Project SKY-EYE

Applying UAVs to Forest Fire Fighter Support and Monitoring

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Motivation

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- UAVs 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 UAVs 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 UAVs with other aerial resources.
  - Specific UAV mission design for fire fighting operations.
  - Specific technological requirements needed to be integrated in the UAV 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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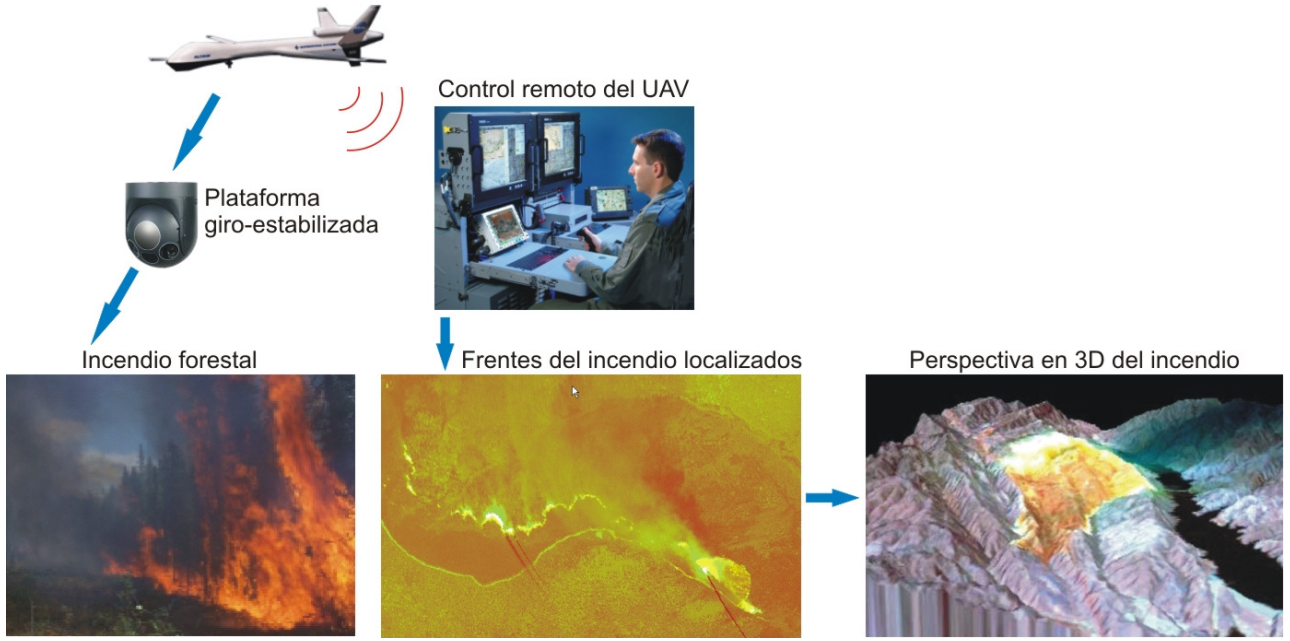
- System conceptual view:

  allow detection/monitoring of forest fires...



- But which are the real application limits?

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 UAV 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

- Background
- Elements that condition UAV application
- Proposed system architecture
  - Mid-scale / large scale solutions
- Technology innovation
  - Distributed system architecture
  - Mission control
  - Communication gateway
- Application domains
- Conclusions

Background

- Multiple initiatives to evaluate the potential application of UAV to help forest fire fighting:
  - Firebird 2001 Fire Fighting Management Support System
  - ERAST / FiRE NASA Project Design
  - 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

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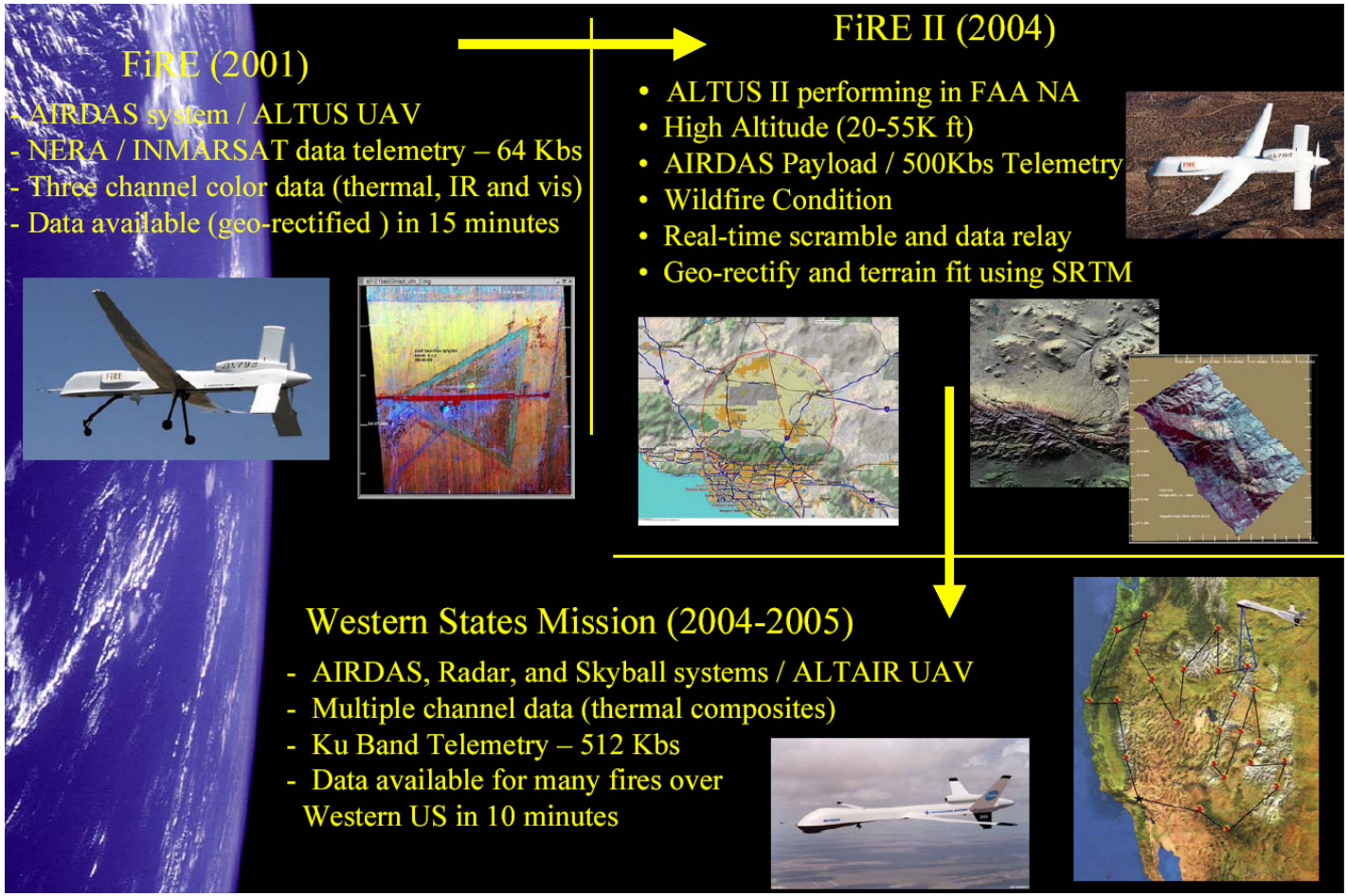
- Nationwide long term project:



Szendro Fire Department, Hungary

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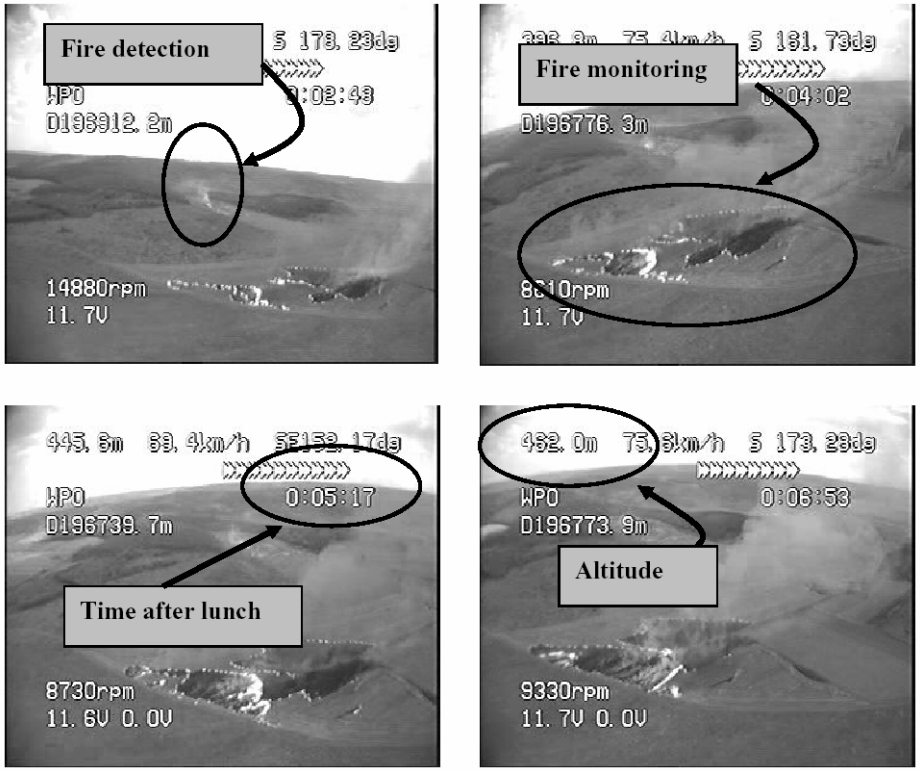
- Small UAVs used for early fire detection:
  - Low cost simple approach (non-IR cameras, etc).
  - UAV integrated into the fire department operations



Elements that condition UAV application

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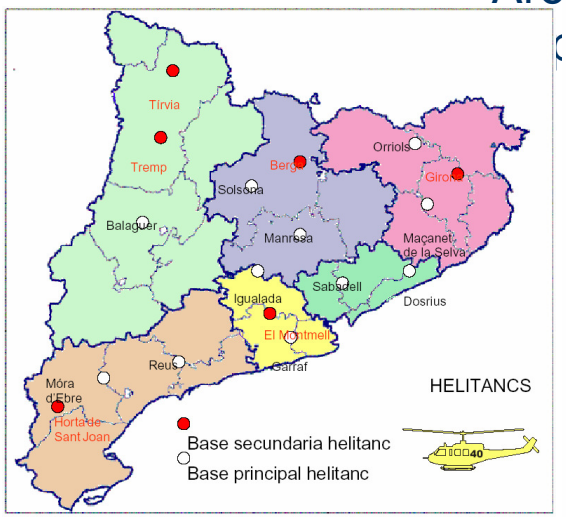
- UAV application to detect/monitor forest fires has several crucial issues that must be taken into account.
- Many ongoing efforts are failing because one or more of them are not properly taken into account.
  - Geographical application area.
  - Integration with firefighters own systems
  - System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

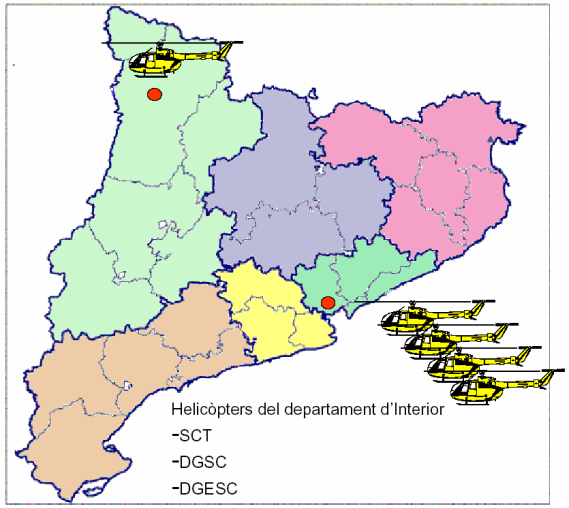
Geographical situation

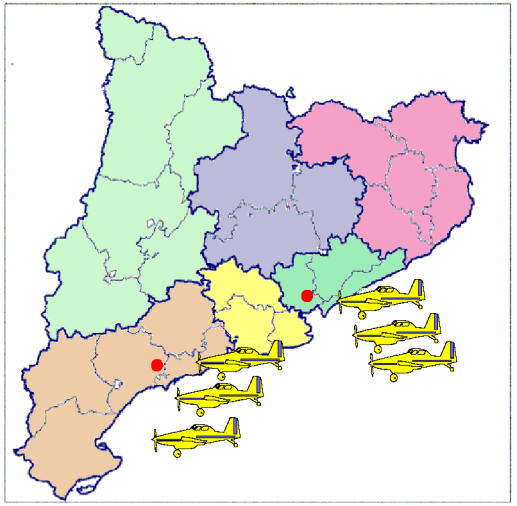
- Fire extinction responsibility is decentralized by regions.
- Inter-region / central government cooperation available if necessary.

Area: 31 932 km2
Population: 6.704.146
Fires during 2006: 629
Burnt area: 3404 Ha

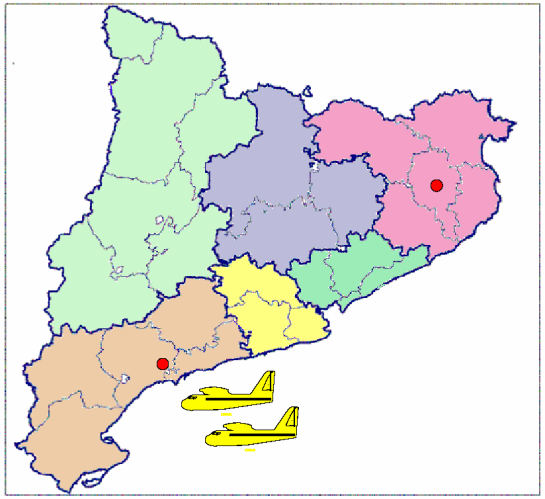
Available aerial resources



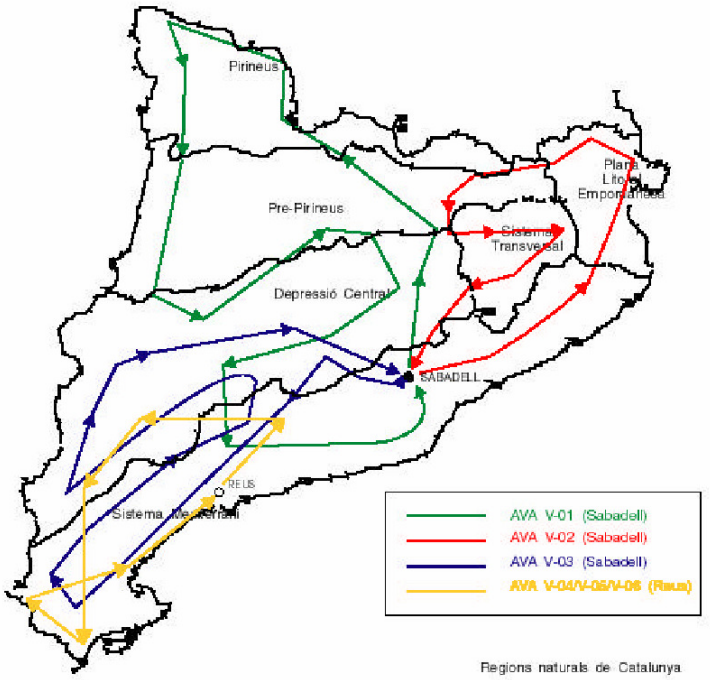




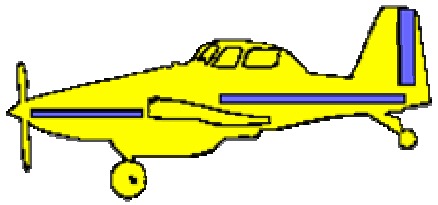
Canadair CL-215 T	amfibis 5.500 x 2 = 11.000 l.
As 350 B	helicòpter suport HS 500 x 4 = 2.000 l.
Air Tractor 802 F	avió vigilància i atac AVA 3.200 x 6 = 19.200 l.
EC – 135	H–03 H-05 (polivalent amb funcions d'helitanc) 900 x 2= 1.800 l.
6 Bell 212 + tanc 4As 350 B3 + tanc	helitanc HLT 1.200 x 10 = 12.000 l.
BO- 105 s5	H-02 helicòpter polivalent 600 x 1 = 600 l.



