UAV & SAR 2017
DRONES IN
RESCUE OPERATIONS

Rome, March 29th, 2017

VIGILI DEL FUOCO CORPO NAZIONALE

UAV-based photogrammetric 3D modelling and surveillance of forest wildfires

Research @ RFSAT Ltd

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Research for Science and technology (RFSAT) Ltd

AF3 Project: Overview

Project:	Advanced Forest Fire Fighting
Abbreviation:	AF3
Description:	AF3 project provides a significant improvement to the efficiency of current fire-fighting operations and to the protection of human lives, environment and property by developing innovative technologies and means to ensure a high level of integration between existing and new innovative systems.
Period:	1st May 2014 - 30th April 2017 (extended to end of July 2017)
Coordinator:	SELEX Galileo S. p. A.
Funding scheme:	Collaborative Project (CP) Large scale integrating project (IP)
WP topic:	Preparedness for & management of large scale forest fires
Consortium:	19 partners from 10 countries
Project funding:	€ 12.986.616

AF3 Advanced Forest Firefighting

AF3 Project: Generic Architecture

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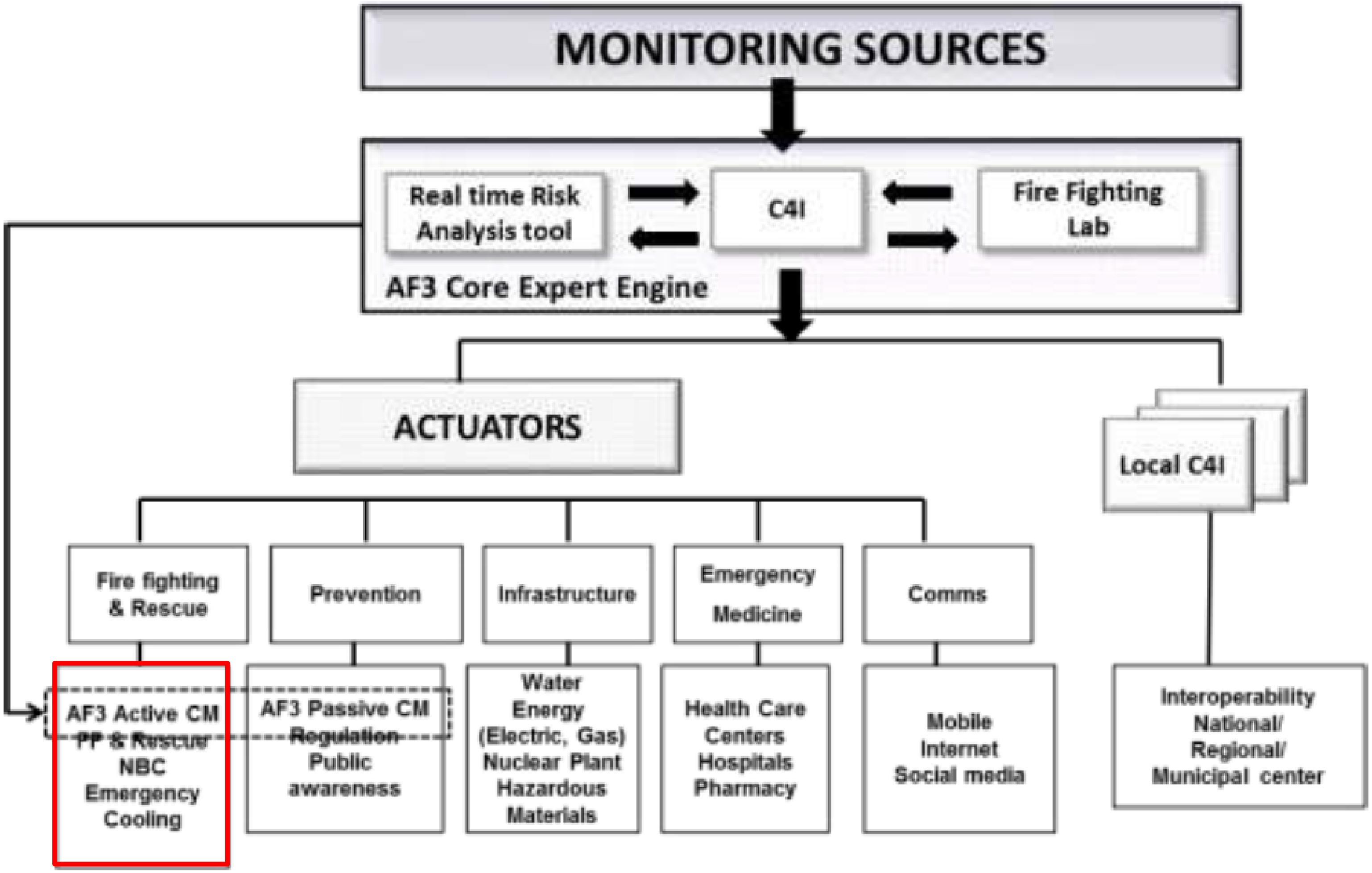


