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Custom Sine Waves Are Enough for Imitation Learning of Bipedal Gaits with Different Styles

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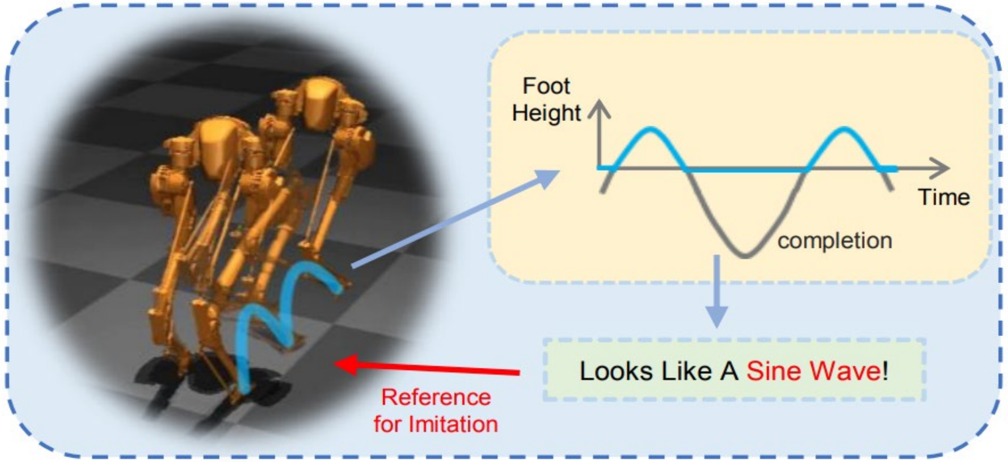
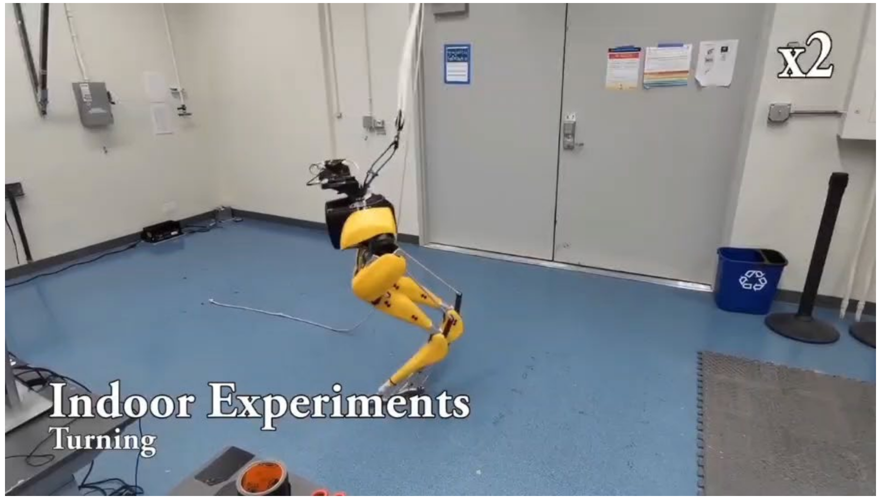
Presenter: Chong Zhang



Introduction

- Deep Reinforcement Learning (DRL)
  - A new solution to legged locomotion
  - An easy solution to dynamics modelling

[Miki, T. , et al. Science Robotics, 2022]

