The ONERA ReSSAC Unmanned Autonomous Helicopter : Visual Air-to-Ground Target Tracking in an Urban Environment

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ONERA
THE FRENCH AEROSPACE LAB
retour sur innovation

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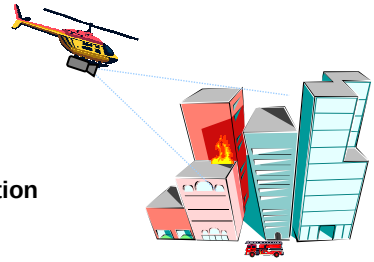
Mission Scenario

Mission Goal :

To detect, localize, and pursuit a moving ground target
- in an unknown urban environment
- by using vision information

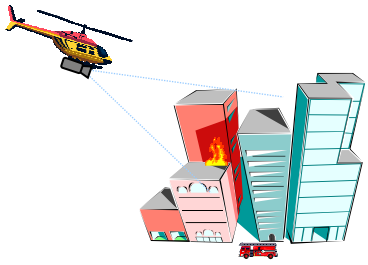
Operation Phases :

- ϕ **1. Obstacle Mapping**
- ϕ **2. Target Search & Detection**
- ϕ **3. Target Tracking**

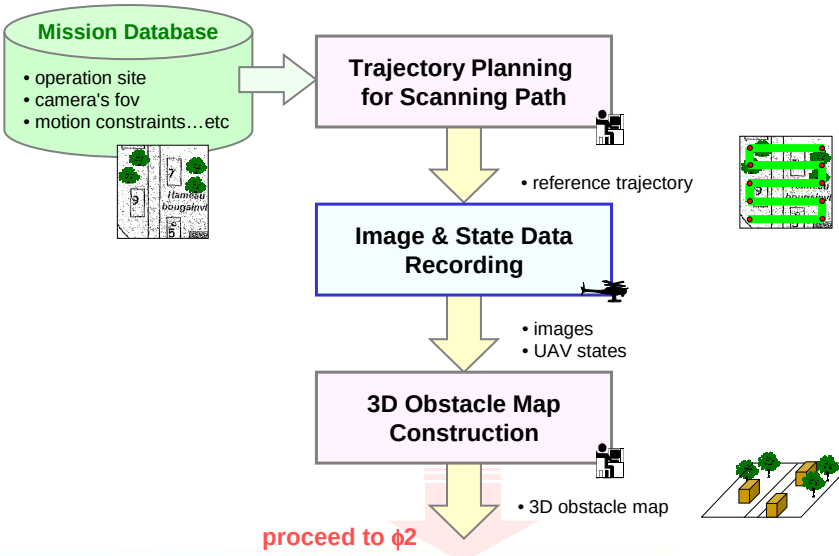


Outline

- **Obstacle Mapping**
- **Target Search & Detection**
- **Target Tracking**
  - vision based tracking
  - compensating for GPS loss
  - optimizing guidance for better tracking
- **Decision & Control integration**
  - architecture
  - simulation and flight experiments
- **Conclusion and perspectives**



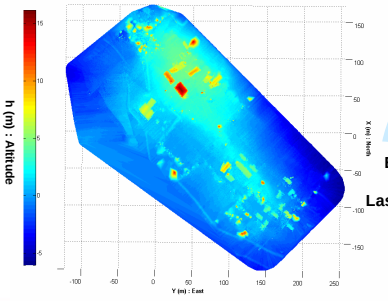
ϕ1 : Obstacle Mapping



Elevation Map from Laser Range Finder

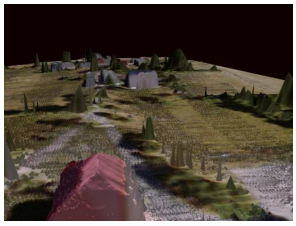
5

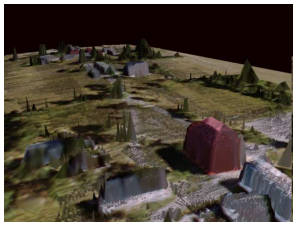
Aerial Image



Elevation Map
from
Laser Range Finder

3D Obstacle Model





ϕ2 : Target Search & Detection

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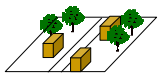
from ϕ1

