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Development of a Smart System for Early Detection of Forest Fires based on Unmanned Aerial Vehicles

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***Abstract*—The naturally occurring wildfires and the people-related forest fires are events, which in many cases have significant impact on the environment, the wildlife and the human population. The most devastating among these events usually start in unpopulated remote areas, which are difficult to inspect or are not constantly being monitored or observed. This gives the local small-sized fires enough time to evolve into full-scale wide-area disasters, which in turn makes their suppression and extinguishing very difficult.**

In this paper, we present an autonomous system for early detection of forest fires, named THEASIS-M. The presented system represents a solution that is based on a combination of innovative technologies, including computer vision algorithms, artificial intelligence and unmanned aerial vehicles.

In the first part of the study, we provide an overview on the present applications of the UAVs in the forestry domain. The paper then introduces the general architecture of the THEASIS-M system and its components. The system itself is fully autonomous and is based on several different types of UAVs, including a fixed-wing drone, which provides the overall forest monitoring capabilities of the proposed solution, and a rotary-wing UAV that is used for confirmation and monitoring of the detected fire event. The widely used technologies for computer vision and image processing, which are used for the detection of fire and smoke in the real-time video streams sent from the UAVs to the ground control station, are highlighted in the next section of this study. Finally, the experimental tests and demonstrations of the proposed THEASIS-M system are presented and briefly discussed.

***Index Terms*—Unmanned aerial vehicles, computer vision, artificial intelligence, early detection of forest fires, autonomous system for fire detections**

I. Introduction

The unmanned aerial vehicles (UAVs), which are often also called drones, are advancing in many different application areas and the forestry domain is no exception. Activities, which previously were demanding or involving the use of human-operated agricultural machines or ground and aerial vehicles, can now be executed using drones at relatively lower costs and way easier. While the UAVs cannot yet fully replace the humans in all forestry-related activities, their capabilities and functionalities are constantly improving and these systems are being used for more and more complex and advanced tasks. The most trivial and widely-known application of the unmanned aerial vehicles in the agricultural and forestry domain is for observation purposes [1]. With the help of different UAVs and their on-board camera systems, local authorities, property owners and law-enforcing agencies can monitor any area of interest and can identify illegal activities, including unauthorised logging, poaching or harvesting [2]. The use of UAVs leads to the prevention of significant financial losses from the aforementioned and other criminal activities, but at the same time it is also leading to the saving of many endangered species, to the better management and maintenance of natural parks, to the preservation of trees and bushes and correspondingly to delays of the global warming processes [3].

The applications of the UAVs have been well-documented with their huge potentials, benefits and impacts [3-7, 14-18]. The data collection, remote measurements, estimation of the forest coverage, calculation of the biomass of the trees and evaluation of the different attributes of the forest vegetation are among the many examples of how the UAVs can be used for scientific activities, studies and protection of the forests.

The precision forestry and the modern forestry management processes involve interesting drone-related activities, including the mapping of the forests, the canopies and the canopy gaps [15], the development of ortho-photo maps and the creation of 3D models of the forest areas [16]. While many of these activities can be implemented using standard optical cameras, some of mentioned mapping and measuring activities require more advanced payloads, such as laser-based LiDAR systems [17], Global Positioning System (GPS) or inertial measurement units (IMUs) for estimation of the heights of the objects on the ground [18].

The majority of the above-mentioned examples can be categorized as passive applications of the UAVs in the forestry domain. These activities are not characterized by any direct impact or manipulation on the environment, the trees or the forests in general. With the recent advancement in the UAV-related technologies, it is now also possible to involve the UAVs in active applications in the forestry domain. The tree planting with UAVs is among these applications and represents the process of fast and efficient distribution of seeds or seedlings in the remote or inaccessible forest areas. Spraying or spreading fertilizers in the forest areas is another good example of an active application of the UAVs in the forestry domain [4].

It is clearly seen that UAVs have been used in many applications with well-documented benefits and impacts in the forestry domain, especially in modern forestry control, management, protection and conservation. This study investigates and considers the use of the UAVs for early detection and monitoring of forest fires, for actual fighting and extinguishing of wildfires and for post-fire damage assessment to be the applications with the highest significance and impact in the forestry domain. The THEASIS-M autonomous system for early detection of forest fires, which is presented in this paper (Fig. 1), was successfully developed and tested. The system is based on a combination of innovative technologies, including computer vision algorithms, artificial intelligence and UAVs.

