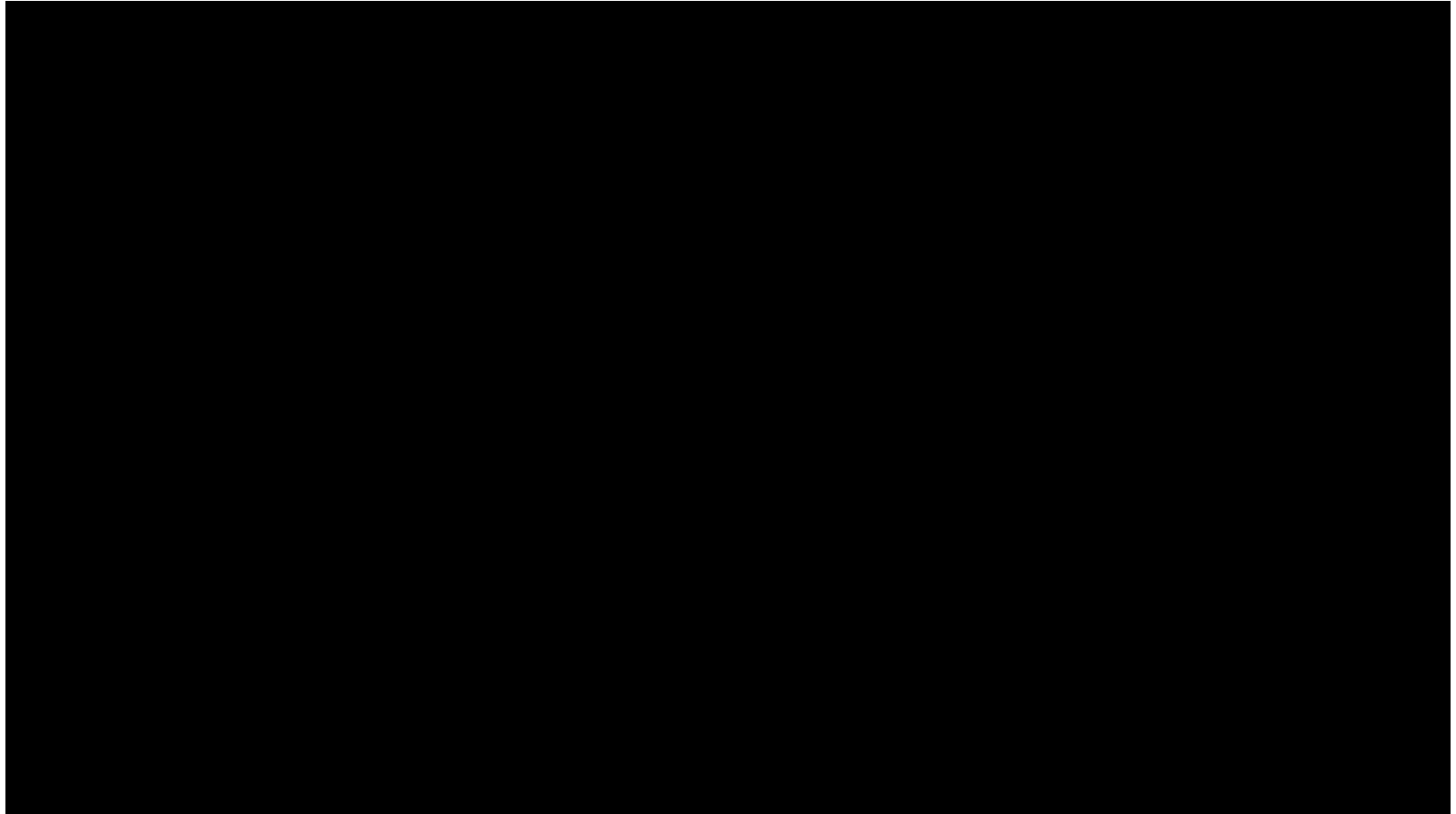


Team CTU at MBZIRC 2020 in Abu Dhabi



Martin Saska



**Multi-robot Systems group,
Czech Technical University in Prague**



<http://mrs.felk.cvut.cz> martin.saska@fel.cvut.cz



Multi-Robot Systems at CTU in Prague

>30 employees + >30 MSc. & Bc. Students
and >30 AUTONOMOUS DRONES



MRS group in years

2015 – 3 employees

2016 – 5 employees

2017 – 8 employees

2018 – 12 employees

2019 – 16 employees

2020 – 22 employees

2021 – 30 employees



3/2017 – MBZIRC 3rd challenge:
1st place \$330.000



2/2020 – MBZIRC 2nd challenge:
1st place \$250.000, TOTAL WINNERS



2019-2020 - DARPA SubT: 2x 1st place
among self-funded teams. \$200k & \$500k



Forming the future of unmanned flights

Development and prototyping
of autonomous aerial systems

Customized platforms for areal
research and development

R&D projects



info@fly4future.com
+420 603 757 148
www.fly4future.com

- Close collaboration with MRS group at CTU in Prague
- 10 R&D engineers for technology transfer from research to products
- 5 new positions starting 10/2021

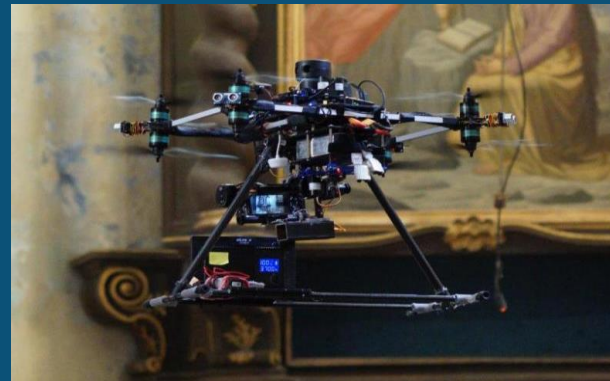
DEVELOPMENT AND PROTOTYPING OF AUTONOMOUS AERIAL SYSTEMS



