Robotic Technologies for Structural Health Monitoring

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About me

who? **Lazaros Nalpantidis**

what? **Cognitive Robotics & Robot Vision**

where? **Robotics, Vision & Machine Intelligence Lab.**

Dept. of Mechanical & Manufacturing Eng.

Aalborg University Copenhagen

Some history

- *-2003, BSc in Physics @AUTH, Greece*
- *-2005, MSc in Electronic Eng. @ AUTH, Greece*
- *-2010, PhD in Robot Vision @ DUTH, Greece*
- *-2012, Postdoc @ KTH, Sweden*
- *-2014, Assist. Professor @ AAU-CPH*
- *-now, Assoc. Professor @ AAU-CPH*

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About our Lab.

- RVMI (Robotics, Vision and Machine Intelligence lab.)
  - @ CPH, Sydhavn
  - invovlevement/coordination of multiple EU/national research project
  - 4 Profs. - 1 postdoc - 4 PhD studs - 2 research assists
  - multiple robots
  - http://rvmi.aau.dk/

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About our Lab.

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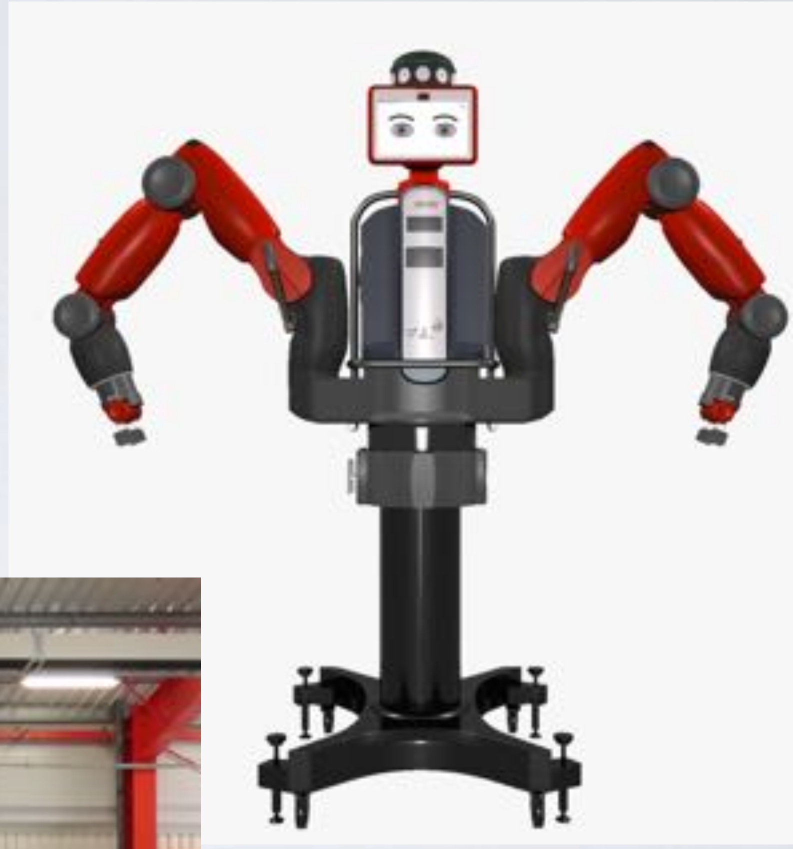

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About our Lab.

- RVMI (Robotics, Vision and Machine Intelligence lab.)
    - expertises:
        - Visual Sensing & Perception
        - Industrial Robots
        - Drones and aerial manipulation
        - Machine Learning and Artificial Intelligence

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the Question

- Why Use Robots for Structural Health Monitoring?

“Working in height is 1 of the top 3 reasons for fatal accidents”, (ERF 2016)

- *safer*
- *cheaper*
- *systematic, objective*
- *environmentally healthy*

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the Need

- Need for Structural Health Monitoring
  - according to *Wikipedia:*
    - SHM: the process of implementing a damage detection and characterization strategy for engineering structures.
    - …observation of a system over time…
    - …periodically updated…
    - … measurements from an array of sensors…
    - …analysis of these features to determine the current state…

the Applications

- Bridges and dams
- Buildings and stadiums
- Vessels and platforms
- Wind turbines
- Large machinery and equipment
- Railways
- Large Pipelines

OUTLINE

- Robots
- Sensors
    - Visual / Multimodal Sensing & Perception
    - 3D Sensing
    - Tactile Sensing
- Relevant Research Projects
- State-of-the-Art Technologies
    - Computer Vision
    - Machine Learning
    - Aerial Manipulation
- Summary and Discussion

ROBOTS

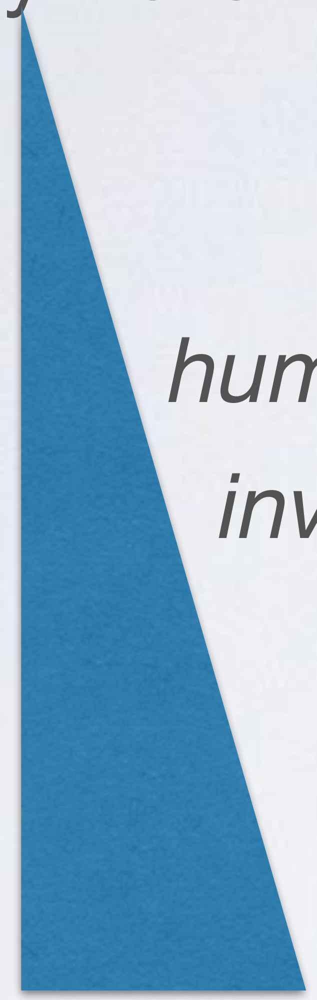
Drones

- 2 main types of Drones
  - Rotorcraft UAV
  - Fixed-Wing UAV

Drones

- no human onboard

Fully Autonomous Operation



human involvement

Teleoperation

Drones

- Typical specs
  - autonomy: up to 1 hour
  - payload: up to 15 Kg
  - speed: up to 70 Km/h

    (not all of them at the same time!!)

