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Preven-T

PREVEN-T DELIVERABLE D.3.1 Creation of an Information System for early forest fire detection and early warning tools

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PREVEN-T Project Profile

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Duration:	18 months

Partners

INTERNATIONAL HELLENIC UNIVERSITY	International Hellenic University (IHU)	Greece
	Military Academy "General Mihailo Apostolski" (MAGMA)	RNM
	National Park Pelister (NPP)	RNM

Document History

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0.2	10/07/2022	Goce Stevanoski (NP Pelister) Monika Kachurova (MAGMA)	1st Draft ready for internal review
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Abbreviations and acronyms

Deliverable	D
Expected Outcomes	EO
International Hellenic University	IHU
Non-governmental organization	NGO
Military Academy General Mihailo Apostolski	MAGMA
National Park Pelister	NPP
Virtual Private Network	VPN
Network Attached Storage	NAS

Executive Summary

PREVEN-T is a 18 month duration project funding from the Interreg IPA Cross-border Cooperation Programme: PREVEN-T – CN2 – SO2.4 – SC049.

The overarching objective of the PREVEN-T project is to is to improve the operational efficiency and the administrative capacity of relevant services in natural disaster management. At the same time project's goal is to enable education, awareness, and sensitization of the local population, so that in cooperation with the competent authorities to have coordinated action to deal with Natural and Technological Disasters and Risks.

The main purpose of this document is to a report the progress of the PREVEN-T project during the deliverable 3.3.1 that is focused on enabling real-time communication and collaboration between researchers and experts from MAGMA and NPP, fostering a collaborative environment for joint projects, knowledge sharing, and expertise utilization. Additionally, strengthen the overall research capabilities and knowledge base of both MAGMA and NPP through this interconnected information system.

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1 Introduction

1.1 Purpose of the document

The purpose of this document is to present the progress in delivering the D3.3 which is a creation of an Information System for early forest fire detection and warning capabilities and to establish a seamless connection between the MAGMA laboratory and the information center of NPP. The deliverable aims to leveraging advanced technologies and cooperation between MAGMA and NPP to achieve the following objective: Creating and deploying Information System for Early Forest Fire Detection and Early Warning Tools (defined as a deliverable D3.3 in the project). Develop an integrated information system that supports collecting data from ground-based observations point, to detect forest fires in their early stages. Design and deploy an information system that supports sending of real-time alerts to relevant personnel at NPP to take proactive measures for fire prevention and containment.

1.2 Intended audience.

The intended audience of this document consists of the following target audience PREVEN-T project partners and the Project Officer at the Managing Authority.

1.3 Work Package Objective

The current technical report refers to WNPP where it's main objective is developing an Information System for monitoring, detection of forest fires and early warning in Pelister National Park will be developed.

1.4 Structure of the document

The document presents the progress in deliverable D3.1 in the following sections: Methodology, System Requirements, System Architecture, Technology stack and tools, System Implementation, Challenges faced during implementation, System Features and Functionality.

2 Methodology

2.1 Description of the Research/Design Methodology Used:

The development of the Early Forest Fire Detection and Early Warning Information System employed a combination of prototyping and experimental research methodologies. The process started in 1st of March 2023 lasted until 31st March 2023, and allowed iterative design improvements and the validation of system components through various testing. The following steps outline the methodology used:

a. Prototyping: The development process began with creating preliminary prototypes of the information system. These prototypes acted as proof-of-concept models, which helped in understanding the system's basic functionalities and identifying potential design flaws.
b. Experimental Research: Based on the initial prototypes, various experiments were conducted to test the efficiency and accuracy of different algorithms and technologies for early forest fire detection. These experiments aimed to explore the optimal combination of sensors, data processing techniques, and communication protocols.
c. Feedback Loop: The experimental results and user feedback from field experts were continually incorporated into the system's design to refine its capabilities further. This iterative process ensured that the system evolved to meet the specific requirements of early forest fire detection and warning.

2.2 Explanation of Data Collection Methods:

In the data collection phase, a two-fold approach was adopted to gather relevant information:

a. Onsite Data Collection: Field surveys and onsite data collection were carried out in regions prone to forest fires. Real-time data was collected from these onsite locations to train and validate the algorithms used in the information system. Figure 1 shows the hot zones most prone to forest fires.
b. Geographic Information System (GIS) Data: GIS data was utilized to augment the onsite data and enhance the system's understanding of the forest's spatial characteristics. Geographic data, such as land cover, topography, and access routes, was integrated into the system to improve fire prediction accuracy and provide more comprehensive early warning alerts.

