Neoscholar - Spring 2024: Robot Dynamics and Control

Lecture 1

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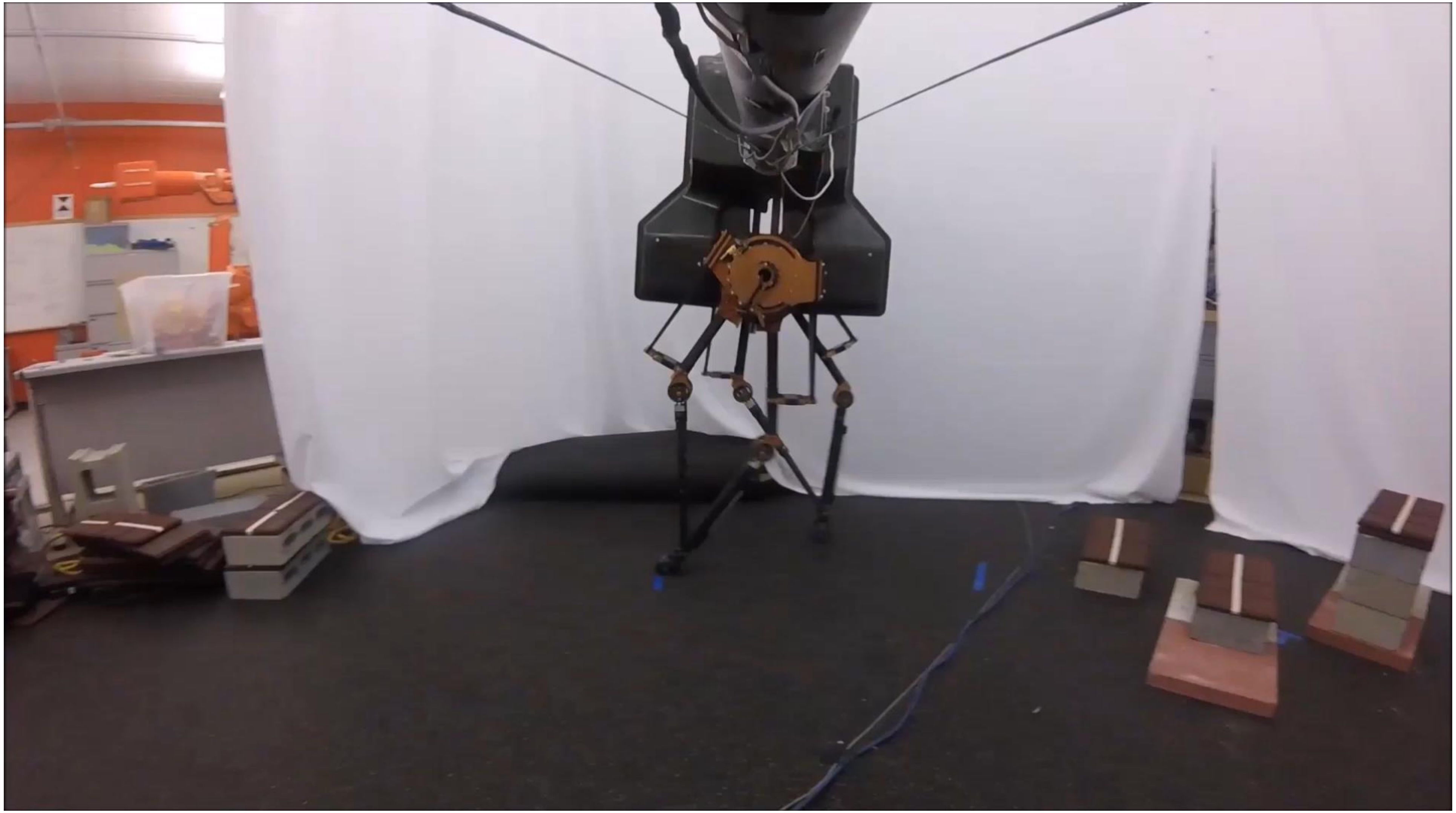
Myself

- Quan Nguyen
  - https://viterbi.usc.edu/directory/faculty/Nguyen/Quan
  - Assistant Professor of AME, USC
  - Postdoctoral Associate, MIT
  - PhD, CMU