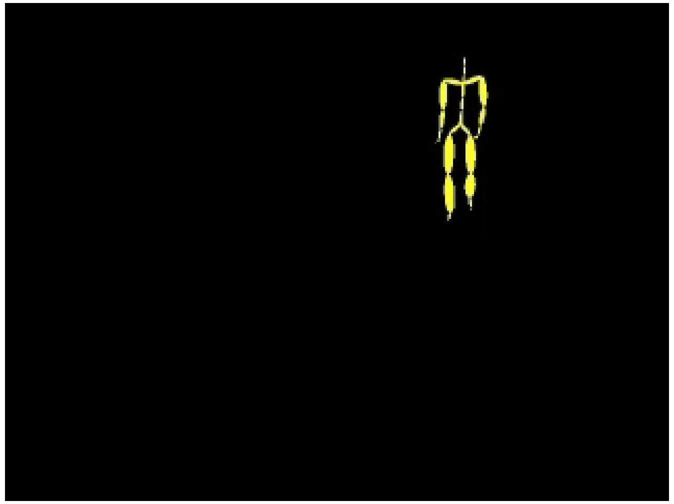


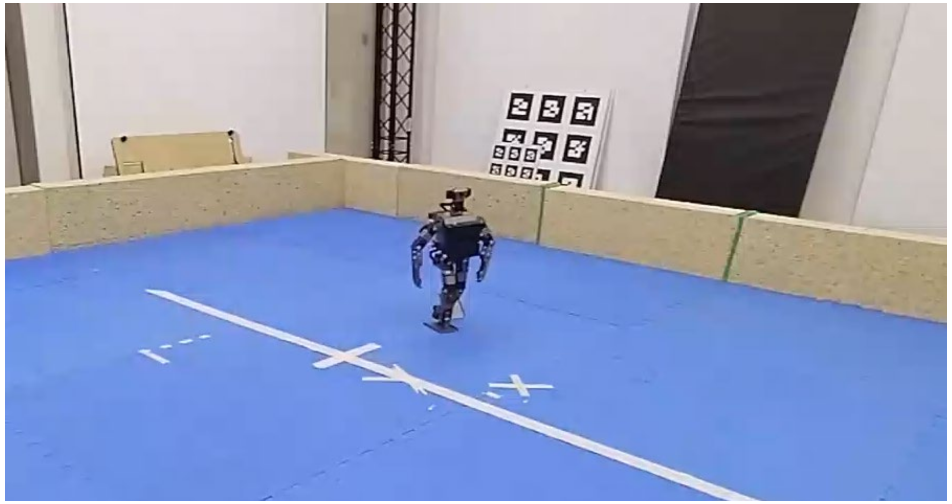
[Li, Z. , et al. ICRA 2021]

Introduction

- DRL implementation for bipedal gaits
  - End-2-end learning: time-consuming
    - Dozens of hours for training [Siekmann, J., et al. RSS 2021, & ICRA2021]
    - GPU-based simulation hasn't shown enough fidelity for bipedal robots.
  - Motion imitation: costly mocaps or manually tuned references
    - Human motion capture is costly and anthropomorphic.

Human motion capture: costly, limited styles, anthropomorphic!





Bohez, Steven, et al. Imitate and Repurpose: Learning Reusable Robot Movement Skills From Human and Animal Behaviors.

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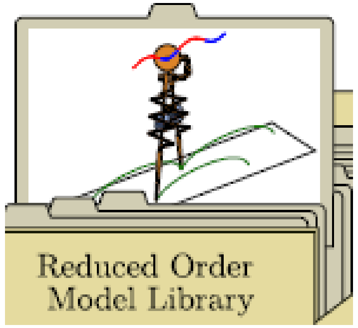
    - Human motion capture is costly and anthropomorphic.
    - Manually tuned references require lots of expert knowledge and efforts.

Manually tuned reference: cheaper than mocaps, requiring knowledge and efforts

Spring Mass Model



Green, Kevin, et al. "Learning spring mass locomotion: Guiding policies with a reduced-order model."

Other choices:
Manually tuned controller: Xie, Z. , et al. IROS 2018
HZD gait library: Li, Z. , et al. ICRA 2021
…

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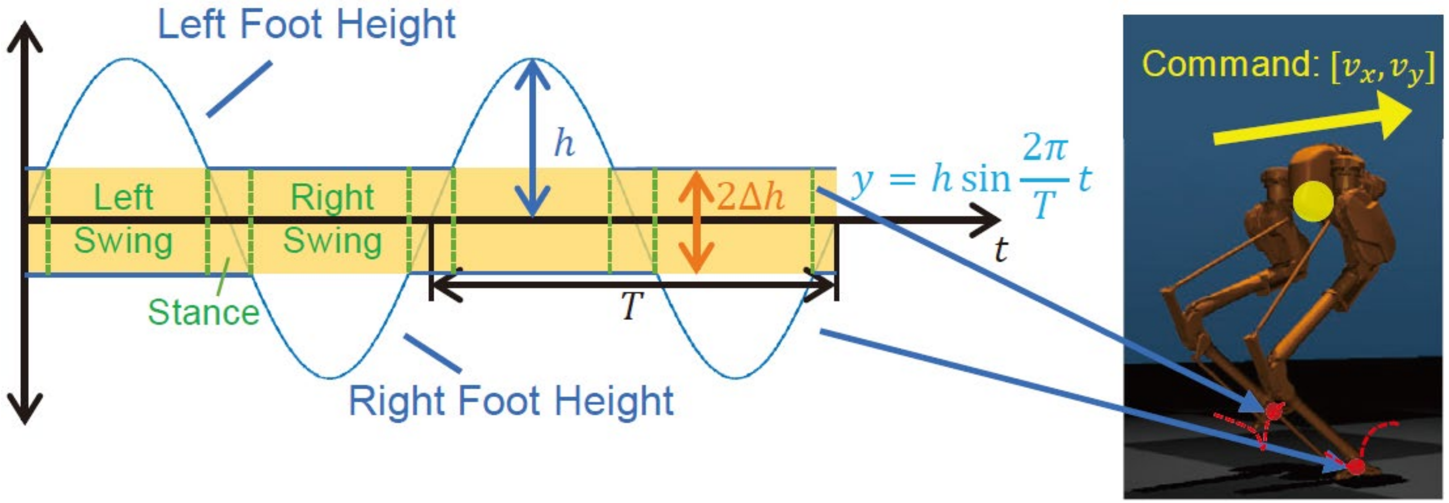
    - Human motion capture is costly and anthropomorphic.
    - Manually tuned references require lots of expert knowledge and efforts.
    - Gait styles are limited to the references and difficult to tune.
  - Massive expert efforts for reward & hyperparameter tuning

