ADVANCES IN UAS FOR FOREST FIRE FIGHTING

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Motivation

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Sensors see through the smoke

Real-time fire monitoring

Reduce risk for humans

Monitoring during night

Motivation

- UAS are aerial platforms capable of autonomous operation and multiple monitoring capabilities: scientific data gathering, environmental control, GIS, etc.
- Fire detection/monitoring is a potential scenario in which UAS may become a real asset in a civil application.
- However, several factors are limiting its development:
  - Understanding the real needs of fire fighting units.
  - Integration of UAS with other aerial resources.
  - Specific UAS mission design for fire fighting operations.
  - Specific technological requirements needed to be integrated in the UAS to allow the true exploitation of the system.

– An specific study is needed if such system should be ever operated by fire fighting personnel.

Motivation

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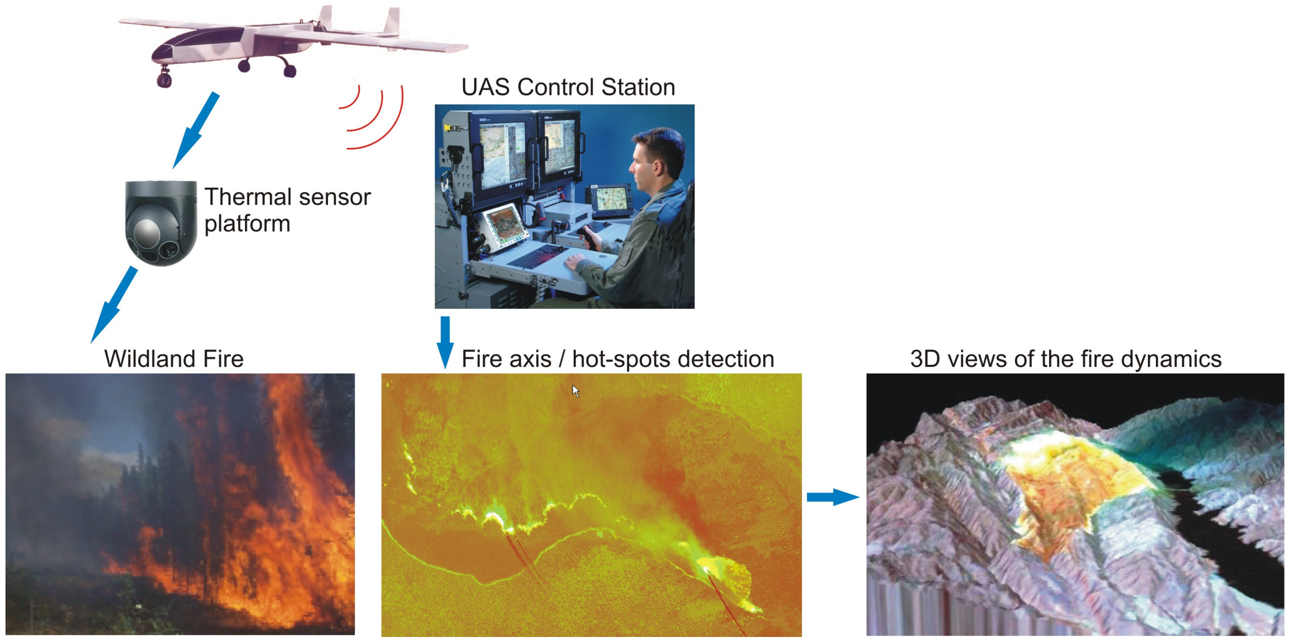
- System conceptual view:

  allow detection/monitoring of forest fires...



- But which are the real application limits?

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Motivation

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- Project **Sky-eye**: Design and prototype a system to be operated by Spanish regional fire-fighters:
  - Identify effective application scenarios in the selected context.
  - Design operational strategies.
  - Identify information flow requirements and implement the technology to support them.
  - Develop a limited UAS platform to evaluate new strategies and systems.
- Joint work with GRAF (Forest Activities Reinforce Group). Elite group created back in 1999 after forest fires started to exceed traditional extinction capabilities.
- GRAF develops new fire extinction strategies and decision taking tools (e.g. based on computer models), even though it remains an operative group.

Outline

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- Background
- Elements that condition UAS application
- Proposed system architecture
- Technology innovation
  - Distributed system architecture
  - Mission control
  - Communication gateway
- Application domains
- Conclusions

Background

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- Multiple initiatives to evaluate the potential application of UAS to help forest fire fighting:
  - Firebird 2001: Fire Fighting Management Support System
  - ERAST / FiRE: NASA Project Design
  - WRAP: NASA / US Forest Service Project
  - Fire detection by Szendro Fire Department, Hungary
  - ….

Firebird 2001

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- MALAT Division of Israel Aircraft Industries
  - Demonstrated a system capable of fire monitoring during 1996 based on the Firebird and Heron platforms:
  - Firebird:
    - Payload 25 kg, endurance 5 h cruise 60 KIAS, operating altitude 15,000ft.
  - Heron:
    - Payload 250 kg, endurance 40 h cruise 80 KIAS, operating altitude 35,000ft.

ERAST / FiRE NASA Project

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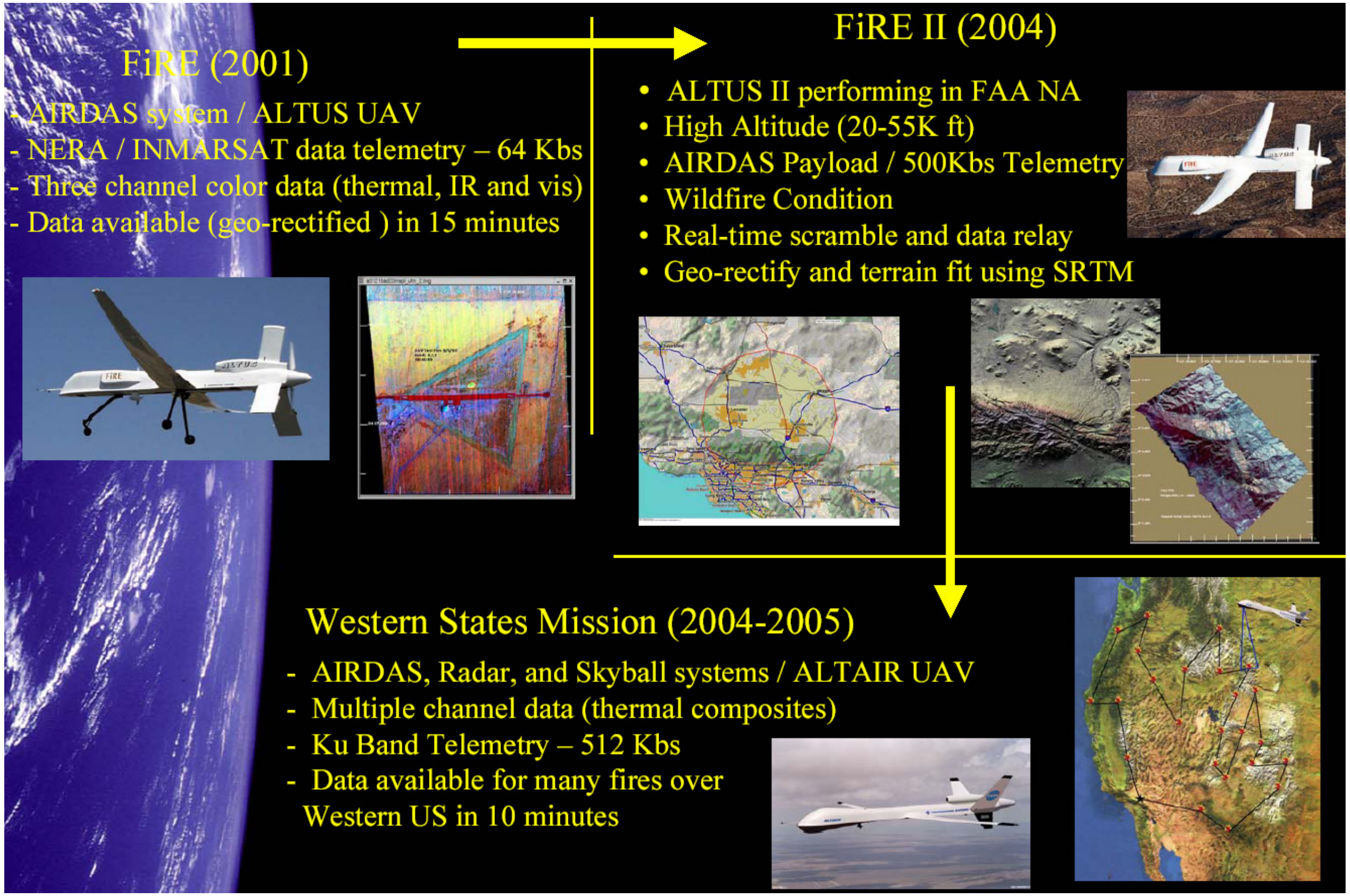
- **ERAST** (Environmental Research Aircraft and Sensor Technology)
  - Develop and flight-demonstrate UAVs for cost-effective science missions
- **FiRE** (**F**irst **R**esponse **E**xperiment)
  - Using UAVs as a wildfire remote sensing platform. Two UAV platforms:
  - ALTUS-II
    - Payload 150 kg, endurance 12 h cruise 65 KIAS, operating altitude 30,000ft.
  - ALTAIR scientific variant of the PREDATOR-B
    - Payload 340 kg, endurance 32 h cruise 151 KIAS, operating altitude 50,000ft.

ERAST / FiRE NASA Project

- Nationwide long term project:



WRAP NASA Project

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- **WRAP** (Wildfire Research and Applications Partnership)
  - Using UAS in a number of real fire monitoring missions over the USA west-coast as a wildfire remote sensing platform.

