SFT VOL. 63 ISSUE 1, 2024, PP. 34–43

Dawid Jurczyński[a)*], Paweł Buchwald[a)]

[a)] *WSB University in Dąbrowa Górnicza / Akademia WSB w Dąbrowie Górniczej*
[*] *Corresponding author / Autor korespondencyjny: dawid.jurczynski2@wsb.edu.pl*

Mechanisms for Data Acquisition to Train Artificial Intelligence Models for Detecting Increased Susceptibility to Fire Situations by Using Internet of Things Devices and Satellite Systems

Mechanizmy akwizycji danych dla celów uczenia maszynowego modeli detekcji wzrostu zagrożenia pożarowego z zastosowaniem urządzeń internetu rzeczy i systemów satelitarnych

ABSTRACT

Purpose: Exploration and developing mechanisms of advanced data acquisition necessary for training an artificial intelligence model capable of effectively detecting areas with increased susceptibility to fire situations. The study focuses on utilizing data from satellite missions and ground-based sensors, which provide both high-resolution imagery and precise data on temperature, humidity, and other environmental factors. By analysing these diverse data sources, the research aims to create a comprehensive and efficient model capable of early detection of potential fire hazards, which is crucial for prevention for fire-prone situations.

Project and methods: It centres on a project that aims to enhance fire detection and management through the integration of artificial intelligence with data acquired from satellite systems and internet of things devices. The methodologies employed in this project involve a combination of advanced data acquisition, machine learning techniques, and the synthesis of diverse environmental data to train artificial intelligence models that can predict and detect fire incidents more effectively.

Results: Significant advancements in fire detection and management have been demonstrated through the integration of artificial intelligence (AI) with satellite data and IoT:

1. Enhanced monitoring capabilities the use of satellite data systems enabled real-time monitoring of thermal anomalies and vegetation health, crucial for early detection and effective monitoring of wildfires. This real-time capability allowed for quicker responses and more informed decision-making in firefighting efforts.
2. Effective integration of data sources: the integration of satellite and surface data proved to be effective in enhancing the predictive capabilities of the fire management systems. This comprehensive approach allowed for a better understanding of fire dynamics and contributed to more accurate and timely predictions.

Conclusions: It could be emphasize the significant benefits and future potential of integrating artificial intelligence with satellite and internet of things data for improving fire detection and management. The integration of satellite imagery and internet of things sensor data is essential for enhancing the predictive accuracy of artificial intelligence systems. This integration allows for a comprehensive assessment of fire risks, providing actionable intelligence that is critical for prevention for fire-prone situations. These conclusions underscore the transformative potential of artificial intelligence in enhancing fire management systems.

Keywords: data acquisition, artificial intelligence, IoT, satellite data systems, fire management systems
Type of article: original scientific article

Received: 26.04.2024; Reviewed: 14.06.2024; Accepted: 01.07.2024;
Authors` ORCID IDs: D. Jurczyński – 0009-0005-7362-9779; P. Buchwald – 0000-0003-2537-7085;
The authors contributed the equally to this article;
Please cite as: SFT Vol. 63 Issue 1, 2024, pp. 34–43, https://doi.org/10.12845/sft.63.1.2024.3;

ABSTRAKT

Cel: Artykuł poświęcony jest zagadnieniu badań i rozwoju zaawansowanych mechanizmów pozyskiwania danych niezbędnych do szkolenia modelu sztucznej inteligencji zdolnego do efektywnego wykrywania obszarów o zwiększonej podatności na sytuacje pożarowe. W pracy skupiono się na wykorzystaniu danych z misji satelitarnych oraz czujników naziemnych, które dostarczają zarówno obrazów o wysokiej rozdzielczości, jak i precyzyjnych danych dotyczących temperatury, wilgotności oraz innych czynników środowiskowych. Poprzez analizę tych różnorodnych źródeł danych, badanie ma

na celu stworzenie kompleksowego i efektywnego modelu zdolnego do wczesnego wykrywania potencjalnych zagrożeń pożarowych, co jest kluczowe w zapobieganiu klęskom żywiołowym i minimalizowaniu ich skutków.
Projekt i metody: Metodologie zastosowane w tym projekcie obejmują połączenie zaawansowanego pozyskiwania danych, technik uczenia maszynowego oraz syntezę różnorodnych danych środowiskowych do szkolenia modeli AI, tak aby mogły przewidywać i wykrywać incydenty pożarowe bardziej efektywnie.
Wyniki: Wykazano wyraźny postęp w wykrywaniu pożarów i zarządzaniu nimi dzięki zastosowaniu integracji sztucznej inteligencji (AI) z danymi satelitarnymi i internetu rzeczy (IoT):

1. Rozszerzone możliwości monitorowania: Wykorzystanie systemów danych satelitarnych umożliwiło monitoring w czasie rzeczywistym anomalii termicznych oraz stanu zdrowotnego roślinności, istotnych z perspektywy wczesnego wykrywania i skutecznego monitorowania pożarów. Ta zdolność pozwoliła na szybsze reakcje i bardziej świadome podejmowanie decyzji w działaniach przeciwpożarowych.
2. Skuteczna integracja źródeł danych: Integracja danych satelitarnych i naziemnych okazała się skuteczna w zwiększaniu zdolności predykcyjnych systemów zarządzania pożarami. To kompleksowe podejście pozwoliło na lepsze zrozumienie dynamiki pożarów i przyczyniło się do dokładniejszych i bardziej aktualnych prognoz.

