and artificial intelligence (AI), are proposed for early fire detection in landfills. This paper presents a concept for an AI-driven fire detection system utilizing computer vision techniques aimed at early landfill fire spread prevention. The proposed system employs the YOLOv8 deep learning model for real-time fire recognition from surveillance footage, ensuring rapid response and improved safety measures. A theoretical experiment was conducted to evaluate the system's efficiency, demonstrating high accuracy in identifying fire incidents while maintaining a low false alarm rate. The structured methodology for data collection, preprocessing, and model training contributed to robust performance across various environmental conditions. However, challenges such as reducing false positives and adapting the model to complex real-world scenarios persist.

Keywords

Computer vision, image processing, landfill fire detection, neural networks, YOLOv8, information system

1. Introduction

In Ukraine, there has been a huge problem of household waste management for many years in a row. Mixed unsorted household waste is taken to an open-air landfill, where it decomposes under the influence of external factors. Atmospheric precipitation, solar radiation and heat release in connection with spontaneous surface and underground fires and fires contribute to unpredictable physical, chemical and biochemical processes at municipal solid waste (next – MSW) landfills, the products of which are numerous toxic chemical compounds in liquid, solid and gaseous states. A dangerous phenomenon of these objects is leachate - a liquid with a complex chemical composition with a pronounced unpleasant smell of biogas, which arises as a result of the accumulation of atmospheric precipitation in the landfill and concentrates within its sole. That is, the main pollutants of the environment caused by the operation of garbage dumps and solid waste landfills are gases (combustion products and the interaction of waste particles) and wastewater (leachate) (Fig. 1) [1].

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* Corresponding author.
† These authors contributed equally.
miroslav.kvassay@fri.uniza.sk (M. Kvassay); andriy1731@gmail.com (A. Kuzmin); maria@khnu.km.ua (M. Kostiuk); o.hlevnoy@ldubgd.edu.ua (O. Khlevnoi); houda.elbouhissi@gmail.com (H. El Bouhissi)
0000-0002-6450-5417 (M. Kvassay); 0009-0005-6489-225X (A. Kuzmin); 0000-0002-9559-4109 (M. Kostiuk); 0000-0003-2846-3480 (O. Khlevnoi); 0000-0003-3239-8255 (H. El Bouhissi)

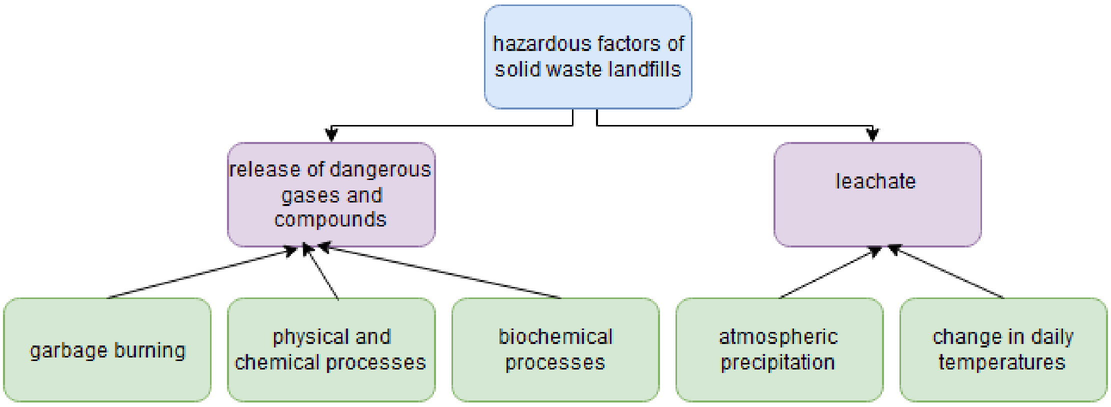

Figure 1: Hazardous factors of solid waste landfills [1].

The fire hazard of garbage depends on the compaction of solid waste landfills. The greater the density of garbage in landfills, the lower the probability of spontaneous combustion fires. The lack of proper access for forces and means to the sources of fire, which are usually located on the slopes of the solid waste landfill, necessitates the creation of new ways of supplying fire-extinguishing substances to ensure the necessary extinguishing, taking into account the following issues:
- large fires in landfills, and mainly steep slopes of garbage storage;
- the absence of a solid entrance, and the accumulation of leachate along the perimeter of the landfill;
- mainly the absence or insufficient number of sources of fire-fighting water supply;
- thick smoke and toxicity of combustion products;
- the possibility of an explosion as a result of accumulation of biogas formations;
- the presence of a large number of cutting and prickly elements in the garbage, which makes it impossible to lay sleeve lines, access of personnel to the cell.