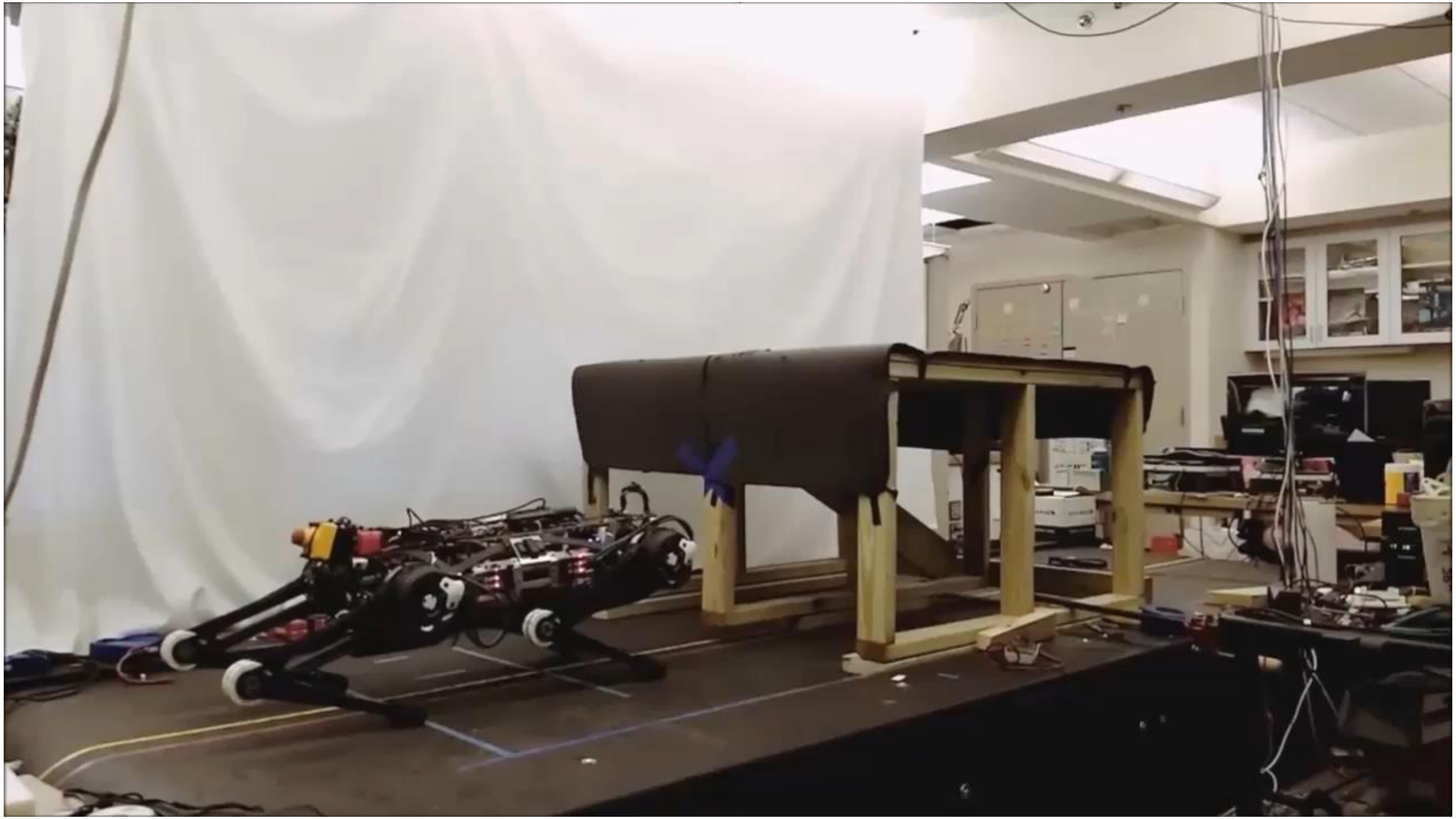
My Research

- Dynamic Robotics and Control Laboratory (https://sites.usc.edu/quann/)
- Control and Learning for Dynamic Robotics
  - Legged robots: quadruped robots, bipedal robots
  - Wheel-legged robots
  - Autonomous vehicles

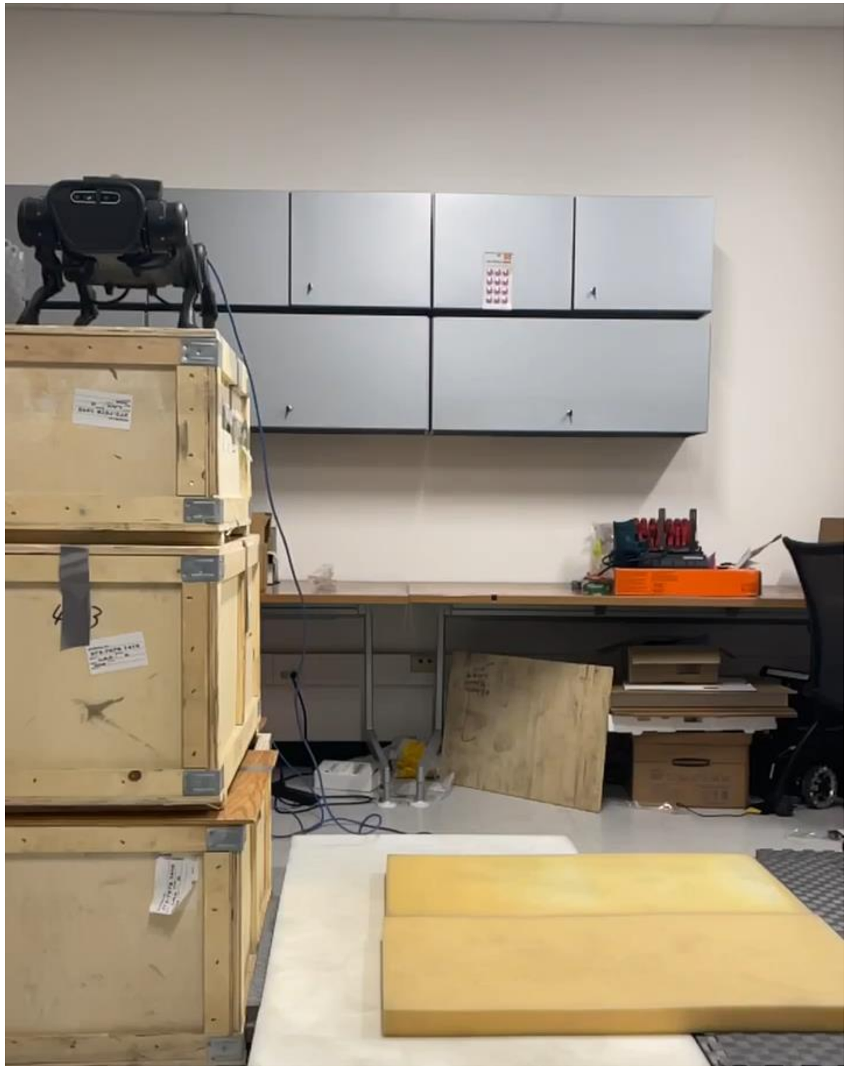
Trajectory Optimization and Gait Library

