Outline

- **Context:** UAV, mission, autonomy, architecture
- Experimental means
- Application 1: visual mapping
- Application 2: automated planning
- Application 3: mobile object tracking
- Application 4: multivehicle coordination for localization
- Conclusion
**Context**

- **UAV** Unmanned Aerial Vehicle: "machine which functions either by the remote control of a navigator or pilot or autonomously, that is, as a self-directing entity"
  

- Autonomous UAV → **AAV** Autonomous Aerial Vehicle

- **UAS** Unmanned Aircraft System = aircraft + control system (Ground Control Station) + control link + other related support equipment

- For military and civil applications: observation, surveillance, exploration, inspection, search and rescue, relay…

**Context**

- **Mission environment**
  - Well-known, poorly known or unknown
  - **Uncertainties**: wind gusts, measurement noise, atmospheric altitude, airspeed variations…
  - Dynamic changes = time-variant
  - No communication link: loss or wanted discretion

- The mission rarely executes as prepared offline

- UAV: "machine which functions either by the remote control of a navigator or pilot or autonomously, that is, as a self-directing entity"
**Autonomy**

- **Autonomy**
  - To execute the mission
  - To adapt to disruptive events

  

  

- **UAS = aircraft + Ground Control Station + control link + other related support equipment → onboard:**
  - Hardware: sensors, actuators, communication devices, payload
  - Software
    - Vehicle navigation
    - Mission management
    - On-board implementation of the whole control loop (perception, situation assessment, decision, and action)

- Implementation of autonomy in a software decisional architecture

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**Architecture**

- **Data fusion**
  - Payload data processing
  - Ex: SLAM (Simultaneous Localization and Mapping) of vehicles, targets, landmarks

- **Situation assessment**
  - High level state model of the whole system: agents, vehicles, environment
  - Real time assessment and prediction of situations → nominal, disrupted, unreachable

- **Supervision**
  - Online control of the execution of planned actions
  - Reactions trigger depending on current and predicted situations
  - Execution of elementary actions: move, perception, communication, replanning

- **Planning**
  - Mission = flight plan, ordered list of dated actions
  - Plan = sequence of actions or policy
  - Offline preparation and online repair or replanning
Architecture

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**Onera experimental means**

- **ReSSAC VTOL**
  - 2 Yamaha ReSSAC-RMax
  - 1 Benzin ReSSAC-Turbo Turbine Vario
  - 2 Benzin ReSSAC-Vario Combustion engine Vario

<table>
<thead>
<tr>
<th></th>
<th>Take-off weight</th>
<th>Including payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>ReSSAC-RMax</td>
<td>90kg</td>
<td>30kg</td>
</tr>
<tr>
<td>ReSSAC-Turbo</td>
<td>30kg</td>
<td>10kg</td>
</tr>
<tr>
<td>ReSSAC-Vario</td>
<td>13kg</td>
<td>3kg</td>
</tr>
</tbody>
</table>

**Onera ReSSAC project initially**

- To develop a VTOL UAS experimental platform in order to demonstrate the feasibility of autonomy capabilities
  - for remotely operated uninhabited air systems
  - with restricted information flows between ground station & UAS
  - for search & rescue scenarios in ill-known environment

- Safely operated experimental VTOL UAS

- French Civil Aviation DGAC authorizations:
  - 2002: line of sight remotely piloted flight
  - 2006: line of sight automatic flight

- “At every moment the UAV remains within a safety flight domain or can be brought to the ground within a safety ground perimeter”
Architecture on ReSSAC-RMax

- Primary processor
  - GPS/INS navigation filter
  - Basic flight controller

- Second processor
  - Decisional architecture

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Architecture on ReSSAC-RMax

- Decisional architecture: based on Orocos = Open RObot COntrol Software
  - Ex. of components for mobile object tracking: Camera, Navigation, Tracking, Estimation et Guidance
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Application 1 – Online visual mapping

- Goal: detect over-ground obstacles
- Use: onboard replanning for low-altitude flight, safe automatic landing, traversability map for ground vehicles...

- Algorithm
  - Based on segmentation of the optical flow between two video frames
  - Optical flow decomposition:
    - Homographic component due to the ground plane
    - Parallax component due to the relief above/below the smooth surface
Application 1 – Online visual mapping

- Efficient optical flow computation
  - Inputs: matched Harris corners between two views
  - Based on Lhuillier’s Quasi-Dense matching algorithm
  - Fast (2Hz) and reliable for aerial nadir images

- Robust estimation of a planar homography model
  - Inputs: matched Harris corners between two views
  - Least Median of Square robust estimation technique
  - Temporal propagation for better robustness
Application 1 – Online visual mapping

• Image classification

• Traversability map for Unmanned Ground Vehicles: ground based Mosaic
  • Projection on the mean ground plane thanks to viewing conditions
  • Fusion operator: biased majority voting
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Application 2 – Emergency autonomous landing