Introduction

- Our motivation
  - Can the references be cheap and easy to obtain?
    - A sine wave suffices!
  - Can the rewards be easy to tune?
    - Few reward terms without special efforts to tune!
  - Can the learning process be efficient?
    - As efficient as those with manually-tuned references!
  - Anything else?
    - Deploy a very simple system and focus on skill learning, as suggested by previous works [Siekmann, J., et al. RSS 2021]:
sim2real and skill learning can be separately treated.

Our Method

- The very simple reference
  - Easy to generate
  - Easy to tune the styles



- The walking styles
  - $h - \Delta h$ for foot clearance: higher or lower
  - $\frac{\Delta h}{h}$ for double-support span: also faster or slower feet up and down
  - T for frequency: higher or lower

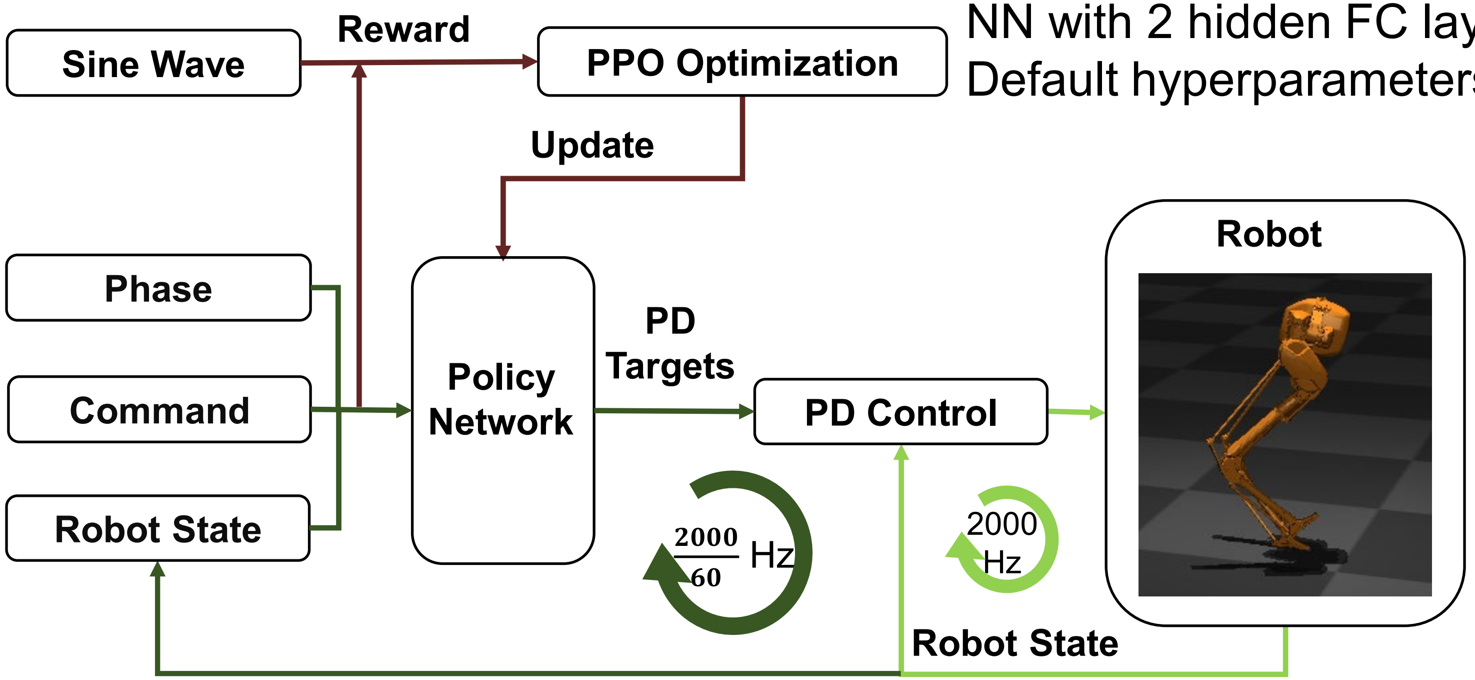
$$h_{\text{ref}_1} = h_{\text{left}} = \max(0, h \sin(\frac{2\pi}{T} t + \phi_0) - \Delta h),$$

