ETH zürich

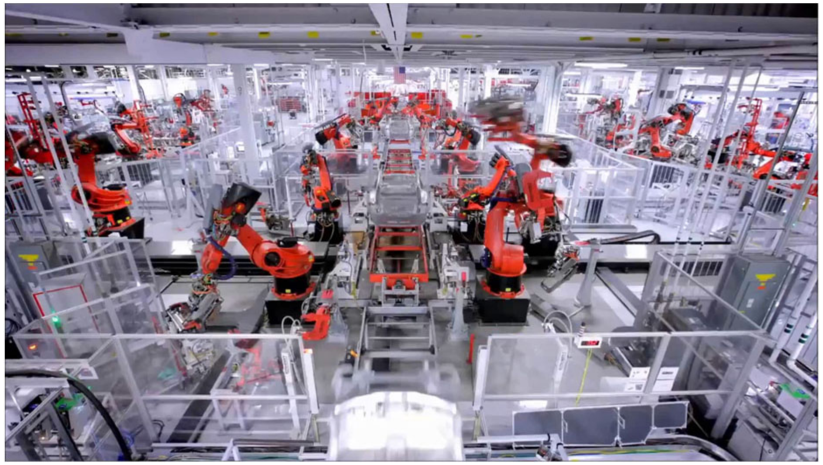
Lecture «Robot Dynamics»: *Introduction*

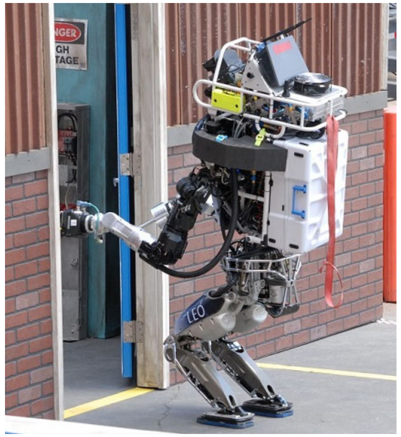
151-0851-00 V

lecture:	HG F3	Tuesday 10:15 – 12:00, every week
exercise:	HG F3	Wednesday 8:15 – 10:00, according to schedule

Marco Hutter, Roland Siegwart, and Thomas Stastny

Robotics
The natural evolution of automation





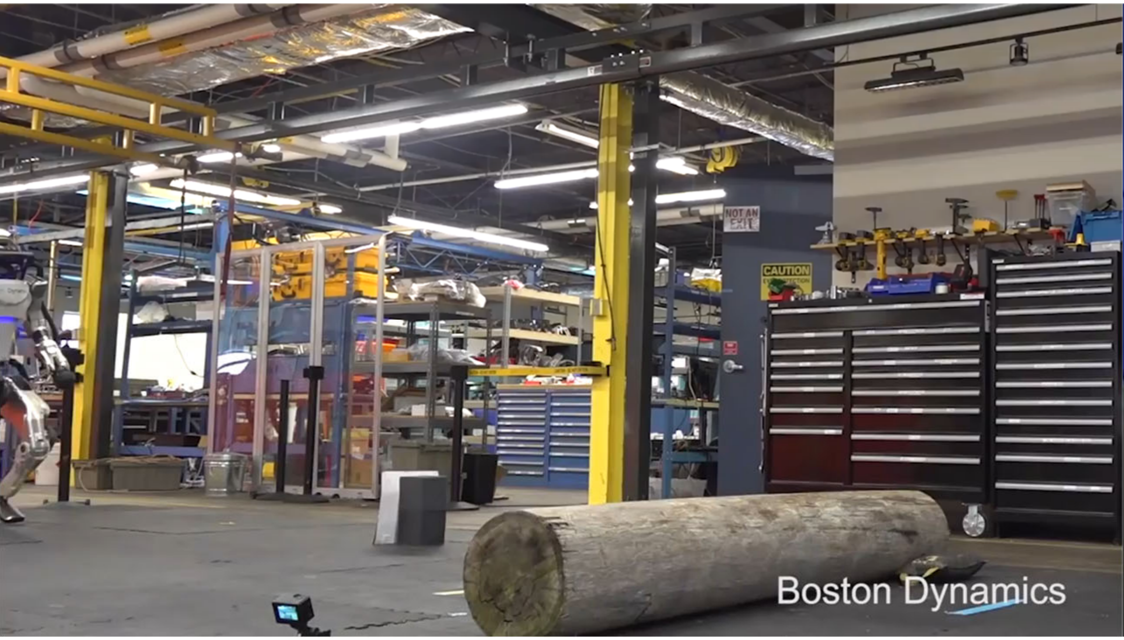
- Huge demand
  - Food security, demography,……
- Growing market and applications
- Big investment by big companies

Why should I understand «Robot Dynamics»

- Robot Dynamics = learn how to model the physical behavior
  - Simulation *(how does my system behave if certain actuator commands are given?)*
  - Control *(inverting causality: if I want to move the robot in a specific way, what actuator commands are necessary?)*
  - 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?)

