Autonomous Aerial Vehicles for GPS-Denied, Cost-Efficient Inspection and 3D Reconstruction - Applications

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Introduction

Manual inspection for mechanical structures

- Predominant method
- Labor intensive
- Subjective: Inspector's focus and experience
- Qualitative
- Traffic detouring
- Safety threats

Provide autonomous aerial platform to carry inspection sensors for automated inspection tasks

Micro Helicopters for Inspection at ETH and JPL

Jet Propulsion Laboratory

ETH Zürich

Autonomous Systems Lab

- PhD Thesis in March 2012
  - "Vision Based Navigation for Micro Helicopters"
- Focus: vision based navigation
  - with visual and inertial sensors
  - no GPS nor artificial markers
  - on-board computation
- European projects involved
  - SFly (www.sfly.org)
  - AIRobots (airobots.ing.unibo.it)

- Since Dec. 2012
  - Autonomous Systems Division
- Focus: mature the technology for real-world applications / inspection
  - Operations close to structure
  - Cluttered area / different lighting
  - Efficient task completion
- Ongoing projects
  - Obstacle avoidance
  - Fail-safe vision based navigation
  - Path optimization / fast inspection

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Vision Based Navigation for Micro Aerial Vehicles

- Goal: Autonomous navigating instrument carrier with light-weight and minimal sensor suite as base for inspection tasks

- Motivation for vision based approach:
  - Only passive sensing, standalone, on-board
    - No link to a ground-station required
    - No environment modification required
  - Lightweight, inexpensive sensors
    - More payload left for inspection sensors
    - Longer battery lifetime and mission times (10g → 1W hovering power)
  - GPS-independent, indoor and outdoor
    - Operation close to and in structures
    - Immune to GPS multi-path issues

artistic impression (www.sfly.org)

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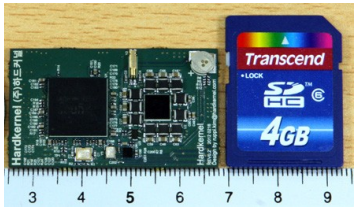
Vision Based Navigation for Micro Aerial Vehicles

Platform Overview

- Preferred MAV: micro multicopter:
  - Agile: fast missions (>5m/s), gust tolerant
  - Redundancy for fail-safe operations
  - Simple construction and maintenance
- Sensors:
  - Camera (single camera so far)
  - IMU (accelerations, angular velocities)

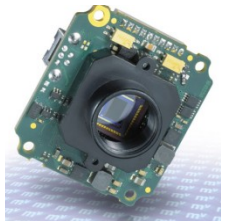
Aggressive Maneuvers (Mellinger et al, 2012)

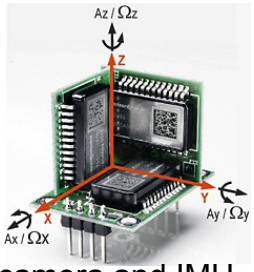
Ascending Technologies Firefly (www.asctec.de)



Exynos QuadCore 1.7GHz: <10g

CameraCube: <2g





Global shutter VGA camera and IMU

10DoF IMU (acc, gyr, mag, air pressure): <10g

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Vision Based Navigation for Micro Aerial Vehicles

Algorithm Overview (state estimation)

- Self-Calibrating:
  - No pre-mission calibration required, fast deployment
  - Adaptive to different platforms
  - Long-term missions in large environments
- On-board:
  - Self-Contained on-board system, simple interface
  - Provides position stabilization and way-point following for higher-level tasks (e.g. inspections
- Modular:
  - Sensor suites: GPS, TotalStation, Camera, ...
  - Fail-safe operation in different environments

It's about the state estimation, not the platform

AscTec Falcon (www.asctec.de)

AscTec Firefly (www.asctec.de)

CrazyFlie Nano (www.bitcraze.se)

Leica Total Station tracking (ASL, ETH)

