ETH zürich

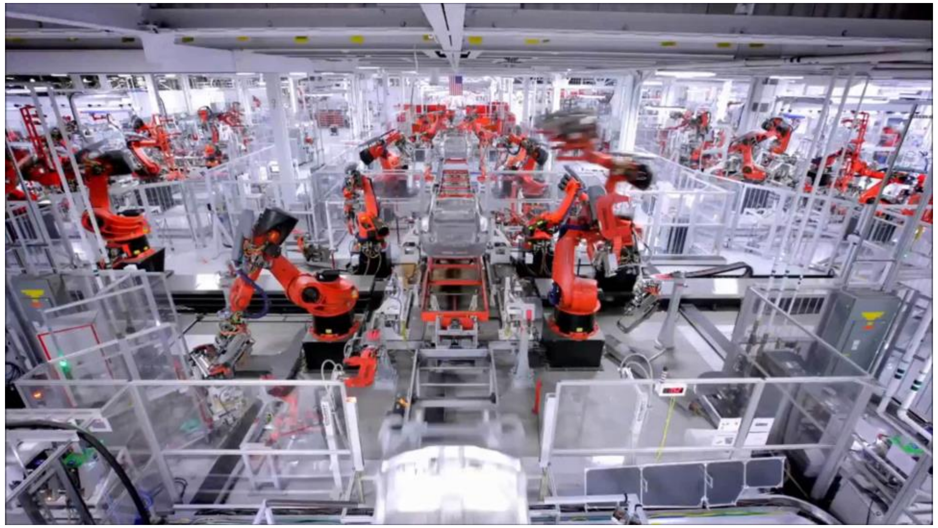
Lecture «Robot Dynamics»: *Introduction*

151-0851-00 V

lecture:	CAB G11	Tuesday 10:15 – 12:00, every week
exercise:	HG E1.2	Wednesday 8:15 – 10:00, according to schedule (about every 2nd week)

Marco Hutter, Roland Siegwart, and Thomas Stastny

Robotics
The natural evolution of automation



- Huge demand
  - Food security, demography,……
- Growing market and applications
- Big investment by big companies

Why should I understand «Robot Dynamics»

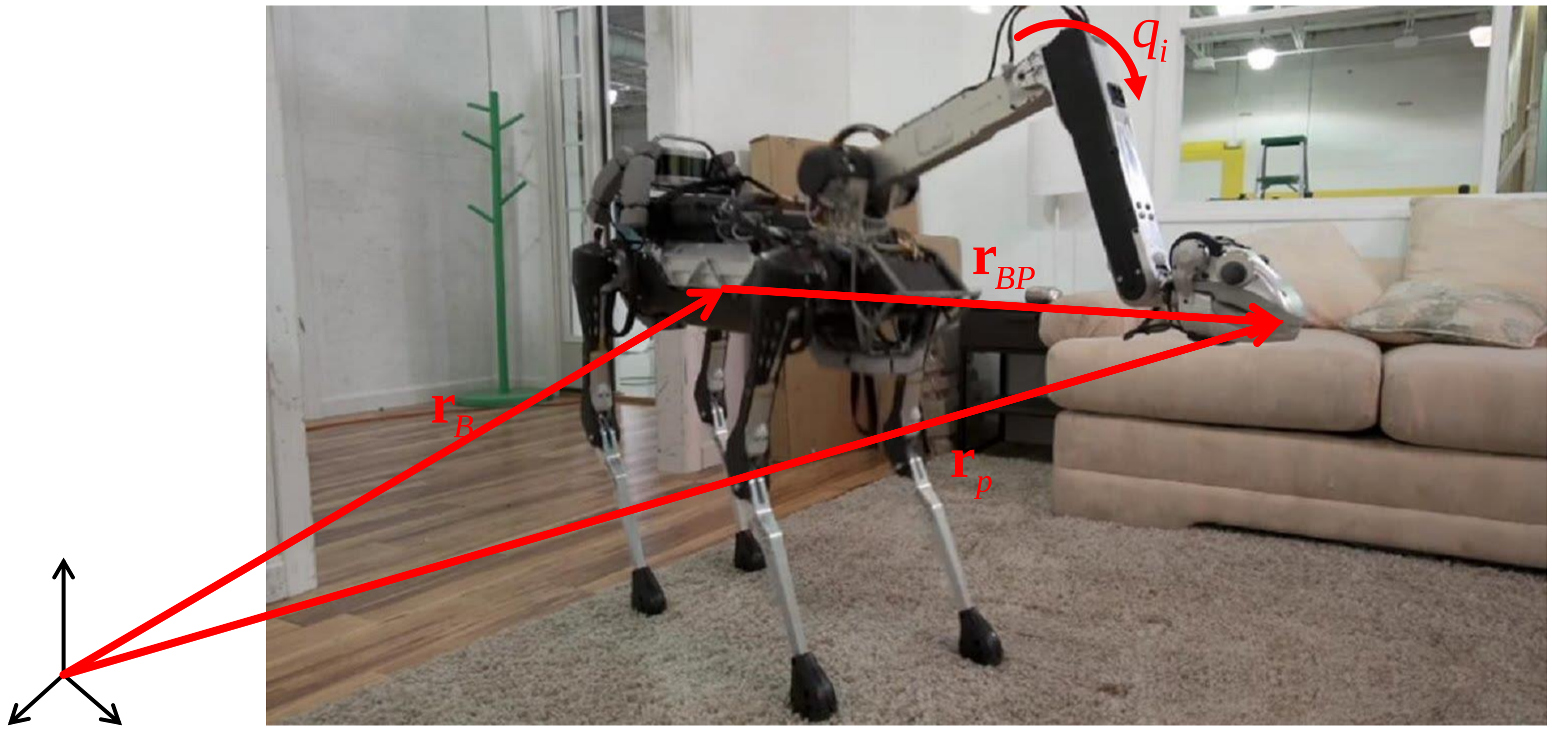
- Robot Dynamics = learn how to model the physical behavior
  - Control *(inverting causality: if I want to move the robot in a specific way, what actuator commands are necessary?)*
  - Simulation *(how does my system behave if certain actuator commands are given?)*
  - Design (what are the dynamic loads on my structure?)
  - Optimization (what are the optimal dimensions of my vehicle?)
  - Actuation (what torque, speed, power etc. is required to move the system as I want?)