Airborne InfraRed Disaster Assessment System (AIRDAS)

Type:	Thermal scan
Bands:	1 (0.61 - 0.68) 2 (1.57 -1.70) 3 (3.60 - 5.50) 4 (5.50 - 13.0)
Calibration:	IR to +600 C.
FOV:	108 degrees
Scan Rate:	4-23 scn / sec.
Width:	720 pixels
Resolution:	8m at 10Kf

WRAP NASA Project

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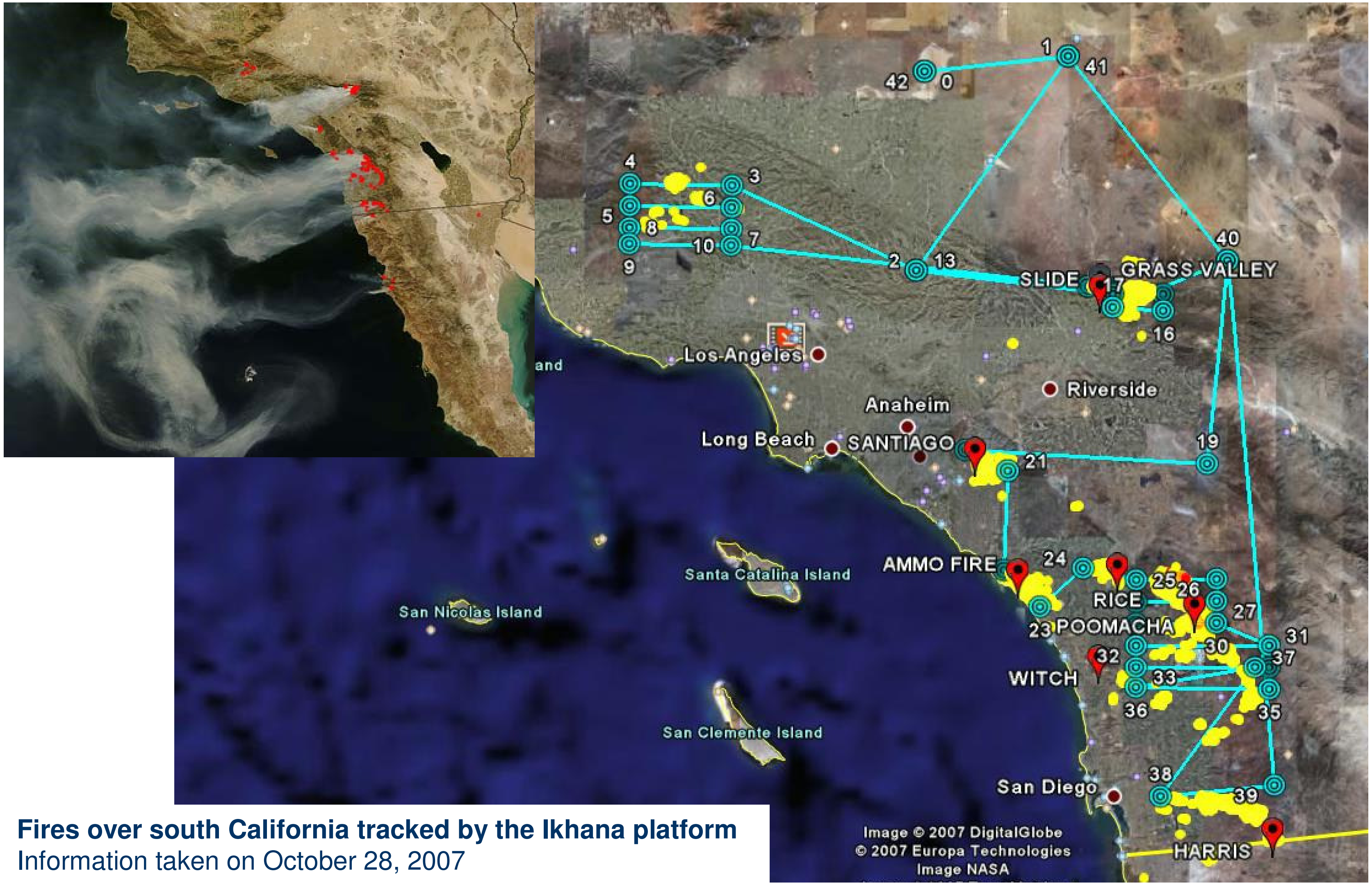
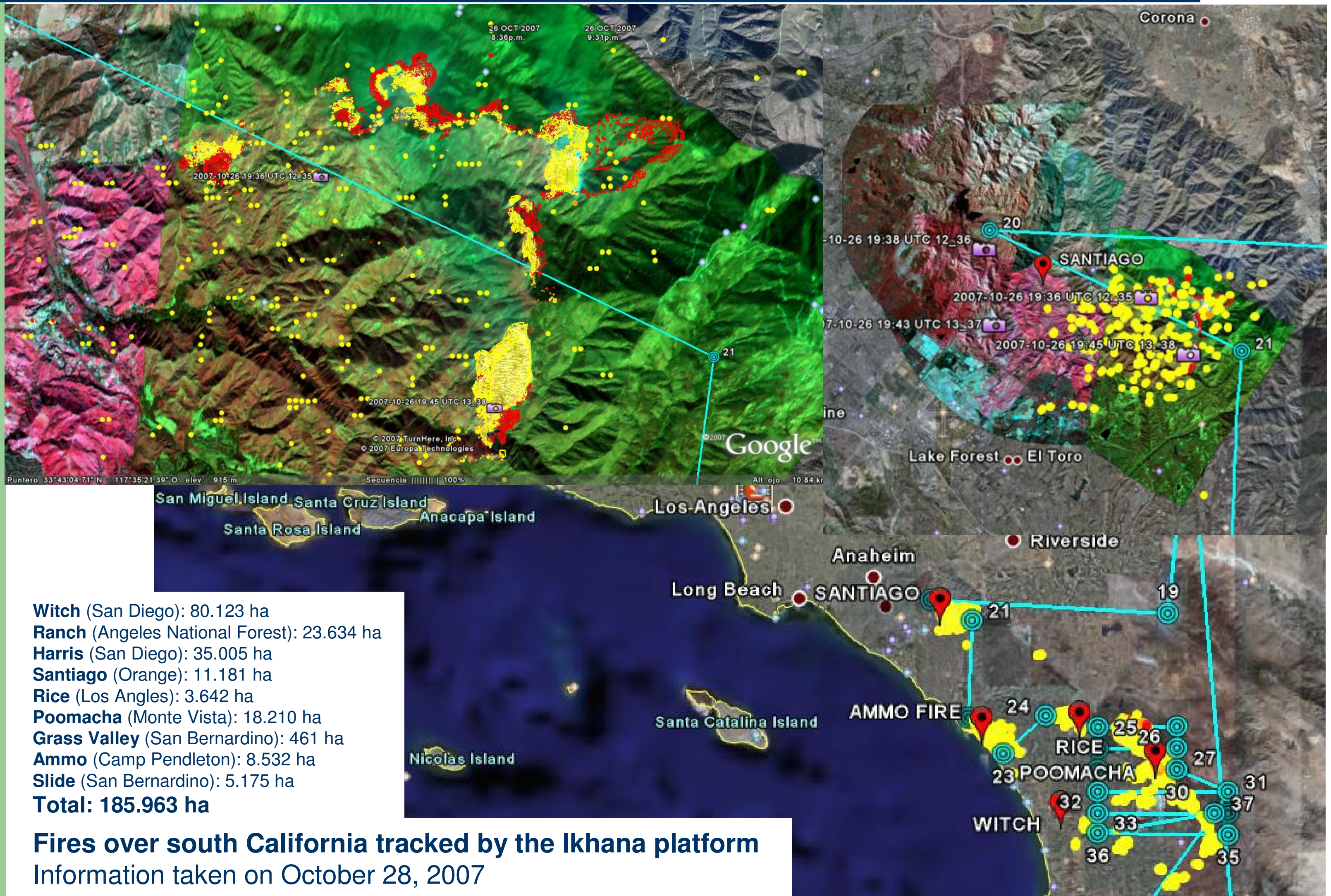


Fires over south California tracked by the Ikhana platform
Information taken on October 28, 2007

WRAP NASA Project

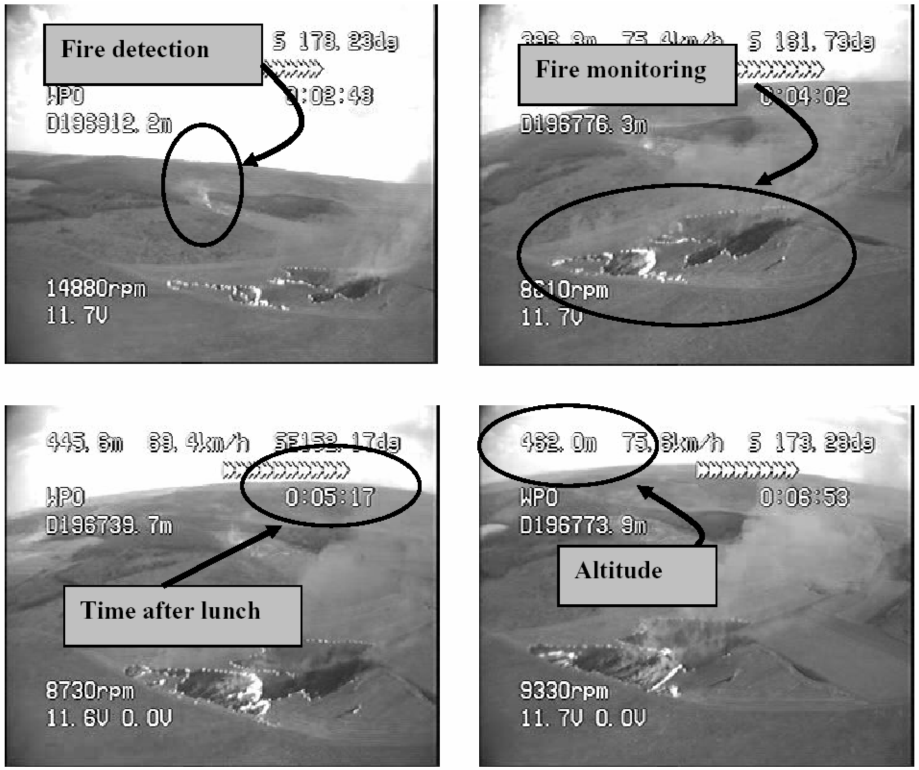


Witch (San Diego): 80.123 ha
Ranch (Angeles National Forest): 23.634 ha
Harris (San Diego): 35.005 ha
Santiago (Orange): 11.181 ha
Rice (Los Angles): 3.642 ha
Poomacha (Monte Vista): 18.210 ha
Grass Valley (San Bernardino): 461 ha
Ammo (Camp Pendleton): 8.532 ha
Slide (San Bernardino): 5.175 ha
Total: 185.963 ha

Fires over south California tracked by the Ikhana platform
Information taken on October 28, 2007

Szendro Fire Department, Hungary

- Small UAS used for early fire detection:
  - Low cost simple approach (non-IR cameras, etc).
  - UAV integrated into the fire department operations



Elements that condition UAS application

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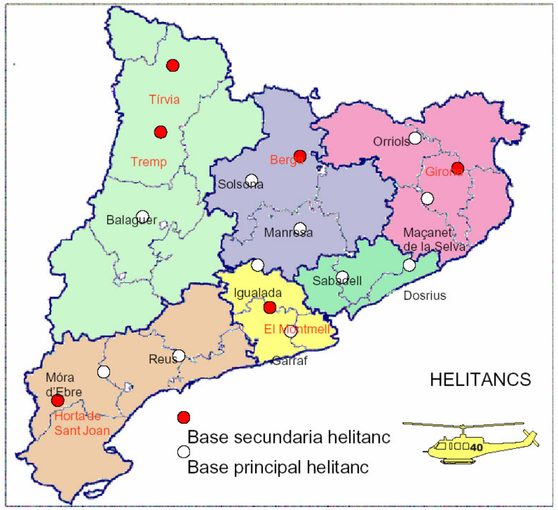
- UAS application to detect/monitor forest fires has several crucial issues that must be taken into account.
- Many ongoing efforts are failing because one or more of them are not properly taken into account.
  - Geographical application area.
  - Integration with firefighters own systems.
  - System acquisition/operation cost.
- The result is a number of potential missions in which UAS may be viable and cost-effective.
- The **Sky-eye** project addresses the Spanish perspective (focused on the Catalonia region).