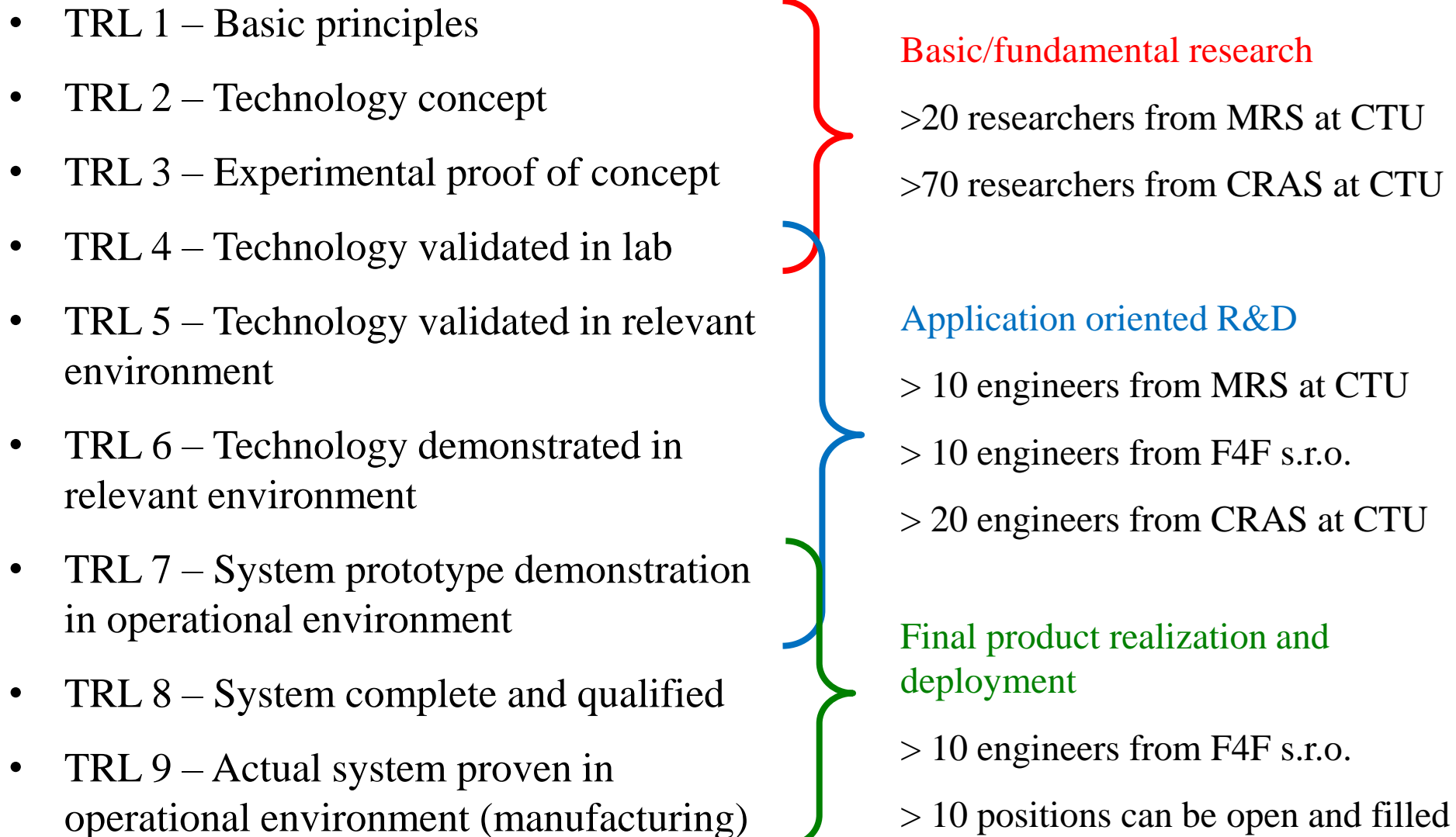
CUSTOMIZED PLATFORMS FOR UAV RESEARCH AND DEVELOPMENT



R&D PROJECTS – APPLICATION FOR FUNDING, PROJECT MANAGEMENT



Complete chain of development of AI smart drone solutions: basic research → application R&D → product realization and deployment



MBZIRC - motivation of the competition

- Attract the best scientists to Abu Dhabi
 - Board of respected professors
 - 15 sponsored teams
 - 5.000.000,- USD
- Get known Khalifa university worldwide
- Motivate UAV research
 - Challenging tasks on the edge of current tech.
 - Scenarios demanded by industry



Khalifa University is
organising the Mohamed
Bin Zayed International
Robotics Competition



MBZIRC 2017 competition:

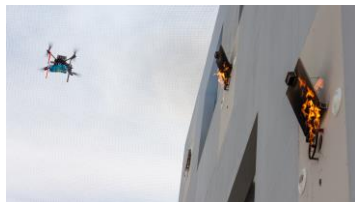
3rd challenge: 1st place \$330.000, 1st challenge: 2nd place, TOTAL: 3rd place



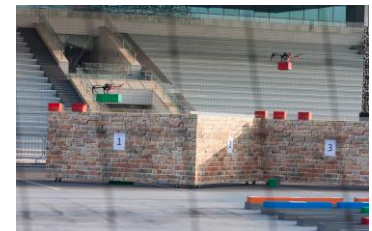
- 1. challenge: Autonomous landing on a moving car
- 2. challenge: Manipulation by a mobile ground robot
- 3. challenge: Searching, localizing, grasping and delivering of objects by a team of autonomous drones.