The rest of the paper is organized as follows. Section II presents materials and methods with the focus on (i) the generalized model of the system for early detection of forest fires using UAVs; (ii) the neural networks, computer-vision algorithms and artificial intelligence technologies for detection of fire and smoke; and (iii) the selection of the functional components for development of the UAV-based fire detection and observation system. Section III presents the experimental demonstrations and results and finally, Section IV presents a summary, brief discussions and conclusions.

II. MATERIALS AND METHODS

A. *Generalized model of the system for early detection of forest fires using UAVs*

The involvement of the UAVs in the antifire-related activities is relatively less expensive, compared to the use of manned aircrafts and satellites, but is also characterized by many disadvantages.

Generally, the UAVs are limited by the present state of the drone manufacturing technologies. Some of these limitations are related to the flight time, the payload capacity and the communication range of the drones. Another disadvantage of the use of the UAVs for firefighting applications is the requirement for proper training of the UAV pilots and operators. The UAVs are also characterised by specific limitations related to their type, size and propulsion systems. The fixed-wing UAVs for fire detection and monitoring are slowly gaining wider approval and acceptance, but still the majority of the used UAVs in this application domain are small-sized rotary-wing drones.

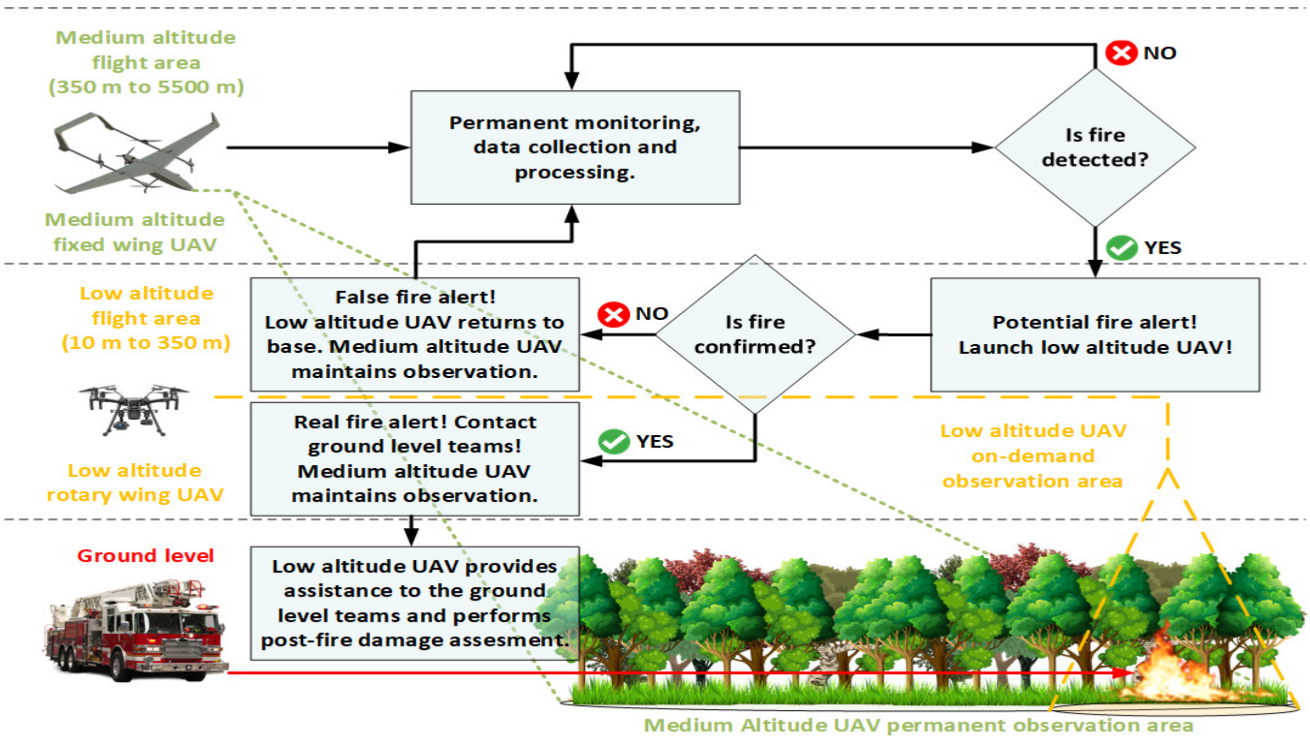

Fig.1. A conceptual model of the proposed THEASIS-M system for early detection and observation of forest fires, which consists of a fixed-wing UAV, as a primary monitoring and observation unit and a secondary rotary-wing drone for confirmation and closer monitoring of the detected fire event and for post-fire damage assessment.