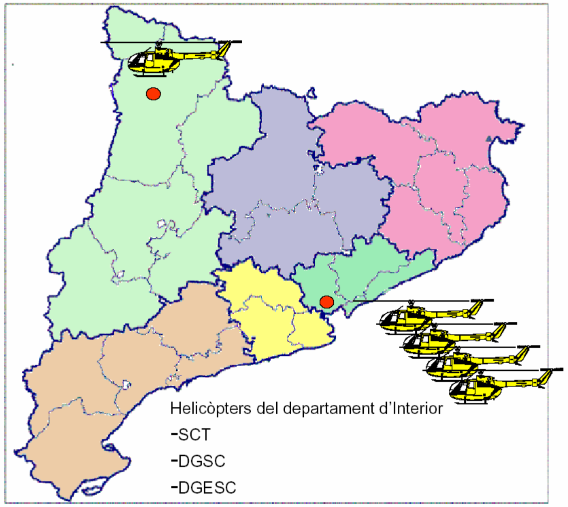
Geographical situation

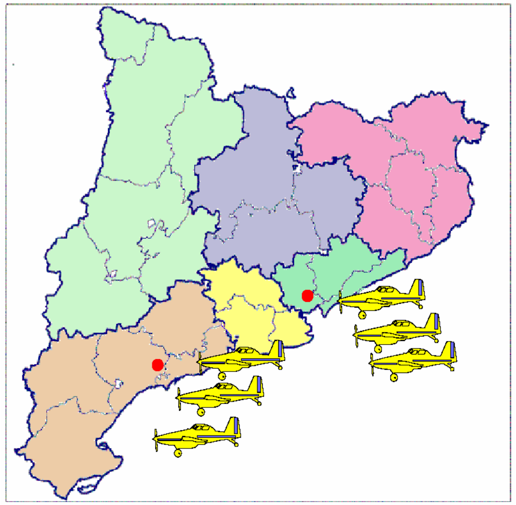
- Fire extinction responsibility is decentralized by regions.
- Inter-region / central government cooperation available if necessary.

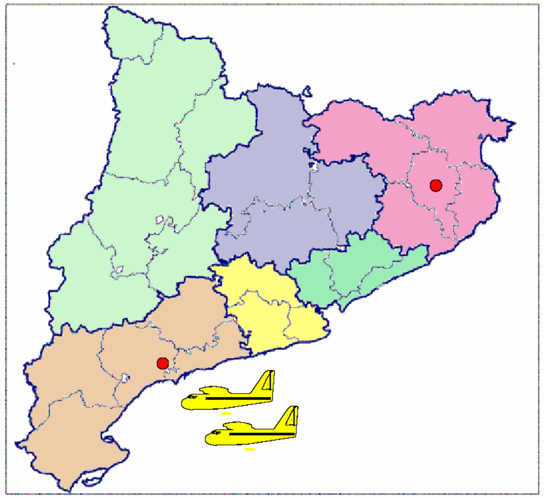
Area: 31 932 km2
Population: 6.704.146
Fires during 2006: 629
Burnt area: 3.404 ha
Worst year (1994): 76.125 ha

Available aerial resources





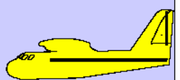




Canadair CL-215 T

amfibis

5.500 x 2 = 11.000 l.



As 350 B

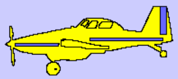
helicòpter suport HS

500 x 4 = 2.000 l.

Air Tractor 802 F

avió vigilància i atac AVA

3.200 x 6 = 19.200 l.



EC – 135

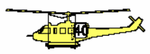
H–03 H-05
(polivalent amb funcions d'helitanc)

900 x 2= 1.800 l.

6 Bell 212 + tanc
4As 350 B3 + tanc

helitanc HLT

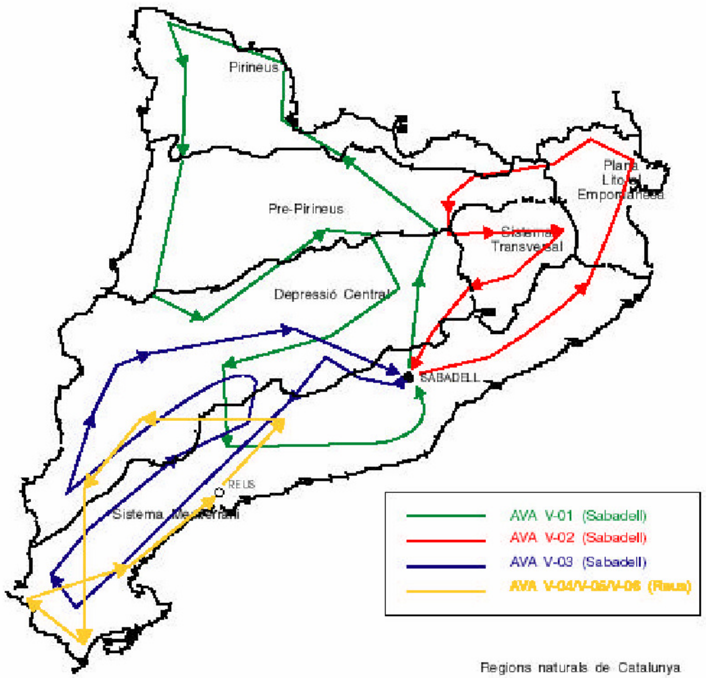
1.200 x 10 = 12.000 l.

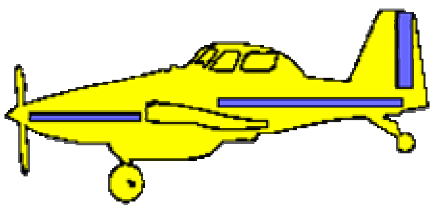


BO- 105 s5

H-02
helicòpter polivalent
600 x 1 = 600 l.

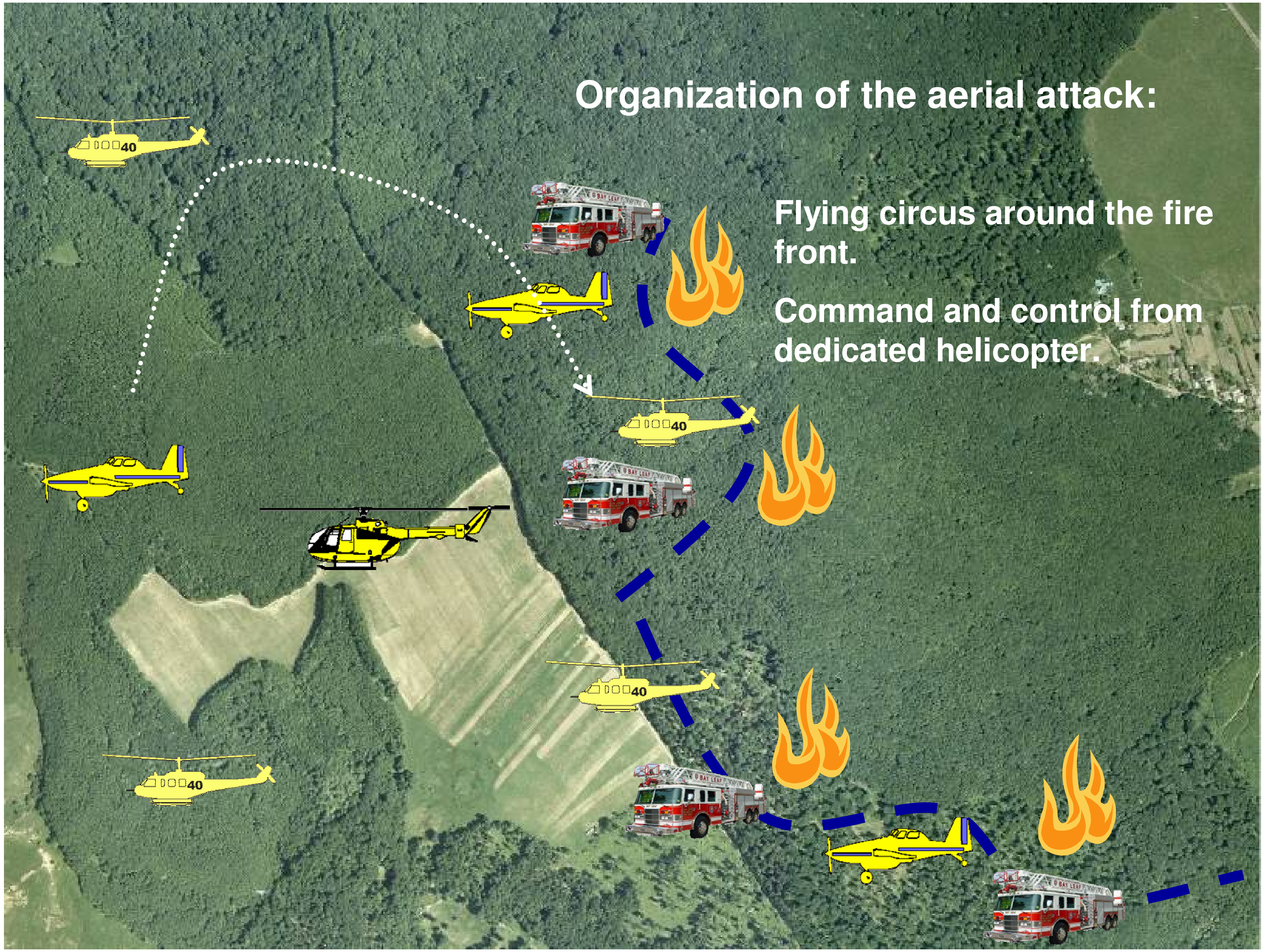
Aircraft operation schemes





- Surveillance and attack airplanes follow predefined routes around the clock during daytime.
- In case of detection first retardant attack is executed
- Rest of available units are used on demand.
- No flying during nighttime.