Wnioski: Można podkreślić znaczące korzyści i przyszły potencjał integracji sztucznej inteligencji (AI) z danymi satelitarnymi i IoT w celu poprawy wykrywania pożarów. Połączenie obrazowania satelitarnego i danych z czujników IoT jest niezbędne do zwiększenia dokładności predykcyjnej systemów AI. Ta integracja umożliwia kompleksową ocenę ryzyka pożarowego poprzez dostarczanie informacji istotnych dla prewencyjnych strategii zarządzania pożarami. Powyższe wnioski świadczą o transformacyjnym potencjale AI w poprawie systemów zarządzania pożarami.
Słowa kluczowe: internet rzeczy, systemy satelitarne, systemy prewencji przeciwpożarowej, sztuczna inteligencja
Typ artykułu: oryginalny artykuł naukowy

Przyjęty: 26.04.2024; Zrecenzowany: 14.06.2024; Zaakceptowany: 01.07.2024;
Identyfikatory ORCID autorów: D. Jurczyński – 0009-0005-7362-9779; P. Buchwald – 0000-0003-2537-7085;
Autorzy wnieśli równy wkład merytoryczny w powstanie artykułu;
Proszę cytować: SFT Vol. 63 Issue 1, 2024, pp. 34–43, https://doi.org/10.12845/sft.63.1.2024.3;

Introduction

Fire incidents, particularly those resulting from uncontrolled and spontaneous combustion of combustible materials in unintended locations and times, pose a significant threat to life and property. Traditional fire detection systems, while essential, often rely on the direct detection of smoke, heat, or flames. These systems can be limited by their reactive nature, responding only after a fire has already started, which sometimes leads to critical delays especially in large, complex environments like industrial areas or forests. The integration of artificial intelligence (AI) into fire detection processes presents a transformative approach to overcoming these limitations. AI technologies offer the potential not only to detect but also to predict fire incidents before they escalate by analysing vast and varied data sources that traditional systems might not effectively utilize. This predictive capability could dramatically reduce the risk and impact of fires, making early interventions possible and potentially saving lives and resources. This chapter aims to delve into the applications for fire detection, with an emphasis on both satellite and surface data acquisition architectures that are crucial for training AI models. This includes examining different types of data inputs, from satellite imagery and internet of things (IoT) sensors, and how these data can be synthesized into actionable intelligence. By integrating AI into fire detection and management systems, there is a unique opportunity to enhance the efficiency and effectiveness of responses to fire emergencies.

The escalating frequency and severity of wildfires globally underscore the necessity of advanced surveillance and environmental monitoring systems to preemptively identify fire risks. This proactive approach is essential not only for safeguarding biodiversity and maintaining ecological balances but also for protecting human communities from catastrophic losses. Wildfires, exacerbated by climate change and human land use, have resulted in significant ecological and economic damages worldwide. Effective monitoring, involving the use of satellite data like those from the MODIS and VIIRS systems, provides invaluable real-time insights into wildfire dynamics, enhancing both the preparedness and responsiveness of firefighting efforts [1, 2].

The aim of this research paper is to explore and develop mechanisms of advanced data acquisition necessary for training an artificial intelligence model capable of effectively detecting areas with increased susceptibility to fire situations. The study will focus on utilizing data from satellite missions and ground-based sensors, which provide both high-resolution imagery and precise data on temperature, humidity, and other environmental factors. Analysing these diverse data sources will allow for the creation of a comprehensive and efficient model capable of early detection of potential fire hazards, which is crucial for preventing natural disasters and minimizing their effects. Integrating these two types of data will not only ensure greater accuracy in detection but also enhance understanding of fire dynamics, essential for optimizing intervention and prevention strategies.

Satellite-based systems such as MODIS (Moderate Resolution Imaging Spectroradiometer) and VIIRS (Visible Infrared Imaging Radiometer Suite) are pivotal for detecting and monitoring wildfires. These systems are capable of identifying thermal anomalies from orbit, providing data crucial for the early detection of uncontrolled fires [3]. Moreover, continuous monitoring can track changes in vegetation health over time, offering predictions about potential fire outbreaks based on observed environmental conditions. Thus, integrating these technologies into national and international fire management strategies is vital for enhancing response strategies and mitigating the impacts of wildfires.

Example model that can be used for estimating the possibility of a fire

The model that was used in previous study [4] integrates environmental factors recorded by the Copernicus program's Sentinel satellites, focusing on the territory of Poland. This approach highlights the potential of satellite technology combined with machine learning algorithms in enhancing fire risk assessments and preventive measures. The data used in this study was sourced from the Sentinel missions under the Copernicus program, specifically from Sentinel-1, Sentinel-2, Sentinel-3, and Sentinel-5P satellites. Data was collected in DataFrame objects, which allows for smooth integration with the MySQL database and the possibility of extending with additional elements. Data preparation involved acquiring daily measurements from these satellites, normalizing the data, and structuring it into a format suitable for machine learning analysis. The geographic area of interest was segmented into 10-kilometer squares across Poland, with each segment being analysed for its unique environmental conditions. Each model was evaluated based on its precision, recall, and the Cohen Kappa Score, which measures the agreement between the predicted and actual classifications. The models were trained on a subset of data and tested on unseen data to assess their generalizability. The models discussed in this chapter demonstrate considerable potential in identifying areas at high risk of fire, thereby enabling timely preventive measures. The aim is to broaden the model's predictive capabilities and adaptability. Enhancing the AI model for fire risk prediction requires a multi-faceted approach that includes expanding the data sources, employing more sophisticated machine learning techniques, and continuously refining the model based on new insights and feedback. These improvements could significantly advance the capabilities of fire risk prediction models, making them more accurate, reliable, and applicable to various geographical and environmental conditions.

