Autonomous Mobile Robot Design

Topic: Last lecture

Dr. Kostas Alexis (CSE)

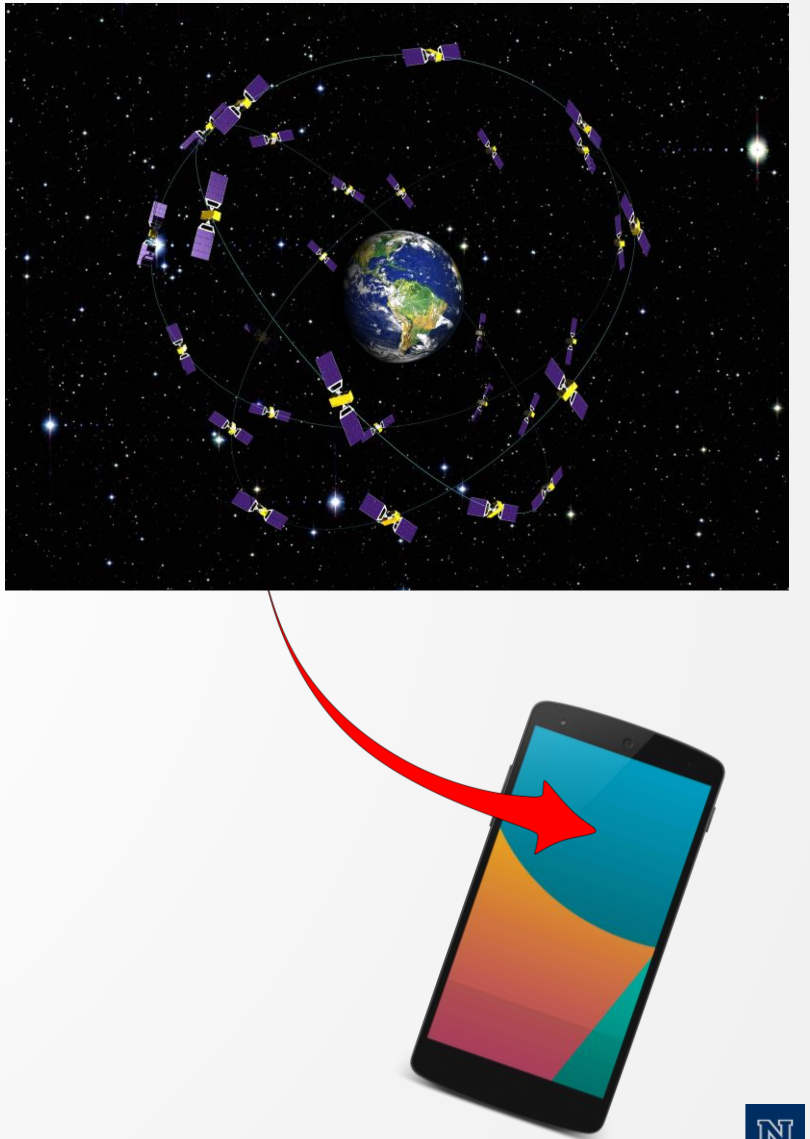
Autonomous Mobile Robot Design

Topic: Let's not forget about GPS

Dr. Kostas Alexis (CSE)

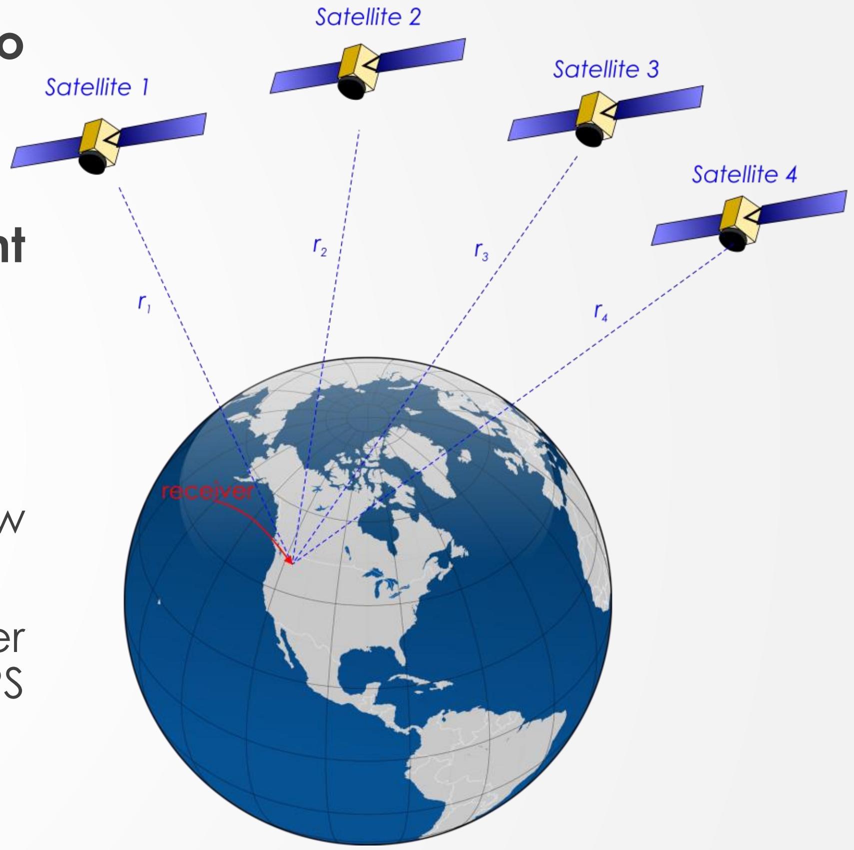
Global Positioning System

- 24 Satellites orbiting the Earth (*and some back-ups*).
- Altitude set at 20,180km
- Any point on Earth's surface can be seen by at least 4 satellites at all times.
- Time-of-Flight of radio signal from 4 satellites to receiver in 3 dimensions.
- 4 range measurements needed to account for clock offset error.
- 4 nonlinear equations in 4 unknown results:
  - Latitutde
  - Longitutde
  - Altitude
  - Receiver clock time offset

