Elective in Robotics
Modeling and Control of Multi-Rotor UAVs

Marilena Vendittelli

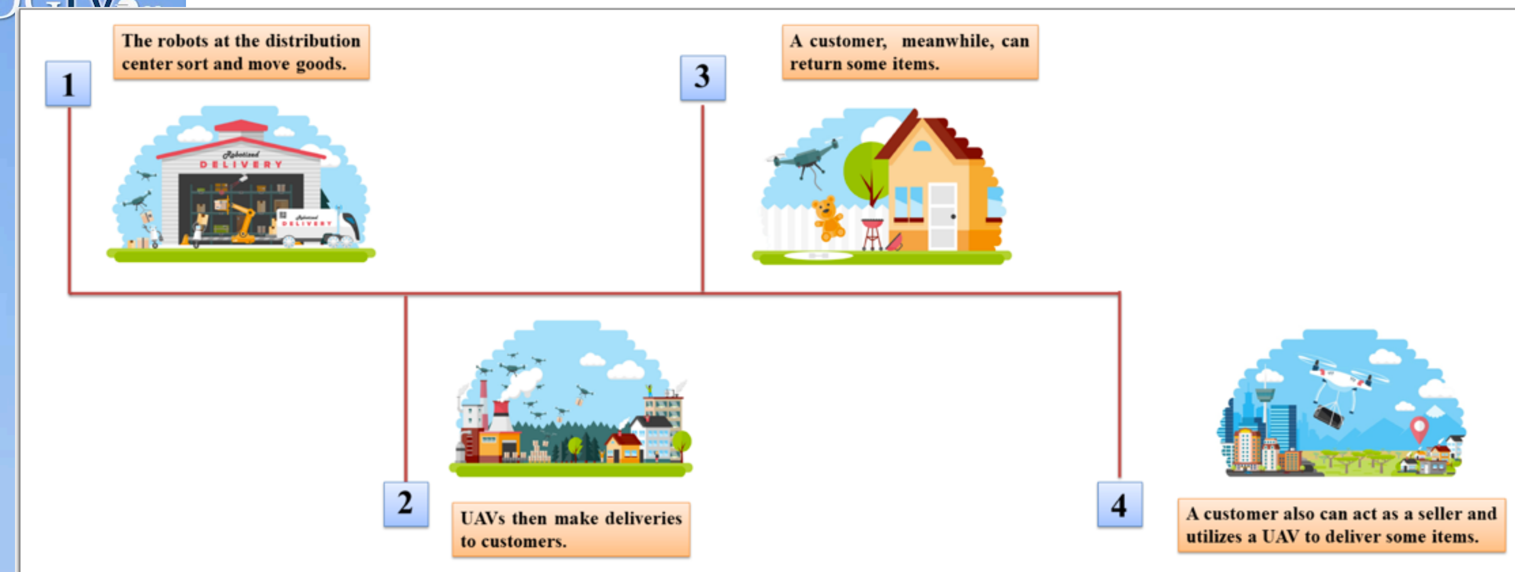
2020
Final projects

SAPIENZA
UNIVERSITÀ DI ROMA

- 7 projects + possible additional ones proposed and **well motivated** by students
- work **must** be carried out in groups of 3-4 students
- programming in C/C++ or Matlab required
- projects must be chosen by November 30
  - **written report** with selected results + pdf, software, videos, **presentation** (all in a shared Drive folder)
- 20 min presentation of the obtained results

- NOTE: projects are alternative to **individual** presentation of a scientific paper
  - presentation assignment: a list of papers will be provided in the e-learning environment

Project 1: External wrench estimation



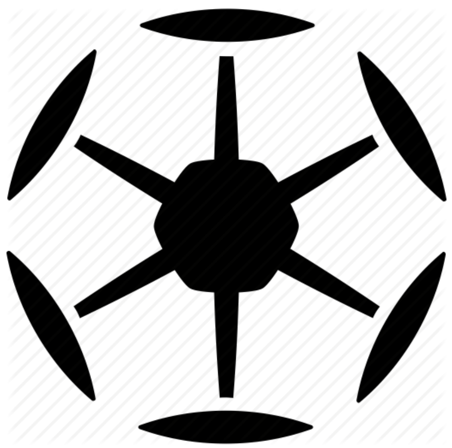
- estimate the external wrench generated by an unknown load placed on an unknown point on the quadrotor frame
- simulation environment at your choice