Satellite monitoring of wildfires: tools and technologies

The increasing frequency and intensity of wildfires worldwide necessitate advanced monitoring techniques that can provide accurate, real-time data to firefighting and disaster management teams. Satellite technology has become a cornerstone in the observation and analysis of wildfire dynamics, offering invaluable tools for detection, monitoring, and post-fire assessment. This chapter delves into the various satellite instruments and systems currently employed to study wildfires, outlining their capabilities, applications, and the data they provide.

The MODIS (Moderate Resolution Imaging Spectroradiometer) Thermal Anomalies / Fire products derive from the 4-micrometer and 11-micrometer radiance measurements captured by the MODIS sensors. The methodology for detecting fires relies on both absolute measures (identifying fires based solely on their thermal signatures) and relative measures (which consider the variation in ground temperatures and sunlight reflection). This approach ensures accurate identification of fire occurrences, which are tracked both day and night, pinpointing their specific locations. The product offers detailed insights, including the criteria for fire detection, confidence levels in detection, and Fire Radiative Power. Additionally, it provides various descriptors for fire-affected pixels and differentiates between active fires, absence of fire, and areas where observation is not possible. The Level-3 Daily fire products consolidate eight days of data, categorizing pixels by their detection confidence levels. This wealth of information supports the monitoring of fire distribution across diverse ecosystems over time, the detection of shifts in fire patterns, the emergence of new fire zones, wildfires, and variations in fire frequency or intensity. Data from MODIS, collected twice daily from the Terra and Aqua satellites at mid-latitudes, results in four daily observations. These observations are crucial for both operational fire management and broader studies on fire behaviour, its impact on ecosystems, atmospheric conditions, and climate change. MODIS sensors on the Terra and Aqua satellites play a pivotal role in global fire monitoring and environmental management. These sensors are instrumental in detecting thermal anomalies and actively tracking wildfires, providing essential data for fire hazard prediction and management. Studies such as those by C. Maffei et al. (2014) highlight the utility of MODIS in analysing land surface temperatures to predict fire hazards, demonstrating its critical role in enhancing our understanding and response capabilities regarding wildfire occurrences [5]. Furthermore, E. Chuvieco et al. (2018) expanded on this by generating a new global burned area product that integrates MODIS reflectance bands and thermal anomalies, illustrating the advancements in burned area assessment and mapping [6]. Additionally, the comparative analysis by P.H. Freeborn et al. (2014) between MODIS and SEVIRI fire detection algorithms underscores MODIS's reliability in diverse geographical settings like the Central African Republic, showcasing its effectiveness in operational fire management [7]. Moreover, the research by C. Maffei and colleagues in 2018 provides insights into the relationship between diurnal land surface temperature anomalies from MODIS and forest fire patterns, further proving the sensor's utility in environmental monitoring and disaster preparedness [8].

The Visible Infrared Imaging Radiometer Suite (VIIRS), an advanced sensor on board the Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites, has significantly enhanced our ability to monitor and analyse environmental phenomena, especially wildfires. VIIRS offers superior fire detection capabilities due to its high-resolution imaging and rapid acquisition of data, which allows for detailed assessments of fire dynamics and its extent. The instrument's design includes a day-night band that captures low-light imagery, providing invaluable information during nocturnal hours — a critical advantage for continuous fire monitoring. Researchers like W. Schroeder et al. (2014)

have demonstrated VIIRS's efficacy in detecting smaller, cooler fires that previous instruments might miss, showcasing its superior sensitivity and broader detection range [9]. Additionally, its applications extend beyond fire detection; VIIRS data have been pivotal in air quality monitoring by tracking smoke dispersion and analysing its impact on atmospheric conditions [10]. This capability is crucial for public health and safety, as it aids in the rapid dissemination of air quality information during fire events. As wildfires grow more frequent and intense due to climate change, tools like VIIRS are essential for providing accurate, timely data to inform response strategies and mitigate the impact of fires on ecosystems and communities.

The Geostationary Operational Environmental Satellites (GOES) and Meteosat series have revolutionized the area of environmental monitoring through continuous observation from a fixed orbit, providing real-time data essential for weather forecasting, climate monitoring, and natural disaster management, including wildfires. These satellites offer unique capabilities due to their geostationary positions, which allow them to monitor atmospheric conditions continuously over specific geographic regions. This continuous monitoring is crucial for detecting and tracking rapid environmental changes, such as the development of thunderstorms or the spread of wildfire smoke. According to studies by A.W. Setzer and M.C. Pereira (2013), GOES and Meteosat have been instrumental in enhancing our understanding and response strategies towards dynamic wildfire events, providing data that supports the deployment of firefighting resources with greater precision and timeliness [11]. Moreover, the high temporal resolution of these satellites enables the detailed observation of diurnal cycles of cloud formation and air temperature, which are critical for accurate weather predictions and studying climate phenomena [12]. The integration of data from GOES and Meteosat into weather prediction models has significantly improved the accuracy of weather forecasts, which is vital for preparing and mitigating against potential natural disasters, including floods and hurricanes [13].