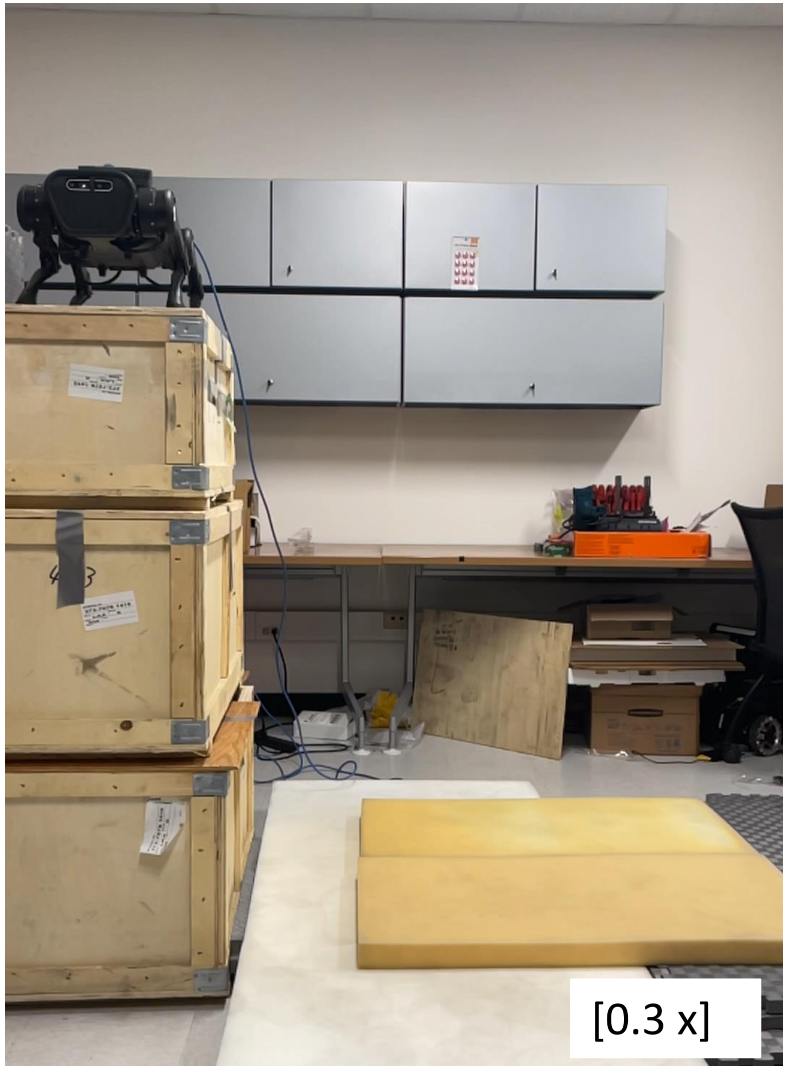


Optimized Jumping of Quadruped Robots



Contact-timing and Trajectory Optimization



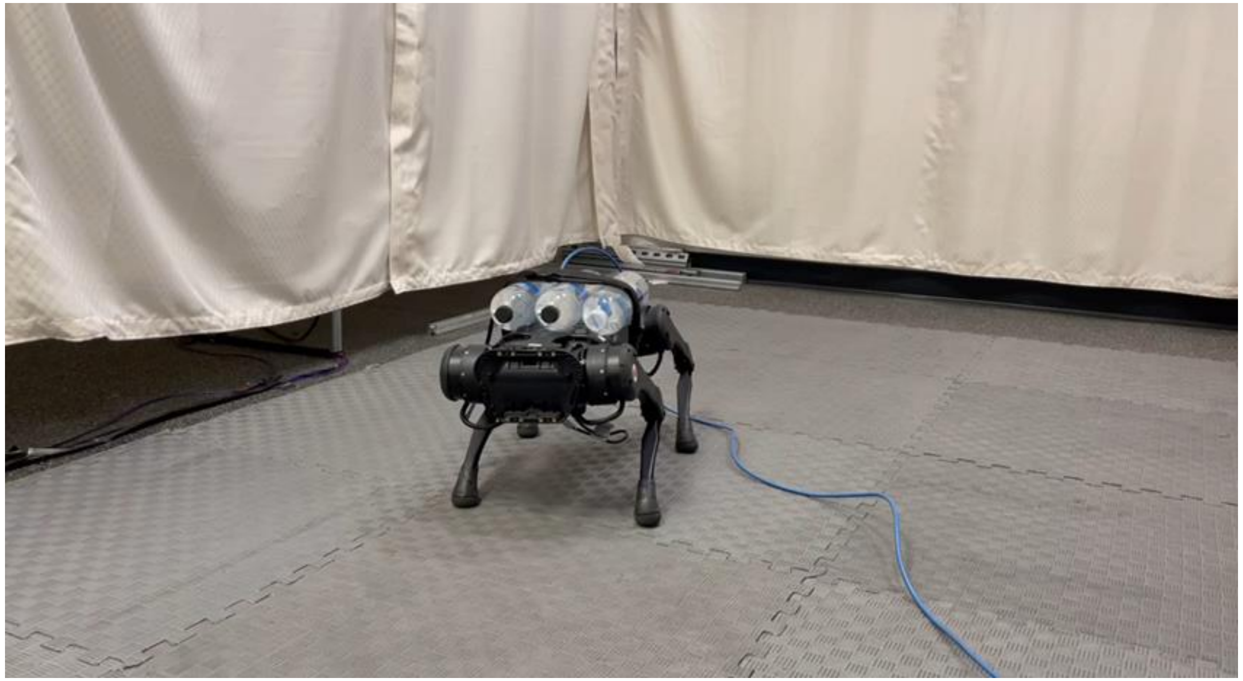


