Integrated Forest Monitoring System for Early Fire Detection and Assessment

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Abstract— **This paper presents a novel system for automatic early detection of wild forest-fire using optical and thermal cameras at ground station and mounted on Unmanned Aerial Systems (UAS). The proposed system can detect and identify forest fires threats in real-time, and at the same time it is capable to notify the interested parties and authorities by providing alerts and important information (e.g. specific location, environmental conditions, etc.). Early recognition and detection of forest fires is a very challenging problem. Numerous potential sources of error leads to an increased rate of false positives (false alarms). The proposed system addresses them by exploiting the complementarities between thermal and optical cameras located at a panoramic static ground location together with the same type of cameras mounted onboard a (or potentially more) UAS. Also, the system is equipped with sensors to monitor and take into account the environmental conditions for the on the fly threat assessment. All data are fused together for an automated risk assessment. The proposed system has been integrated and it is ready for experimental testing and validation in close-to-operational conditions in field fire experiments with controlled safety conditions carry out in Pano Platres forest in Cyprus.**

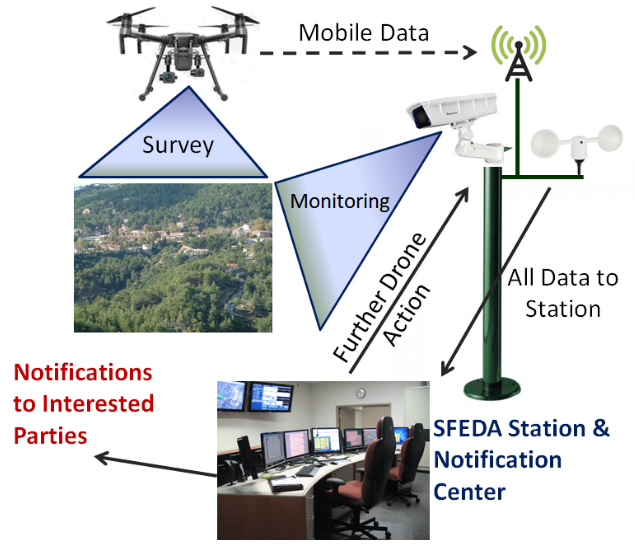

Fig. 1: System's overview.

I. INTRODUCTION

Forest fires, also known as wild fires, are uncontrolled fires occurring in wild areas and cause significant damage to natural and human resources. The BalkanMed area was subject to more than 800 wildfire events during 2014 alone. These fires have spread over 20 Kha of which 25% have been Natura 2000. Wild fires are deadly events, destroying infrastructures, world heritage sites, wildlife habitats and timber, and also releasing CO_2 in the atmosphere. The effects from the large and reoccurring fires in combination with wrong post-fire management practices are devastating for both natural environment and human communities. Early wildfire detection contributes greatly in the forest protection and reduces considerably the extend of burned forest land.

Preservation of forests contributes to the significant reduction of Greenhouse Gas (GHG) removal towards improvement of the resilience of ecosystems to climate change while minimizes the impact of extreme weather phenomena such as flooding. Therefore, it is a very important to develop a system for early detection of wild fires towards protecting the environment contributing to the climate change resiliency.

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Traditionally, the common forest fires detection method is to use towers, located at high points, where a person looks for fires. Nowadays, automatic forest fires detection techniques and video surveillance systems have already be developed. All these systems are employing passive and active sensors, in order to create alarms when fires occur.

Forest fires are extremely complex physico-chemical processes, reflecting the different materials, the rouged terrain, the changing environmental conditions. The complexity of these phenomena leads to a large number of different signals produced during a forest fire, signals that can be intercepted by the fire detection sensors. The vast variety of fire detection sensors are comprised of:

- Video cameras. Their usability is based on smoke recognition during the day and fire flame recognition during the night.
- Infrared (IR) thermal imaging cameras. Their usability is based on detection of heat flux from the fire, [1], [2].
- Optical spectrometry that identifies the spectral characteristics of smoke, [3].
- Light detection and ranging systems that measure laser light backscattered by the smoke particles, [4].
- Radio-Acoustic Sounding System for remote temperature measurements and thermal sensing of a particular

forest region, [5].
- Acoustic Volumetric Scanner that recognizes the fire acoustic emission spectrum as a results of acoustic fire sensing, [6].
- Sensor network based system (in most cases wireless sensors). A number of sensor nodes are deployed in forest, measuring different environmental fire detection related variables, [7], [8].