• 3D obstacle map



Mission Database

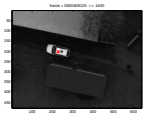
• camera's fov
• motion constraints…etc

Trajectory Planning for Search Path

• reference trajectory

• target characteristics (color, size, shape…)

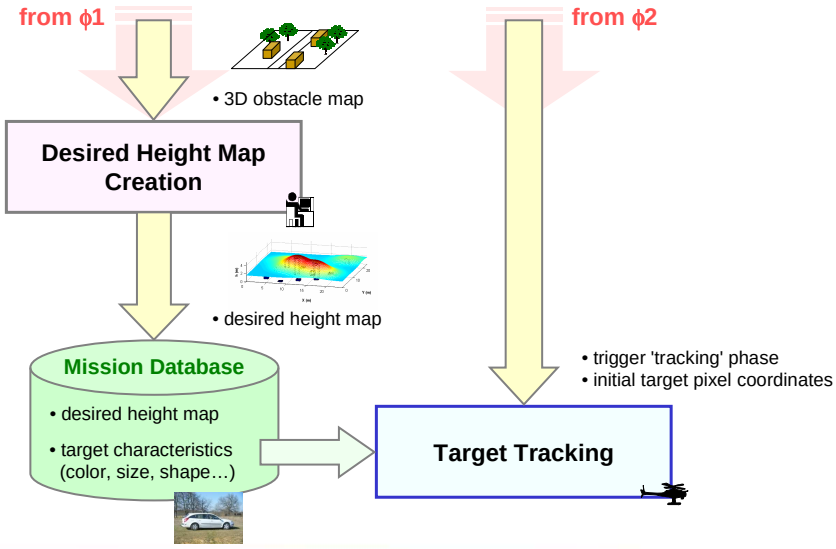
Target Search & Detection



• trigger 'tracking' phase
• initial target pixel coordinates