Therefore, *an important task of science is to find methods and means that will prevent fires at landfills, and in the event of their occurrence, to detect them as early as possible* in order to reduce the spread of harmful substances into the environment.

2. State-of-the-art

In Ukraine, there are numerous cases of fires at landfills and solid waste landfills. In the course of the research, we analyzed a number of publications and news of electronic mass media publications and, based on the analysis, compiled a table of landfill fires that occurred in Ukraine over the past 20 years. The results of the analysis are presented in Table 1.

Table 1
Analysis of the largest landfill fires that occurred in Ukraine

№	Year of occurrence	Place	Area occupied with fire	Causes and consequences. Additional information
1	July 21, 2007	Near Uzhorod	6 hectares	In July 2007, the solid waste landfill in Uzhorod burned for three days. Due to the high temperature and heat, it was not possible to localize the fire. The fire spread to new areas. 11 emergency vehicles were working at the scene. At the landfill, tractors and excavators were leveling the garbage so that you could reach the fire in the layers of garbage [2,3].

2	June 7, 2011	near Kharkiv	5900 m3	One of the largest fires occurred on June 7, 2011, at the Dergachyv solid waste landfill in Kharkiv. The fire was extinguished with the help of 17 tanker trucks, 4 units of special equipment, as well as bulldozers and other equipment of communal services, which created artificial ravines and ditches. In addition to firefighters, representatives of radiological and chemical control worked at the scene. The total capacity of the landfill is 5,900 thousand m3, including the capacity of the first stage - 1,800 thousand m3.
3	June 23, 2011	near Sevasto-pol	700 m3	On June 23, 2011, a large fire broke out in Sevastopol at a spontaneous landfill near the waste incineration plant. The flame covered an area of 700 square meters; difficulties arose due to the lack of hydrants, as fire engines could not fill up with water. To extinguish the fire, 10 units of fire-fighting equipment were used, in addition, four water carriers of communal enterprises, as well as employees of the Sevastopol Forestry. The open fire was extinguished seven hours after its discovery.The cause of the fire was burning grass near the landfill.
4	June 21, 2016	near Mykola-yiv	2,5 th. m3	In Mykolaiv, on June 21, 2016, a large-scale fire broke out at a spontaneous dump near the city cemetery. As the employees of the State Service for Emergency Situations reported, the fire covered about 2.5 thousand square meters. Mainly plastic was burning, as well as old car tires and various construction debris. Poisonous smoke from the fire drifted over the city. Despite the heat, people had to close their windows. When plastics are burned, a poisonous substance is formed - dioxin, which can cause oncological diseases [4].
5	May 28, 2016	Velyki Hrybovy-chi (around 10 km from the centre of Lviv)	100 th. m3	On May 28, 2016, a large fire broke out on the territory of the Hrybovytsky landfill. Soon there was a collapse of solid household waste at the landfill, as a result of which three rescuers died under the rubble. On May 29, residents of the village of Velyki Hrybovichi blocked the road to garbage trucks that were taking garbage from Lviv to the landfill. The fire was extinguished on May 30. On June 8, the fire broke out again, they tried to put it out with the help of firefighting planes [5,6].
6	19 July, 2023	near Rivne	300 m2	A fire broke out at a landfill near Rivne, probably due to self-ignition of methane landfill gas. Six tankers of the State Emergency Service; tactical robot; 35 rescuers; three local fire brigades; auxiliary equipment and employees of KATP-1728. "The fire probably started as a result of chemical processes, in particular, the rotting of solid household waste," the report says [7].
7	May 24, 2023	near Lutsk	150 m2	On Wednesday, May 24, a fire broke out near Lutsk at a landfill in the village of Bryshche. The following worked at the scene: 13 rescuers; 3 units of equipment; 2 bulldozers; 2 dump trucks; a "Spetskomuntrans" car that delivered 6 tons of water [9].

8	July 24, 2024	near Kharkiv	500 m2	On July 23, a fire broke out on the territory of a landfill near the village of Starovirivka, Krasnograd District, Kharkiv Region. It was possible to localize the fire within an hour, in general, the liquidation lasted almost five hours. There are no casualties. The cause of the fire is being investigated. Firefighters of the fire and rescue service, firefighters of the local fire brigade of the village of Slobozhanske, and adapted equipment of a local agricultural enterprise were involved in extinguishing the fire [8].