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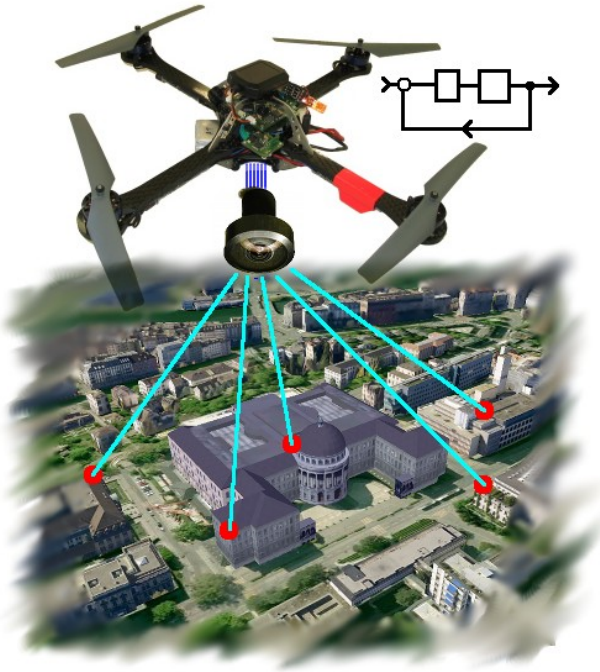
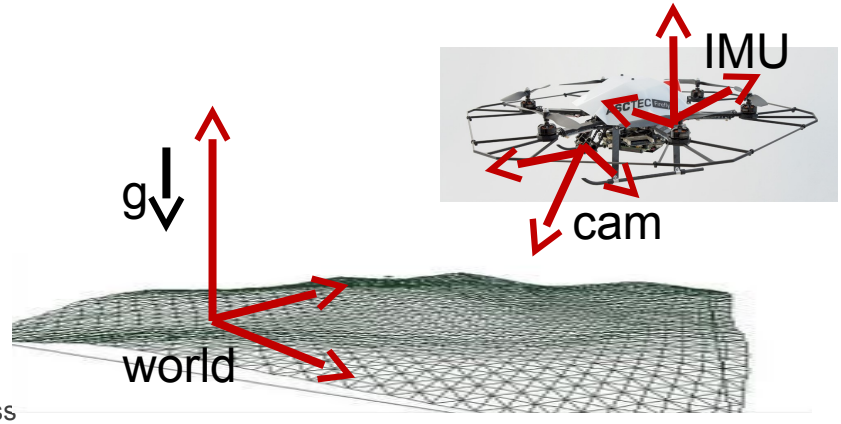
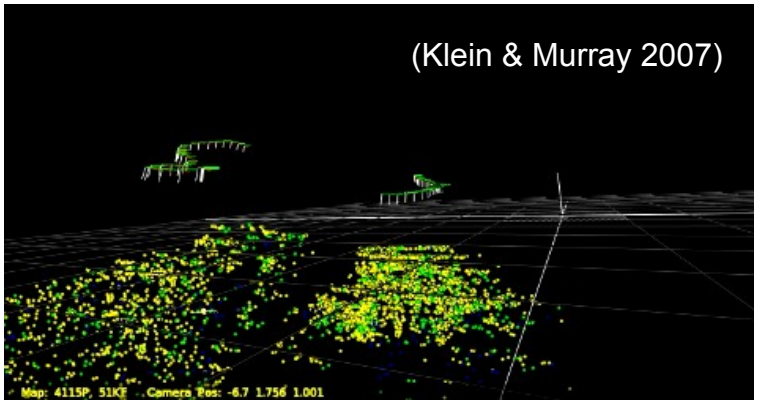
Vision Based Navigation for Micro Aerial Vehicles

Algorithm Details (state estimation)