proceed to ϕ3

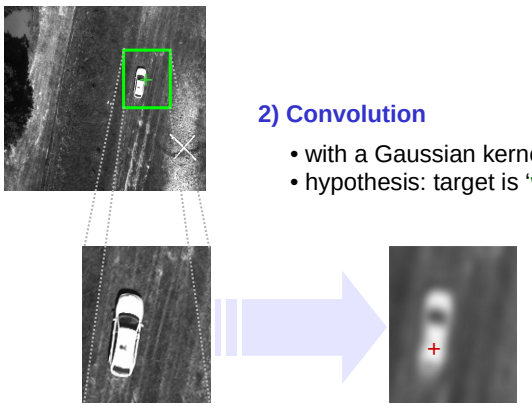
ϕ3 : Target Tracking



Target Tracker

1) Window Selection

- centered at a predicted target position

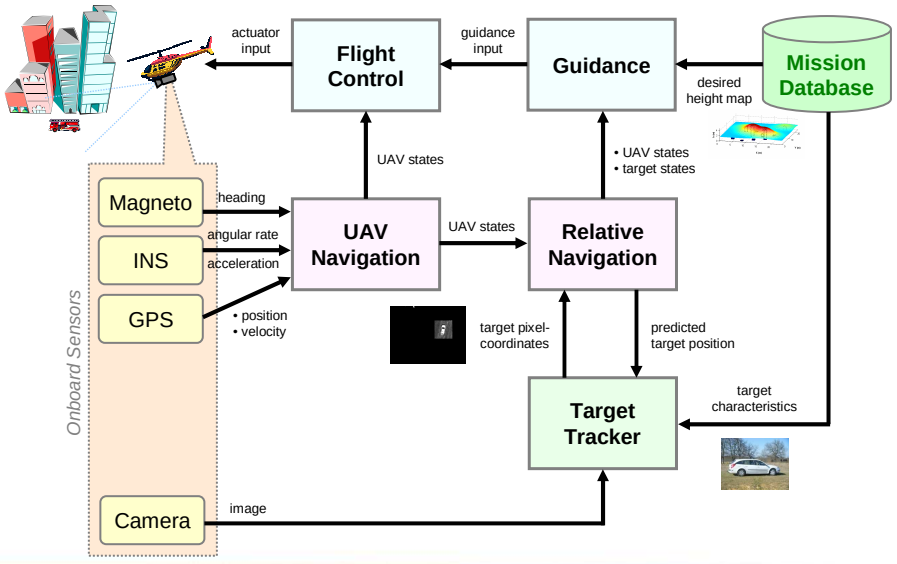


2) Convolution

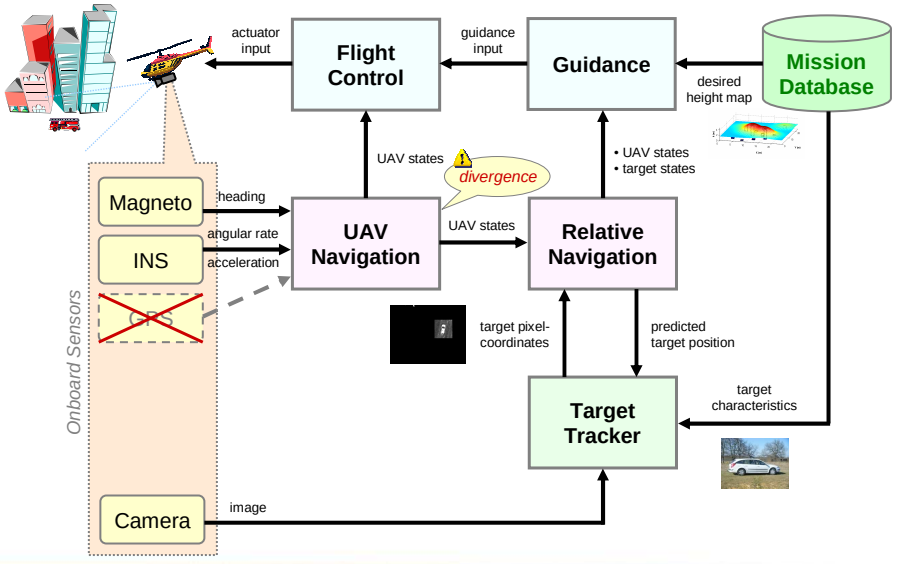
- with a Gaussian kernel of target size
- hypothesis: target is 'whiter' than background

