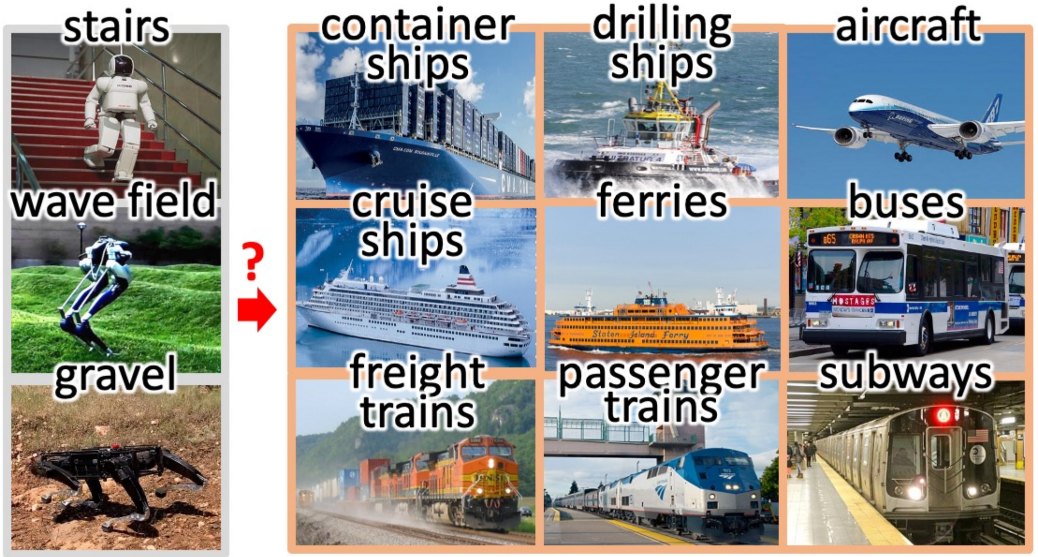
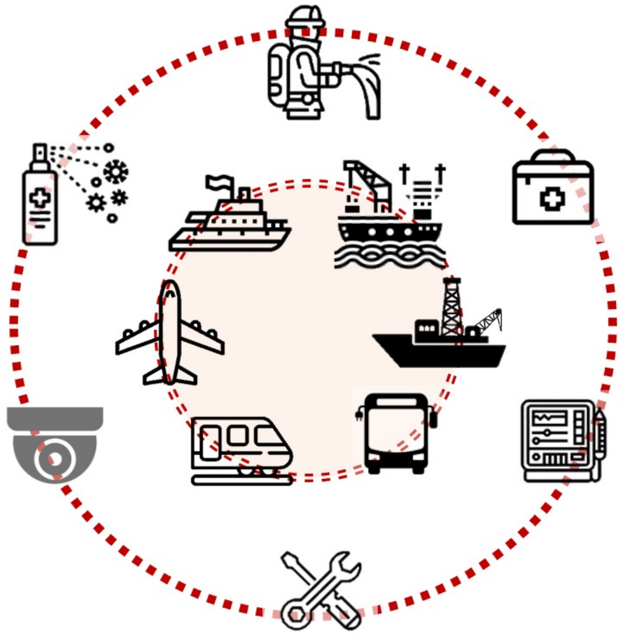
CAREER: A Hybrid Filtering and Robust Control Framework for Legged Robot Locomotion on Dynamic Rigid Surfaces

Yan Gu, University of Massachusetts Lowell (UML)

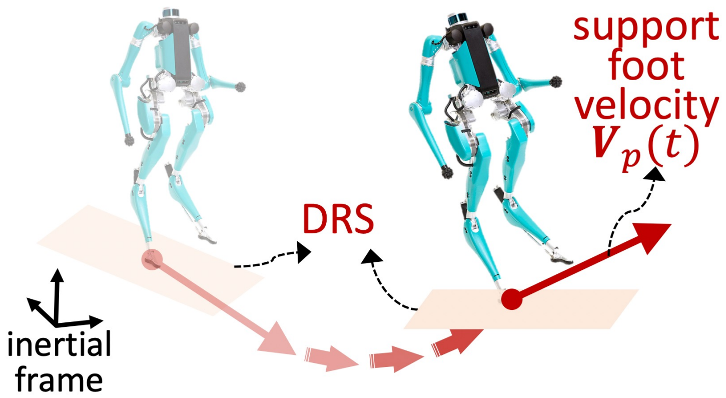
Legged locomotion on dynamic rigid surfaces (DRS) is a new robot functionality



Applications of DRS locomotion



Hybrid, time-varying robot dynamics



Research Goal: To draw upon modeling, state estimation, feedback control, and theory of hybrid systems to create a model-based control framework that explicitly addresses hybrid, time-varying legged robot dynamics for producing provably stable locomotion on a DRS.