bibliography

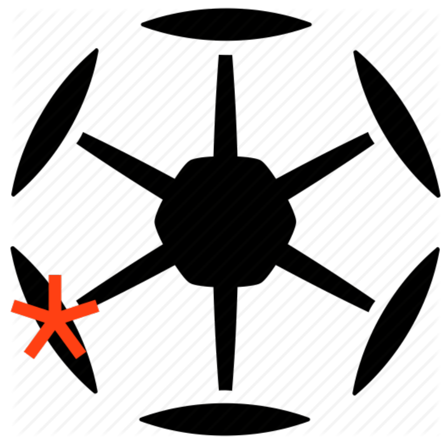
- Tomić, Teodor and Lutz, Philipp and Schmid, Korbinian and Mathers, Andrew and Haddadin, Sami, "Simultaneous Contact and Aerodynamic Force Estimation (s-CAFE) for Aerial Robots," International Journal of Robotics Research (IJRR), 2019 [PDF]

Project 2: Fault-isolation for multi-rotor UAVs

supervised by Prof. A. Cristofaro



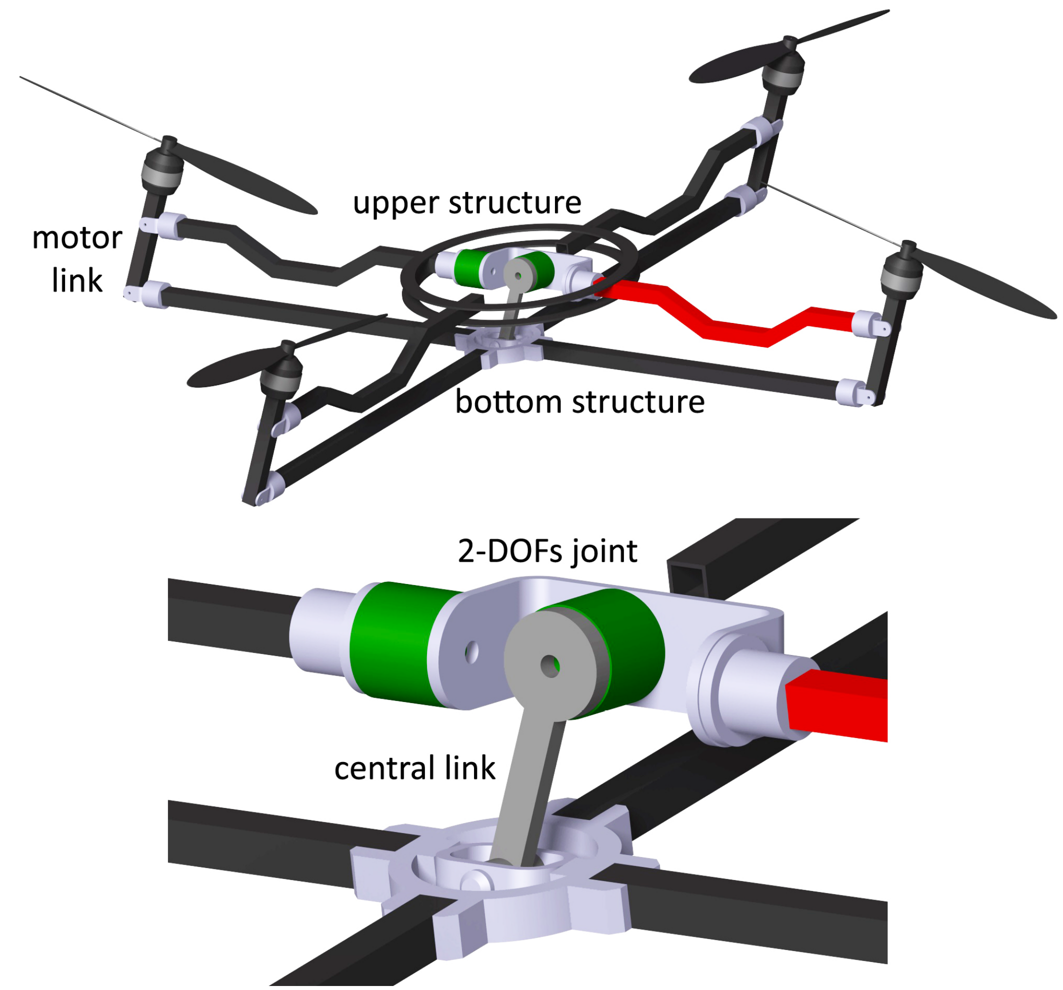
- consider a system with n≥2 pairs of rotors
- assume that one rotor fails
- design observers and compute residuals to isolate the fault
- extend the technique to handle simultaneous faults



bibliography

- J. Chen, R.J. Patton and H.-Y. Zhang, Design of unknown input observers and robust fault detection filters, Int. J. of Control, 1996
- L. Imsland et al., On non-linear unknown input observers - applied to lateral vehicle velocity estimation on banked roads, Int. J. of Control, 2007
- Z. Cen et al., Robust fault diagnosis for quadrotor UAVs using adaptive Thau observer, J. Intelligent & Robotic Systems, 2014