The Advanced Very High Resolution Radiometer (AVHRR) on board of NOAA satellites has been a cornerstone in earth observation and environmental monitoring since its first deployment. AVHRR sensors provide comprehensive coverage with their ability to capture data in visible, near-infrared, and thermal infrared bands, facilitating a wide range of applications from weather forecasting to vegetation and ocean studies. In the context of wildfire management, AVHRR's capabilities are particularly valuable. It offers critical data for the detection and analysis of thermal anomalies associated with wildfires, enabling early detection and continuous monitoring of such events. The sensor's broad spatial coverage and frequent revisits over the same area allow for effective tracking of fire progression and post-fire assessments. Studies by K.B. Kidwell (1991) and Y.J. Kaufman and C.O. Justice (1998) highlight AVHRR's pivotal role in developing algorithms of fire detection and enhancing our understanding of fire dynamics on a global scale [14, 15]. Furthermore, AVHRR data has been integral in studying land surface phenology, aiding in the prediction of fire-prone areas by analysing vegetation health and moisture levels, crucial for assessing fire risks [16].

The Landsat program, initiated in 1972, has been pivotal in providing continuous satellite imagery, crucial for environmental monitoring, agricultural planning, and disaster management, including wildfire assessment. The multi-decadal dataset from Landsat offers unparalleled insights into the changes in land use and vegetation cover over time, facilitating long-term ecological monitoring and helping identify areas at increased risk of wildfires due to changes in land cover and climatic conditions. Studies by D.P. Roy et al. (2005) demonstrate the utility of Landsat data in tracking the recovery of ecosystems post-fire, providing essential information for land management and rehabilitation efforts [17]. Furthermore, the fine spatial resolution of Landsat images allows for detailed assessments of burn severity and the precise delineation of fire perimeters, aiding in the accurate estimation of fire-affected areas, as highlighted in 2007 by J.D. Miller and A.E. Thode [18].

The Sentinel satellites, part of the European Union's Copernicus program, represent a revolutionary advancement in earth observation, providing high-resolution optical, radar, and atmospheric monitoring data. These satellites are instrumental in real-time environmental and disaster scenarios, particularly in fire detection and monitoring. The Sentinel-2 mission, with its high-resolution multispectral imager, captures wider swaths of land more frequently, enabling timely updates on fire spread and intensity. The availability of these data supports critical fire management activities, including the deployment of firefighting resources and the planning of evacuation routes. Sentinel-3 further complements this by offering products that monitor the thermal state of the earth's surface and the distribution of smoke plumes from fires, essential for assessing air quality and health impacts as discussed in studies in 2015 by A.P.S. Pacheco et al. [19].

Data acquisition for the artificial intelligence model

In the design and implementation of an artificial intelligence model, adding the right features is a crucial element that significantly impacts the model's effectiveness and accuracy. Adding relevant features can enhance the model's understanding of the data it processes and improve its predictive or classification capabilities. Key reasons for incorporating new features include increasing model accuracy, as well-fitted features can reveal important patterns that enhance prediction outcomes. Additionally, incorporating new features can help avoid overfitting by balancing the model and enabling it to perform better on unseen data. Introducing new features also leads to a deeper understanding of data characteristics, uncovering previously unnoticed correlations that are essential for the model's tasks. In dynamic environments where data and conditions can change, regularly reviewing and updating the feature set is crucial for the model to adapt to new trends and maintain its relevance and effectiveness. Furthermore, in cases where the model is used for the needs of individual users or specific market segments, adding targeted features can significantly improve its efficiency by addressing unique needs and preferences. Therefore, the process of adding new features to an AI model should be considered an integral part of model development, requiring continuous analysis and optimization to create more comprehensive, adaptive, and effective AI solutions.

For monitoring wildfires using MODIS (Moderate Resolution Imaging Spectroradiometer) data in machine learning models, several MODIS products can be particularly useful. Here are the most relevant ones:

- MOD14/MYD14 – Thermal Anomalies / Fire products: these are the primary MODIS products for detecting active fires and thermal anomalies. They provide daily global coverage at 1 km resolution. The thermal anomalies are indicative of fires and other high-temperature events;
- MCD64A1 – Burned Area Product: this product maps the locations of burned areas after a fire has occurred, using a monthly composite of surface reflectance from both the Terra and Aqua satellites. It provides essential data for assessing the extent and damage of fires;
- MOD13/MYD13 – vegetation Indices (NDVI/EVI): these products provide measures of vegetation health by calculating the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) from MODIS reflectance data. They help in assessing the fuel availability for fires and monitoring vegetation recovery post-fire;
- MODIS Atmosphere Products (MOD04/MYD04 – Aerosol Products): these include data on aerosols which can be useful for understanding air quality impacts due to smoke from wildfires.

The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument, provides several products that are highly useful for wildfire monitoring and can be integrated into machine learning models to enhance fire detection, monitoring, and analysis. Here are some of the key VIIRS products that are particularly valuable for this purpose:

- VIIRS Active Fire Product (VNP14IMGTDL_NRT and VJ114IMGTDL_NRT): this product detects thermal anomalies such as fires using the VIIRS 375 m resolution data. The product provides near-real-time data, which is crucial for timely fire detection and for deploying emergency response services effectively. It identifies the locations of active fires within the pixel, provides the intensity of the fire, and can differentiate between flaming and smouldering fire stages.
- VIIRS Burned Area Product (VNP64A1): similar to the MODIS burned area product, the VIIRS burned area product provides monthly global data on the locations where fires have burned. This information is essential for assessing the extent of damage caused by wildfires, managing recovery efforts, and planning mitigation strategies to prevent future fires.
- VIIRS 375 m Active Fire Day/Night Band (DNB): the DNB provides data that can detect and characterize the brightness of the fires. It is useful for night-time fire detection and can provide details on the spread and intensity of fires under low-light conditions.
- VIIRS Atmosphere Products: these include aerosol and other atmospheric data which can be crucial for understanding the air quality impacts of smoke from wildfires. Products such as the VIIRS Aerosol Optical Depth (AOD) provide information about particulates in the air, which can be useful for health advisories and air quality management during and after wildfire incidents.