Spot-mini (Boston Dynamics)

One of the most versatile dynamic robots

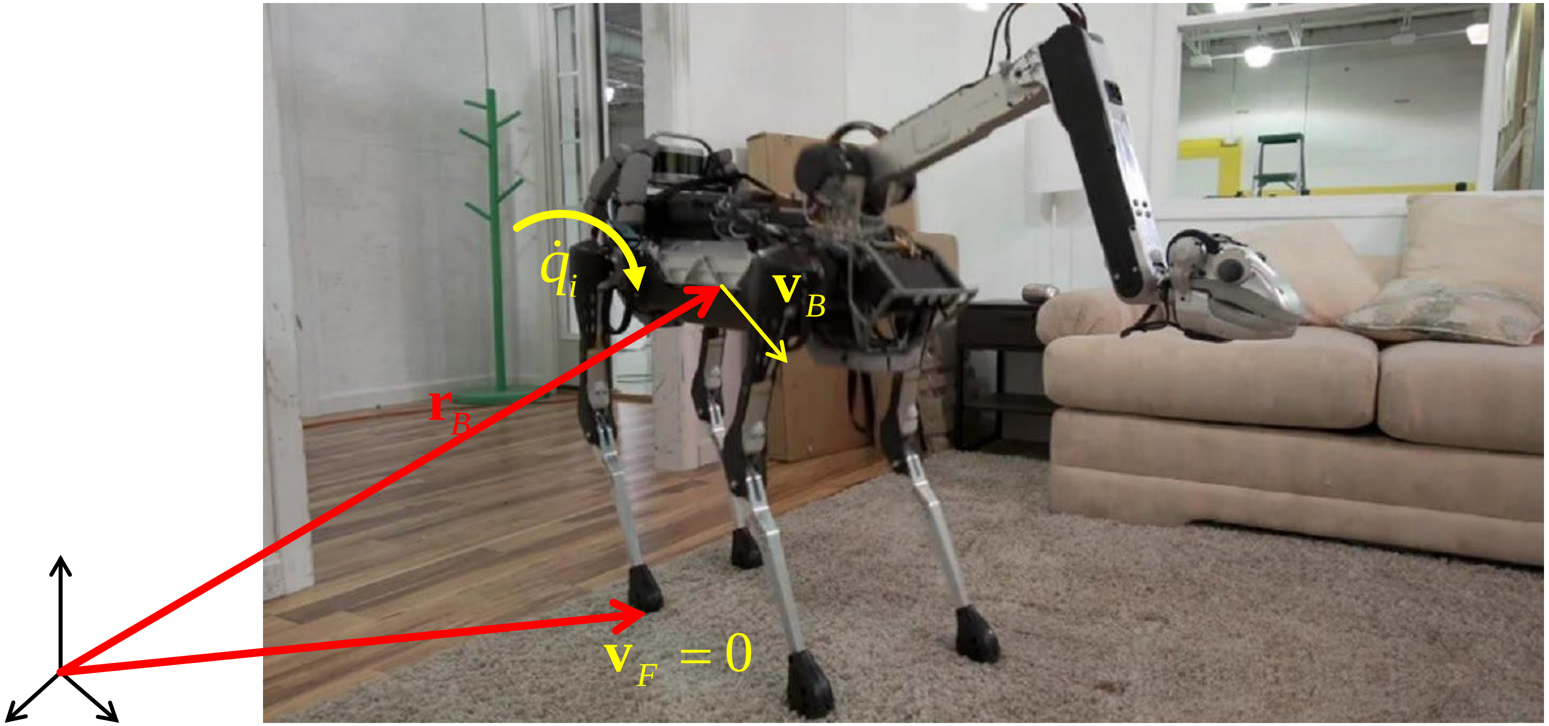
Kinematics, Dynamics, and Control of Quadruped + Manipulator