$$h_{\text{ref}_2} = h_{\text{right}} = \max(0, h \sin(\frac{2\pi}{T} t + \phi_0 + \pi) - \Delta h).$$

Our Method

- The very simple system

Stable-Baselines3 Library
NN with 2 hidden FC layers (512 units)
Default hyperparameters



Our Method

- The very simple rewards

[Peng, X. B. , et al. SIGGRAPH 2018]: joint position, joint velocity, end-effector position, and CoM position (4) terms for imitation; task specific terms for performance

[Xie, Z. , et al. IROS 2018]: joint position, pelvis position, and pelvis orientation (3) terms for imitation; shin spring term for regularization

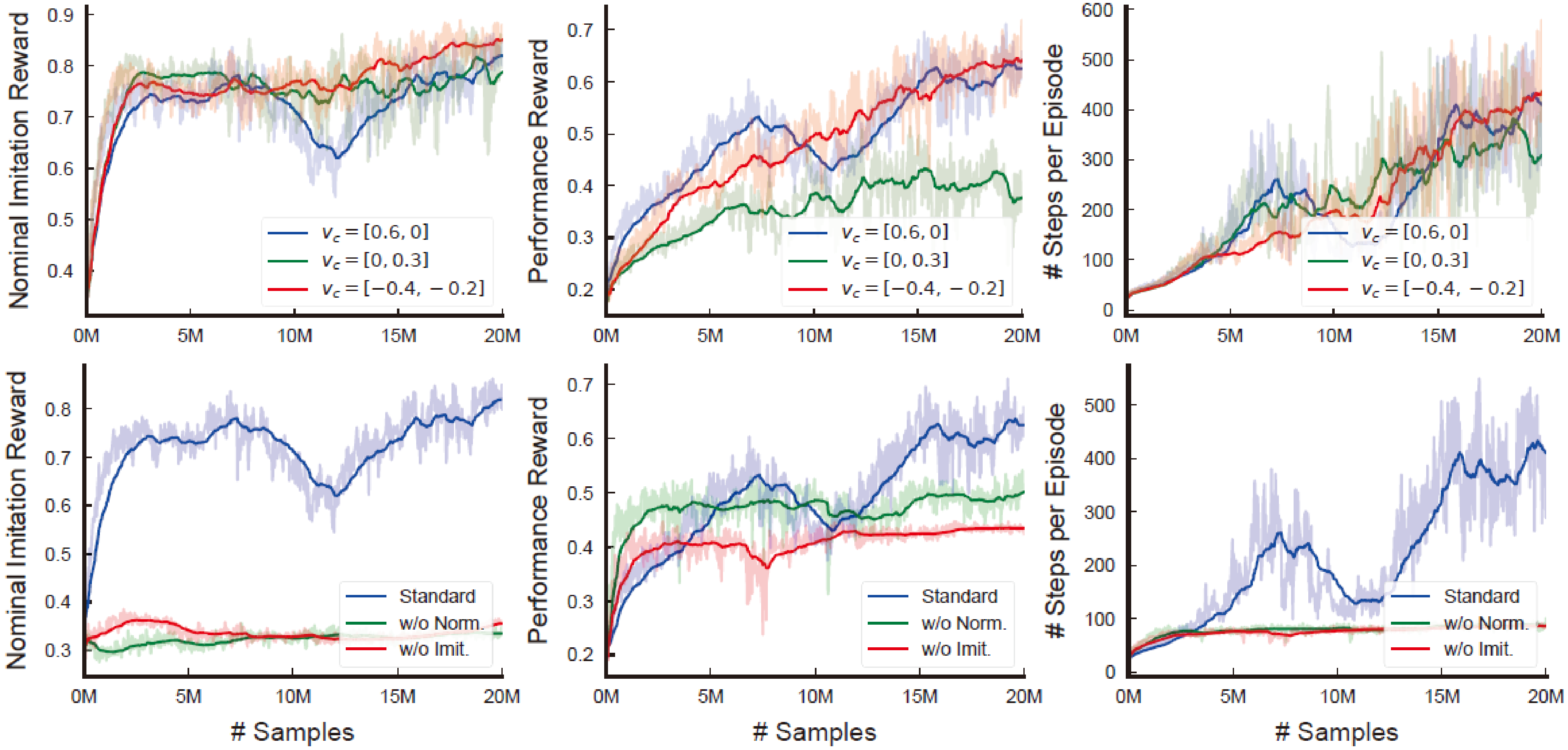
[Li, Z. , et al. ICRA 2021]: joint position, pelvis position, pelvis translational velocity, pelvis rotation, and pelvis rotational velocity (5) terms for imitation; 2 terms for regularization