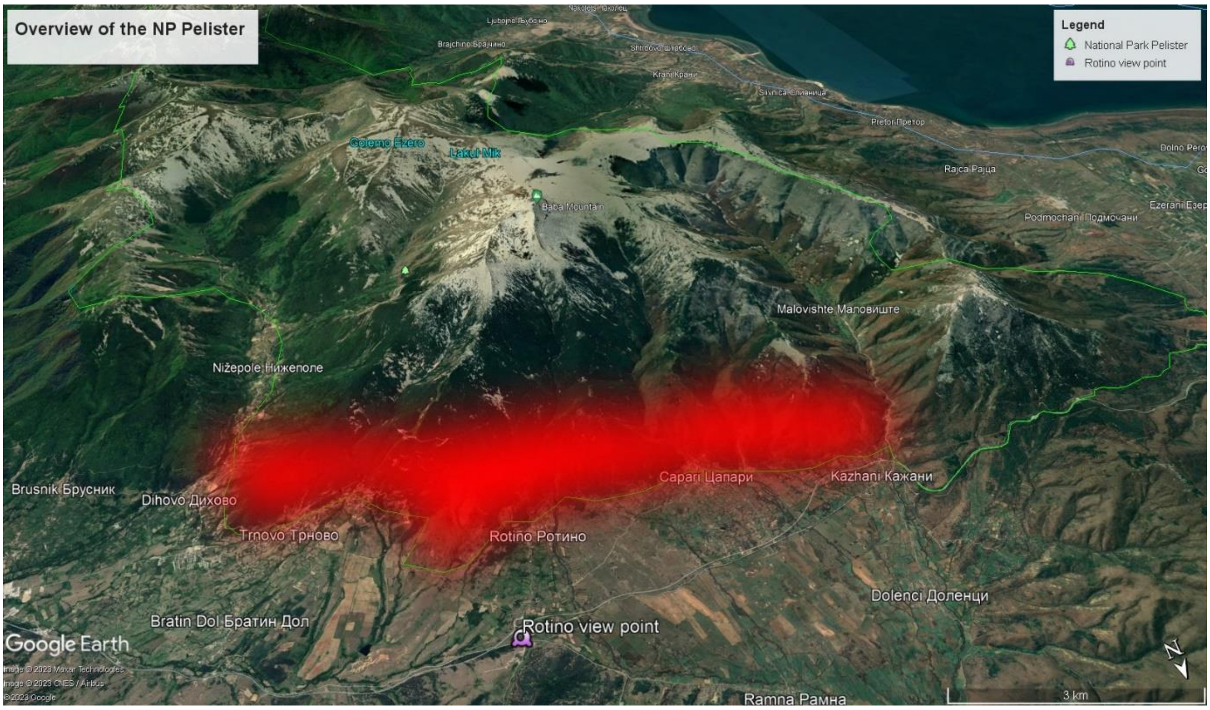

Figure 1: Overview of the hot zones in the NPP Pelister

2.3 Details of the System Design and Development Process

The system design and development process followed the following steps:

a. Laboratory Development: The initial phases of the information system were developed in controlled laboratory conditions. Using the prototyping methodology, a working prototype was created based on the experimental research results and onsite data analysis. This prototype integrated various algorithms, data processing techniques, and GIS functionalities.

Figure 2: Camera setup in the laboratory environment

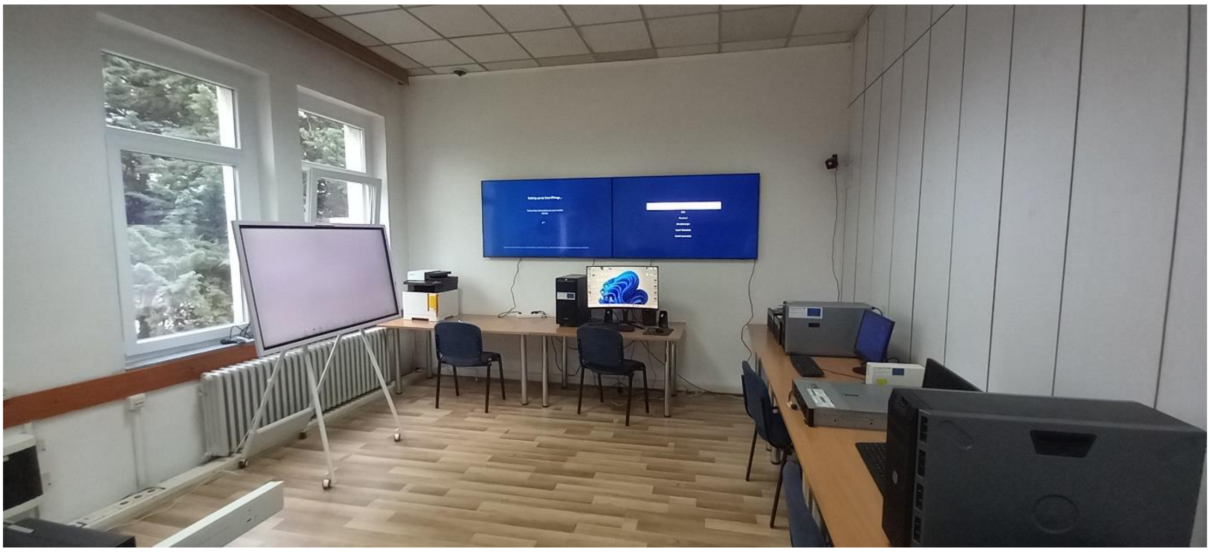

Figure 3: Overview of the laboratory environment

b. Integration of Field Deployment: After successful testing in the laboratory, the information system was deployed in selected outdoor areas where real-time data collection took place. This field deployment allowed for the evaluation of the system's performance under actual fire-prone conditions and verified its effectiveness in early detection and warning, figure 4.

Figure 4: Deployment of the system in outdoor environment

c. System Optimization: The data collected during the field deployment provided valuable insights into system performance. The system was continuously optimized and fine-tuned based on the observed outcomes, aiming to minimize false positives, reduce response times, and enhance overall accuracy.
d. Full-Scale Deployment: With successful results from the field deployment, the Early Forest Fire Detection and Early Warning Information System was ready for full-scale deployment in multiple high-risk forest regions. The system was implemented on a broader scale, integrated with local authorities' response systems, and made accessible to relevant stakeholders, figure 5 and 6.