- Features
  - Waypoint navigation
  - Sensor mount stabilization
  - Multiple sensors
  - Built-in collision avoidance
  - Wind Compensation

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Drones

- Multispectral Imaging

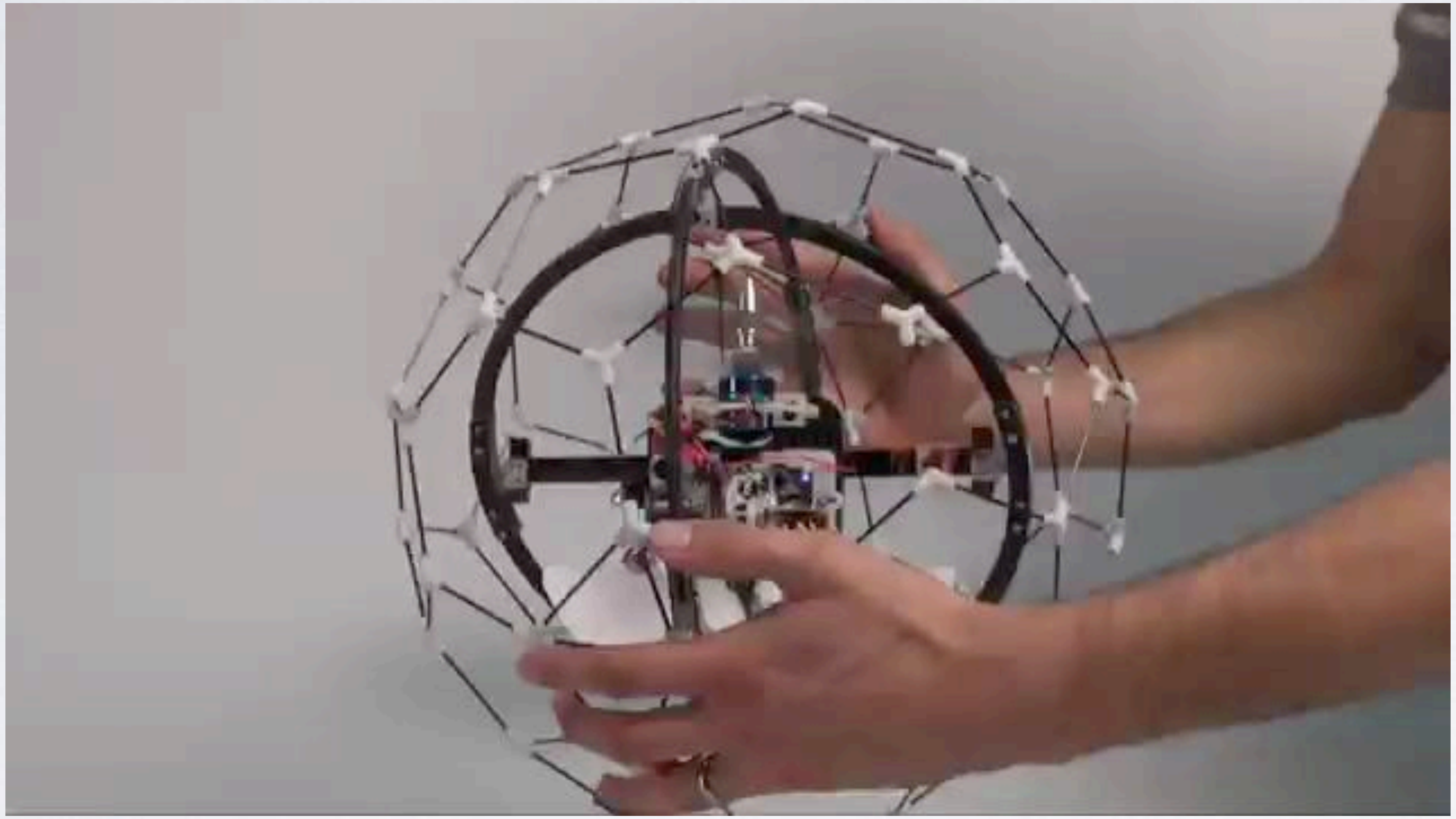
from: www.sensefly.com

Drones

- Inspection
  - protected rotors
  - onboard navigation cameras
  - ultrasonic sensors

Drones

- Inspection
  - close-up inspection (collision tolerance!)