Ours: **1 term for imitation**, 2 terms for performance, 1 (but can be more) term for regularization and 1 term for early termination

Our Method

- The very simple rewards: $0.5r^I + 0.5r^P + r^R + r^T$
  - Imitation:
    - $r^{I*} = \exp(-\frac{\text{dist}^2(h_{\text{ref}}, h_{\text{foot}})}{0.05^2})$, $r^I = \frac{r^{I*} - 0.4}{1.0 - 0.4}$: a penalty for surviving without pursuing imitation
  - Performance:
    - $r^P = 0.75\exp\left(-\frac{\text{dist}^2(v_{\text{pelvis}}, v_{\text{command}})}{\max(0.1^2, 0.5\|v_{\text{command}}\|^2)}\right) + 0.25\exp\left(-\frac{\text{dist}^2(ori_{\text{pelvis}}, ori_{\text{standing}})}{0.1}\right)$
  - Regularization:
    - $r^R = 0.1\exp(-\frac{\text{dist}^2(q_{\text{shin}}, \mathbf{0})}{0.001})$
  - Termination:
    - $r^T = -10$ if early termination else 0 : triggered when fall or "derail" too far

Results



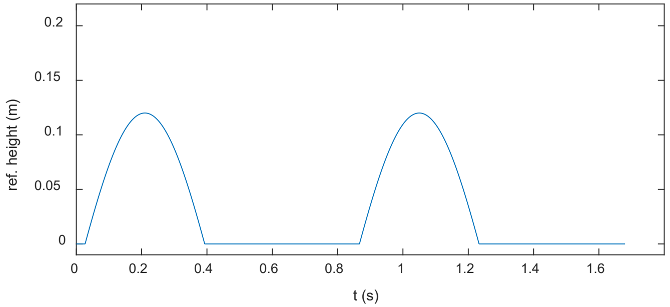
3-5 hours on an ordinary desktop!

Existing works:

Dozens of M steps for imitation learning

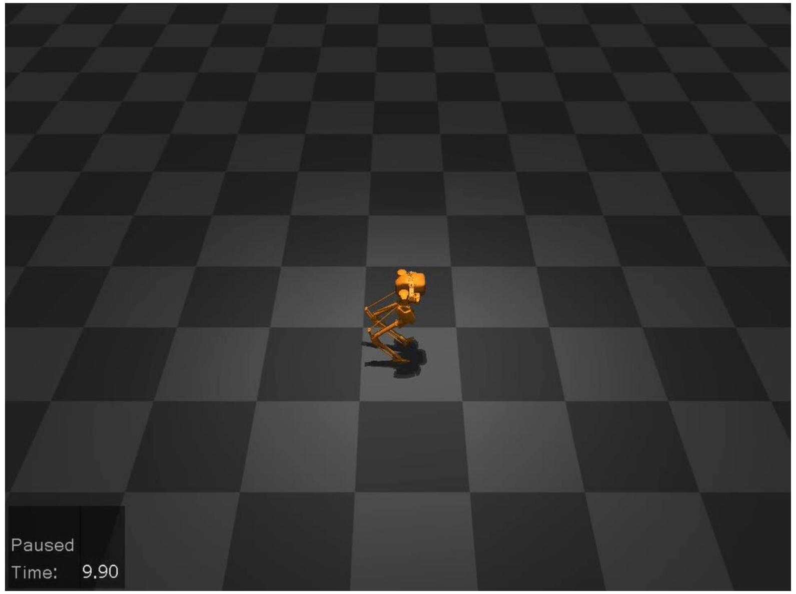
Hundreds of M steps for end2end learning

