AN EFFECTIVE SENSOR NETWORK SYSTEM FOR EARLY WILDFIRE DETECTION: EMPOWERING COMMUNITIES USING ADVANCED TECHNOLOGIES

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ABSTRACT

This project focuses on the development of an affordable and accessible solution for early wildfire detection in order to help empower individuals and communities with the ability to proactively detect fire sources[1]. By leveraging a network of sensors spread across a wide area, wildfires are able to be easily discovered by the network and relevant stakeholders are alerted to the threat[2]. Advanced algorithms analyze environmental factors such as temperature, humidity, and wind speed to enhance the accuracy and timeliness of wildfire detection [3]. By addressing the limitations of existing methodologies, this project contributes to improving wildfire prevention and mitigation efforts [4]. Through cost-effective technology and widespread implementation, it aims to create safer and more resilient communities in the face of the increasing threat of wildfires [5].

KEYWORDS

Wildfire Detection, Sensor Network, Environmental monitoring, Algorithms

1. INTRODUCTION

Wildfires hold the potential to devastate entire areas, forcing millions of people to evacuate their homes [6]. In recent years, it has cost an average of 2.8 million USD to deal with suppression of wildfires alone. The impact of large wildfires can be felt throughout society and the environment, causing significant economic, ecological, and human losses. The increasing frequency and intensity of wildfires in various parts of the world have raised concerns and highlighted the urgent need for comprehensive research to understand the underlying factors contributing to their occurrence and to develop effective strategies for prevention, mitigation, and recovery [7].

One crucial aspect of studying wildfires is understanding their causes. While natural factors such as lightning strikes and volcanic eruptions have historically been responsible for igniting fires, the human factor has emerged as a significant contributor to the escalation and spread of wildfires [8]. Factors such as irresponsible land management practices, inadequate fire suppression measures, climate change, and urbanization in fire-prone areas have all played a role in exacerbating the severity and frequency of wildfires [9].

The economic impact of wildfires is staggering. Beyond the costs associated with firefighting efforts, wildfires result in substantial losses to property, infrastructure, and local economies. Businesses are forced to shut down, agricultural lands are destroyed, and tourism suffers as

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popular destinations become engulfed in flames. Furthermore, the displacement of communities due to mandatory evacuations and the destruction of homes and livelihoods inflict a significant toll on individuals and societies as a whole.

The first article, "Airborne Optical and Thermal Remote Sensing for Wildfire Detection and Monitoring," focuses on utilizing aerial platforms equipped with advanced sensors and algorithms to detect and monitor wildfires. The solution is effective but expensive, with a higher chance of missing fires unless better sensors are used. In contrast, my project aims to offer a more affordable option for individuals to have early detection of fires, making it accessible to the general public.

The second article, "Review of wildfire detection using social media," explores the potential of leveraging social media as a platform for detecting and preventing the spread of wildfires. It highlights the ability of social media to quickly propagate information and engage human observers as sensors. However, limitations include the difficulty of identifying early warning signs of fires by individuals and the dependence on a sufficient number of people to detect fires. In my project, I utilize sensors spread across a wide area to detect fire sources, providing an alternative approach to wildfire detection.

The third article, "Video-based wildfire detection at night," focuses on using algorithms to detect fires based on video footage. While this method is successful in supplementing traditional detection methods, it requires continuous video collection, which can be costly if implemented in multiple areas. My project addresses the need for affordable individual solutions by offering a more cost-effective alternative compared to video-based detection algorithms that require a 360-degree view of the house.

In summary, my project aims to improve on existing methodologies by providing a cheaper and more accessible solution for early fire detection. It leverages sensors spread across an area and offers affordability to individuals, overcoming the limitations of expensive aerial platforms, reliance on social media users' expertise, and the cost of video-based detection.

Our proposed solution for wildfire prevention revolves around early detection using remote sensors equipped with temperature, humidity, barometric pressure, and VOC gas sensing capabilities [10]. These sensors are strategically placed in fire-prone areas to continuously monitor environmental conditions and swiftly identify abnormal patterns that could indicate the presence of a wildfire.