Also, a number of systems that use Charge-Coupled Device (CCD) cameras and Infrared (IR) detectors installed on top of towers. Automatic video surveillance systems cannot be applied to large forest fields easily and cost effectively [9]–[11]. Thus, for large forest areas either aeroplanes or Unmanned Aerial Vehicles (UAV) are used to monitor forests [12]–[14]. Monitoring via planes can be costly, and the probability of accidents rises in the case of fires. On the other hand UAVs are very promising alternative, due to much lower costs and risks.

Furthermore, a number of forest fire detection systems are based on satellite imagery [15], [16]. The accuracy and reliability of satellite-based systems are largely impacted by weather conditions. Clouds and rain absorb parts of the frequency spectrum and reduce spectral resolution of satellite imagery which consequently affects the detection accuracy. The most critical issue in a forest fire detection system is immediate response in order to minimize the scale of the disaster. Therefore, a constant surveillance of the forest area is required. Current medium and large-scale fire surveillance systems do not accomplish timely detection due to low resolution and long period of scan. Therefore, there is a need for a scalable solution that can provide real time fire detection with high accuracy.

The main objective of this work is to model and develop a synergistic integration of mature technologies based on UAVs, stationary thermal/optical cameras assisted by a fire risk assessment model. In this paper, the development of an integrated forest monitoring system for early fire detection and assessment by using efficient hardware and software solutions is addressed. The proposed system could enable interested parties to react immediately, accurately and appropriately to a forest fire event. Also, it is a very important tool, especially for the local authorities, in order to ensure an accurate fire monitoring system and the same time to decrease the false alarms and the human stress.

This integrated system's approach offers the necessary and important automation for early fire detection and assessment, improving the current status of forest fire monitoring and surveillance systems at a more effective local level. The proposed system is completely appropriate, suitable and cost effective for forest monitoring and fire prevention in small islands, villages and mountain areas hard to approach.

Another important asset of this system is the use of UAV. The drone actions increase further the situation status information and therefore, decrease very significantly the false alarm events. Thus, the system is more sensitive and able to detect whether a real fire event may occur.

The most innovative feature of our work is the integration

Fig. 2: Integrated system main components.

of a large scale sensor for having small cost, continuous information available with smaller resolution, together with on demand high-resolution information obtained with a fast mobile sensor mounted on the UAV. This combination provides high quality information, high resolution, minimization of false events, while keeping the overall cost of the system small enough to be deployable on large scale. The very small time on which the UAV can reach the area of interest due to the fact that it is locally deployable, w.r.t. a manned plane that has to take off from a far off base, greatly reduces the time to response.

Moreover, a very important aspect, regarding the early forest fire detection, is that the time is running very quickly, meaning that the first second of an event is very crucial. Otherwise, the fire has exponential evolution and it is very hard to control and to restrict it. The forest fire extinguishers have to deal with a extremely hard task, since for the first second of fire a glass of water may be effective, for the first minute of fire a bucket of water may be enough, for the first five minutes it is needed to use a fire truck, but subsequently the fire may be uncontrollable. The proposed system is based around a single drone, but it is easily extendable to a larger number of drones, and offers a very sensitive and highly robust information, that allows a very quickly and effectively detection, prevention and reaction to fire events.