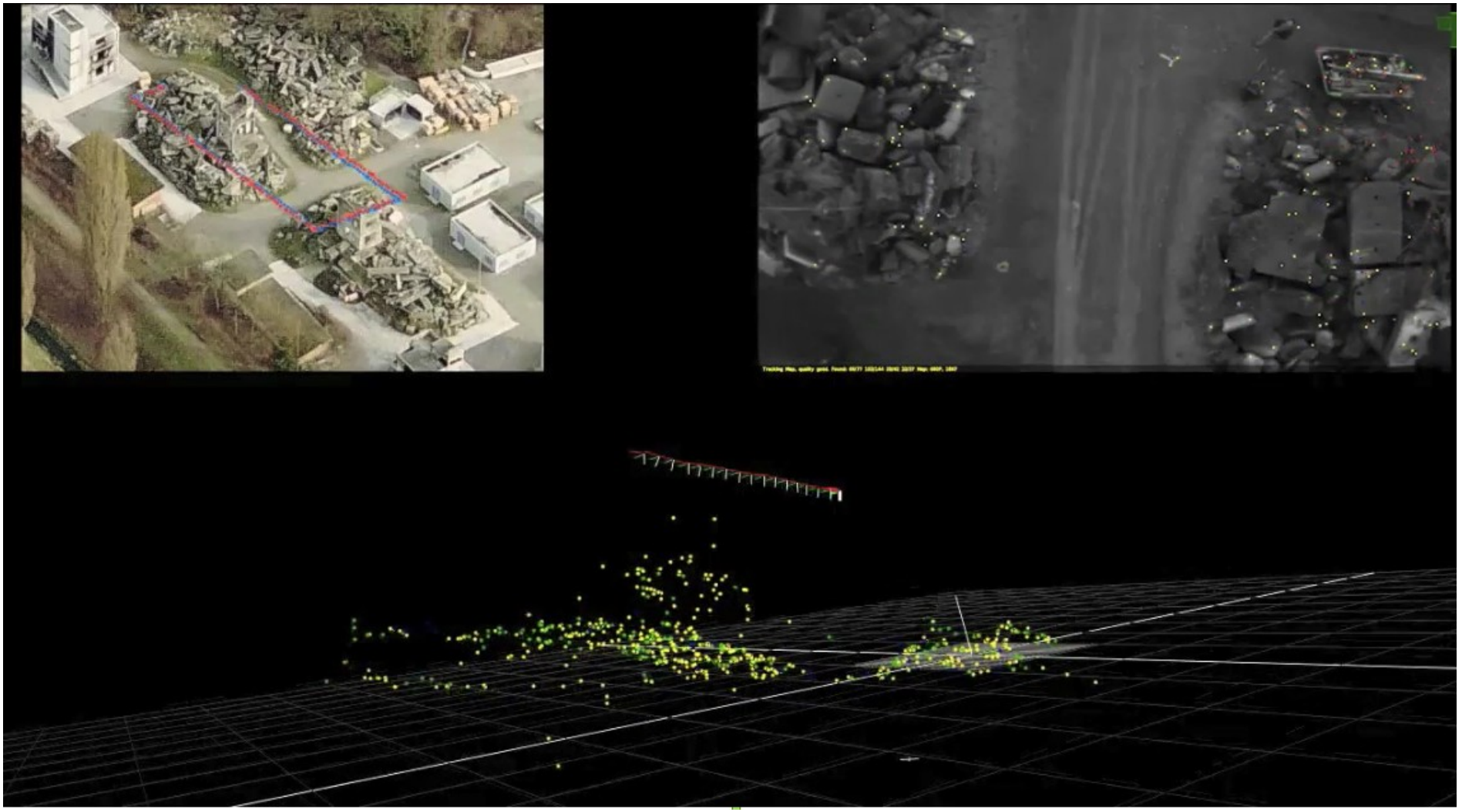


- Visual pose computation:
  - Based on visual SLAM [Klein & Murray, 2007]
  - Adapted to real-time, on-board visual odometry
  - 6DoF pose (position, attitude) at 30Hz
- State estimation for MAV control
  - Extendend Kalman Filter based
  - Estimation rate (i.e. pose control) at 1kHz