Aircraft operation schemes



Elements that condition UAS application

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- Geographical application area:
  - Relatively small area; operations under responsibility of local government and therefore with limited budget.
  - Externalized aerial resources except C&C helicopters.
  - UAS to be operated by external providers.
- Integration with fire fighters own systems:
  - Aerial operators see opportunities but do not want to see a UAS mixed in their airspace!!
  - Ground firefighters are eager to receive any available technology innovation.
  - Even though existing legal limitations and pilots opposition, ground firefighters suggest several application scenarios with strict manned/unmanned separation.

Elements that condition UAV application

- System acquisition/operation cost:
  - Limits designs to light tactical UAS, either aircrafts or helicopters.
  - Key goal is to achieve high availability within the regional area.
  - Larger UAS should be seen as nationwide strategic resource, e.g. HALE platforms.
  - Objective is an small fleet of tactical UAS that may cover one or at most two simultaneous operations.

Proposed system architecture

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- Lines of work in the Sky-eye project:
  1. Identify effective application scenarios in the selected context and design appropriate operational strategies.
     - Contacts with many firefighter organizations and individuals
     - Application scenarios change depending on user capabilities and geographical conditions
     - Human-Machine Interface critical when non-IT users are involved
  2. Identify operational and information flow requirements and implement the technology to support them.
     - No support exists for civil mission development
     - Highly dependent on the selected autopilot
     - Information flow – management – exploitation: key points to create an usable system for non-IT users
- In this presentation we concentrate on the technological aspects of the Sky-eye project

Proposed system architecture

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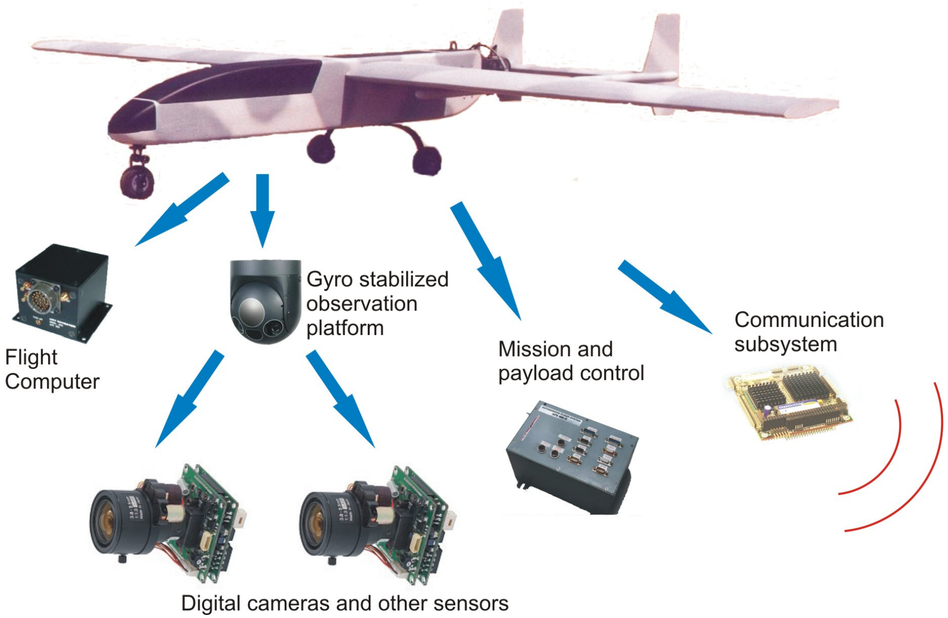
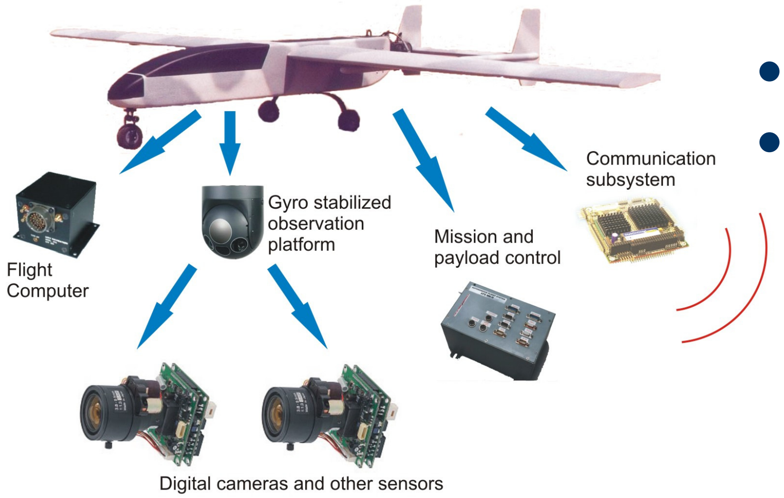
- Communication Architecture of the monitoring system oriented to mission management and information flow.
- Data acquired by UAS distributed to those responsible of fire management: from ground squad to decision center.
- System divided into four components:
  - **UAS**: designed for data acquisition and autonomous operation.
  - **Mobile Control Station**: responsible for UAS tactical control (flight operations), data gathering and processing.
  - **Squad Information Terminal**: receives selected information from the UAS or the MCS to the ground squads.
  - **Data Processing Center**: strategic control of multiple ongoing operations, data storage for post-fire analysis, high-level coordination and decision center.

Proposed system architecture

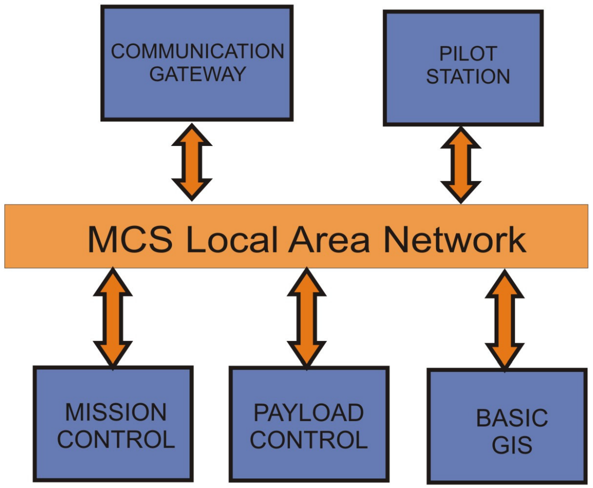
- UAS components:
  - Platform
  - Flight Computer System
  - Payload: non-gimbaled CCD, CMOS, IR, thermal, etc.
  - Mission / Payload Control System
  - Communication System



Proposed system architecture



- Communications are essential.
- However, long range air-ground not necessary

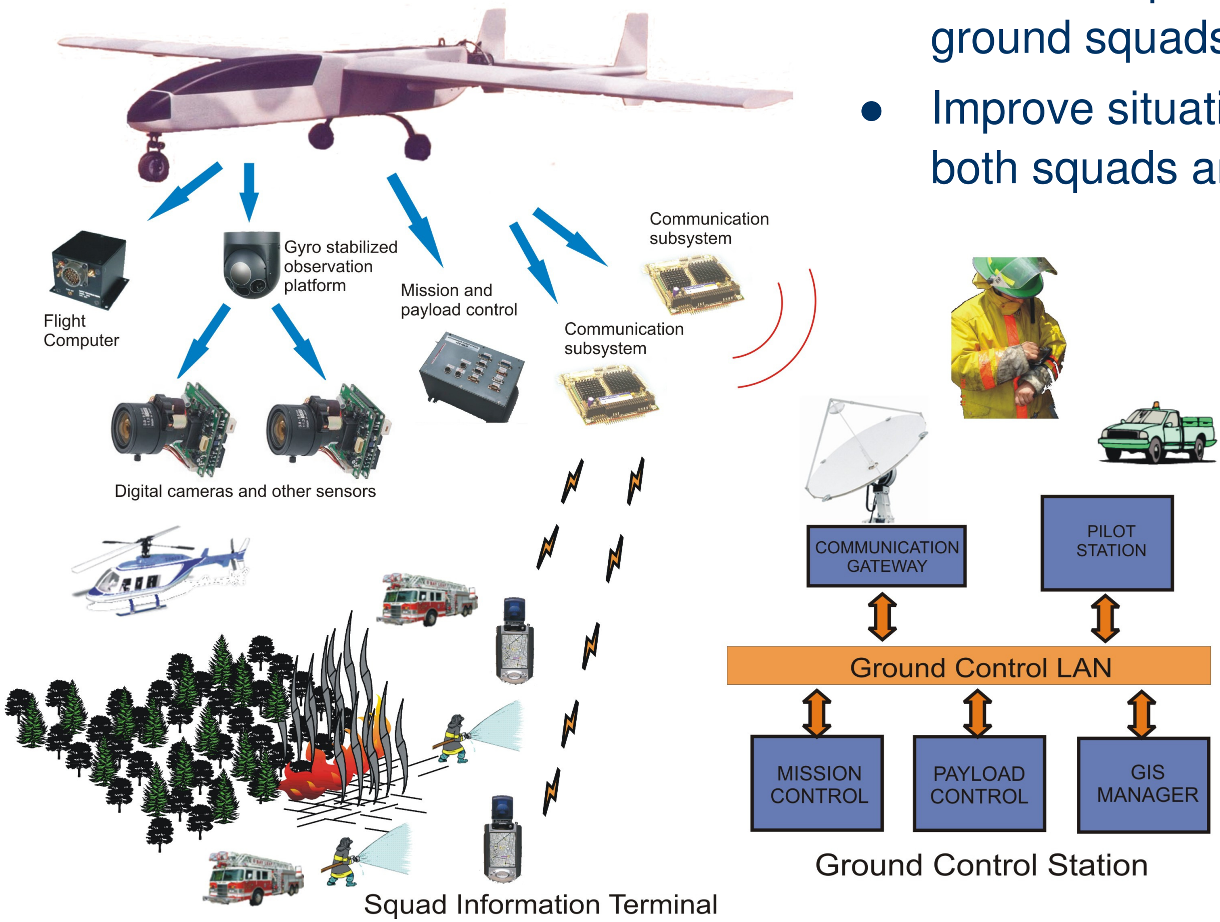


MCS: Mobile Control Station

- Should allow to operate the UAS as an independent unit.
- Essential data and raw data should be available almost real-time.