- Joint position ⇔ task space position $\mathbf{r} = \mathbf{r}(\mathbf{q})$



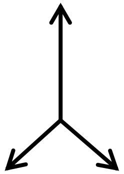
Kinematics, Dynamics, and Control of Quadruped + Manipulator

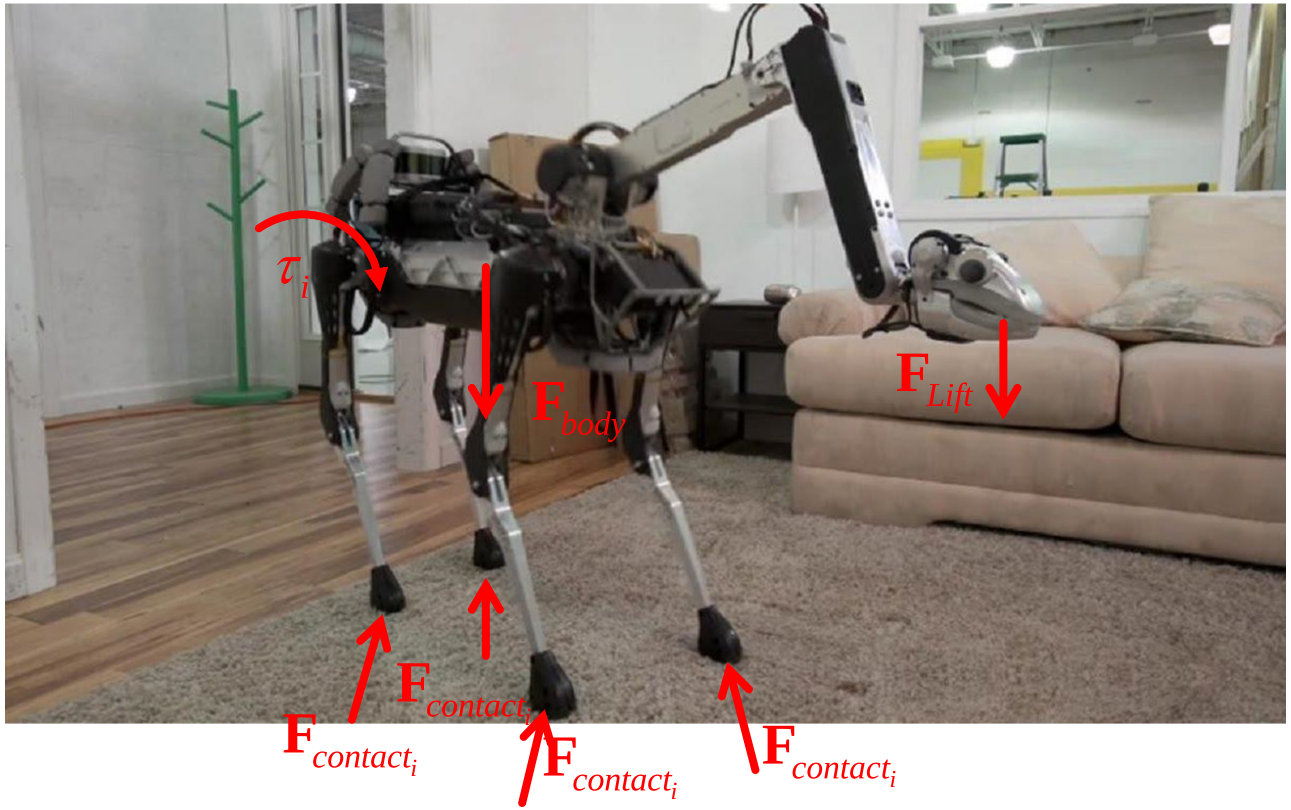
- Joint velocity ⬄ task space velocity $\dot{\mathbf{r}} = \mathbf{J}\dot{\mathbf{q}}$