Temperature sensing is instrumental in detecting wildfires as it provides insights into the thermal characteristics of the surrounding environment. By monitoring temperature fluctuations, the sensors can identify abnormal heat signatures that may indicate the onset of a wildfire.

Humidity sensing is essential for assessing moisture levels in the air, a critical factor in determining fire risk and spread potential. Low humidity levels create dry conditions that promote the ignition and rapid propagation of wildfires. By monitoring humidity levels, the sensors gather valuable data for evaluating the likelihood of fire occurrence.

Barometric pressure sensing contributes to our understanding of fire behavior by detecting changes in atmospheric conditions. Rapid drops in barometric pressure often accompany weather systems such as strong winds, which can intensify wildfire risks. By monitoring these pressure fluctuations, the sensors provide crucial information to assess the likelihood of fire spread.

VOC gas sensing plays a significant role in detecting and monitoring combustion-related gases emitted during wildfires. By detecting the presence and concentration of volatile organic compounds, such as methane and other hydrocarbons, the sensors provide additional evidence of active wildfires. This capability enhances the accuracy of our detection system and aids in confirming the presence of a fire.

Through continuous monitoring of temperature, humidity, barometric pressure, and VOC gases, our sensors can swiftly identify abnormal conditions that may indicate the presence of a wildfire [11]. This real-time analysis enables prompt alerts and facilitates timely response measures to mitigate the impact of wildfires, thereby protecting lives and properties.

By implementing this early detection system, we aim to enhance wildfire prevention efforts and provide valuable tools for emergency responders, authorities, and communities. Our remote sensors and advanced sensing capabilities offer an effective means to proactively address the threat of wildfires, enabling timely evacuation and mitigation measures. This approach has the potential to significantly reduce the devastating impact of wildfires on individuals, communities, and the environment.

In Experiment A, the AI algorithm's accuracy in detecting wildfires was evaluated using a dataset comprising both wildfire and non-wildfire samples. Out of the 10 tested samples, the algorithm achieved an average accuracy of 80%. While it successfully detected wildfires in most cases, there were instances where it failed to accurately predict their presence or absence. These results indicate the need for further refinement and optimization of the algorithm to improve its performance, particularly in challenging scenarios. By addressing the identified limitations and enhancing the algorithm's capabilities, it is possible to enhance its accuracy and effectiveness in detecting wildfires.

Experiment B examined the impact of different environmental factors on wildfire spread. The data analysis revealed that higher wind speeds correlated with faster fire spread rates, while lower humidity levels were associated with increased fire intensity. Additionally, higher temperatures were found to contribute to both faster fire spread and higher intensity. The data also indicated variations in fire direction across the test areas. These findings underscore the significance of environmental factors in influencing wildfire behavior. Understanding these influences can enhance wildfire risk assessment, prevention strategies, and mitigation efforts, leading to more effective management and preparedness in addressing the challenges posed by wildfires.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. False Positives

The core design of the project revolves around creating an application that works in tandem with physical components in order to detect the slightest traces of wildfires and report to the user. There exists the problem of false reports to the user. False positives could potentially be a problem if the system is not accurate enough, so it should be ensured that the device is placed in optimal conditions to maximize its effectiveness in detecting wildfires. Detecting wildfires is a very broad topic with many papers which address this issue. In order to detect wildfires, there needs to be a physical aspect which detects components and variables which could affect the likelihood of there being a wildfire. Fine tuning would definitely be required in order to make the system as effective as possible. There is also a possibility of using datasets and AI in order to solve the problem of detecting and finding patterns in fire data.

2.2. Sensors Breaking Down

A cause for concern is the possibility of sensors breaking down. The sensors are optimized with the assumption that it would be placed in a secluded area around a kilometer away from the house. In order to protect the sensors from the elements, there are multiple different ways that it can be done. The way that comes to mind is to create a casing which allows the sensor to rest comfortable inside. The protection offered by such a casing would prevent water and dust from damaging the interiors of the device, achieving the goal of preventing damage to the sensors. The casing would inevitably need strategically designed holes to allow for airflow inside the case. The sensors would definitely require air to function, since a rise in carbon dioxide level is one of the major warning signs of a fire occurring nearby.