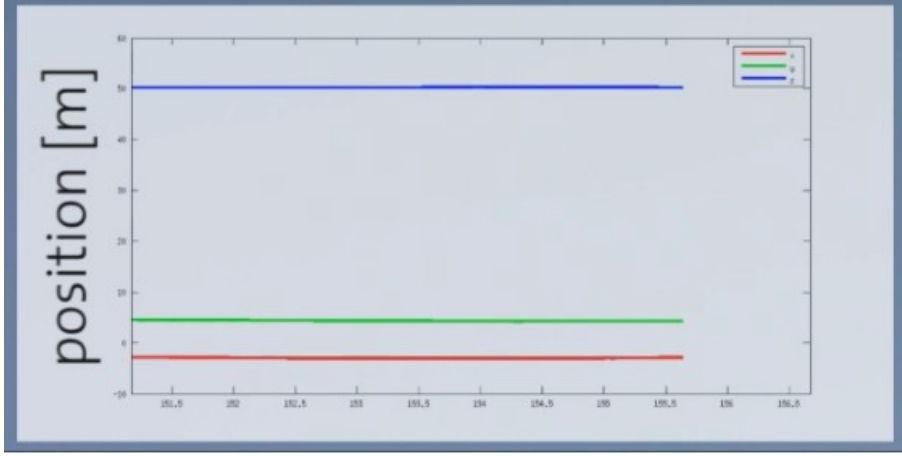


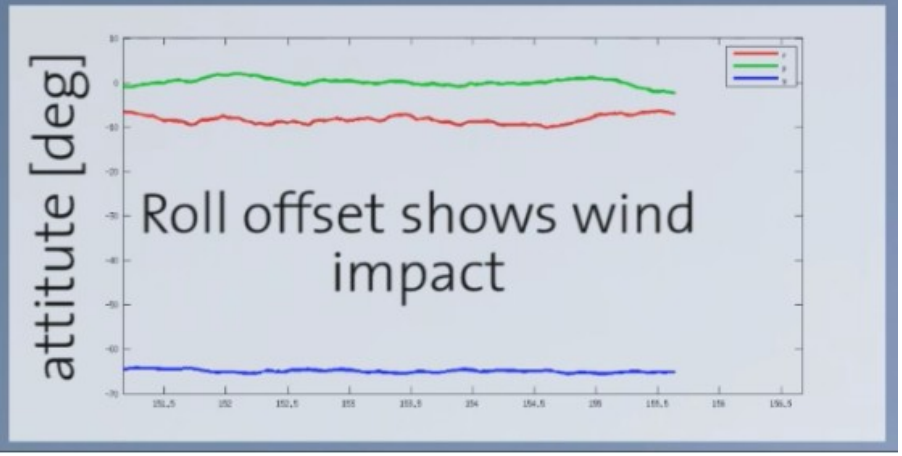
Applications: Reconnaissance in Desaster Areas (www.sfly.org)



Applications: Precise Navigation in High Altitudes (www.sfly.org)

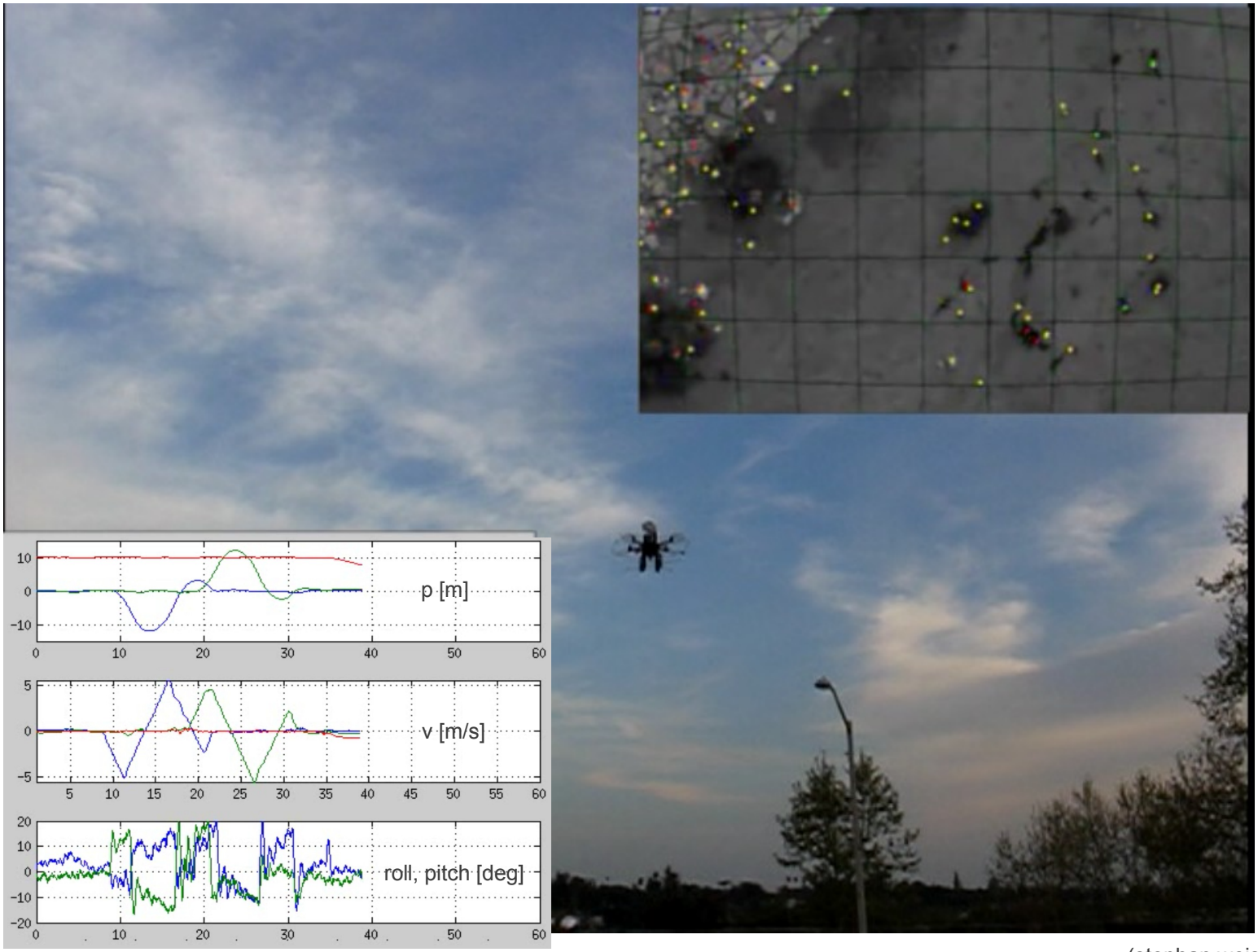
Top height 50m. Stable hovering and yaw commands in windy conditions.