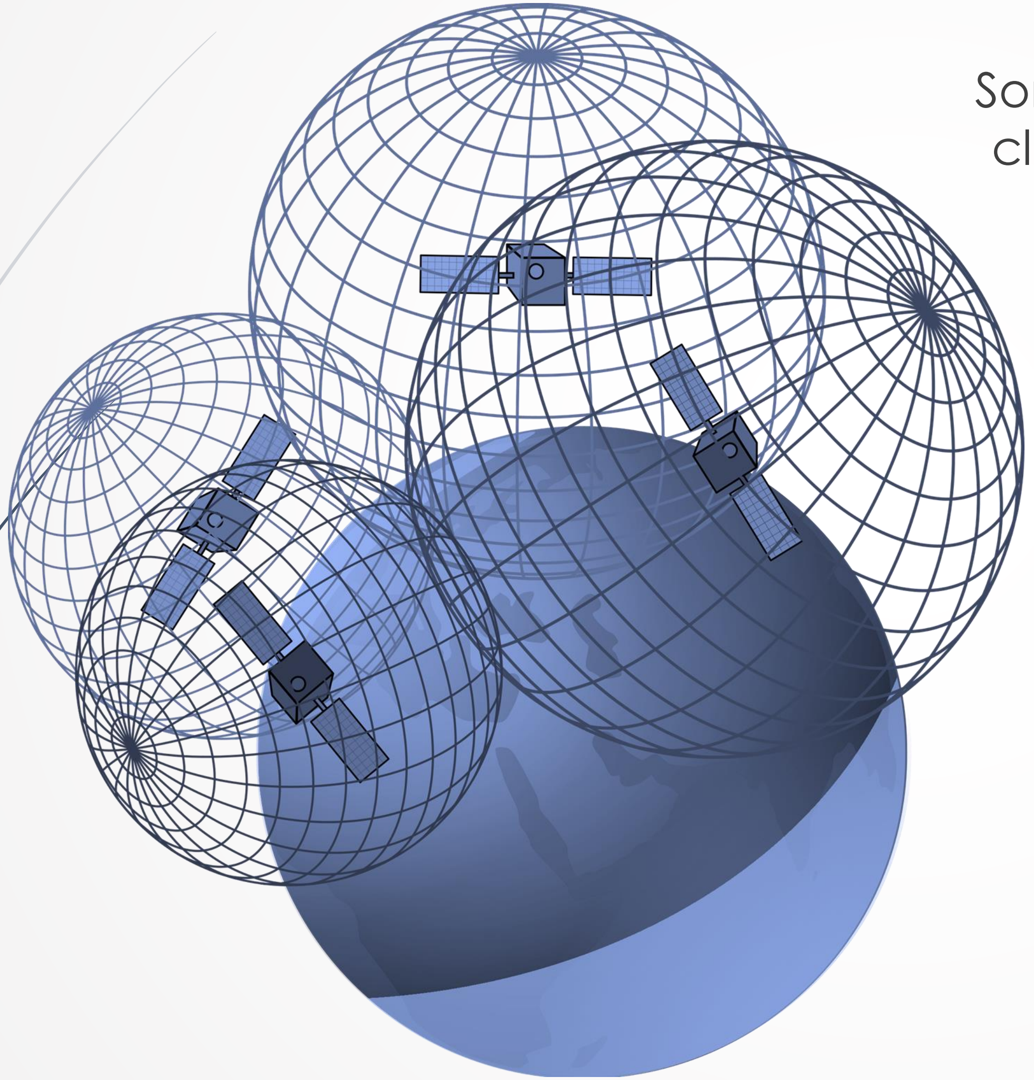


Global Positioning System

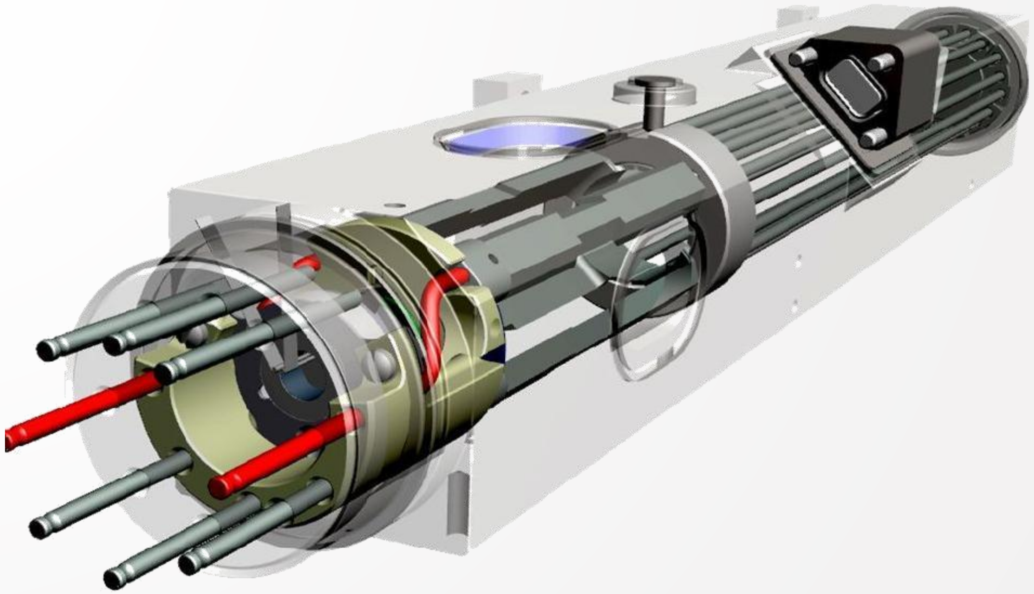
- **Time-of-Flight of the radio signal from satellite to receiver used to calculate pseudorange.**
  - Called pseudorage to distinguish it from true range.
- **Numerous sources of error in time-of-flight measurement:**
  - Ephemeris Data – errors in satellite location
  - Satellite clock – due to clock drift.
  - Ionosphere – upper atmosphere, free electrons slow transmission of the GPS signal.
  - Troposphere – lower atmosphere, weather (temperature and density) affect speed of light, GPS signal transmission.
  - Multipath Reception – signals not following direct path
  - Receiver measurement – limitations in accuracy of the receiver timing.
- **Small timing errors can result in large position deviations:**
  - 10ns timing error leads to 3m pseudorange error.



GPS Trilateration



Some math and an atomic clock-based "stopwatch"

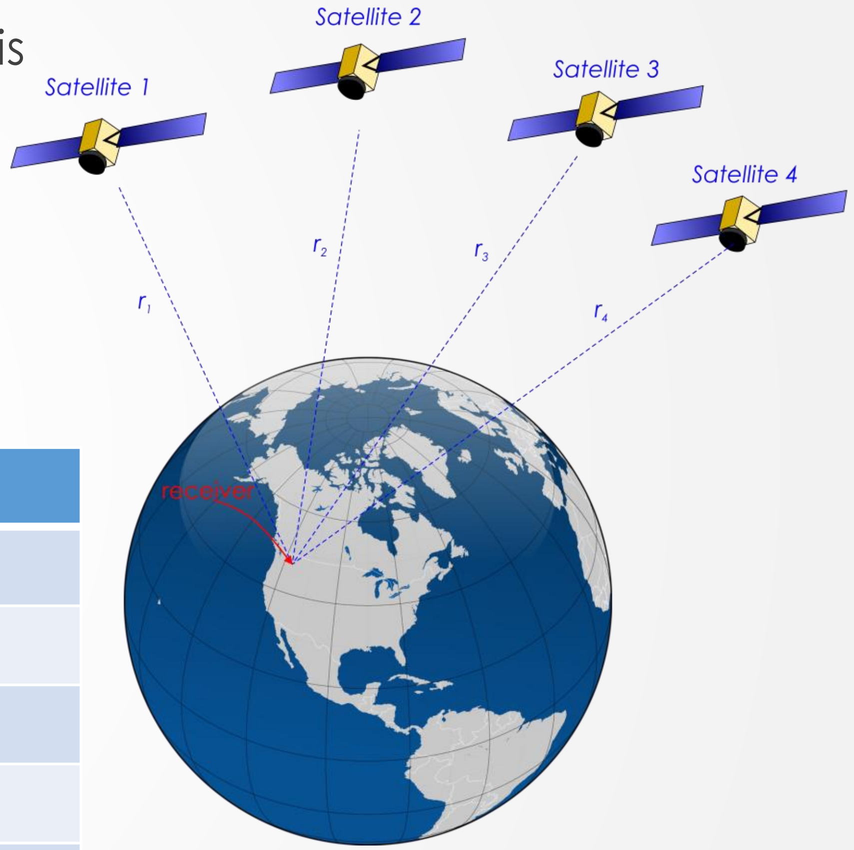


GPS Error Characterization

- Cumulative effect of GPS pseudorange errors is described by the **User-Equivalent Range Error (UERE)**.
- **UERE has two components:**
  - Bias
  - Random