For wildfire monitoring using machine learning models, data from Geostationary Operational Environmental Satellites (GOES) and Meteosat can be extremely useful. Both satellite systems offer products that are well-suited for real-time monitoring and analysis of wildfires. Here are some of the key products from each system:

- GOES Fire Detection and Characterization Algorithm (FDCA): this product provides high-resolution, near-real-time detection of hot spots associated with fires. The FDCA product uses data from the Advanced Baseline Imager (ABI) on GOES to detect thermal anomalies, providing crucial information on the location and intensity of wildfires. It offers rapid update cycles (as frequent as every 5 minutes), which is essential for monitoring fast-changing fire conditions;
- GOES Aerosol/Smoke Product (GASP): this product offers data on aerosol concentrations, including smoke from wildfires, in the atmosphere. It helps in tracking the dispersion of smoke, which is critical for assessing air quality impacts and issuing health advisories;
- GOES-R Series ABI Products: the ABI sensor provides high spatial and temporal resolution imagery that is ideal for observing and analysing the environmental conditions surrounding wildfires. The imagery can be used to monitor weather conditions that may influence fire behaviour, such as wind patterns and humidity;
- Meteosat SEVIRI Fire Radiative Power (FRP) Products: these products provide valuable data on the radiative power of fires, which can be used to estimate the heat output of wildfires. This information is crucial for understanding the intensity and potential spread of fires;
- Meteosat Natural Colour RGB: this composite product uses data from multiple spectral bands to create imagery that can help in the visualization of smoke and ash plumes from wildfires, aiding in both monitoring and management efforts;
- High Rate SEVIRI (HRS) Data: HRS provides frequent updates (every 5 to 15 minutes), allowing for the monitoring of wildfires in near-real-time. This is particularly useful for tracking the development and movement of fires throughout the day.

The Advanced Very High Resolution Radiometer (AVHRR) on NOAA satellites provides valuable data that can be effectively integrated into machine learning models for wildfire monitoring. AVHRR has been a crucial tool in earth observation for decades, offering a wealth of data that helps in tracking various environmental phenomena, including wildfires. Here are some of the key aspects and products derived from AVHRR data that are particularly useful for wildfire applications:

- AVHRR Thermal Anomalies and Fire Products: these products provide critical information on active fires by

detecting hot spots and thermal anomalies with AVHRR's infrared and thermal sensors. The data is useful for identifying areas where fires are active, providing crucial inputs for real-time monitoring and decision-making in wildfire management;
- AVHRR Global Vegetation Index (GVI): this index is derived from AVHRR data and is used to monitor vegetation health and stress. For wildfire monitoring, the GVI can help predict areas at high risk of fire by indicating regions with dry or stressed vegetation, which are more susceptible to burning;
- AVHRR Local Area Coverage (LAC) and Global Area Coverage (GAC): these data products offer detailed imagery with a resolution high enough to observe and analyse land surface characteristics relevant to fire behaviour; LAC provides high-resolution data (1 km at nadir) that is particularly useful for detailed analysis of fire-affected areas, while GAC offers broader coverage (4 km at nadir) useful for monitoring larger regions;
- Surface Reflectance Products: these products provide information about the reflectivity of the Earth's surface, which is crucial for assessing the extent of burned areas and for monitoring post-fire recovery. Changes in surface reflectance before and after a fire can provide insights into the severity and impact of fires on vegetation cover.

For wildfire monitoring and analysis, data from Landsat and Sentinel satellites offer unique advantages, especially when integrated into machine learning models. Both satellite programs provide high-resolution imagery that is crucial for detailed assessments of land cover, vegetation health, and the extent of fire damage:
- Landsat Thermal Data: Landsat satellites, particularly the Landsat 7 and Landsat 8, carry sensors that capture thermal imagery, which can be used to detect hotspots and ongoing fire activities. This thermal data is essential for identifying active fires and for mapping the areas that are still burning;
- Normalized Difference Vegetation Index (NDVI) from Landsat: this index, derived from Landsat imagery, indicates the health and density of vegetation. Areas with low NDVI values might be more susceptible to wildfires, and changes in NDVI over time can help assess the damage caused by fires and monitor recovery;
- Landsat Burned Area Products: these products provide information about the location and extent of burned areas. The high spatial resolution of Landsat data (30 meters for most bands) allows for precise mapping of fire-affected regions, crucial for damage assessment and recovery planning;
- Sentinel-2 Multispectral Imagery: Sentinel-2 provides high-resolution optical imagery that is highly effective for monitoring land cover changes due to wildfires. The 10-meter resolution in some bands is particularly valuable for detailed assessments of vegetation health before and after fires;
- Sentinel-1 SAR Data: the Synthetic Aperture Radar (SAR) data from Sentinel-1 can penetrate smoke and cloud cover, providing reliable imaging regardless of weather conditions. This capability is crucial for ongoing monitoring of wildfires, especially under conditions where optical sensors might be hindered;
- Sentinel-3 Land Surface Temperature and Fire Radiative Power Products: Sentinel-3 offers products that measure the thermal conditions of the Earth's surface and the radiative power of fires, respectively. These products are useful for understanding the intensity of ongoing fires and for post-fire effects analysis.