Aircraft operation schemes

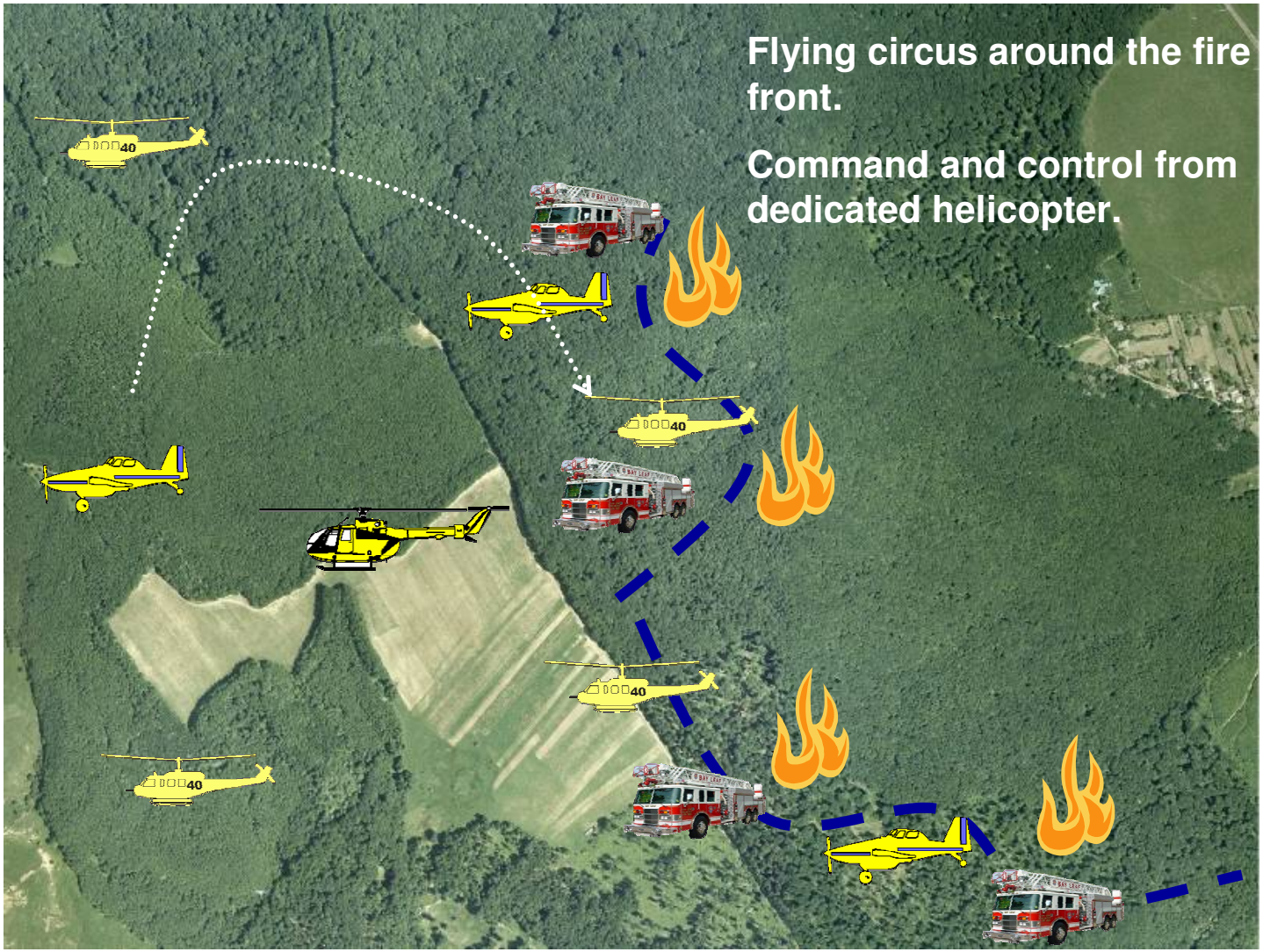


Regions naturals de Catalunya



- 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 UAV application

- Geographical application area:
  - Relatively small area; operations under responsibility of local government and therefore with limited budget.
  - Externalized aerial resources except C&C helicopters.
  - UAVs to be operated by external providers.
- Integration with firefighters own systems:
  - Aerial operators see opportunities but do not want to see a UAV 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

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

Proposed system architecture

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- Communication Architecture of the monitoring system oriented to mission management and information flow.
- Data acquired by the UAV should be securely distributed to all entities responsible of fire management: from ground squad to decision center.
- System divided into three components:
  - **UAV**: its objective is data acquisition and maximal autonomous operation
  - **Mobile Control Station**: responsible for UAV tactical control (flight operations) and data gathering and processing
  - **Data Processing Center**: strategic control of multiple ongoing operations, data storage for post-fire analysis, high-level coordination and decision center.

Proposed system architecture

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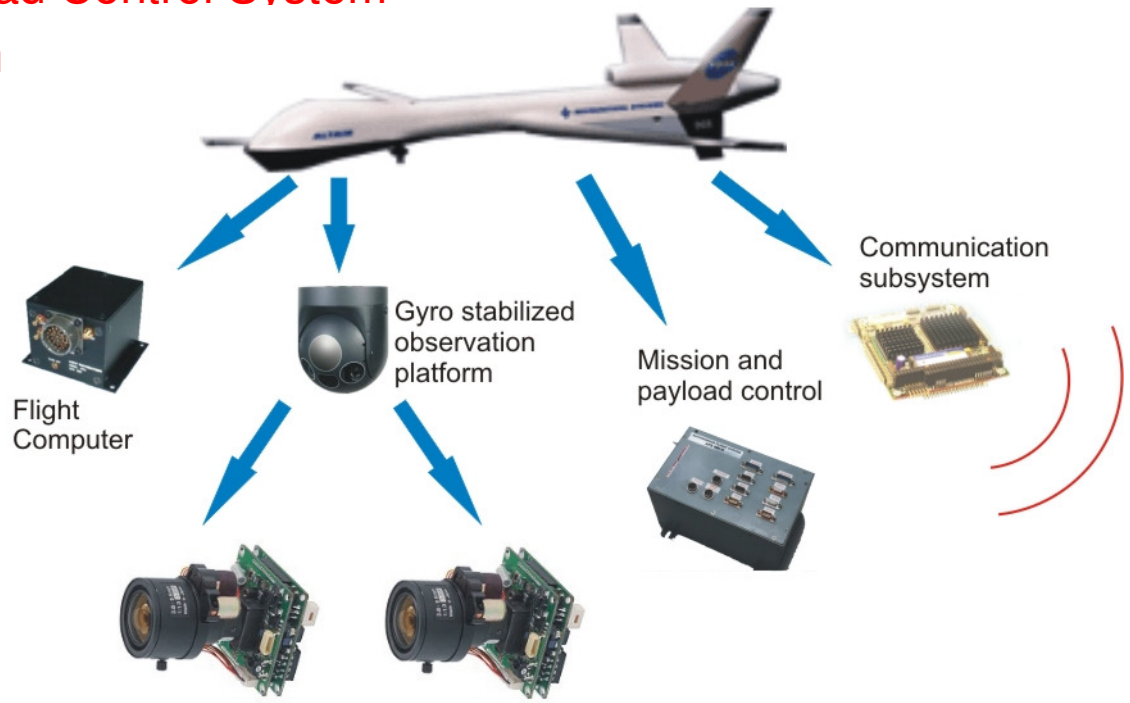
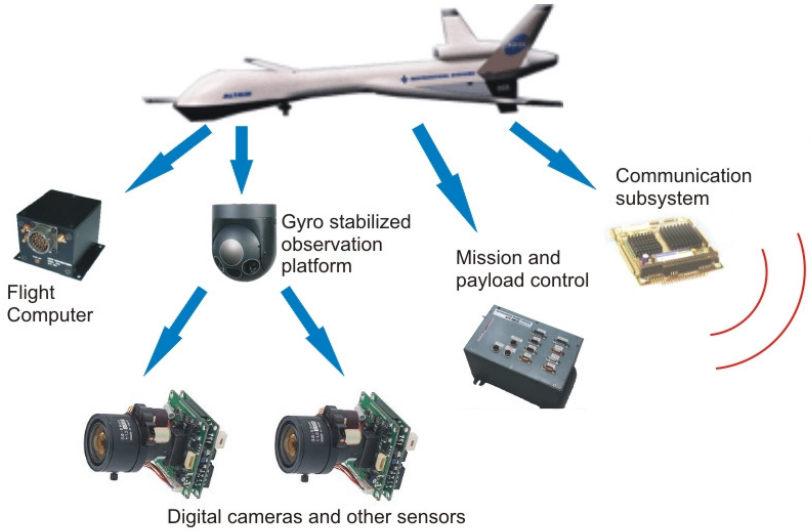
- UAV components:
  - Platform
  - Flight Computer System
  - Payload: non-gimbaled CCD, CMOS, IR, thermal, etc.
  - Mission / Payload Control System
  - Communication