Applications: Fast and Robust Mission Execution (JPL)

Jet Propulsion Laboratory



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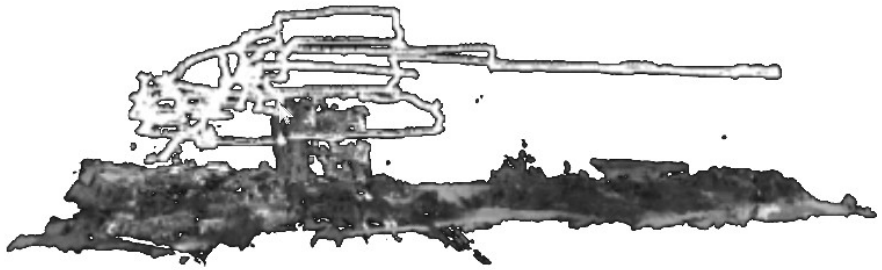
Applications: 3D Scene Reconstruction (JPL, ETH)



CVG, ETH (www.sfly.org)

JPL

Applications: Indoor Inspection (AIRobots)

Inspection of Industrial Facilities

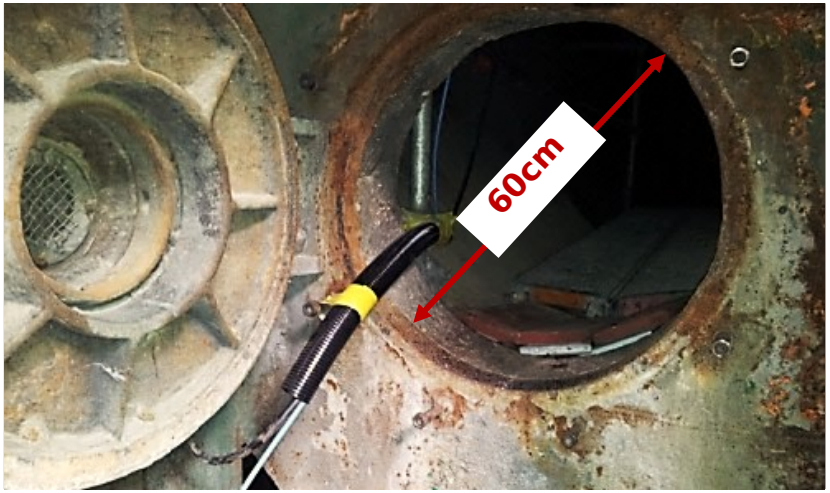
- Outages are expensive: 1day=$1Mio
- Deploy MAVs for fast and possibly "hot" autonomous inspection

ASL, ETH (airobots.ing.unibo.it)