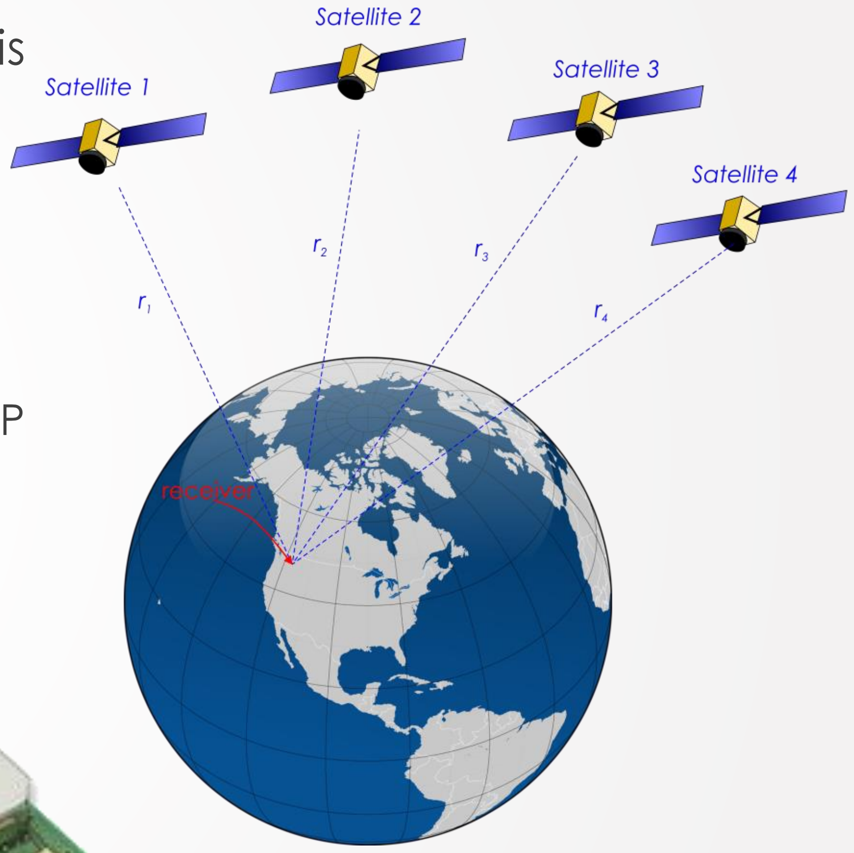
1σ, in m

Error source	Bias	Random	Total
Ephemeris data	2.1	0.0	2.1
Satellite clock	2.0	0.7	2.1
Ionosphere	4.0	0.5	4.0
Troposphere monitoring	0.5	0.5	0.7
Multipath	1.0	1.0	1.4
Receiver measurement	0.5	0.2	0.5
UERE, rms	5.1	1.4	5.3
Filtered UERE, rms	5,1	0.4	5.1



GPS Error Characterization

- Effect of satellite geometry on position calculation is expressed by dilution of precision (DOP).
  - Satellites close together leads to high DOP.
  - Satellites far apart leads to low **DOP**.
  - DOP varies with time.
  - Horizontal DOP (**HDOP**) is smaller than Vertical DOP (**VDOP**):
    - Nominal HDOP = 1.3
    - Nominal VDOP = 1.8



Total GPS Error

- **Standard deviation of RMS error in the north-east plane:**

$$E_{n-e,rms} = \text{HDOP} \times \text{UERE}_{rms} \Rightarrow$$
$$E_{n-e,rms} = (1.3)(5.1) = 6.6\text{m}$$

- **Standard deviation of RMS altitude error:**

$$E_{h,rms} = \text{VDOP} \times \text{UERE}_{rms} \Rightarrow$$
$$E_{h,rms} = (1.8)(5.1) = 9.2\text{m}$$

- As expected: an **ellipsoidal error model**.

SenseSoar

Flight Tests:
Dynamics and Onboard Avionics Evaluation
May, 24th 2013

ICARUS
Integrated Components for Assisted Rescue and Unmanned Search operations

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Autonomous Systems Lab

Autonomous Mobile Robot Design

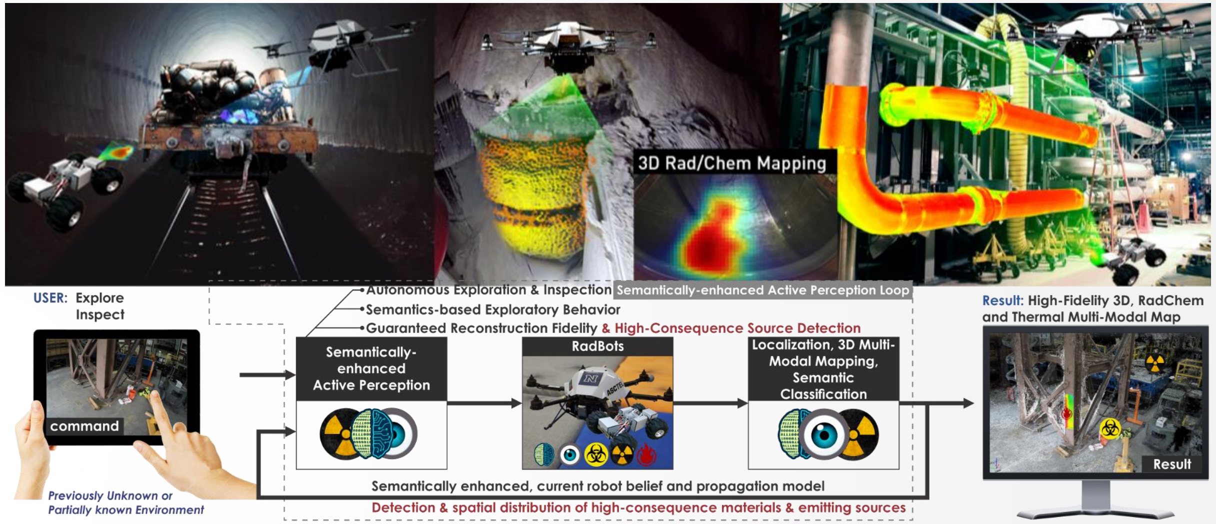
Topic: Discussing some Research Projects

