Autonomous Mobile Robot Design

Dr. Kostas Alexis (CSE)

Course Goals

- To introduce students into the holistic design of autonomous robots - from the mechatronic design to sensors and intelligence.
- Develop the capacity to design and implement robotics.
- Combine theory with intuition and practice.
- Go through the process of robot design and development based a semester-long project.

Course Approach

- **Teaching Modules:** Each teaching module will be as independent as possible. At the same time, each one of them will end with an overview of on-going research challenges.
- **Coding Examples:** Each teaching module is accompanied with a wide set of coding examples.
- **Project-oriented:** Most of your effort will be to work on your team-based semester project. This is how you will learn to work on robotics!
- *Be Proactive & Autonomous:* come and discuss what you want to understand better or what you want to know more about. Grow your own ideas.

Course Teaching Modules

- **Module 1 – Introduction:** Get a broad understanding about robotics.
- **Module 2 – Propulsion and Vehicle Dynamics:** Understand robot propulsion and locomotion principles as well as the description of vehicle dynamics through the relevant equations of motion.
- **Module 3 – Perception and State Estimation:** Learn how on-board estimation of the vehicle full pose (position and orientation) takes place, how the robot perceives the environment, localizes itself and maps its surroundings.
- **Module 4 – Guidance and Control:** Learn how to design high-performance robot motion controllers and guidance laws.
- **Module 5 – Path Planning:** Learn how to develop algorithms for autonomous path planning for aerial robotics.
- **Module 6 – Remote Control:** Work on robot graphical user interfaces and understand the role of different communication channels.

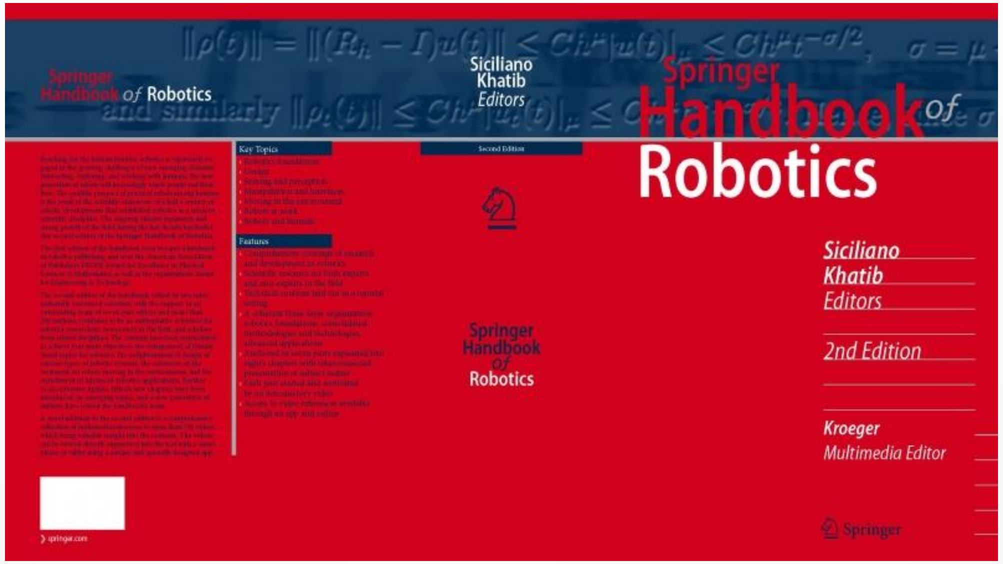
Course Material

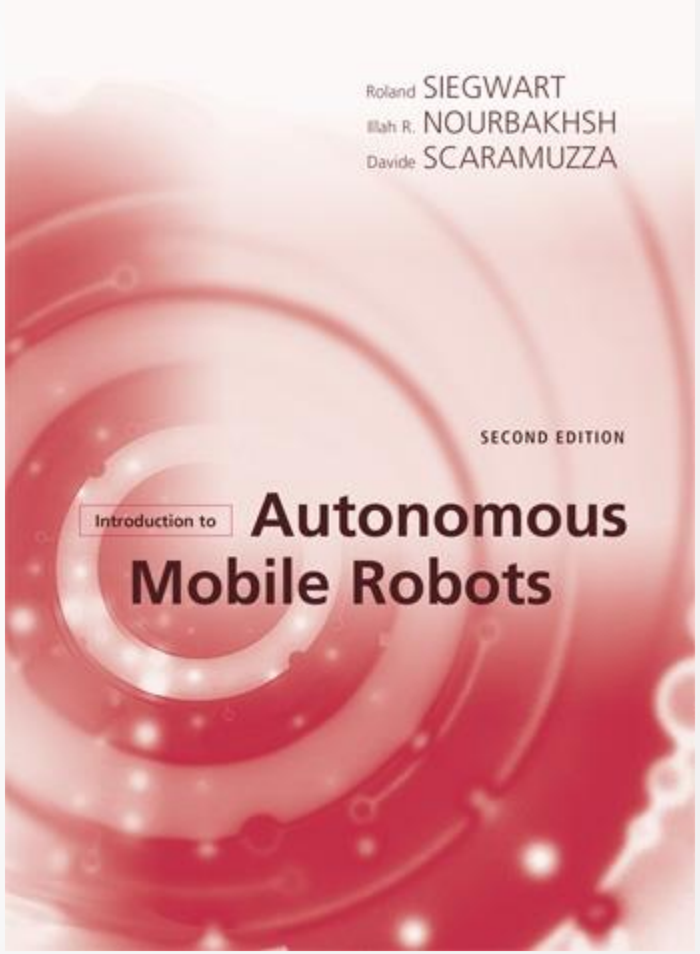
- **Textbook:** Roland Siegwart, Illah Reza Nourbakhsh and Davide Scaramuzza, "Introduction to Autonomous Mobile Robots", Second Edition, MIT Press.
- **Textbook:** B. Siciliano, O. Khatib (editors), "Handbook of Robotics", 2nd Version, For "Flying Robots" chapter (co-author by Dr. Alexis) send an e-mail
- **Lecture Slides:** Used for the classroom presentations and also as a way for notes keeping and direct reference to the course contents.
- **Code Examples:** several examples in MATLAB, Python, C++ and special focus on ROS and the Pixhawk autopilot.
- **Open-Source Aerial Robots Simulator:** a complete simulation environment for advanced designs.

- **Get the course material:** The complete set of the relevant materials are available at: http://www.kostasalexis.com/autonomous-mobile-robot-design.html

Reference Textbook

- Roland Siegwart, Illah Reza Nourbakhsh and Davide Scaramuzza, **"Introduction to Autonomous Mobile Robots"**, Second Edition, MIT Press
- B. Siciliano, O. Khatib (editors), Springer **“Handbook of Robotics”**, Second Edition, Springer-Verlag





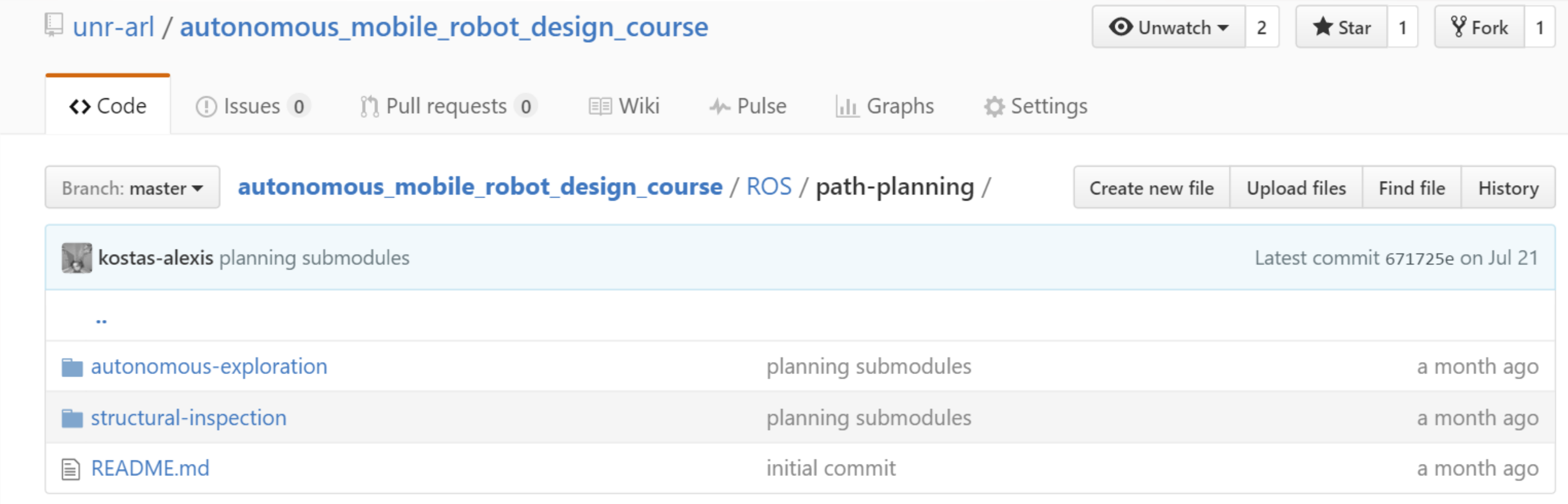
Code Examples

- **Dedicated course repository:**
  - https://github.com/unr-arl/autonomous_mobile_robot_design_course/
  - MATLAB, Python, C++, ROS, Pixhawk examples and more
  - Control, Path Planning, Computer Vision, State Estimation, Dynamics and more