Figure 5: Deployment of the system at Rotino view point

Figure 6: Camera system deployed at Rotino view point

In conclusion, the development of the Early Forest Fire Detection and Early Warning Information System relied on a combination of prototyping and experimental research methodologies. The collection of onsite data and integration of GIS data added robustness to the system's design. After laboratory development, the system was field-tested and later deployed on a larger scale, contributing to enhanced forest fire detection capabilities and timely warnings, ultimately aiding in mitigating the devastating impact of forest fires.

3 System Requirements

3.1 Overview of the functional requirements

By incorporating its features and functionalities, the information system offers on-demand access to visual imagery, supports visual detection of forest fires, and promptly alerting of authorized personnel, which enables a rapid response to counter forest fires effectively. The system has internet connectivity that establishes a reliable internet connection to enable real-time data transmission and updates, ensuring seamless data exchange between the information system and remote devices/sensors. It provides on-demand visual imagery to authorized users, allowing them to access real-time high-resolution images of the forested area through the application interface for detailed analysis.

To ensure security, the system implements secure user authentication mechanisms, restricting access to only authorized personnel and applying access control to designated users for specific functionalities. It employs data encryption and security measures to protect sensitive information. Moreover, the system provides comprehensive user training to ensure efficient usage and offers ongoing technical support to address any issues that may arise for users.

3.2 Overview of the non-functional requirements

Performance: The system is engineered to exhibit exceptional performance capabilities. It is designed to process and analyze visual imagery in real-time, ensuring swift and accurate data analysis. Additionally, the system's responsiveness is remarkable, as it promptly issues fire detection alerts to authorized personnel within a remarkable response time of less than 30 seconds.

Reliability: The system's reliability is of paramount importance, characterized by a minimum uptime of 99.9%. This ensures uninterrupted availability for critical monitoring and detection, instilling confidence in its continuous operation. Furthermore, the system is fortified to handle potential failures gracefully, swiftly recovering from any unforeseen events.

Scalability: Emphasizing scalability, the system accommodates the seamless integration of additional remote sensors and data sources to support the expansion of the monitoring area. Furthermore, its robust architecture enables it to effortlessly cater to an increasing number of simultaneous users, scaling up to six users without compromising its superior performance.

Usability: The user interface is thoughtfully crafted to offer utmost usability and intuitive interaction. Its user-friendliness reduces the learning curve, requiring minimal training for authorized personnel to efficiently navigate and utilize the system's features.

Security: Security is ingrained at every level of the system. Authentication and authorization mechanisms safeguard access to the system and sensitive data, ensuring that only authorized personnel can interact with it.

Interoperability: The system seamlessly integrates with other systems through its support for standard data formats and communication protocols. This interoperability facilitates efficient data exchange and collaboration between the system and external entities, optimizing overall performance.

Maintainability: The system's design embodies maintainability, emphasizing modularity and code reusability. This strategic approach simplifies future enhancements and updates, streamlining maintenance efforts. Furthermore, the system is accompanied by comprehensive documentation, serving as a valuable resource for seamless system maintenance and swift troubleshooting.

Compliance: The system strictly adheres to relevant environmental and safety regulations governing information systems. Compliance with these guidelines ensures that the system operates responsibly, mitigating adverse impacts.

Environmental Adaptability: The system is engineered with robustness, enabling it to withstand harsh environmental conditions. Its hardware and sensors are designed to endure extreme temperatures and adverse weather conditions, ensuring sustained performance under diverse environmental scenarios.

Regulatory Compliance: The system strictly adheres to regulatory requirements specific to the regions of its deployment. It aligns with local laws and guidelines, demonstrating the project's commitment to compliance and responsible operation within the designated jurisdictions.

4 System Architecture

The Early Forest Fire Detection and Early Warning Information System's high-level architecture, outlined in figure 8, plays a pivotal role in achieving the system's objectives. The architecture has been meticulously designed to provide on-demand access to visual imagery, process real-time sensor data, enable early fire detection, and issue prompt alerts to authorized personnel. Additionally, it emphasizes scalability, security, and compliance with relevant regulations and standards.