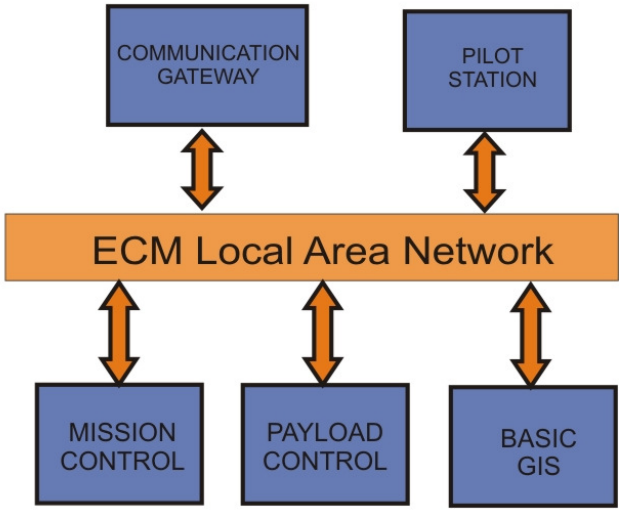


Proposed system architecture



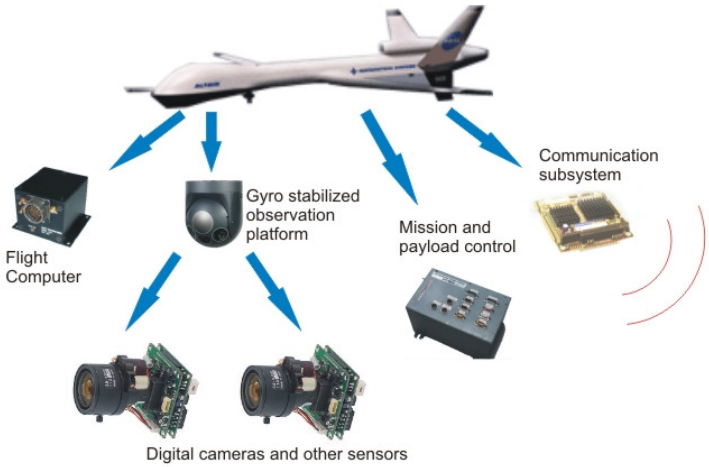
- Communications are essential.
- However, long range air-ground not necessary

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

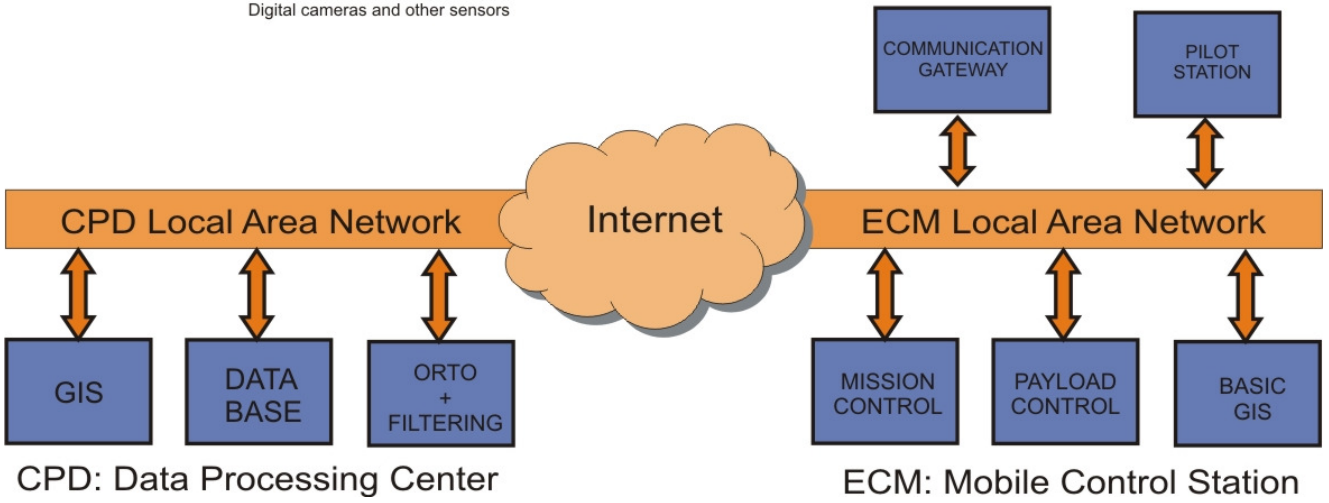


ECM: Mobile Control Station

Proposed system architecture



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



Technology innovation

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- Reliable autopilots for UAVs exist, but they don't address mission/payload control and are not flexible enough to include the functionalities needed.
- UAV 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:
  - Distributed system architecture based on "service providers"
  - Specific "Mission management" concept
  - Autopilot gateway to improve autopilot and flight plan capabilities
  - Communication gateways make communications more flexible

Distributed system architecture

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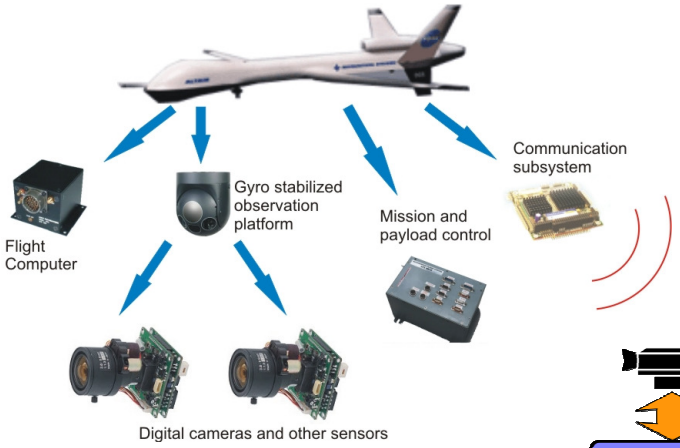
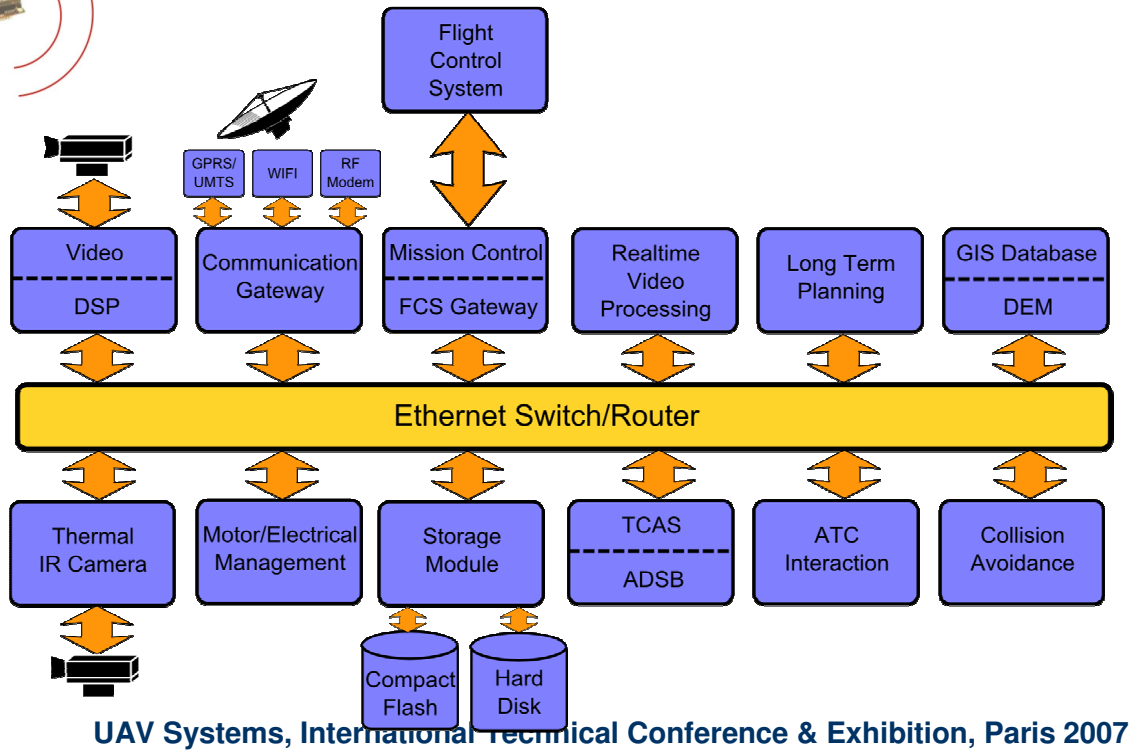
- UAV seen as a distributed system among a LAN.