As can be seen from Table 1, most of the fires occurred in the period from the end of May to the end of July, that is, the cause was the spontaneous ignition of combustible substances (accumulated methane and biogas) and flammable hazardous waste as a result of high air temperatures and low rainfall in the warm season. That is, it is extremely difficult to warn or prevent the occurrence of such fires. Therefore, there is a need to develop methods and means of their early detection and control.

Landfill fires can be classified as fires in open areas, which are extremely difficult to detect early. Usually, when they are noticed, the fire has already covered a large area, which makes it difficult to extinguish, requiring the involvement of many units of special equipment and rescuers. In addition, there is a risk of rapid spread of the fire to nearby areas due to the wind, which threatens to burn forest strips, plantations, fields and even residential areas.

In the course of the study, an analysis of scientific publications, methods and means of fire detection in open areas was carried out. The results of the analysis are presented in Table 2.

Table 2
Analysis of scientific publications, methods and means of fire detection in open areas

№	Author s year	Country	Techno-logy used	Description of the method
1	Sharma A. et.al [10], 2020	India	WSN, UAVs, IoT	The purpose is to implement a system for the prevention of cities from disasters that may occur surrounding a smart city towards the deployment of sensor networks and IoT.
2	Fengmei C. [11], 2020	China	Survei-llance monitoring (SM), IoT, Deep Learning, CNN	The system operates using a network of distributed sensor nodes that are interconnected with each other and the server. These sensors can detect humidity, temperature, and other environmental factors. The proposed system's architecture consists of three main components: IoT devices, user applications, and web interfaces or services. The IoT devices within the surveillance network collect and monitor environmental data, which is processed in real-time.
3	Sunghetha A. et.al [12], 2020	Ethiopia	IoT, UAVs, WSN	The paper integrates IoT and cloud technologies to provide an efficient fire detection system. This system allows for the monitoring and collection of real-time information in a cost-effective and moderate manner.

4	Xu R. et.al [13], 2021	China	Ensemble learning, YOLOv5, EfficientNet	Two powerful object detectors (Yolov5 and EfficientDet) with different expertise are integrated to make the whole model more robust to diverse forest fire scenarios. Then, a leader (EfficientNet) is introduced to guide the detection process to reduce false positives.
5	Mukhiddinov M. et.al. [14], 2022	Korea, Uzbekistan	YOLOv4	The system facilitates early fire detection in indoor environments. For real-time fire detection and alerts, it utilizes image brightness and a new convolutional neural network that incorporates an enhanced YOLOv4 model with a convolutional block attention module.
6	X. Chen et al. [15], 2022	USA	UAVs, CNN	The authors present FLAME2, a dual-feed prescribed fire imaging dataset collected by unmanned aerial systems in a ponderosa pine forest using side-by-side visual and thermal camera feeds. Also, they apply deep learning-based analysis methods to the dataset to accurately label and segment, frame by frame, pixels with fire and/or smoke present.
7	Fatma M.Talaat & Hanaa ZainEldin [16], 2023	Egypt	YOLOv8, fog and cloud computing	The paper introduces an enhanced fire detection approach for smart cities using the YOLOv8 algorithm, known as the Smart Fire Detection System (SFDS). By harnessing the power of deep learning, SFDS can identify fire-specific features in real time. This approach aims to increase the accuracy of fire detection, minimize false alarms, and offer a more cost-effective solution compared to traditional methods.

The works presented in Table 2, although they offer the practice of applying modern information technologies, such as the Internet of Things, neural networks and computer vision, but they are mainly aimed at detecting forest and field fires and do not solve the problem of detecting fires in landfills. Therefore, it was decided to consider ready-made industrial solutions and projects aimed at identifying this problem.

One of the commercial solutions, already presented at the market is Open-area Smoke Imaging Detection (OSID) - a technology tailored for large, open spaces. It enables early detection and response, helping to save lives and prevent service disruptions [17]. However, this technology is mostly designed for warehouses, airport terminals, train stations, stadiums, museums and shopping malls, i.e. large area, but not under the open air. Moreover, the cost of one OSID unit is 201,88 GBP – 429,65 GBP, depending on the model and technical characteristics, which makes this technology not affordable for municipal infrastructure.