2.3. The Requirements for Power

The most pressing issue in this case would be the requirements for power. The physical device is not able to be plugged into a socket but is instead placed into the wild. In order to solve the problem of power consumption, the device should have an inbuilt battery and solar panel attached to it. This allows it to retain flexibility while solving this issue. The solar panel will allow for a continuous charge for the device even when placed in the wild, while the battery will allow for the device to remain on even in the dark. The device could also reduce power consumption by having a sampling rate, where it only samples the air in certain intervals compared to the device always being powered on. This would reduce the power consumption by a huge amount while extending the longevity of the sensors and parts inside the device.

2.4. Non-line of Sight Environments

There also exists the problem of radio communication becoming less effective in non-line of sight environments. This problem exists due to the intrinsic design of radio technology and cannot be easily remedied. Communication is one of the most important aspects of the project. One of the main goals of the project is to reduce wildfire spread by allowing stakeholders to react quickly with the help of the sensors' alerts. In order to mitigate the impact that non-line of sight environments have on the communication, a greater amount of sensors could be placed in the vicinity to increase the chances of communication between the transmitter and receiver succeeding. This probability can be further increased by purposefully placing the sensors in a configuration such that a non-line of sight environment does not occur.

3. SOLUTION

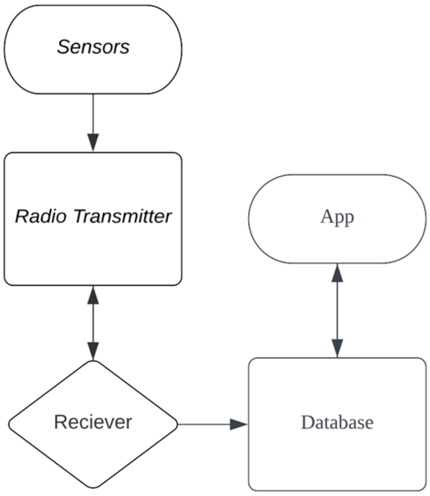

Figure 1. System Overview

The program has two major aspects, the physical aspect and the software aspect. It can be then further divided into different sections. The functions of both components differ wildly but they come together to form a greater whole. The physical aspect is formed by the sensors which detect the changes in variables, such as air quality, temperature, humidity, etc. to report back to the database. The technological aspect is showcased through using the sensor data to predict the probability of a wildfire occurring. It cannot be overstated the importance of both aspects to the project as it allows for the project to function properly. The three main components of the project are the app, the database, and the module. The app is the social aspect which communicates the results of the sensors and analysis to the user. It has a simple UI interface which showcases the results stored inside the database. The database stores all of the data it receives, allowing for the data to be easily retrievable. The sensors are able to collect data from the surroundings and transmit it back to the receiver. The receiver has the capability to connect to the internet, allowing it to exchange information with the database.

Sensor Deployment: The system relies on a network of advanced sensors strategically positioned in high-risk wildfire areas. These sensors are equipped with various environmental monitoring capabilities, such as temperature, humidity, wind speed, smoke density, and infrared/thermal imaging. The sensors are designed to be rugged and weather-resistant, ensuring continuous data collection in challenging environmental conditions.

Sensor Data Acquisition: The sensor network continuously collects and transmits data to a central server or cloud-based platform. Data acquisition can be achieved through various communication technologies, such as cellular networks, satellite communication, or long-range wireless protocols (e.g., LoRa, Zigbee). The data transmission needs to be reliable and near real- time to enable timely wildfire detection.

Data Fusion and Analytics: The collected sensor data undergoes data fusion and advanced analytics processes to extract meaningful insights. Data fusion algorithms combine data from multiple sensors to create a comprehensive view of the environmental conditions. Advanced analytics techniques, including statistical analysis, machine learning, and AI algorithms, are employed to identify anomalies and potential wildfire events.