Adaptive Force-based Control for Legged Robots

USC

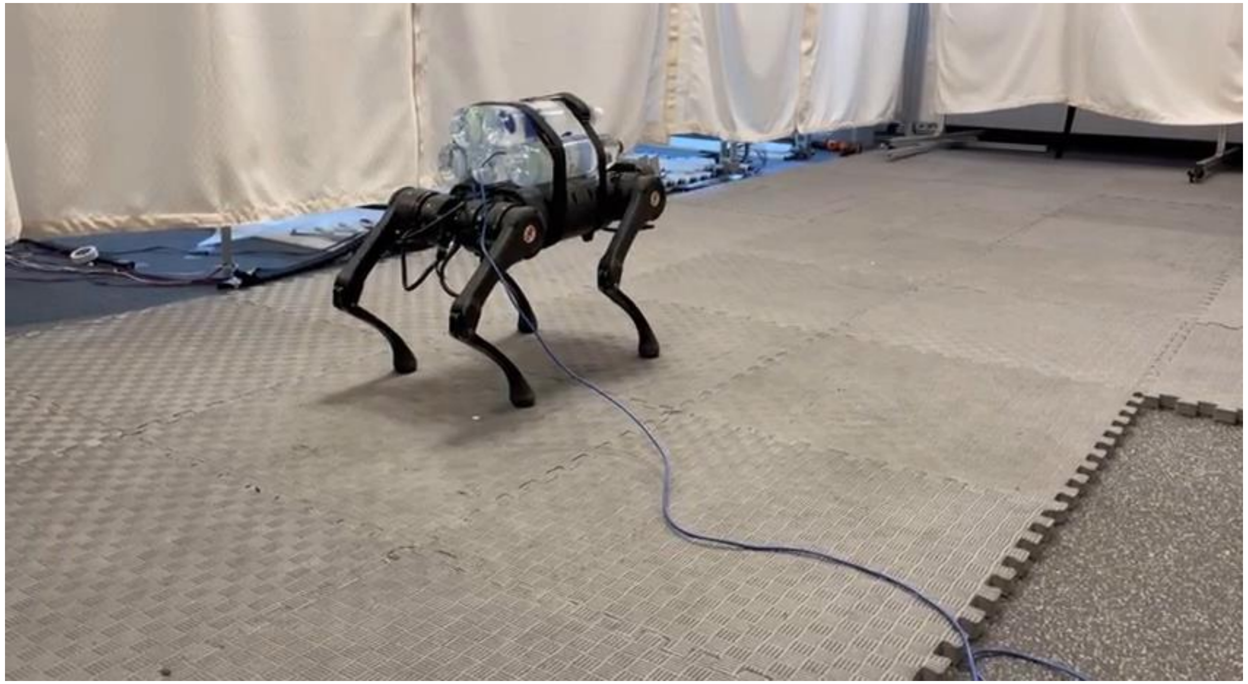
Conventional MPC

unknown 3 kg load



Adaptive MPC