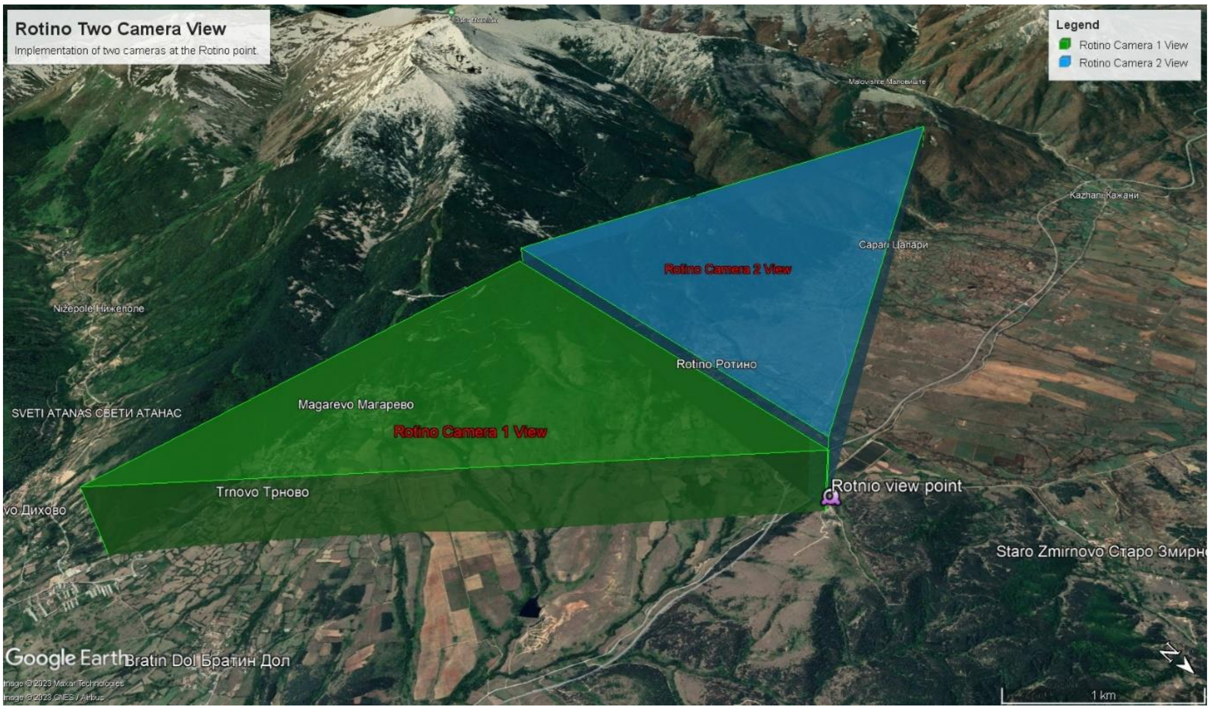

Figure 7: Graphical representation of the covered area from Rotino view point

The architecture diagram in figure 8 visually represents the interconnected modules, data pathways, and communication channels that underpin the system's seamless operations. Each component's role and functionality are detailed in the appendix, providing stakeholders, technical experts, and interested parties with a clear understanding of the system's operations.

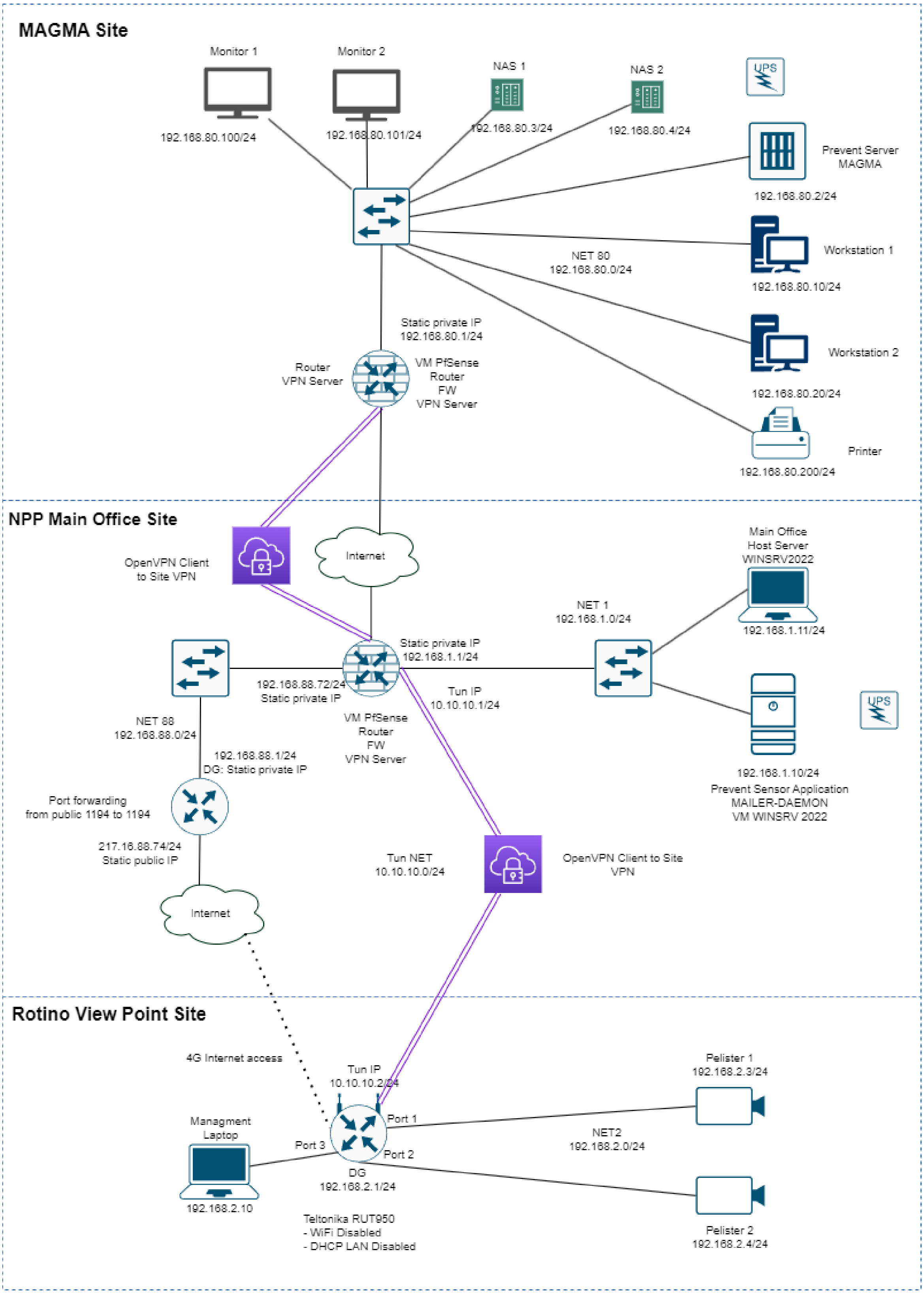

Figure 8: System Architecture

5 Technology stack and tools used

The successful development and deployment of the Early Forest Fire Detection and Early Warning Information System was made possible by an integrated and robust technology stack comprising a wide range of tools. This comprehensive technology stack enabled seamless data processing, real-time monitoring, secure communication, and efficient collaboration. The key components of the technology stack include:

5.1 Hardware components

Solar-Powered PTZ Cameras Dahua DH-SD6C3432XB-HNR-AGQ-PV

The system employs solar-powered Pan-Tilt-Zoom (PTZ) cameras strategically placed across the observed forest area. These advanced cameras are equipped with solar power panels that provide sustainable and eco-friendly energy. The cameras offer versatile control over their movement, allowing forest rangers to pan, tilt, and zoom to specific areas of interest. The cameras capture high-resolution video footage, ensuring clear visuals during the monitoring of the forest area.

Dell Servers

High-performance Dell servers serve as the backbone of the information system. These servers handle data processing, storage, and management tasks. They are equipped with powerful processors, ample memory, and redundant storage solutions to ensure reliability, scalability, and data redundancy.

Network Attached Storage (NAS)

The NAS unit acts as a centralized storage repository for all captured video footage, as well as other critical data. It provides scalable storage capacity and supports various RAID configurations for data protection. The NAS is accessible by authorized users and devices, ensuring efficient data sharing and collaboration.

Workstations

Two workstations equipped with high-resolution displays are positioned in a the MAGMA laboratory. These workstations serve as centers for surveillance of the forest area and working od development and research. They are equipped with powerful processors, ample memory, and dedicated graphics cards to facilitate real-time monitoring, video analysis, and data management tasks.

Display Monitors

Display monitors are strategically placed in the main room of the MAGMA laboratory. These monitors provide live video feeds from the PTZ cameras and can display alerts, notifications, and information relevant to the operations of the facility. They enhance situational awareness and facilitate quick decision-making.

5.2 Software components

Microsoft Server Infrastructure: The system's backend was powered by Microsoft Server Infrastructure, providing a reliable and scalable foundation for data storage, management, and processing.

PfSense: PfSense, a powerful open-source firewall and routing platform, played a critical role in securing the system's network infrastructure. It provided advanced firewall capabilities, traffic shaping, and network monitoring, ensuring a high level of network security and performance.

OpenVPN: The implementation of OpenVPN allowed for secure and encrypted communication between remote devices/sensors and the central information system. This ensured that sensitive data transmitted over the internet remained protected from potential threats.

Networking Tools: Various networking tools, such as Wireshark and Nmap, were employed for network analysis, troubleshooting, and monitoring. These tools offered insights into network performance and helped identify and resolve potential bottlenecks.

6 System Implementation

Implementation of the Early Forest Fire Detection and Early Warning Information System involved several crucial steps, including building a server infrastructure, incorporating security mechanisms, defining the right communication protocols, and setting and optimizing visual parameters and streaming. The period of implementation was from 1st April 2023 to 10th of June 2023.

6.1 Building Server Infrastructure

The server infrastructure formed the backbone of the information system. It involved setting up a reliable and scalable Microsoft Server Infrastructure. This infrastructure provided a centralized platform for data storage, processing, and management. The implementation included deploying high-performance servers equipped with adequate processing power, memory, and storage to handle the system's computational demands.

6.2 Incorporating Security Mechanisms

Ensuring the security of the information system was of paramount importance. Robust security mechanisms were incorporated at multiple levels to safeguard against unauthorized access, data breaches, and potential threats. VPN protocols were implemented for secure data transmission over the network.

6.3 Choosing the Right Communication Protocols

Selecting appropriate communication protocols was critical to enabling seamless and secure data exchange between remote devices/sensors and the central information system. OpenVPN was chosen as the VPN protocol for establishing encrypted and secure communication channels. This allowed remote sensors to transmit data securely to the central system, ensuring the integrity and confidentiality of the transmitted information.

6.4 Setting and Optimizing Visual Parameters

Accurate and real-time visual imagery analysis was essential for early fire detection. The system's visual parameters, such as image resolution, color channels, and exposure settings, were carefully selected and optimized. This process involved fine-tuning the cameras and sensors to capture high-quality images of the forested areas. Proper calibration was conducted to ensure consistency and accuracy in the collected visual data.

6.5 Streaming Optimization

Efficient streaming of visual data was crucial for real-time monitoring and analysis. Various optimization techniques were employed to reduce latency and bandwidth consumption during data streaming. This included compressing the visual data, implementing adaptive bitrate streaming, and using caching mechanisms to store frequently accessed data locally.

By focusing on these implementation aspects, the Early Forest Fire Detection and Early Warning Information System achieved its objectives of providing accurate and timely fire detection alerts to authorized personnel. The system's robust server infrastructure ensured reliability and scalability, while the incorporation of security mechanisms safeguarded against potential threats. The selection of appropriate communication protocols enabled secure data exchange, and setting and optimizing visual parameters ensured accurate visual analysis. Efficient streaming optimization further enhanced the system's real-time monitoring capabilities, making it a valuable tool in combating forest fires effectively.