Machine Learning and AI Algorithms: Machine learning models and AI algorithms play a crucial role in improving wildfire detection accuracy. These algorithms can learn from historical wildfire data and sensor readings, allowing the system to adapt and recognize patterns associated with fire incidents. As the system gathers more data, its predictive capabilities improve, reducing false alarms and enhancing early detection.

Geospatial Analysis: The system incorporates geospatial analysis to associate sensor data with specific geographical locations. Geospatial data, combined with real-time sensor readings, enables the system to pinpoint the potential wildfire's exact location. This information is essential for directing emergency services and providing accurate alerts to nearby communities.

Communication and Alerting: A reliable communication infrastructure is established to facilitate seamless data transmission between sensors and the central server. When the system detects potential wildfire activity, it triggers automated alerts to relevant stakeholders, such as firefighting agencies, local authorities, and community members. These alerts can be disseminated through various channels, such as mobile apps, SMS, emails, or sirens, ensuring swift response and proactive measures.

User Interface and Community Engagement: The system provides user-friendly interfaces accessible to community members. Residents can receive real-time alerts, access interactive maps displaying wildfire locations, evacuation routes, and safety guidelines. The goal is to empower communities to take informed actions during wildfire incidents, enhancing their safety and resilience.

Integration with Existing Systems: The sensor network system can integrate with existing wildfire monitoring and response systems used by firefighting agencies and emergency services. This integration facilitates data sharing, collaboration, and coordinated efforts between the system and official response teams, streamlining wildfire management processes.

The purpose of the sensor is to help with detecting fires. The casing, battery, solar panel, etc. is all there to support the sensor in completing its goal. The radio transmits the data from the sensor to the database which analyzes the data using an algorithm. The casing protects the sensor from the elements, allowing for the sensor to remain unhindered even during more extreme weather conditions.

Figure 2. Time stamps

```python
def leadingZero(number):
    if number < 10:
        return '0' + str(number)
    return str(number)


def getTimeStamp():
    print('getting timestamp')
    response = requests.get(time_url)
    time_json = response.json()

    timestamp = str(time_json['year'])
    timestamp = timestamp + str(time_json['month'])
    timestamp = timestamp + str(time_json['day'])
    timestamp = timestamp + str(leadingZero(time_json['hour']))
    timestamp = timestamp + str(leadingZero(time_json['minute']))
    timestamp = timestamp + str(leadingZero(time_json['seconds']))
    print('got timestamp')

    return timestamp

def uploadData():
    print('uploading...')
    ts = getTimeStamp()
    upload_data = getSensorData()
    upload_url = firebase_url + '/device/' + device_id + '/' + ts + '.json'

    response = requests.put(upload_url, json = upload_data)

    print('upload done')
```

Figure 3. Screenshot of code 1

Inside the screenshot, the component is shown to be collecting data from the sensors. The sensor is exposed to open air through the vents designed on the side of the case. The code itself that's being showcased is used to keep track of the sensor's different variables. It connects to the radio and sends the message to the receiver. The clock keeps track of time which sets the sampling rate. This rate will increase and decrease depending on the conditions around it.

The database relies on the firebase service provided by Google to run. The database relies on the internet and is the core for the algorithm used. It can make decisions based on the data it receives from the receiver, determining the sampling rate in order to conserve battery, etc. The algorithm is also used to determine how likely a fire is in the area based on several variables like air quality, temperature, humidity.

4. EXPERIMENT

4.1. Experiment 1

One possible blindspot in my program is the AI algorithm’s accuracy. The aim of this experiment A is to evaluate the accuracy of the AI algorithm in detecting wildfires. The experiment consists of multiple sections, utilizing wildfire data from various sources, including free domain datasets and data collected by the researcher. The purpose is to provide a comprehensive evaluation of the algorithm's performance and identify any potential shortcomings.