II. SYSTEM DESCRIPTION

The proposed system consists of stationary cameras that monitor the designated survey area, Fig. 1. At the same time it monitors the environmental conditions and assesses the threats on the fly based on parameters such as temperature, wind speed and wind direction. All data are fused together at an automated risk assessment operation. If a threat is detected with a risk assessment rating above a predefined threshold, interested parties such as municipality, forest protection service and firebrigate officers get notified through an SMS message and/or emails. If more data is required, a drone carrying visual and thermal camera is deployed, collecting more data for an accurate risk analysis. The additional data are fused with previous data for an updated risk assessment iteration. Interested parties get notified for every step of the

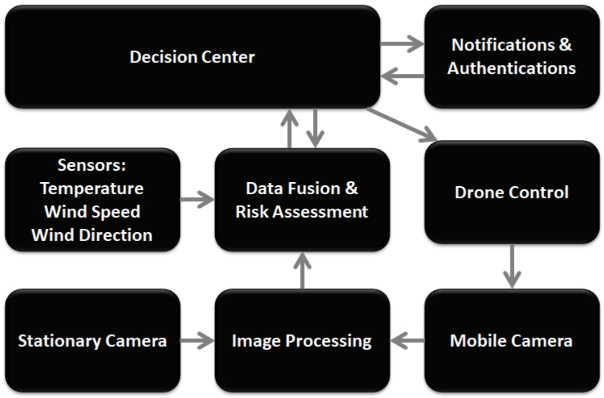


Fig. 3: System's designing and modules.

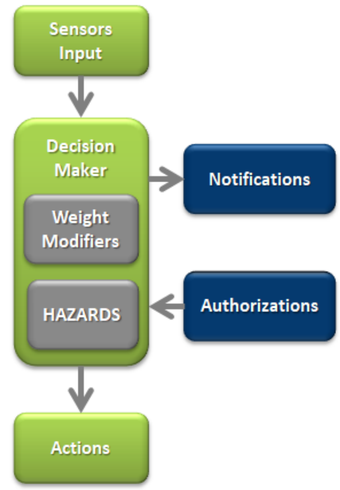


Fig. 4: Central decision module operation.

procedure and give their consent for critical steps of the procedure. The system can be a powerful tool that enable the key authorities to take decisions based on accurate data, Fig. 2.

III. SYSTEM DESIGNING

A crucial design parameter was the use of mature technologies, ideally off the shelf, since the goal is a system with high deployability. The main idea of the design is to build a completely scalable and robust system, that allows additions or/and removals of constituents without further modification. Central to the system, is the central decision module. This is developed using Robot Operating System (ROS). This main module must be responsible for any system's decision and also, is the responsible module to automatically detect and control all the peripheral modules, assesses the situation, Fig. 3. This module takes into account all inputs from sensors, evaluates conditions and notifies interested parties when necessary.

Furthermore, the required system's components, except the decision making module, are an image processing module which must be responsible for any data processing coming from the visual and thermal cameras, Fig. 3. Also, very important components are the environmental conditions processing modules. These modules must be on charge in order to analyze the environmental sensor data, like the wind speed and direction, the temperature conditions, as well as the online weather information.

Moreover, since a UAV must be in charge in order to collect more data when it is needed, a very important module must be a drone control module. The "brain" of the system is the critical risk assessment module that inform the overall system when a fire danger is occurred. The completion of the system's design needs to incorporate a notifications and authentications module, that must be responsible for any communication with the authorities and interested parties.

The main sensors of the proposed system are the optical and thermal cameras of the static station. Whenever extra information is required an aerial unit can be deployed for extra optical and thermal data. Optical and thermal sensors will be using algorithms for smoke and fire detection at an image processing module, identifying and assessing threats.

Other sensors that are used are environmental sensors (temperature, wind speed, wind direction, humidity, etc.), as well as on-line forecast information. These sensors can be located on site or at various locations connected to the central processing station remotely. The system is developed in a modular architecture, allowing future sensor additions to the system seamlessly.