Modern mobile manipulators by Boston Dynamics

Some of the most versatile dynamic robots



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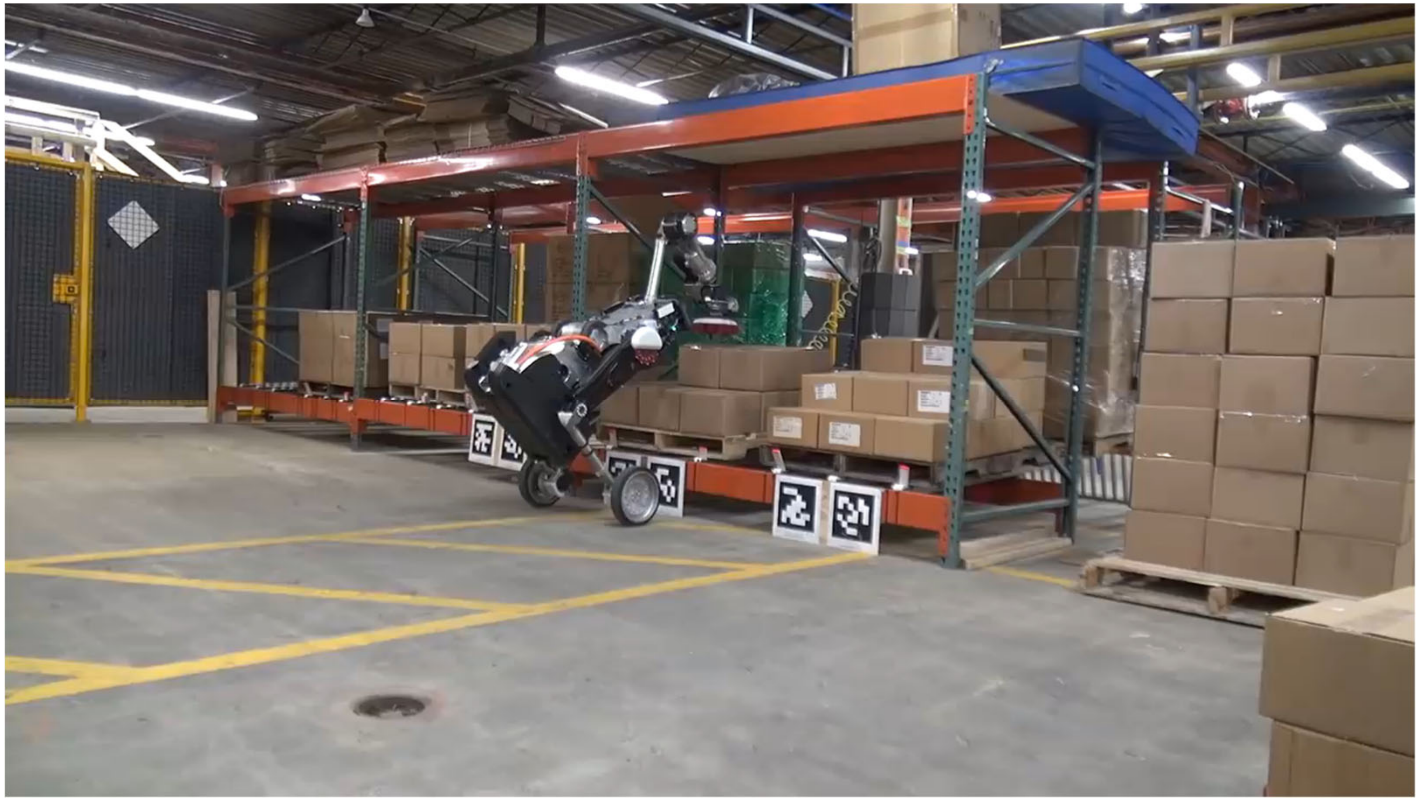
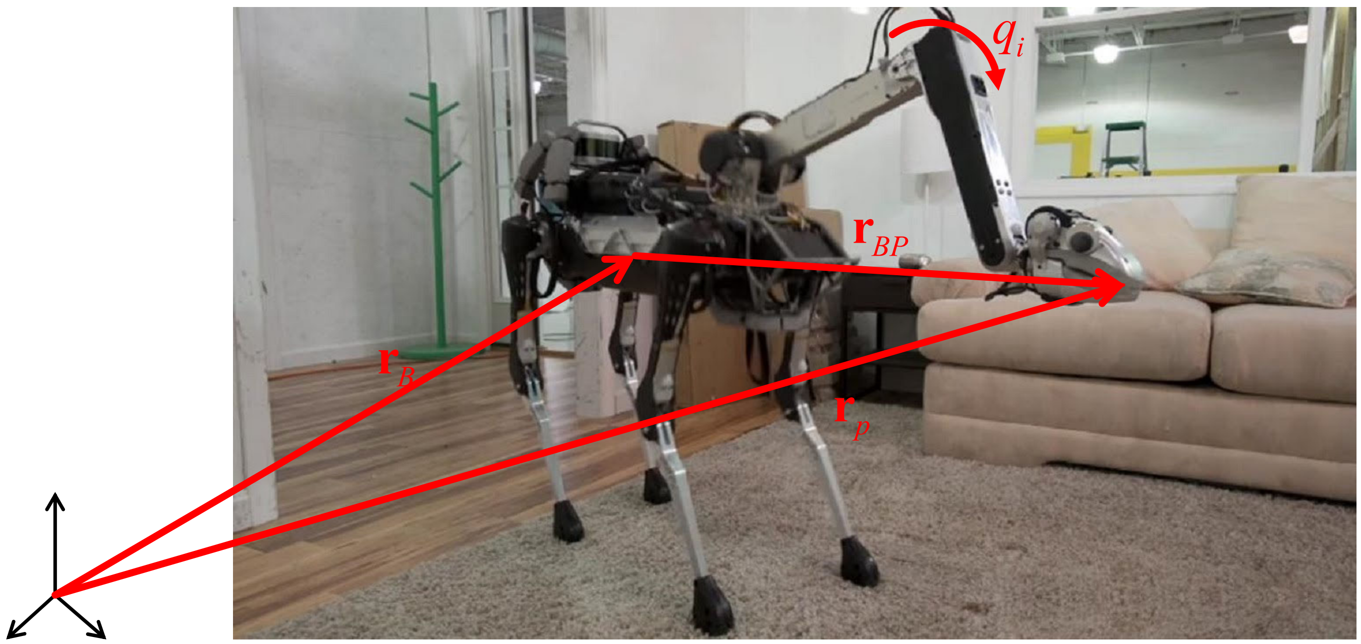