MBZIRC 2020 competition:

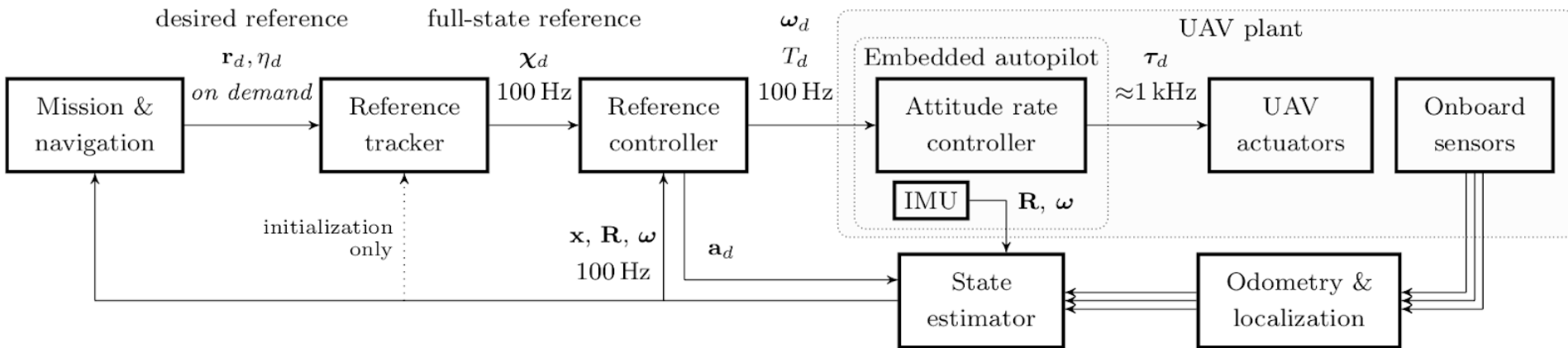
2nd challenge: 1st place \$330.000, 1st challenge: 2nd place, TOTAL: 1st place



- 1. challenge: to capture and neutralize intruder UAVs
- 2. challenge: to autonomously locate, pick, transport and assemble different types of brick shaped objects to build pre-defined structures
- 3. challenge: to autonomously extinguish a series of simulated fires in an urban high rise building



MRS UAV System - Control Architecture



- Mission & Navigation - provides high-level reference (position + heading, 4D trajectory)
- Reference (MPC or SE(3)) tracker - feasible feedforward reference for the feedback controllers
- Reference Controller - estimates control disturbances and outputs attitude rate command to Pixhawk
- Attitude rate controller - PID loop on attitude rate, creates control commands to individual motors
- Odometry & Localization - UAV position (velocity) based on sensory data, examples: Laser SLAM, ViSUAL SLAM, Optic Flow, ...
- State estimator - a bank of estimators and filters produces a set of hypothesis (estimates) of the UAV state; switching between sensor configurations in flight
- Open source: **>300 registered active users**

Báča JINT 2021, Petrлік RA-L 2020, Báča JFR 2019

Design your own drone with MRS system

<https://dronebuilder.fly4future.com>

Drone Builder

F4F

Home

Preconfigured platforms

UAVs

Component categories

Frames

ESCs

Motors

Propellers

Accumulators

Radio Transceivers

Flight Controllers

GNSS Antennas & Modules

On-board Computers

UAVs

Sizes

ALL SMALL MIDDLE LARGE

Usage


ALL INDOOR OUTDOOR INDOOR & OUTDOOR

Middle-sized platform for indoor autonomous flights

A ready-to-fly unmanned aerial system suitable for indoor inspections and mapping. Flight time ~25 min.

Middle Indoor Holybro X500

4 motors




+ 1 -

Full-equipped large-size platform

A ready-to-fly unmanned aerial system with Tarot T18 frame suitable for heavy loads.

Large Outdoor Tarot T18

8 motors



+ 0 -

4011.4 g Holybro X500

4 motors

UAVs

Middle-sized platform for indoor autonomous flights 1 x -

Frames

Holybro X500 1 x -

ESCs

Turnigy MultiStar BLheli_32 ARM 51A Race Spec ESC 2~6S (OPTO) 4 x -

Motors

T-Motor MN3510 700KV 4 x -

Propellers

P13x4.4 4 x -

Accumulators

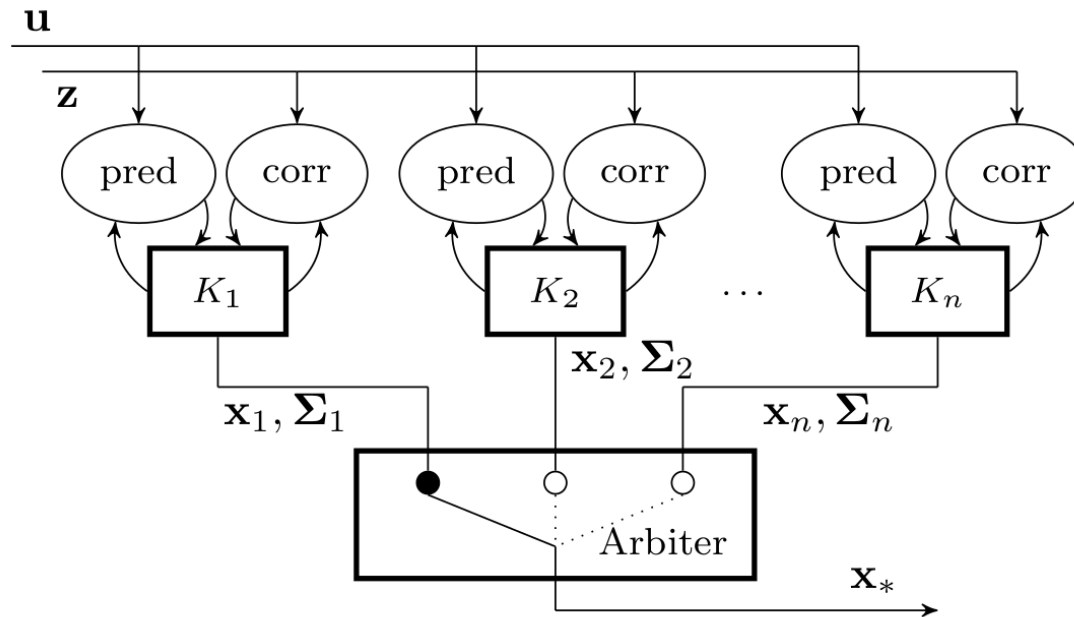
LiPo Tattu 8000mAh 2 x -

Radio Transceivers

Optima SL 1 x -

Flight Controllers

MRS UAV System - State estimation and sensor fusion system



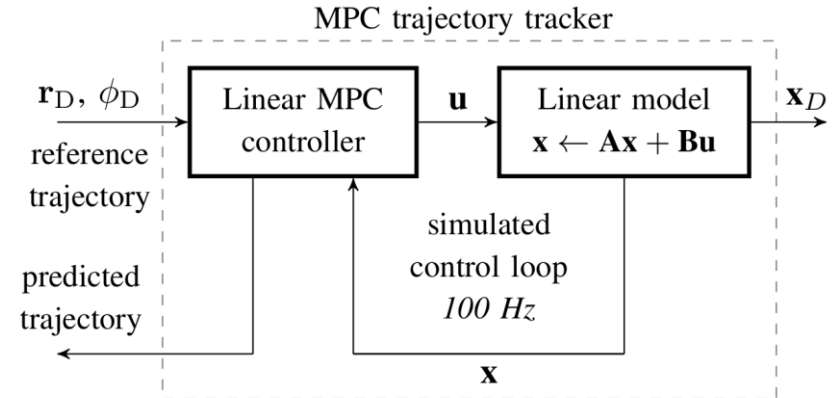
- Bank of real-time estimators for various combination of odometry inputs
- One hypothesis chosen by an arbiter as the main output used for feedback control
- Estimators are switched in case of sensor malfunction
- UAV state is estimated in multiple frames of reference simultaneously