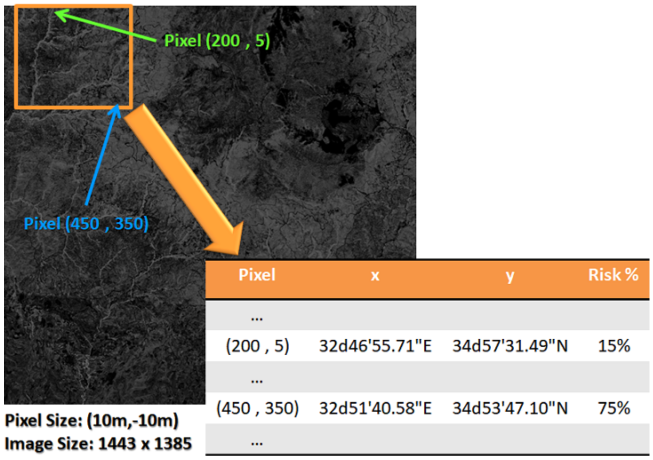
A. Central Decision Module

The central decision module is the most important module of the system. Its operation is depicted in Fig. 4. This component is the supervisor that controls every system's operation and function. It is responsible to connect with every other module and to receive all the inputs from the system sensor or operation. All the decision and necessary action of the system is issued by this module, e.g. the drone deployment in order to operate and survey in a specific location, etc. Also, it is monitoring all the system modules' health, and the same time it is able to handle any notifications and authentications messages, as well as any other required actions.

Another important characteristic of this module structure is its scalable design without a need of the code modifications when a new component is added or changed. This design characteristic is crucial for the system to work "on the wild", since different components will be added, and the continuous operation must be guaranteed.

B. Drone Control Module

The drone control module is responsible for managing the drone actions and plans. A pilot must be in charge during the whole drone's mission, since the legislation requires that the drones flight must be under human surveillance. Also, a pilot must be responsible for all the necessary regulations during the automated flight. To this end, the system issues a required path which will be transferred to the drone as a mission file. An appropriate Software Development Kit (SDK) monitors



Pixel	x	y	Risk %
...			
(200 , 5)	32d46'55.71"E	34d57'31.49"N	15%
...			
(450 , 350)	32d51'40.58"E	34d53'47.10"N	75%
...			

Fig. 5: Risk assessment map and information.

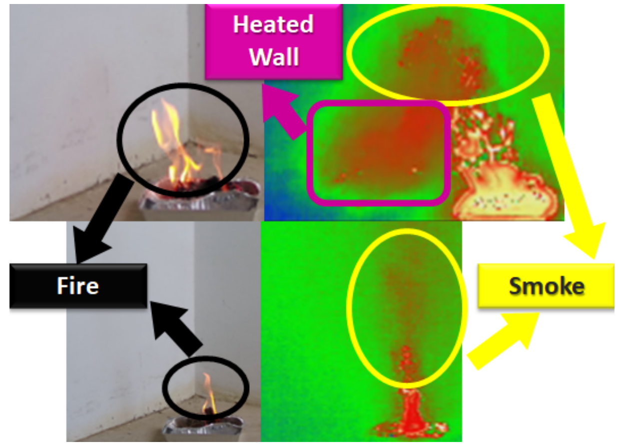


Fig. 6: **Left:** optical, **Right:** thermal cameras examples of the segmented fire regions in a controllable fire scene.

the drone and the camera attitude. All the captured images will be processed at control station.

An appropriate algorithm (e.g. a randomly search algorithm) will to navigate the drone over the forest. An automated model with well-defined procedures will enable the drone to navigate autonomously. The components of those procedures are the following:

- **Automated take off and land procedures:** During this procedure the drone will be able to take off at a specific altitude above the ground and start its mission. As for the land procedure, we will adopt an inverse model of take off.
- **Motion planner:** this algorithm will generate a feasible path from drone's take-off location to possible location of fire, using a predefined map.
- **Flying pattern over the fire:** this module will command drone to fly above the fire with a predefined pattern (cycle,square,etc).

C. Data Fusion and Risk Assessment Module

The data fusion and risk assessment module is responsible to manage all the information coming from the sensors and the environment, combining them with the risk assessment tool, in order to conclude the information regarding the place and the level of fire risk in the area.

All inputs in the proposed system must have the same information template in order to be enable the automatic processing of the current environmental risk situation. The proposed system is designed such as all the information inputs to include unique names, exact locations, sensor's specific types and values, as well as the estimated probability of a risk and its exact location.

The risk assessment tool is based on a predefined map of the forest area, that is useful in order to extract the risk of fire in a specific place, Fig. 5. More specifically, this map contains all the necessary information for each place, in the form of pixel raster. Therefore, for each region there are available the exact location, as well as the risk of fire based on its local morphology and topology. The algorithm utilized for calculating the fire risk to balance efficient representation and accuracy.