Narcea power plant boiler units

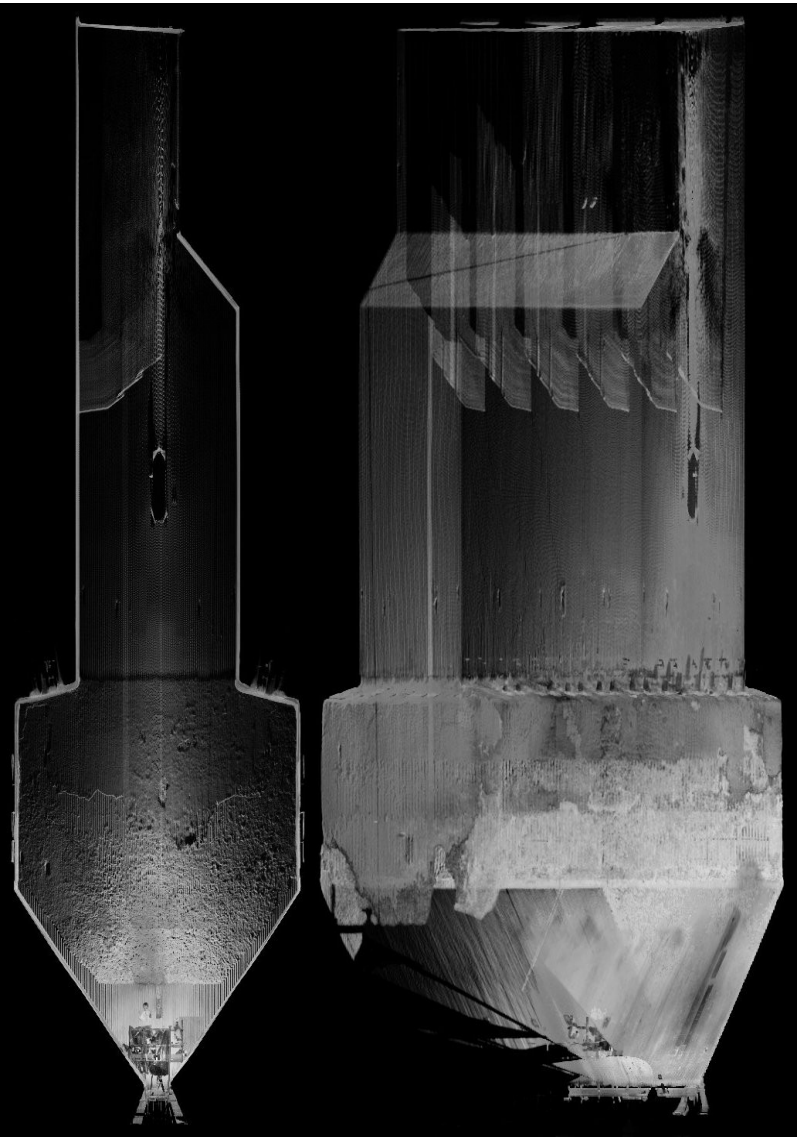
Chimney stack

Flare system

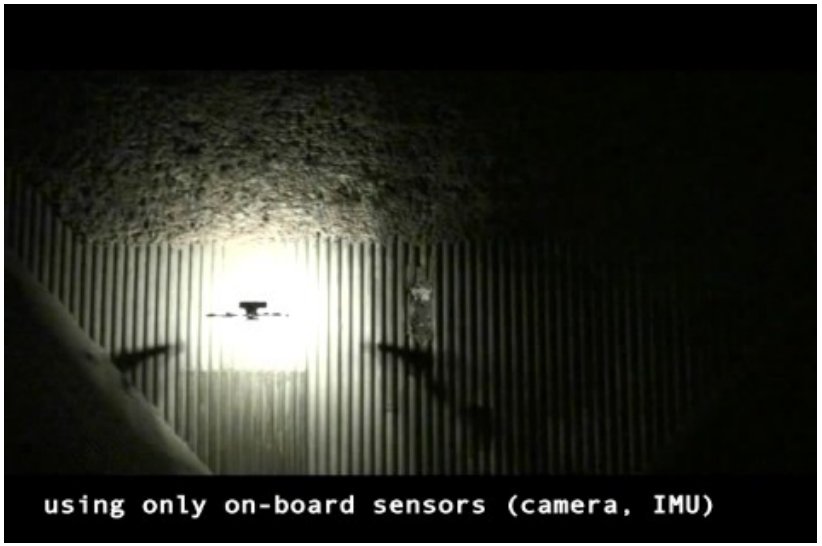


Access to boiler unit II

Applications: Indoor Inspection (AIRobots)

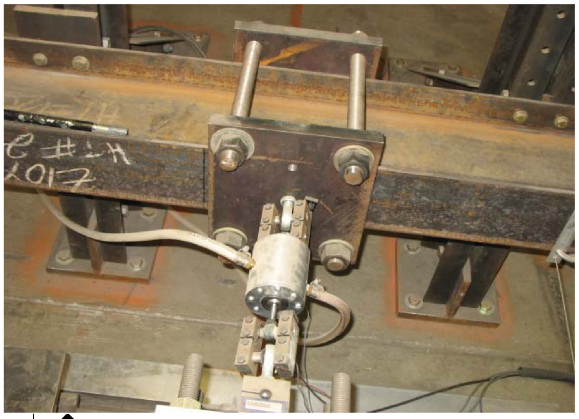


Nikolic et al. (IEEEAC 2013)



Change Detection Using Virtual Scene Reconstruction (JPL/USC)