Distributed system architecture

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- 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 **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.

Distributed system architecture

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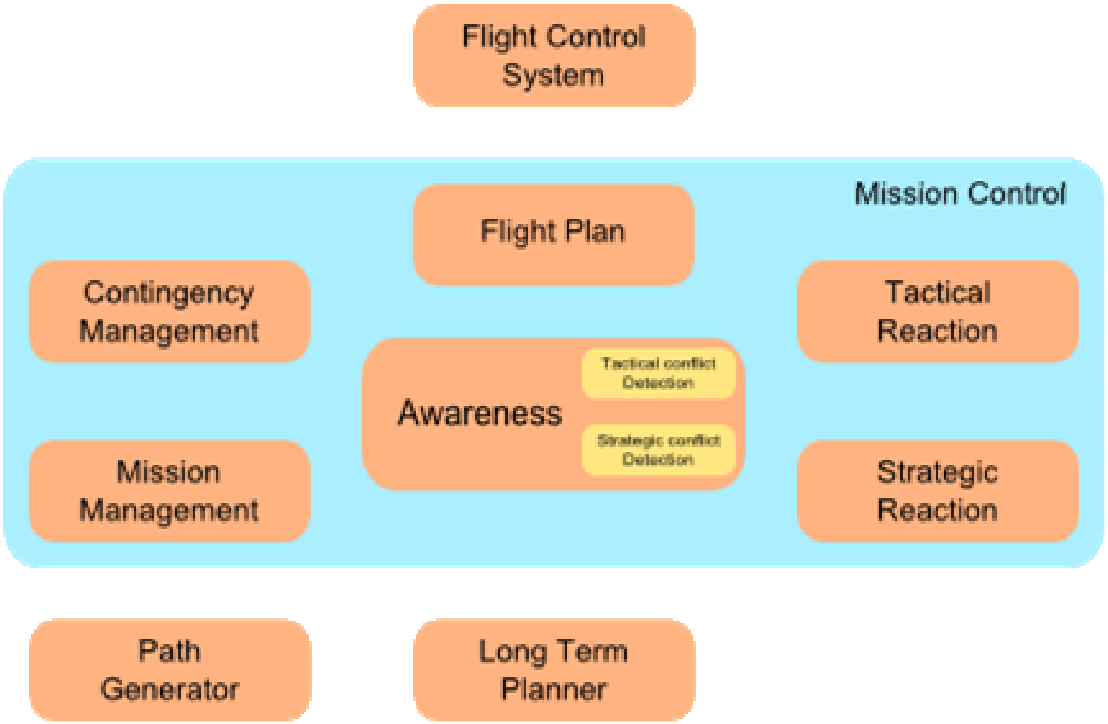
- Main characteristics of the SOA-based architecture:
  - **Dynamic service discover**. Services can be identified when the system goes online or later during operation.
  - **Remote execution**. Consumer simply sends a service request and its parameters. Later on it will get results.
  - **Module self-description**. Each module provides a description of the services that it can provide. Services may shut down or be set up dynamically. Multiple equivalent services may be available adding a level of redundancy.
  - **Two naming policies**. Services are identified by clear and sound names, while internally translated into IP/Port identifiers (like DNS).
  - **Data streaming**. For high rate of change data a continuous service request is inefficient. Service "*subscription*" should be used in this case.

Mission control

- The mission control is a set of services that orchestrate the whole operation of the UAV.
- Its function is to link the flight plan that the UAV 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.