Some examples are described in the Fig. 5, where the pixel $(200, 5)$ corresponds to a low risk region (15%), since it is a river place, while the pixel $(450, 350)$ corresponds to a higher risk of fire region (75%), a fact that reflects the specific type of trees.

D. Notifications and Authentications Module

The notification and authentication module is responsible for the communication between the system and the responsible authorities and interested parties. To this end, the system is equipped with the ability to send notifications, alerts and information of the current status. Also, the system is capable to send more information and rapid updates the users frequently, based on the alerts. Furthermore, the system is featured with the process of collection and/or sending status reports according to a schedule or upon a request.

Another important feature of this module is the authentication of decisions, since for some actions authentication is required. For example when the risk of fire or the presence of fire/smoke the static camera control maybe need the user intervation.

The notifications to interested parties are performed using SMS. For SMS notifications a GPRS system is connected to the base station computer. With the same module authorisations could be given. For example for the drone to take off an SMS should be sent from a specific number (or list of numbers) authorizing the drone deployment.

The system is capable to send different types of status notifications to interested parties, as following:

- **Preprogrammed status notifications:** These are sent on a designated time with information on the maximum threat level during the day. The information include the level of threat, the time it occurred and the position it occurred.
- **Requested status notifications:** at any time, an interested party could request a status report through SMS.

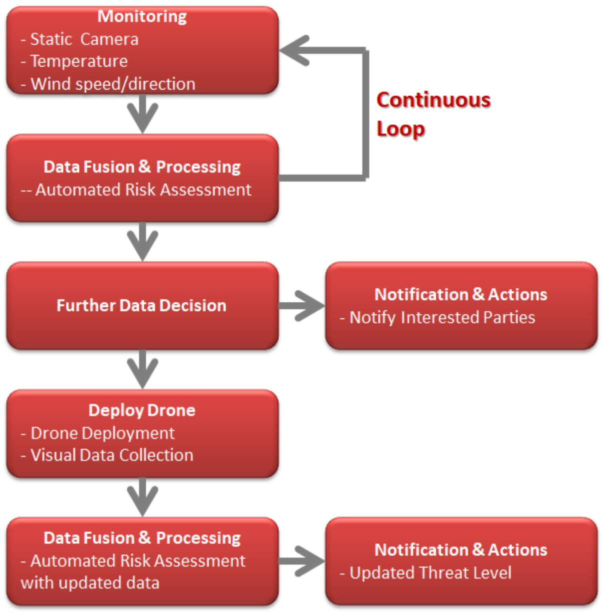


Fig. 7: Intergraded system's data processing flowchart.

The base station sends the current status report to the interested party requesting it.

- **Update report status notifications:** once the threat level is raised, through the risk assessment, above a programmed threshold all interested parties receive notifications. These notifications include drone status (deployed, landed) as well as the threat level updated assessment.

E. Image Processing Module

The image processing module is responsible to analyze the data captured by the system's cameras, both thermal and optical. The detection of fire or/and smoke using the images from the cameras is the indication of fire alert. The images first are captured by the static cameras and when it is needed, the drone deployment provides further images by the moving cameras. These last images are very important for fire identification purposes. Images are analyzed for deciding whether there is a fire or smoke in the scene in order appropriate actions be activated.

This module concerns an image segmentation method based on temperature and color images captured by the thermal and optical camera. Thermal camera is used for fire and smoke detection and identification by exploiting the high temperature of fire and smoke and their variability with respect to other objects existing in the forest scene. If the flame is "visible" from the thermal camera it produces high intensity values in the infrared spectra.

Some example of these kind of images are depicted in Fig. 6, where a pair of optical (left) and thermal (right) images that captures the same part of a scene and the same time of instant, are presented. The bottom pictures show the segmented fire regions in a controllable fire scenes, during the beginning of a fire for both the optical and thermal

Fig. 8: Integrated thermal and optical bi-spectrum network positioning system HIKVISION DS-2TD6266.