UAV surveillance & 3D modelling
NIR Spectral-based fire sensing

Fire detection

- IR detectors typically not as sensitive as visible light (silicon) devices and offer lower resolution
- IR detectors in general require cooling (bolometers as an exception)
- Small fires may lead to larger burns and can be used also as predictors of the fire spread.
- Classical approach to forest fire detection/monitoring is satellite and/or thermal imaging
- Small fires (sub-pixel events on satellite images) are indistinguishable from specular reflections.
- Detector measures the total power. For a particular pixel, the same power can be obtained from warm reflective surface over large area (false event) or a cold background with fire ('true" event).
- Distinguishing a fire requires a differential condition e.g. by comparing with adjacent pixels.
- A large, hot fire will saturate a detector designed to look at Earth-ambient temperatures (300K)

- **Biomass fires are usually composed of only few components**
  - Significant (by weight): C (45%), H (5.5%), **O (41%)** and N (3.5%)
  - Traces: **K (up to 7%)**, Na (0.1%), P (up to 1%) and Ca (up to 5%)

- Alkali metals have special characteristics, making them suitable for narrow line detectors:
  - Alkalis have a filled shell core to electrostatically shield outer electron from positive nucleus
  - Alkalis are very reactive, forming strong ionic compounds and are the 'ion-pumps'
  - Alkalis are ubiquitous in living material
  - In fires alkalis excite and atoms ionise, recombine with other atoms producing emission line

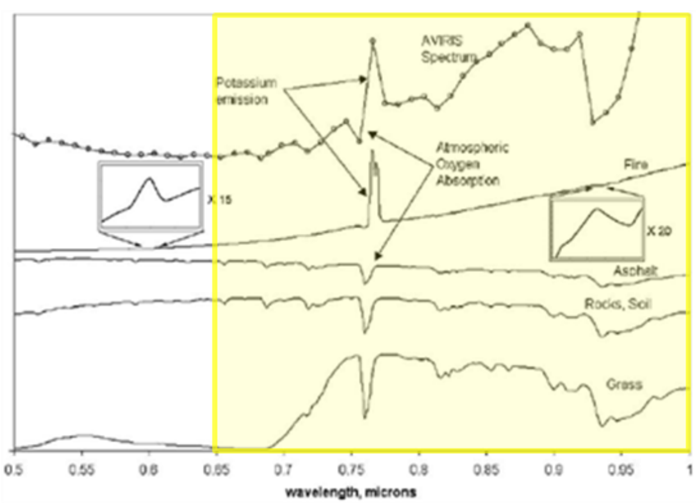
Fire detection using NIR spectrometry

Principle of operation:

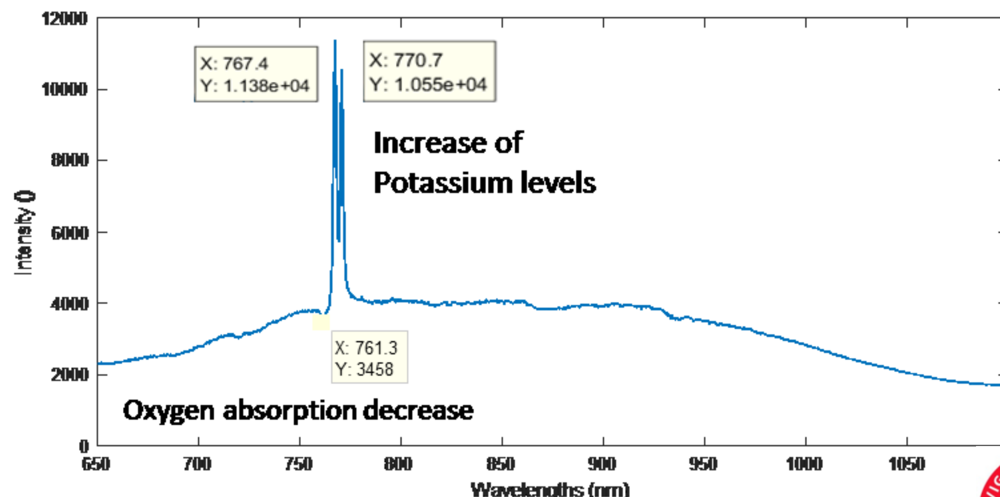
- detection of potassium & oxygen absorption peaks in NIR spectrum
- Ionized potassium created easily distinguishable peaks near 767.4nm and 770.7nm
- Oxygen absorption causes small drop in NIR spectrum near 761nm
- Potassium emission is specific to flaming combustion. When sensing together with blackbody emission, detecting warm or hot spots, there is the potential to separate smouldering from flaming vegetation.