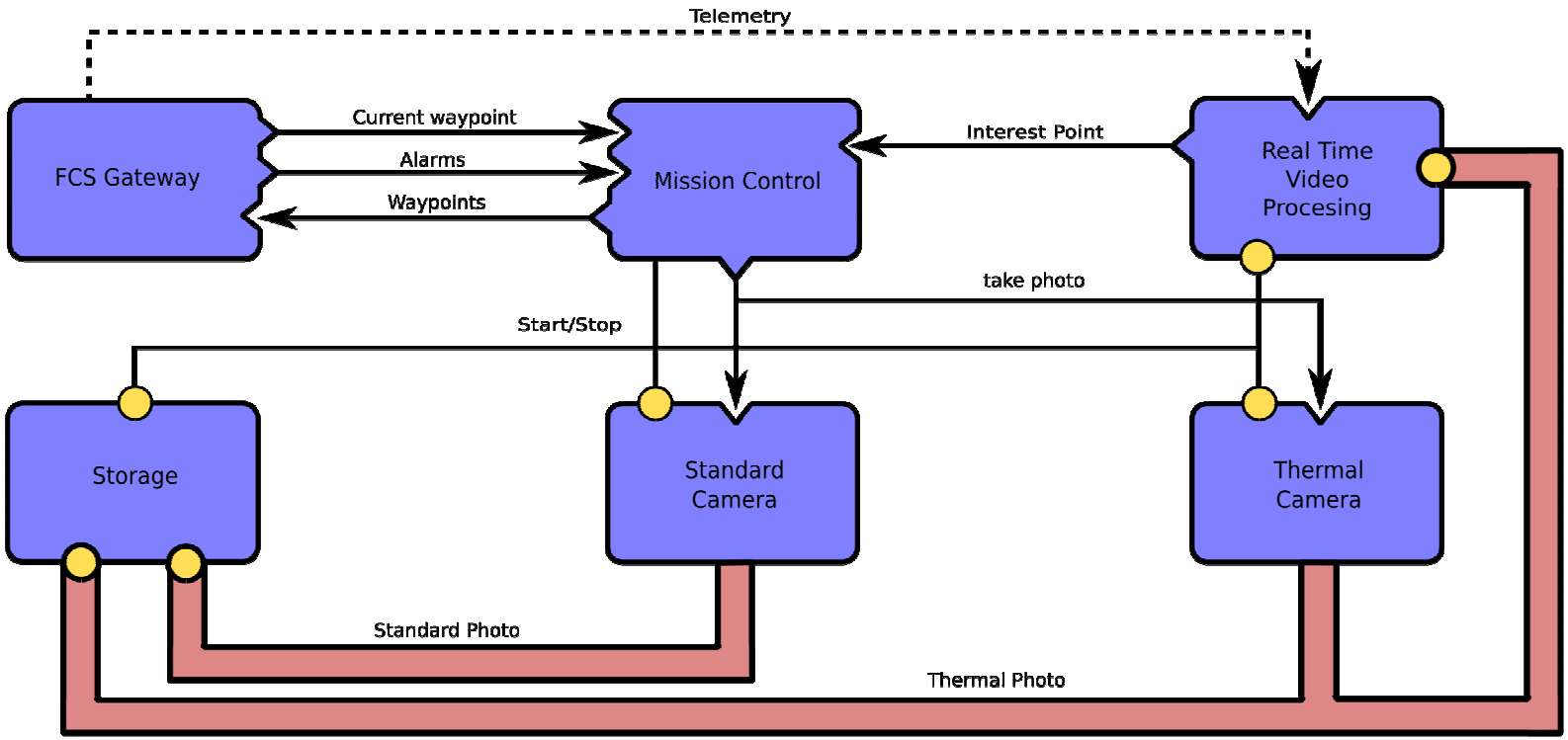
Mission control

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

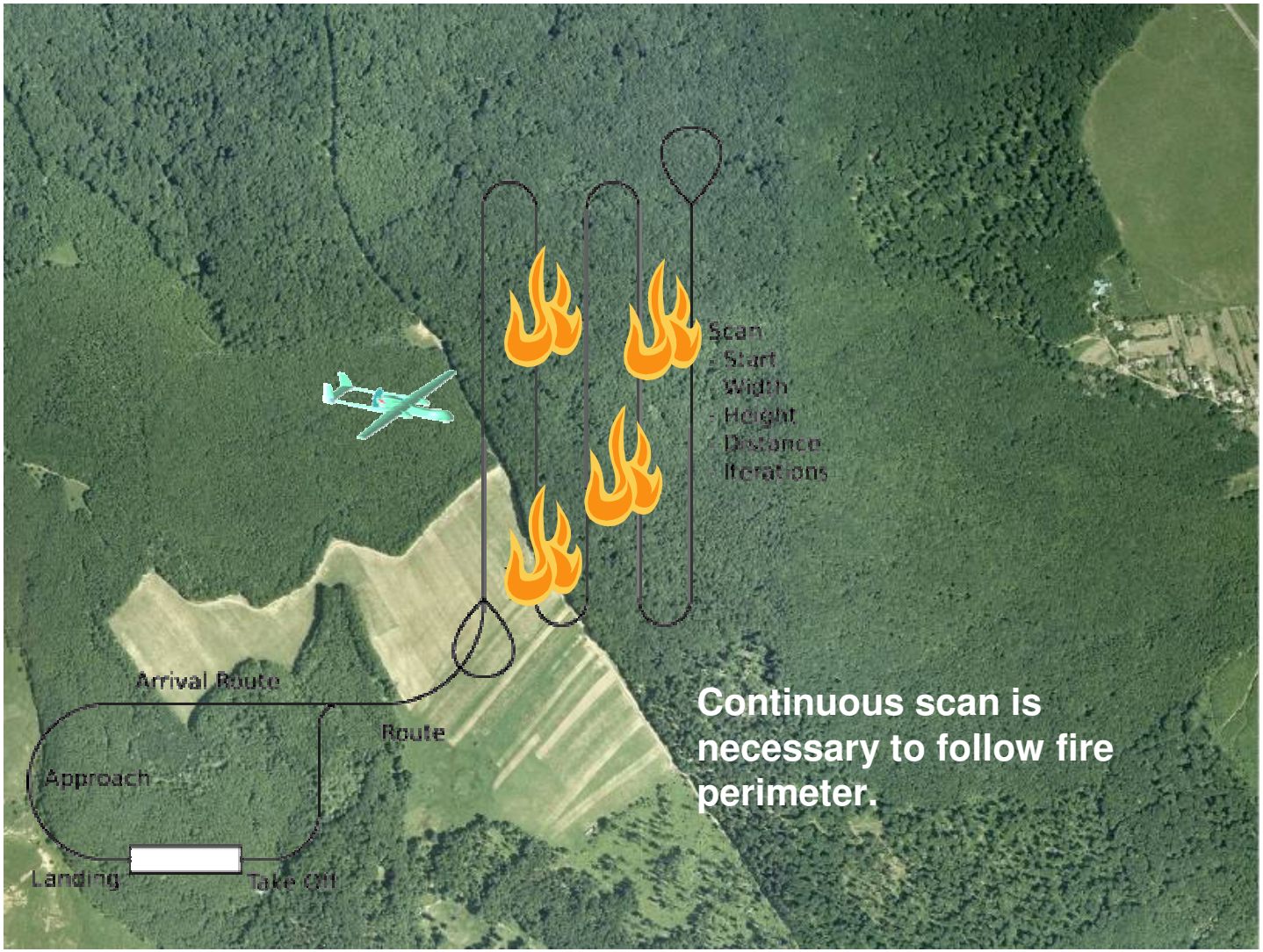


Mission control

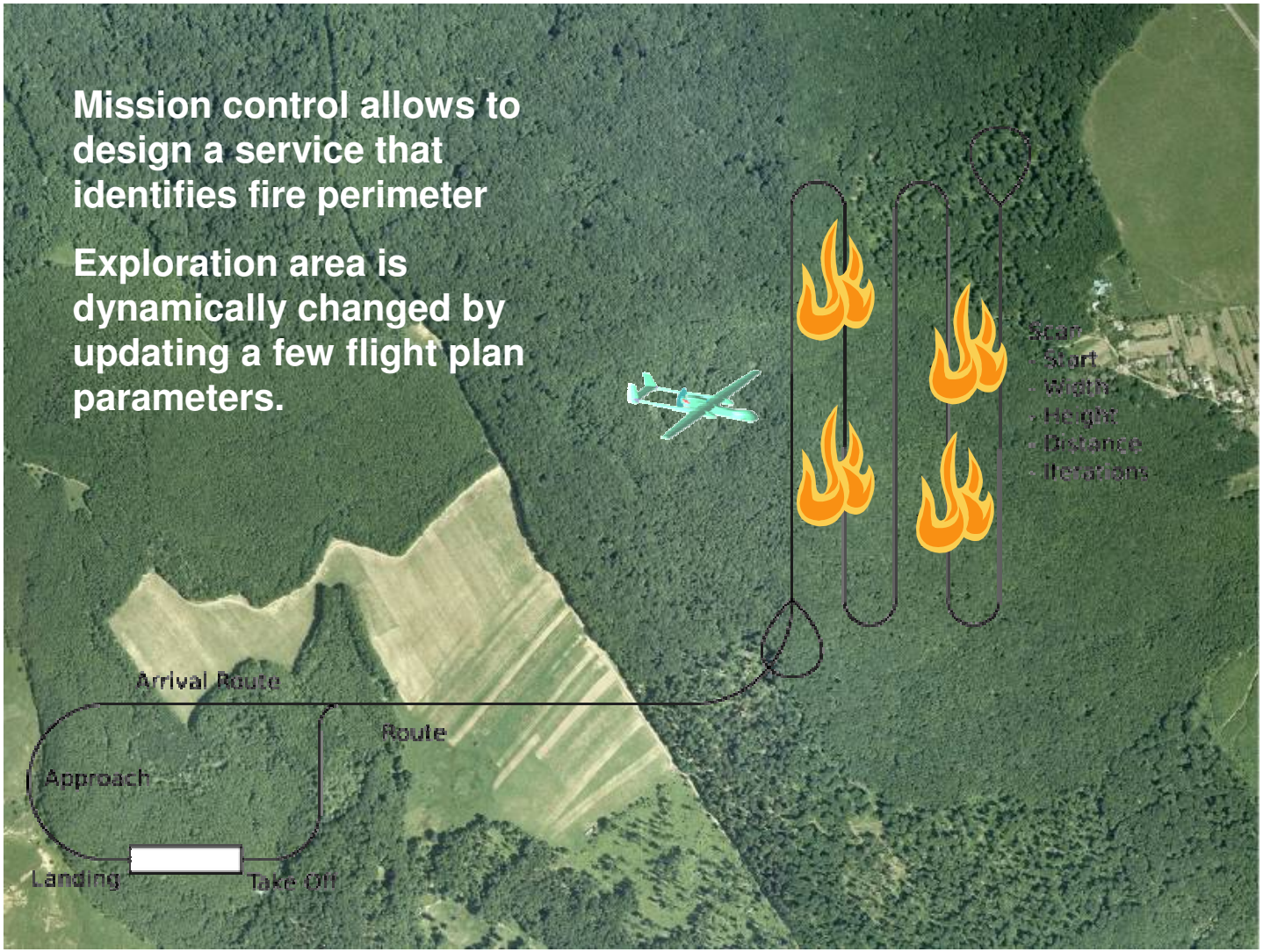
- Mission is formally specified through visual tools:
  - Relations between services are specified by flow diagrams
  - Dynamic activities through event-based systems.



Mission control



Mission control



Communication gateway

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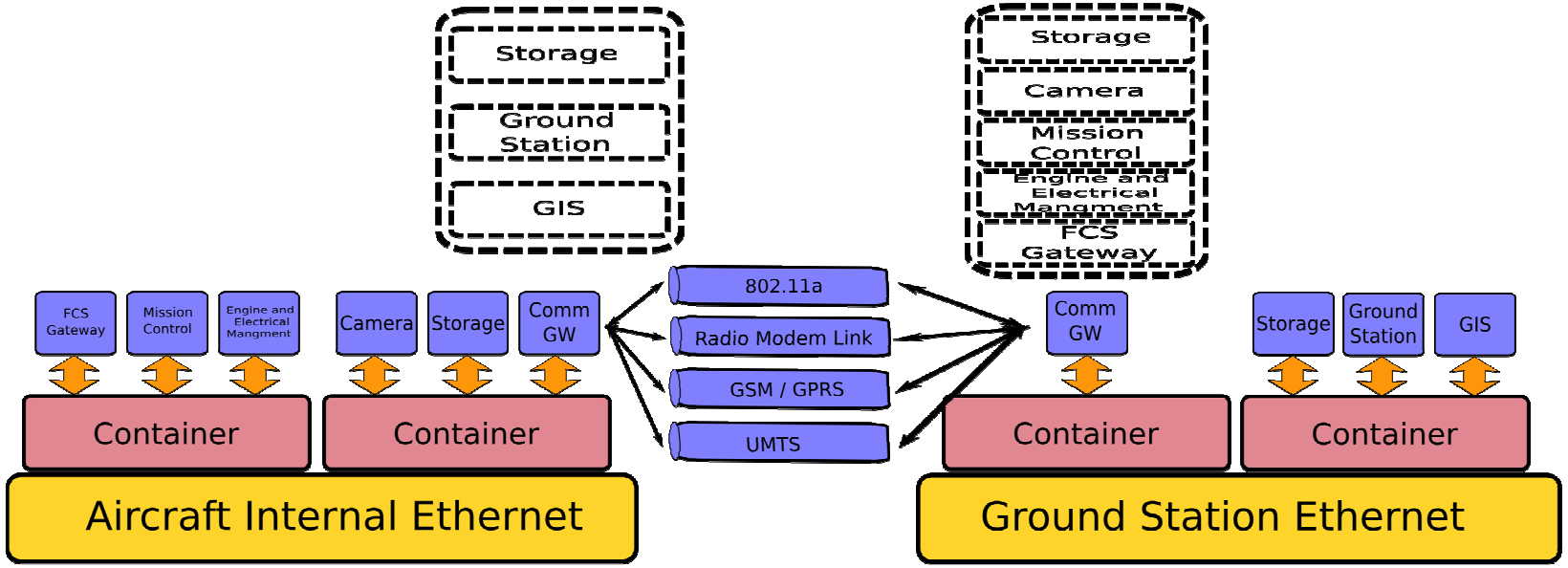
- UAVs usually have different communication links: RF, SATCOM, wireless WANs, GPRS/UMTS.
- Throughput, range and specially cost may differ a lot depending on the link and the actual state of the UAV.
- Inter-UAV and UAV to base station communications are considered different issues, complicating application 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.