kostas-alexis python examples		Latest commit 56ccb50 6 minutes ago
ROS	planning submodules	10 minutes ago
github	initial commit	3 hours ago
matlab	planning submodules	10 minutes ago
pixhawk	initial commit	3 hours ago
python	python examples	6 minutes ago
.gitmodules	planning submodules	10 minutes ago
README.md	initial commit	3 hours ago

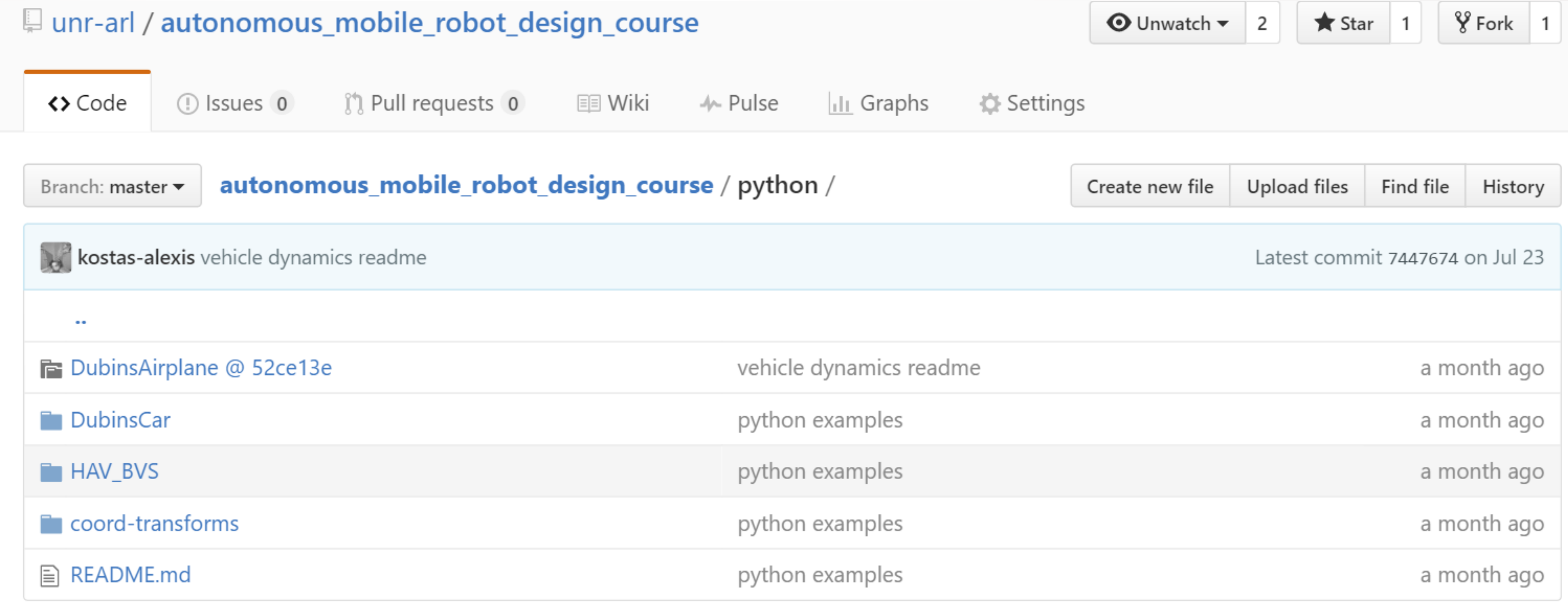
Code Examples

- **Dedicated course repository - examples**



Code Examples

- **Dedicated course repository - examples**



Code Examples

- **Dedicated course repository - examples**

unr-arl / autonomous_mobile_robot_design_course

Unwatch 2 | Star 1 | Fork 1

Code | Issues 0 | Pull requests 0 | Wiki | Pulse | Graphs | Settings

Branch: master — autonomous_mobile_robot_design_course / matlab /

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kostas-alexis differential robot path following — Latest commit f8d4423 17 days ago

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code-generation	initial commit	a month ago
control-systems	differential robot path following	17 days ago
image-processing	removing old dependency	22 days ago
localization-mapping	initial commit	a month ago
official-user-guides	initial commit	a month ago
path-planning	rrt grow example	18 days ago
propulsion-systems	initial commit	a month ago
state-estimation	initial commit	a month ago
trajectory-generation	initial commit	a month ago
vehicle-dynamics	updating readme	a month ago
README.md	initial commit	a month ago

Simulator Tools

- **Open-Source simulator for Aerial Robotics:** http://www.kostasalexis.com/rotors-simulator3.html

Literature and Links

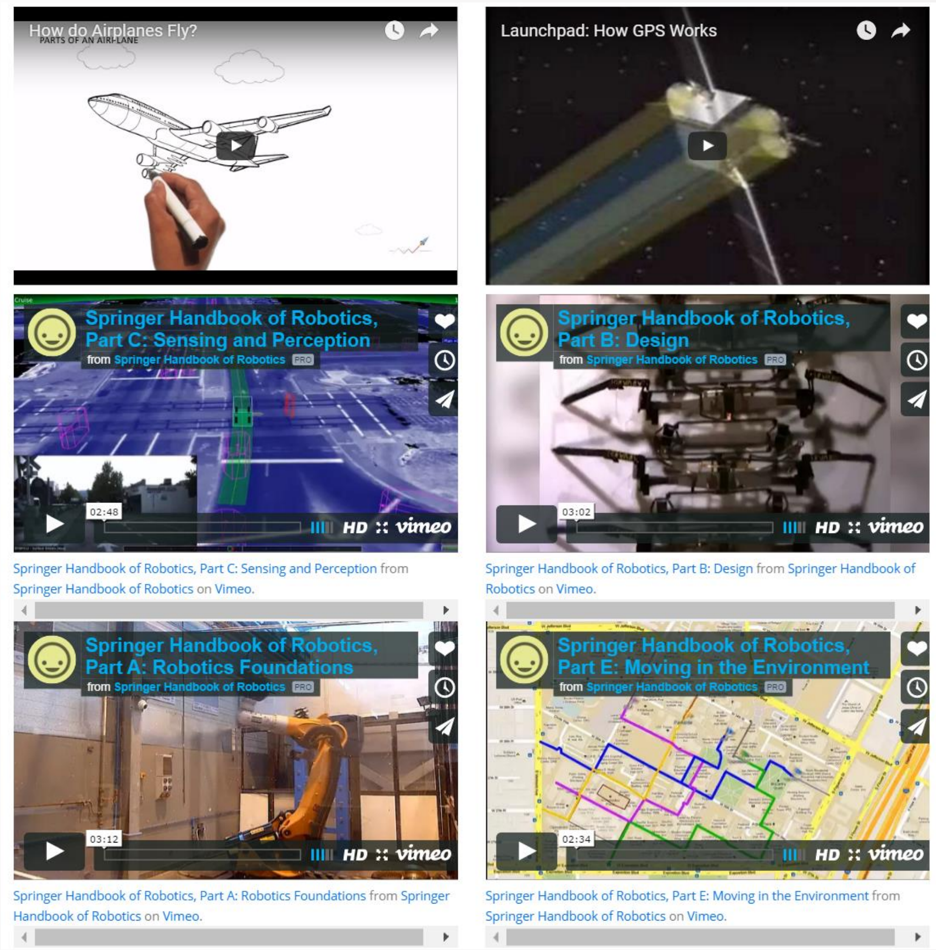
- Literature references
- Tutorials
- Further coding examples
- User guides
- …