3) Selection of point with highest value

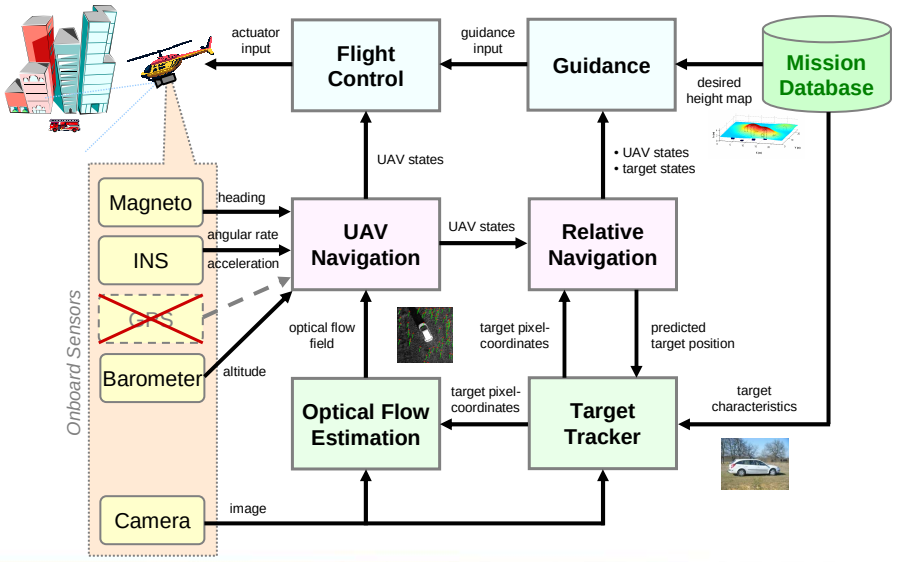
UAV Onboard System for ϕ3



UAV Onboard System for ϕ3



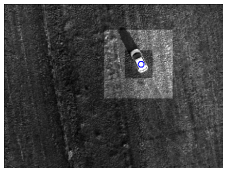
UAV Onboard System for ϕ3 w/o GPS



Optical Flow Estimation

1) Window Selection

- centered at a detected target position



2) Feature Point Selection

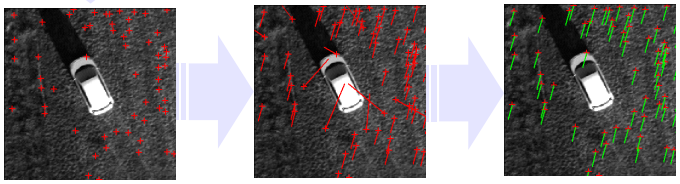
- Harris detector

3) Feature Matching

- Cross co-relation

4) Affine Approximation

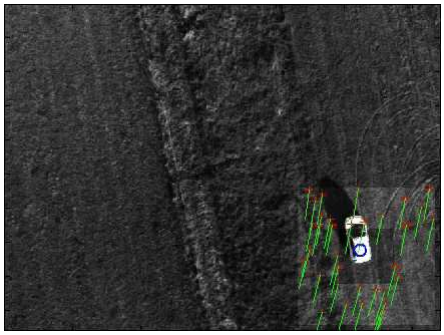
- RANSAC



Optical Flow Measurements

- **Offline Simulation**

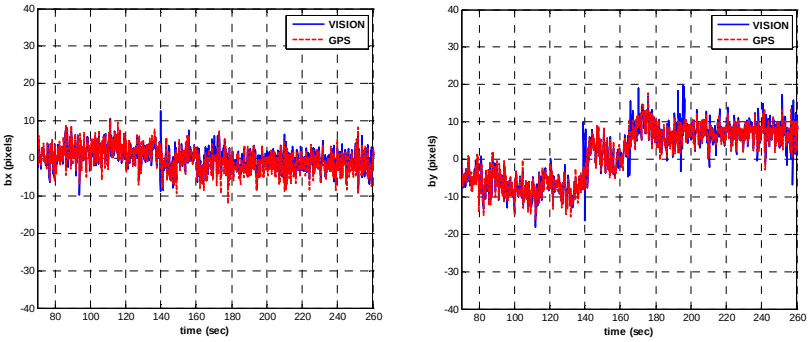
  - With actual image sequence of onboard camera images



Optical Flow Measurements

- **Online in-flight processing**

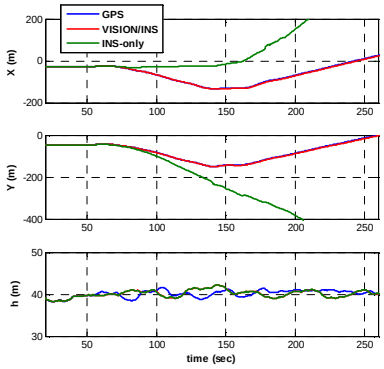
  - Compared with the optical flow estimated from GPS velocity measurement
  - @ 7 Hz
  - optical flow in pixels/seconds along X axis ... ... and along Y axis