Báča JINT 2021, Petrlik RA-L 2020

MRS UAV System - State estimation and sensor fusion system

$$\min_{\mathbf{u}_{[t]}, \mathbf{x}_{[t]}} V(\mathbf{x}, \mathbf{u}) = \frac{1}{2} \sum_{i=1}^{m-1} \left(\mathbf{e}_{[i]}^T \mathbf{Q} \mathbf{e}_{[i]} + \mathbf{u}_{[i]}^T \mathbf{P} \mathbf{u}_{[i]} \right)$$

$$\begin{aligned} \text{s.t. } \mathbf{x}_{[t+1]} &= \mathbf{A}\mathbf{x}_{[t]} + \mathbf{B}\mathbf{u}_{[t]}, & \forall t \in \{0, \dots, m-1\} \\ \mathbf{x}_{[t]} &\leq \mathbf{x_max}_{[t]}, & \forall t \in \{1, \dots, m\} \\ \mathbf{x}_{[t]} &\geq \mathbf{x_min}_{[t]}, & \forall t \in \{1, \dots, m\} \end{aligned}$$



- Real-time full-state UAV reference generator with 8-second prediction horizon
- Linear MPC in a simulated inner loop onboard a UAV
- State box constraint satisfaction up to snap
- Integrated mutual UAV collision avoidance
- Position, velocity, acceleration, jerk, and snap reference at 100 Hz

Báča IROS 2018, Báča JFR 2019

MBZIRC 2020 Summary

Challenge #1

CTU in Prague, UPenn, NYU



Penn
UNIVERSITY of PENNSYLVANIA



EAGLE.ONE®

Autonomous anti-drone solution

WE ARE HIRING: 20+ positions

- Autonomous drone hunter
- Onboard sensing and AI
- Safe target capture and delivery

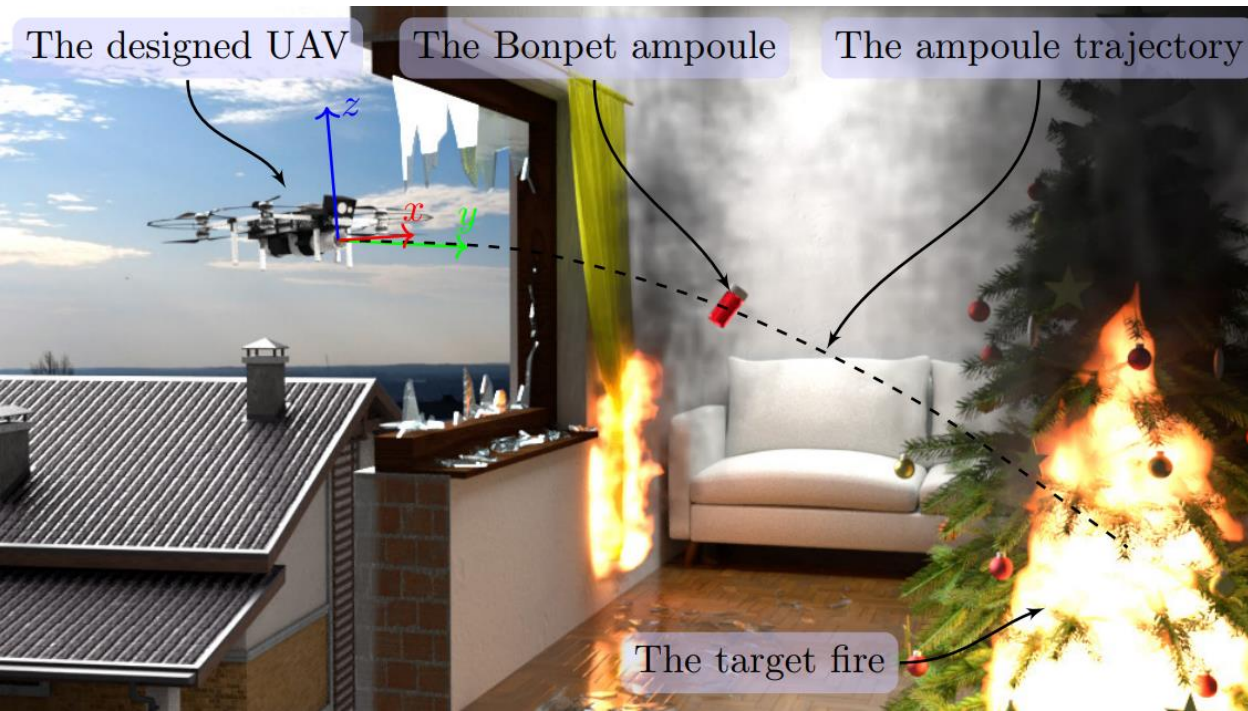






DOFEC – Discharging Of Fire Extinguishing Capsules

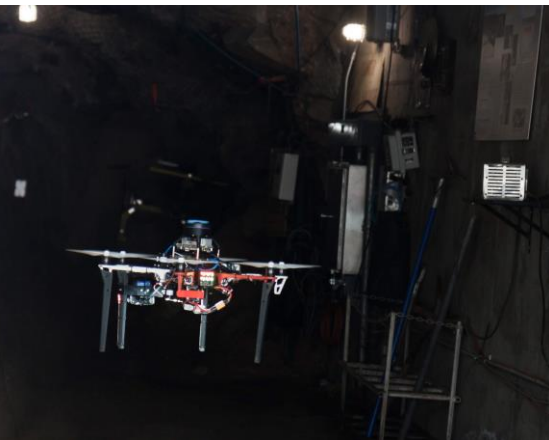
- Autonomous fast fire extinguishment in aboveground floors
- Fire detection using an onboard thermal camera and its localization by a depth camera
- Precise discharge of ampoules with a fire from an onboard launcher