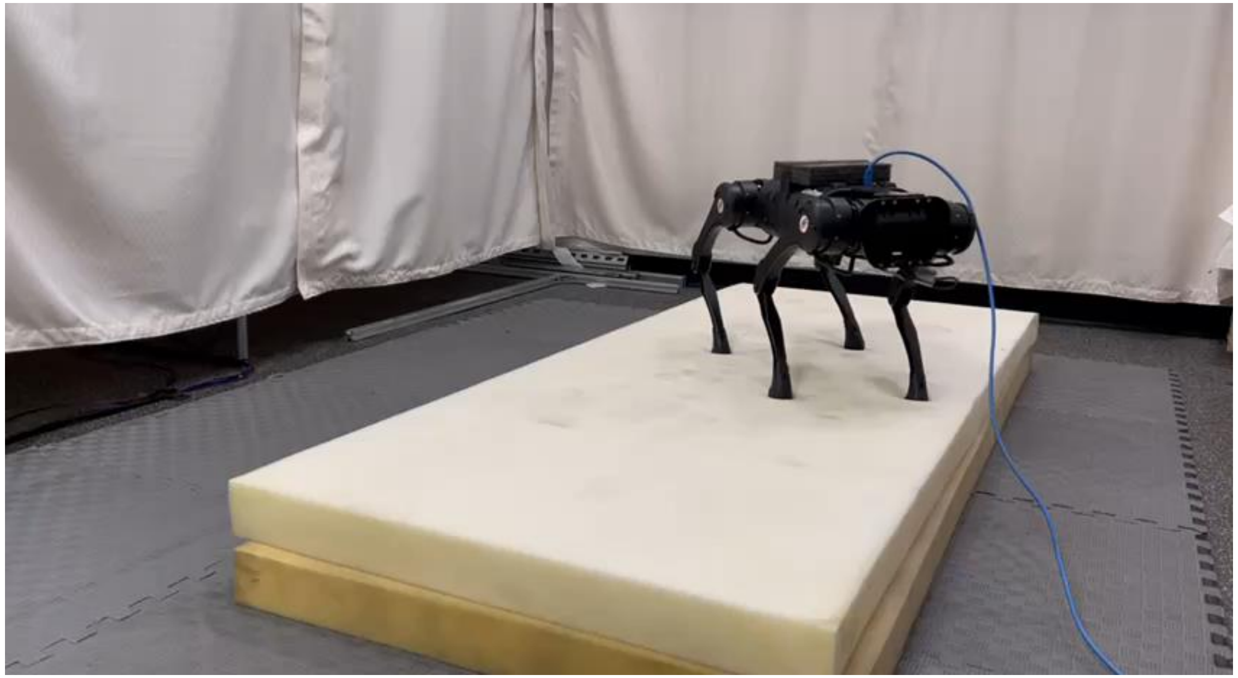
unknown 5 kg load



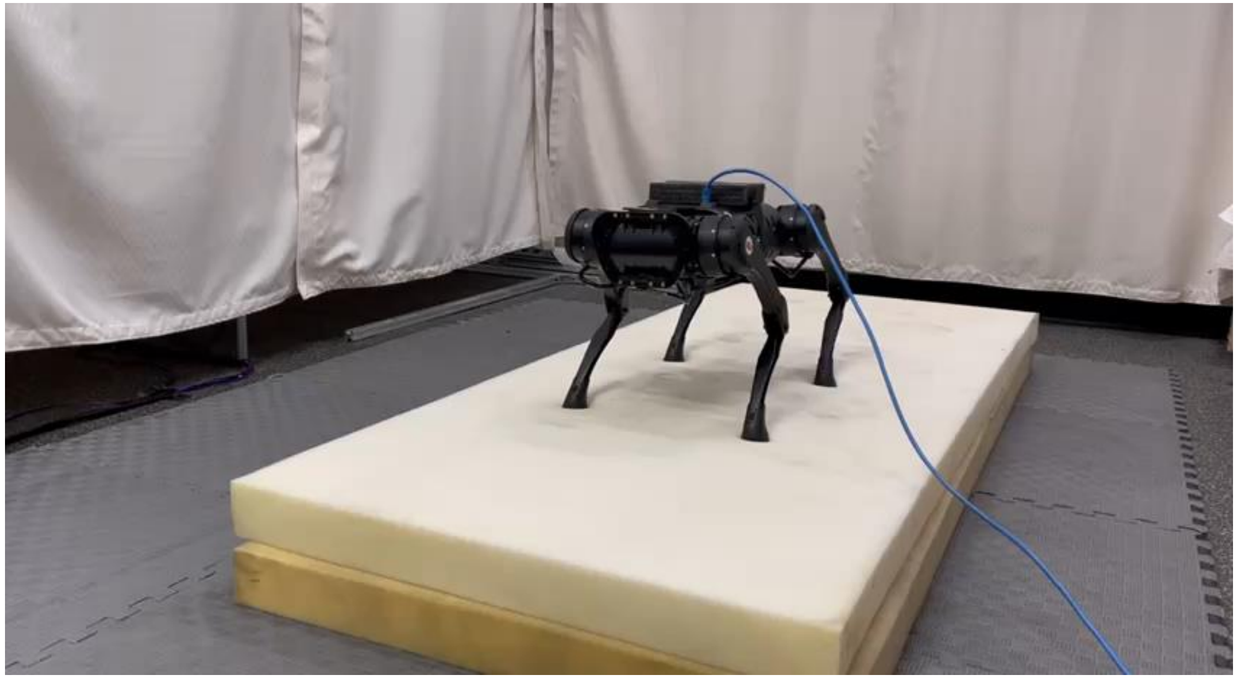
Adaptive Force-based Control for Legged Robots