Kinematics, Dynamics, and Control of Quadruped + Manipulator

- Joint torque ⬄ motion / external forces $\mathbf{M}\ddot{\mathbf{q}} + \mathbf{b} + \mathbf{g} + \mathbf{J}_{ext}^{T}\mathbf{F}_{ext} = \mathbf{S}^{T}\boldsymbol{\tau}$





Robot Dynamics
Lecture goals

- Kinematic and dynamic modeling of robotic systems:
  - Manipulators (position and force control)
  - Legged robots
  - Rotary wing systems
  - Fixed wing airplanes

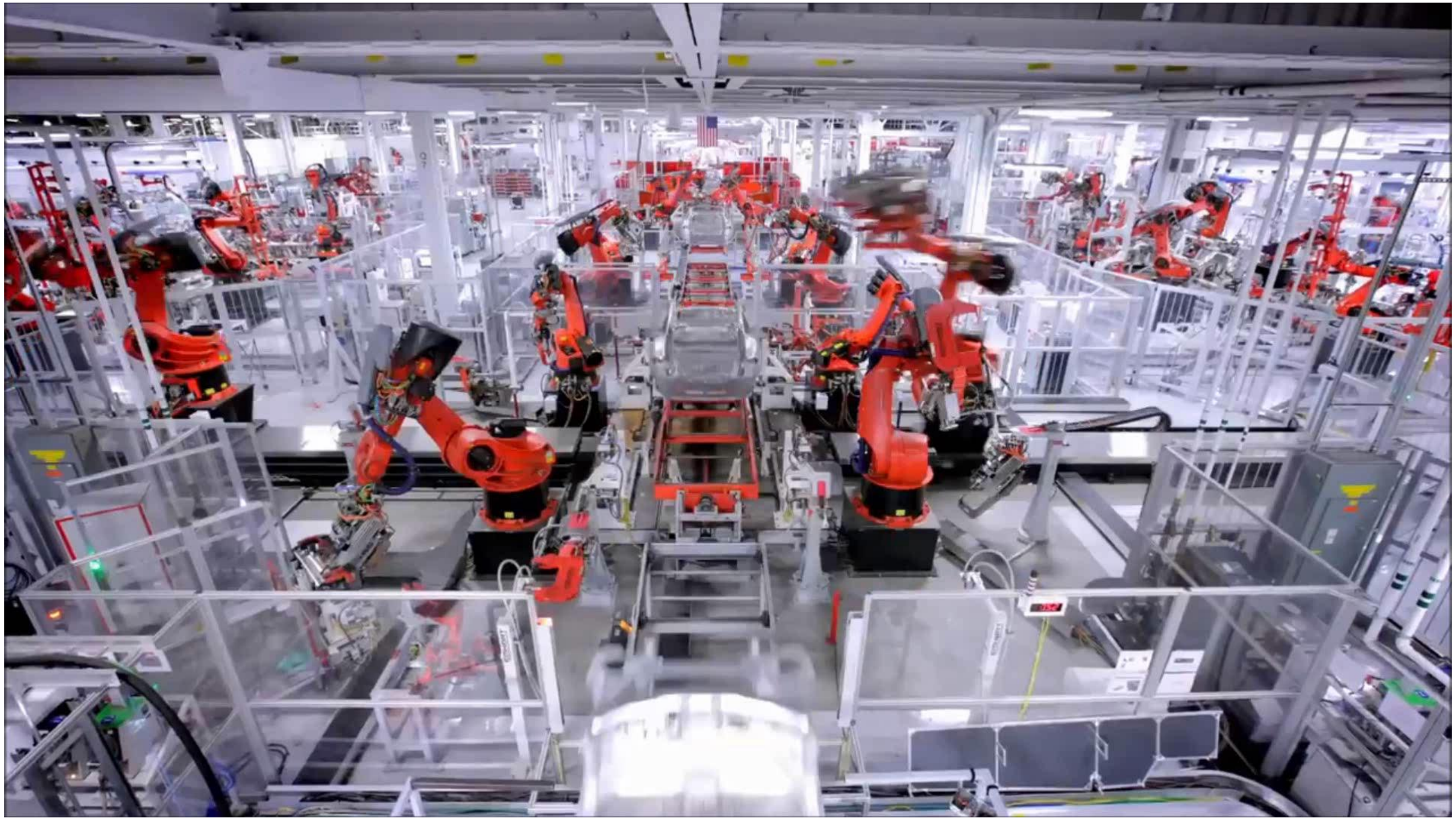
$$\mathbf{M}\ddot{\mathbf{q}}+\mathbf{b}+\mathbf{g}+\mathbf{J}_{ext}^{T}\mathbf{F}_{ext}=\mathbf{S}^{T}\boldsymbol{\tau}$$