Proposed system architecture

- UAS can operate as relay to ground squads.
- Improve situation awareness of both squads and ground control



Proposed system architecture

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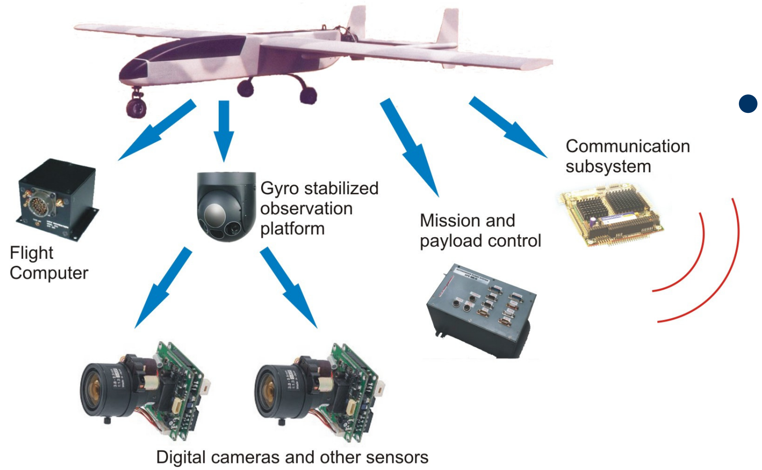
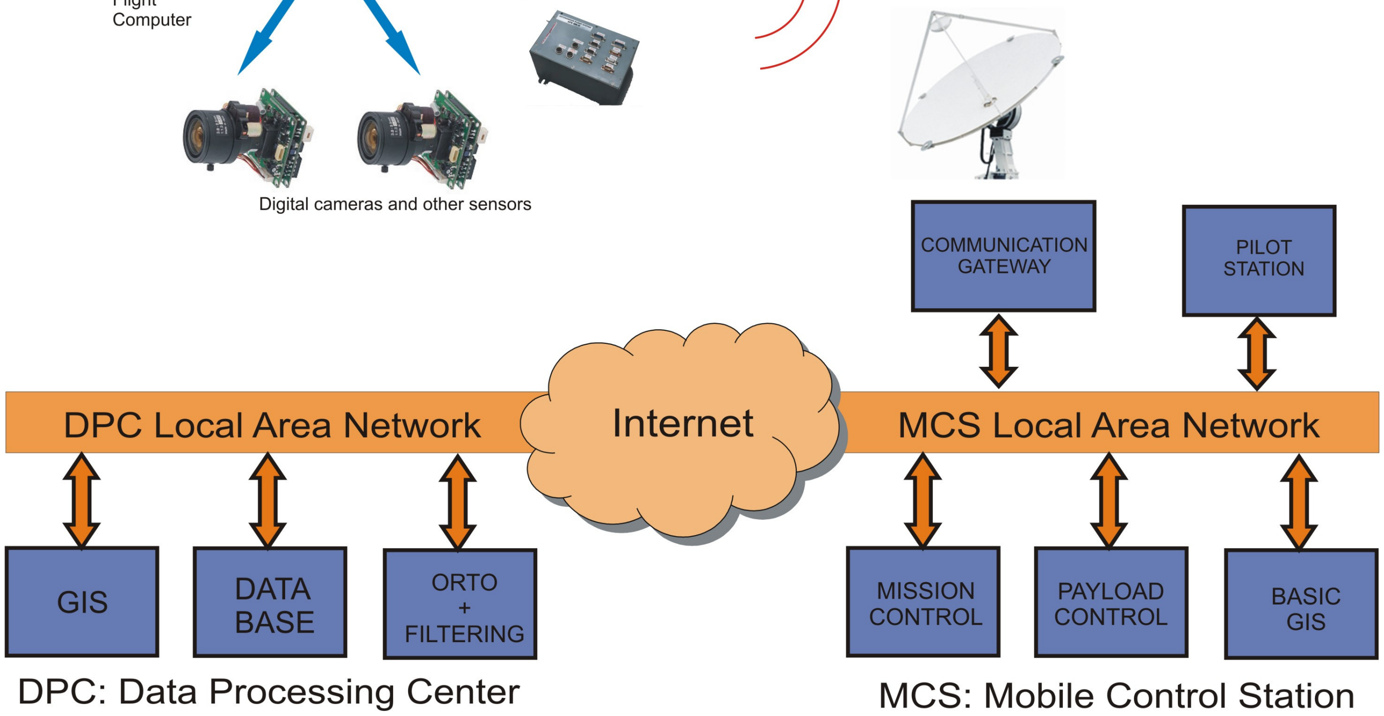


- Full data stored in Data-Bases for post fire analysis
- Selected information to be inserted in Internet (VLAN) to be shared with main C&C center or other entities.

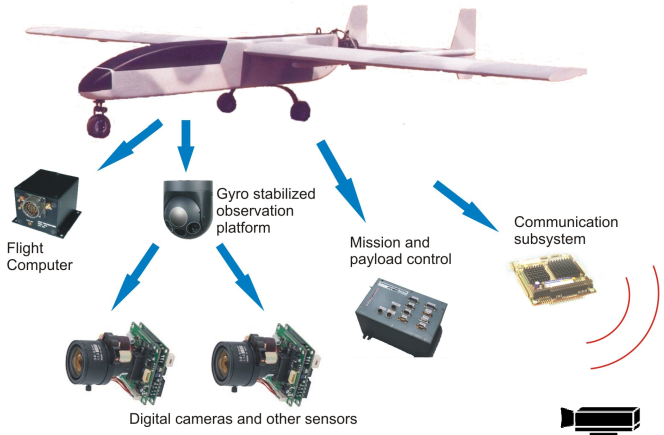


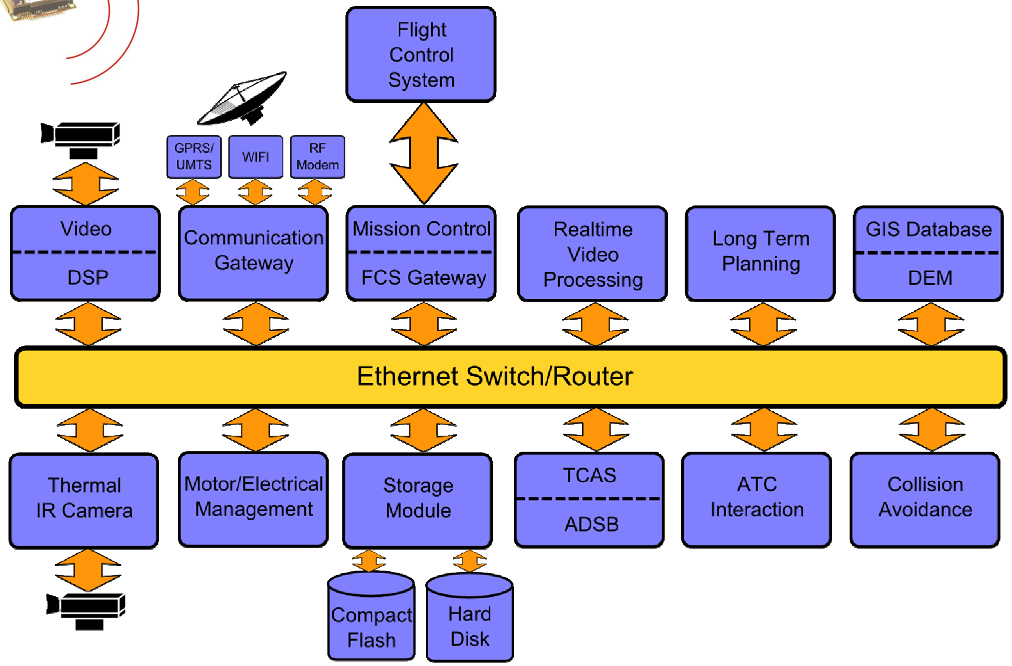
Technology innovation

- Reliable autopilots for UAS exist, but they don't address mission/payload control and are not flexible enough to include the functionalities needed.
- UAS users can buy an airframe / autopilot, but are forced to design their own mission/payload control.
- Future modifications may involve lots of redesign effort.
- Decided to innovate to improve mission management and communications among subsystems:
  1. Autopilot abstraction model to improve flight plan capabilities
  2. Specific "Mission management" concept
  3. Communication gateways make communications more flexible
  4. Distributed system architecture based on "service providers"

Distributed system architecture

- UAS seen as a distributed system among a LAN.





Distributed system architecture

- Goal of this communication architecture:
  - Provide **simple**, **lightweight**, yet powerful communication schemes to allow the effective development of distributed applications.
  - Capable of being implemented even in **small embedded microcontrollers.**
- We suggest using a service-oriented scheme, similar to what is used in Web-Services in the Internet domain.
- Alternatives exist (e.g. CORBA) but have disadvantages:
  - Force to use the object-oriented paradigm in the communications.
  - Prior knowledge of the structure of the application is necessary.
  - Far from being a low-weight protocol.

Distributed system architecture

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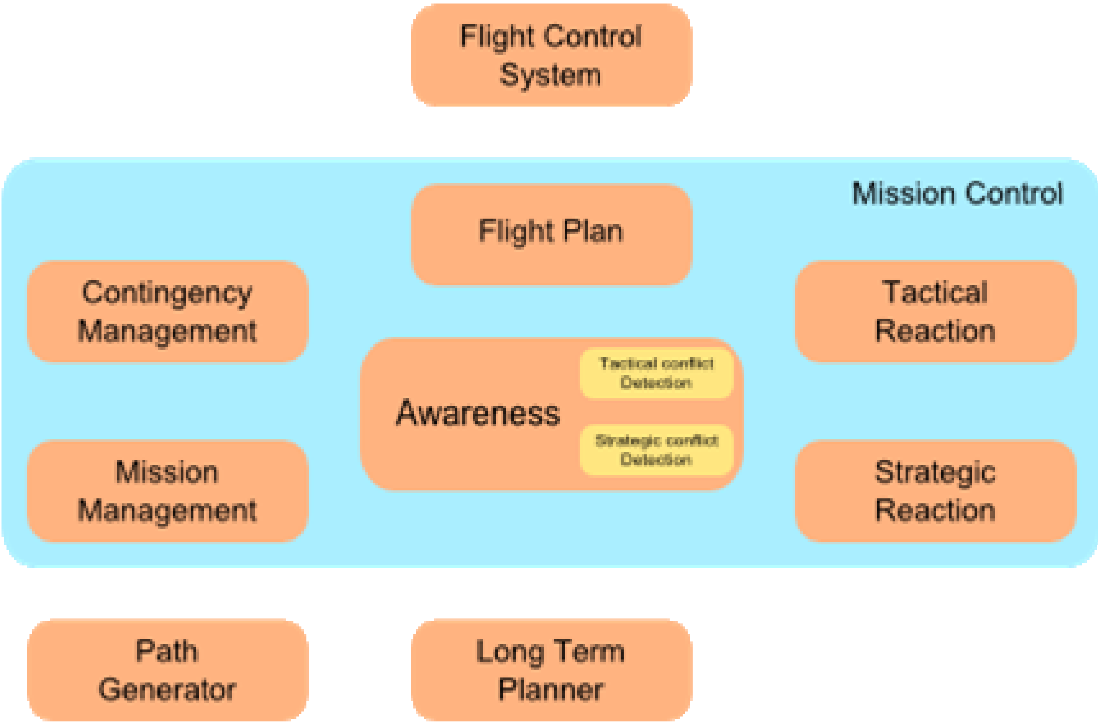
- Service oriented architectures (SOA):
  - Wide spread use in web services (Internet) and home automation (UPnP).
  - Goal is to achieve loose coupling among interacting components.
  - A service is a unit of work done by the the **service provider** to satisfy a request from a **service consumer.**
  - Provider and consumer are dynamic roles played by software agents.
- SOA favors using loosely coupled components to minimize dependencies and therefore maximize interoperability, flexibility, extensibility and reusability.