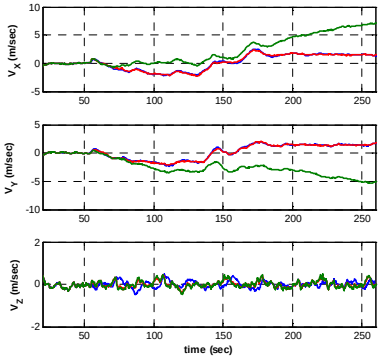
Vision / INS UAV Navigation

- **Offline Simulation of GPS loss navigation with flight test data**

• UAV Position Estimation

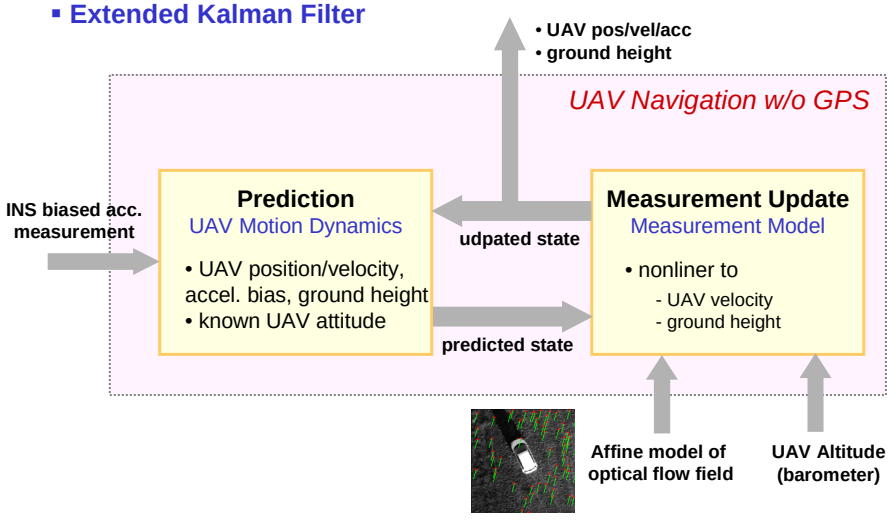


• UAV Velocity Estimation



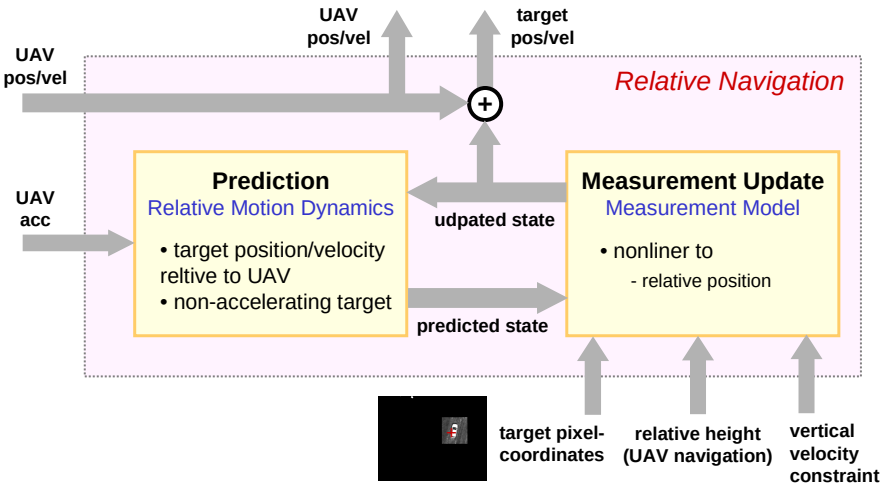
UAV Navigation

- **Extended Kalman Filter**



Relative Navigation

- **Extended Kalman Filter**



Guidance

- **Objective**
  - Horizontal motion : **Target Tracking**
  - Vertical motion : **Obstacle Avoidance** - by following a desired height along the horizontal trajectory

- **Reference Trajectory :** $\hat{X}_d = \begin{pmatrix} \hat{X}_t \\ \hat{Y}_t \\ -h_d(\hat{X}_v, \hat{Y}_v) \end{pmatrix}$ target position / desired height

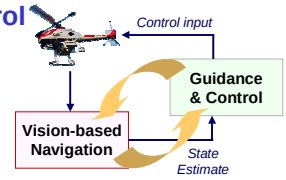
- **Nominal Guidance (LQR)**
  - Minimize **Total Cost = (Tracking Error) + (Control Effort)**

$$a_v = -K_p(\hat{X}_v - \hat{X}_d) - K_d(\hat{V}_v - \hat{V}_d) + \hat{a}_d$$

Estimation error can cause poor tracking performance!!

Guidance (Cont'd)

- **No Separability between Estimation & Control**
  - Navigation performance highly depends on relative motion
  - Guidance performance directly depends on estimation accuracy



- **One-Step Ahead Optimal Guidance ***
  - Minimize **Expected Total Cost** under an assumption that there will be one more measurement at one time-step ahead.

$$a_v = \underbrace{-K_p(\hat{X}_v - \hat{X}_d) - K_d(\hat{V}_v - \hat{V}_d) + \hat{a}_d}_{\text{Nominal Input}} + \underbrace{\Delta a}_{\text{Additional Input}}$$

* *Y. Watanabe «Stochastically Optimized Monocular Vision-Based Navigation and Guidance» PhD Thesis, Georgia Institute of Tehcnology, 2008.*