In addition, the majority of the forest fire detection and monitoring solutions, which are based on the fixed-wing UAVs, require complex and expensive launching and landing systems or even runways. This makes them unsuitable for many rapid response operations and activities, especially in remote and unpopulated areas, as this disadvantage introduces delays related to the preparation of the drone or the setup of the launching mechanisms.

Nowadays, the battery powered UAVs are the dominant technology on the market. The present technological state of the battery manufacturing processes is allowing the drones to stay in the air for up to 90 minutes. However, the flight duration is extremely dependant on the environmental conditions and on various drone characteristics, like the number of the motors, the wight of the drone, etc. While the available flight time is suitable for many different activities, the fire-related actions can demand longer operation periods.

By taking under consideration the majority of the presented and discussed disadvantages of the UAVs and the related to them technologies, we have developed a complex fire detection and observation system, which was named THEASIS-M (Fig.1). This system is based on previous research efforts and practical experiments conducted under the SFEDA transnational project, which was completed by several institutions from Greece, Cyprus and Bulgaria [19].

The primary UAV in the THEASIS-M system is a medium altitude fixed-wing UAV. This drone provides the overall forest monitoring capabilities of the system and is used for the initial detection of fire and smoke in the observed area. The detection can be accomplished with the use of both the optical or the thermal camera of the drone. To obtain a constant monitoring of the planned zone, the primary UAV is set to maintain its predefined initial flightpath, even if smoke or fire is detected mid-flight. In this way, the THEASIS-M system can report the detection of fire and smoke in multiple locations, instead on just focusing on the first one, which can also be false-positive.

Once the primary UAV reports the detection of fire or smoke, the estimated coordinates of the event are transmitted to a ground control station, logged and recorded in a database and then forwarded to a secondary UAV which is a low altitude UAV (Fig. 1). The purpose of using the secondary UAV is to conduct a closer inspection at the location of the reported event and then to confirm or deny the presence of fire or smoke. The secondary UAV can be a multi-rotor UAV with a high-resolution optical and thermal camera, but with reduced flight altitude and duration capabilities.

B. Neural networks, Computer-Vision algorithms and Artificial Intelligence technologies for detections of fire and smoke

With the rapid advancements in the area of the Computer Vision (CV) and Artificial Intelligence (AI), modern smart visual surveillance systems have been successfully developed for many applications, including for detection of fire and smoke, for real-time evaluation and optimal decision-making in firefighting and rescue operations, etc. [5-7]. Fundamentally, the ability of the machines to learn, gain experience, adjust to new inputs, make adaptive decisions and perform different tasks in a human-like manner is generally described under the popular term Artificial Intelligence. Machine learning (ML) is an AI technology that allows the computer systems to predict outcomes. For this purpose, the system uses historical data as input and predicts new output values. The ML methods, which are used in the development of an AI system, can vary. Some of the most widely known technologies are the symbolic regression, support vector machines, decision trees and random forests, as well as the algorithm for k-nearest neighbours.

The neural networks are probably the most popular among all of the machine learning technologies. There are several types of neural networks, but probably the most widely used for image detection and computer vision are the convolutional neural networks. Usually, they are formed by an input layer, several interconnected or fully connected hidden layers with multiple neurons, where the computation and decision making takes place, and an output layer, as shown in Fig. 2. The links between neurons in the network are parameterized with weights, which dictate the importance of the input value.

In order to develop an AI-solution for the fire and smoke detection, individual frames have to be periodically extracted from the real-time video stream from the UAV. These still images are then inputted into a pretrained neural network for analysis and decision-making. Although the input can be provided to an untrained neural network, the trained ones are outputting much better results. The algorithms designed to do object detection are categorized into two major groups, including one-stage and two-stage object detectors. The members of the first group are characterised with high inference speeds, while these from the second group have high localization and recognition accuracy.