Fig. 9: Intergraded drone dji MATRICE 210 with dual downward gimbals, optical camera dji ZENMUSE X5S (left) and thermal dji ZENMUSE XT (right).

camera. The pictures above depict the status of fire after some time instances. It is obvious that some times the smoke presence is not captured by the optical camera, while the thermal camera can successfully detect the smoke. For this reason measurements of thermal camera can be used to improve the system's accuracy.

While smoke is a very useful factor for early fire detection, because of its faster appearance in camera's view, it isn't visible during the night time, due to the low luminance of the scene. This necessities the combination of optical and thermal cameras. The algorithms utilized for this fusion process, are versatile. For the initial deployment of the system, simpler, off the shelve algorithms are utilized. Deployment of more complex algorithms is easy due to the modular nature of the system, while we believe that the real data obtained from the experiments will reveal the adequacy of the utilized algorithms.

IV. SYSTEM INTEGRATION

The intergraded system operation is based on the data processing procedure as depicted in Fig. 7.

All information collected by the static cameras (optical and thermal) and the environmental conditions (temperature, wind conditions, forecast, etc.) is processed by the data fusion module, in combination with the risk assessment map. The continuous monitoring of those data detect whether a threat is appearing. The system is collecting and sending status report as it is scheduled.

If a threat is close to a predefined level, whether something is detected, and/or the environmental conditions are critical, the system has the ability to inspect a suspicious specific location more frequently by rearrange camera's operations.

When the level of risk is above a threshold the system notify the authorities to alert them about the threat. At the same time the system sent the command to the drone in order to act immediately and drive it to a specific location. Also, the responsible pilot, who is in charge to survey the drone flight, is informed to take care of any drone actions.

In this situation all the information is collected by all the cameras and the sensors is used by the system to rapidly assess and identify the exact location of the fire and to estimate its evolution, in order to help the authorities to act immediately and accurately.

The integrated system it is ready for experimental testing and validation in close-to-operational conditions in field fire experiments with controlled safety conditions carry out in Pano Platres forest in Cyprus.

The stationary cameras are placed in a hill to cover panoramically the village and the forest, as depicted in Fig. 8. The intergraded system consists of a thermal and optical bi-spectrum network positioning system HIKVISION DS-2TD6266.

The used AUV system is depicted in Fig. 9. The intergraded system consists of a drone dji MATRICEe 210 with dual downward gimbals, an optical camera dji ZENMUSE X5S and a thermal camera dji ZENMUSE XT.

The control center that collect and process all the information and system's actions and operations, is placed at the village of Pano Platres, to be under control of municipality, forest protection service and firebrigate officers.

V. CONCLUSIONS

This paper presents a novel integrated system for automatic early detection of wild forest-fire. The proposed system consists of stationary optical and thermal cameras that monitors the designated survey area. At the same time it monitors the environmental conditions and assesses the threats on the fly based on parameters such as temperature, wind speed and wind direction. All data are fused together at an automated risk assessment operation.

If a threat is detected with a risk assessment tool rating above a critical threshold, interested parties get notified through an SMS message and/or emails, and a drone carrying optical and thermal cameras is deployed, in order to collect more data for an accurate risk analysis. Interested parties get notified for every step of the procedure and give their consent for critical steps of the procedure. The system can be a powerful tool that enable the key authorities to take decisions based on accurate data. The great advantage of the system is the combination of steady and mobile sensors, that result in a minimization of the cost w.r.t. the obtained resolution.

The proposed system has been integrated and it is ready for experimental testing and validation in close-to-operational conditions in field fire experiments with controlled safety conditions carry out in Pano Platres forest in Cyprus.

The experimental phase will provide us with crucial data regarding the efficacy of the setup. Improvements on specific components will be guided by the results of the experimental phase. Moreover, we are already working on extending the system capabilities, by adding a number of drones and fusing the appropriate data, by working on a complete autonomous system that can be used without supervision, given a relaxing of the regulations. A detailed economic analysis of the efficacy of this system compared to alternative solutions is also under completion. Specifically the system is compared either to a system of mounted high resolution sensors, to a system of mount low resolution sensors(network of cheap sensors), to a system of large scale surveillance (manned airplane or satellite) where the response time, the cost, the resolution and the overall robustness is modeled to further quantify the advantages of the system.

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