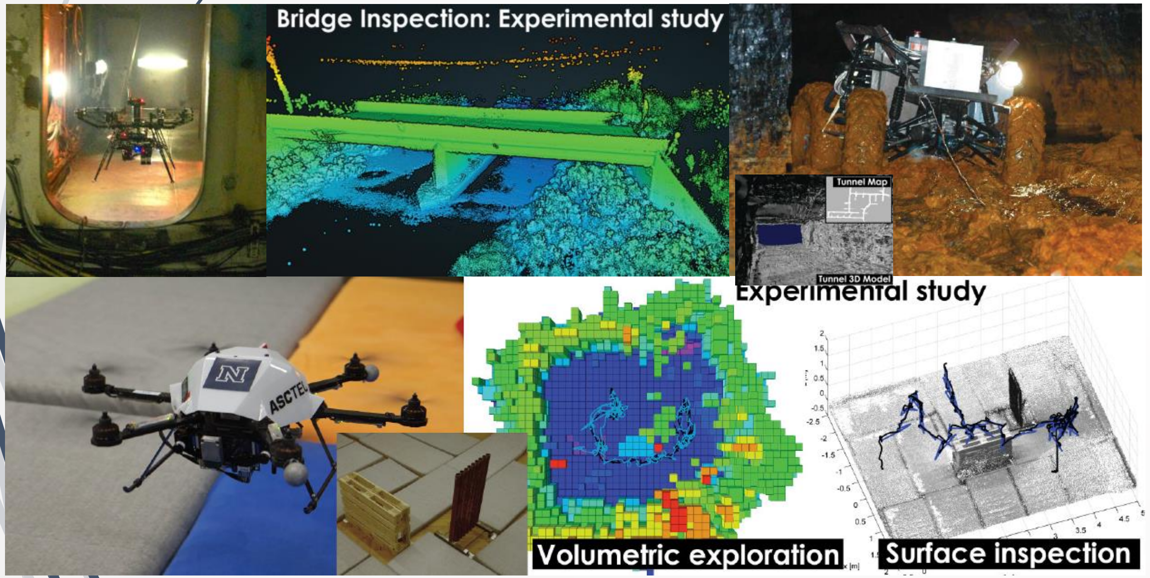
Dr. Kostas Alexis (CSE)


RadBots

Multi-modal characterization of DOE-EM facilities

- Combined roving and flying robots to characterize DOE-EM facilities.
- Identification and semantic classification of tanks, pipes, and other important structures to intelligently focus the robot exploration and inspection tasks.
- Traversability analysis for robust robot navigation.
- Radiation, chemical, and heat spatial maps are fused with 3D models of the environment.





- Integrated planning and multi-modal perception for comprehensive mapping of nuclear facilities.
- Augmented exploration-planning to account for the radiation, chemical, and heat estimates.
- Coordination of aerial and ground robots to maximize the capabilities of both platforms.
- Demonstration in DOE-EM relevant, nuclear analog facilities towards advanced technology readiness.
- Course curriculum development and K-16 outreach.

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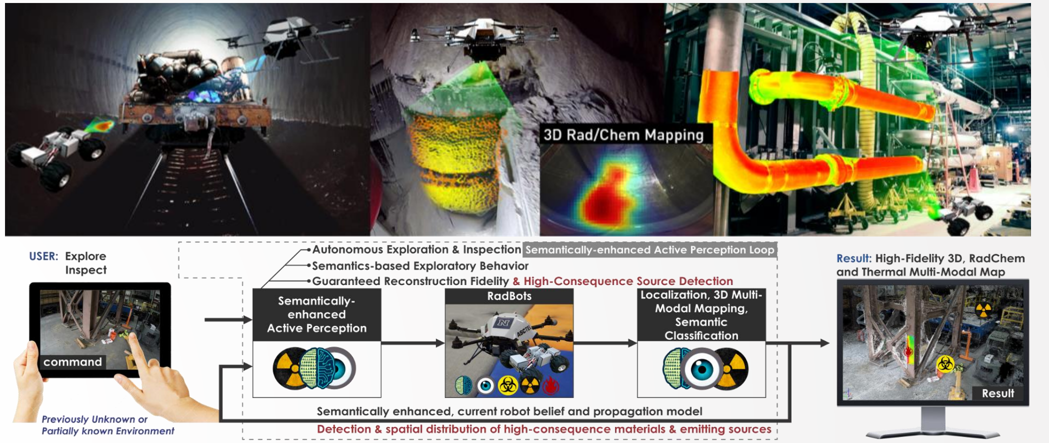
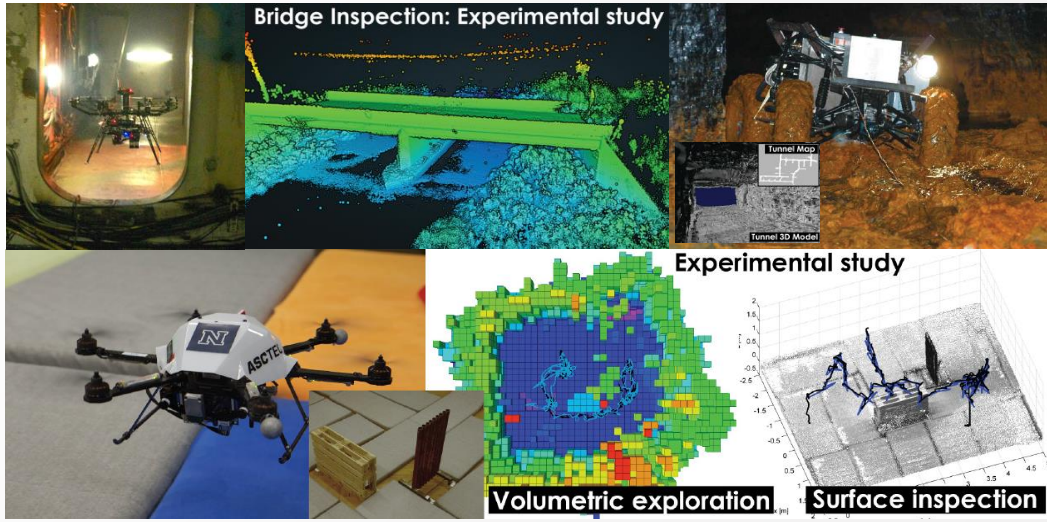
Multi-modal characterization of DOE-EM facilities

- **Research Objective 1: Multi-modal mapping**
  - Visually-degraded localization and mapping
  - Robust and high-resolution mapping
  - Fusion of IR/UV/Radiation sensing with 3D modeling
- **Research Objective 2: Active Perception Exploration**
  - Unknown environment exploration
  - Uncertainty-aware planning for navigation and amapping
- **Research Objective 3: From Robots to RadBots**
  - Integration of IR and UV cameras (as analog to radiation)
  - Robot development and system integration
- **Robot Team:** 2 Aerial Robots and 1 Ground Robot
- **Field Evaluation: Priority of our Research**
  - At Tunnels such as (or actually) the PUREX Tunnel 1 and 2
- **Project Team:**
  - Carnegie Mellon University, The Robotics Institute
  - University of Nevada, Reno, Autonomous Robots Lab





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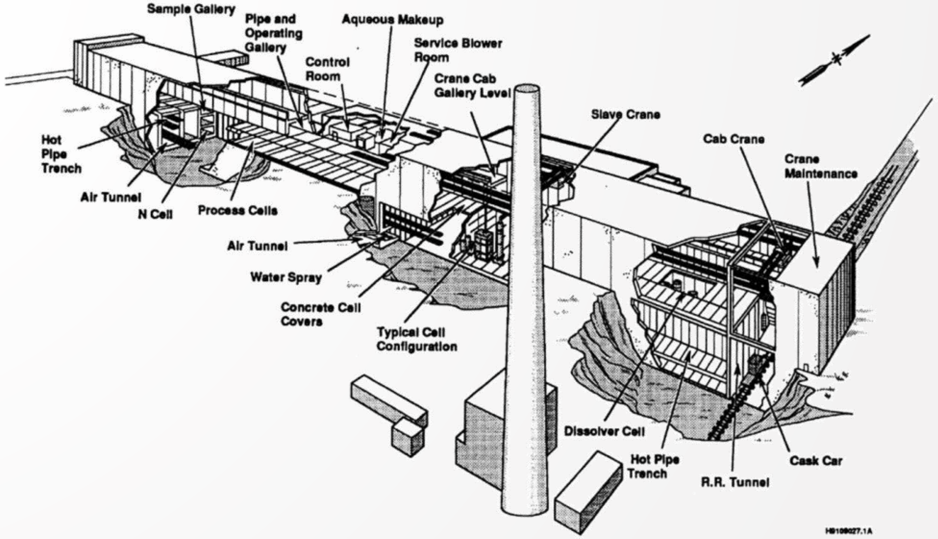