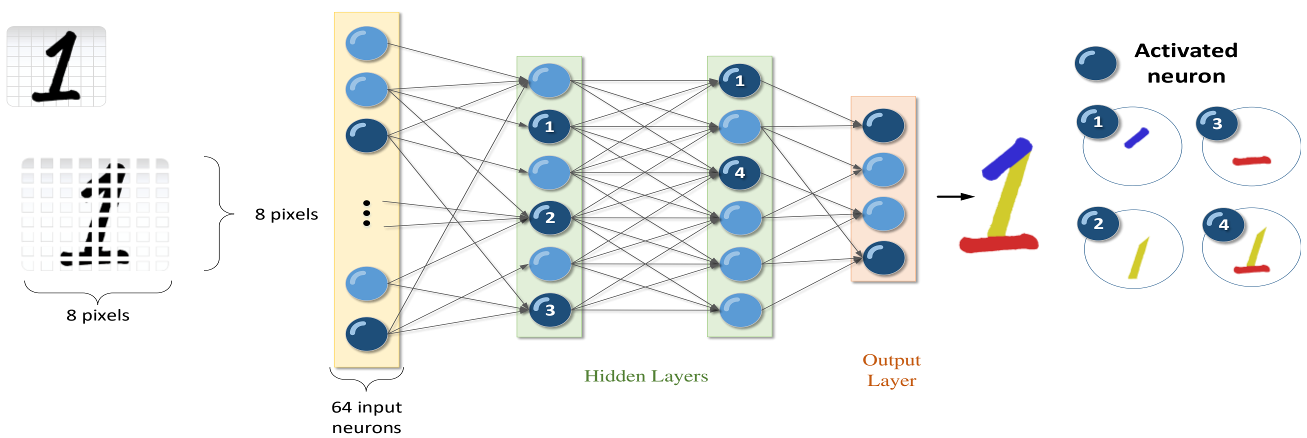

Fig.2. A general neural network model used in image detection, recognition and computer vision

In our study, we have used the Region-based Convolutional Neural Network (R-CNN) approach, which combines rectangular region proposals with convolutional neural network features [8, 9]. R-CNN is a two-stage detection algorithm, where the first stage identifies a subset of regions in an image that might contain an object and the second stage classifies the object in each region. The input data used for the training of the neural network consists of 1080 images and is divided in a set for training of the network (864 images or 80% of all used images) and a set for testing (the remaining 20% of all images or 216 images). If more images are used for the training set, the model could become more accurate. In this case, however, there is a trade-off between the model speed and the model accuracy, which must be taken into consideration.

C. *Selection of the functional components and the elements of the THEASIS-M system*

Prior to the testing and experimental evaluation of the proposed system for early detection of forest fires, the drone market was analysed and studied and the UAVs most suitable for the planned purposes were selected, purchased, modified and deployed.

The ALTi Transition-F vertical take-off and landing (VTOL) fixed-wing UAV [10], was selected as the primary aircraft for the discussed system. The ALTi Transition-F is one of the leading fixed-wing UAVs on the market. The Technical specifications of the drone are presented in Table I.

The ALTi Transition-F is ultra-compact, efficient and affordable system, which is able to take-off and land vertically in space-restricted locations using its four battery powered motors, with the following key technical specifications: (i) the flight endurance is up to 12 hours, which is achieved using an internal combustion engine, (ii) the dimensions of the wingspan, length and height are respectively 3000 mm, 2300 mm and 525 mm; (iii) the maximum take-off weight of the drone is 16 kg.

The main wings of the ALTi Transition-F are removable as shown in Fig. 3, which significantly reduces the UAV carry-size and allows for the rapid deployment, transport and storage.

TABLE I. SPECIFICATIONS OF THE UAV ALTI TRANSITION F [11]

Parameter	Description
Transportation Case	Pelican Air 1555 Travel Case
GCS Computer	Intel NUC 7i 3BNH + Logitech Keyboard & Mouse
GSC Display	ASUS 15.6" LED HD Monitor
Digital Data/Video Link	Microhard MIMO 2.4Ghz PMDDL24S0 ENC
Airside 2.4Ghz Antenna	Omni directional aircraft antenna
GSC 2.4Ghz Antenna	Omni directional GCS antenna
Aircraft Controller	Spektrum DX Controller
Long Range C2 Control Link	TBS Crossfire System
GCS Panel System	GCS enclosure with voltage monitor and connectors
Power Battery Pack	GCS power pack battery set

The UAV in our experiments was equipped with a NightHawk 2 EO/IR camera [11] with 20x zoom and thermal image resolution of 640x480 pixels. The camera weighs only 250 grams, which causes almost no effect on the drone performance and is not reducing its endurance significantly.