DARPA Subterranean Challenge - Tunnel Circuit

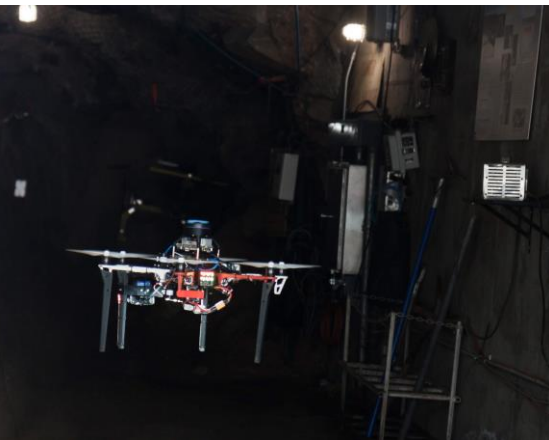
- Multi-robot team designed for exploration underground environment
- DARPA SubT Tunnel Circuit - 8/2019: **1st place** among self-funded teams, 3rd place in total. **\$200 000 prize**





DARPA Subterranean Challenge - Urban Circuit

- Multi-robot team designed for exploration underground environment
- DARPA SubT Urban Circuit - 2/2020: **1st place** among self-funded teams, 3rd place in total. **\$500 000 prize**



CTU-CRAS-NORLAB

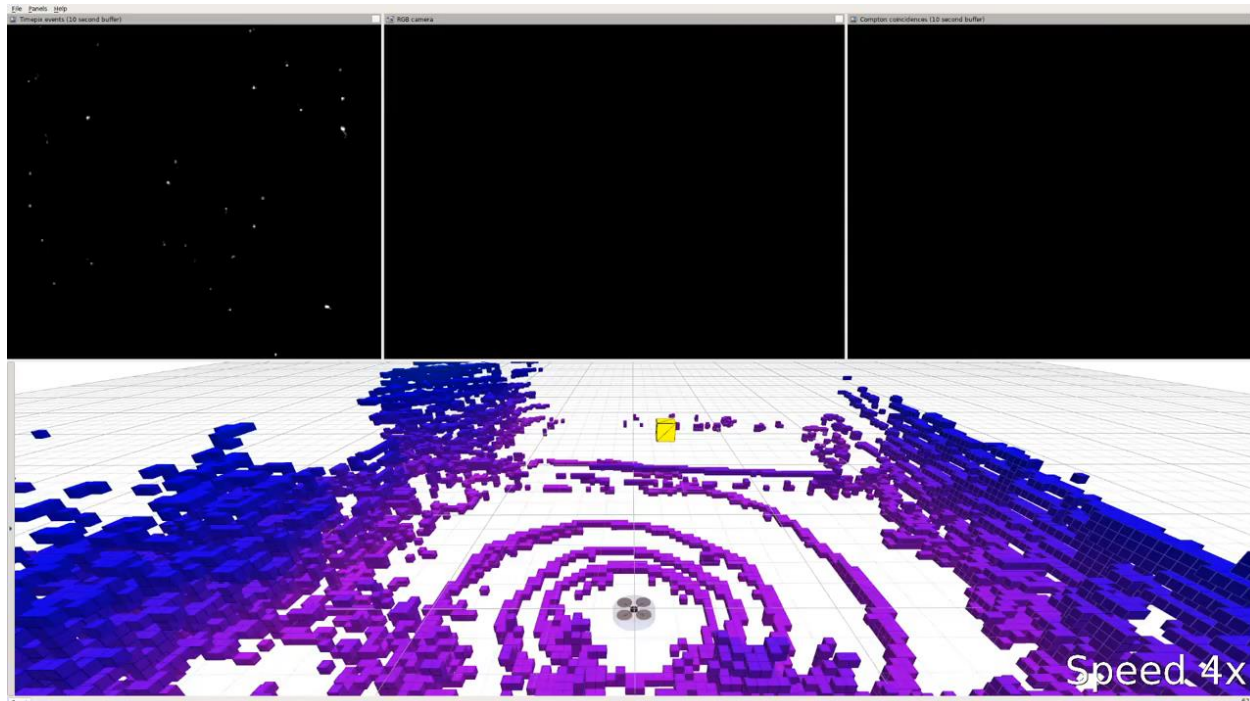
@DARPA Subterranean Challenge
URBAN CIRCUIT



<http://robotics.fel.cvut.cz/cras/darpa-subt/>
<http://mrs.felk.cvut.cz/projects/darpa>

RADRON – Fast localization of a static/moving source of radiation

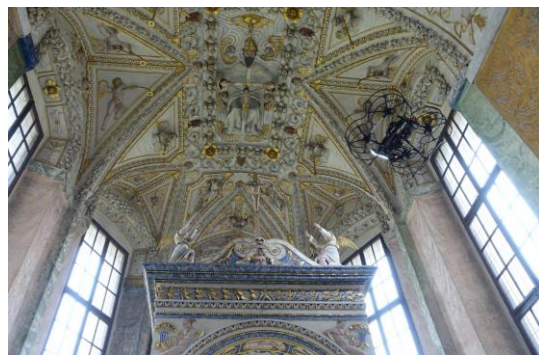
- Moving detectors are more efficient
- Multiple cooperating drones – faster detection and moving object localization
- Indoor & outdoor deployment - no external localization; LIDAR based SLAM
- Compton camera sensor used (ADVACAM Timepix3) - directional information for incoming gamma radiation



Documentation of dark areas of large historical buildings by a formation of unmanned aerial vehicles