An interesting study that began in Ukraine in May 2021 is a satellite system for early detection of forest fires. The American spacecraft Suomi NPP and JPSS-1 photograph the territory of Ukraine 14 times a day (Figure 2). And if (as soon as) a so-called "thermal anomaly" is detected, i.e. a fire, the early warning algorithm is activated. According to the head of the State Space Agency of Ukraine, within 30 minutes after a fire is recorded by a satellite, the heads of the nearest fire brigades, foresters and rescuers will have detailed data on the fire, a map and will be able to start extinguishing it in the initial stages, save human lives, property, animals and, in fact, dozens of thousands of hectares of forest. According to the report, the accuracy of the data received reaches 90%, which is a very high indicator. The system works 24/7/365. Currently, 14 regions of Ukraine are connected to the system, mainly southern, northern and western regions [18].

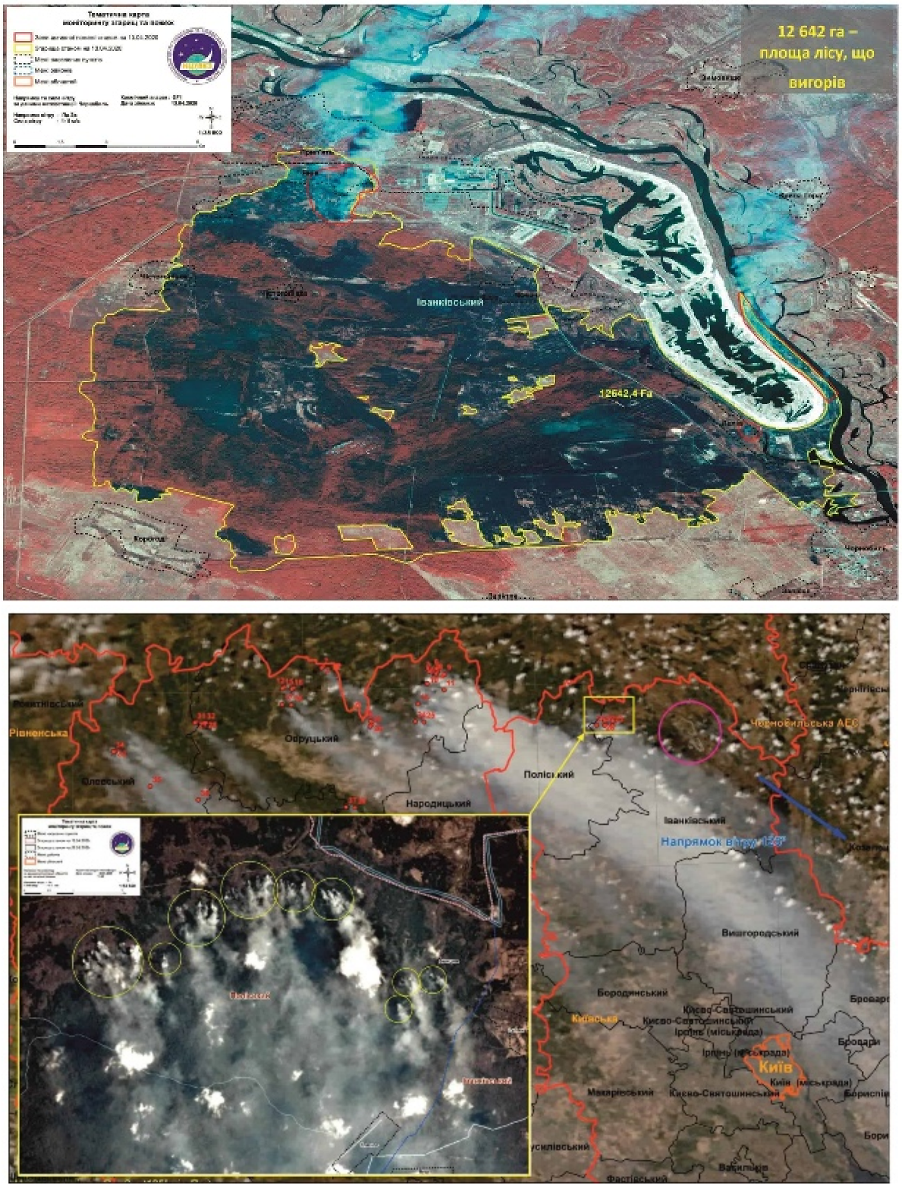

Figure 2: Satellite image of a forest fire [18]

However, this technology does not solve the problem of early detection of fires in landfills, as it is designed for a larger coverage area. Therefore, the task of detecting a fire at a landfill is still relevant.