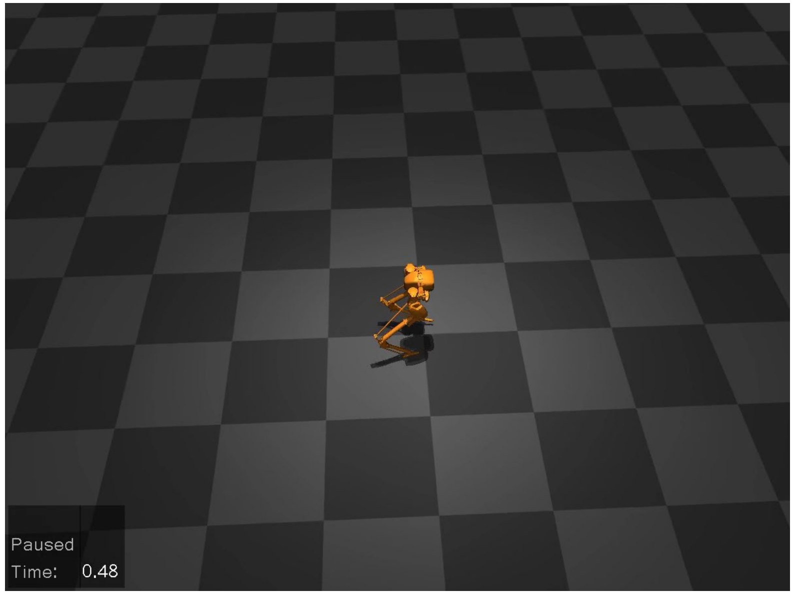
Results



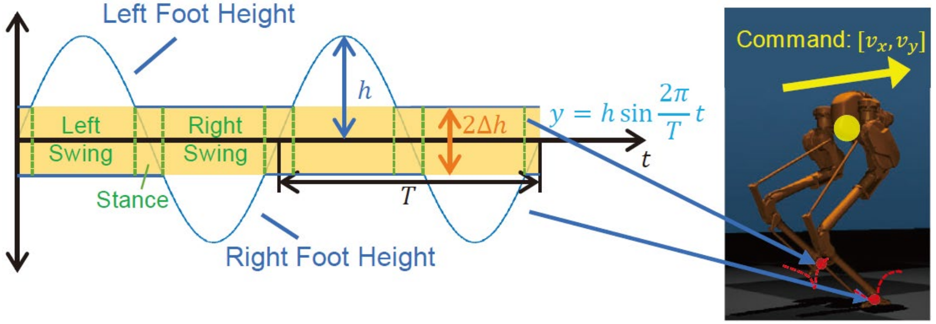
- Same reference, different velocities

$v_x = 0.6\text{m/s}, v_y = 0\text{m/s}$ $v_x = 0\ \text{m/s}, v_y = 0.3\text{m/s}$ $v_x = -0.4\text{m/s}, v_y = -0.2\text{m/s}$