Useful Tutorials

- Python Tutorial:
  - Official Python Tutorial
  - Beginner's Guide to Python
  - IPython Tutorial
- C++ Tutorial:
  - Tutorial from cplusplus.com
  - PenguinProgrammer Tutorial
- Robot Operating System (ROS):
  - Introductory Course
  - Official Guided Tutorials
  - ROS Wiki
  - A Gentle Introduction to Catkin
  - Building Modular ROS Packages
  - ROS Cheatsheet
- MATLAB & Simulink Tutorials:
  - Documentation and Tutorials from Mathworks
  - Interactive Control Systems Tutorial
  - Learn Differential Equations
  - MATLAB OnRamp Interactive Learning
  - Aerospace Toolbox Examples
  - MATLAB and Quadrotors!
  - MATLAB Robotics Toolbox
- Ubuntu:
  - Cheat Sheet
- Git repository system:
  - Tutorial
  - Documentation
  - Cheat Sheet
- Tools to design aerial robots:
  - eCalc - Online RC Calculator

Video Explanations

- Video explanations for special topics from selected resources.

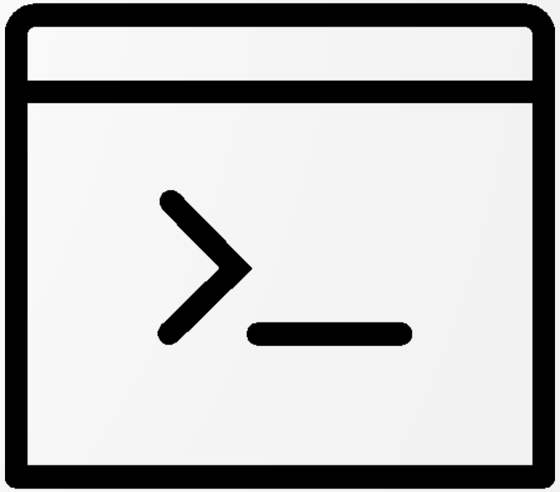


Course Grading System:

- **Project-based:**
  - **Design Project with intermediate report: 80%**
    - **90% in cases of excellence**
  - **Final Exam: 20% (or 10% in case of project excellence)**
- **Exam-based:**
  - **Project: 40%**
  - **Mid-term Exam: 20%**
  - **Final Exam: 40% (up to 60% in case of excellence)**
- **Homework: +**10% (as a bonus)

Tentative scale (curve will be applied)

- **Grade >= 90:** A
- **80 <= Grade <= 89:** B
- **70 <= Grade <= 79:** C
- **60 <= Grade <= 69:** D
- **59 >= Grade:** F



Autonomous Robot Challenges

Propulsion and Vehicle Dynamics

How do I move?

Autonomous Robot Challenges

Propulsion and Vehicle Dynamics

Aerial Robotics

Ground Robotics

Autonomous Robot Challenges

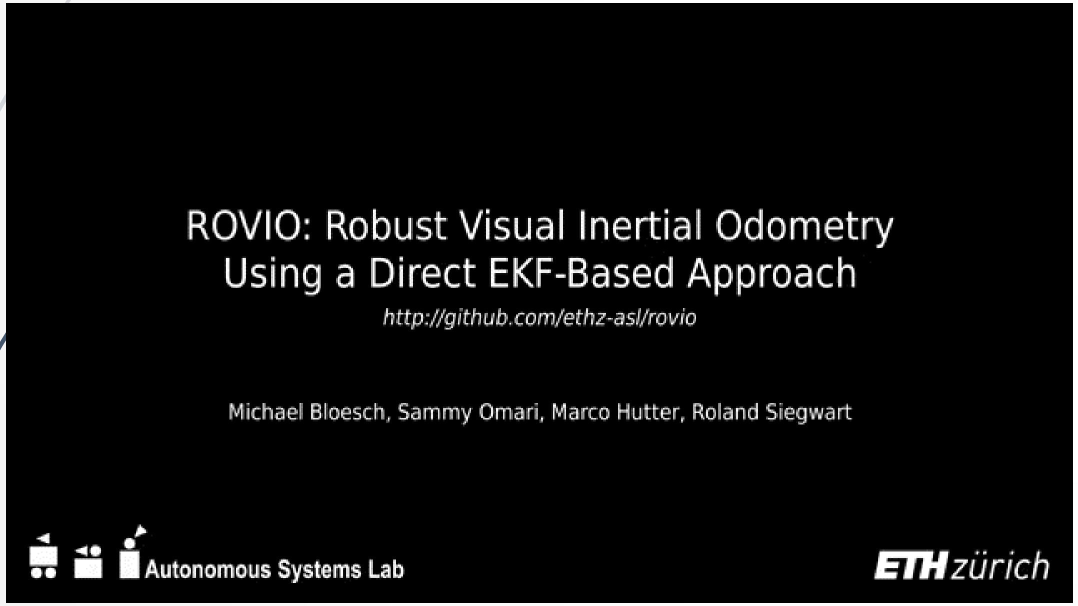
Perception and State Estimation

Where am I?
What is my
environment?

Autonomous Robot Challenges

Perception and State Estimation

Visual-Inertial SLAM



Application to Aerial Robotics

Autonomous Robot Challenges

Guidance and Control

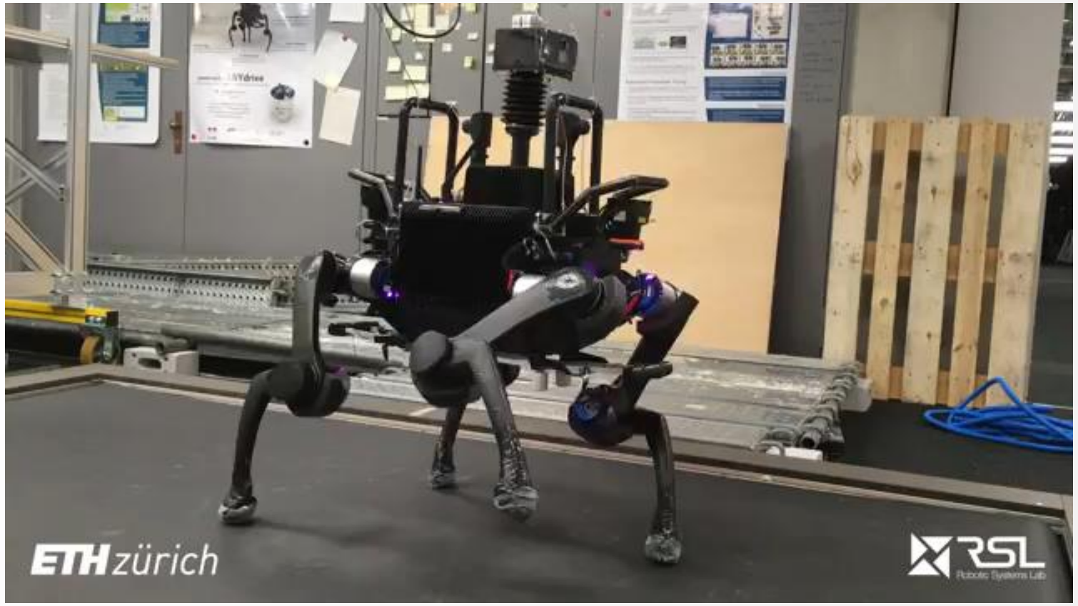
How do I control where to go?