3. Computer vision-based information system for landfill fire detection

The proposed information system for detecting fires at landfills consists of three subsystems: the surveillance subsystem, the image recognition subsystem, and the response or alarming subsystem. Decomposition diagram of the described above system is presented in Figure 3.

The surveillance subsystem consists of external surveillance cameras that the landfill is equipped with to ensure security and round-the-clock surveillance. From the camera, the video is sent to the image recognition subsystem from the video stream, where the video is segmented into frames that are checked using algorithms based on a convolutional neural network for the presence of smoke and fire (the algorithm will be described in more detail later). The result is then sent to the alarm system. If there is no fire, the system returns to receiving and processing new video frames. If smoke or fire is detected, the alarming algorithm is activated.

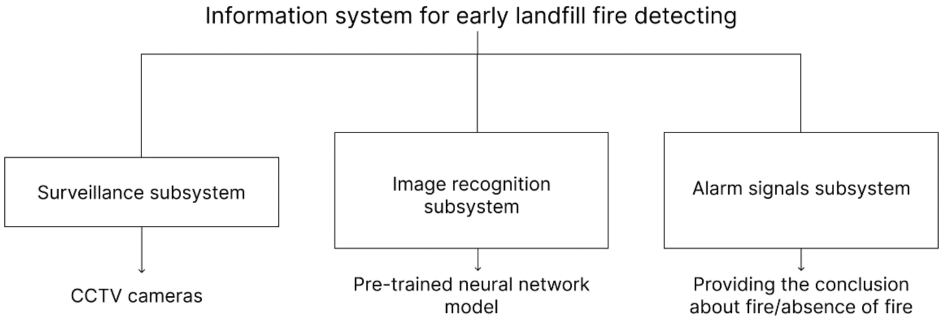

Figure 3: Decomposition diagram of information system for early fire detection.

The extended structure displaying general architecture of the proposed system is presented in Figure 4.

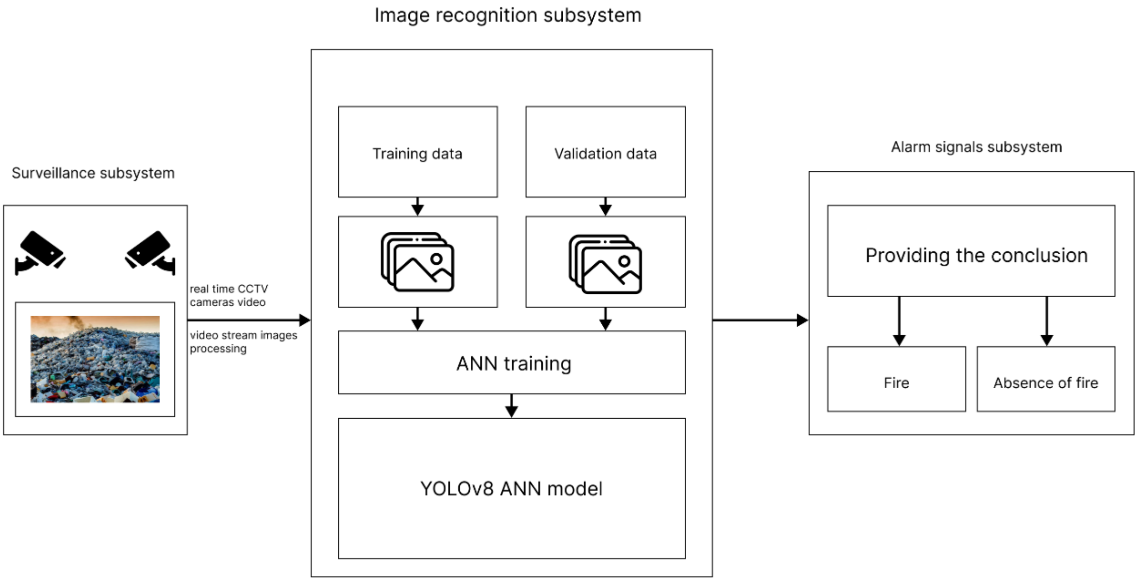

Figure 4: An extended structure of computer vision-based information system for landfill fire detection.

4. Results & discussion

To evaluate the efficiency and accuracy of an image recognition-based fire detection system using a YOLOv8 artificial neural network (ANN) model it was decided to perform a theoretical experiment. The system integrates a surveillance subsystem, an image recognition subsystem, that was presented in [22]and an alarm signal subsystem to identify fire occurrences in real-time video streams from CCTV cameras installed at waste disposal sites. The experiment consists of the experimental setup, which includes hardware and software requirements collecting, data collection and preprocessing, model training, testing and validation, experiment procedure itself and expected outcome evaluation. The experiment flow is schematically presented in Figure 5.