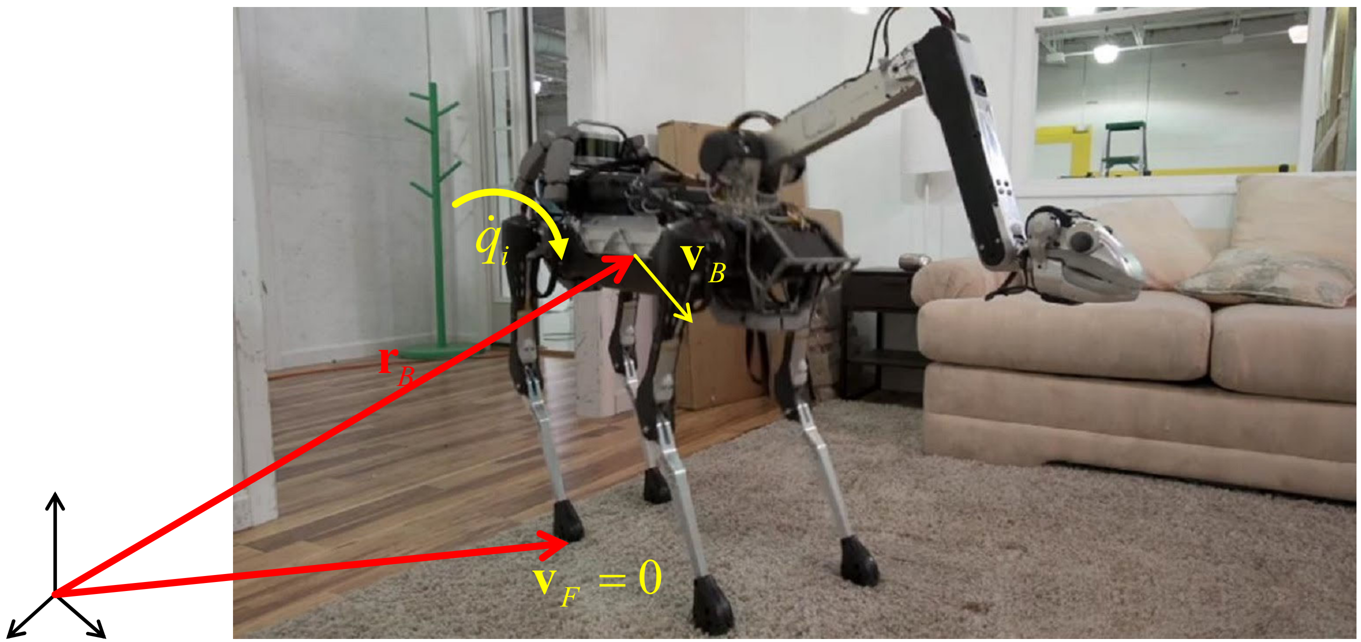
Kinematics, Dynamics, and Control of Quadruped + Manipulator

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



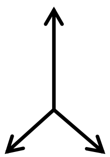
Kinematics, Dynamics, and Control of Quadruped + Manipulator