Autonomous Robot Challenges

Guidance and Control

Aerial Robotics

Ground Robotics



Autonomous Robot Challenges

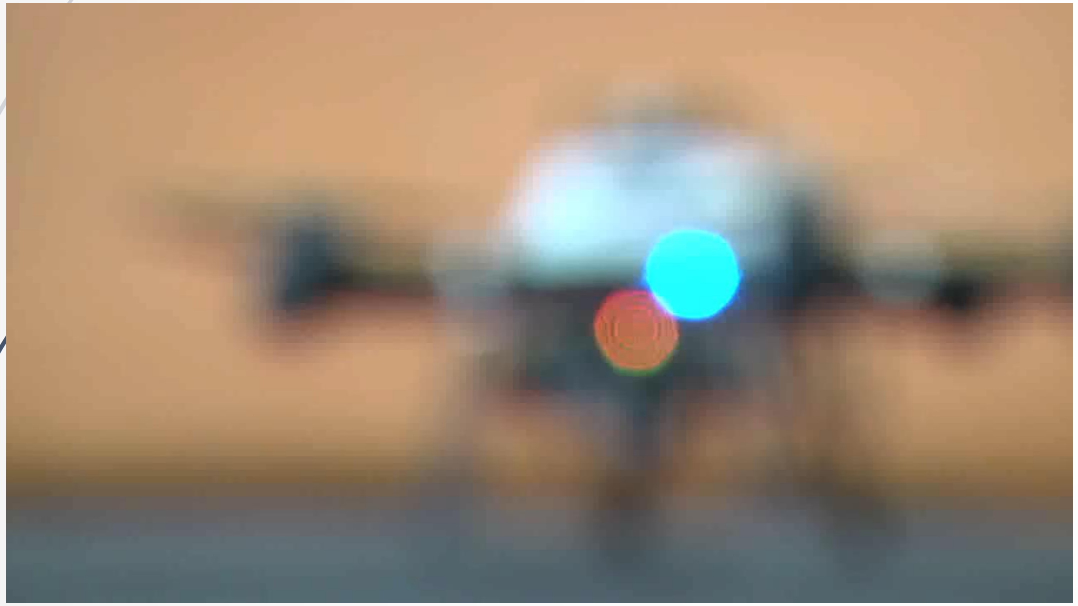
Path Planning

How do I plan my motion and actions?

Autonomous Robot Challenges

Path Planning

Aerial Robotics



Ground Robotics

Autonomous Robot Challenges

Artificial Intelligence (not part of this course)

How to handle abstract tasks?

Autonomous Robot Challenges

Remote Control and GUI design

How to provide a good interface to the human?

Autonomous Robot Challenges

Remote Control and GUI design

Augmented Reality

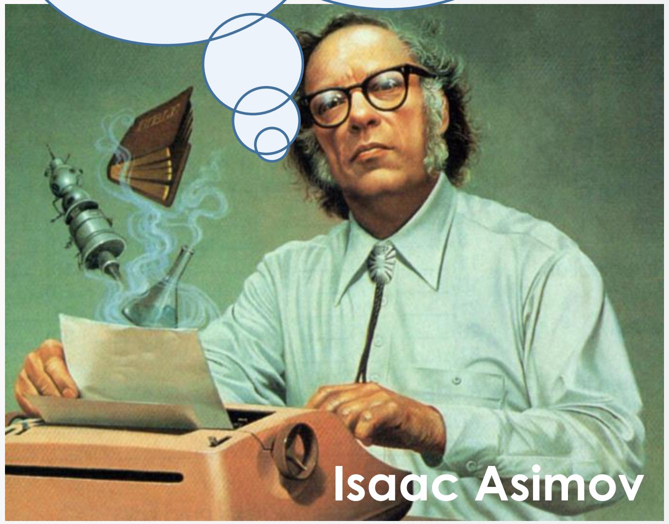
Classical GUI

What are the challenges ahead?

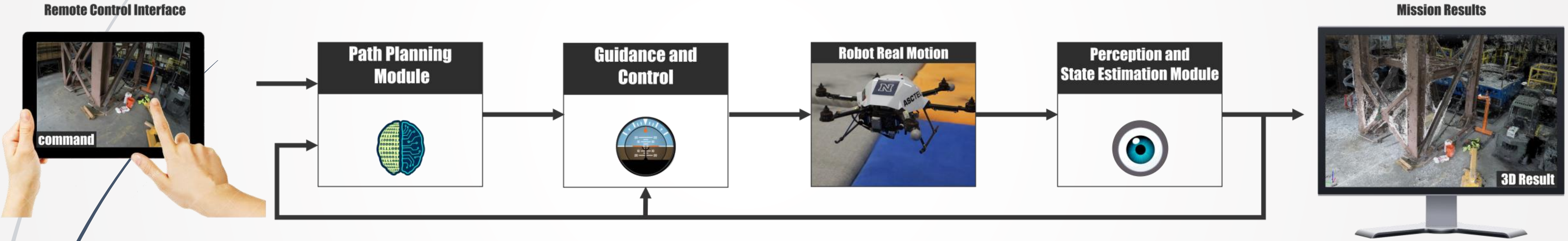
No sensible decision can be made any longer
without taking into account not only
the world as it is, but the world as it will be. ***I.A.***

- a robot may not injure a human being or, through inaction, allow a human being to come to harm
- a robot must obey orders given it by human beings except where such orders would conflict with the first law
- a robot must protect its own existence as long as such protection does not conflict with the first or second law

- Can we operate robots without having special skills?
- Can robots actively explore and navigate their environments and act on it?
- Can we assign complex tasks to autonomous robots?
- Can we ensure collision avoidance?
- Can we trust robots to operate within the urban landscape? Can we trust them to operate next to us or work for/with us?



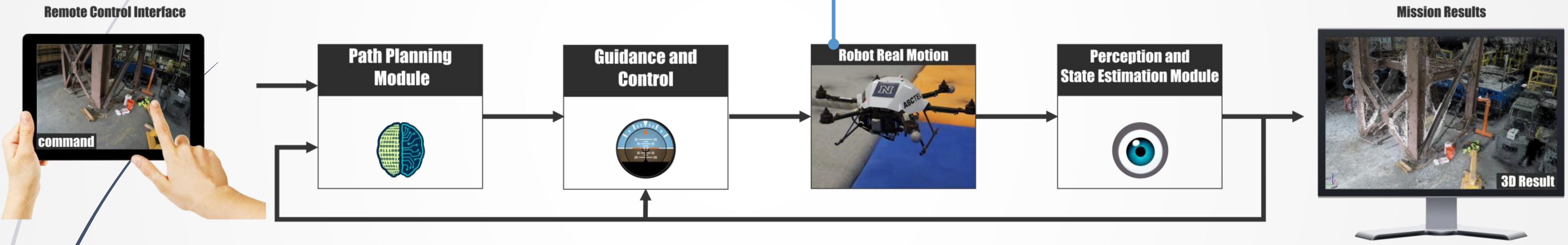
The Basic Robot Loop



Block diagram of the main loops running at every robot

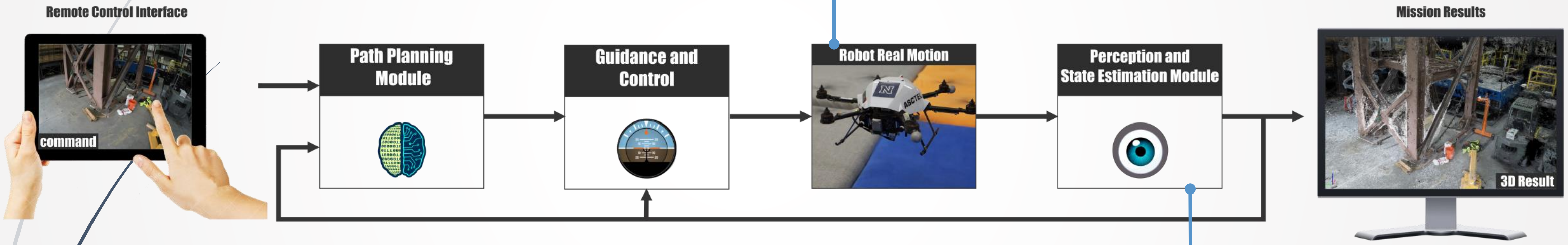
The Basic Robot Loop

- Real-life Robot expressing its dynamic behavior in response to the control inputs and external disturbances



The Basic Robot Loop

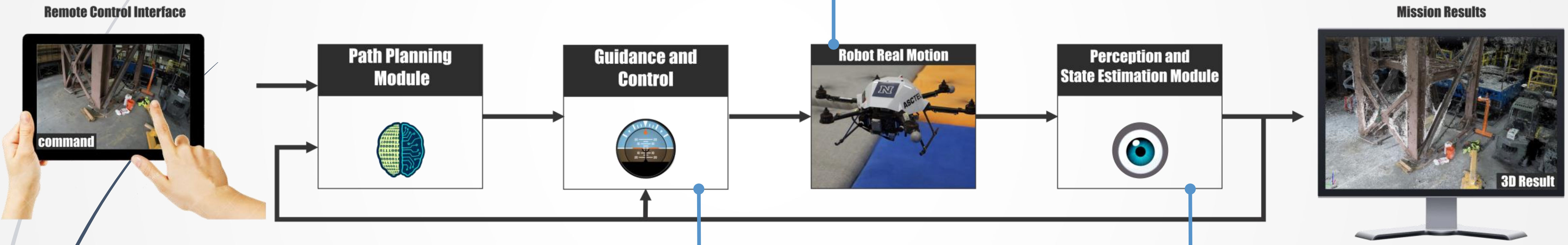
- Real-life Robot expressing its dynamic behavior in response to the control inputs and external disturbances