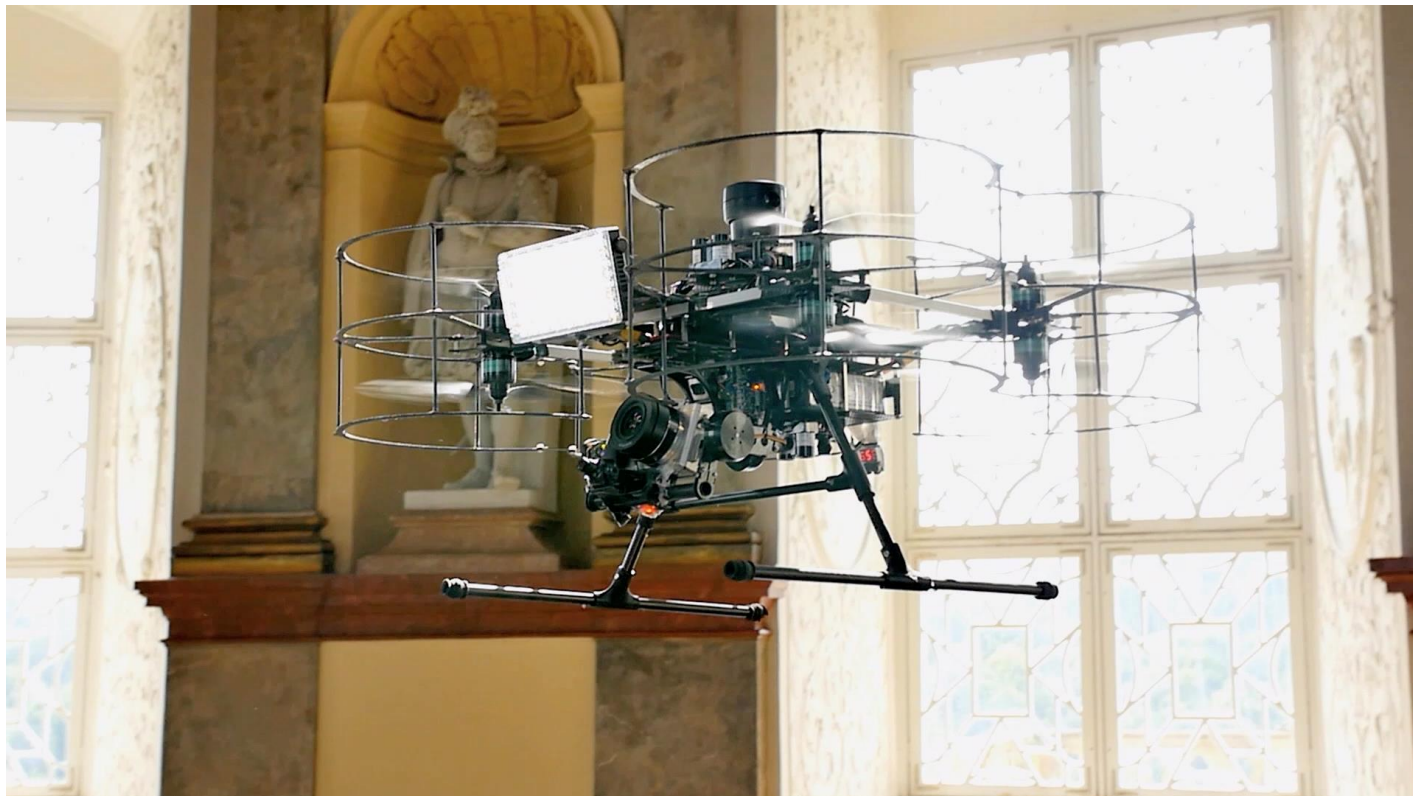


vs.



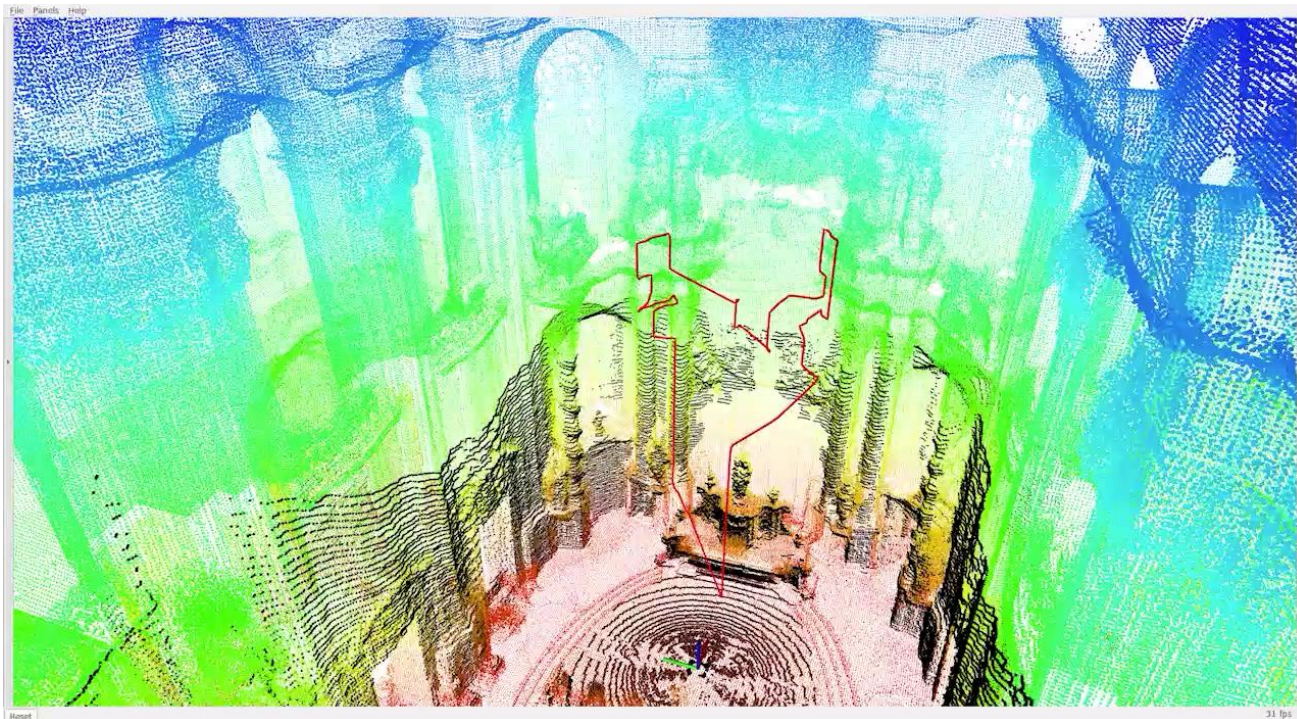
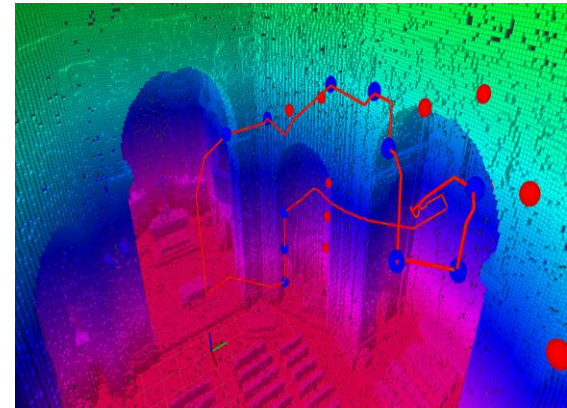
Autonomous and semi-autonomous indoor inspection