Experimental Platform

- **ONERA ReSSAC UAV Helicopter**

- **YAMAHA RMax**
- length = 3.63 (m), height = 1.08 (m)
- empty weight = 58 (kg), max takeoff weight = 93 (kg)
- GPS, INS, compass, barometer, camera, LRF

- **Onboard Processors**

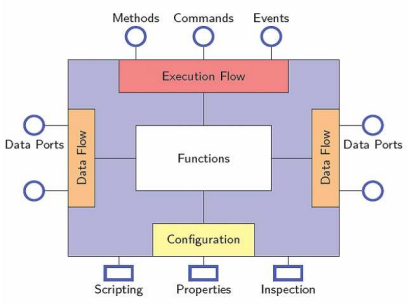
- Primary processor : PC/104 with Pentium 266 MHz

  - GPS/INS navigation filter
  - Security flight controller
- Second processor : PIP11(MPL) hardware unit

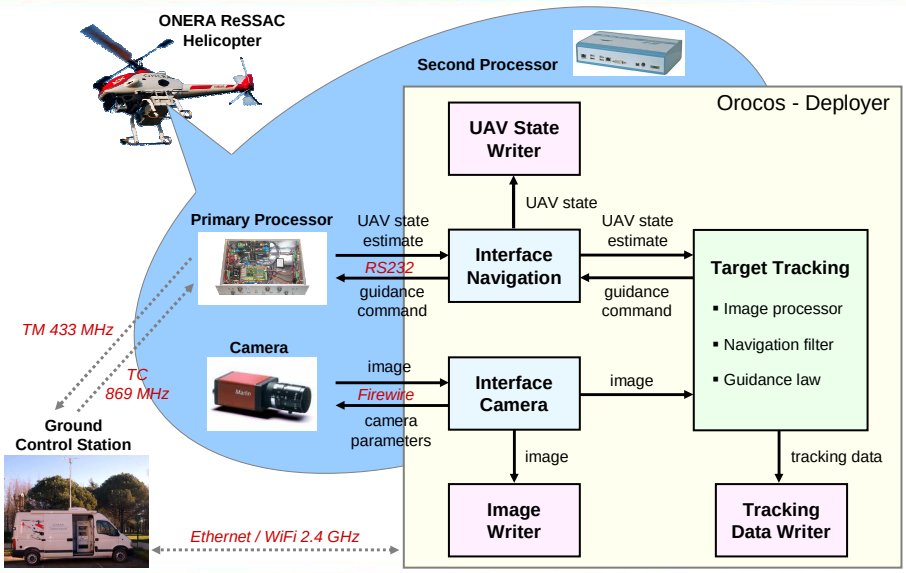
  - Pentium M 1.8GHz
  - RS-232, Firewire, Ethernet
  - Decision architecture

Decision Architecture

- **GNU/Linux Debian**
- **Generic Decision & Control Architecture**
- **OROCOS (Open RObot COntrol Software)**
  - Open source C++ robotics library (http://www.orocos.org)
  - Real-time toolkit
  - Component based application
    - Data ports
    - Services