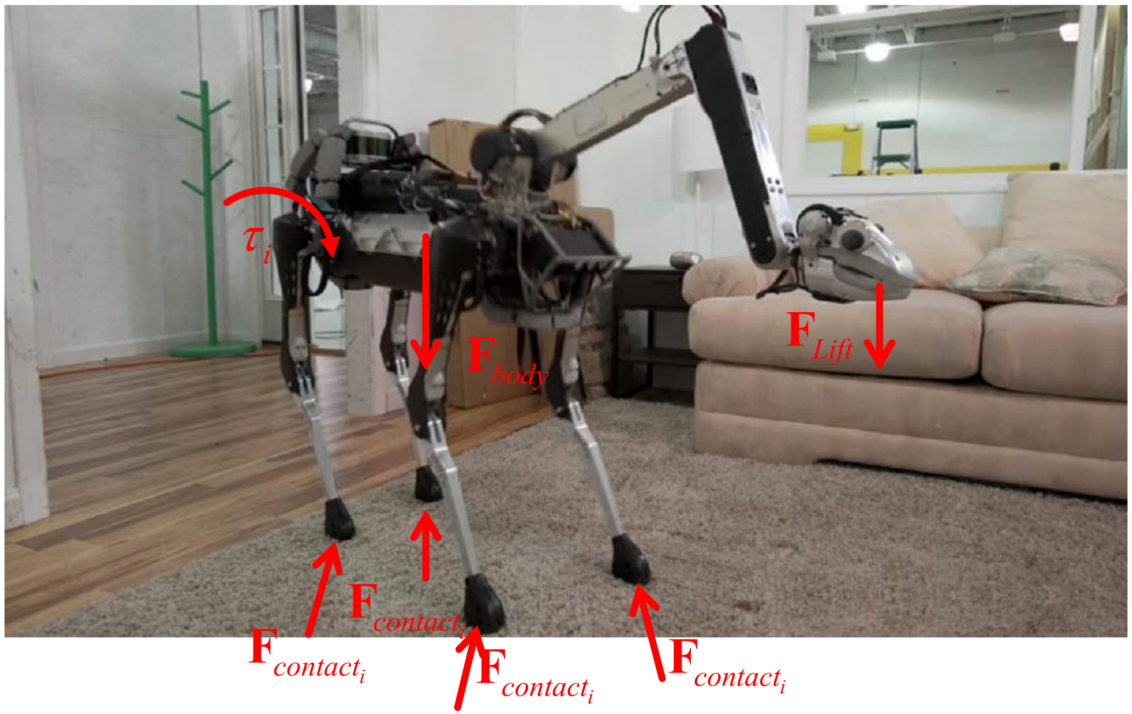
- Joint velocity ⇔ task space velocity $\dot{\mathbf{r}} = \mathbf{J}\dot{\mathbf{q}}$