7 Challenges faced during implementation and their solutions

During the implementation of the Early Forest Fire Detection and Early Warning Information System, some challenges were encountered, affecting the availability of live data streaming and system performance. Below are the challenges faced and their respective solutions:

7.1 Challenge: 4G Connection and Availability of Live Data Streaming

Explanation: In remote forest areas where the system was deployed, stable and reliable internet connectivity was a major challenge. The 4G connection in these areas often experienced fluctuations, leading to interruptions in live data streaming from onsite sensors. This hindered real-time monitoring and timely fire detection.

Solution: To overcome this challenge, additional network equipment in the form of a 4G router was installed. The 4G router enabled stronger and more consistent internet connectivity, ensuring a stable data connection between the remote sensors and the central information system. By bolstering the 4G connection, live data streaming was significantly improved, enhancing the system's real-time monitoring capabilities.

7.2 Challenge: Low Internet Bandwidth at the NPP Information Center

Explanation: The NPP Information Center, where the central server infrastructure was initially located, experienced low internet bandwidth due to the heavy load of data transmission and processing. This resulted in slow data exchange and compromised the system's performance.

Solution: To address the issue of low internet bandwidth, the server infrastructure was relocated to the main NPP location, where higher internet bandwidth was available. This relocation allowed for improved data transmission rates and faster processing times. By leveraging the higher internet bandwidth at the main NPP location, the system's overall performance and responsiveness were significantly enhanced.

By effectively addressing these challenges with appropriate solutions, the Early Forest Fire Detection and Early Warning Information System was able to overcome various obstacles and deliver accurate and timely fire detection alerts. The system's enhanced real-time monitoring capabilities and improved data streaming enabled efficient and proactive measures to prevent forest fires effectively.

8 System Features and Functionality

The Early Forest Fire Detection and Early Warning Information System offers a comprehensive set of features and functionalities that enable efficient and proactive monitoring and detection of forest fires. These features include live streaming capabilities for real-time monitoring, on-demand visual overview of the designated forest area, and autonomous detection of forest fires with immediate alerting to authorized personnel.

8.1 Live Streaming Capabilities for Monitoring:

The system is equipped with live streaming capabilities that enable real-time monitoring of the designated forest area. This feature allows authorized personnel, such as forest rangers and emergency responders, to access a live video feed from strategically placed cameras installed on Rotino View Point. The live stream provides a continuous and up-to-date view of the forested region, allowing stakeholders to monitor the area closely for any signs of fire or potential fire hazards. The real-time video feed is essential for timely decision-making and immediate response to emerging fire incidents.

8.2 On-Demand Visual Overview of the Area:

In addition to live streaming, the system provides on-demand visual overviews of the designated forest area. Authorized users can access high-resolution images and visual data of the forest at any time through the system's user interface. These on-demand visual overviews offer a comprehensive and detailed snapshot of the entire forested region. Users can zoom in and out, pan across the area, and analyze the visual data to assess the forest's condition and identify potential fire risks. This feature allows for a more comprehensive analysis and planning, aiding forest management and emergency preparedness.

8.3 Autonomous Detection of Forest Fires and Alerting:

The system’s autonomous detection capabilities played a critical role in early fire detection. The alerting mechanism was set to be through email communication, ensuring that relevant stakeholders were promptly notified. This autonomous detection and alerting feature significantly reduced response times, allowing for a swift and coordinated response to combat the fire at its early stages, thereby minimizing its potential impact.

The integration of object detection algorithms was central to the model system's capabilities. The YOLOv5 model, known for its speed and accuracy, was chosen for real-time fire detection. The model was trained using an extensive fire and smoke instances dataset to ensure its proficiency in differentiating between normal and anomalous conditions.

The selection of YOLOv5 was driven by its unparalleled speed and accuracy, both of which were vital for prompt fire detection in dynamic environments.

The YOLOv5 model served as the linchpin of the system's early fire detection prowess. Leveraging the principles of You Only Look Once (YOLO), this model was meticulously integrated into the system's architecture to process video feeds in real time. It is important to note that the system's real-time capability corresponds to one frame per second, where each frame is treated as an individual data point.

Before integration, the YOLOv5 model underwent an exhaustive training process. A diverse and extensive dataset containing a plethora of fire and smoke instances was meticulously curated. Through iterative training cycles, the model was fine-tuned to recognize subtle differentiators between normal and fire-related visual cues. This meticulous training approach ensured that the model's predictions aligned accurately with ground truth data.

The YOLOv5 model's exceptional speed allowed it to process each frame within milliseconds, ensuring that potential fire incidents were promptly identified. Its accuracy, borne out of extensive training, enabled the system to differentiate between benign fluctuations and genuine fire occurrences. The model's efficiency was particularly crucial for nighttime fire detection, where visibility challenges necessitate rapid and precise anomaly recognition.

The real-time video streaming, operating at one frame per second, enabled the system to extract and send a single frame via email in the event of a potential fire detection. This approach ensured that stakeholders received a clear visual representation of the anomaly, aiding swift assessment and decision-making. The streamlined approach minimized email data usage while providing vital information in a concise format.

Before integration, the YOLOv5 model was meticulously trained using an extensive dataset comprising fire and smoke instances. The model was trained iteratively, adjusting hyperparameters and fine-tuning its weights to maximize its accuracy in fire and smoke detection. Rigorous validation was conducted to ensure that the model's predictions aligned with ground truth data. First, a model was trained with over 20,000 fire and smoke images as well as nighttime fire and smoke images. 40% of the total number of images were for potential fires in daytime conditions, 40% were for nighttime conditions, and the remaining 20% of the images were without objects - fire in the image. After training the model, it was added to the Streamlit application script, providing real-time fire detection.