from: www.flyability.com

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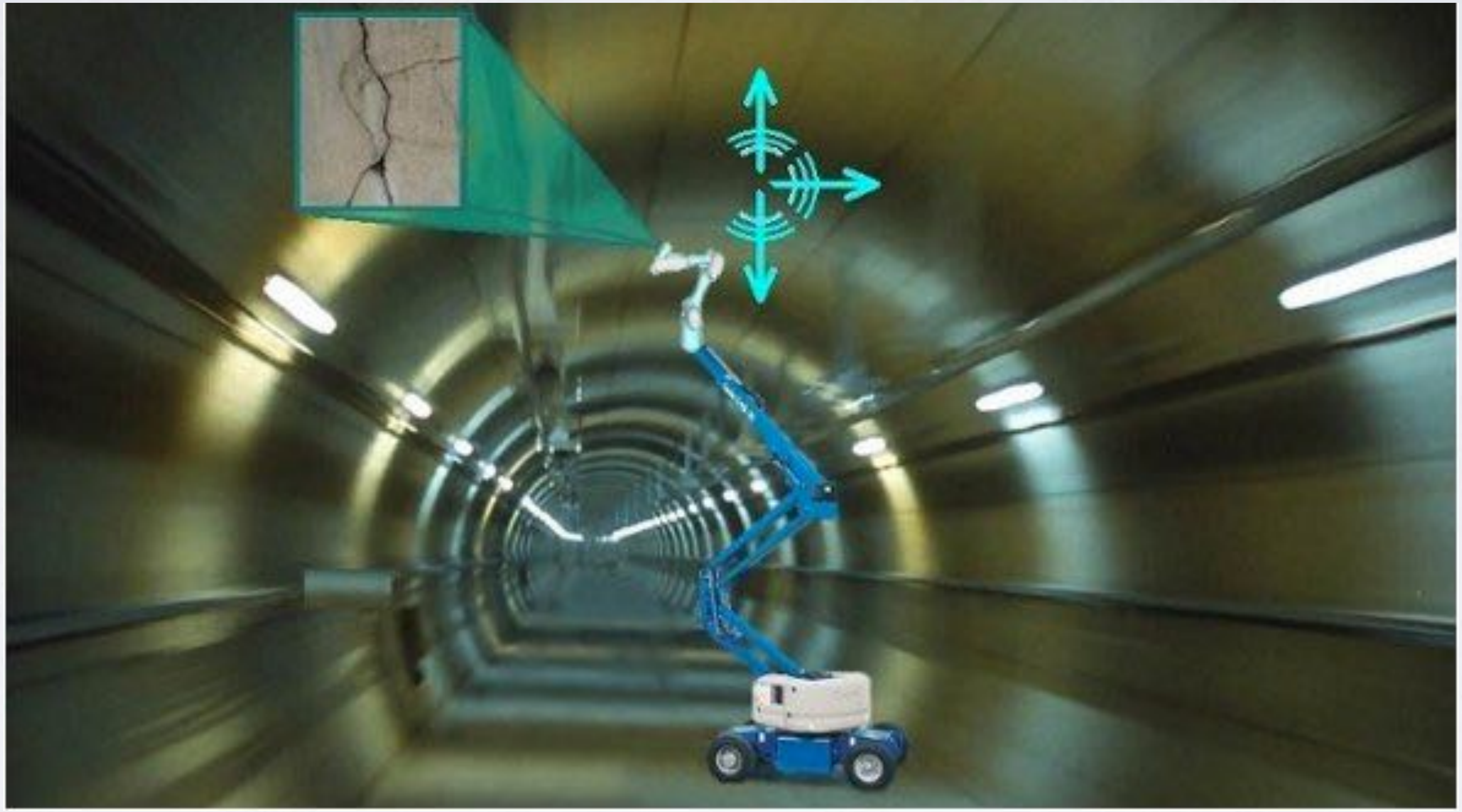
Mobile Robots

Mobile Robots



from: [*www.robo-spect.eu*]

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Mobile Robots

- similar to drones
    - however, manipulation with Mobile Robots are much easier

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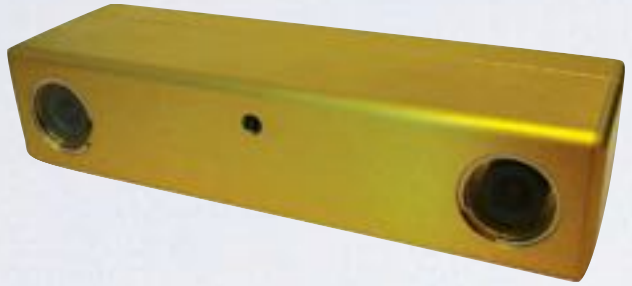
SENSORS

SENSORS

- Plethora of available sensors
  - Vision
    - Still HD images
    - Video streams
    - 3D sensors
      - large scale 3D reconstruction
      - comparison against 3D models
  - Multispectral Imaging (IR, thermal, …)
  - Tactile Sensors
  - Force/Torque Sensors