- Inertial Navigation System
- Localization & Mapping
- Sensor Fusion
- Semantic Understanding

The Basic Robot Loop

- Real-life Robot expressing its dynamic behavior in response to the control inputs and external disturbances



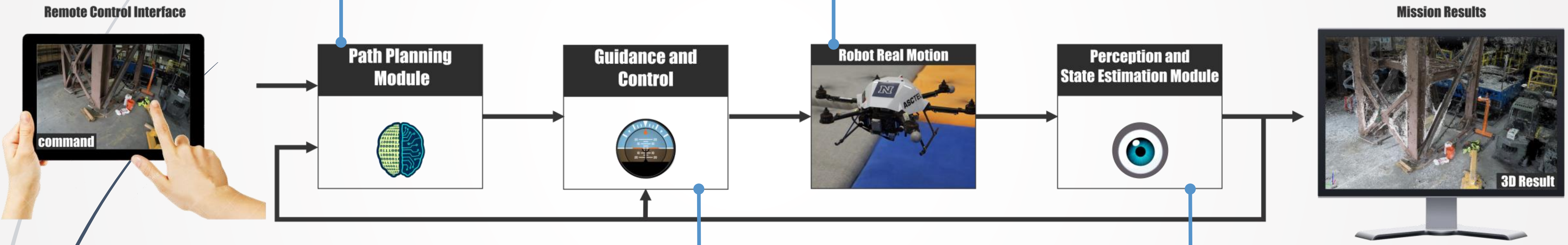
- Control and Guidance system responsible for ensuring vehicle stability and reference trajectory tracking as well as disturbance rejection.

- Inertial Navigation System
- Localization & Mapping
- Sensor Fusion
- Semantic Understanding

The Basic Robot Loop

- Path planning in order to compute the path the robot should follow to ensure safe navigation and execute the desired mission.

- Real-life Robot expressing its dynamic behavior in response to the control inputs and external disturbances



- Control and Guidance system responsible for ensuring vehicle stability and reference trajectory tracking as well as disturbance rejection.

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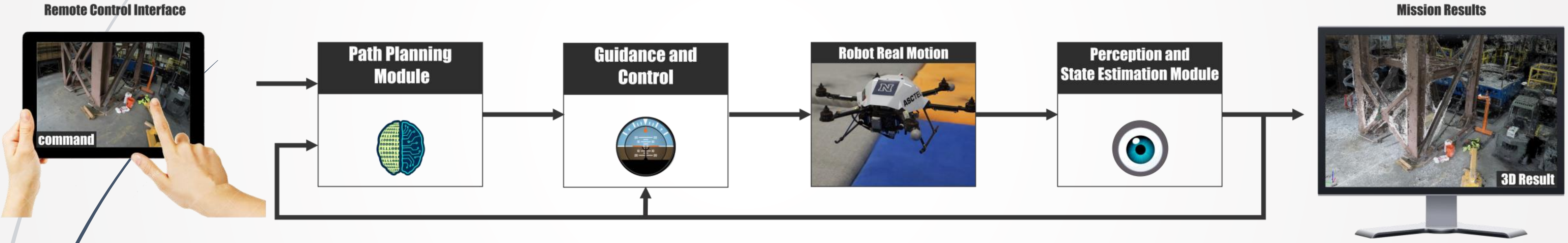
The Basic Robot Loop

A hard real-time system with relatively limited computational resources!

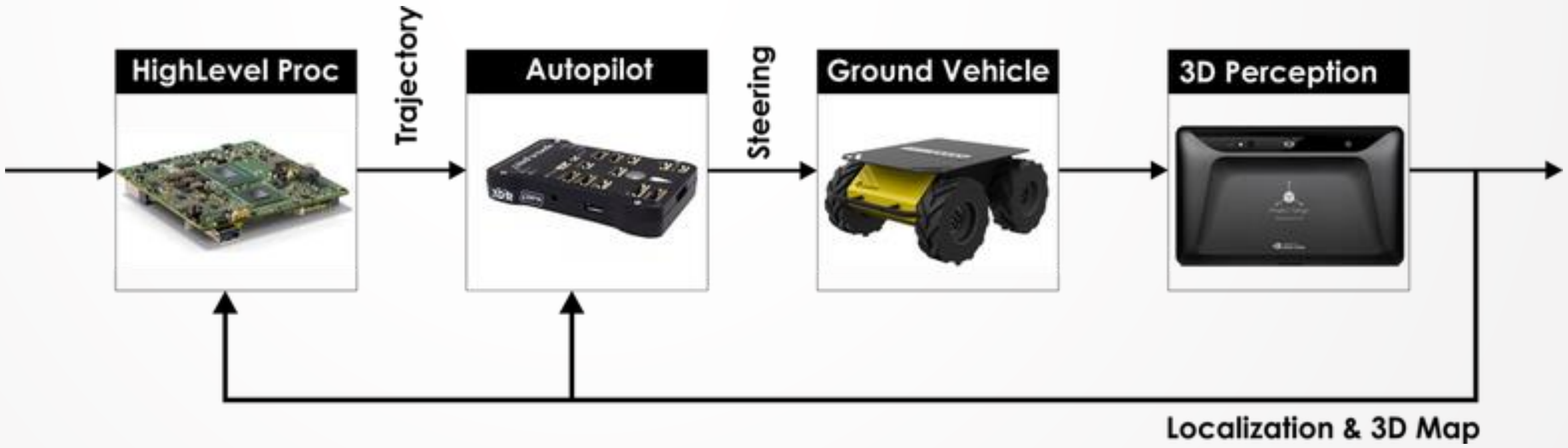


Course Projects

- This course is organized around a semester-long project to be handled by a team of students.
- Each student team will have available funds up to $2,000 to acquire the hardware required to implement the robotics challenge.
- All projects are significantly involved and set state-of-the-art research challenges to you.
- All projects will require some serious teamwork.

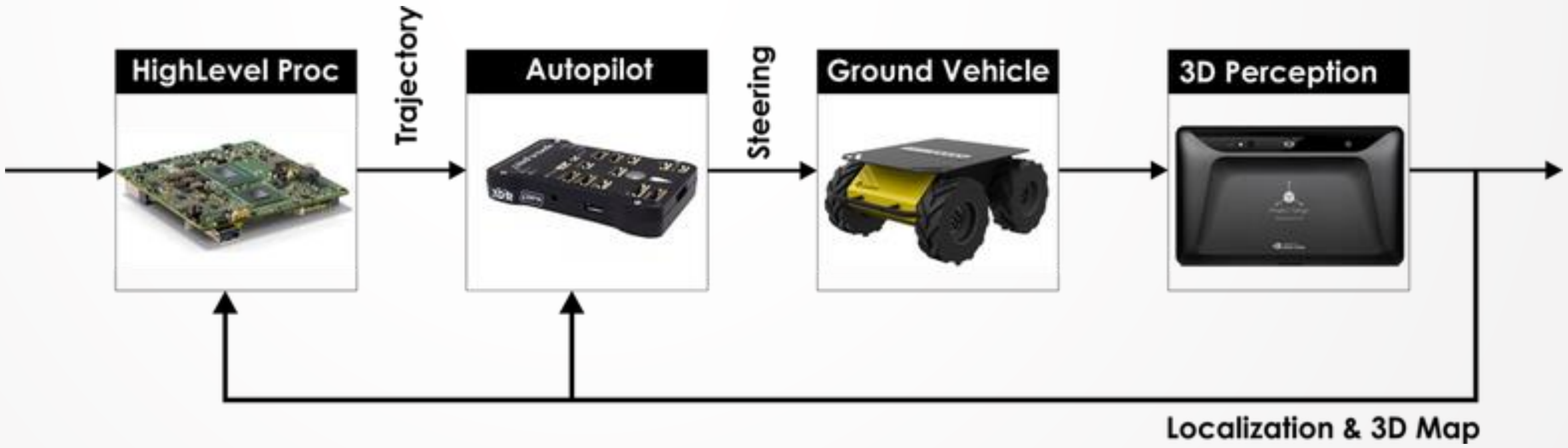
Project 1: Autonomous Cars Navigation Systems

- Autonomous transportation systems not only is an ongoing research trend but also a key factor for the progress of our societies, safety of transportation, more green technologies, growth and better quality of life. The goal of this project will be to develop a miniaturized autonomous car able to navigate while mapping its environment, detecting objects in it (other cars) and performing collision-avoidance maneuvers. To achieve this goal, the robot will integrated controlled steering and a perception system that fuses data from cameras, an inertial measurement unit and depth sensors therefore being able to robustly performing the simultaneous localization and mapping task. Finally, a local path path planner will guide the steering control towards collision-free paths.