Kinematics, Dynamics, and Control of Quadruped + Manipulator

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





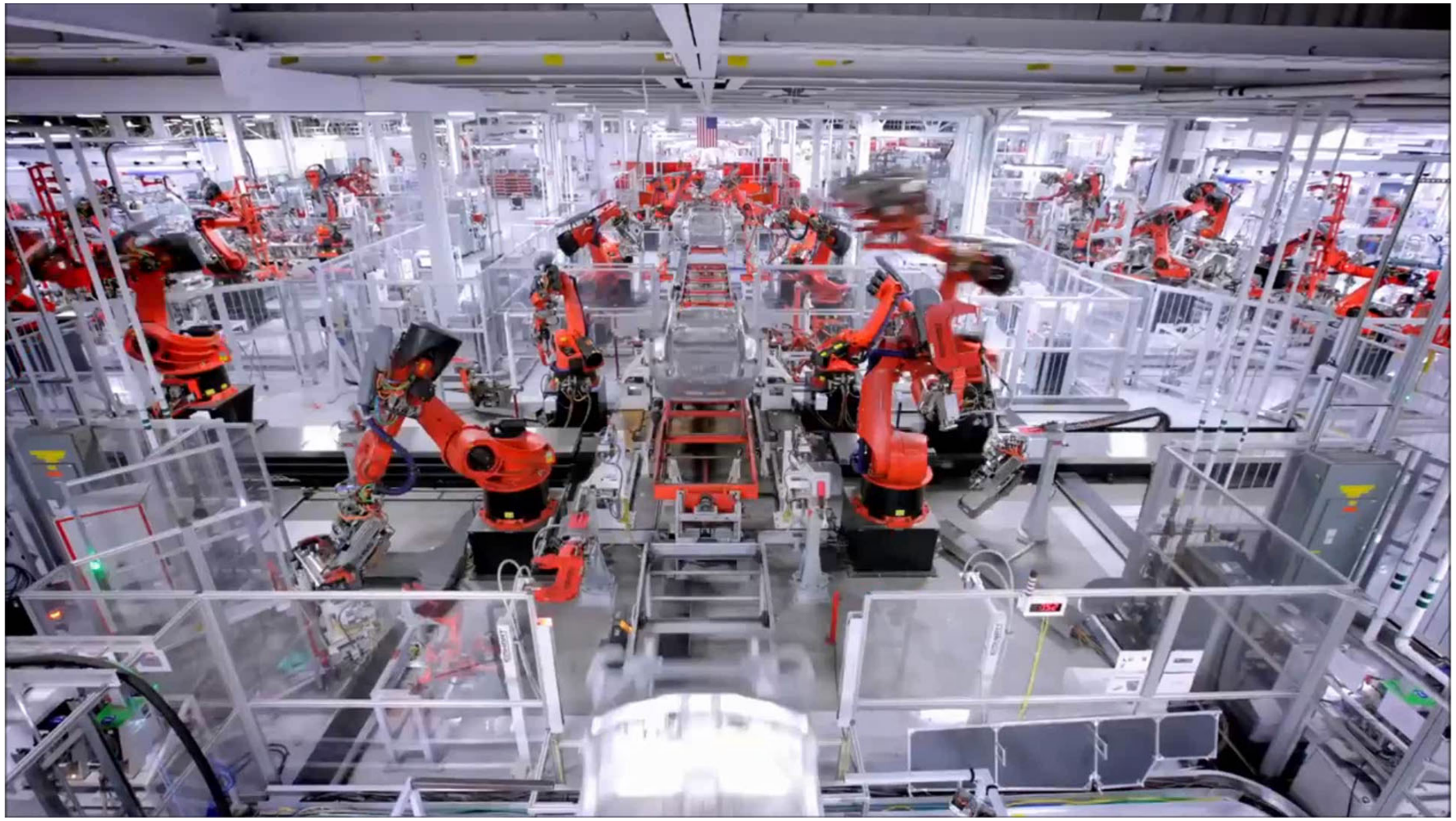
Robot Dynamics
Lecture goals

- Kinematic and dynamic modeling of robotic systems: $\mathbf{M}\ddot{\mathbf{q}} + \mathbf{b} + \mathbf{g} + \mathbf{J}_{ext}^T \mathbf{F}_{ext} = \mathbf{S}^T \boldsymbol{\tau}$
  - Manipulators (position and force control)
  - Legged robots
  - Rotary wing systems
  - Fixed wing airplanes
- 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 *simulation, planning and control* of robotic systems

Real systems!
not planar toy problems

17.09.2019	Intro and Outline	Course Introduction; Recapitulation Position, Linear Velocity			
24.09.2019	Kinematics 1	Rotation and Angular Velocity; Rigid Body Formulation, Transformation	25.09.2019	Exercise 1a	Kinematics Modeling the ABB arm
01.10.2019	Kinematics 2	Kinematics of Systems of Bodies; Jacobians	02.10.2019	Exercise 1a	Differential Kinematics of the ABB arm
08.10.2019	Kinematics 3	Kinematic Control Methods: Inverse Differential Kinematics, Inverse Kinematics; Rotation Error; Multi-task Control	09.10.2019	Exercise 1b	Kinematic Control of the ABB Arm
15.10.2019	Dynamics L1	Multi-body Dynamics	16.10.2019	Midterm 1	Programming kinematics with matlab
22.10.2019	Dynamics L2	Floating Base Dynamics	23.10.2019	Exercise 2a	Dynamic Modeling of the ABB Arm
29.10.2019	Dynamics L3	Dynamic Model Based Control Methods	30.10.2019	Exercise 2b	Dynamic Control Methods Applied to the ABB arm
			06.11.2019	Midterm 2	Programming dynamics with matlab