Communication gateway

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- The functions of the *Communication Gateway* are the following:
  - Separate data packets directed to the UAV's internal LAN from those directed to external nodes (e.g. one or more base-stations).
  - Route these packets through the selected communication link according to capacity/cost criteria.
  - Monitor all communication links and route the traffic between the UAV and the base station.
  - Keep updated state of each potential link to determine actual capacity/availability (measured through ping packets).
- Equivalent Gateways should be present on the ground, although not necessarily each one controlling all links.

Application domains

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- **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

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- Early morning or late afternoon UAVs 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

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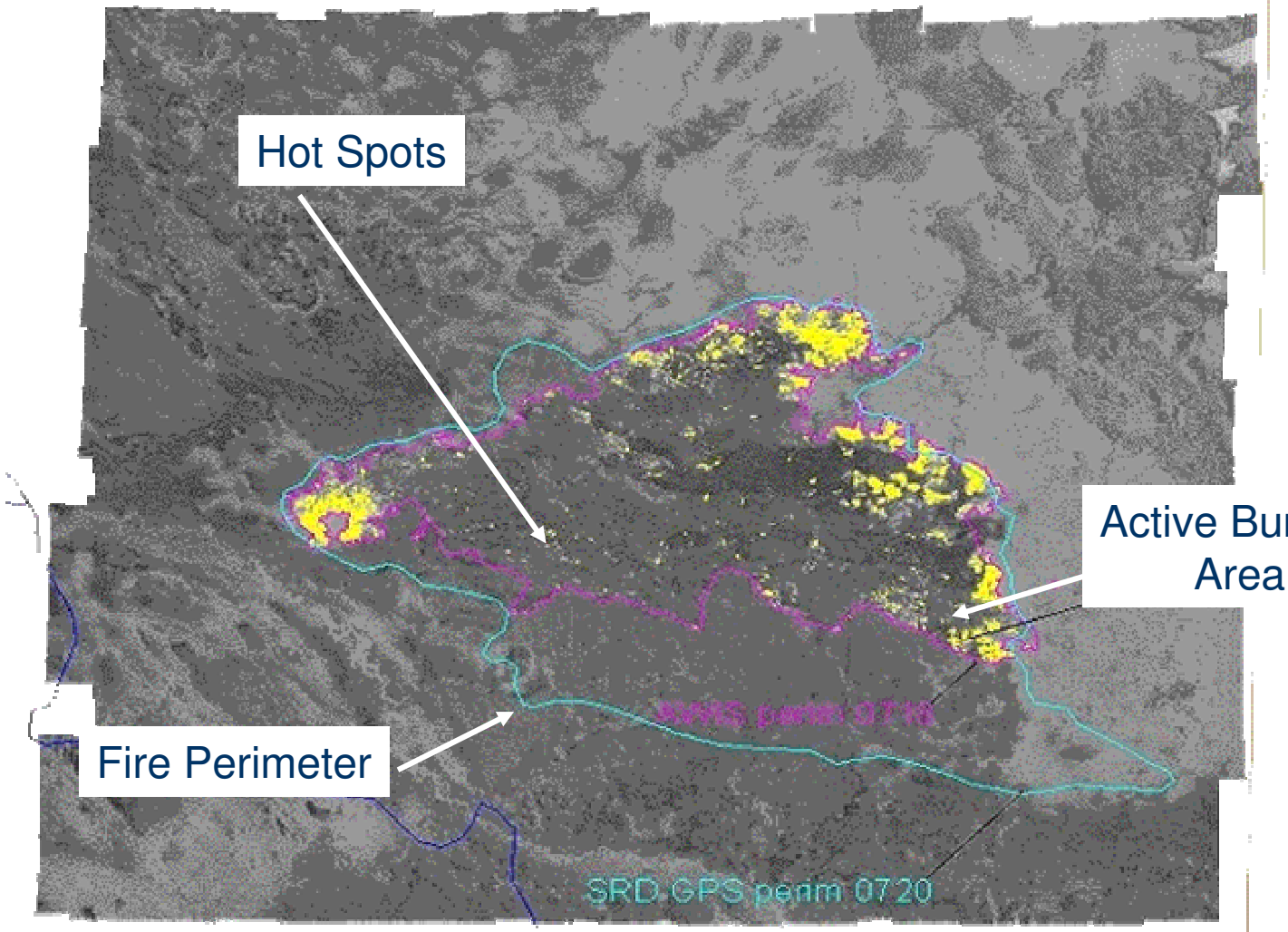

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Application domains

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- 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

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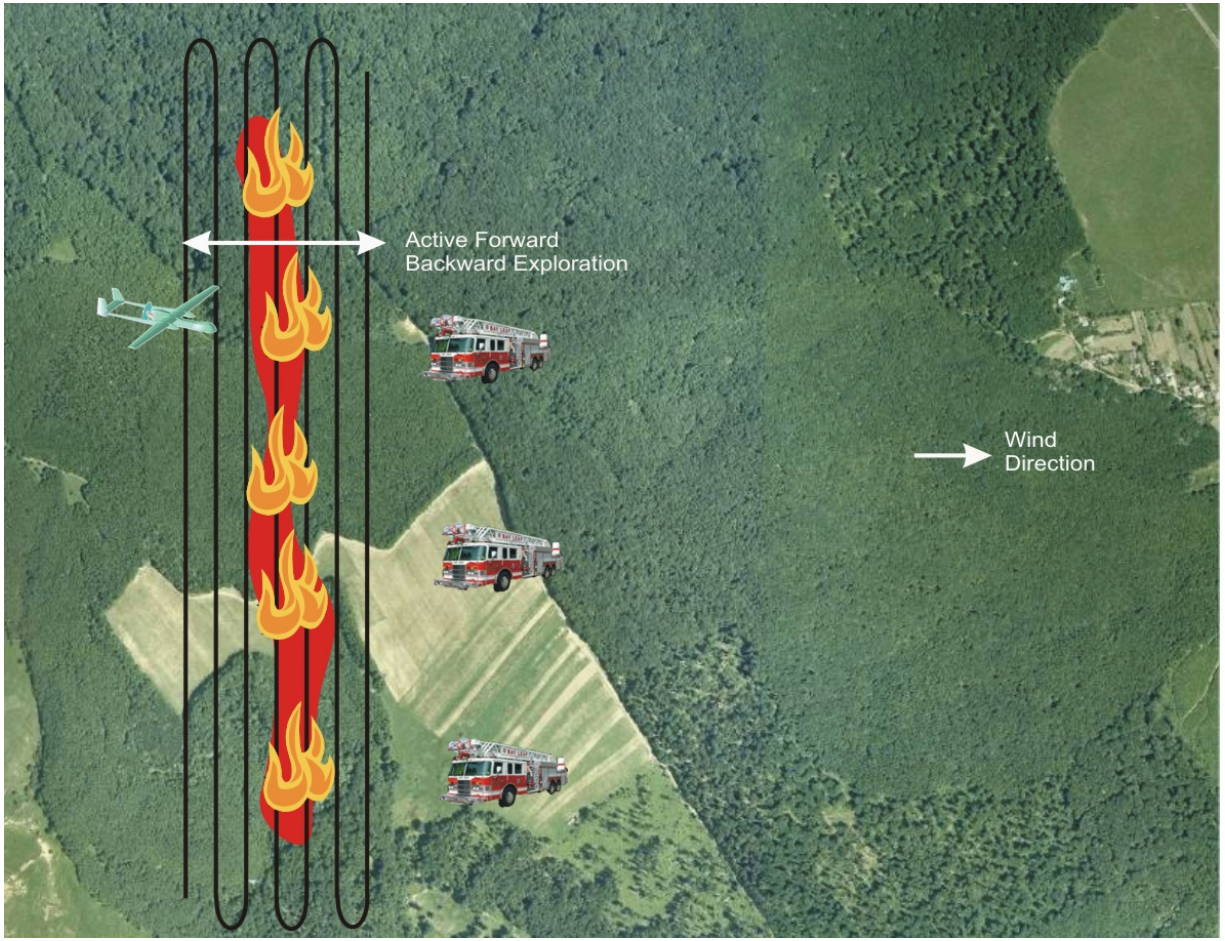
- Prescribed fire front should be dynamically followed:



Application domains

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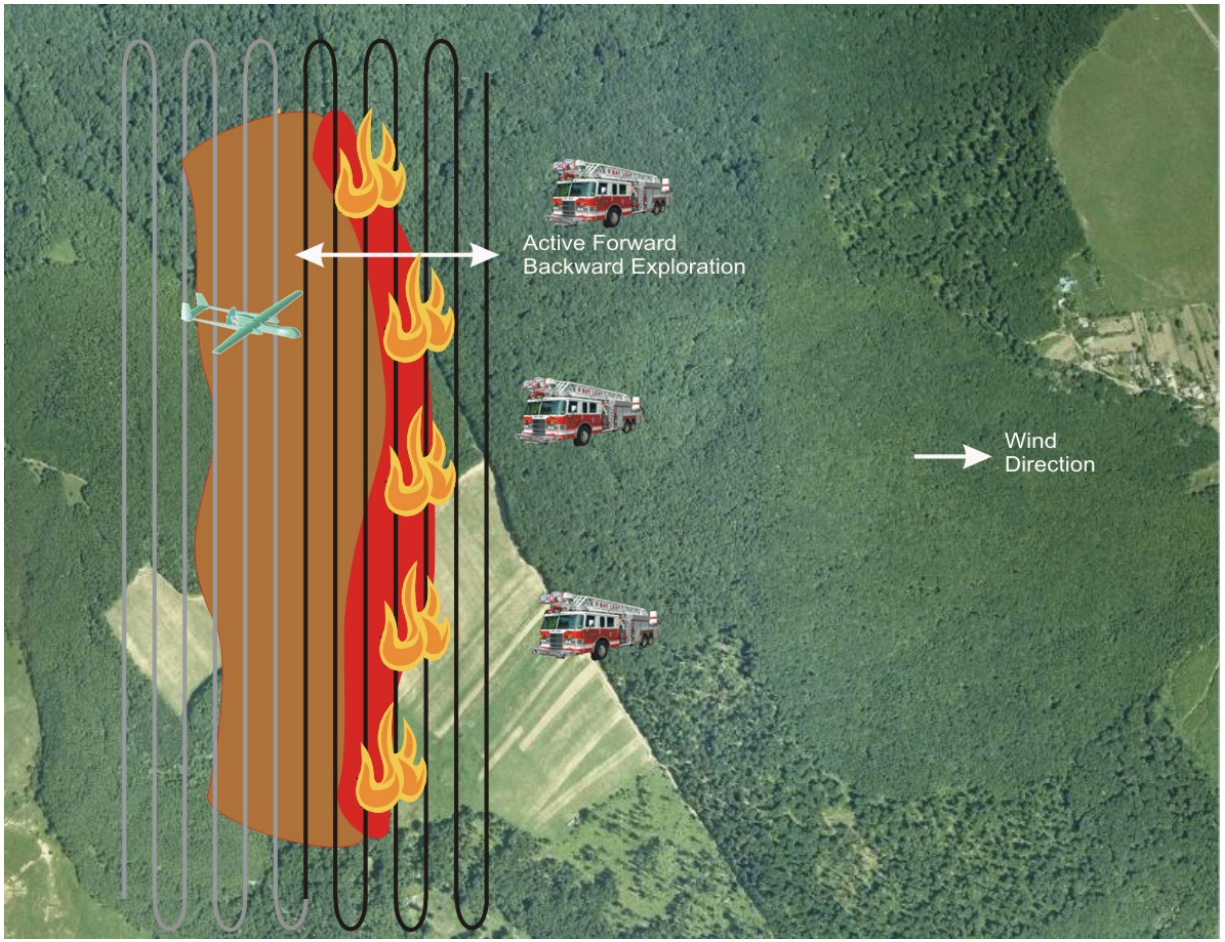

Application domains

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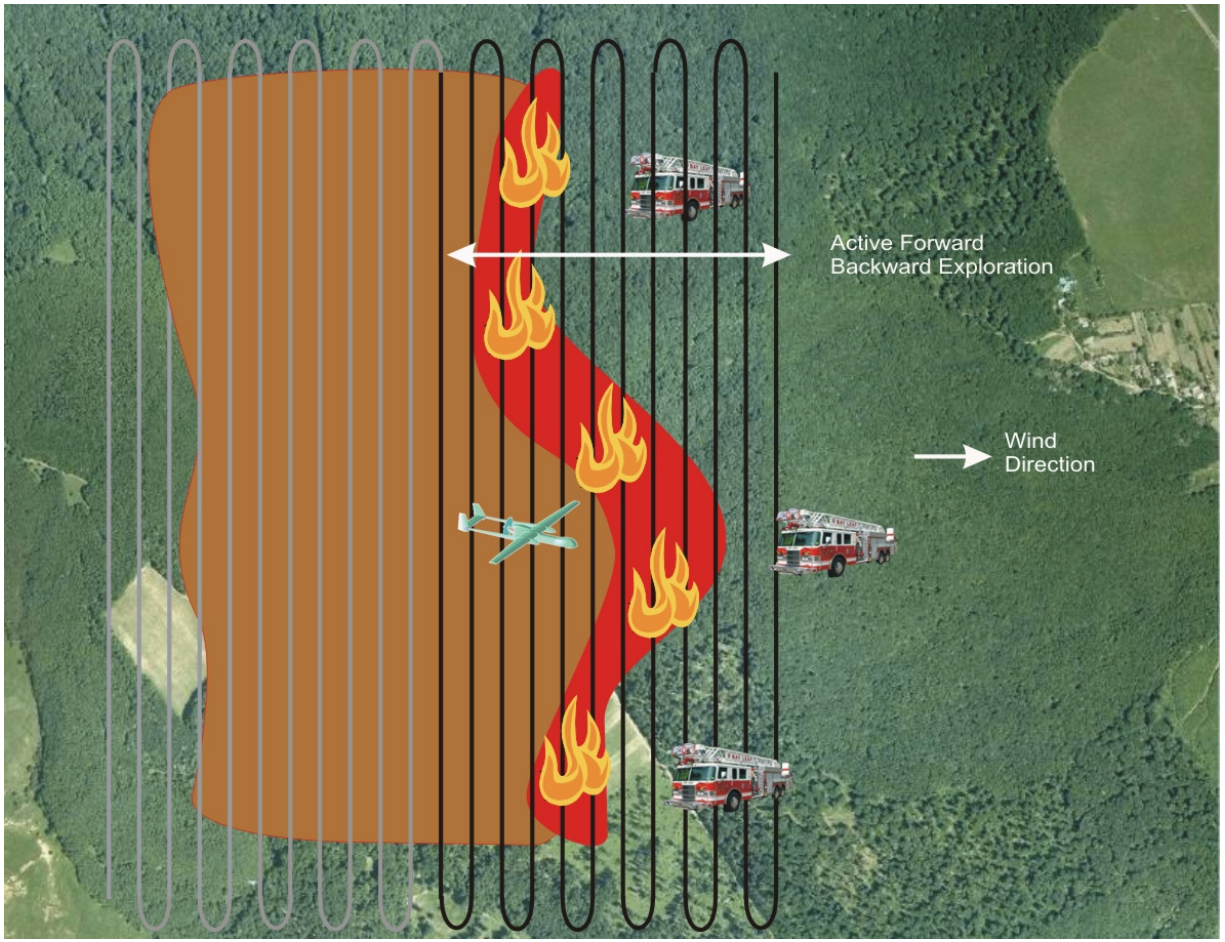

Conclusions

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- Forest fire monitoring is an interesting civil application for UAVs that may become a commercial market.
- Integration of the UAV in the airspace is a bottleneck but still interesting application areas exist.
- Integration of the UAV 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 UAV operation, required hardware/software systems and information flow processes.
- UAV platform is currently undefined.