Mission control

- The mission control is a set of services that orchestrate the whole operation of the UAS.
- Its function is to link the flight plan that the UAS follows and the operation executed by the payload.
- Mission may dynamically change as fire evolves, therefore updated flight plans should be computed.
- Given that operational requirements change from mission to mission, additional or improved quality payload can be added just by including new or inherited services.

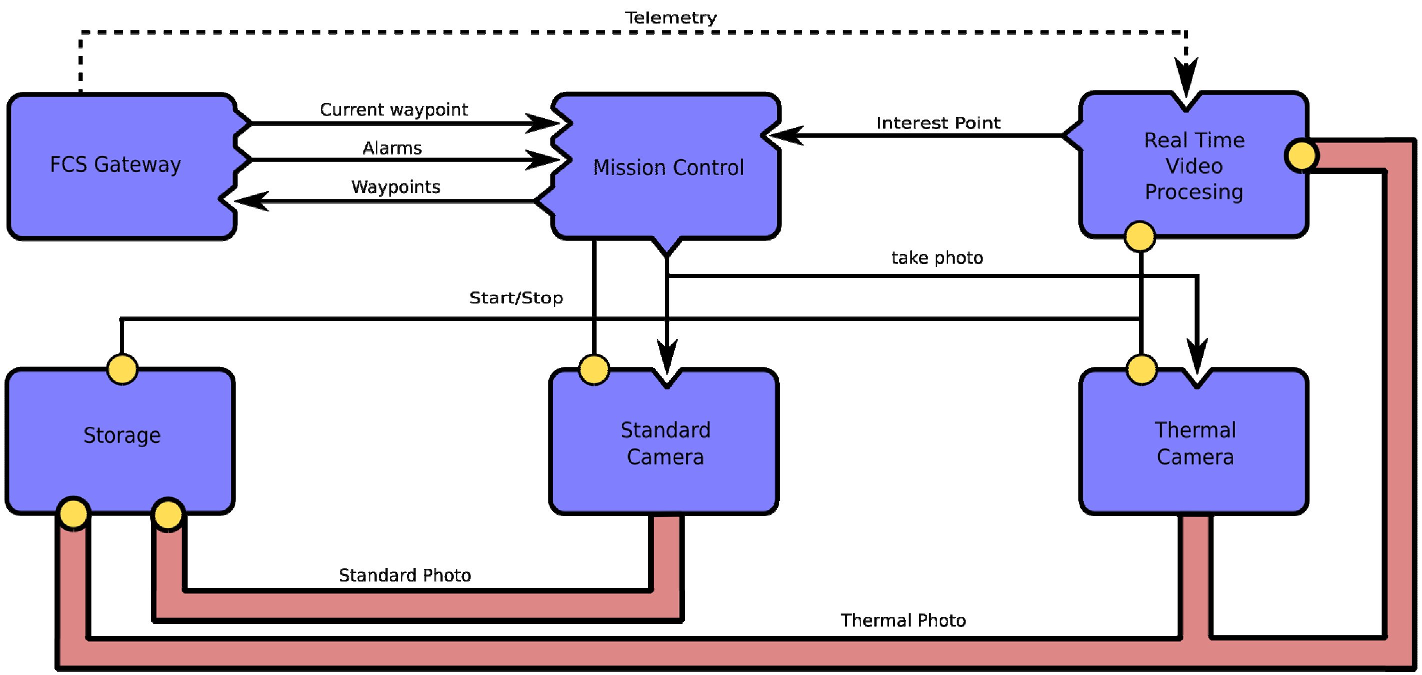
Mission control

- The mission control is composed of several services to manage required functions not available in commercial autopilots.

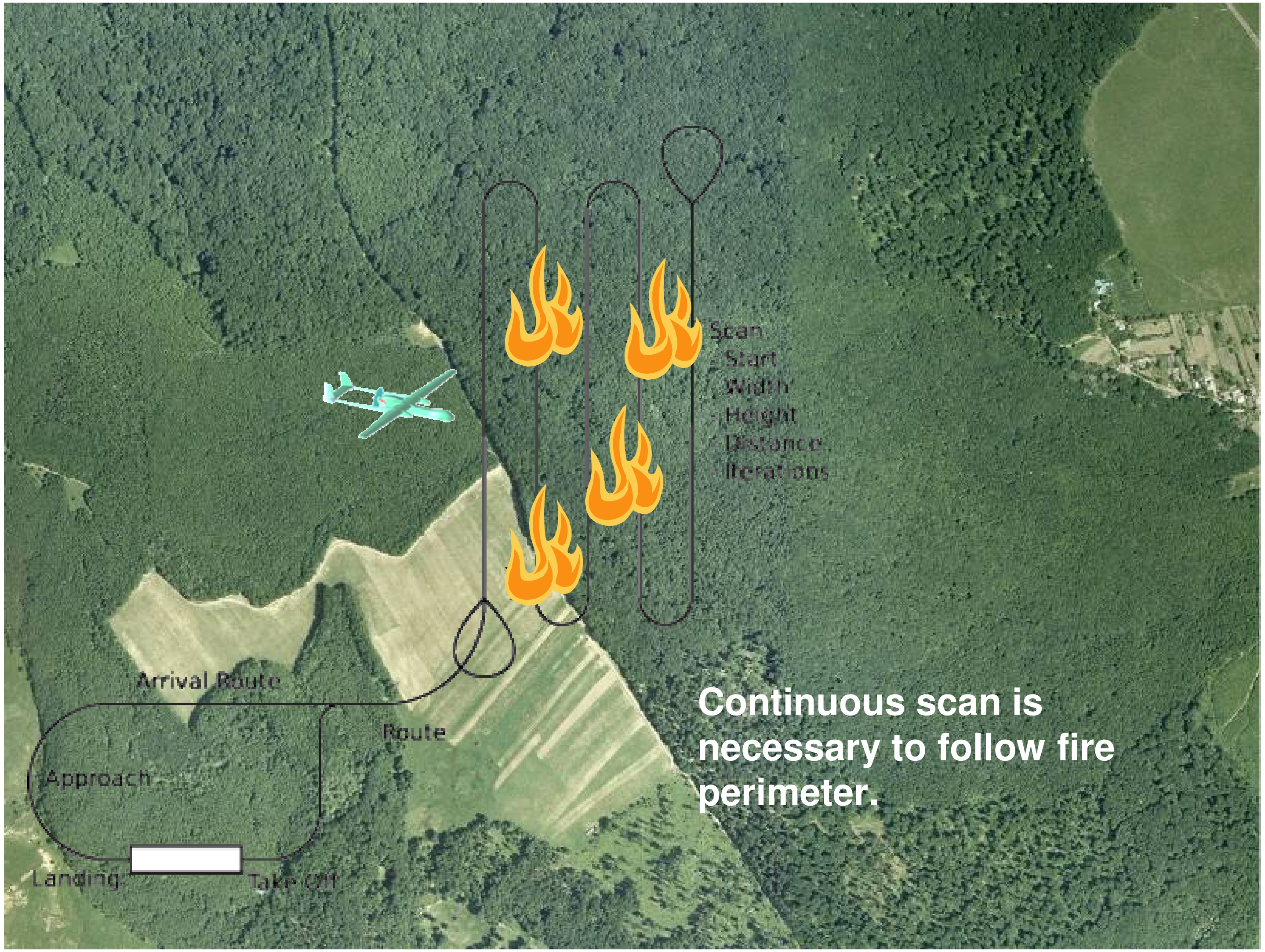


Mission control

- Mission is formally specified through visual tools:
  - Relations between services are specified by flow diagrams
  - Dynamic activities through event-based systems.



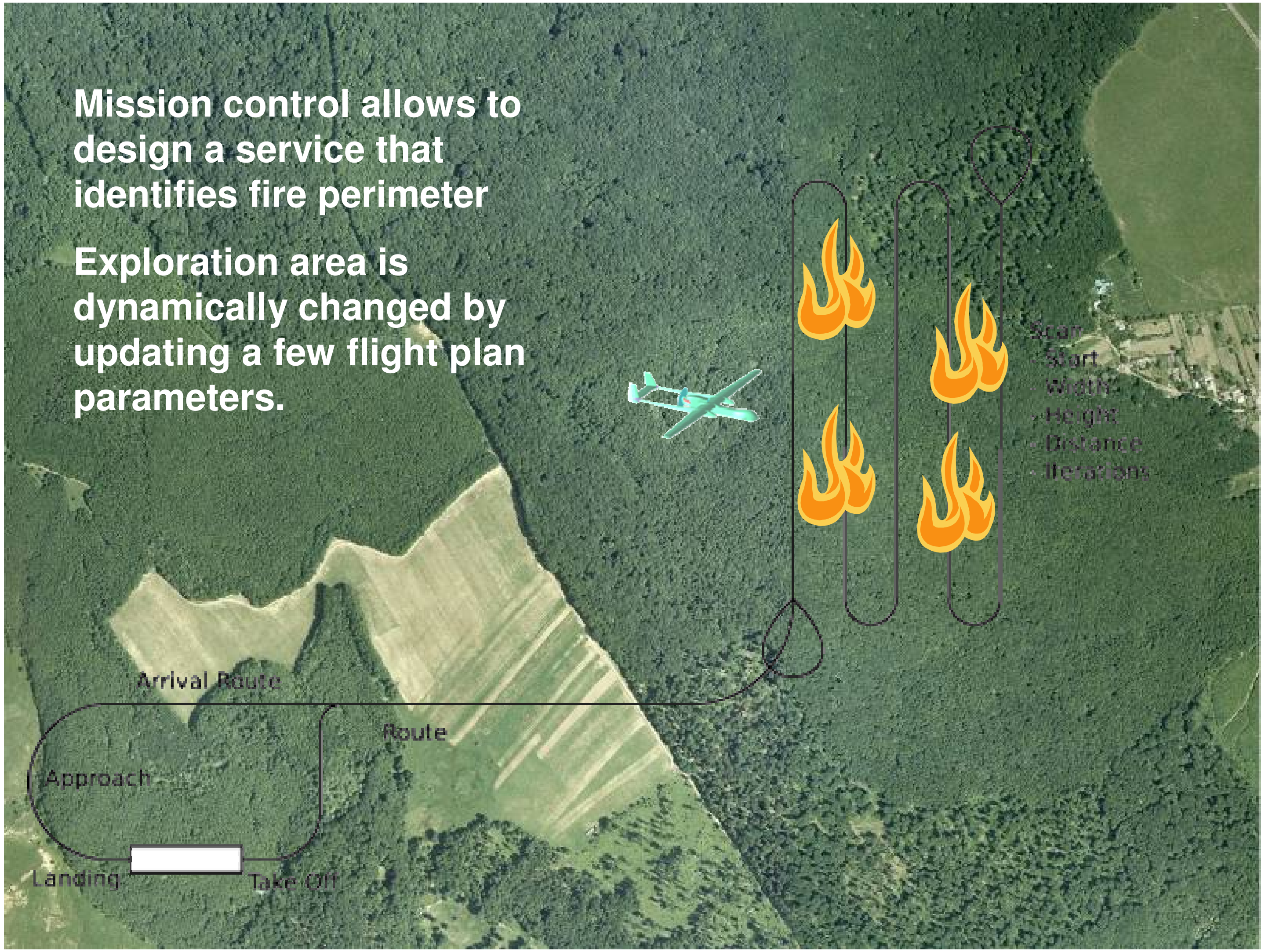
Mission control



Mission control

Mission control allows to design a service that identifies fire perimeter

Exploration area is dynamically changed by updating a few flight plan parameters.