Walking on Soft Terrain with Unknown Impact Model

Conventional MPC



Adaptive MPC

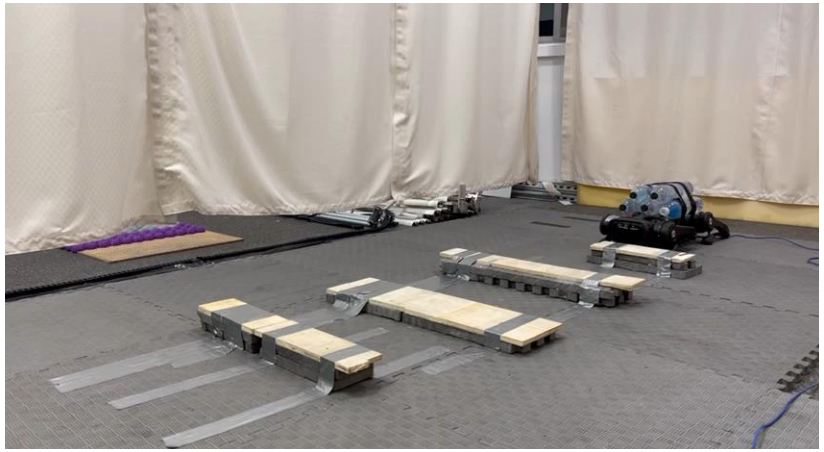


Navigating Various Terrains

Grass

Gravel

Rough Terrain



Slope

Running with Different Gaits

Trotting

Unknown 5 kg load

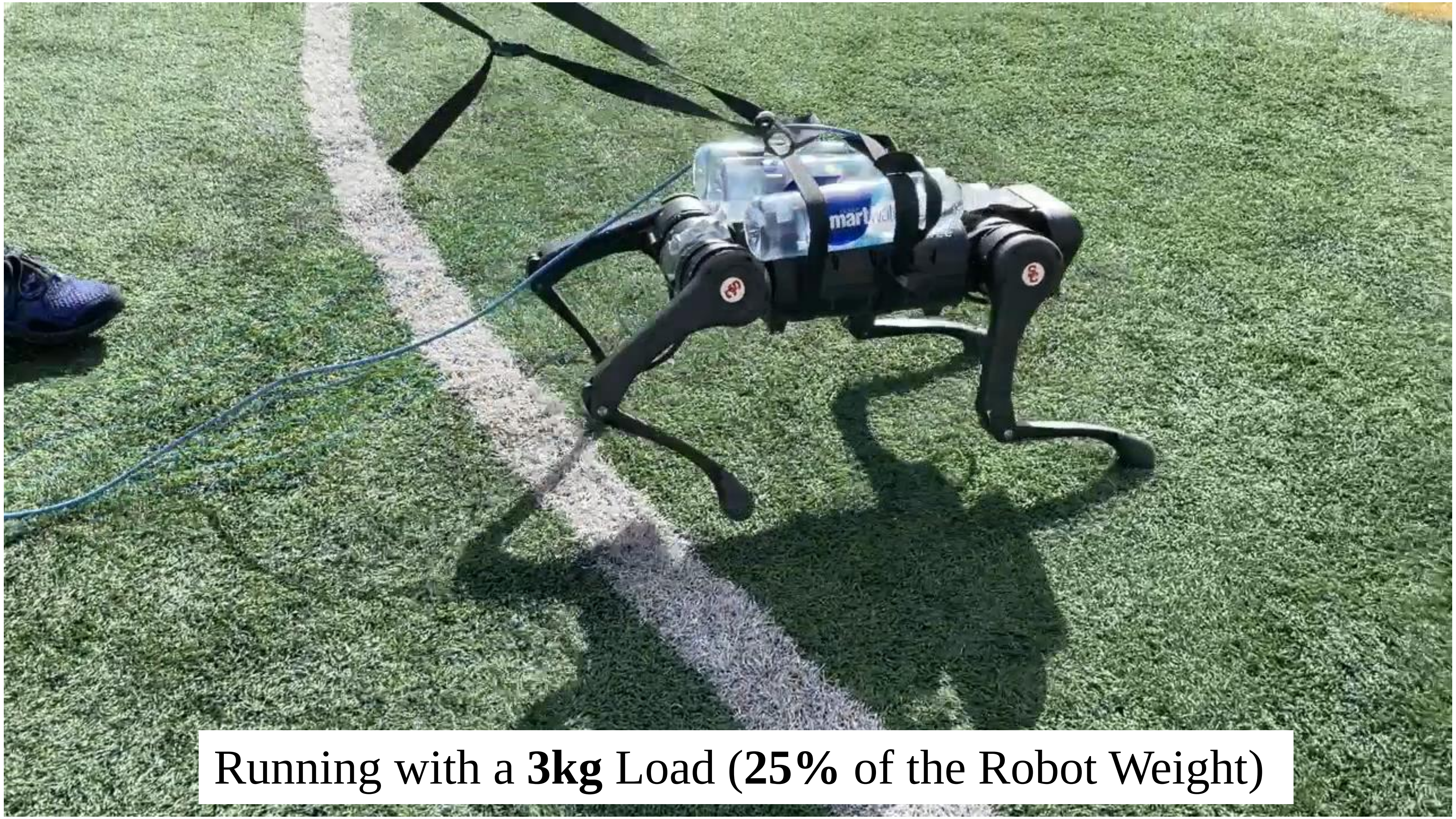