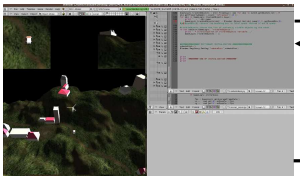


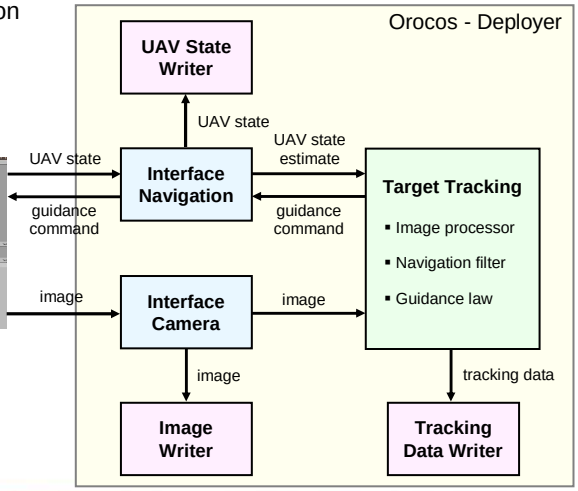
ReSSAC Embedded System



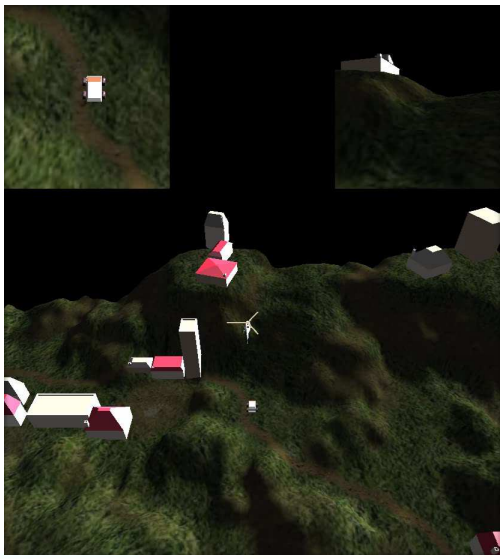
Software-in-the-loop Simulation

- **OpenRobots Simulator** (https://launchpad.net/openrobots-simulator)
  - Blender + Yarp + Python
    - multiple robots
    - 3D environments
    - sensor measurements
    - images





Closed-loop Target Tracking Simulation



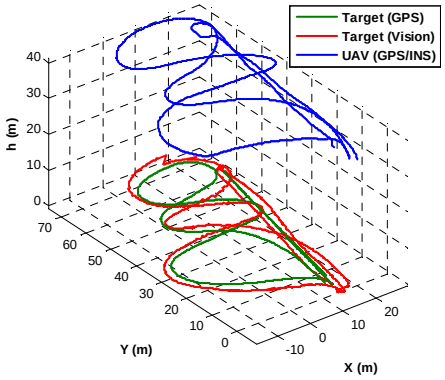
Closed-loop Flight of Target Tracking

- **The first success**
  - September 30, 2009 @ Esperce

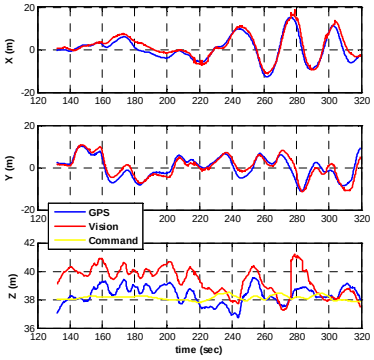
onboard camera image

Closed-loop Flight of Target Tracking

- UAV and Target Trajectories

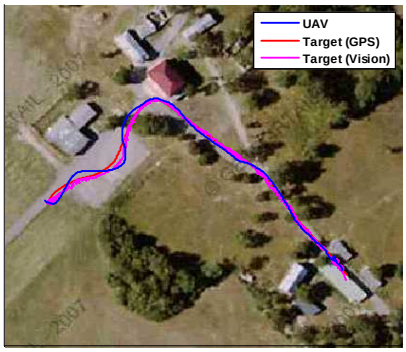


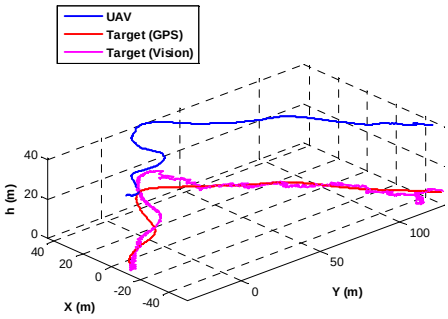
- Relative Position Estimation



Closed-Loop Flight of Target Tracking

- **in the combat training village**
  - December 09, 2009 @ Caylus





Conclusion

- **UAV Visual Air-to-Ground Target Tracking**
  - Optical flow estimation
  - Vision/INS UAV navigation in case of GPS loss
  - System evaluation through simulations and flights
- **Future Work**
  - Closed-loop flight without GPS (temporarily)
  - Target search & tracking scenario demonstration in flight
  - Integration with reactive obstacle avoidance (see & avoid)
  - Integration with 3D motion planning
- **Scenario extension**
  - Integration with decision making: motion & perception planning
    - Cooperative multi-robot system


Thank you for your attention !
Questions ?
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