Project 3: Simulation model and control of a fully actuated quadrotor



- Matlab implementation of the simulation model and control of a fully actuated quadrotor with a 2-DOFs tilting mechanism

bibliography

- Marcin Odelga, Paolo Stegagno and Heinrich H. Bülthoff, A Fully Actuated Quadrotor UAV with a Propeller Tilting Mechanism: Modeling and Control, 2016 IEEE International Conference on Advanced Intelligent Mechatronics (AIM) Banff, Alberta, Canada, July 12–15, 2016

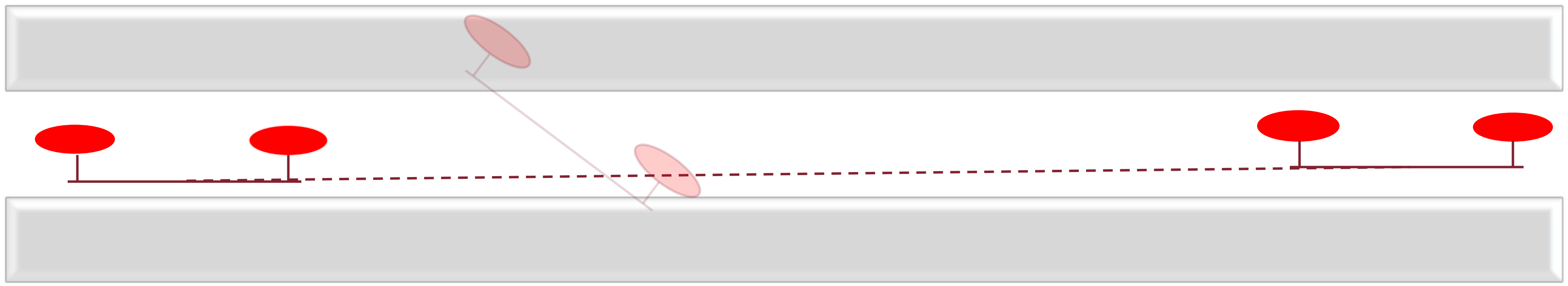
Project 4: Local controllabilty and actuators failure

- Matlab implementation of the simulation model of an octorotor
- analysis of the effect of actuators failures on local controllability

bibliography

- Majd Saied, Hassan Shraim, Benjamin Lussier, Isabelle Fantoni, Clovis Francis, Local controllability and attitude stabilization of multirotor UAVs: Validation on a coaxial octorotor, Robotics and Autonomous Systems 91 (2017) 128–138

Project 5: Local controllabilty and motion planning



consider the problem sketched in the figure

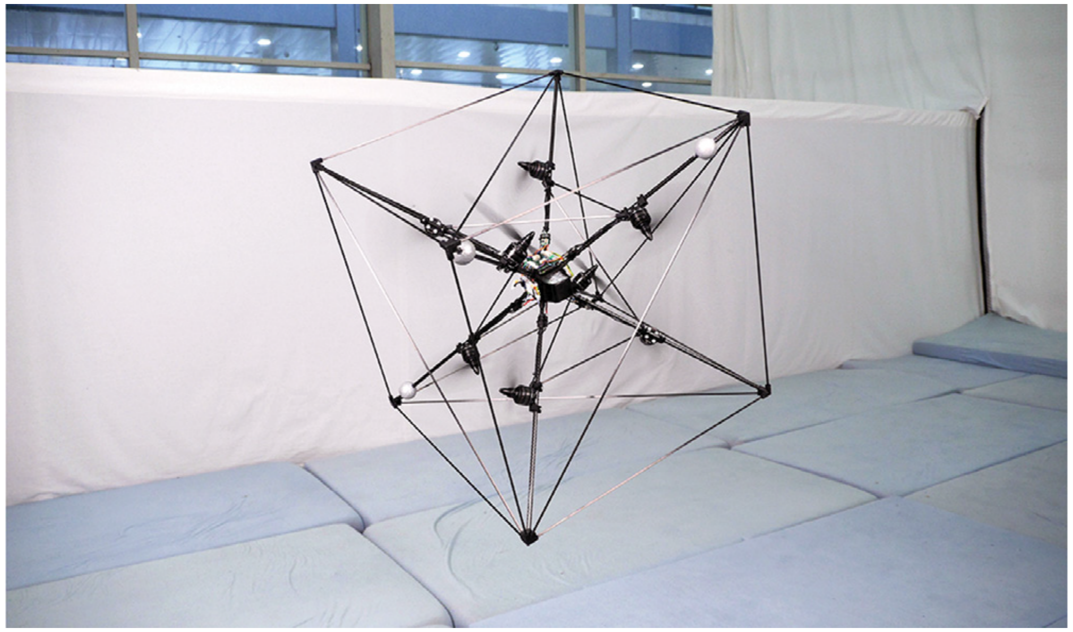
- a geometric, collision-free, path is not dynamically feasible for a quadrotor
- is it always possible to find dynamically feasible approximating paths arbitrarily close to the original geometric one?