Bounding

Unknown 3 kg load

Robust High-speed Running via DRL

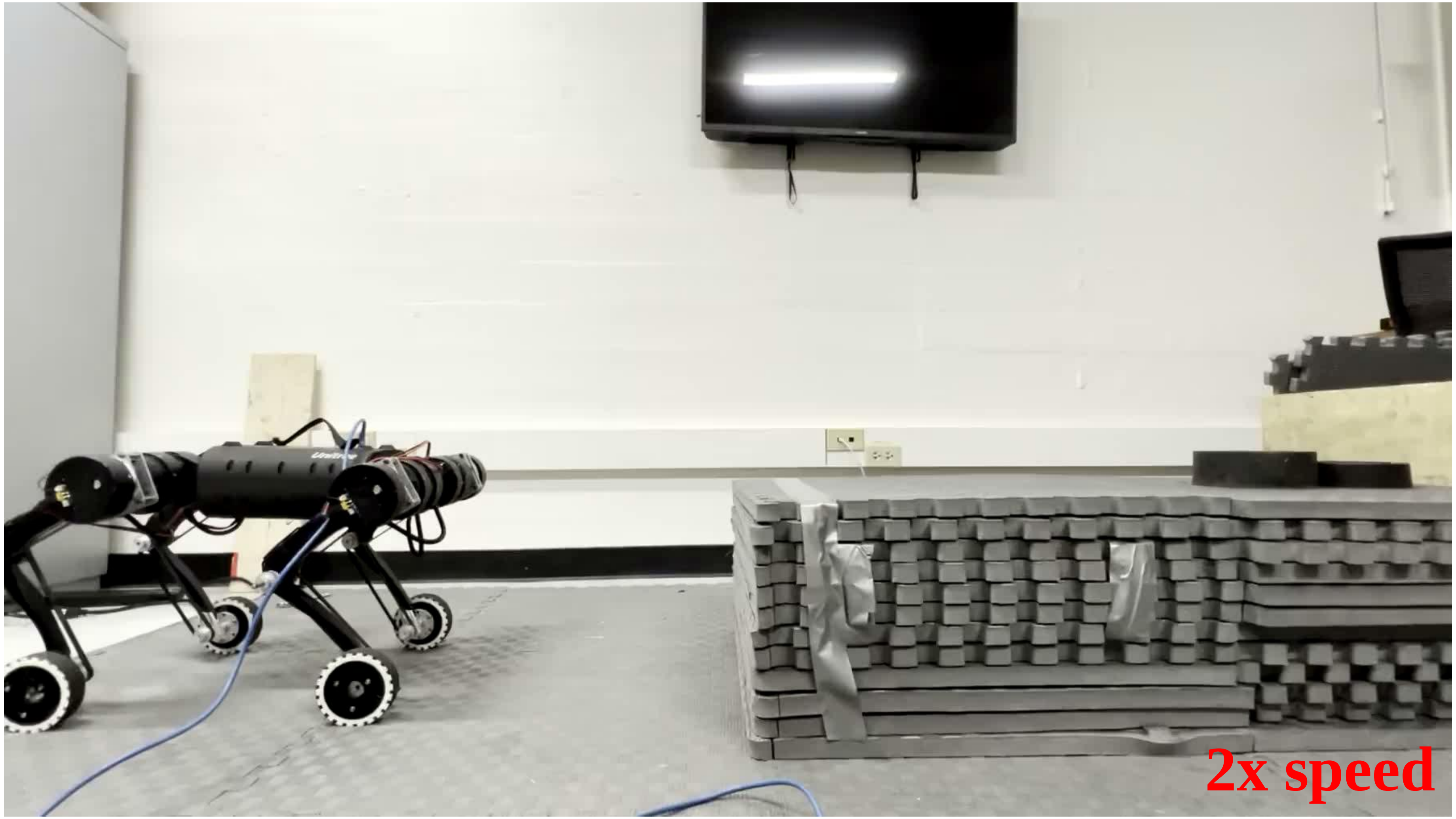
Running on a Bumpy Grass Field

Robust High-speed Running via DRL



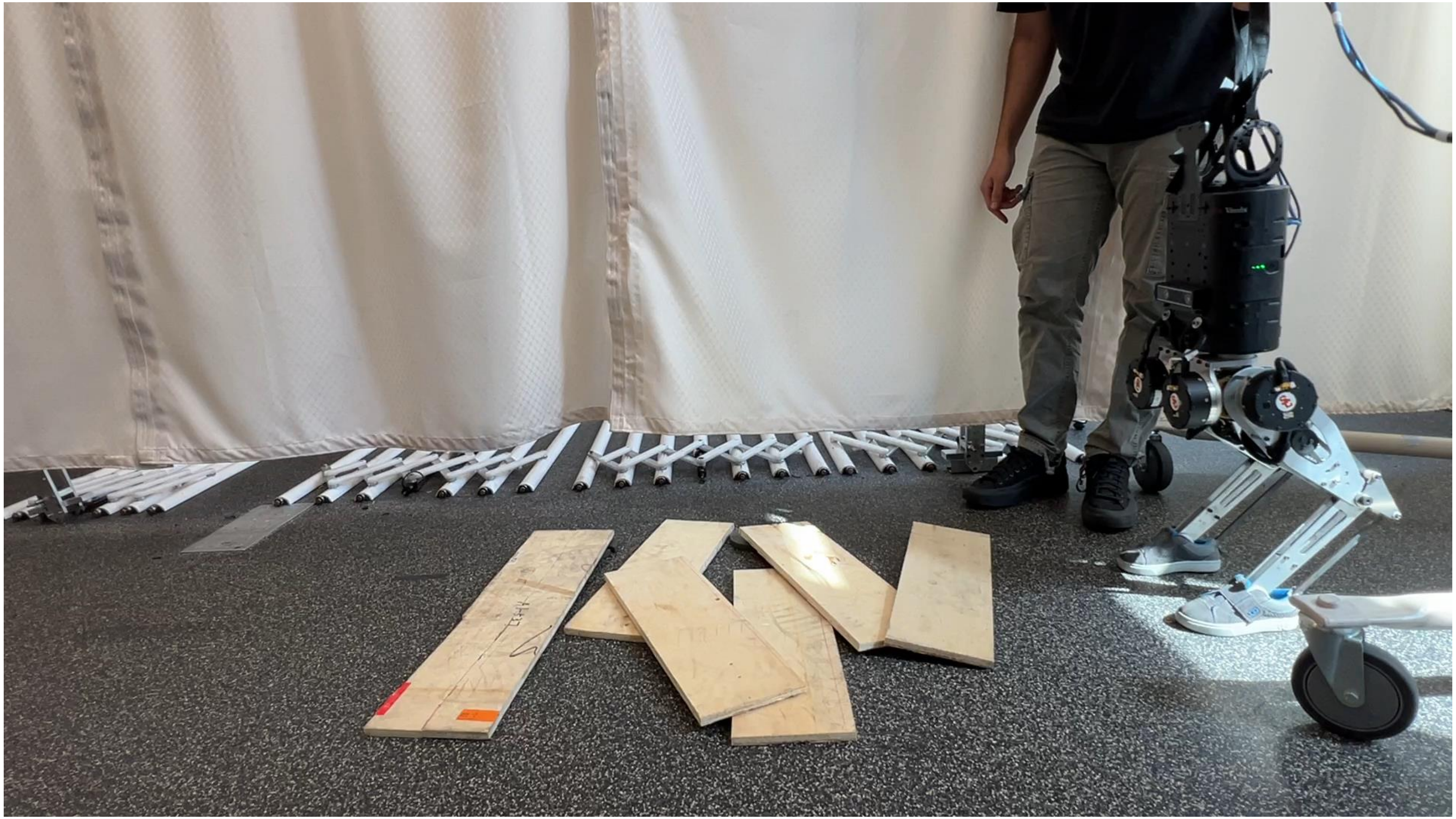
Running with a **3kg** Load (**25%** of the Robot Weight)