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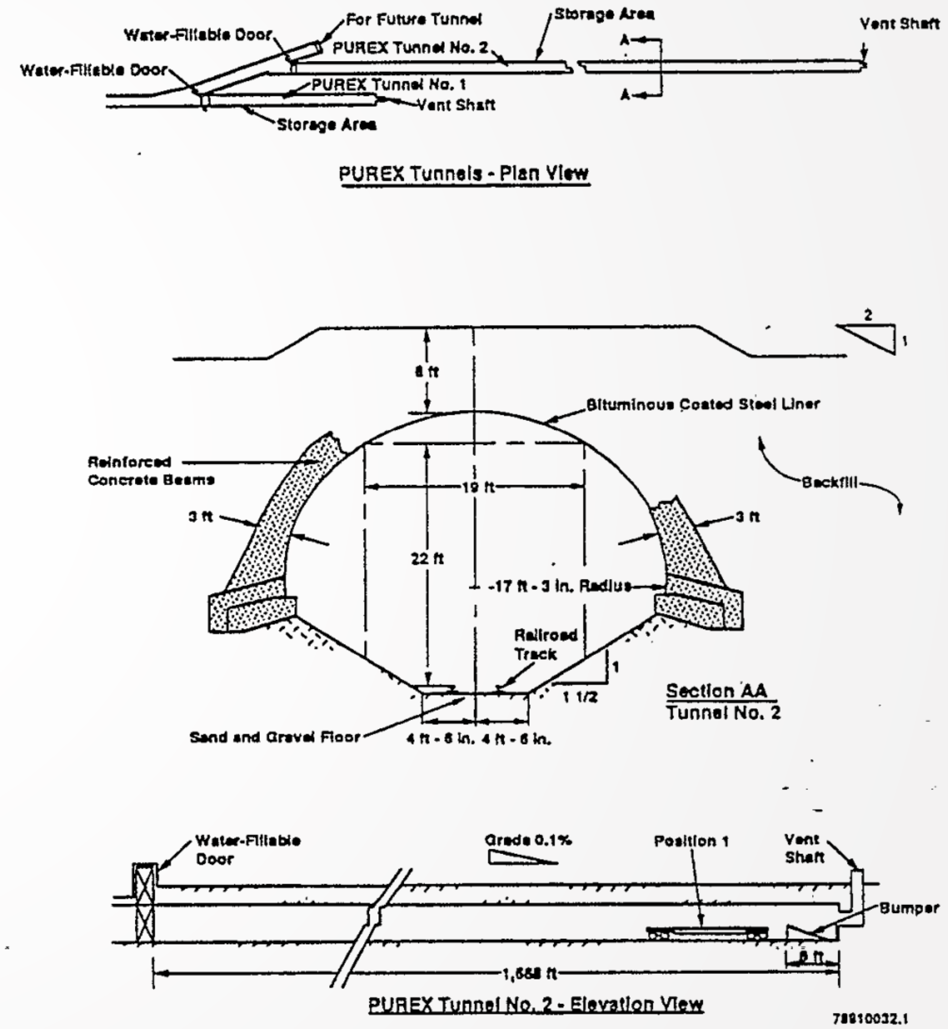
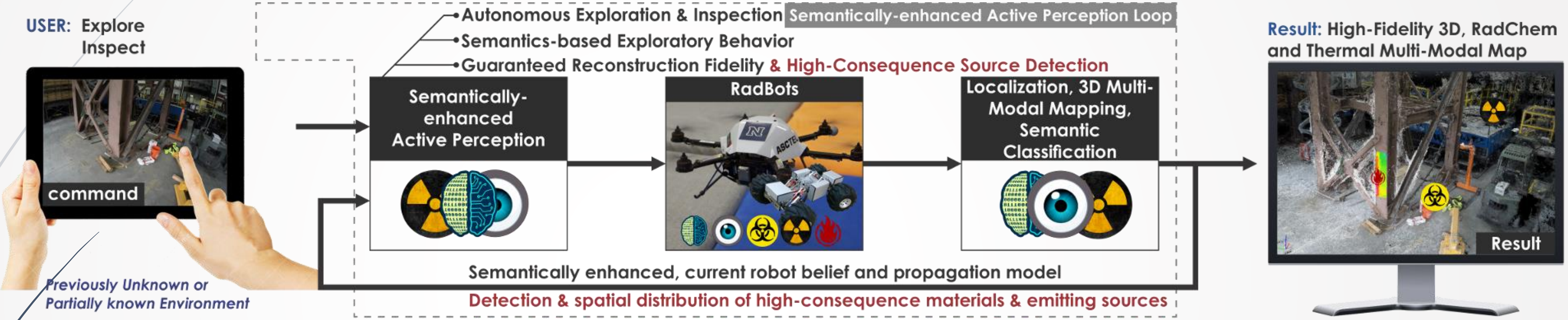


Multi-modal characterization of DOE-EM facilities



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Exploration and Mapping in Visually-degraded Environments
Preliminary results

C. Papachristos, S. Khattak, F. Mascarich, K. Alexis

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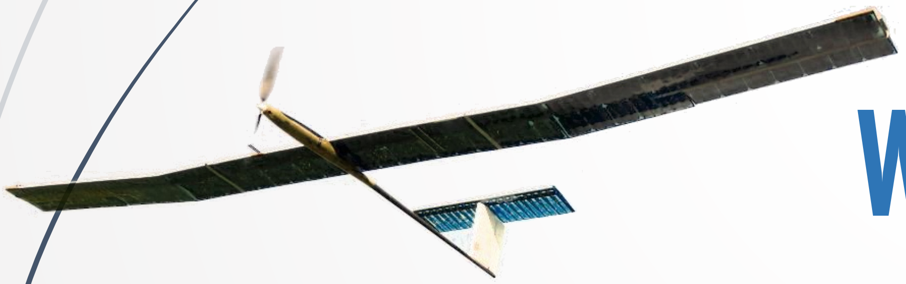
This material is based upon work supported by the Department of Energy under Award Number [DE-EM0004478]

AtlantikSolar – Flying Forever

It all starts with a good idea

Can we make a low-altitude UAV capable of flying forever?



What would it take?

What is the limit?

Go Solar, lightweight, autonomous

Optimized Design → Unprecedented Endurance

- Airframe
- Solar panels
- Batteries
- Propulsion
- Autopilot

- 24h+ Multi-day autonomous flight operation
- Multi-modal Sensing

What makes it different?