• Objective: to map a rectangular zone and quickly find a place to land
  • Minimize duration

• Long-term planning:
  • Scanning → automated mapping gives candidate landing zones, not necessarily landable
  • Zooming → landable zones
Application 2 – Automated planning

- Automatic generation of strategies or action sequences that achieve a given objective knowing an initial state and actions effects
- Development of a generic Orocos component to be interfaced with existing planners
- Provide immediate services on demand to other components: full reactivity to action requests

Application 2 – Automated planning

- State machine
Application 2 – Experiments

- Experiments on a high dimensional search & rescue mission, and random challenging benchmarks

- Video: Emergency autonomous landing

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Application 3 – Mobile object tracking

• Goal: to detect, localize, and pursue a moving ground target in an unknown urban environment by using vision information

  • Obstacle mapping = gather environmental information from high and safe altitude \( \Rightarrow \text{cf. application 1} \)
  • Target search & detection = local search at low altitude
  • Target tracking = pursue the target while avoiding obstacles

Application 3 – Simultaneous Navigation & Tracking

• Image processor
  • Target tracker
  • Optical flow field estimation (by feature point matching)

• Navigation filter
  • Extended Kalman Filter (EKF)
Application 3 – Optical flow field estimation

- Offline simulation with flight test data
  - Actual sequence of onboard camera images
  - Onboard sensor measurements

![Graph showing optical flow field estimation with different data sources: GPS/INS, Vision/INS, and INS-only.](image)

Application 3 – Dual control guidance problem

- Guidance Objective
  - Horizontal motion for target tracking
    - Follow the target trajectory
  - Vertical motion for obstacle avoidance
    - Follow the safety altitude profile along the horizontal trajectory

- One-Step-Ahead suboptimal guidance

![Diagram illustrating the dual control guidance problem with vision-based navigation and control](image)
Application 3 – Software in the loop Simulation

  - Blender + Yarp + Python
  - Multiple robots
  - 3D environments
  - Sensor measurements
  - Images

Application 3 – Closed Loop Flight

- September 30, 2009 @ Esperce

onboard camera image
Application 3 – Closed Loop Flight

- In the combat training village
  - December 09, 2009 @ Caylus

- Flight demonstrations to public
  - INTRA Demonstration Day, June 24, 2010 @ Fontevraud
  - UAV Show Europe, September 15-16, 2010 @ Bordeaux-Mérignac

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Application 4 – Action project

- Prospective Research Programme: Cooperation of multiple heterogeneous vehicles, 2007 – 2013

- “Investigate the available means and design future technologies in order to upgrade the performance of the localization function within a network of heterogeneous autonomous vehicles”

- Funding: French Defence procurement agency DGA MI (Maîtrise de l’Information)
- Follow-up: DGA TT ( Techniques Terrestres) et DGA TN ( Techniques Navales)

- Localization of: friends, foes, targets, landmarks, obstacles
- GPS-independent localization means, as much as possible

- Scientific experiments involving multiple uninhabited vehicles

Application 4 – Air-ground scenarios

- 4 air-ground scenarios, from 2 to 12 vehicles (AAV and AGV)
- Infrastructure surveillance mission: localization and tracking of non-cooperative targets
- Growing complexity: areas, targets, disruptive events…
Application 4 – Air-sea scenarios

- 2 air-sea scenarios, with 2 and 3 vehicles (AAV, AUV, ASV)
- Securing mission
- Fight against water pollution mission

Application 4 – Scientific work

- Vehicles already load a local decisional architecture for their one-vehicle missions
- Objectives: implement above each local architecture a decisional architecture for cooperation

Mono and multi:
Application 4 – Scientific work

• Data fusion
  • Data processing for the localization function
  • SLAM (Simultaneous Localization and Mapping) of vehicles, targets and landmarks
  • Layered environment modeling
  • Tracking of targets

• Planning
  • Plan = sequence of actions or policy
  • Coordination for cooperation: rendez-vous, communication
  • Offline preparation and online repair or replanning

• Supervision
  • Online control of the execution of planned actions
  • Reactions trigger depending on current and predicted situations
  • Execution of elementary actions: move, perception, communication, replanning

Application 4 – Morse simulator, release 0.4

• http://www.openrobots.org/wiki/morse/
Application 4 – Target tracking at sea

- January 2011 @ Argeles-sur-mer (Mediterranean sea)

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**Conclusion**

- Using UAVs as data acquisition platform and as measurement instrument is crucial for autonomy objectives, in order to close the whole control loop (perception, situation assessment, decision, and action).

- On-going work on laser mapping for obstacle avoidance.

- Elaboration of geomatic products (Digital Elevation Model, orthomosaic) from video and lidar data.