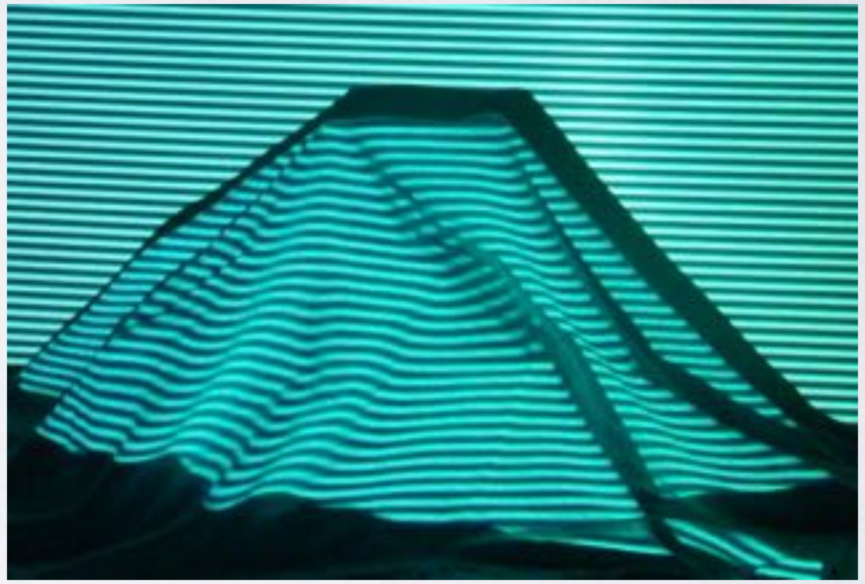
SENSORS

3D sensors



- Stereo

- Structured light



- Time of Flight

- LIDAR

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