Small-scale UAVs

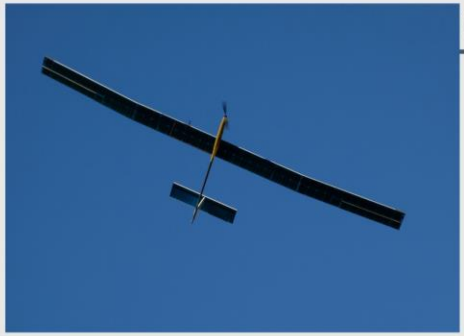
- Low endurance
- Easy handling

Large-scale UAVs

- High endurance
- Complex handling

Small-scale, Long-endurance, Low-altitude Solar-powered UAVs

- Low complexity
- Hand launchable
- Low altitude operation – critical applications
- Multi-day (24+) continuous flight



Critical applications

Wildfire Detection

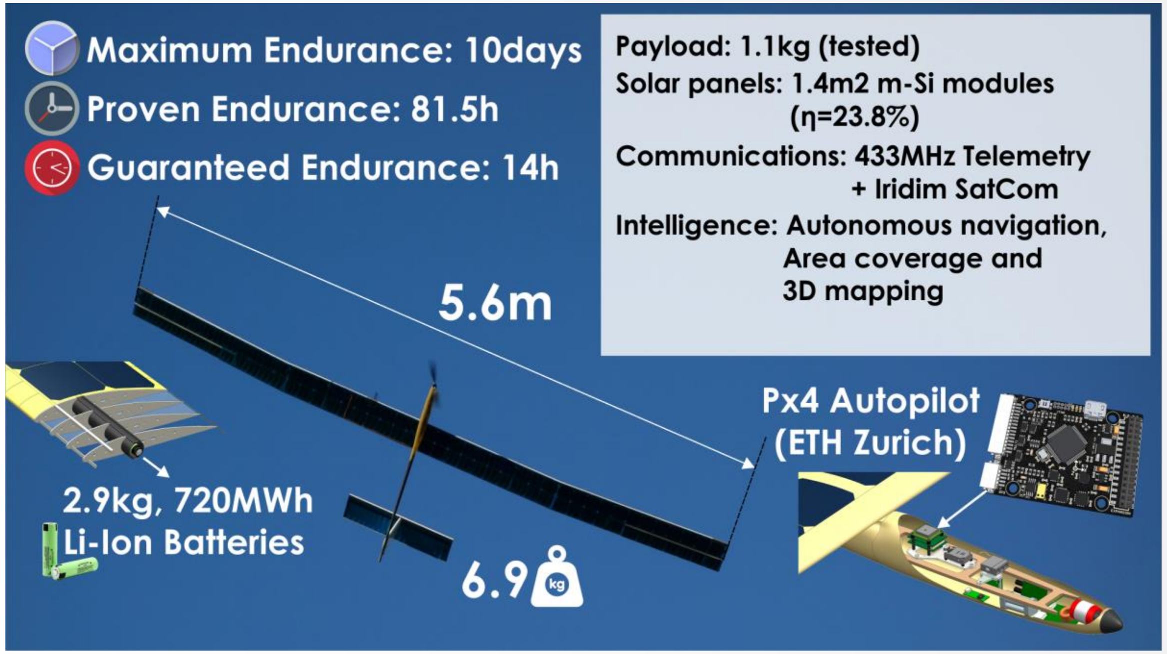
Search & Rescue

Inspection Missions

Climate Control

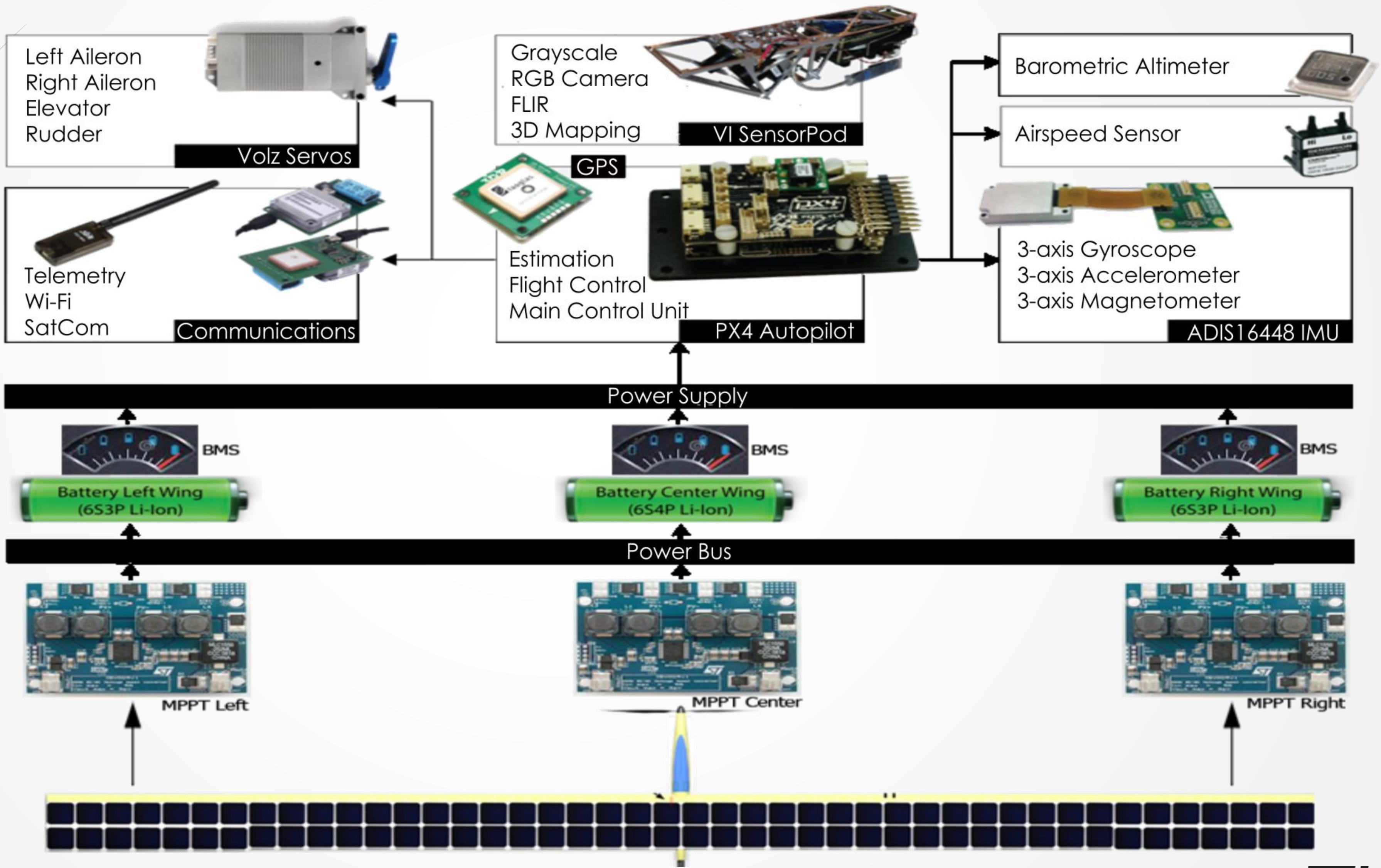
An overview of the AtlantikSolar UAV

- Low-Altitude, Long-Endurance Solar UAV.
- Up to 10days of continuous flight – proven world record of 81.5h.
- Hand launchable and rapidly deployable.
- Fully autonomous – minimum user supervision.
- Varying sensing options.