2022 NRI & FRR Principal Investigators' Meeting
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Technical Approach and Innovations:

- Creation of physics-based models describing the hybrid, time-varying robot dynamics associated with legged locomotion on a DRS.
- Derivation of a real-time, provably convergent state estimator that explicitly addresses the hybrid, time-varying robot behaviors of DRS locomotion.

Provably stabilizing control for hybrid time-varying dynamics

Continuous-phase dynamics:

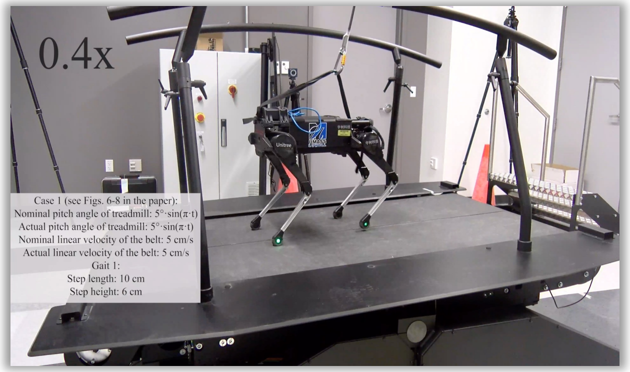
$$\begin{cases} M\ddot{q} + h(q,\dot{q}) = J^T F + Bu \\ J\ddot{q} + \dot{J}\dot{q} = A_p(t) \end{cases}, \quad \text{if } (t, q, \dot{q}) \notin S$$

Landing-impact dynamics (i.e., state-triggered jumps):

$$\begin{bmatrix} q^+ \\ \dot{q}^+ \end{bmatrix} = \Delta(q^-, \dot{q}^-, V_p^+), \quad \text{if } (t, q, \dot{q}) \in S$$

Foot-landing event:

$$S := \{t, q, \dot{q}: \ h_{sw}(t, q) = 0, \dot{h}_{sw}(t, q, \dot{q}) < 0\}$$



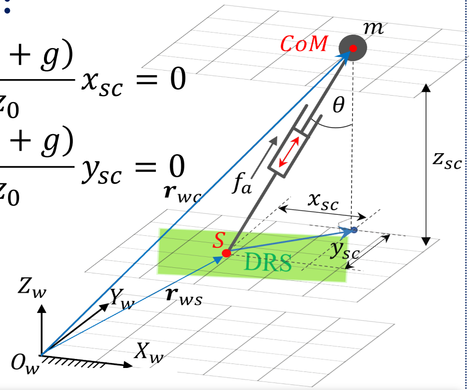
(*Preliminary work*: A. Iqbal, Y. Gao, Y. Gu, IEEE TMECH, 2020.)

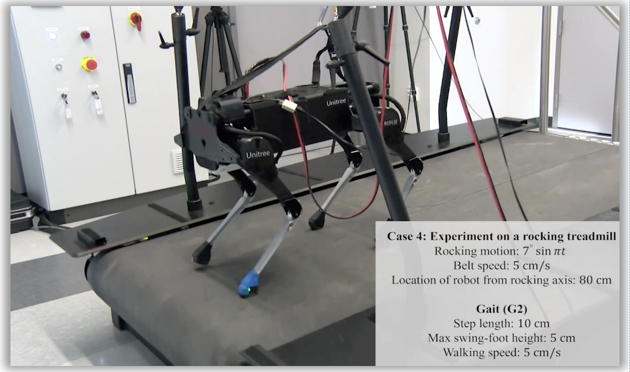
Linear inverted pendulum (LIP) model for DRS locomotion

DRS-LIP:

$$\ddot{x}_{sc} - \frac{(\ddot{z}_{ws} + g)}{z_0} x_{sc} = 0$$

$$\ddot{y}_{sc} - \frac{(\ddot{z}_{ws} + g)}{z_0} y_{sc} = 0$$





(A. Iqbal, S. Veer, Y. Gu, IFAC MECC 2021 & manuscript in preparation.)