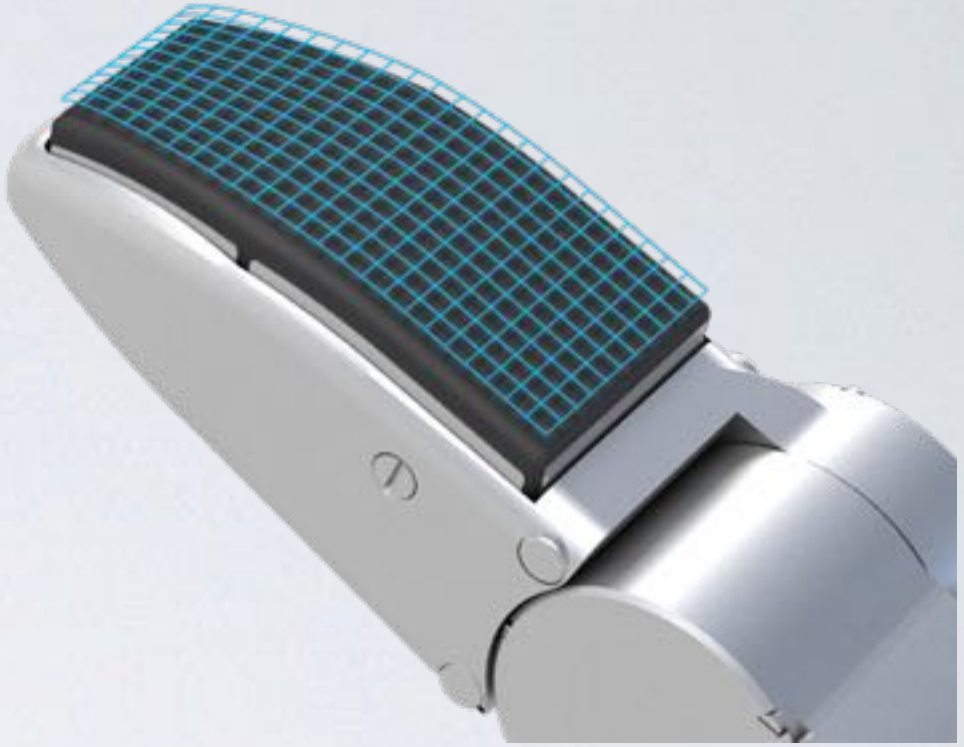
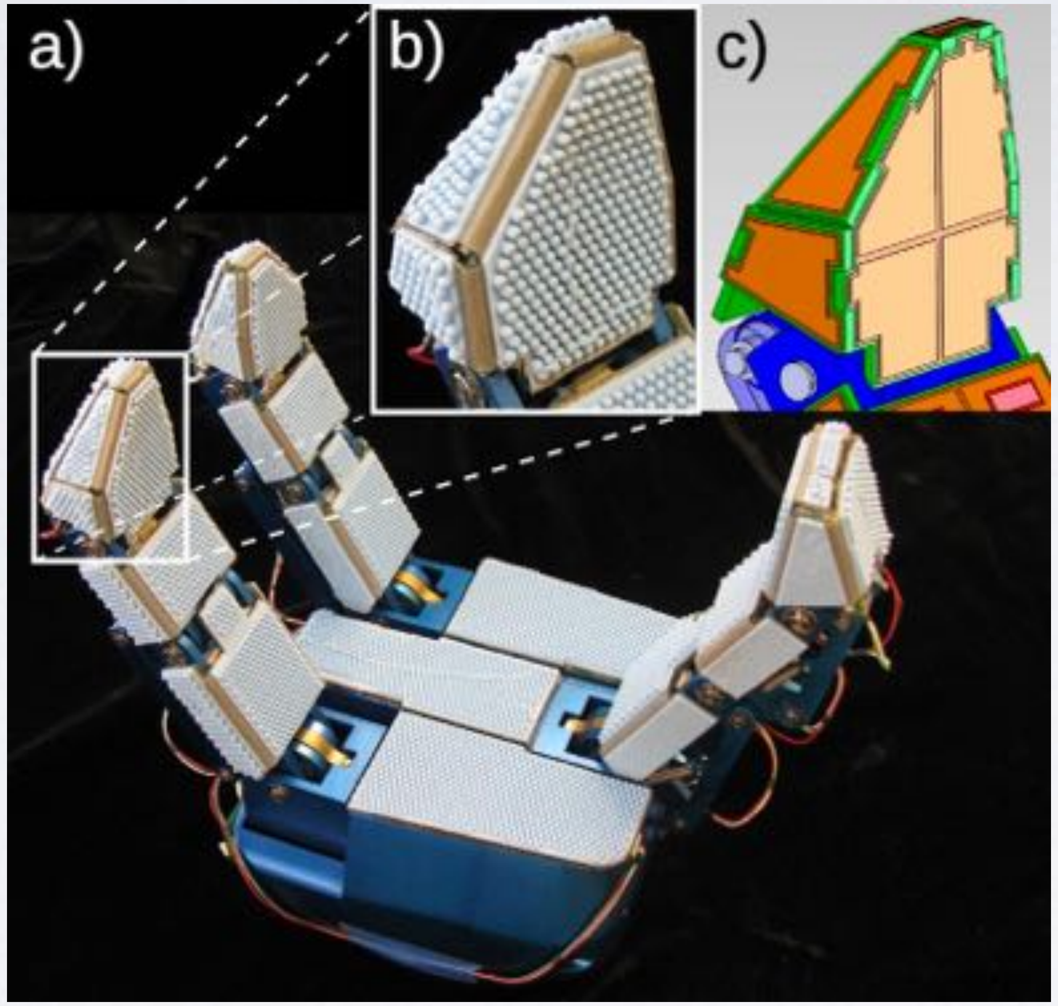
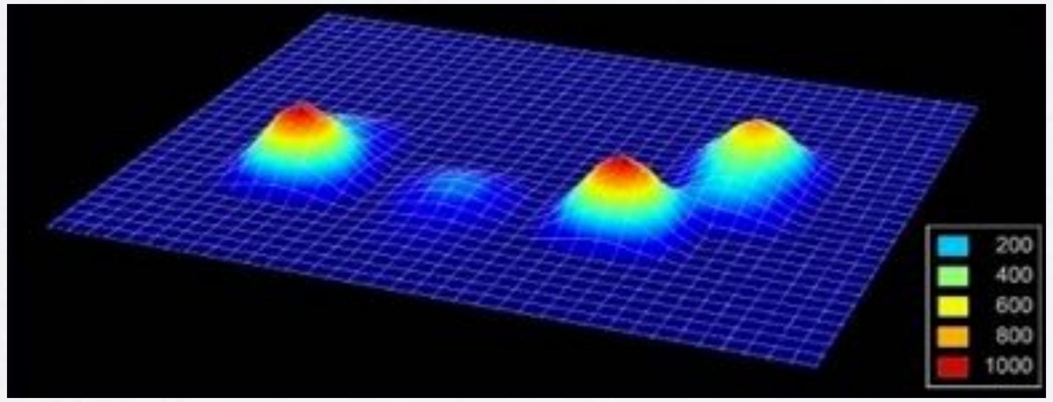
SENSORS