Integrating data from Landsat and Sentinel into machine learning models can significantly enhance wildfire detection, monitoring, and management capabilities. The combination of thermal, optical, and radar data provides a comprehensive toolkit for analysing fire dynamics, assessing the impact on vegetation and infrastructure, and aiding in the recovery and planning processes. Machine learning models can leverage these diverse datasets to predict fire behaviour, assess risks, and provide timely information for firefighting and land management efforts. The high temporal and spatial resolution of these satellite systems makes them invaluable resources for environmental monitoring and disaster response.

Architecture of a ground measurement system based on internet of things devices

The reduced resolution of measurement information developed on the basis of satellite data and the lower frequency of measurements compared to the capabilities of the terrestrial infrastructure resulted in additional measurement information for model training also being obtained from other sources. The dynamic growth of wireless networks and modern data transmission techniques used in internet of things systems has made the construction of terrestrial measurement networks for monitoring environmental conditions more and more common.

The architecture of the measurement data acquisition system can be designed based on components existing on the market, such as expandable meteorological stations, Gateway devices, and data acquisition components used in the implementation of network protocols for measurement networks. In this type of measurement systems architecture, one can distinguish interrelated components, which are shown in Figure 1. Data collected using such a system can be flexibly adapted to the needs of predictive algorithms based on machine learning.

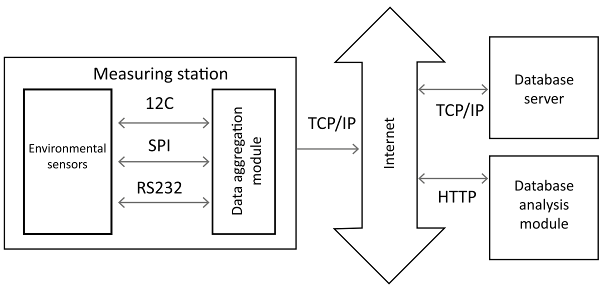

Figure 1. Architecture of a measurement system for detecting local environmental conditions

Source: Own elaboration.

The architecture concept of the proposed system allows for flexible adjustment of the set of sensors to measure environmental conditions and other conditions helpful in predicting the increased risk of fire hazard. The data exchange scenario between the components of the measurement system is as follows:

- the measurement system periodically reads data from sensors and simultaneously archives the data in the local database of the Raspberry Pi device;
- the measuring station sends archived data to the meteorological server with a time interval of 15 minutes. If there is no Internet connection, unsent measurement data will be transmitted on the next attempt;
- the weather server responds to requests from client devices. The services provided by the server have implemented authentication and authorization methods that allow for securing access to data by unauthorized persons;
- client stations download measurement data in two stages. In the first stage, an HTTP GET request is sent, which allows you to download the list of available stations. Then, the station sends a GET request to the server with identification parameters for a given measurement point and data about the time period from which measurement data should be sent. Data is transferred using JSON notation.

Based on the presented architectural concept, it is possible to build a flexible network of measuring devices that allows for monitoring a large area to detect an increased fire risk. The used methods of measurement data transmission enable the selection of appropriate measurement devices in terms of energy efficiency and meet the requirements of compatibility with data integration methods commonly used on the Internet, and IoT networks [20]. This is important due to the needs of the designed system, which is intended to provide unified access to environmental data obtained both on the basis of data from the satellite and data from the network of terrestrial measurement sensors.

Measuring devices used to obtain data on environmental conditions

Modern meteorological and environmental research is based on solid data that enable the analysis of dynamic processes occurring in the environment. Measuring devices play a key role in obtaining information on various environmental conditions. Thanks to them, it is possible to monitor parameters such as temperature, humidity, atmospheric pressure, air pollution level, soil moisture, wind speed and direction, precipitation, sunlight level and many others. The chapter presents selected measuring devices used in environmental research. The devices taken into account are those that are flexible in terms of a wide selection of measurement parameters and enable data acquisition using commonly used communication interfaces with peripheral devices [21].

One device that meets these criteria is the Vantage Pro weather station from Davis. It is used successfully in many projects requiring accurate and continuous measurements of environmental parameters. This is an example of relatively cheap equipment with good measurement parameters. The station allows for the detection of meteorological parameters in real time, has good properties related to operational continuity and reliability parameters, and a well-developed service base – which is important due to the need to constantly maintain the operation of the system as a whole. The station models offered by the manufacturer include both basic and advanced devices with the possibility of expansion with a network of additional sensors. The basic software supplied with the device allows for integration of local measurement environment with other measurement sets. Data from selected points are made available via the Internet, but can also be read via the RS232 serial communication interface. Thanks to this, it is possible to use this device in the infrastructure of many IT systems. It is also important that the manufacturer uses an open communication protocol based on a text recording standard for data transmission, which allows for designing own programming solution and adapt the remaining components responsible for data acquisition. For this reason, numerous third-party extensions are being developed that are compatible with the Vantage Pro device, which increases its range of applications. The appearance of the Vantage Pro weather station is shown in Figure 2.

Figure 2. Vantage Pro weather station
Source: https://www.davisnet.com.

Figure 3. WatchDog measuring station
Source: https://www.specmeters.com.