Project 1: Autonomous Cars Navigation

- Task 1: Sensing modules and Processing Unit Integration
- Task 2: Autopilot integration and verification
- Task 3: Robot Localization and mapping through fusion of RGBD/Visual-SLAM
- Task 4: Static/Dynamic Obstacle Detection
- Task 5: Robot car motion collision-free planning
- Task 6: Robot Evaluation and Demonstration in the Autonomous Robot Arena and the UNR campus

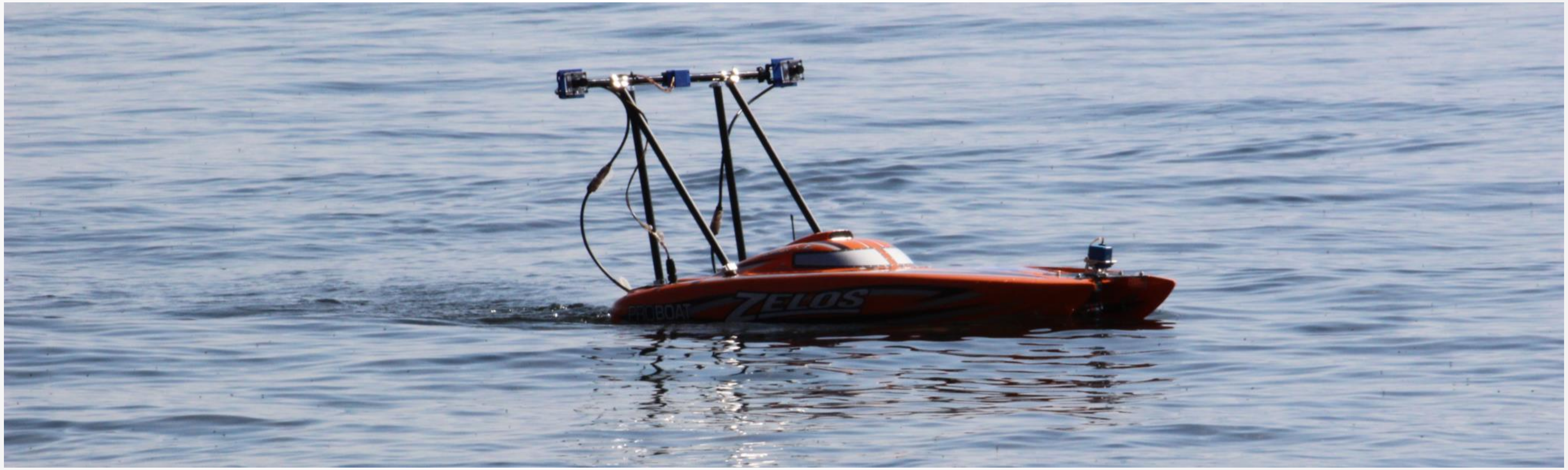


Project 2: Robots to Study Lake Tahoe!

- Water is a nexus of global struggle, and increasing pressure on water resources is driven by large-scale perturbations such as climate change, invasive species, dam development and diversions, pathogen occurrence, nutrient deposition, pollution, toxic chemicals, and increasing and competing human demands. The goal of this project is to design and develop a platform that can be used on the surface of a lake to quantify the water quality changes in the nearshore environment (1-10 m deep). The platform would be autonomous, used to monitor the environment for water quality (temperature, turbidity, oxygen, chl a) at a given depth.
- **Collaborators:** Aquatic Ecosystems Analysis Lab: - http://aquaticecosystemslab.org/

Project 2: Robots to Study Lake Tahoe!

- Task 1: Autopilot integration and verification
- Task 2: Sensing modules and Processing unit improvements
- Task 3: Robot Localization and Mapping using Visual-Inertial solution
- Task 4: Fused visible light/thermal fusion for unified 3D reconstruction
- Task 5: Robot boat autonomous navigation for shoreline tracking
- Task 6: Robot Evaluation and Demonstration



Project 3: Aerial Robotics for Climate Monitoring and Control

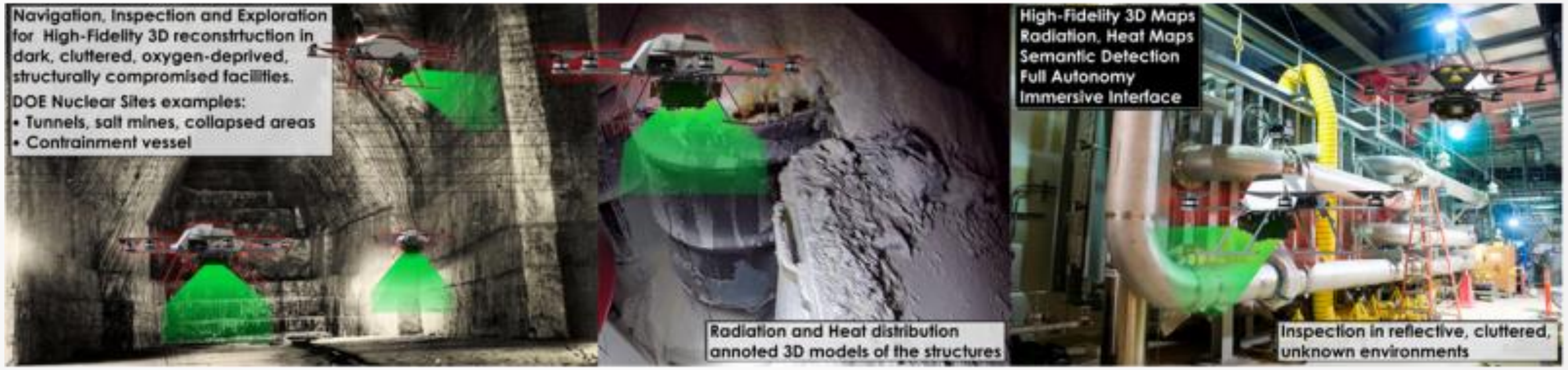
- Within this project you are requested to develop an aerial robot capable of environmental monitoring. In particular, an “environmental sensing pod” that integrates visible light/multispectral cameras, GPS receiver, and inertial, atmospheric quality, as well as temperature sensors. Through appropriate sensor fusion, the aerial robot should be able to estimate a consistent 3D terrain/atmospheric map of its environment according to which every spatial point is annotated with atmospheric measurements and the altitude that those took place (or ideally their spatial distribution). To enable advanced operational capacity, a fixed-wing aerial robot should be employed and GPS-based navigation should be automated.
- **Collaborators:** Desert Research Institute - https://www.dri.edu/

Project 3: Aerial Robotics for Climate Monitoring and Control

- Task 1: Autopilot integration and verification
- Task 2: Sensing modules and Processing unit integration
- Task 3: Integration of Visual-Inertial SLAM solution
- Task 4: Development and integration of atmospheric sensors (CO/CO2, aerosol)
- Task 5: Environmental-data trajectory annotation and estimation of spatial distributions
- Task 6: Real-time plane extraction for landing
- Task 7: Robot Evaluation and Demonstration