Real systems!
not planar toy problems

- Objective of the course
  - Deepening an applied understanding of how to model the most common robotic systems
  - Extending the background in kinematics, rotations, and dynamics of multi-body systems
  - Modeling of actuation forces
  - Apply the models in control
- Provide tools to work in the field of *design and control* of robotic systems

19.09.2017	Intro and Outline	Course Introduction; Recapitulation Position, Linear Velocity			
26.09.2017	Kinematics 1	Rotation and Angular Velocity; Rigid Body Formulation, Transformation	26.09.2017	Exercise 1a	Kinematics Modeling the ABB arm
03.10.2017	Kinematics 2	Kinematics of Systems of Bodies; Jacobians	03.10.2017		
10.10.2017	Kinematics 3	Kinematic Control Methods: Inverse Differential Kinematics, Inverse Kinematics; Rotation Error; Multi-task Control	10.10.2017	Exercise 1b	Kinematic Control of the ABB Arm
17.10.2017	Dynamics L1	Multi-body Dynamics	17.10.2017	Exercise 2a	Dynamic Modeling of the ABB Arm
24.10.2017	Dynamics L2	Floating Base Dynamics	24.10.2017		
31.10.2017	Dynamics L3	Dynamic Model Based Control Methods	31.10.2017	Exercise 2b	Dynamic Control Methods Applied to the ABB arm

Application 1: Industrial Robots



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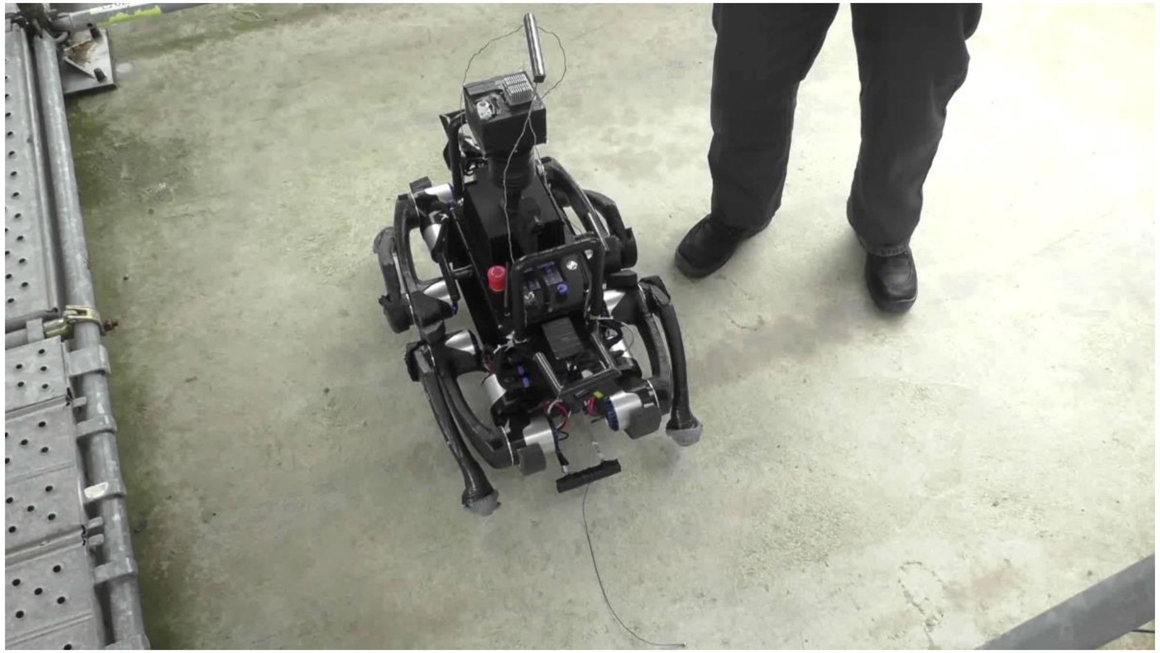
07.11.2017	Legged Robot	Dynamic Modeling of Legged Robots & Control	07.11.2017	Exercise 3	Legged robot
14.11.2017	Case Studies 1	Legged Robotics Case Study	14.11.2017		