- Safe scanning of historical objects *Petráček, RAL 2020*
 - Multi modal onboard sensing (high sensor redundancy)
 - Assistive technologies for safe autonomous and semi-autonomous flight
- Various documentation techniques require different levels of autonomy
- Cooperation with National Heritage Institute
- 15 objects scanned so far (including Chateau Kromeriz on UNESCO list)

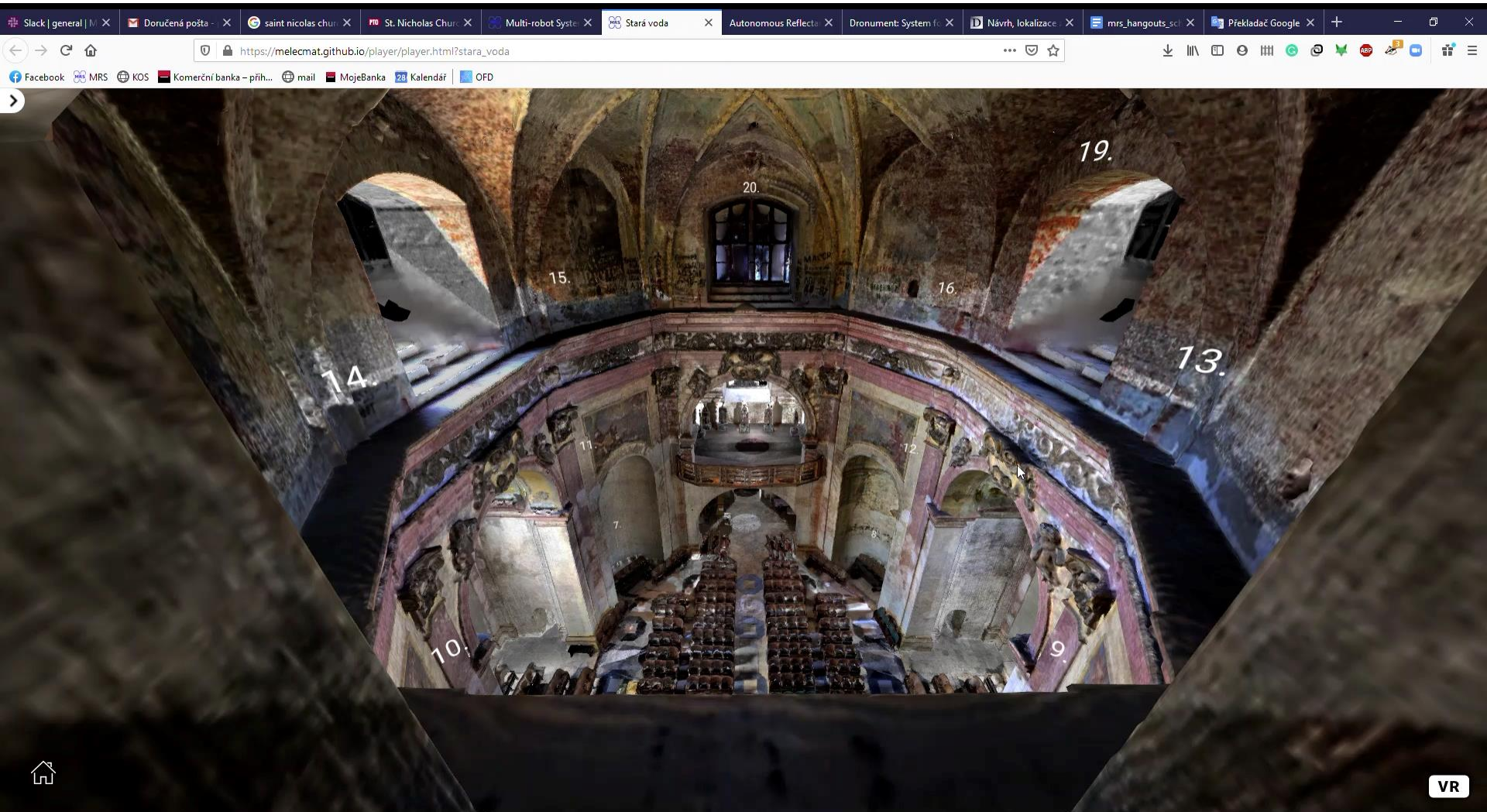


Autonomous and semi-autonomous indoor inspection

- Objects to capture defined in a map obtained by 3D terrestrial laser scanner
- Autonomous following a trajectory connecting required camera positions
- 3D map used for robot/robots localization
- Data from 3D onboard lidar fused with the 3D model
- Camera triggered automatically from an onboard PC