Reference: A. Vodacek, R. Kremens, et al, "*Spectral Features of Biomass Fires*", Digital Imaging and Remote Sensing Laboratory (RIT)

Expected absorption effects of atmospheric gases for materials common for forest fires (obtained from controlled burn [reference])

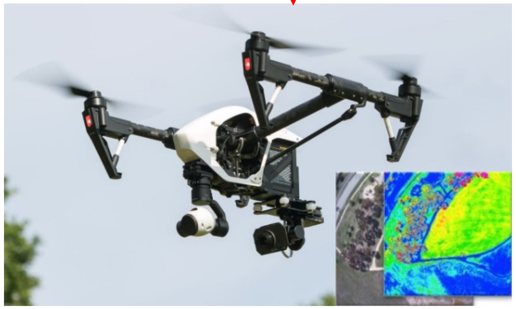


Samples of measured data from the developed NIR spectrometer during life firefighting tests in Athens (left)



Using micro-UAVs for fire monitoring

- UOW's DJI Inspire 1 micro-UAV crashed during the trials in Athens. As such, it will be unavailable for tests in Israel. A backup DJI Mavic Pro will be used.
- NIR Spectrometer sensor for re-ignition detection will be presented in handheld version
- Furthermore, the thermal camera designed for Inspire 1 will NOT be presented in Israel
- Mavic Pro will be used in Israel to demonstrate:
  - Real-time surveillance of the incident area
  - Autonomous imaging over pre-defined mission area for 3D modelling



- Current work focuses on:
  - **Simultaneous visual & thermal imaging** for:
    * improving situation awareness in incident management
    * improving damage analysis using multispectral 3D area models
  - **Simulation of autonomous (swarm) UAV control**:
    * DJI Simulator is to be used to lower risks of accidental crashes
    * Uses a physical drone, but does NOT take it off
    * Swarm control capability is still TBC

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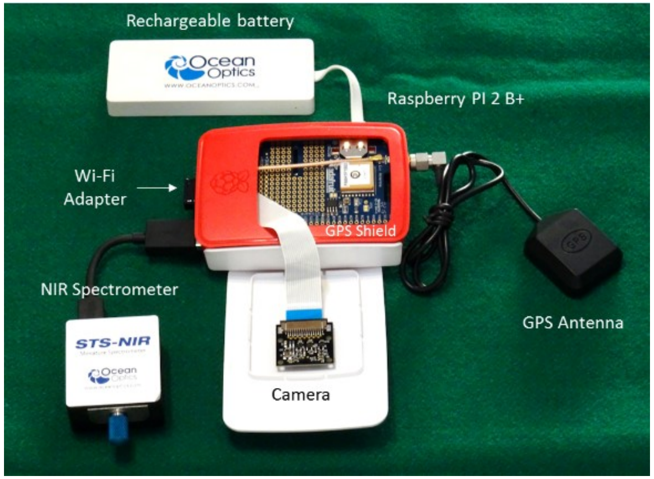
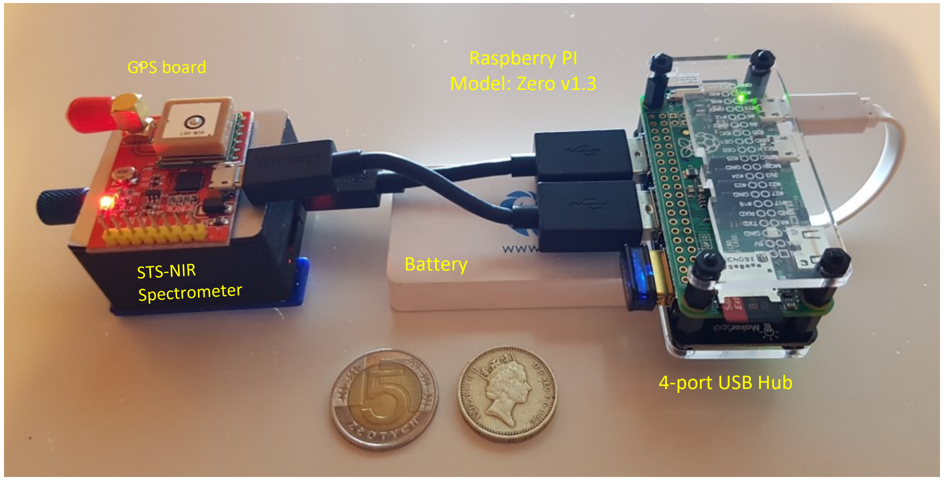
Micro-NIR Spectrometer Sensor for UAVs