Fig.3. The UAVs used in the THEASIS-M system for early detection and monitoring of wildfires – (from left to right) the ground control station of the ALTi Transition F, the DJI Matrice M210 RTK drone with its case, remote controller and RTK station and the ALTi Transition F with its wings removed.

To confirm or deny the detection of the fire or smoke, the DJI Matrice 210 RTK drone [12] was selected as the secondary rotary-wing UAV in the THEASIS-M system, as shown in Fig. 3. The technical specifications of the DJI Matrice 210 RTK are presented in Table II.

TABLE II. SPECIFICATIONS OF THE DJI MATRICE M210 DRONE [12]

Parameter	Description
Package Dimensions	790×390×290mm
Dimensions (unfolded)	887×880×378 mm
Dimensions (folded)	716×220×236 mm
Folding Method	Folded Inward
Diagonal Wheelbase	643 mm
Number of Batteries	2
Weight (TB55)	Approx.4.57kg (with two standard batteries)
Max Take-off Weight	6.14KG
Max Payload (2 TB55)	Approx.1.57kg (with two standard batteries)
Folding Method	Folded Inward
Diagonal Wheelbase	643 mm
Max Wind Resistance	12 m/s
Operating Temperature	-4° to 113° F (-20° to 45° C)
IP Rating	IP43

The DJI Matrice 210 RTK drone is IP 43 certified, therefore, it can withstand humidity and can fly in the foggy or rainy conditions. In addition, the drone has a dual downward gimbal, which allows it to carry simultaneously two cameras. The DJI Matrice UAV, in our experiments, was equipped with an Zenmuse XT2 thermal camera [13], which integrates a high-resolution FLIR thermal sensor and a 4K visual camera with stabilization and processing technology for fast transformation of the aerial data into powerful insights.

III. EXPERIMENTAL DEMONSTRATIONS AND RESULTS

To evaluate the functionality of the developed THEASIS-M system and its efficiency, several experimental tests were carried out. Some of them were aimed at the testing and evaluation of the AI-based solution for the fire and smoke detection (Fig.4, left), while others were actual experiments with the full-scale system (Fig. 4, right).

The actual field experiments with the system were conducted on the territory of a national park in the Northern-central Region of Bulgaria as shown in Fig. 5. To test the efficiency of the system, several smoke traps and controlled fire sites were created.

The developed THEASIS-M system is a proof-of-concept that several UAVs can be used within one system and can provide the reliable and efficient detection of the forest fires. In all experiments, the detection algorithm of the primary UAV in the system was able to identify the smoke or fire locations and the coordinates of the sites were sent to the secondary UAV for the closer inspection and confirmation of the events.

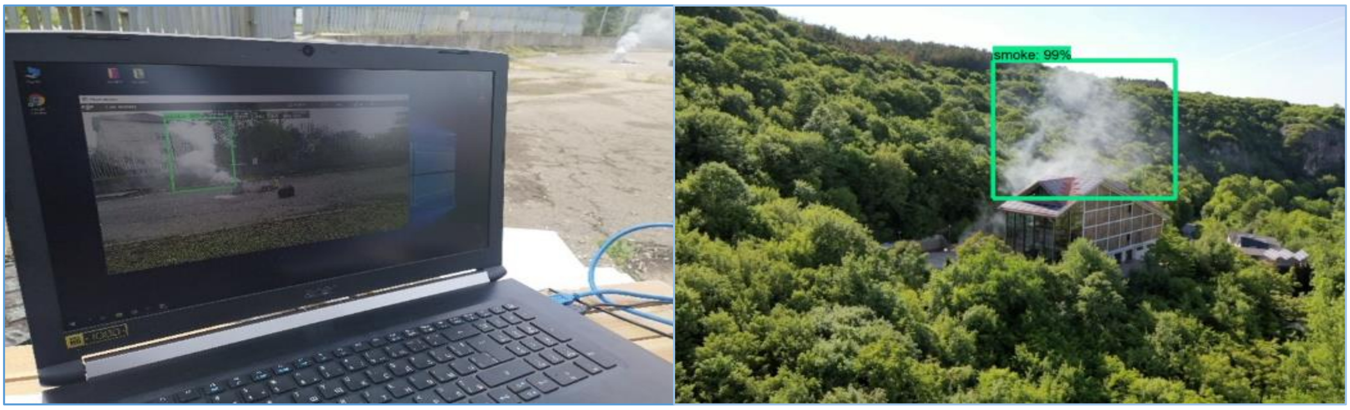

Fig.4. Evaluation of the AI-based solution for detection of fire and smoke during the ground-based tests (left) and real-time detection of smoke during the experimental tests at the nature park (right).