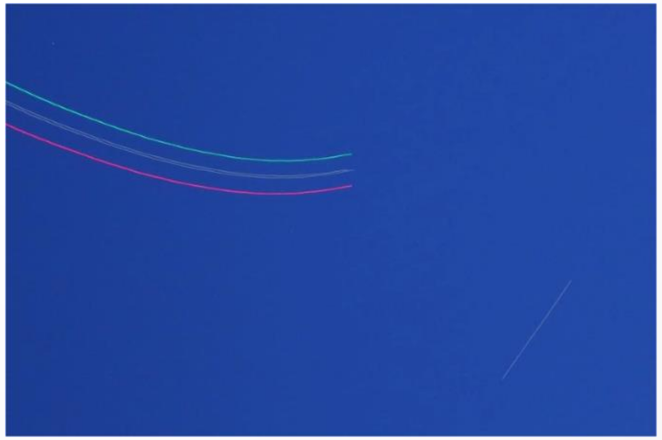
Optimized system design – Advanced Robotic Autonomy

What is under the hood?



81.5h Continuous Flight – World Record

- **First test flight:** November 2012
- **First solar-powered flight:** September 2013
- **First autonomous flight:** April 2014
- **First 24+h flight:** June 2015 (28h)
- **World Record:** July 2015, 81.5h continuous flight (4 days, 3 nights), 2316km total

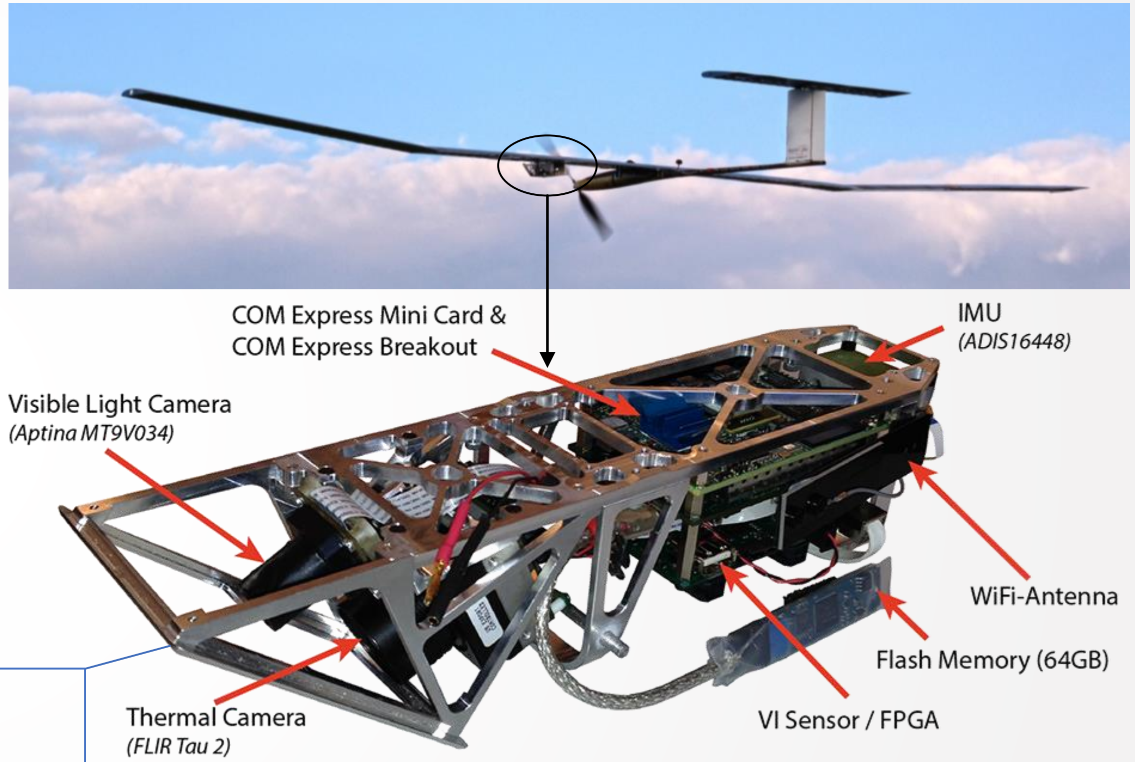


July 17th, 17:42

3d:08:10:58 h

What are the application use-cases?

- Large-scale 3D Mapping
- Environmental, Wildlife Monitoring
- Climate Monitoring and Control
- Search and Rescue
- Rapid Communications Deployment



- **Versatile Sensor Pod**
  - Visual-Inertial navigation
  - Multiple Visible light and thermal or multispectral cameras
  - Real-time depth sensing and 3D Mapping

What are the application use-cases?

- Large-scale 3D Mapping
- Environmental, Wildlife Monitoring
- Climate Monitoring and Control
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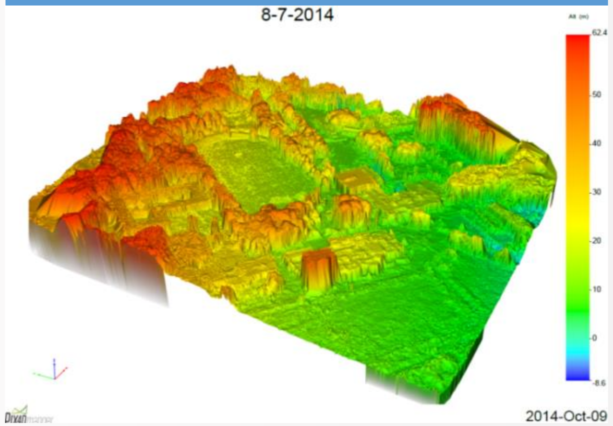
- Rapid Communications Deployment

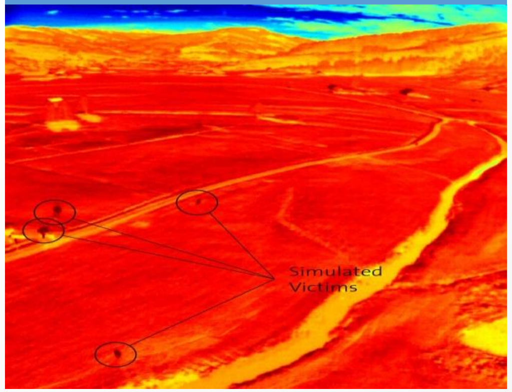
6h mapping flight

3-D mapping (SHERPA project)



Let's watch a bit of it!

Victim Detection



SAR support flights (ICARUS project)

A Solar-Powered Hand-Launchable UAV for Low-Altitude Multi-Day Continuous Flight

Philipp Oettershagen, Amir Melzer, Thomas Mantel, Konrad Rudin,
Rainer Lotz, Dieter Siebenmann, Stefan Leutenegger, Kostas Alexis and Roland Siegwart

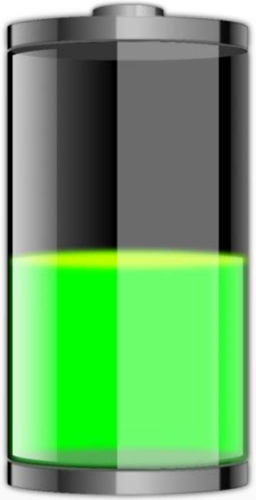
Atlantik Solar

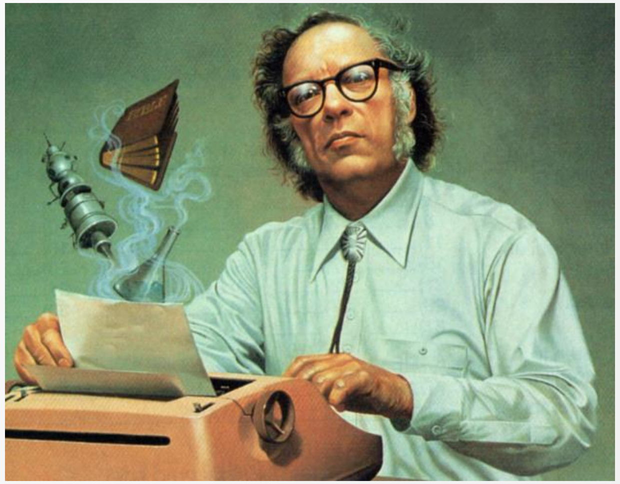
ETH Zürich

What is next?