Application 1: Industrial Robots



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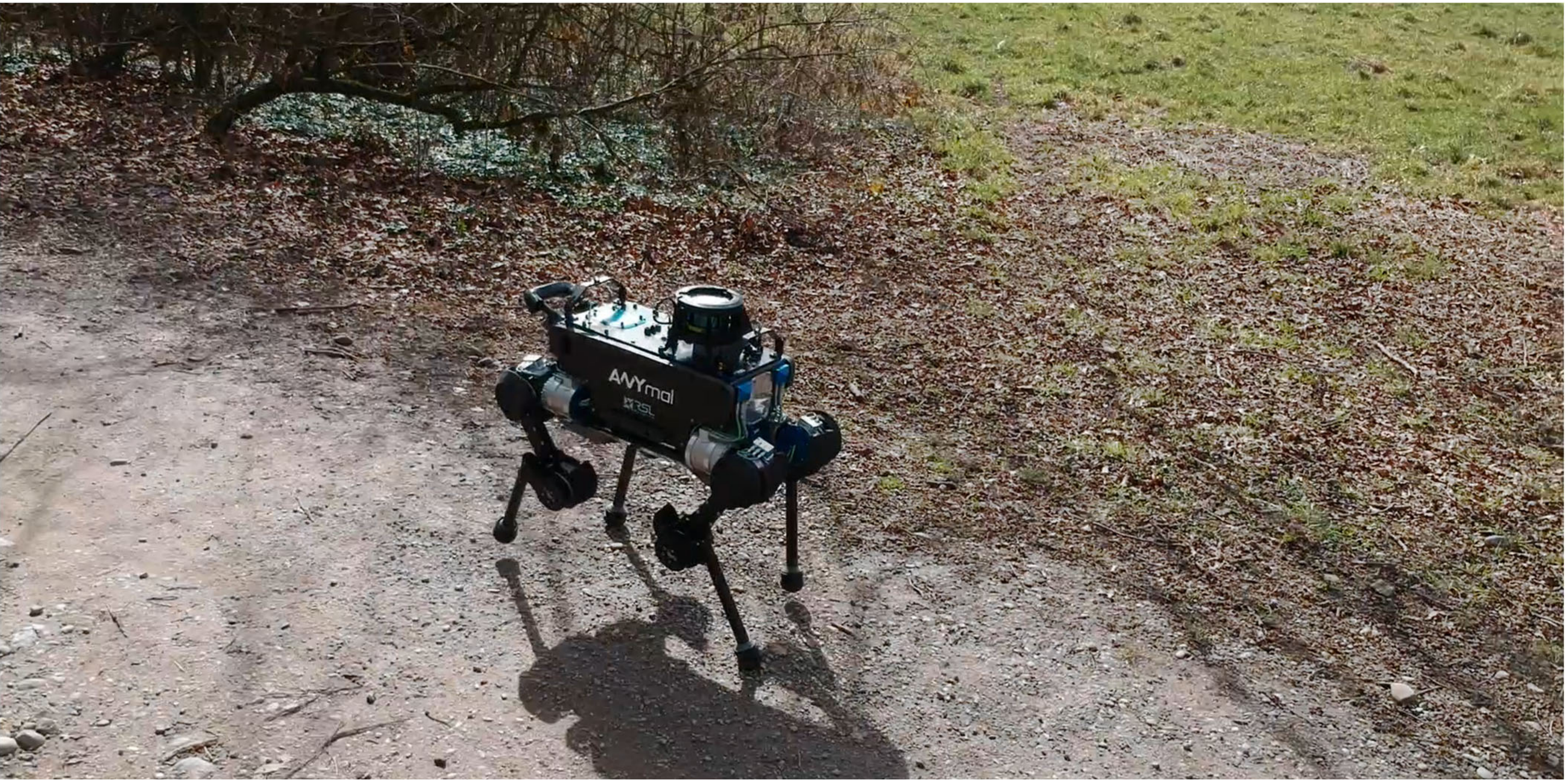
05.11.2019	Legged Robot	Dynamic Modeling of Legged Robots & Control	06.11.2019	Midterm 2	Programming dynamics with matlab
12.11.2019	Case Studies 1	Legged Robotics Case Study	13.11.2019	Exercise 3	Legged robot
19.11.2019	Rotorcraft	Dynamic Modeling of Rotorcraft & Control	20.11.2019		
26.11.2019	Case Studies 2	Rotor Craft Case Study	27.11.2019	Exercise 4	Modeling and Control of Multicopter
03.12.2019	Fixed-wing	Dynamic Modeling of Fixed-wing & Control	04.12.2019		
10.12.2019	Case Studies 3	Fixed-wing Case Study (Solar-powered UAVs - AtlantikSolar, Vertical Take-off and Landing UAVs – Wingtra)	11.12.2019	Exercise 5	Fixed-wing Control and Simulation
17.12.2019	Summery and Outlook	Summery; Wrap-up; Exam			