The application is made in such a way that it streams the videos from the cameras for 3 minutes and pauses for 10 minutes, to reduce the consumption of the Internet. At a maximum of 30 minutes, it sends an email to the stakeholders, also to reduce Internet consumption.

An integral aspect of the architecture was the integration of automated email notification systems. This component, triggered by the Streamlit application model for detecting fire or smoke incidents, introduced additional codes in the Python programming language script and ensured that stakeholders were immediately informed of potential fire incidents. The integration involved establishing a communication channel between the system and the designated e-mail addresses. The goal was to send an e-mail to the affected party from a separate Outlook account with a separate application password, including an attachment - a frame image and text with the probability as an accuracy variable. on the fire.

The user interface, developed using the Streamlit framework, was designed for intuitive interaction. This phase involved the creation of visually appealing displays that showcased live camera feeds, real-time object detection outcomes, and system notifications.

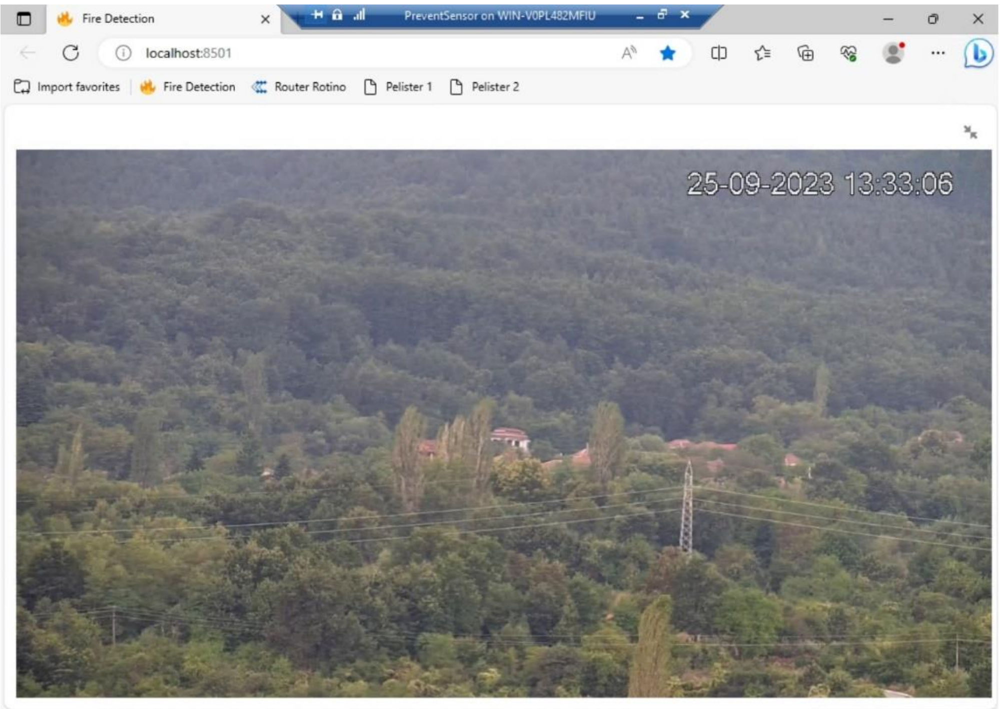

Figure 9: Streamlit application 1

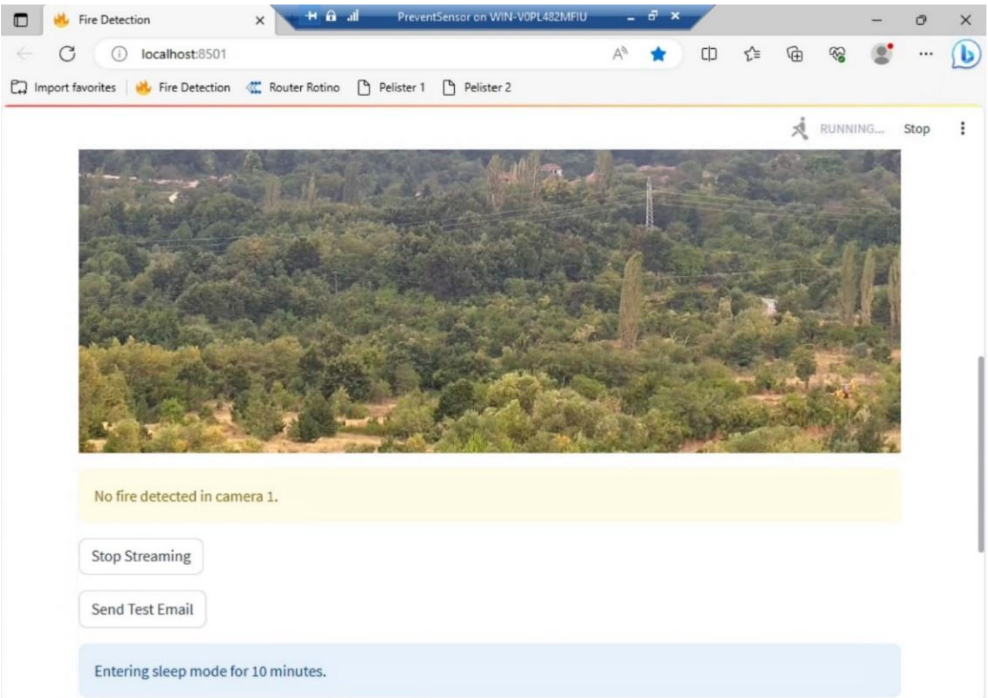

Figure 10: Streamlit application 2

Extensive testing and debugging were conducted to validate the integration of software components. Rigorous testing scenarios were devised to assess the responsiveness of the user interface, the accuracy of object detection, and the system's ability to handle various usage patterns and scenarios.