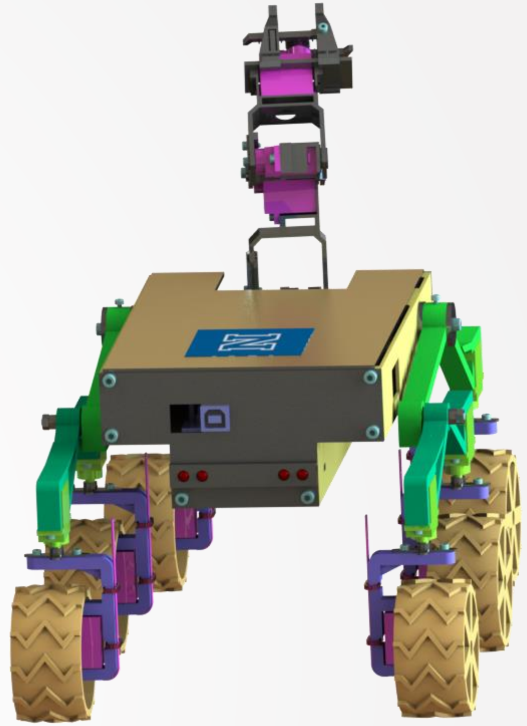
- Superior Autonomy and Robot Intelligence to enable complex operation execution
- Robustify endurance – enable "anytime" solar-powered, multi-hour, low altitude UAV flight
- High-impact, pioneering application use cases: climate monitoring and support, long-term observation, state-wide mapping and surveillance.

Sky's (should be) the limit





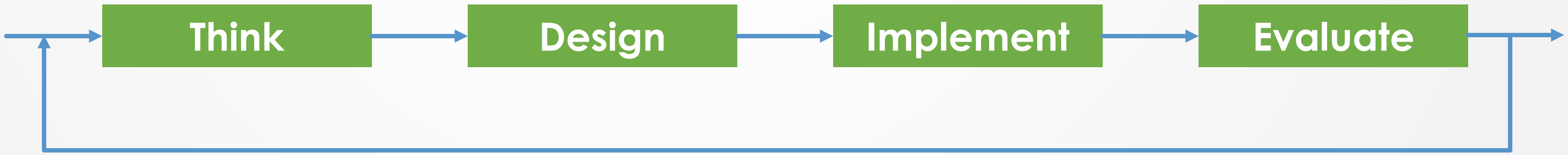
Other Research Directions & Ideas



Other research directions and ideas?

How-to: Brainstorming a research idea

- Step 1: Envision a problem, an application, a challenge worth to be solved.
- Step 2: Consider some basic way that it could be approached – most probably people already approached it in a similar simple way.
- Step 3: Study, organize papers, classify works, study again and eventually (after a lot of studying) conclude if the problem is worth pursuing, if people have already addressed it well or not.
- If it seems a great opportunity and a great challenge go after it! But first define the particular areas and scientific fields that could help in its solution and others haven't mastered yet.
- Make a plan and follow a fundamental loop to enhance your creativity:



Working with us

- Contact us. Express your interest! Tell us why you like robotics.
- Check what we are working on at the moment.
- Pick a broad field. For example: mapping, planning, control, aerial robots, ground robots, underwater robots, space robots, swarming robots etc.
- Arrange a meeting and let’s sit down and discuss. If you have an idea about how your ideas could help our work then that’s great. But even if not, don’t worry. Be proactive and through this process you will find something you like.
- Work on it! Insist and don’t give up. To give birth to something new, some pain is expected.

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Concluding remarks

Concluding remarks

Robotics are cool!

Concluding remarks

Robotics are very cool!

Concluding remarks

amazing!

Robotics are ~~very cool!~~

What book to read during holidays (for robots)?

- I. Asimov, “Robot Visions”
- I. Asimov, “Robot Dreams”
- I. Asimov, “Caves of Steel”
- K. Capek “RUR: Rossum’s Universal Robots” [coined the term “robot”

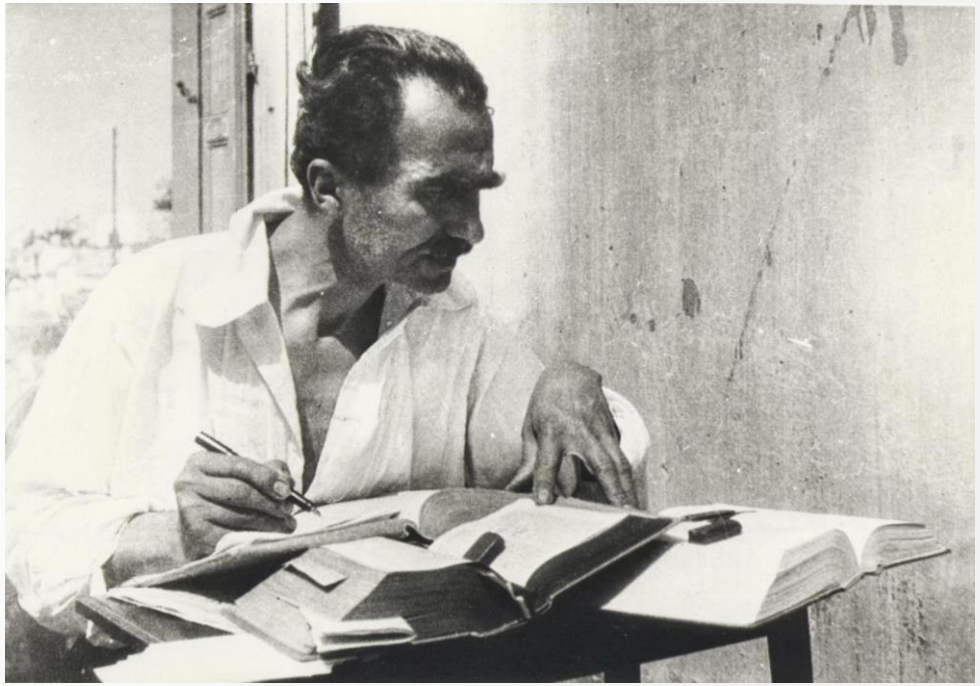
Watch “Wall E”

or if you are in to old stuff – Google “Talos”

Concluding remarks

“ Within this arena, which grows more stable night after day, generations work and love and hope and vanish. New generations tread on the corpses of their fathers, continue the work above the abyss and struggle to tame the dread mystery. How? By cultivating a single field, by kissing a woman, by studying a stone, an animal, an idea ”

N. Kazantzakis, Ασκητική (Salvatores Dei)




Thank you!
Please ask your question!