Pose Optimization for Wheel-legged Robots



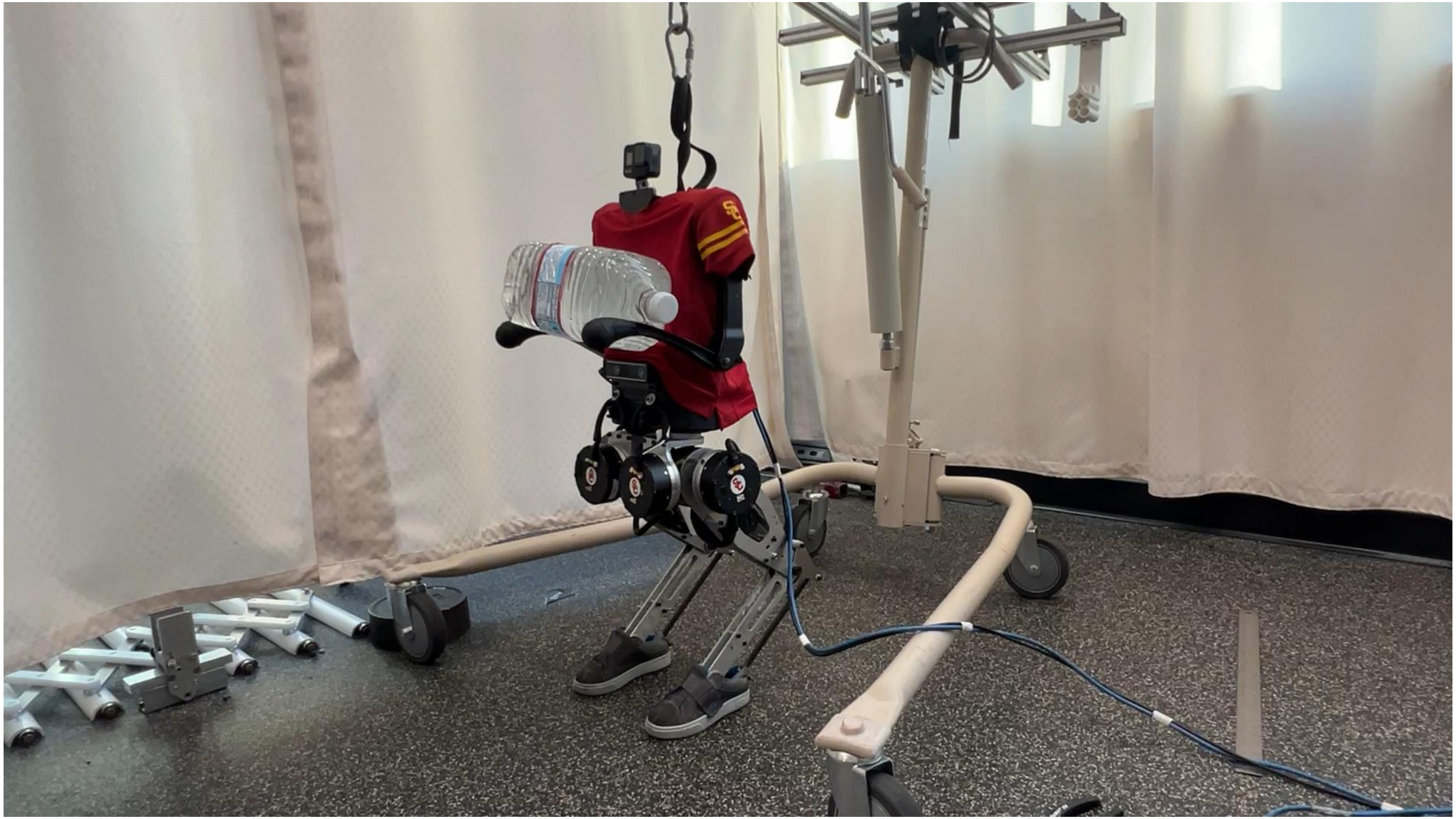
Rolling up an obstacle of **0.3m** height

Force-and-moment-based MPC for Bipedal Robots



Force-and-moment-based MPC for Bipedal Robots

Force-and-moment-based MPC for Bipedal Robots



Robotics

- This is a very broad field
  - Robot design
  - **Control** (focus of this course)
  - Path planning, behavior planning, decision making,…
  - Computer vision, sensing, localization,…
  - …
- Focus of the course:
  - Robot dynamics and control techniques
  - Application:
    - Robot manipulation: robot arms (fixed base)
    - Robot locomotion: mobile robots (UAVs/ drones, autonomous vehicles, legged robots,…) (floating base)

Course Syllabus

- Course content:
  - Robot kinematics & dynamics
    - Robotics arm
    - Mobile robots (UAVs/ drones, self-driving cars, legged robots,…)
  - Robot control:
    - LQR (Linear Quadratic Regulator)
    - MPC (Model Predictive Control)
    - Force control, impedance control
    - Nonlinear control
    - …
  - Trajectory optimization

Model Predictive Control

Di Carlo, et al. "Dynamic locomotion in the MIT Cheetah 3 through convex model-predictive control." *IROS 2018*

Model Predictive Control

Grady, et al. "Robust Sampling Based Model Predictive Control with Sparse Objective Information." *RSS* 2018.

Trajectory Optimization

Katz, et al. "Mini cheetah: A platform for pushing the limits of dynamic quadruped control." *ICRA* 2019.

Trajectory Optimization

Loianno, et al. "Estimation, control, and planning for aggressive flight with a small quadrotor with a single camera and IMU." *RAL 2016*

Trajectory Optimization

SpaceX Falcon Heavy & Starman, 2018

Trajectory Optimization

Blackmore, et al. "Lossless convexification of control constraints for a class of nonlinear optimal control problems." *Systems & Control Letters* 2012.

http://larsblackmore.com/

https://www.aa.washington.edu/facultyfinder/behcet-acikmese

Course Syllabus

- **Textbook:**
  - No required textbook for this course
  - Recommended resources (check the syllabus)
- Software for HW: **MATLAB**
  - I will not teach programming in this course. You will need to learn it by yourself.
  - We will provide detailed instructions as much as possible for you to learn it.
  - We will have a tutorial session on MATLAB to teach you basic functions.
- **Grading breakdown**
  - Weekly HWs: 35%
  - Midterm exam: 25%
  - Final exam: 35%
  - Participation: 5%

  Total: 100%

Course Syllabus

- **Participation** (5%):
  - Regularly attending lectures
  - Actively engaging in class discussion

Teaching Style

- Will mostly use handwriting for my lectures
  - It takes me more time to write down the notes.
  - It may help you to understand and remember the lecture better. (We will have a lot of math in this course.)
  - I will upload the note after each lecture, but I encourage students to take notes during the lecture.
- From the 2nd lecture onward => very few slides.

Basic concepts

- **Feedback control**
  - Car driving and feedback control