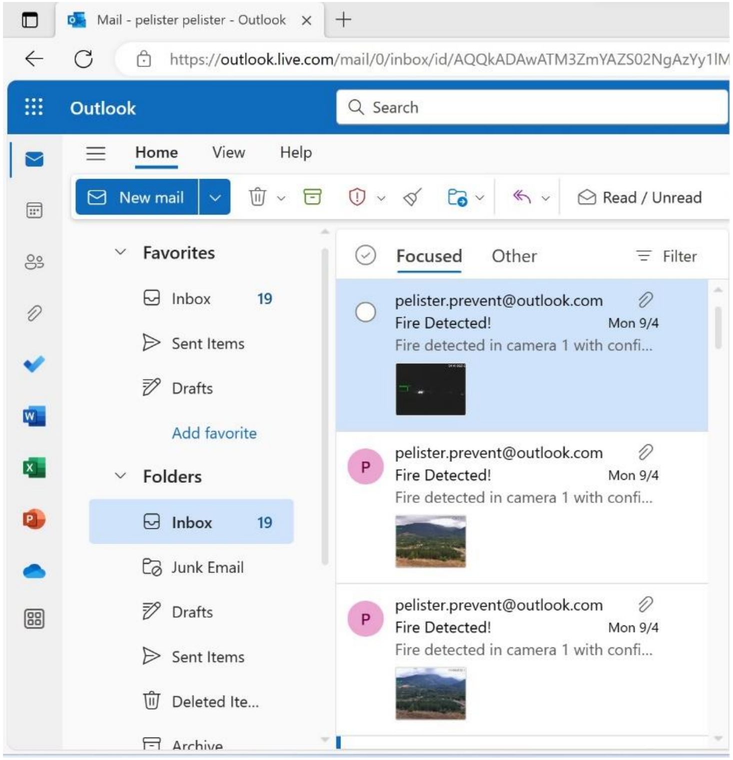

Figure 11: Testing E-mail notification

The accuracy and precision of the object detection model were rigorously assessed using ground truth data. Detection results were compared against actual fire and smoke instances to determine false positive and false negative rates. Adjustments to model parameters were made to enhance accuracy as necessary.

9 Conclusion

9.1 Recapitulation of Project's Purpose and Achievements

The primary purpose of the project was to develop and implement an Early Forest Fire Detection and Early Warning Information System. The project aimed to leverage advanced technology to detect forest fires at their early stages, enabling timely response and effective firefighting measures. Throughout the project, various activities were undertaken to achieve this objective, and the following key achievements were accomplished:

1. Comprehensive Project Documentation: The project successfully created and maintained comprehensive project documentation. This included administrative activities, progress reports, and organization and tracking of all project documents. The meticulous documentation ensured clear records of project activities, milestones, and outcomes, facilitating transparency and accountability.
2. Support for Communication Strategy Implementation: The project actively supported the implementation of the communication strategy set by the Contracting Authority. The team followed the Communication Plan, engaged in effective communication with project officers and partners, and ensured widespread dissemination of information about the program, its objectives, and benefits. This communication approach promoted public awareness and engagement, garnering support for the project.
3. Analysis and Deployment of Detection Tools: Extensive analysis of the coverage area was conducted to determine the appropriate range for deploying the forest fire detection tools. The team identified strategic locations to install detection equipment, maximizing the system's coverage and efficacy in identifying fire incidents.
4. Development of Network Physical and Logical Plans: The project successfully designed network physical and logical plans for system communication. This step ensured seamless data exchange and connectivity between remote sensors and the central information system, enabling real-time monitoring and data analysis.
5. Onsite Installation of Detection Equipment and System Infrastructure: The team executed onsite installation of the forest fire detection equipment and system infrastructure. This involved deploying sensors, cameras, and communication devices in the designated forest areas, setting up the necessary hardware and networking components, and ensuring the system's functionality and reliability.
6. Building and Deploying Machine Learning Model Infrastructure: The project developed and deployed a robust machine learning model infrastructure for forest fire detection. Advanced algorithms and AI techniques were incorporated to analyze visual imagery and sensor data, autonomously detecting fire incidents with high accuracy.
7. Communication with Laboratory System Infrastructure: The team established seamless communication with the laboratory system infrastructure. This integration facilitated data exchange and analysis between the forest fire detection system and the central information system, ensuring a comprehensive approach to fire detection and early warning.
8. Platform Testing and Documentation Preparation: The project conducted thorough testing of the information system platform to verify its performance and functionality. Additionally, the

team prepared all necessary documentation for the information system, ensuring a well-documented and structured resource for system maintenance and future enhancements.

9. Providing a Streamlit application for early fire detection: The installation of essential software components, including the integration of the Streamlit framework and the YOLOv5 model, further underscored the system's efficiency and responsiveness.

10. Through these achievements, the Early Forest Fire Detection and Early Warning Information System successfully fulfilled its purpose of proactively detecting forest fires, enabling prompt response, and contributing to effective fire management and protection of natural resources. The project's dedication to comprehensive documentation, effective communication, and cutting-edge technology deployment played a pivotal role in its success, making it a valuable tool in combating forest fires and safeguarding our environment.

• References