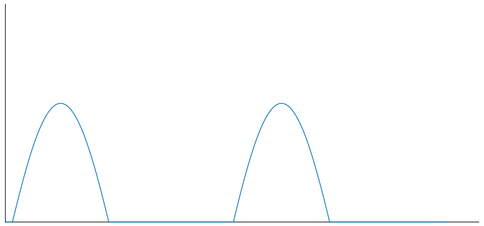


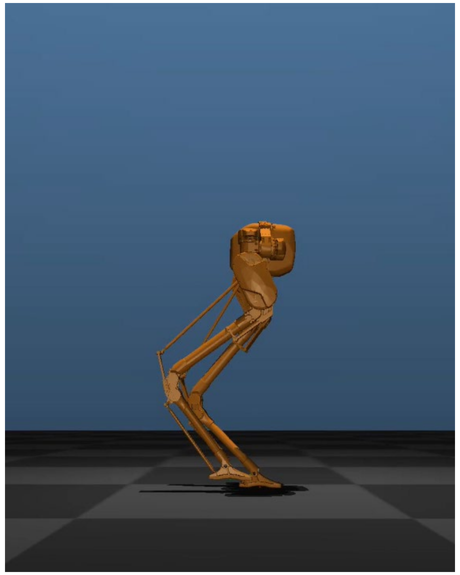
Results

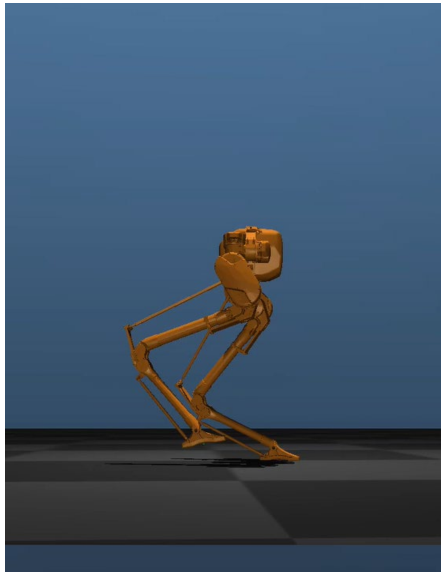


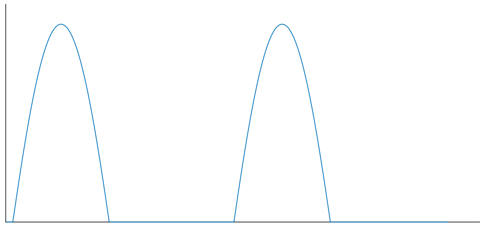
- Different styles: changing $h - \Delta h$

$h - \Delta h = 0.12$ $\qquad$ $h - \Delta h = 0.2$



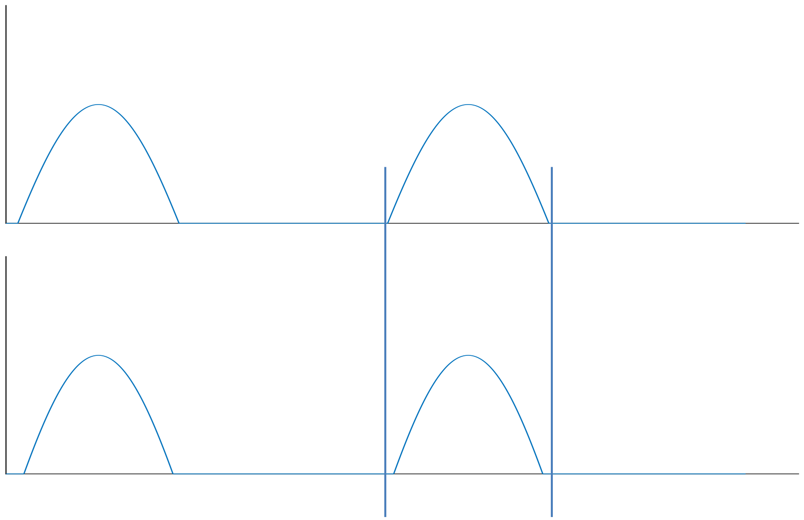






Results

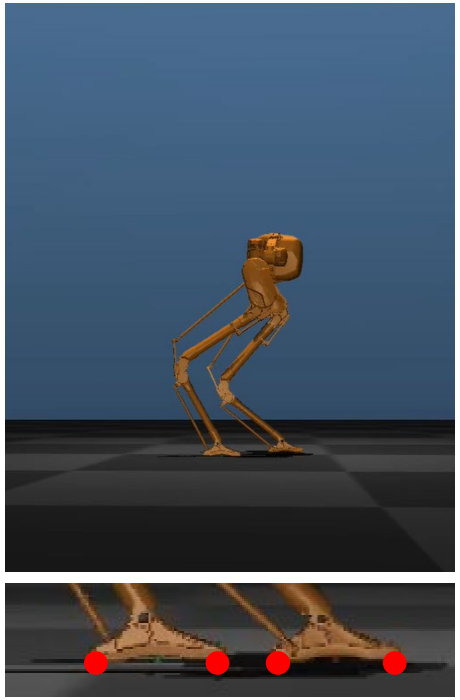
- Different styles: changing $\Delta h/h$