ETH Quadrupedal Robots

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



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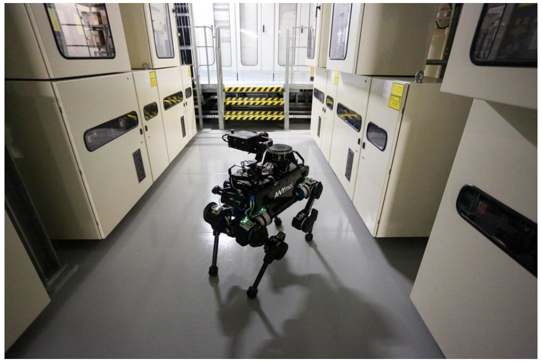
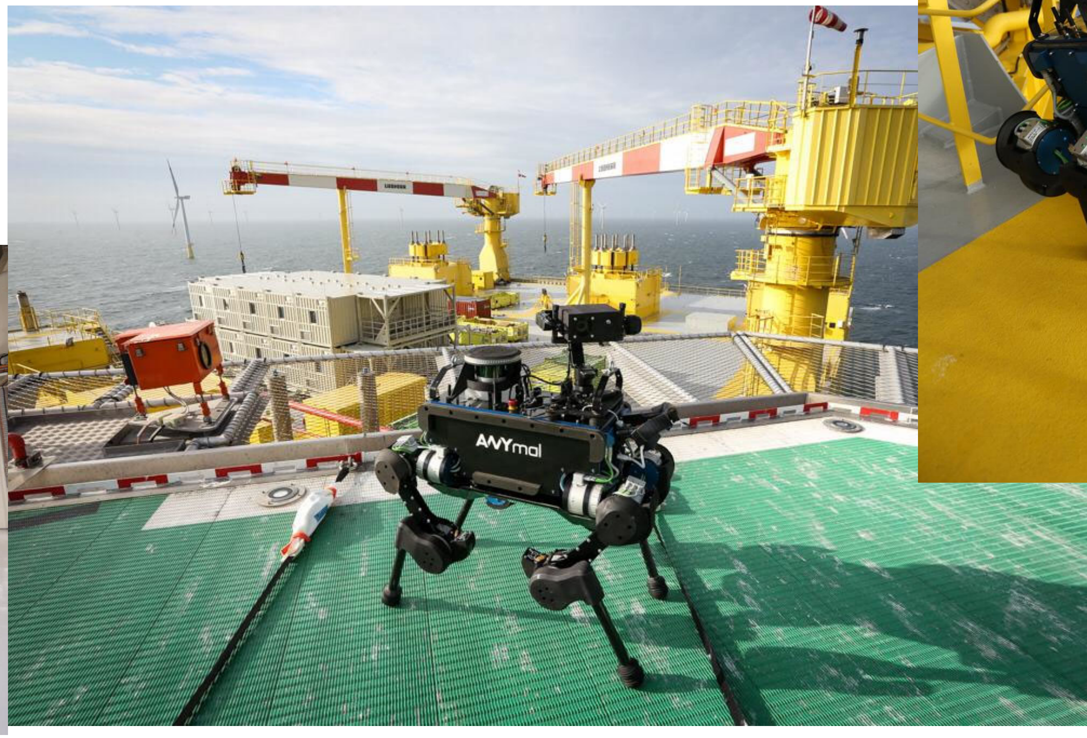
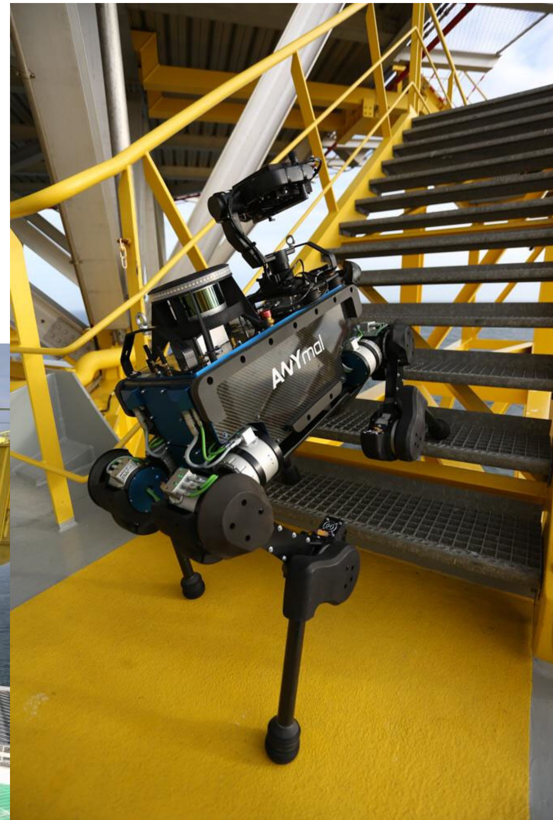
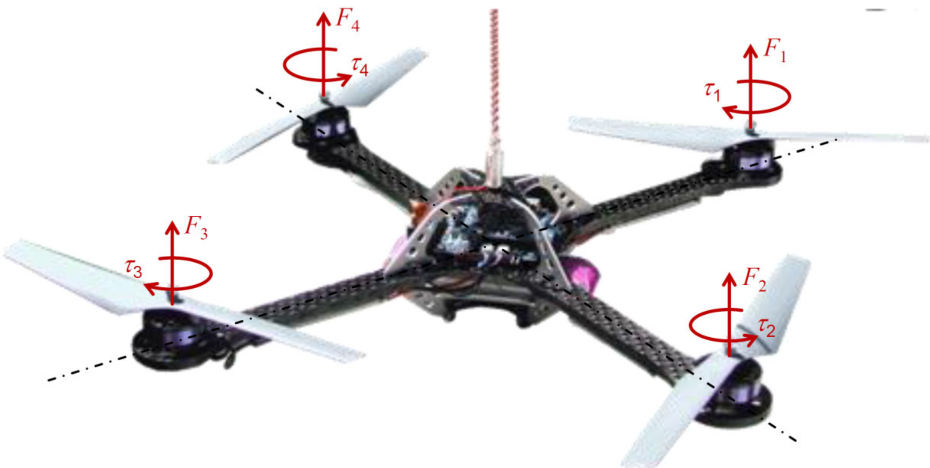