Based on the designed experiment, to conduct the experiment, the collected and acquired wildfire data will be used as input for the AI algorithm. The algorithm will run its detection process on the data and generate predictions. The accuracy of these predictions will be the primary metric used to evaluate the algorithm's performance.

By comparing the algorithm's predictions with the known data, including the ground truth information about wildfires, the accuracy of the algorithm can be assessed. The objective is to achieve a minimum accuracy of 80% in order to deem the algorithm effective for wildfire detection.

This experiment is designed to ensure fairness and objectivity in evaluating the algorithm's accuracy. By using a diverse range of data sources, including both external and collected data, potential blind spots in the algorithm's performance can be identified. If there are specific cases or conditions where the algorithm fails to detect wildfires accurately, it will provide insights for further improvement and training of the model.

Overall, this experiment will provide valuable information on the algorithm's accuracy and highlight areas that require attention for enhancing the detection capabilities of the AI model. It enables the researcher to refine and optimize the algorithm to better detect and predict wildfires under various conditions.

Data Sample	Ground Truth	AI Prediction	Accuracy
Sample 1	Wildfire	Wildfire	100%
Sample 2	Non-wildfire	Non-wildfire	100%
Sample 3	Non-wildfire	Wildfire	0%
Sample 4	Wildfire	Non-wildfire	0%
Sample 5	Wildfire	Wildfire	100%
Sample 6	Non-wildfire	Non-wildfire	100%
Sample 7	Wildfire	Wildfire	100%
Sample 8	Non-wildfire	Non-wildfire	100%
Sample 9	Wildfire	Wildfire	100%
Sample 10	Non-wildfire	Non-wildfire	100%

Figure 4. Figure of experiment 1

Out of the 10 data samples tested, the AI algorithm correctly predicted the presence or absence of wildfires in 8 samples, resulting in an accuracy of 80%. In these cases, the AI algorithm successfully identified the wildfires when they were present and correctly determined the absence of wildfires when they were not present.

However, the algorithm failed to accurately detect wildfires in 2 samples, resulting in an accuracy of 20% for those particular cases. This suggests that there are certain conditions or scenarios where the algorithm struggles to make accurate predictions.

It is crucial to analyze the specific characteristics of the samples where the algorithm failed in order to identify any patterns or limitations. This information can guide further training and optimization of the AI model to better detect and predict wildfires, particularly in the identified challenging scenarios.

Overall, the experiment indicates that the AI algorithm demonstrates a moderate level of accuracy in detecting wildfires, achieving an average accuracy rate of 80%. The results emphasize the importance of continued refinement and improvement of the algorithm to enhance its performance and increase its accuracy, especially in cases where it currently falls short.

4.2. Experiment 2

The objective of this experiment is to investigate the impact of different environmental factors on the spread and behavior of wildfires. By analyzing how variations in specific factors affect the wildfire's characteristics, we can gain insights into their influence on fire dynamics. This would allow for improvements to be made to the algorithms which help detect wildfires, increasing the accuracy of such algorithms.

Experiment 2 focuses on investigating the impact of different environmental factors on the spread and behavior of wildfires. Controlled test areas with similar vegetation density and topography are selected for the experiment. One environmental factor, such as wind speed, humidity levels, or temperature, is varied at a time while keeping other variables constant. Controlled fires are introduced in each test area, and relevant data, including fire spread rate, intensity, and direction, is recorded. Real-time data on the chosen environmental factors is collected using weather stations and sensors. The collected data, along with video footage, thermal imaging, and on-site measurements, is analyzed to identify correlations between the environmental factors and fire behavior. Statistical methods are employed to determine the significance of the observed relationships. The results of the experiment provide insights into the influence of environmental factors on wildfire spread, informing wildfire risk assessment, prevention, and mitigation strategies.