- **Tactile Sensors**

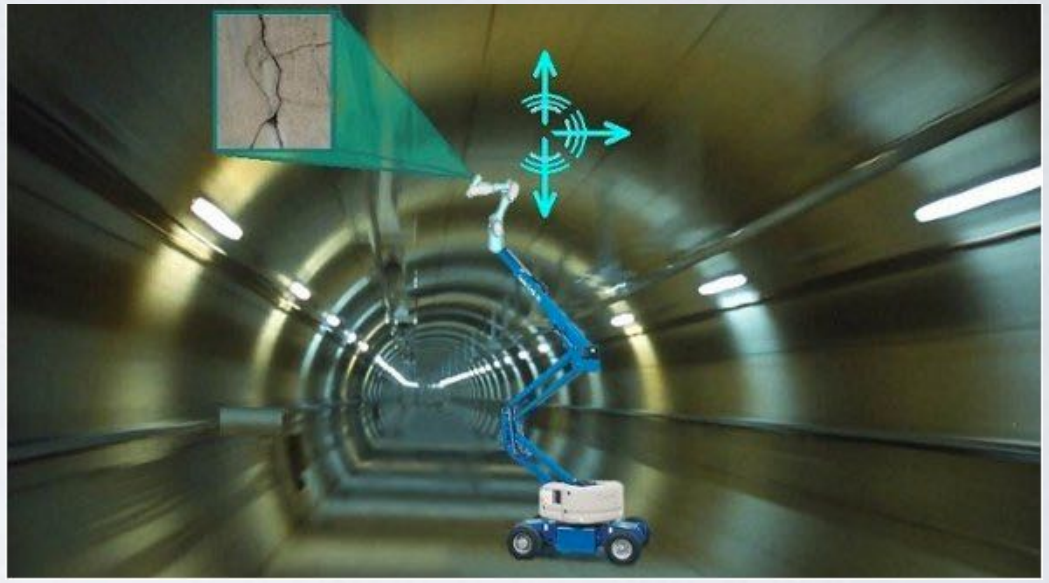




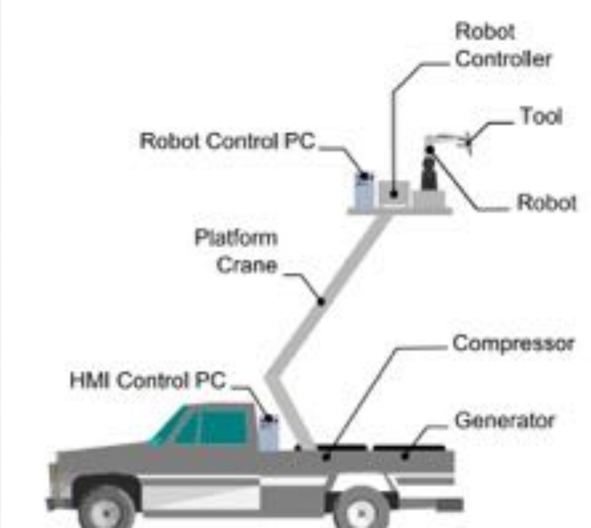
PROJECTS

PROJECTS

ROBOTIC INSPECTION with Mobile Robots



- ROBO-SPECT - FP7 - http://www.robo-spect.eu/
  - fully automated tunnel inspection system
- PETROBOT - FP7 - http://petrobotproject.eu/
  - “aims to develop a series of (small mobile) robots which can be used by inspectors to conduct remote **inspection of pressure vessels** and storage tanks widely used in the oil, gas and petrochemical industry”
- TUNCONSTRUCT - FP6
  - Robots monitoring and inspecting cracks in underground structures



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PROJECTS

ROBOTIC INSPECTION AND MAINTENANCE with Drones

- AERОBI - H2020
  - Aerial Robotic System for In-Depth Bridge Inspection **by Contact**
    - Sensors (Cameras, Lasers, Ultra-sonic sensors) + Robotic Arm
    - Non-destructively measure the depth of cracks and deformation
    - Accessibility without heavy scaffolding/ropes/elevators (quick & safe)
    - Reduced road closing time
    - Less equipment needed
    - Faster inspection with 3D mapping capabilities
    - Quick structural assessment
    - Reduced cost

PROJECTS

ROBOTIC INSPECTION with Drones

- AEROWORKS - H2020 - http://www.aeroworks2020.eu
  - Collaborative Aerial Robotic Workers
    - multiple heterogenous drones
    - dexterous manipulation
    - advanced perception

  for inspection and maintenance.

PROJECTS

ROBOTIC INSPECTION with Drones

- AEROARMS - H2020 - http://www.aeroarms-project.eu
  - Drones with
    - multiple arms
    - advanced manipulation capabilities
    - for inspection and maintenance

grab and dock with one arm… and perform dexterous accurate manipulation with another arm

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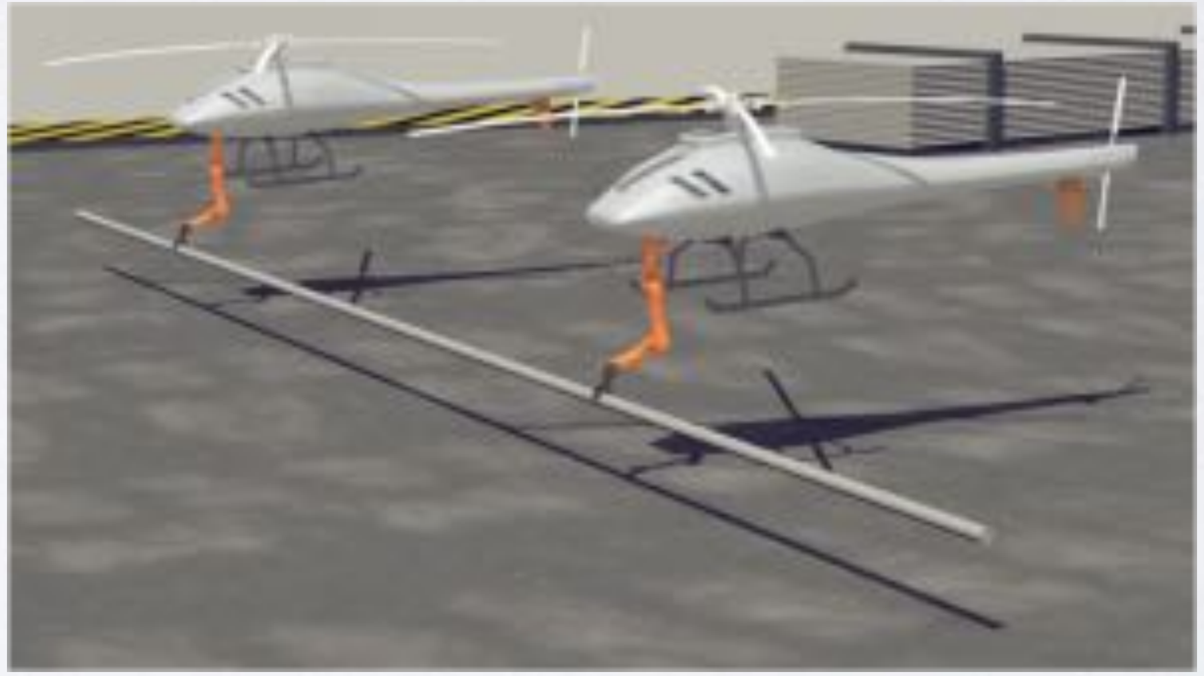
PROJECTS

ROBOTIC INSPECTION with Drones

- ARCAS - FP7 - http://www.arcas-project.eu/
  - Multiple drones with manipulators, cooperating for
    - assembly and
    - structure construction