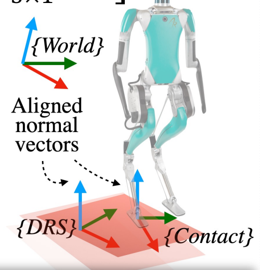
Hybrid invariant filtering

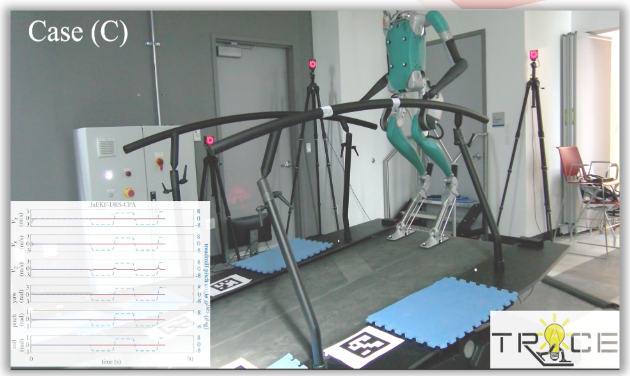
Right-invariant observation:

$$\begin{bmatrix} h_R(\tilde{q}_t) \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \\ 0_{3\times1} \end{bmatrix} = X_t^{-1} \begin{bmatrix} \tilde{R}_t^{DRS}(\tilde{q}_t) \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \\ 0_{3\times1} \end{bmatrix} + V_{1,t}$$

Identity error jump map:

$$\Delta(X_1 X_2) = X_1 \Delta(X_2)$$
$$\Delta(X_1 X_2) = \Delta(X_1) X_2$$





(Y. Gao, C. Yuan, Y. Gu, IFAC MECC 2021 & manuscript under review.)

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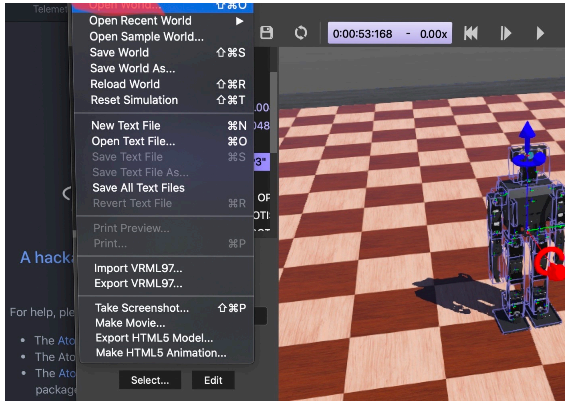
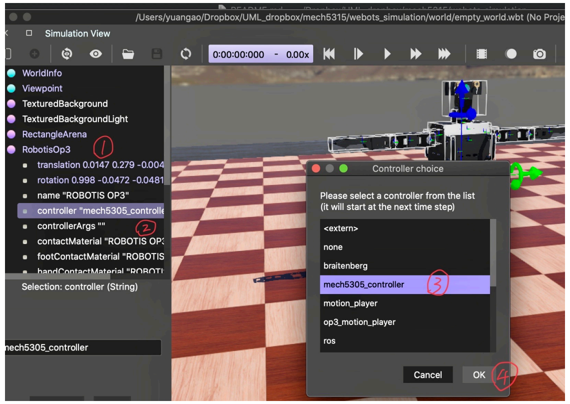
Scientific Impact:

- The research outcomes could be generalized to dynamic deformable surfaces (e.g., tree branches and sea ice) for monitoring and protecting natural lands such as forests and the arctic, as well as to autonomous locomotion on nonstationary (rigid or deformable) surfaces.

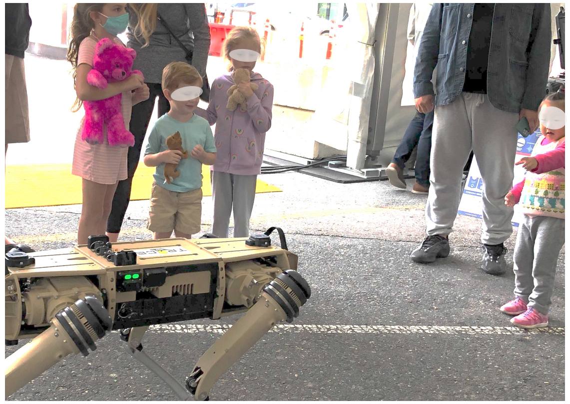
Outreach and Education:

- Strengthening UML's robotics curriculum for undergraduate and graduate students.
- Outreach to K-12 students and the general public during MassRobotics' Robot Block Party.
- Providing robotics research experiences for undergraduate underrepresented minority and female students at UML.





Course project website: https://github.com/TRACE-Lab/MECH-5305-Introduction-to-Legged-Locomotion



Robot Block Party event website: https://www.massrobotics.org/2021/10/05/robo-boston-and-massrobotics-4th-annual-robot-block-party/

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