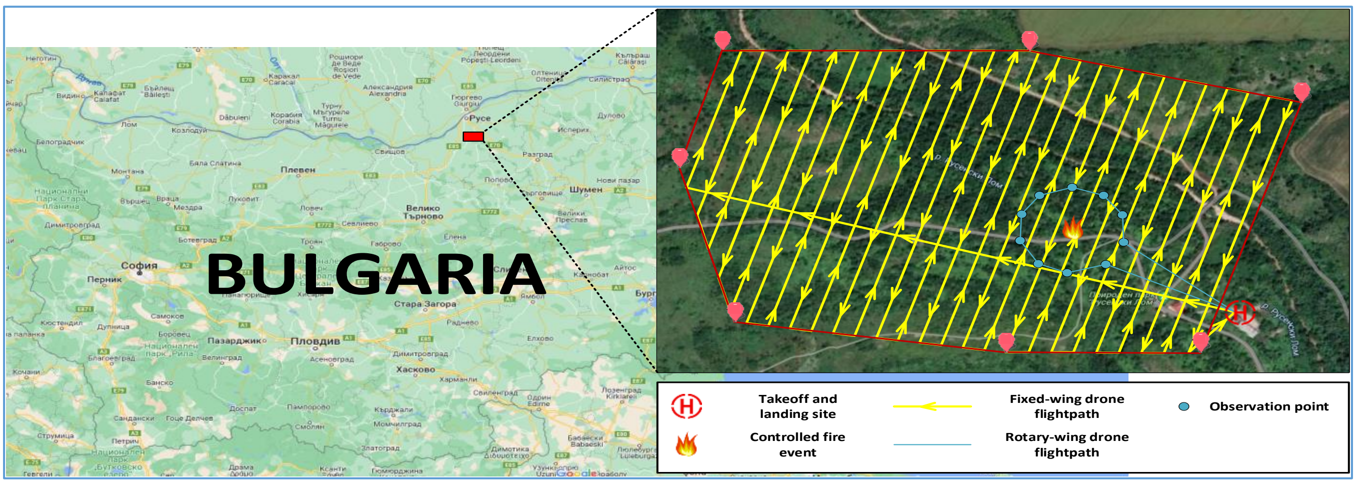

Fig.5. The location of the test site for the THEASIS-M system with the flightpath for the fixed-wing UAV, one of the controlled fire sites and the flightpath undertaken by the secondary UAV upon the report of the detected fire event.

IV. Summary and Conclusions

The use of aerial systems for fire detection, monitoring and extinguishing is not a new concept. Prior to the wide acceptance of the UAV technologies, the fire detection, monitoring and fighting activities were implemented using manned aircrafts – special firefighting airplanes and helicopters, which have huge internal or external water tanks. The quick response time and the improved access to remote areas made the manned aircrafts crucial and highly demanded tools in the fight against wildfires. Nevertheless, firefighting is a very dangerous activity and is related to numerous risks, which have led to many incidents and the loss of firefighting aircrafts and crews. Therefore, there is an emerging need to look for a less risky solution to deal with the fire detection, monitoring and extinguishing.

The advances in the area of the micro and nano technologies and the spacecraft construction made the development of general-purpose non-military satellites possible. Naturally, it was a logical thing to develop solutions and systems for fire detection and monitoring from space. While this technology is characterized by zero direct risk to humans, it is unfortunately also very expensive to implement and very complex to manage and operate. Recently, it became possible to use the advancement in the UAV-related technologies in the forestry domain [1-9, 14-18], including for fire detection, monitoring and suppression.

This study presented the conceptual model of the THEASIS-M smart system for early detection of forest fires and a successfully developed and tested proof-of-concept prototype that is based on this model. The system includes a fixed-wing UAV, which provides the overall forest monitoring capabilities, and a rotary-wing UAV, which is used for confirmation and monitoring of the detected fire event. The THEASIS-M system can also be implemented using a set of two rotary-wing UAVs. The proposed solution can be subject to additional improvements and can be integrated with the available fire detection systems, including these based on stationary cameras or satellite images.

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