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STATE-OF-THE-ART TECHNOLOGIES

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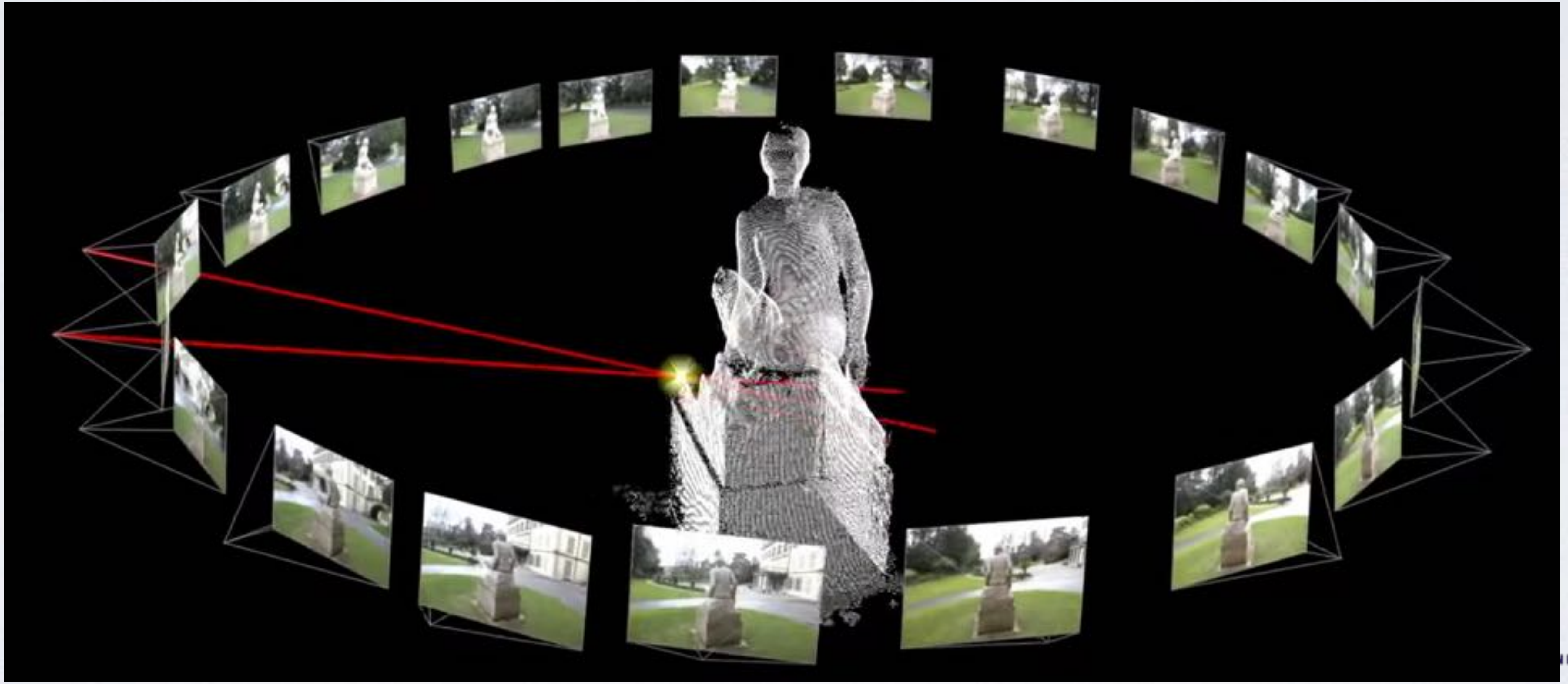
COMPUTER VISION

- 3D sensing - 3D reconstruction



STATE-OF-THE-ART TECHNOLOGIES

COMPUTER VISION

- 3D sensing - SLAM - 3D reconstruction
  - Drones:
    - image stabilization
    - unknown cam position
    - how to **plan** efficient paths

STATE-OF-THE-ART TECHNOLOGIES

COMPUTER VISION

- Image Processing for Inspection
  - based on pixel intensity and spatial relations
  - morphological operations
  - filtering
  - shape analysis

no need for annotated data

STATE-OF-THE-ART TECHNOLOGIES

COMPUTER VISION

- Digital Image Correlation
  - Known to the Computer Vision community under other names!
    - Many pixel/patch similarity measures (Cross-correlation is just one)
    - Many linear/no-linear optimization techniques
    - Techniques to compensate
      - different view points
      - varying illumination conditions