Another device useful for obtaining local measurement data on environmental conditions is the set of WatchDog measurement stations (see Figure 3) from Spectrum Technologies Inc. This device is intended for agrometeorological applications. It allows the user to configure measurement sensors that can be used in the monitoring process. A big advantage is the ability to connect any sensor operating in a 4–20 mA current loop to the measurement system. The device allows the acquisition of measurement data from sensors to the main station via a wired micro network. The main data aggregation station is equipped with an RS232 interface, which allows data acquisition to processing modules in the form of a controller or a microcomputer. It is also possible to integrate the device with the manufacturer's data archiving and sharing architecture. The device enables communication with the GSM network using an additional expansion module. Together with the expansion module, the manufacturer also provides dedicated SIM cards that are associated with a private APN. This improves the security of network transmission. This solution allows for data acquisition with time intervals from 1 min to 60 min. The data is also buffered on the device side, which ensures that it can be read later in the event of a network failure. The data acquisition module has an automatic function that allows for storing measurements for a period of 183 days or sending them directly to a dedicated server. The manufacturer also includes software for data management and device configuration. Similar to the VantagePro station, the device uses an open text protocol to acquire measurement data, which allows it to be used with external systems and proprietary software. The WatchDog measuring station can be equipped with a set of external dedicated sensors, and even design your own dedicated measuring devices based on open communication methods used in the device. An example of sensors extending the station's measurement capabilities is shown in Figure 4.

Figure 4. Extended sensors for the WatchDog measuring station (rainfall sensor, air humidity sensor, humidity sensors)

Source: https://www.specmeters.com.

System for transmission measurements and data pre-processing

The original measurement system allowed for the expansion of the functionality of the measurement station with additional functionalities, including integration with server data processing mechanisms. The use of hardware platforms used in the implementation of internet of things solutions meant that the measuring station with expansion modules could be powered by solar panels. This makes it possible to run the device as a fully autonomous measurement system.

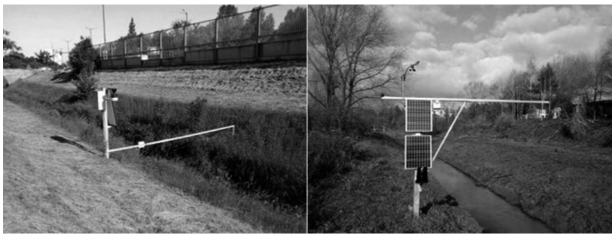

Figure 5. Original installation for the acquisition of local environmental data

Source: Own elaboration.

The operation of this system was tested over a 6-month period, including the winter months. Despite the weaker sunlight characteristic of the latitude of southern Poland, the operation of the station did not require additional power supply. Due to the need to integrate the measurement system with data storage modules via the Internet, it was also necessary to power the GSM modem. Effective methods of implementing measurement data acquisition also allowed GSM communication modules to be powered only from solar panels. The flexible architecture model of the measurement system also allowed the measurement system to be expanded with water level sensors. Additionally, the collected water level data may be useful in forecasting other threats, such as flooding. The appearance of the measuring stations with solar panels is shown in Figure 5. Photos of the installed stations with measuring modules were taken thanks to InfoMet Katowice.

Conclusions

Autonomous measurement systems offer increasing opportunities to collect data necessary to predict threats such as fires. To effectively train predictive models to recognize potential threats, it is necessary to collect diverse data covering various aspects of fire risk resulting from environmental conditions and local measurements from risk areas. This process can be time-consuming, but the use of satellite data, combined with data from local measurement systems, can significantly reduce the time needed to collect enough examples to train models.

The growing popularity of local environmental monitoring systems and their availability on the Internet is expanding the scope of monitored areas [22, 23]. The architecture of the monitoring system presented in the article effectively integrates data from various sources. Thanks to its flexible and open architecture, with the ability to adapt communication interfaces to various devices, the measurement system can be easily expanded by adding new data sources regarding environmental conditions.

The collected data enables early detection of fire and flood threats, which allows for more effective protection of monitored areas [24, 25]. Automating monitoring methods also reduces the need to involve large staff in the threat detection process. The presented monitoring method, which combines satellite data with local measurements and uses automated prediction methods, opens up many application possibilities in various areas of prevention, including protection against fire threats.

Literature

[1] Giglio L., Schroeder W., Justice Ch.O., *The Collection 6 MODIS active fire detection algorithm and fire products*, "Remote Sensing of Environment" 2016, 178, 31–41, https://doi.org/10.1016/j.rse.2016.02.054.

[2] Schroeder W., Prins E., Giglio L., Csiszar I., Schmidt Ch., Morisette J., Morton D., *Validation of GOES and MODIS active fire detection products using ASTER and ETM+ data*, "Remote Sensing of Environment" 2008, 112(5), 2711–2726, https://doi.org/10.1016/j.rse.2008.01.005.

[3] Justice C.O., Giglio L., Korontzi S., et al., *The MODIS fire products*, "Remote Sensing of Environment" 2002, 83, 1–2, 244–262, https://doi.org/10.1016/S0034-4257(02)00076-7.

[4] Jurczyński D., Grzebień K., *Estimating the possibility of a fire using satellite missions*, "Security Forum" 2023, 7, 1, 163–177, https://doi.org/10.26410/SF_1/23/12.

[5] Maffei C., Alfieri S., Menenti M., *Time series of land surface temperature from daily MODIS measurements for the prediction of fire hazard*, in: Advances in forest fire research, X.V. Domingos (ed.), 1024-1029, https://doi.org/10.14195/978-989-26-0884-6_111.

[6] Chuvieco E., Lizundia-Loiola J., Pettinari M.L. et al., *Generation and analysis of a new global burned area product based on MODIS 250 m reflectance bands and thermal anomalies*, "Earth Syst. Sci. Data" 2018, 10, 2015–2031, https://doi.org/10.5194/essd-10-2015-2018.