ETH Quadrupedal Robots

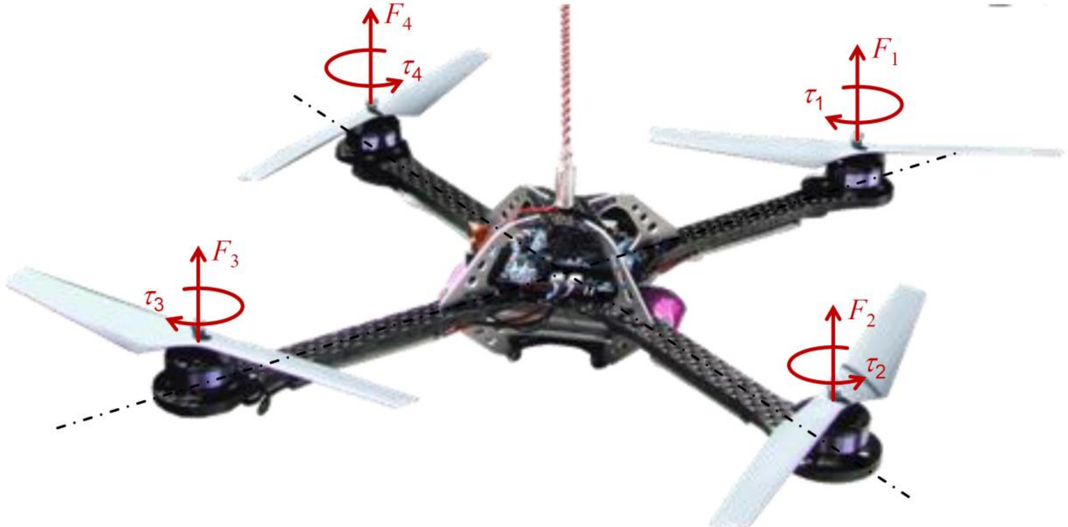
- Hybrid dynamics (impulse)
- Contact constraints
- Constraint constistent dynamics
- Internal forces
- …

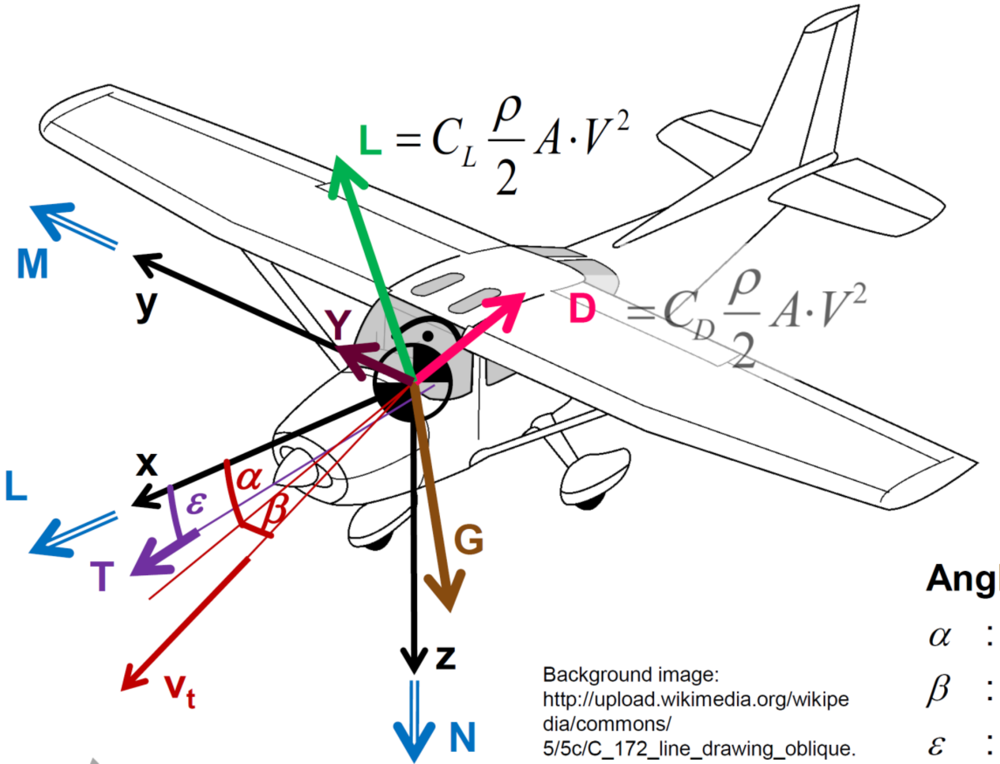
- Applications in industrial inspection and search and rescue



Dynamics of Airplane and Rotorcraft

- Understanding system dynamics is essential for control $\mathbf{M}\ddot{\mathbf{q}}+\mathbf{b}+\mathbf{g}+\mathbf{J}_{ext}^{T}\mathbf{F}_{ext}=\mathbf{S}^{T}\boldsymbol{\tau}$





Background image: http://upload.wikimedia.org/wikipedia/commons/5/5c/C_172_line_drawing_oblique.