find the theoretical conditions allowing or preventing the adoption of the two-steps planning paradigm based on a preliminary geometric path planning followed by its approximation by a feasible one; provide simulations to illustrate your proof (simulation environment at your choice)

bibliography

- Majd Saied, Hassan Shraim, Benjamin Lussier, Isabelle Fantoni, Clovis Francis, Local controllability and attitude stabilization of multirotor UAVs: Validation on a coaxial octorotor, Robotics and Autonomous Systems 91 (2017) 128–138

Project 6: CoppeliaSim model of a fully actuated OM multirotor aerial vehicle



- implement the simulation model with basic position and attitude control of an omnidirectional multirotor aerial vehicle at your choice, from the catalog provided in the bibligraphic reference below
- simulation environment: CoppeliaSim

bibliography

- Mahmoud Hamandi, Federico Usai, Quentin Sablé, Nicolas Staub, Marco Tognon, Antonio Franchi, Survey on Aerial Multirotor Design: a Taxonomy Based on Input Allocation, https://hal.archives-ouvertes.fr/hal-02433405

Project 7: Complementary filter for state estimation

$$
\begin{aligned}
\dot{\hat{R}} &= \hat{R}(\Omega_{\mathrm{IMU}} - \hat{b})_\times - \alpha_\times \\
\dot{\hat{b}} &= k_b \alpha \\
\alpha_\times &= (\frac{k_a}{g^2}((\hat{R}^T\ \vec{z}_{\mathrm{I}}) \times \bar{a}_{\mathrm{IMU}}) + \frac{k_m}{|{}^{\mathrm{I}}m|^2}((\hat{R}^T\ {}^{\mathrm{I}}m) \times m_{\mathrm{IMU}}))_\times + \dots
\end{aligned}
$$

$$
{}^{\mathrm{I}}a_{\mathrm{IMU}} = R a_{\mathrm{IMU}} \simeq \hat{R} a_{\mathrm{IMU}} \simeq -g\hat{R}\ \vec{z}_{\mathrm{I}} - g\hat{R}D\hat{R}^T v
$$

$$
\Downarrow
$$

$$
v = -\frac{1}{g}(\hat{R}D\hat{R}^T)^{-1}({}^{\mathrm{I}}a_{\mathrm{IMU}} + g\hat{R}\ \vec{z}_{\mathrm{I}})
$$

$$
\dot{\hat{v}} = -g(\hat{R}\ \vec{z}_{\mathrm{I}} + \hat{R}D\hat{R}^T\hat{v}) - k_w(\hat{v} - v)
$$

- implementation of the complementary filter in (I) for the CoppeliaSim quadrotor model provided in the e-learning environment
- possibly include the improved dynamic model provided in (II)
- simulation environment ar your choice

bibliography

(I) R. Mahony, T. Hamel and J. M. Pflimlin, "Nonlinear Complementary Filters on the Special Orthogonal Group," in IEEE Transactions on Automatic Control, vol. 53, no. 5, pp. 1203-1218, June 2008. doi: 10.1109/TAC.2008.923738

(II) R. C. Leishman, J. C. Macdonald Jr., R. W. Beard, and, T. W. Mc Lain, Quadrotors and Accelerometers - State Estimation with an Improved Dynamic Model, IEEE Control Systems Magazine, DOI: 10.1109/MCS.2013.2287362