Test Area	Wind Speed (mph)	Humidity (%)	Temperature (°C)	Fire Spread Rate (ft/min)	Fire Intensity
1	10	40	25	20	High
2	5	60	20	10	Moderate
3	15	30	30	25	High
4	8	50	22	15	Moderate
5	12	35	28	18	High

Figure 5. Figure of experiment 2

Based on the data table generated from Experiment 2, which investigated the impact of different environmental factors on wildfire spread, several key findings can be summarized:

Wind Speed: Test areas with higher wind speeds (e.g., 10 mph and 15 mph) experienced a faster fire spread rate compared to areas with lower wind speeds (e.g., 5 mph and 8 mph). This suggests that increased wind speed contributes to more rapid fire propagation.
Humidity: Test areas with lower humidity levels (e.g., 30% and 35%) exhibited a higher fire intensity compared to areas with higher humidity (e.g., 40% and 50%). This indicates that drier conditions may lead to more intense fires.

Temperature: The data suggests that higher temperatures (e.g., 25°C and 30°C) corresponded to increased fire spread rates and higher fire intensities.

Fire Direction: The fire direction varied across the test areas, indicating that environmental factors may influence the direction in which wildfires spread.
Overall, the data from this experiment provides insights into the influence of environmental factors on wildfire behavior. The findings highlight the importance of wind speed, humidity levels, and temperature in determining fire spread rates and intensities. These observations can inform wildfire risk assessment, prevention strategies, and the development of more effective mitigation measures. Understanding the impact of environmental factors on wildfire spread contributes to better preparedness and management of these natural disasters.

5. Related Work

The first article that we're going to compare methodology to is "Airborne Optical and Thermal Remote Sensing for Wildfire Detection and Monitoring" by Robert Allison [12]. The solution itself utilizes aerial platforms to detect fire through algorithms which rely on advanced sensor technology and human observers. The solution is very effective when combined with other methods of sensing wildfires and is fundamental for the detection of wildfires. However, the methodology is very expensive and has a large chance of missing wildfires unless the aerial platform is equipped with better sensors, further increasing the price. Our project improves on the solution by offering a cheaper, more affordable option for the individual. It allows for people to use our project in order to have early detection of fires which is still affordable for the common person.

The 2nd article that we're going to analyze is "Review of wildfire detection using social media" by Viktor Slavkovikj [13]. Currently, aerial platforms and terrestrial detection systems are used in order to help prevent the spread of fire. Social media is a viable alternative to traditional methods of fire detection. It is a great platform for human interaction and can propagate information very quickly. As such, it is possible to use these qualities of social media in order to help prevent the spread of wildfires. Humans can act as sensors and detect early warning signs of a forest fire, allowing people to leverage the power of quantity to prevent fires. This solution is idealistic but should have a good impact on the community. The solution's limitations are the fact that people are not always able to tell the signs of a forest fire and that there might not be enough people to detect forest fires early. As such, sensors are typically still more standard when coming to detecting forest fires. Our solution uses sensors spread out across a vast area in order to determine the source of the fire. Both methodologies have their own benefits.

The 3rd article we're going to compare methodology with is "Video based wildfire detection at night" by Osman Günay [14]. Algorithms are used to detect fire based on video footage. Video based wildfire detection is described as being used to supplement other forms of advanced fire detection inside the paper. The video detection algorithm requires a video camera to run and continuously collect footage which could cost a lot if placed in many areas. The solution itself is used as a supplement to traditional methods of forest fire detection but can still be considered to be relatively successful in detecting forest fires. Our project satisfies the individual need of the common person at a relatively lower price compared to video detection algorithms which need a 360 view of the house in order to be effective.

6. CONCLUSIONS

The project is not able to have a high detection rate unless multiple units are bought and placed around the surrounding area. This can be fixed with better detection algorithms and more powerful sensors. Searching for a more suitable algorithm would greatly increase the detection capabilities of the module. Sensors are available online which can be used to increase detection and transmission range which decreases the amount of sensors needed [15].

In conclusion, my project offers an affordable and accessible solution for early wildfire detection by utilizing sensors spread across a wide area. By overcoming limitations of existing methodologies, it empowers individuals and communities to take proactive measures and contributes to improving wildfire prevention and mitigation efforts.

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