- Embedded STS-NIR spectrometer from Ocean Optics used for the UAV-based fire sensing: https://oceanoptics.com/product/sts-nir-microspectrometer/
  - *Spectral range*: 650-1100 nm
  - *Optical resolution*: 1.5 nm FWHM (w/ 25 um slit)
  - *Signal-to-noise ratio*: >1500:1 (at maximum signal)
  - *Dynamic range*: 4600:1 single acquisition
  - *Connectivity*: USB and RS-232
  - *Integration time*: 10 µs - 10 seconds with custom integration time
- RASPI v.3 (1st version) and RASPI-Zero v.1.3 (2nd version) used for on-board computer and WEB server
- Additional multi-constellation GNSS receiver precisely geolocates and timestamps the measurements
- **NEXT STEPS**: UAV power (DC-DC) will reduce need for own battery, soldered USB connection will reduce cables

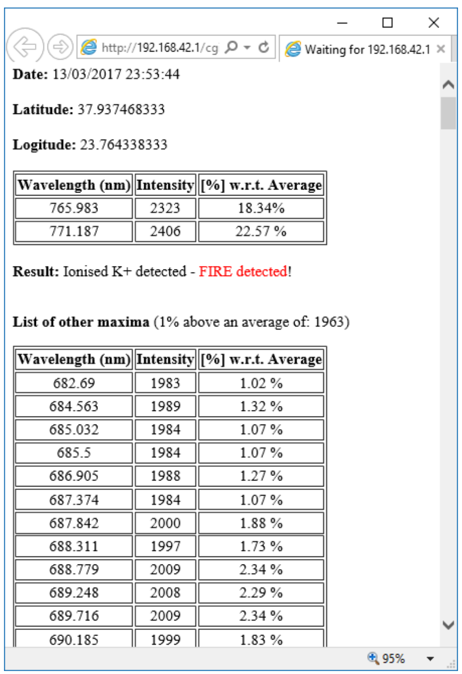




Micro-NIR Spectrometer Sensor for UAVs

- Embedded WEB server was written in PHP using templates provided in the SDK from Ocean Optics
- ***Features***: capture, configuration and data transfer, accessible remotely via on-board WEB server
- Clients can make direct connection to the drone for accessing NIR sensor information
- ***New features:*** custom configurations, peak-based waveform analysis for determining existence of potassium emission with oxygen absorption for creating fire alerts, geolocation of measurements via independent GNSS unit.

GNSS satellites



http://192.168.42.1/cg Waiting for 192.168.42.1

Date: 13/03/2017 23:53:44

Latitude: 37.937468333

Logitude: 23.764338333

Wavelength (nm)	Intensity	[%] w.r.t. Average
765.983	2323	18.34%
771.187	2406	22.57 %

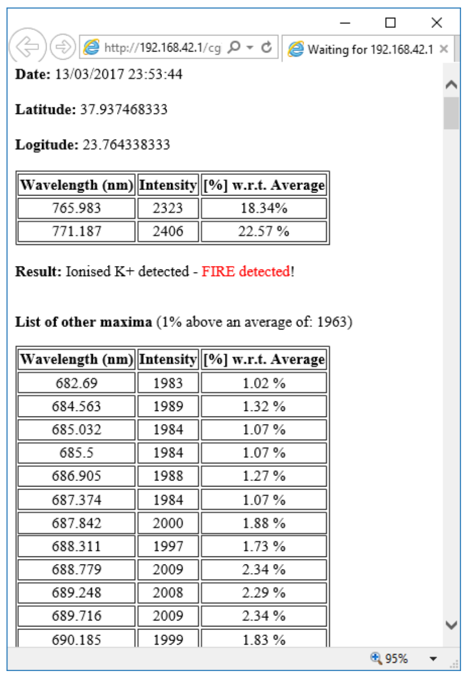
Result: Ionised K+ detected - FIRE detected!