STATE-OF-THE-ART TECHNOLOGIES

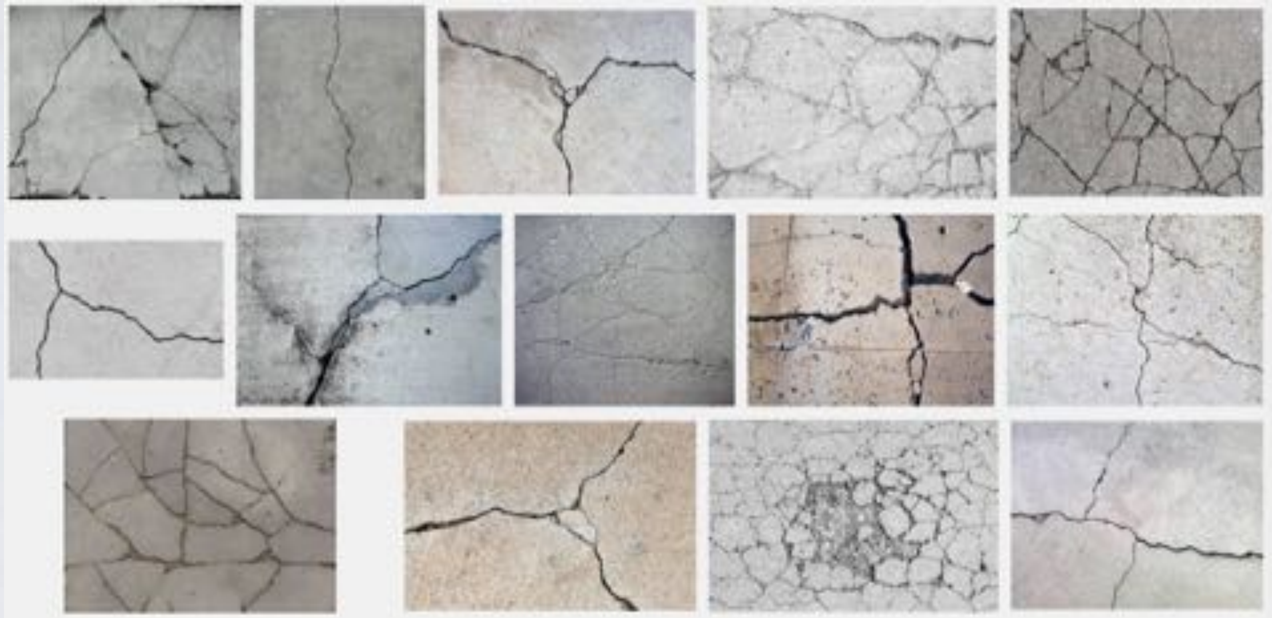
Machine Learning - Artificial Intelligence

- Beyond sensing…
  - How can you tell a crack on a concrete wall from sensor data?
    - A system should be able to learn this (as a human expert does)

STATE-OF-THE-ART TECHNOLOGIES

Machine Learning - Artificial Intelligence

Positive Examples



Negative Examples

new sample

STATE-OF-THE-ART TECHNOLOGIES

Machine Learning - Artificial Intelligence

- Supervised Learning
  - Classification (crack / no crack)
  - Regression (severity 0%-100%)

- based on some hand-crafted features (edges, Points of Interest, Texture,…)

- need for MANY annotated data

- the system can continue learning during its lifetime!

STATE-OF-THE-ART TECHNOLOGIES

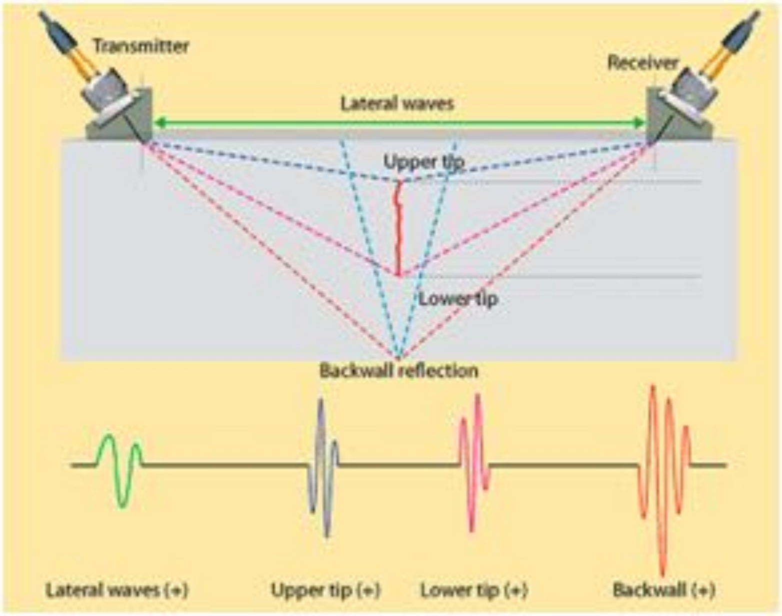
Machine Learning - Artificial Intelligence

- Deep Learning
  - can the system come up with good features without our supervision (unsupervised feature learning) ?
  - Deep Learning has been successfully applied to many vision problems (e.g. autonomous driving)

STATE-OF-THE-ART TECHNOLOGIES

Aerial Manipulation

- In Structural Health Monitoring we are usually targeting Non-Destructive Testing.
  - Visual Inspection is often not enough
  - Physical interaction is some times required
  - Crack dimensions require contact
    - ultrasonic Time of Flight (stable contact between the transducer and the surface)
    - Piezoelectric MEMS “needles”



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SUMMARY & DISCUSSION

SUMMARY & DISCUSSION

- Flight Duration — is it enough to perform our intended tasks?
    - better batteries
    - multiple drones working serially or in parallel
- Are inspection results reliable and reproducible?
- Can we perform inspection in real-time (or fast enough?)
- Data Overflow — huge amount of generated data
    - semantic inspection
    - can an autonomous robot tell what is important and just focus on that?
- What are possible through synergies between Civil Eng. and Roboticists?

THANKS !!

Robotic Technologies for Structural Health Monitoring

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