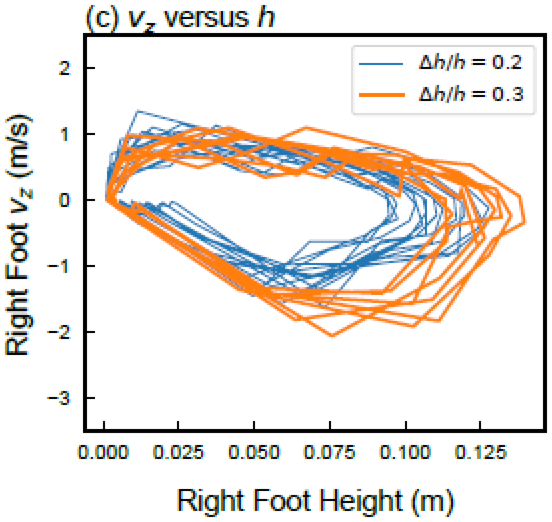


Contact Points Before Lift

$\Delta h/h = 0.2$

$\Delta h/h = 0.3$

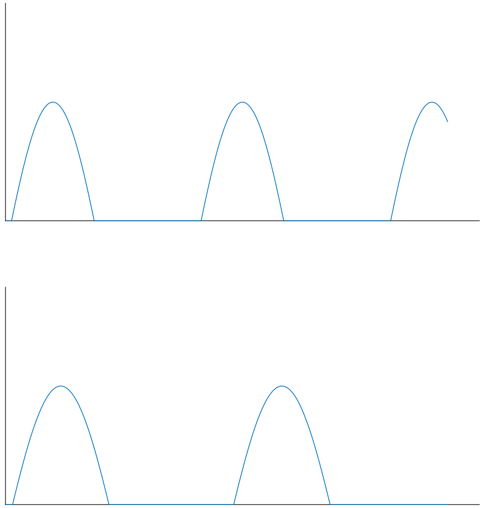


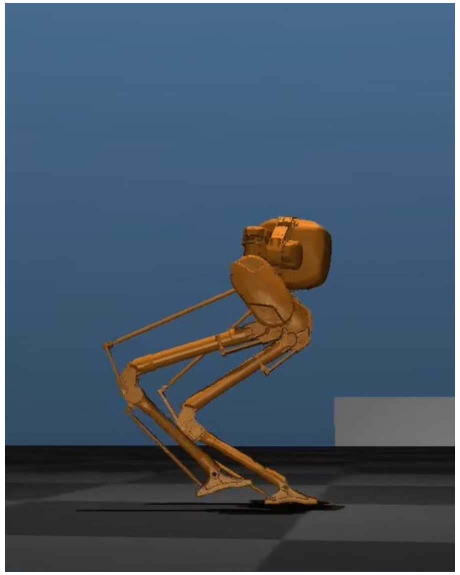


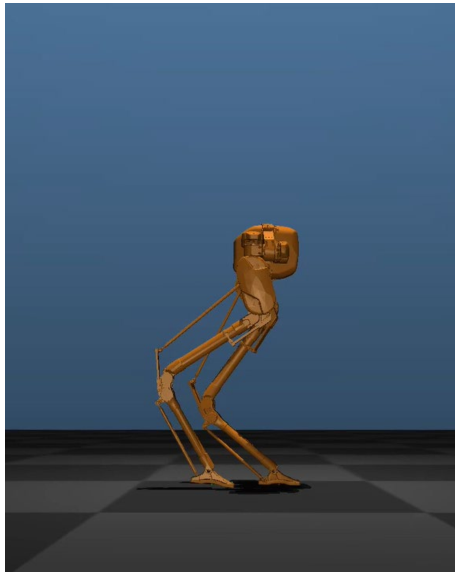
Results

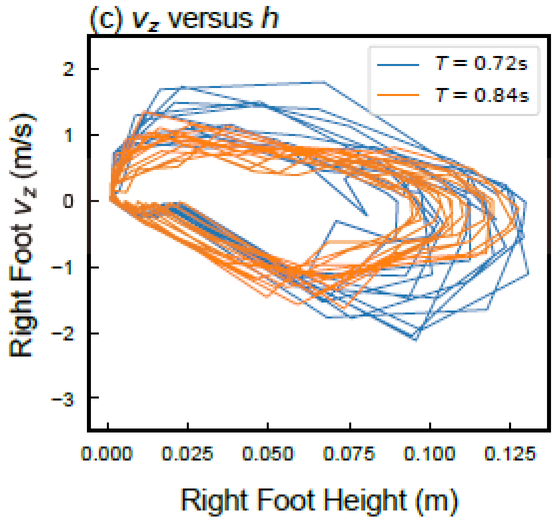
- Different styles: changing T

$T = 0.72$ s $\quad$ $\mathrm{T} = 0.84$ s









Future Works

- What we have done:
  - Using this technique to verify the agility of a bipedal robot that is undergoing iterative design

- What's the next:
  - To adapt the sine waves to more periodical motions
  - To achieve sim2real on different robot platforms

Thanks for watching!

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Codes and this PPT: https://github.com/WooQi57/sin-cassie-rl