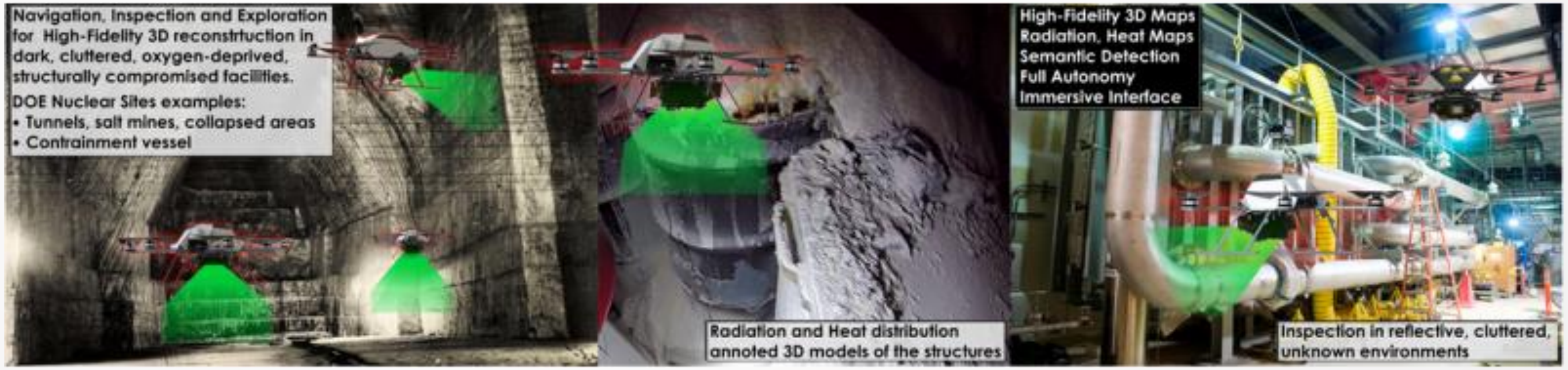
Project 4: Aerial Robotics for Nuclear Site Characterization

- A century of nuclear research, war and accidents created a worldwide legacy of contaminated sites. Massive cleanup of that nuclear complex is underway. Within this project in particular, the goal is to develop multi-modal sensing and mapping capabilities by fusing visual cues with thermal and radiation camera data alongside with inertial sensor readings. Ultimately, the aerial robot should be able to derive 3D maps of its environment that are further annotated with the spatial thermal and radiation distribution. Technically, this will be achieved via the development of a multi-modal localization and mapping pipeline that exploits the different sensing modalities (inertial, visible-light, thermal and radiation camera). Finally, within the project you are expected to demonstrate the autonomous multi-modal mapping capabilities via relevant experiments using a multirotor aerial robot.



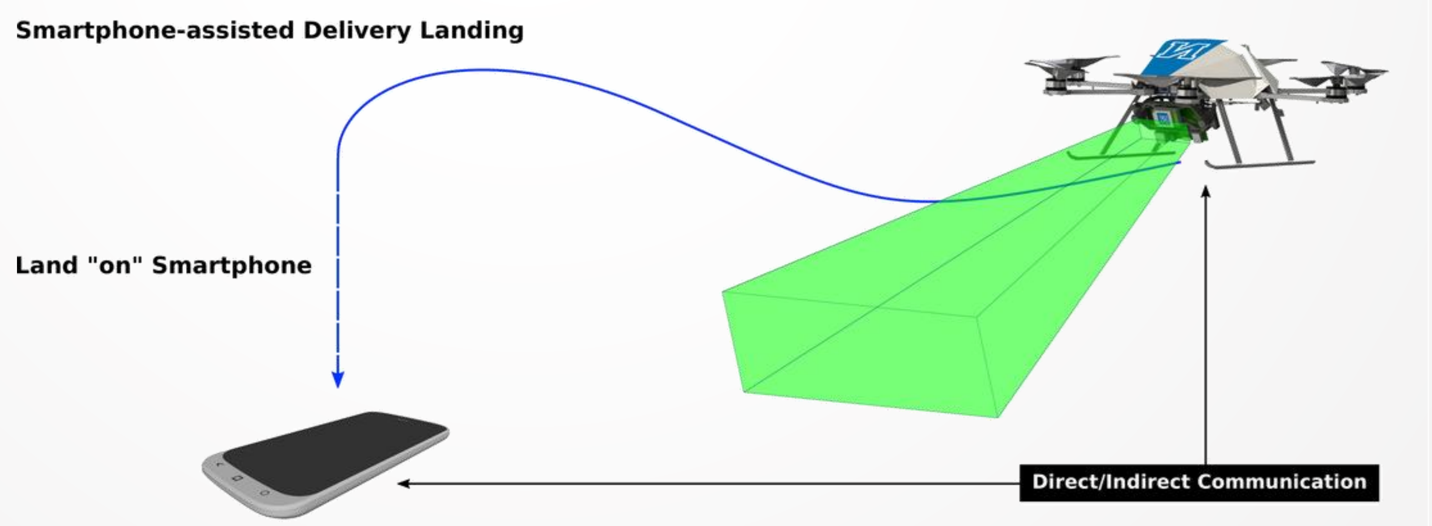
Project 4: Aerial Robotics for Nuclear Site Characterization

- Task 1: Thermal, LiDAR, Radiation Sensing modules integration
- Task 2: Thermal camera-SLAM
- Task 3: Multi-modal 3D maps
- Task 4: Estimation of spatial distribution of heat and radiation
- Task 5: Heat/Radiation source seek planning
- Task 6: Robot Evaluation and Demonstration in the Autonomous Robots Arena and a tunnel-like environment.



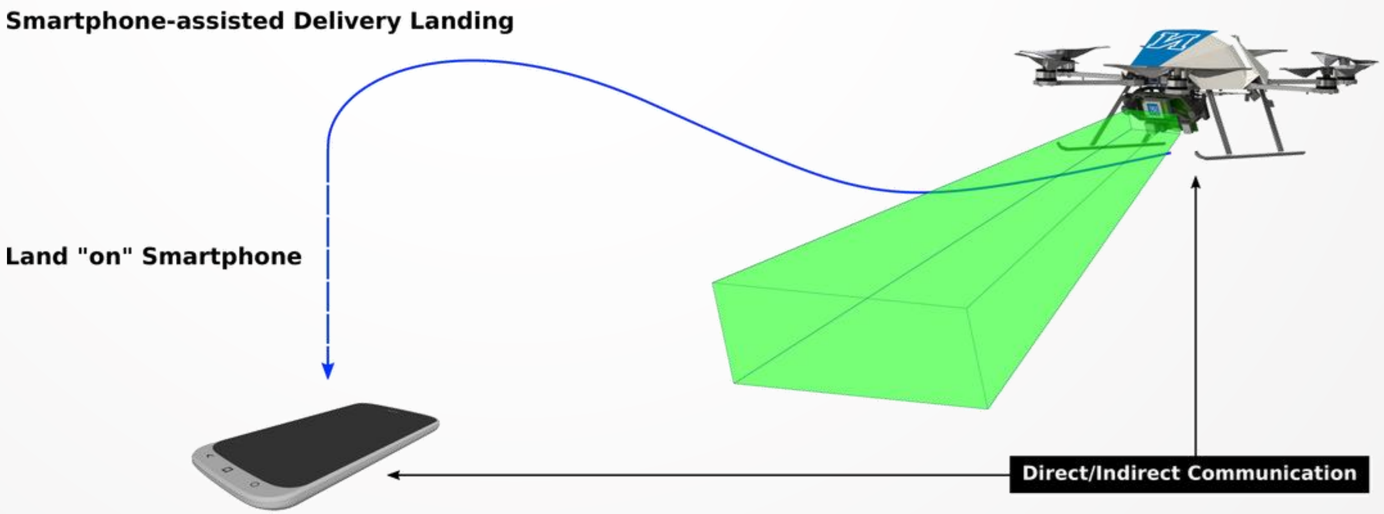
Project 5: Smartphone-assisted Delivery Drone Landing

- The goal of this project is to develop a system that exploits direct/indirect communication between a smartphone and the aerial robot such that delivery landing "on top" of the smartphone becomes possible. Such an approach will enable commercial parcel delivery within challenging and cluttered urban environments. Within the framework of the project, we seek for the most reliable, novel but also technologically feasible solution for the problem at hand. The aerial robot will be able of visual processing and may implement different communication protocols, while the smartphone should be considered "as available" on the market.
- **Collaborators:** Flirtey - http://flirtey.com/



Project 5: Smartphone-assisted Delivery Drone Landing

- Task 1: Autopilot integration
- Task 2: Camera systems integration
- Task 3: Robot-to-Phone and Phone-to-Robot cooperative localization
- Task 4: Visual-servoying phone tracking
- Task 5: Autonomous Landing on phone
- Task 6: Robot Evaluation and Demonstration