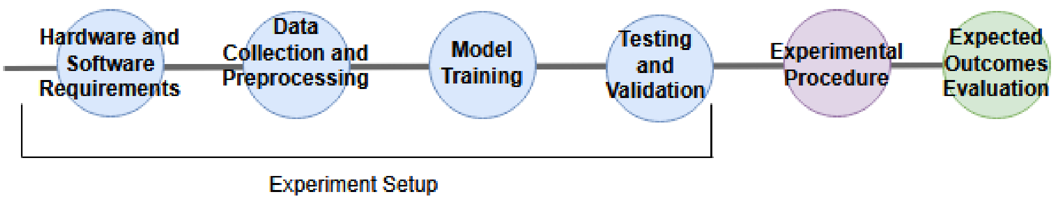

Figure 5: General diagram of an experiment flow.

4.1. Experiment setup. Hardware and software requirements

For the qualitative experiment data, we need CCTV surveillance cameras with high-resolution video capabilities, computational server with a GPU-enabled processor for deep learning model training and inference []. Python programming language is used for data analysis along with OpenCV, PyTorch, and YOLOv8 libraries. A dataset that consisting of fire and non-fire images, labeled for supervised learning [31].

Data Collection and Preprocessing. The system captures real-time video streams from surveillance cameras monitoring waste disposal sites. Image frames are extracted and preprocessed, including resizing, normalization, and augmentation to enhance generalization. The dataset is split into training (80%) and validation (20%) subsets. We can either take a ready-made dataset for the experiment or compile the own one as it is proposed in [27].

Model Training. The YOLOv8 ANN model is trained using the labeled dataset to classify images as "fire" or "absence of fire." The training process involves optimizing the model parameters using a loss function and gradient descent algorithm. Hyperparameters such as learning rate, batch size, and number of epochs are tuned to maximize accuracy.

Testing and Validation. The trained YOLOv8 model is evaluated on the validation dataset to measure its performance. Key metrics such as precision, recall, F1-score, and accuracy are calculated to assess the model's effectiveness. Confusion matrices and ROC curves are used for further analysis.

Experimental Procedure consists of the following steps:

- Deploy the trained YOLOv8 model on the computational server.
- Process real-time video streams to extract image frames for analysis.
- Input the images into the trained ANN model to classify fire presence.
- If fire is detected, an alarm signal is triggered in the alarm signals subsystem.
- The results are logged, and false positives/negatives are analyzed to refine the model.

4.2. Expected outcomes evaluation

The system should detect fire incidents with high accuracy while minimizing false alarms. The performance of the model should be robust in different lighting and environmental conditions. The results of this experiment will provide insights into improving automated fire detection systems for waste management areas. This experiment establishes a structured approach to evaluating an AI-based fire detection system. The findings will contribute to advancements in real-time fire detection technologies, ensuring quicker responses to fire outbreaks in critical environments.

Conclusions

In the case of this study the cases of fires at municipal solid landfills were considered. We analyzed the causes and the consequences of the fire cases in Ukraine for the last 20 years and highlighted that the most frequent causes of the fires were the methane accumulation and spontaneous combustion due to high temperatures and the presence of flammable substances in landfills. As for the consequences, in addition to the release of harmful and toxic substances into the atmosphere, soil and water bodies, fires in landfills have claimed human lives. Therefore, it is advisable to look for solutions using modern information technologies, the Internet of Things and artificial intelligence for the early detection of spontaneous combustion in landfills. After all, the earlier the problem is detected, the easier it is to overcome it.

This paper proposes the concept of an information system for detecting fires in landfills using computer vision and highlights the importance of AI-driven solutions in enhancing fire detection and prevention, contributing to improved safety measures in high-risk environments.

Also, a theoretical experiment was proposed to validate the operation of the proposed system. The results of the experiment demonstrate the potential of AI-based fire detection systems in improving fire safety and response times. The YOLOv8 model exhibited high accuracy in identifying fire incidents while maintaining a low false alarm rate. The structured approach to data collection, preprocessing, and model training ensured reliable performance under varying environmental conditions. However, challenges such as reducing false positives and adapting the model to complex real-world scenarios remain.

Future work of the authors should focus on integrating additional sensor data, improving model robustness, and deploying the system in diverse waste management facilities to validate its effectiveness in real-world applications. Also, the authors plan to mitigate the errors occurred during the experiments.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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