Moments

L : Roll moment
M : Pitch moment
N : Yaw moment

Forces

L : Lift
D : Drag
Y : Sideslip force
T : Thrust
G : Weight

Angles

α : Angle of attack
β : Sideslip angle
ε : Thrust-vector angle

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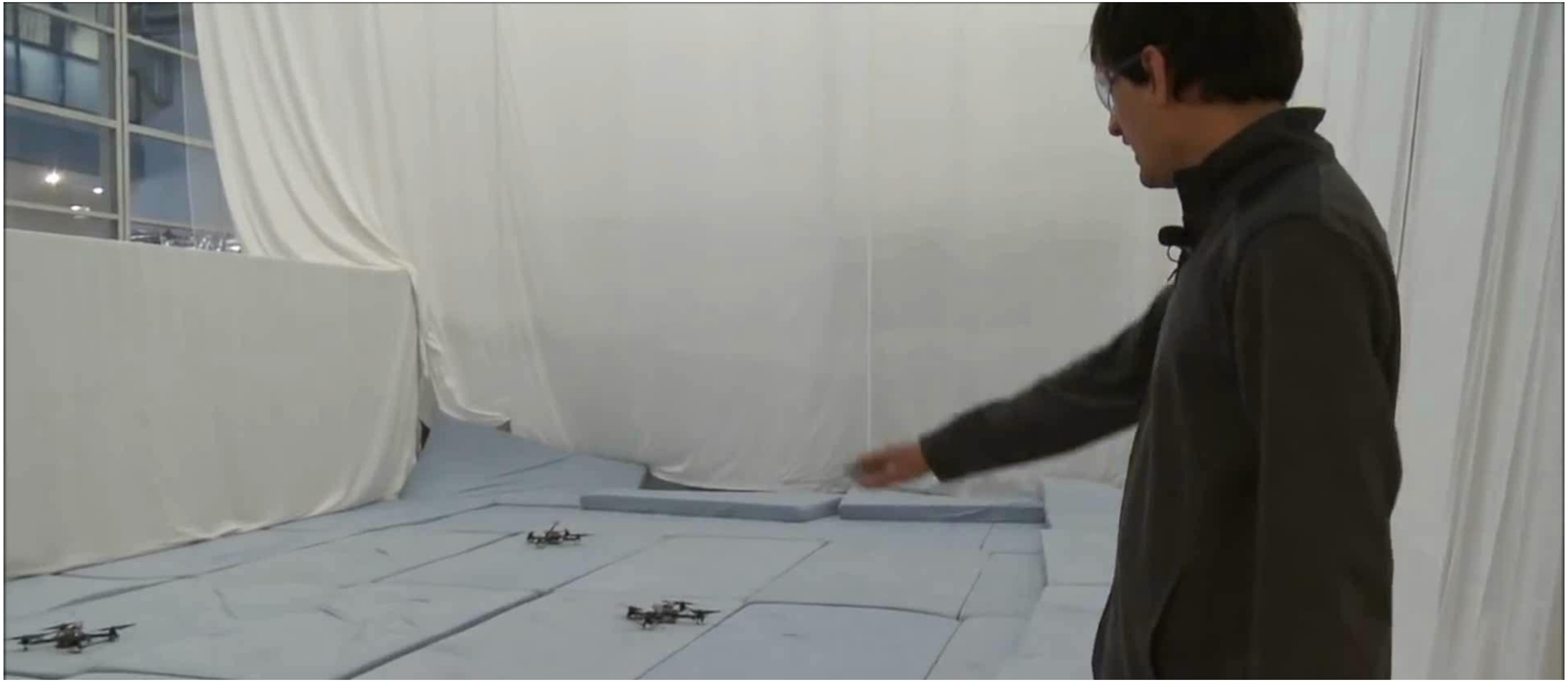
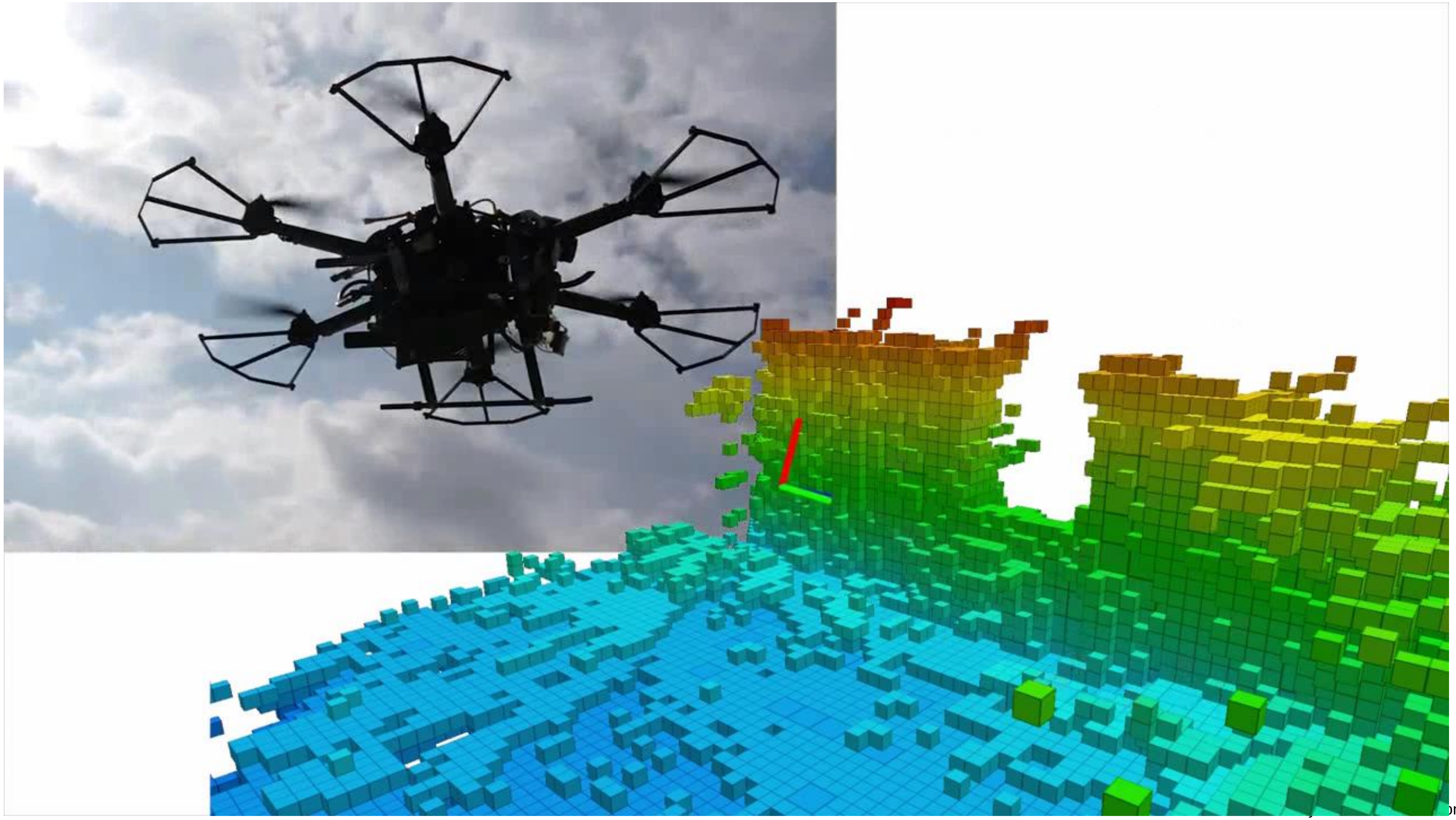
14.11.2017	Case Studies 1	Legged Robotics Case Study	14.11.2017		
21.11.2017	Rotorcraft	Dynamic Modeling of Rotorcraft & Control	21.11.2017	Exercise 4	Modeling and Control of Multicopter
28.11.2017	Case Studies 2	Rotor Craft Case Study	28.11.2017		