[7] Freeborn P.H., Wooster M.J., Roberts G., Xu W., *Evaluating the SEVIRI Fire Thermal Anomaly Detection Algorithm across the Central African Republic Using the MODIS Active Fire Product*, "Remote Sens." 2014, 6, 1890–1917, https://doi.org/10.3390/rs6031890.

[8] Maffei C., Alfieri S.M., Menenti M., *Relating Spatiotemporal Patterns of Forest Fires Burned Area and Duration to Diurnal Land Surface Temperature Anomalies*, "Remote Sens." 2018, 10, 1777, https://doi.org/10.3390/rs10111777.

[9] Schroeder W., Oliva P., Giglio L., Csiszar I.A., *The New VIIRS 375m active fire detection data product: Algorithm description and initial assessment*, "Remote Sensing of Environment" 2014, 143, 85–96, https://doi.org/10.1016/j.rse.2013.12.008.

[10] Zhang X., Kondragunta S., Ram J., Schmidt C., Huang H.C., *Near-real-time global biomass burning emissions product from geostationary satellite constellation*, "Journal of Geophysical Research: Atmospheres" 2017, 117(D14), 122, https://doi.org/10.1029/2012JD017459.

[11] Setzer A.W., Pereira M.C., *Amazonia biomass burnings in 1987 and an estimate of their tropospheric emissions*, "Ambio" 2013, 22(1), 37–42.

[12] Schmetz J., Pili P., Tjemkes S., Just D., Kerkmann J., Rota S., Ratier A., *An Introduction to Meteosat Second Generation (MSG)*, "Bulletin of the American Meteorological Society" 2002, 83(7), 977–992.

[13] Menzel W.P., Purdom J.F.W., *Introducing GOES-I: The first of a new generation of Geostationary Operational Environmental Satellites*, "Bulletin of the American Meteorological Society" 1994, 75(5), 757–781, https://doi.org/10.1175/1520-0477(1994)075<0757:IGITFO>2.0.CO;2.

[14] Kidwell K.B., *Global Vegetation Index user's guide*, NOAA Technical Report NESDIS, 1991, 107.

[15] Kaufman Y.J., Justice C.O. et al., *The MODIS fire products*, "Remote Sensing of Environment" 2002, 83 (1–3), 244–262, https://doi.org/10.1016/S0034-4257(02)00076-7.

[16] Stöckli R., Vermote E., *The operational land imager: Remote sensing of forest cover and biophysical trends*, "Remote Sensing of Environment" 2006, 100(1), 75–89.

[17] Roy D.P., Lewis P.E., Justice C.O., *Burned area mapping using multi-temporal moderate spatial resolution data—a bi-directional reflectance model-based expectation approach*, "Remote Sensing of Environment" 2002, 81(1–2), 263–286, https://doi.org/10.1016/S0034-4257(02)00077-9.

[18] Miller J.D., Thode A.E., *Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR)*, "Remote Sensing of Environment" 2007, 109(4), 66–80, https://doi.org/10.1016/j.rse.2006.12.006.

[19] Pacheco A.P.S., Fernandes K., Chaves M.E., *Assessment of fire severity and land cover change in a Mediterranean landscape using remote sensing and GIS*, "Remote Sensing of Environment" 2015, 156, 460–473.

[20] Buchwald P., *Wykorzystanie systemów teleinformatycznych i pomiarowych do dystrybucji danych na potrzeby prognozowania infekcji roślin uprawnych*, w: *Wybrane Aspekty Informatyki Biomedycznej*, P. Kostwa (red.), Wydawnictwo WSB, Dąbrowa Górnicza 2014.

[21] Buchwald P., Granosik G., Gwiazda A., *Internet Rzeczy i jego przemysłowe zastosowania*, Wydawnictwo PWE, Warszawa 2022.

[22] Naderpour M., Rizeei H.M., Ramezani F., *Forest Fire Risk Prediction: A Spatial Deep Neural Network-Based Framework*, "Remote Sensing of Environment" 2021, 13, 2513. https://doi.org/10.3390/rs13132513.

[23] You X., Zheng Z., Yang K., Yu L., Liu J., Chen J., Lu X., Guo S., *A PSO-CNN-Based Deep Learning Model for Predicting Forest Fire Risk on a National Scale*, "Forests" 2024, 15, 86, https://doi.org/10.3390/f15010086.

[24] Chukalin A.V., Kovalnogov V.N., Fedorov R.V., Chamchiyan Y.E, Kornilova, M.I., *Verification of the Digital Twin of the Atmospheric Boundary Layer in the Area of the Wind Farm Based on Telemetry Data and Meteorological Measurements*, "IJIRMPS" 2023, https://doi.org/10.37082/IJIRMPS.ICTIMESH-23.13.

[25] Guo N., Liu J., Di K. et al., *A hybrid attention model based on first-order statistical features for smoke recognition*, "Science China Technological Sciences" 2024, 67, 809–822, https://doi.org/10.1007/s11431-022-2449-1.

DAWID JURCZYŃSKI, M.SC. ENG. – software developer, research scientist and teaching assistant at WSB University in Dąbrowa Górnicza. Fascinated by the opportunities presented by the use of satellite data and artificial intelligence.

PAWEŁ BUCHWALD, PH.D. ENG.– research Scientist at WSB and Academic Lecturer. Scientifically, focuses on modern issues of computer graphics and the application of mobile devices, as well as data processing systems. Associated with companies in the IT industry implementing modern IT solutions. An enthusiast of modern technologies in the field of AR and VR.