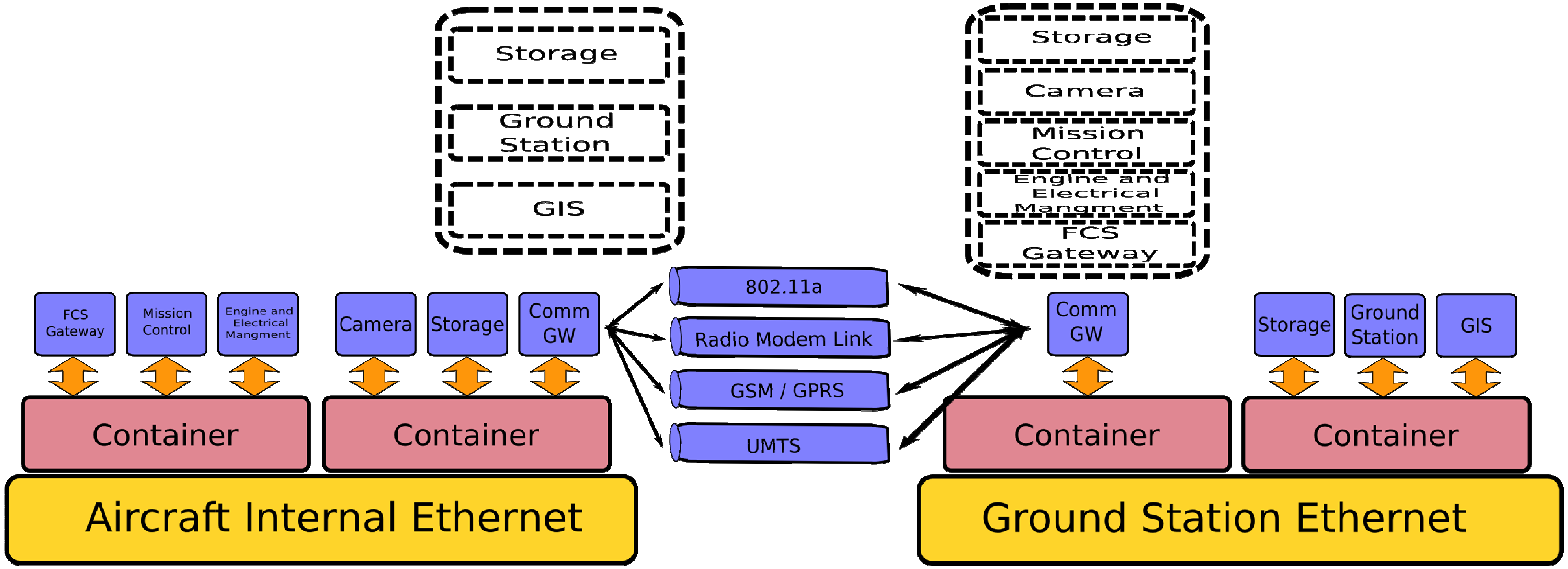


Communication gateway

- UAS usually have different communication links: RF, SATCOM, wireless WANs, GPRS/UMTS.
- Throughput, range and specially cost may differ a lot depending on the link and the actual state of the UAS.
- Inter-UAS and UAS to base station communications are considered different issues, complicating application development.
- A single computation module (the *communication gateway*) will concentrate most communication links: RF, SATCOM, GPRS/UMTS.
  - These links are generally accessed through serial point-to-point buses.
  - Each one can be transformed into a network interface by linking it with the PPP protocol.

Communication gateway

- Objective is to provide a software layer that abstracts this complexity from the actual applications:
  - Mapping all communication links as a single interface point.
  - Monitoring the quality of each link in order to provide Quality-of-Service with the *better* cost at each point in time.



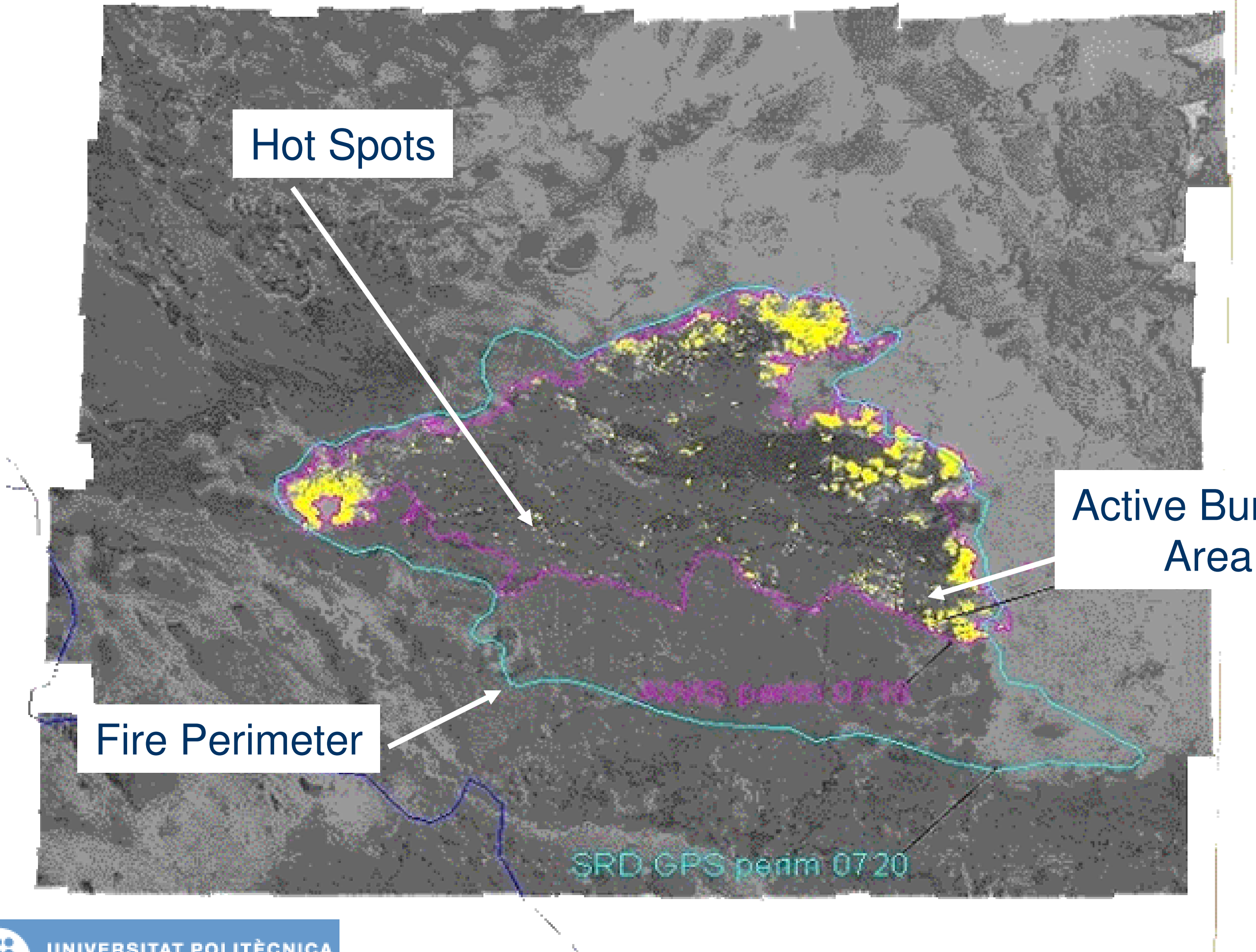
Application domains

- **GRAF** identified three viable application scenarios:
  - Final fire mop-up with detection of remaining hot-spots
  - Prescribed burning monitoring for security and fire behavior analysis
  - Fire monitoring during night. To be developed based on previous experience.
- Guarantees no interference with standard aerial resources.
- Goal is to progressively develop the system for all three situations.
- Detection is not a goal because in populated areas existing detection networks are efficient enough.

Application domains

- Early morning or late afternoon UAS can scan to detect **hot spots**.
- Mostly interested in hot spots located on the perimeter.
- Information needed in real time for immediate reaction:
  - By ground teams
  - By attack airplanes/helicopters
- May have significant impact on operational cost because:
  - Crucial assets can be removed from the fire scenario much earlier
  - Other fires may receive much faster additional support
  - Increases confidence on the state of the burned area