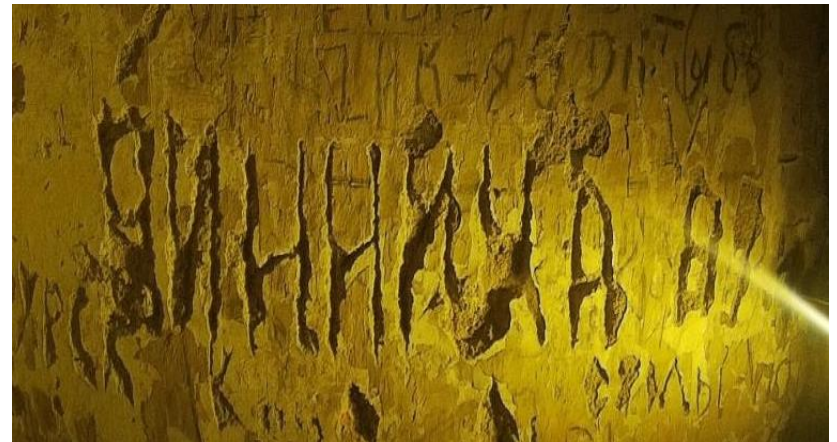
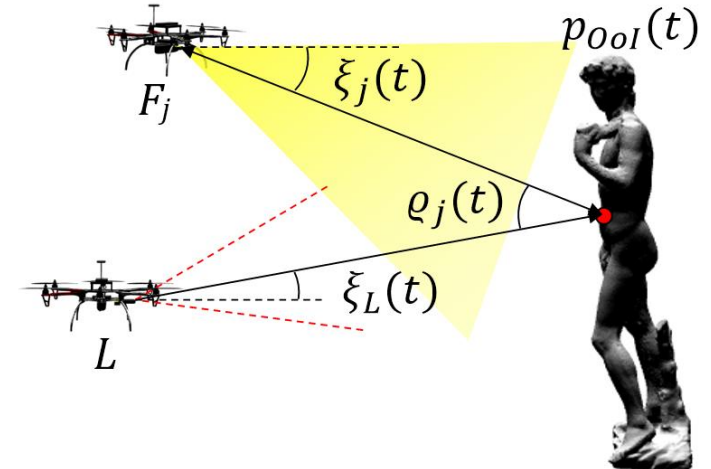
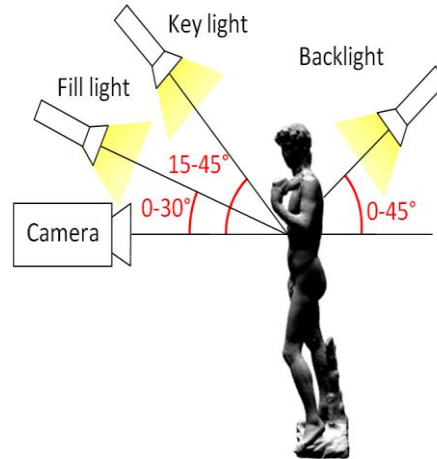
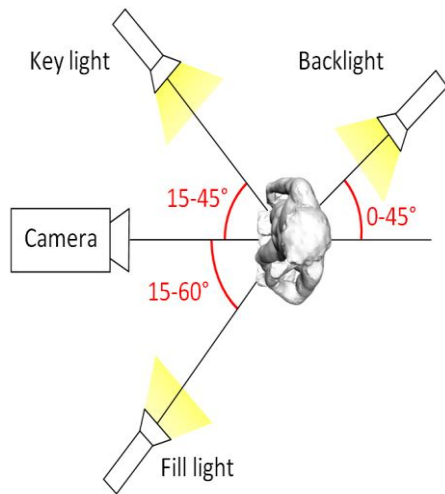


Autonomous inspection of historic buildings using multiple MAVs



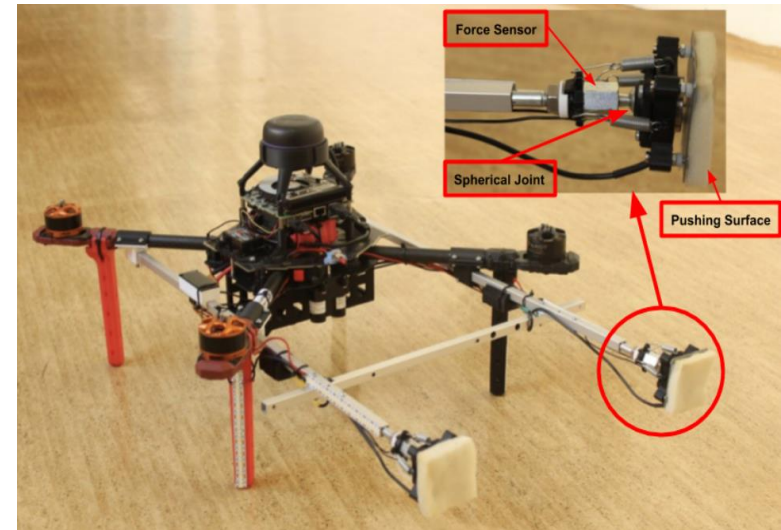
Three points lighting

- Problems with illumination in historical objects
- Cooperation of multiple UAVs



Raking light

- Lighting technique widely used for surface inspection in cultural heritage tasks
- Requires positioning light in a tight angle with respect to captured surface
- Safe flying a few centimeters from the wall requires wall interaction
- Admittance force-based UAV-wall control
- Necessary also for remote placement of smart sensors



Smrčka 2021 ICUAS

Reflectance transformation imaging (RTI)

- Image-based rendering method widely used in cultural heritage applications
- Enables interactive displaying of objects under varying lighting conditions
- Used for surface inspection

Krátký, RAL 2020

Autonomous Reflectance Transformation Imaging by a Team of Unmanned Aerial Vehicles

Vit Kratky, Pavel Petracek, Vojtech Spurny, Martin Saska

IR and UV reflectography

- Requires flying in very dark conditions almost without the ability to control the UAV manually
- Long exposure times (tens of seconds)
- UAVs providing light from directions that cannot be achieved from the ground
- Cooperation of multiple UAVs required





AERIAL-CORE: AERIAL COgnitive integrated multi-task Robotic system with Extended operation range and safety

H2020 ICT-10-2019-2020: Robotics Core Technology
December 1, 2019 – December 1, 2022

- 9 universities - key UAV groups in Europe, 6 strong European end-users
- Complete inspection and maintenance of large linear infrastructures
- Long range (Several kilometres) inspection of the infrastructure
- Maintenance activities based on aerial manipulation
- **Aerial co-working safely and efficiently helping human workers in inspection**