List of other maxima (1% above an average of: 1963)

Wavelength (nm)	Intensity	[%] w.r.t. Average
682.69	1983	1.02 %
684.563	1989	1.32 %
685.032	1984	1.07 %
685.5	1984	1.07 %
686.905	1988	1.27 %
687.374	1984	1.07 %
687.842	2000	1.88 %
688.311	1997	1.73 %
688.779	2009	2.34 %
689.248	2008	2.29 %
689.716	2009	2.34 %
690.185	1999	1.83 %

95%

Sensor configuration



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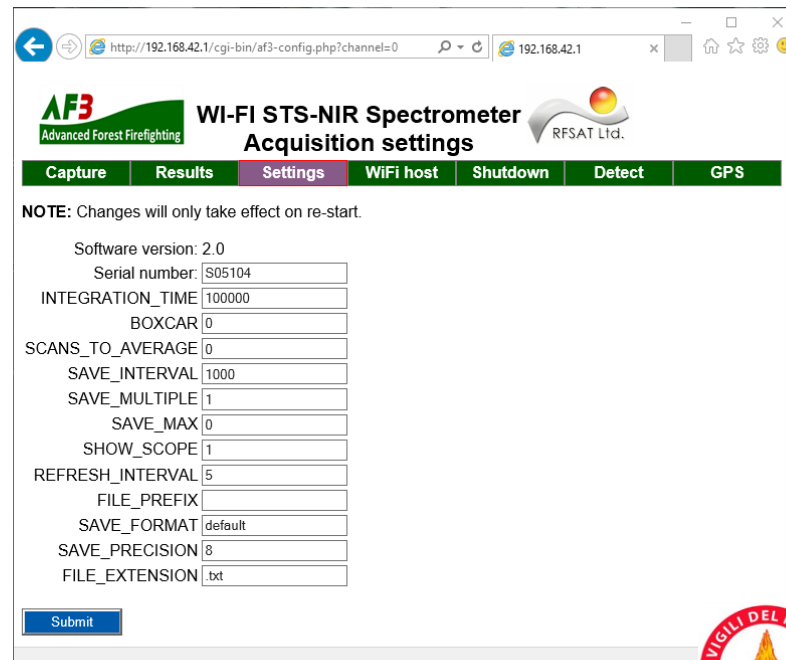
95%

Fire detector with list of all peaks detected



http://192.168.42.1/cgi-bin/af3-config.php?channel=0 192.168.42.1

AF3 Advanced Forest Firefighting

WI-FI STS-NIR Spectrometer Acquisition settings

RFSAT Ltd.

Capture | Results | Settings | WiFi host | Shutdown | Detect | GPS

NOTE: Changes will only take effect on re-start.

Software version:	2.0
Serial number:	S05104
INTEGRATION_TIME	100000
BOXCAR	0
SCANS_TO_AVERAGE	0
SAVE_INTERVAL	1000
SAVE_MULTIPLE	1
SAVE_MAX	0
SHOW_SCOPE	1
REFRESH_INTERVAL	5
FILE_PREFIX	
SAVE_FORMAT	default
SAVE_PRECISION	8
FILE_EXTENSION	.txt

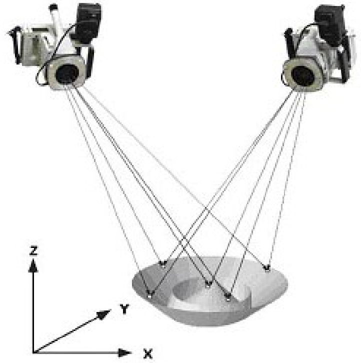
Submit

Photogrammetric 3D area modelling

Photogrammetry is used to make measurements from photos for recovering exact positions of surface points.

Images acquired from UAVs can be used to create 3D models of the area for:

- estimation of forestation and volume of biomass under tree canopies, i.e. potential flammable material
- identification of urban areas and damage analysis after the incidents (one of purposes in the AF3 project)
- Images should be taken autonomously using pre-defined fly paths, although free-flights might be useful too
- Commercial photogrammetric software: Pix4D tools, Autodesk ReMake, Agisoft Photoscan, Artec 3D Studio etc.
- The 3D modelling is a very computationally intensive process, hence cannot be practically done in real-time
- Processing time may be lowered using e.g. NVidia GeForce graphics cards (taking advantage of their CUDA cores)
- Time ranges from tens of minutes to hours, depending on images, target resolution and available computer type
- Best used for advance surveillance of forest areas and assessment of damages
- During firefighting accuracy may lower due to smoke, dust and air turbulences
- Model scans be also built from thermal images (trials in Leon)



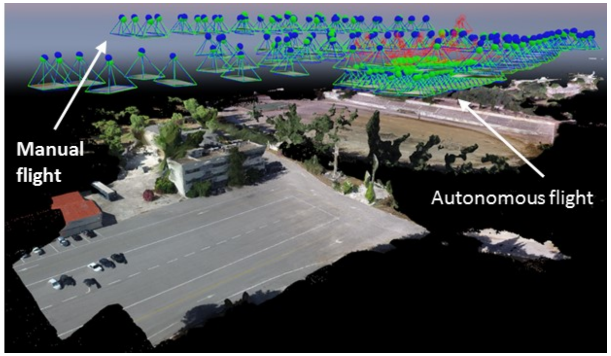
1st trials in Athens (May 2016)