Application domains

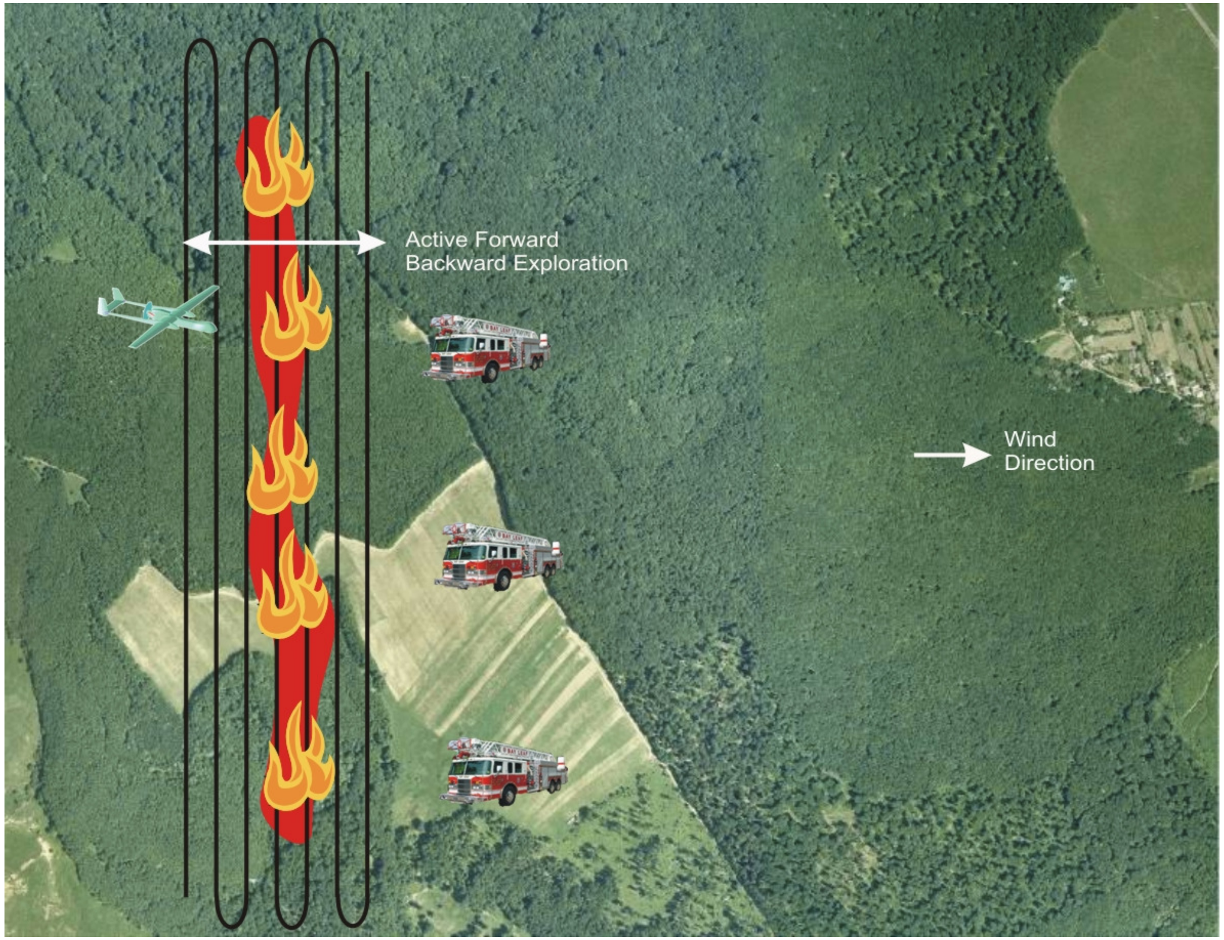


Application domains

- Prescribed burning is a valuable asset used by fire fighters.
  - Partially burns existing fuel in the forest, reducing the severity of future fires in the same area.
  - Good opportunity to understand fire behavior (e.g. usage of counter-fires).
- Interested in a monitoring system for prescribed burning:
  - Safety reasons
  - Record dynamic fire evolution for further analysis (FireParadox EU project may subcontract service)
- Usually no additional aerial resources in the area.
- Experimentation platform to evaluate a full-scale system

Application domains

- Prescribed fire front should be dynamically followed:



Application domains

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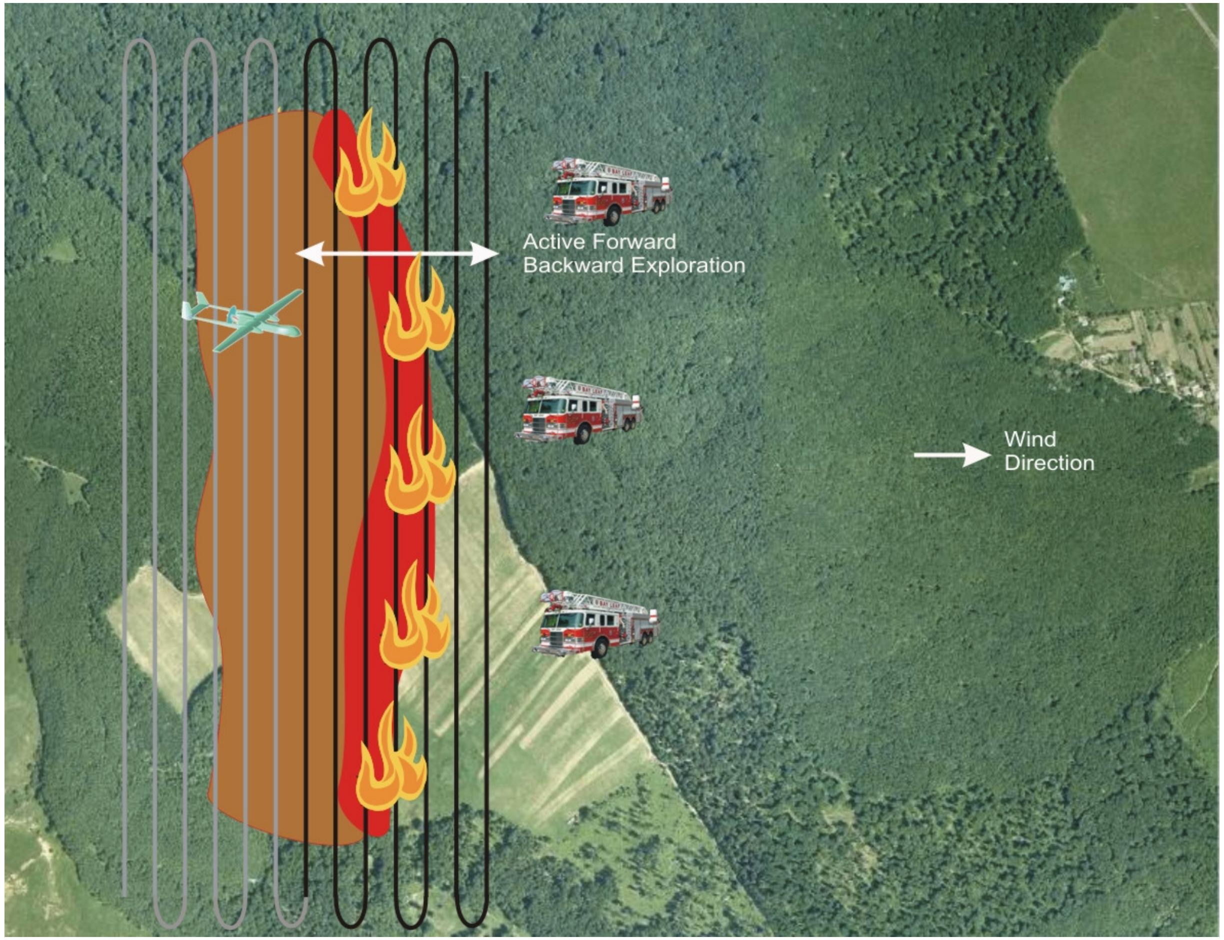

Application domains

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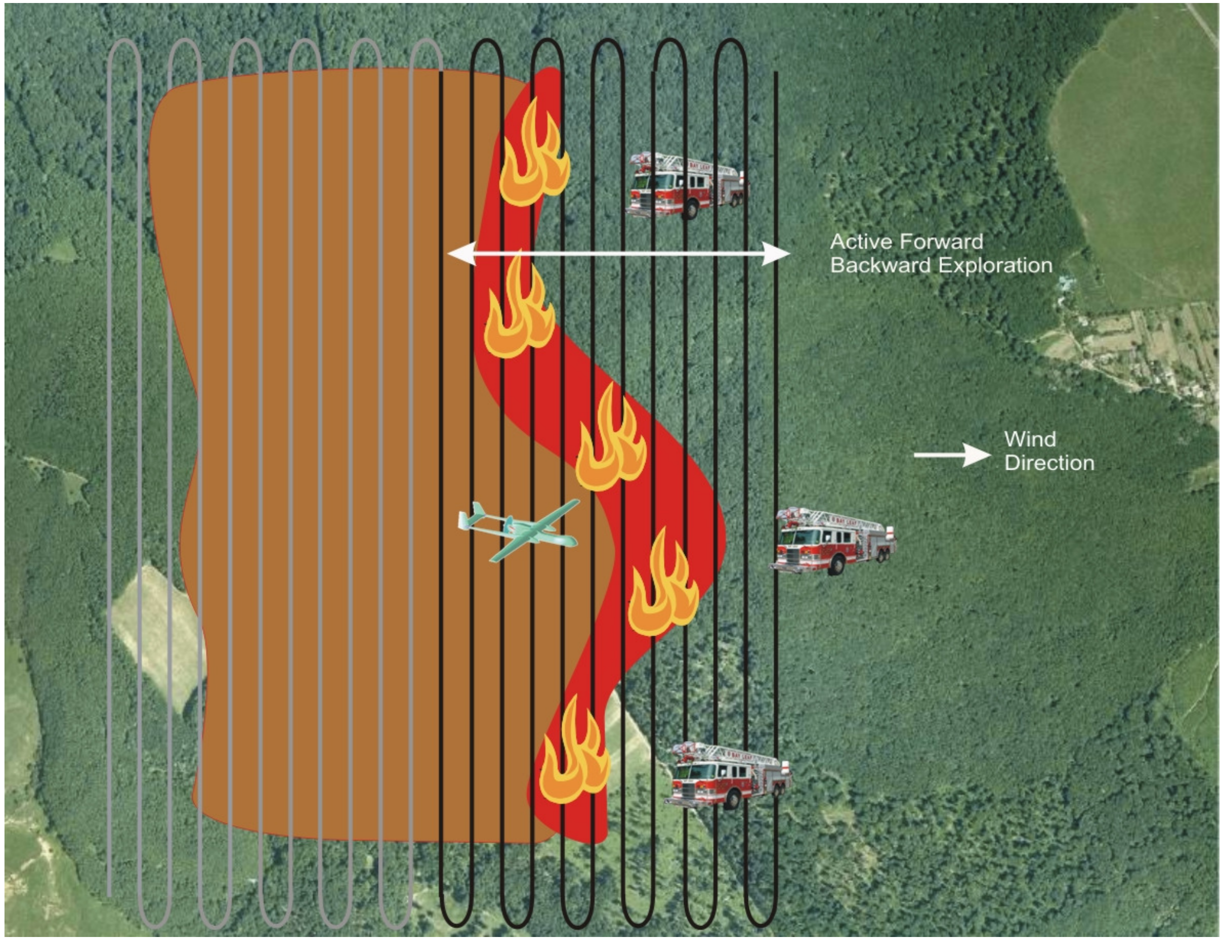

Conclusions

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- Forest fire monitoring is an interesting civil application for UAS that may become a commercial market.
- Integration of the UAS in the airspace is a bottleneck but still interesting application areas exist.
- Integration of the UAS operation with overall fire extinction system is the main obstacle to overcome.
- Not all geographical scenarios are equivalent; countries with large unpopulated areas require emphasis in "*detection*".
- **Sky-eye project** is currently focusing on UAS operation, required hardware/software systems and information flow processes.