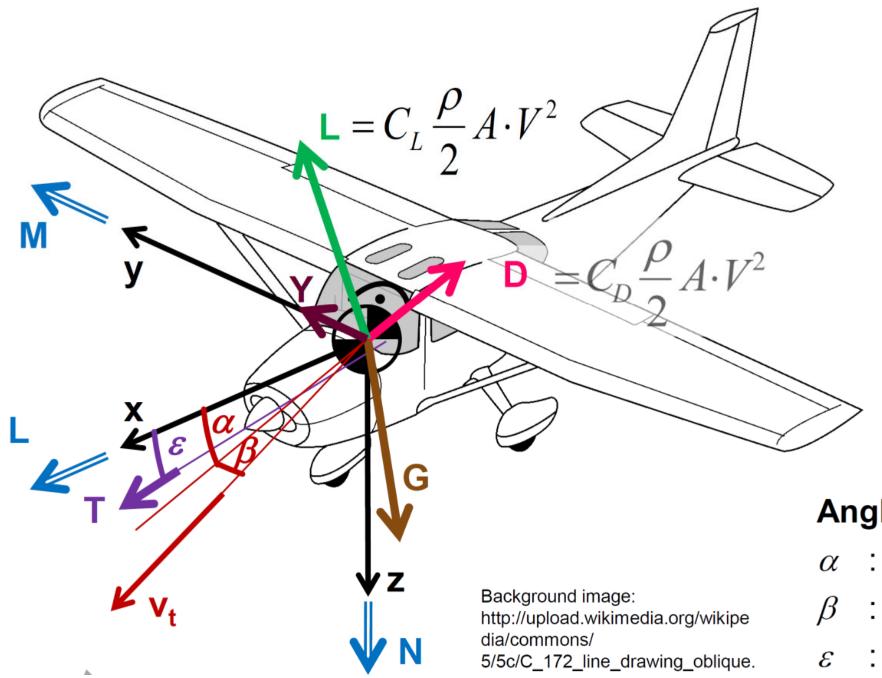




Dynamics of Airplane and Rotorcraft

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





Moments

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

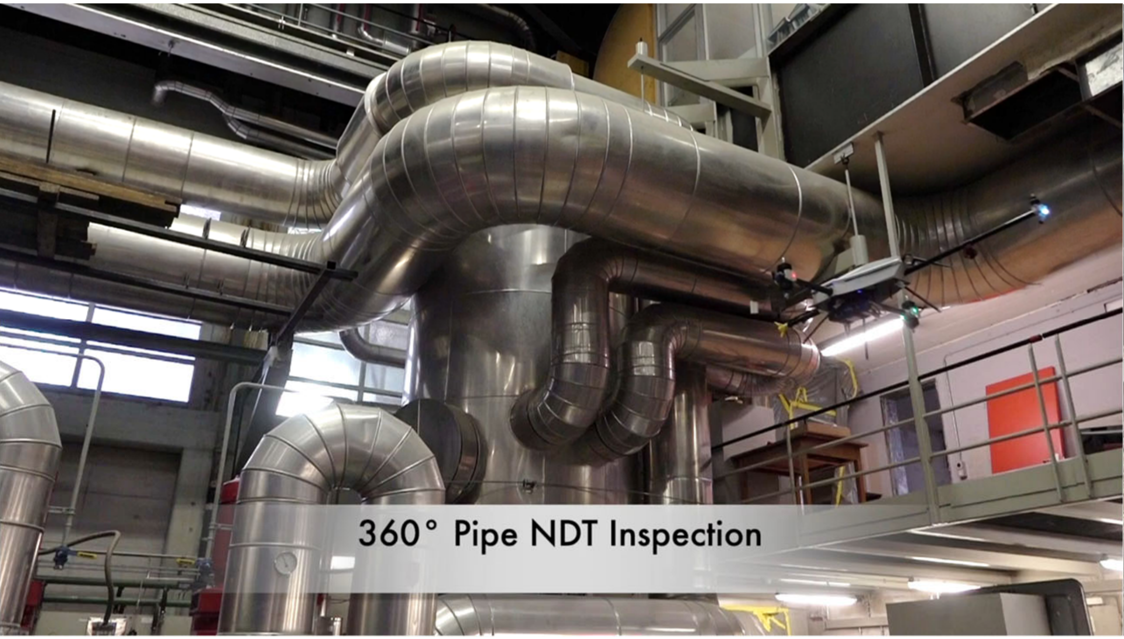
Forces

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

Angles

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

Dynamics and Control of Flying Vehicles



Flying machine arena, IDSC, ETH Zurich

Atlatic Solar

Arctic Ice Inspection

Lecture Material

- Official lecture material on piazza.com
  - Script on kinematics and dynamics
  - Slides (online) *[complete slides will be provided after lecture]*
- Class preparation
  - Read the sections in the script
- 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 HG F3
  - Theory
  - Short recap of all important questions at the beginning of every lecture
  - Quizzes (similar to what you can expect in exam)
- Exercise HG F3
  - Short recapitulation of lecture [Jan Carius]
  - Real problems at robotic systems (e.g. ABB industrial arm)
  - Matlab => bring along a laptop
  - Two optional exercise exams (count 15% each if improving)
- Case Studies
  - State of the art engineering and research at selected examples
  - Not primarily relevant in exams (only some multiple choice questions)

Lecture Rules - Questions

- Ask questions during the lecture
  - I’m happy if the lecture becomes a discussion
- Use piazza.com
  - https://piazza.com/ethz.ch/fall2019/151085100l
  - Discuss questions with me, TAs, and peers
  - Helps us to revisit topics in lecture and exercise class
- Write an email
  - Personal meetings with me or TAs

Exam

- Exercise exam online available
- Content
  - Multiple choice questions
    - Up to half of the questions can be defined by you
    - Everyone can post up to 1 question after every lecture on piazza
    - Rest will come from us
  - Kinematics and dynamics
    - Similar to the quizzes in the lecture
  - Robot specific
    - Legged robots
    - Rotor craft
    - Fixed wing
- Intermediate exams (counts 15% each if improving)
  - Similar to exercise with MATLAB