Autopilot Solution: Pixhawk

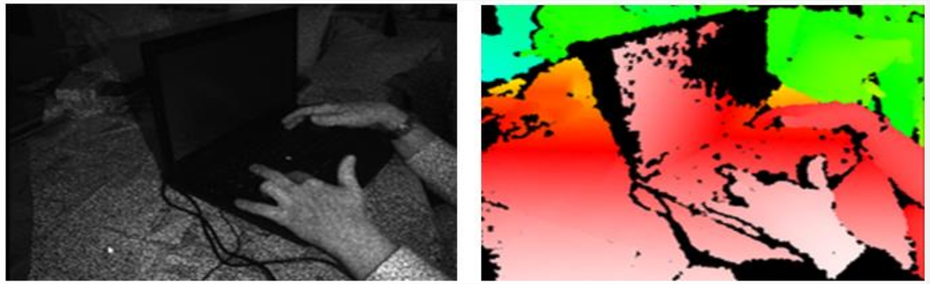
- Open-source project (PX4) started at ETH Zurich
- Currently supports rotorcrafts, fixed-wing vehicles, rovers, boats and more.
- Robust autopilot solution with large supporting community.
- Under extensive redesign at the period. Many new products are expected to come.

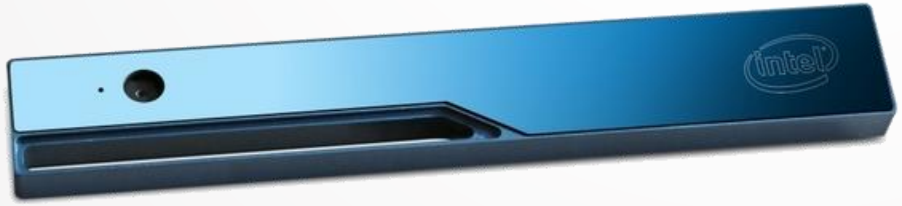
Visual-Inertial SLAM

- Robust localization and mapping approach: performs much better compared to camera-only solutions.
- Will be the basis for all projects – further sensing modalities will be integrated when relevant (e.g. thermal camera or LiDAR)

Time-of-Flight RGB-Depth Sensors

- Sensing systems that capture RGB (visual) images along with per-pixel depth information. This can be achieved either via stereo rigs or the use of time-of-flight concepts.
- Microsoft Kinect created a new class of sensing solutions that quickly found great application in robotics.
- Since then, a wide set of sensors with very low-cost have been released.





High-level processing and Middleware

- For the most advanced functionalities such as mapping or path planning, a second processing level is typically employed.
- We look for a system that can support Linux installation and ability to run the Robot Operating System (ROS).
- Robot Operating System (ROS) is a collection of software frameworks for robot software development providing operating system-like functionality on a heterogeneous computer cluster.

ROS

Course Projects

- Team projects involving approximately 6 students
- Holistic experience. Student team responsible to assign internal role and split the project into subtasks.
- Finite budget per project: $2,000
- Place within the university to work on the project
- Weekly supervision meeting
- Code examples available for all steps of your student project
- Potential of scientific publication from all of the proposed projects!

Course Projects

- Each team should have a combination of graduate and undergrad students.
- Graduate students are expected to be able to lead the team.
- How to use the budget of $2,000 should be based on a complete proposal of your team and some discussion after that.
- Every team will have a weekly meeting at a fixed time to discuss progress and coordinate the next moves.
- Testing should happen first in the Autonomous Robots Arena when possible.

Course Projects

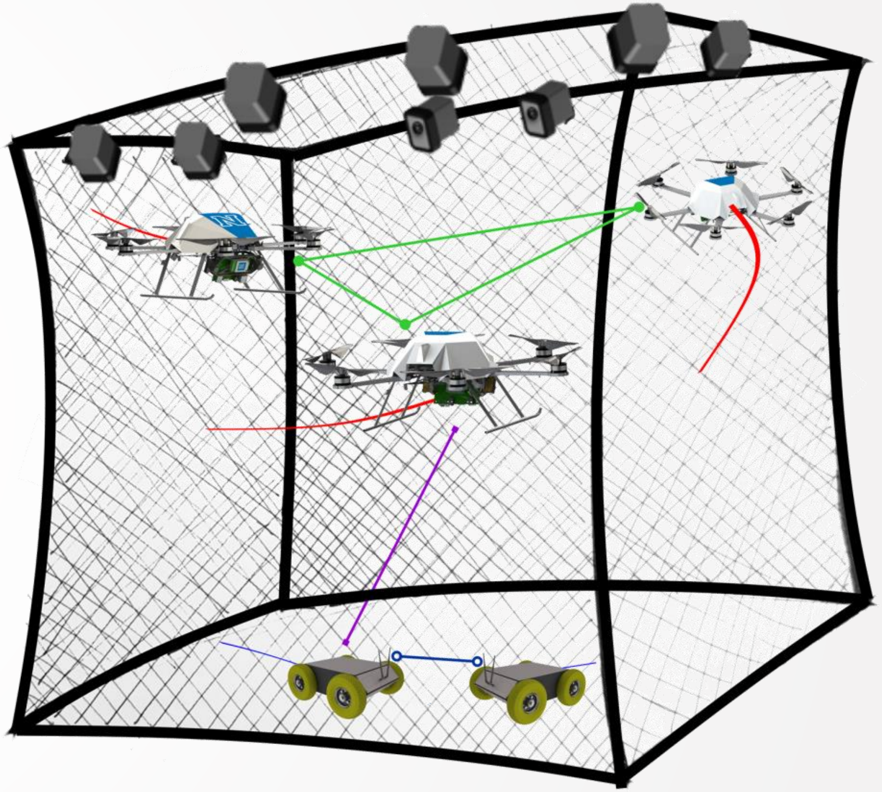
- **Indicate your project preference at kalexis@unr.edu**
- Work on developing your team! Be autonomous and proactive!
- Create Github account if you don’t have one. At your e-mail, also share with me your github account username.

Testing in the Autonomous Robots Arena

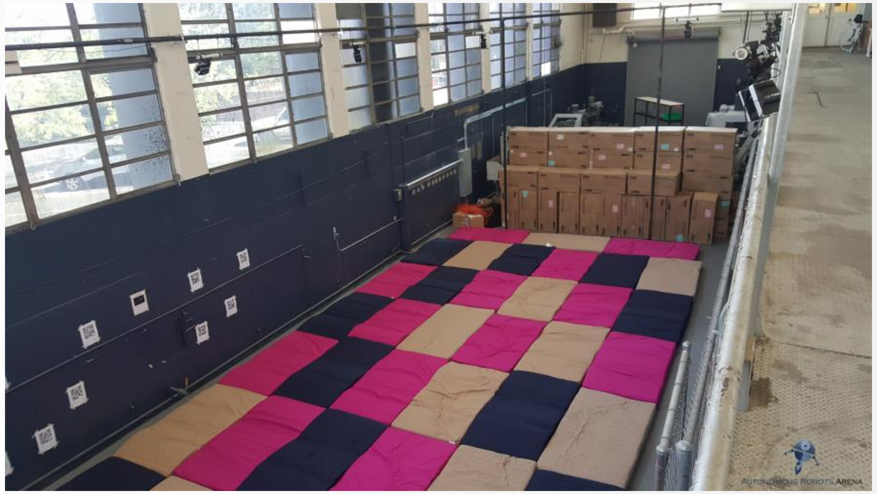
- Indicate your project preference at kalexis@unr.edu
- Work on developing your team! Be autonomous and proactive!
- Create Github account if you don't have one. At your e-mail, also share with me your github account username.

The vision

- To create a prototype facility for large scale, rapid development and testing of autonomous robots.
- Go beyond motion-capture controlled volumes.
- Create formal experiment design and evaluation.
- Abstract sensors, controllers, path planners and other fundamental robotic loops – allow structured integration and ability to continuously upgrade.



Ongoing set-up



- Motion Capture-enabled volume of 15x7x5m
- Sub-mm, Sub-degree accuracy of pose estimation
- >$100,000 infrastructure

Scheduling your experiment

- Once ready to test a functionality in your robot, appointments can be arranged via e-mail at kalexis@unr.edu. An online system will be available soon.

Thank you!

Please ask your question!