Dynamics and Control of Flying Vehicles



Flying machine arena, IDSC, ETH Zurich

UAV – inspection and aerial manipulation



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05.12.2017	Fixed-wing	Dynamic Modeling of Fixed-wing & Control	05.12.2017	Exercise 5	Fixed-wing Control and Simulation
12.12.2017	Case Studies 3	Fixed-wing Case Study (Solar-powered UAVs - AtlantikSolar, Vertical Take-off and Landing UAVs – Wingtra)			

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19.12.2017	Summery and Outlook	Summery; Wrap-up; Exam			

Lecture Material

- Official lecture material (online on lecture homepage)
  - Script on kinematics and dynamics
  - Slides (online) *[complete slides will be provided after lecture]*
  - Exercise exam

- Additional readings
  - Handbook of Robotics (Siciliano, Khatib)
    - http://link.springer.com/referencework/10.1007/978-3-540-30301-5
  - Robotics – Modelling, Planning and Control (Siciliano, Sciavicco, Villani, Oriolo)
    - http://link.springer.com/book/10.1007%2F978-1-84628-642-1

Lecture Setup

- Lecture CAB G11
  - Theory
  - Quick examples on paper

- Exercise HG E1.2
  - Real problems at robotic systems (e.g. ABB industrial arm)
  - Matlab => bring along a laptop or join a colleague

- Case Studies
  - State of the art engineering and research at selected examples
  - Not primarily relevant in exams (only some multiple choice questions)

Lecture Rules

- If things are unclear, immediately interrupt and ask
  (I’m happy if the lecture becomes a discussion)

- Write a mail if things need to be further explained
  - Personal meetings
  - Short recap of all important questions at the beginning of every lecture

- Small exercises during lecture:
  - Try to solve them without help of the solution! (it helps you to understand the difficulties)