First real-life trials in Scaramanga Naval Base near Athens (Greece) in May 2016

Images: DJI Inspire 1 with X3 camera (HD resolution) form altitude of 30 meters over regular corridors

Processing: (1st): 8 core 2.6HGz Intel i7 32GB, (2nd): 8-core 2.8GHz Intel i7 32GB + dual NVidia GeForce GTX 1080 (CUDA)

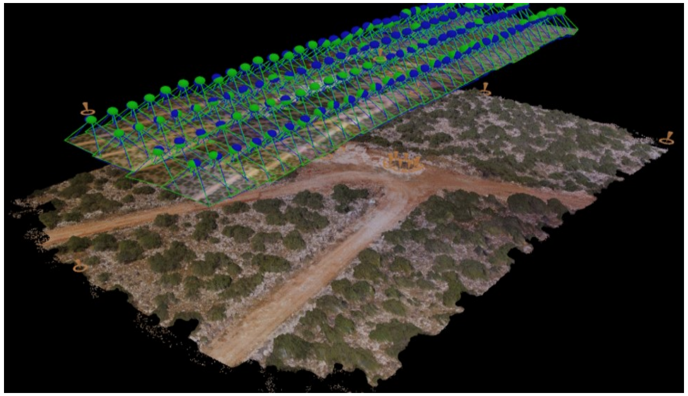
C4I (Naval base) - 300 x 100 meters

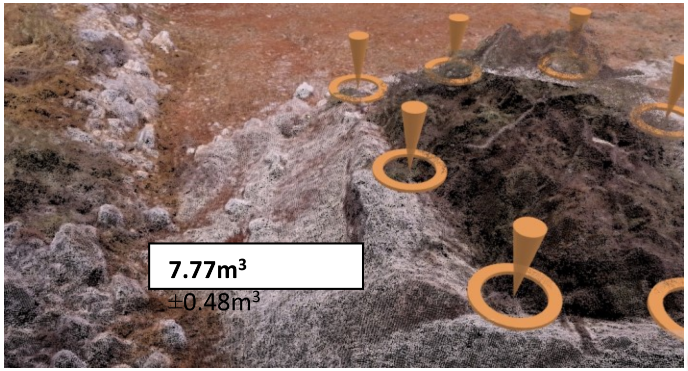


Results

Flight time:	15 min
Image no.:	212 / 120
Resolution:	2cm
Volume error:	~7%
Process time:	~16 hrs ~4hrs

Aerial pellet drop targets – 100 x 30 meters





Advanced Forest Firefighting

2nd trials in Leon, Spain (November 2016)

Second (2nd) real-life trials in Leon (Spain) in November 2016

Images: DJI Matrix 600 with X3 camera (HD) from altitude of 30 meters over irregular corridors

Processing: 8-core 2.8GHz Intel i7 32GB + dual NVidia GeForce GTX 1080 (2 x 2560 CUDA cores)

Results:

Image number: 18

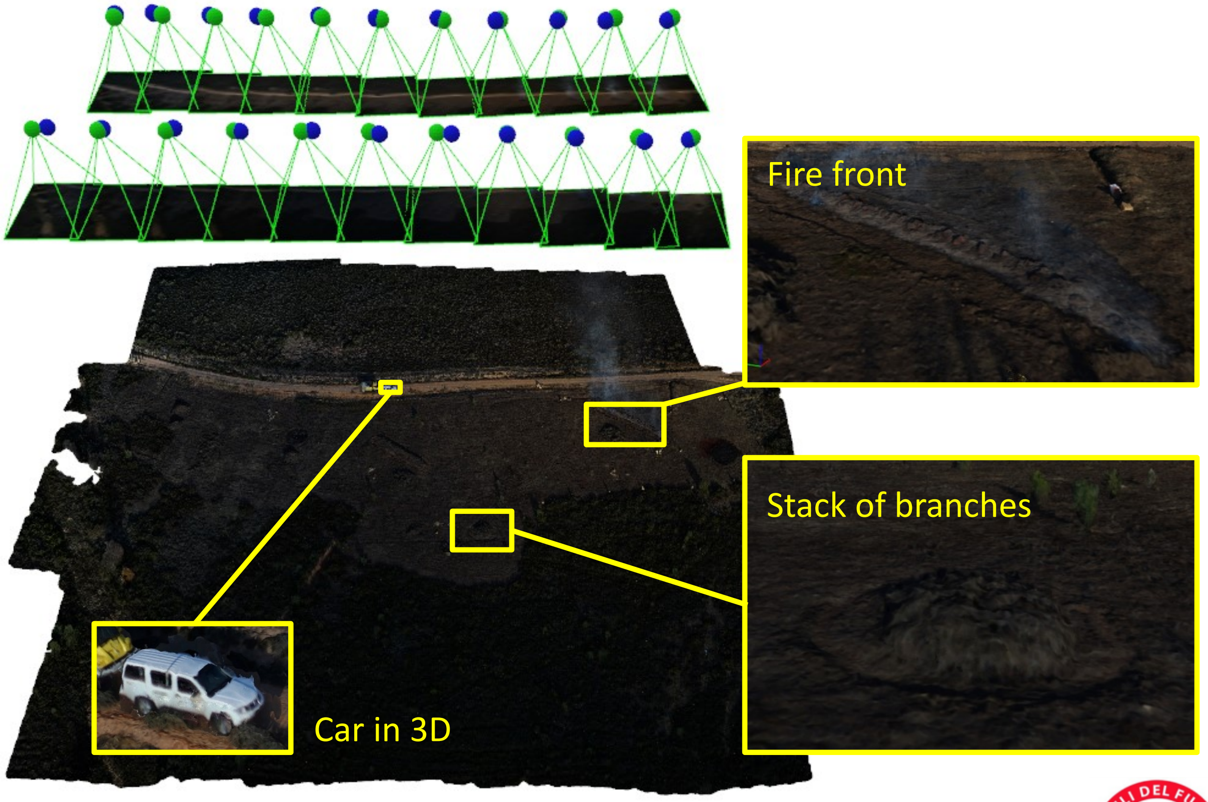
Geocoding: GPS (2 m)

Resolution: single cm

Processing time: ~4hrs

Drawbacks:

- 2-path flight does not give enough image overlap, hence low accuracy
- Visual fire identification difficult for fire front and target assessment



Acknowledgment:
Images captured by TRAGSA with DJI Matrix 600

2nd trials in Leon, Spain (November 2016)

Second (2nd) real-life trials in Leon (Spain) in November 2016

Images: DJI Matrix 600 with FLIR 640 (640 x 512 pixels) from altitude of 30 meters in free flight

Processing: 8-core 2.8GHz Intel i7 32GB + dual NVidia GeForce GTX 1080 (2 x 2560 CUDA cores)

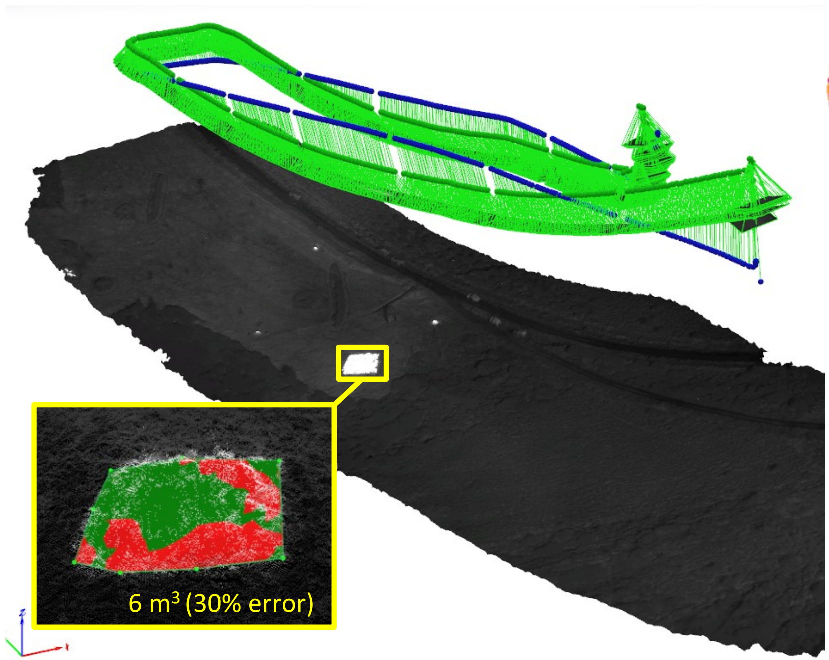
Results:

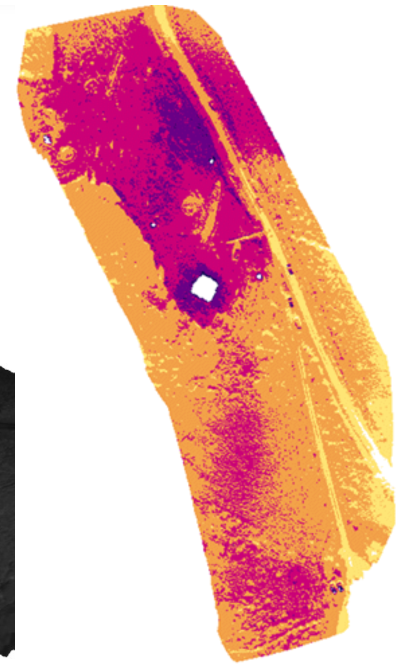
Image number: 2692 (high overlap)

Geocoding: GPS (2 m)

Resolution: single cm

Processing time: ~16-20 hrs





Advantages:

- Clearly visible fire front and fire targets

Drawbacks:

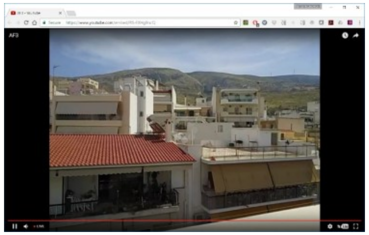
- Many low-resolution images, hence low model and volume resolution
- Images taken in flight (nose down) causing false ground curvature in a model

Acknowledgment:
Images captured by TRAGSA with DJI Matrix 600

Video streaming from micro-UAV to C4I

Real-time video streaming from pilot console to private/public channels:

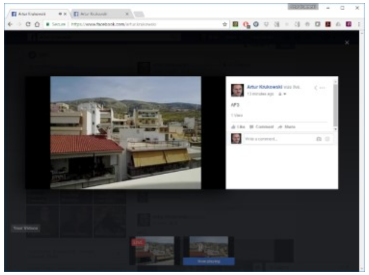
- *Applications*: Built into flight control applications e.g. DGI Go
- *Supports*: YouTube, Facebook Live, custom RTMP (e.g. WOWZA server)
- *Drawbacks*: Slows down flight control application, long delays and service breaks



YouTube streaming

Remote desktop connection from C4I to the pilot controls:

- *Applications*: Team Host (pilot) and Team Viewer (C4I)
- *Features*: Screen sharing & flight control gives full access to Android device
- *Drawbacks*: Not possible to restrict remote access to video only



Facebook Live streaming

Remote desktop connection to local PC, video capture from HDMI and transfer to C4I:

- *Applications*: HTTP Screen (Android-PC) & custom RTSP/RTMP encoder on local PC
- *Features*: Streaming live the screen of the flight console in secure way
- Advantages: Fast connection to local PC via Wi-Fi, private link to C4I (e.g. satcom)
  No losses of speed in the flight control application
  Safety against remote interference with flight controls
  Can be deployed over private network connections (no 3rd party services)

Team Host for Android

Counter rogue drone developments

- Autonomous UAS systems protecting against rogue drones violating restricted incident air spaces
- Early detection of intended intrusion, tracking and localisation of the drone operator
- Effective against common commercial civilian micro drones
- Implements both passive and active countermeasures

Passive Countermeasures

- Detection of remote control signals and/or visual recognition (autonomous UAVs)
- Short-range and/or directional jamming of the communication link to the operator
- Short-range and/or directional jamming and substituting synthetic GNSS signals

Active Countermeasures

- Seizing control of the rogue drone by hacking into control system
- Physical interception / taking down

Ongoing developments

- Coordinated operation of swarm of interception UAVs (remote and autonomous)
- Autonomous mission execution to counter jamming

Conclusions

Use of micro-UAVs has been proven to be a useful tool for wild forest firefighting:

- It can reach areas that are not accessible or risky for firefighters and/or first responders
- They can carry cameras (visual, thermal etc.) and embedded sensors (NIR spectrometer, CO/CO2/smoke sensors etc.)
- Detection of both live fires under tree canopies and re-ignitions after extinguishing fires can be detected/verified
- Drone control can be given over network to remote C4I for both real-life video surveillance and remote flight control
- Streaming video and remote flight controls are feasible:
  * YouTube and Facebook live exhibit very low framerates (<4 fps) and frequent service interruptions
  * Custom streaming engines e.g. WOWZA with good frame rates, have significant delays (even exceeding 30 seconds)
  * Best performance achieved with Team Host for Android: > 15 fps with 3.4Mbps (average) - 13Mbps (peak) rates
- Images/videos (both free flight and regular grid) can be used to produce very accurate 3D models of incident areas
- 3D models may be precise sufficiently to offer precise understanding of (potentially) burning biomass, even < 5%
- Autonomous surveillance missions may be performed (predefined paths or autonomous using custom applications)
- Two real firefighting trials in AF3 project have confirmed above conclusions (final test planned in Israel, April 2017)