Jet Propulsion Laboratory



Current view

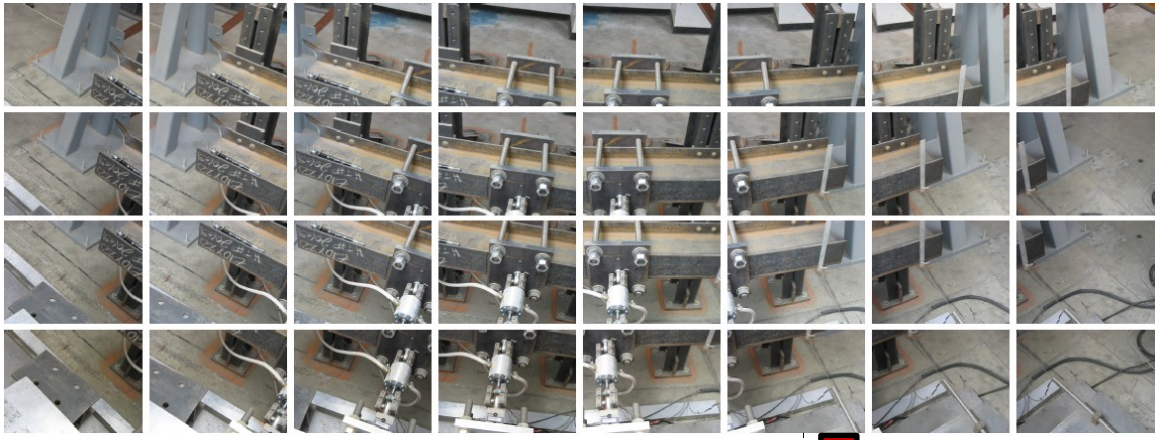
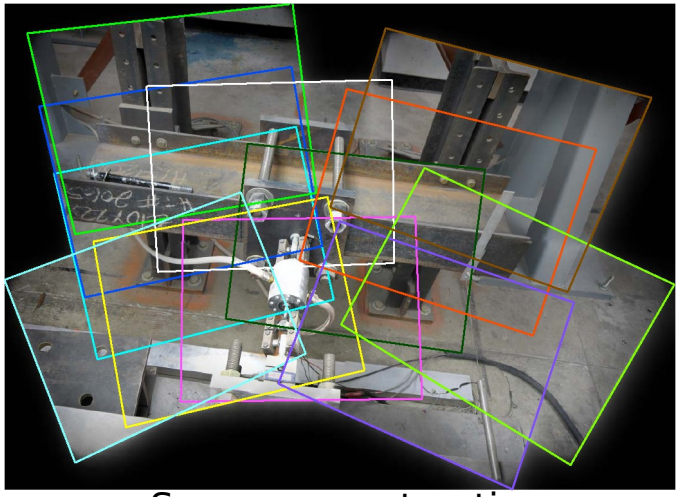
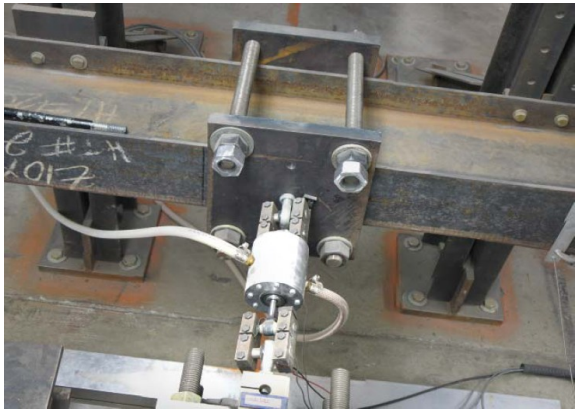


Image database



Scene reconstruction



Virtual scene

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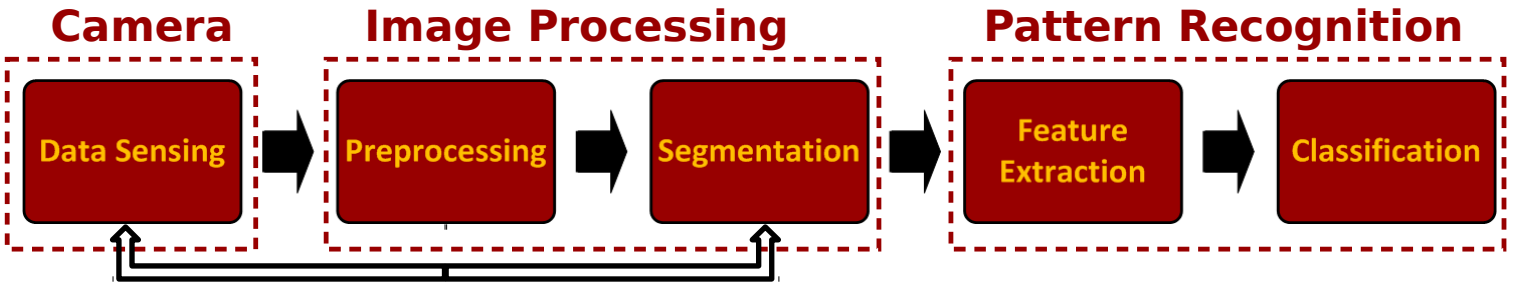
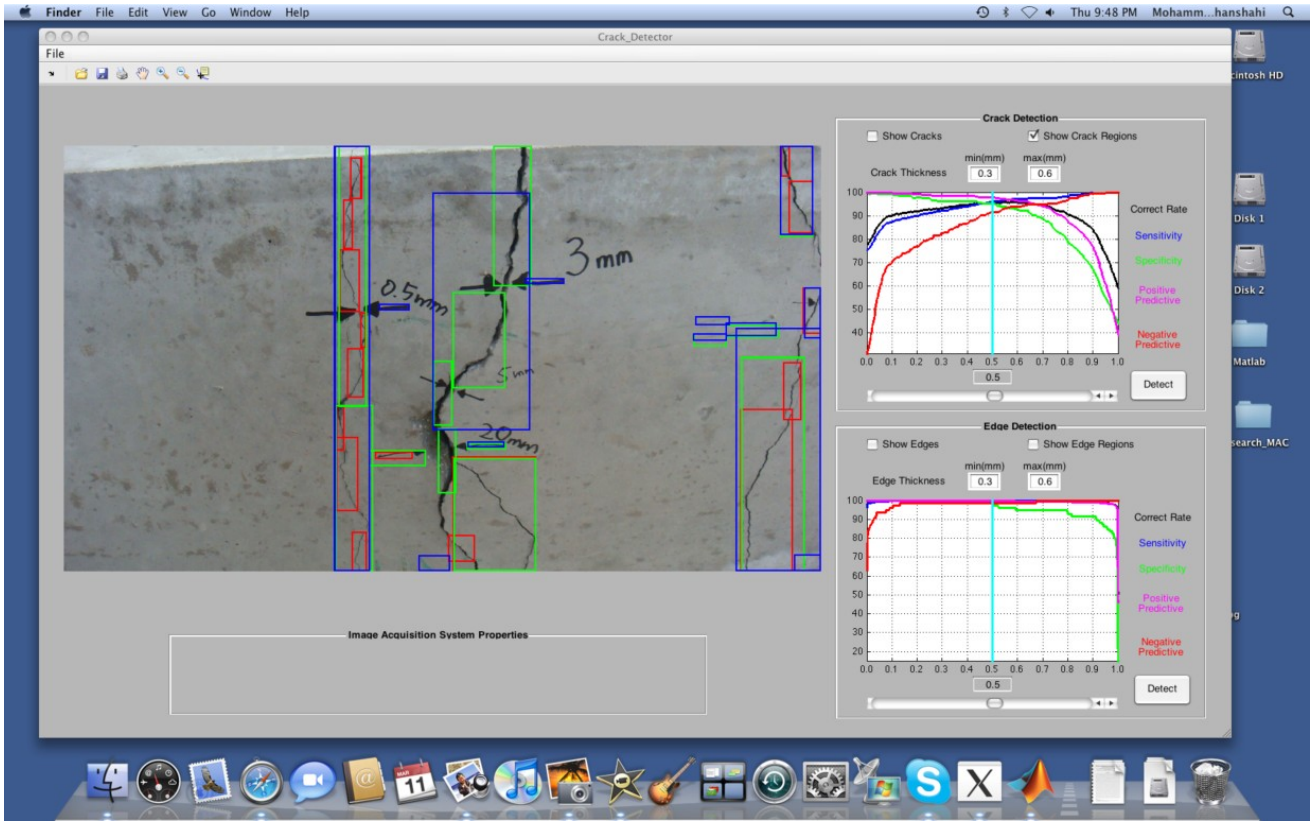
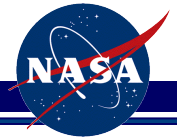
Adaptive Image-Based Crack Detection (JPL/USC)





Summary and Next Steps



- Pure vision based navigation tested under real conditions
  - Enables autonomous indoor and outdoor inspection and reconstruction
  - Works in unprepared environments without external sources (GPS, markers)
  - Lightweight sensor suite keeps payload for inspection equipment
  - Self-contained on-board system
- Improvements: Efficient and fail-safe user-centered operation
  - Inspection-point identification and trajectory generation
  - Obstacle avoidance
  - Fast navigation close to structure
- Next steps: Towards real applications meeting the user's needs

Q & A