DARPA Grand Challenge Event -2
Progress and Tepra Paper

The Ohio State University

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Outlines

- Review of Event & Challenge for OSU
- TEPRA Paper and Progress
- Modifications Needed
- Related Work and Future Plans

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Event and Challenge for OSU

Event 2 (Rough Terrain Walking)

——To design new gaits and control scheme for Hubo to walk on rough terrains

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Experiment Environment Created

- Sand
- Grass
  - Short
  - Tall
- Rocks

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Major Contributions of our TEPRA Paper

- Study the characteristics and modeling of the thre e kinds of rough surfaces - grass, sand, and rocks
- Develop two new types of gaits

  - Step-over gait

  - Ski-type quadruped gait

  for negotiating rough terrain

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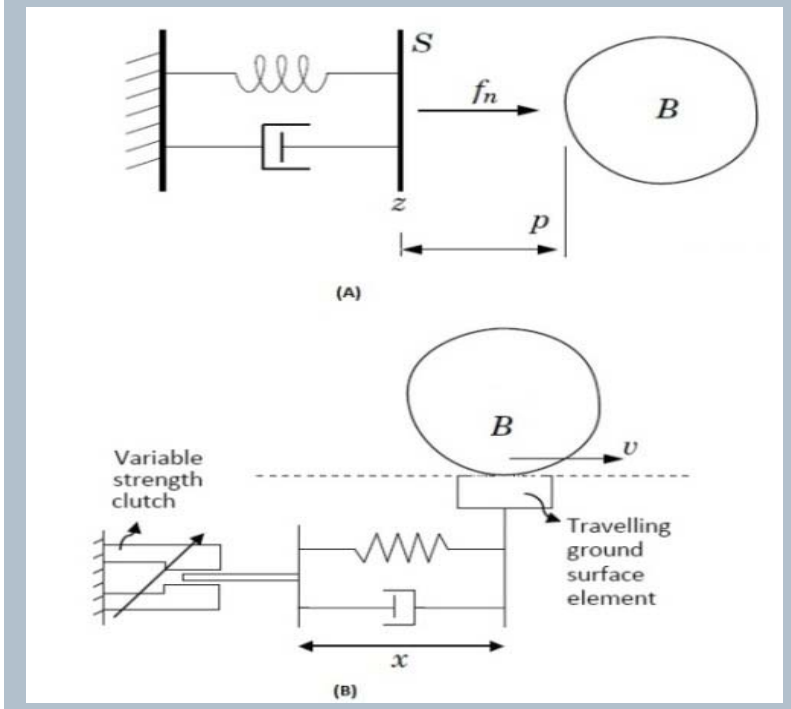
Characteristics and Modeling of Rough Surface

- Modeling vertical and friction forces



$$f_N = \begin{cases} 0 & if\ p > z \\ \max(0, -K_N z^n - D_N p^n \dot{p}) & \text{if } p = z \end{cases}$$

$$f_T = \begin{cases} -\mu f_N & if\ f_{stick} < -\mu f_N \\ \mu f_N & if\ f_{stick} > \mu f_N \\ f_{stick} & if\ otherwise \end{cases}$$

$$f_{stick} = -K_T x - D_T v$$

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Characteristics and Modeling of Rough Surface - continued

- Grass: hybrid layer surface with a solid base and a compliant top layer
- Sand: relationship between subsidence of sand with the vertical load:

$$F = kb(\frac{z}{b})^n A$$

  - *(L. Zhang, L. Wang, F. Wang, K. Wang, 2009)*
- Rocks: highly rugged and irregular
- All these 3 kinds of surfaces allow deformations, resulting in instability problems

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Proposed New Gaits for Rough Surface Walking

– **Step-over gait**

Basic Idea:

1. Lift swinging foot high to avoid tripping due to numerous small obstacles on rough terrain
2. Achieve better compliance when the foot put down

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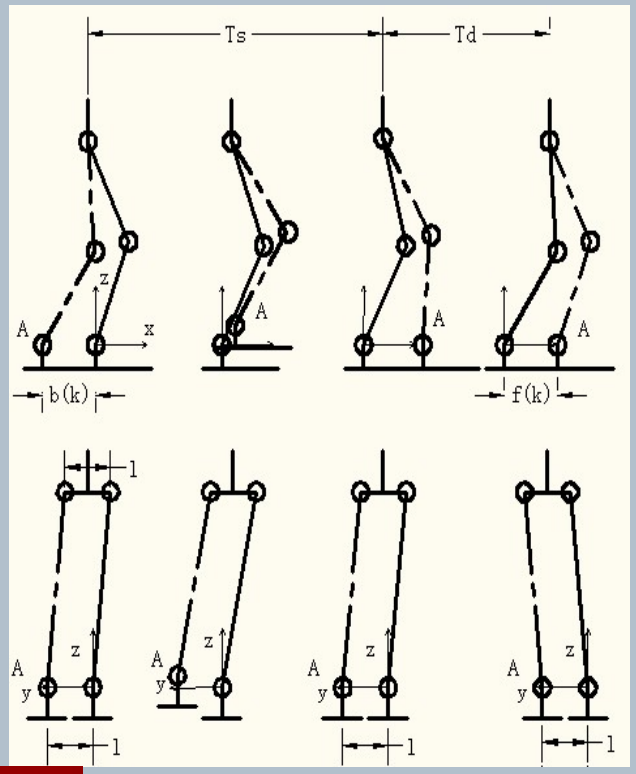
Step-over gait trajectories

- Consider both single support (SSP) and double support (DSP) phases
- Design adequate boundary conditions
- Develop smooth trajectories between



$$
\begin{cases}
x_a(k(T_s+T_d)) = b(k) \\
x_a(t) = f(k) \quad when\ k(T_s+T_d)+T_s \le t \le (k+1)(T_s+T_d) \\
\dot{x}_a(k(T_s+T_d)+T_s) = 0 \\
y_a\big(k(T_s+T_d)\big) = l \\
y_a(t) = l \quad when\ k(T_s+T_d)+T_s \le t \le (k+1)(T_s+T_d) \\
\dot{y}_a(k(T_s+T_d)+T_s) = 0 \\
z_a\big(k(T_s+T_d)\big) = \bar{z}(k) \\
z_a(t) \ge 1.1h(k) \qquad when\ k(T_s+T_d)+\varepsilon T_s \le t \\
\qquad\qquad \le k(T_s+T_d)+(1-\varepsilon)T_s \\
z_a(k(T_s+T_d)+T_s) = \tilde{z}(k) \\
z_a(k+1)(T_s+T_d) = -\tilde{z}(k+1)
\end{cases}
$$

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Step-over gait – Advantages and Problems

Advantages:

- Avoiding small obstacles completely
- Vertical landing for easy compliance
- Adaptive foot height at the beginning of each step to avoid different sizes of obstacles

Problems:

- Not very energy-efficient
- Cannot achieve high speed
- Marginal stability

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Experiment Video

..\Tutorial\IMG_0242.MOV

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Proposed New Gaits for Rough Surface Walking

– Ski-type Quadruped Gait

- Basic Idea: For really tough conditions, quadruped walking will be much more stable than biped walking
- Unfortunately, Hubo has a limitation in the range of hip joints, which prevents the waist from fully bending to put the arm on the ground. Also arms are too short and weak.

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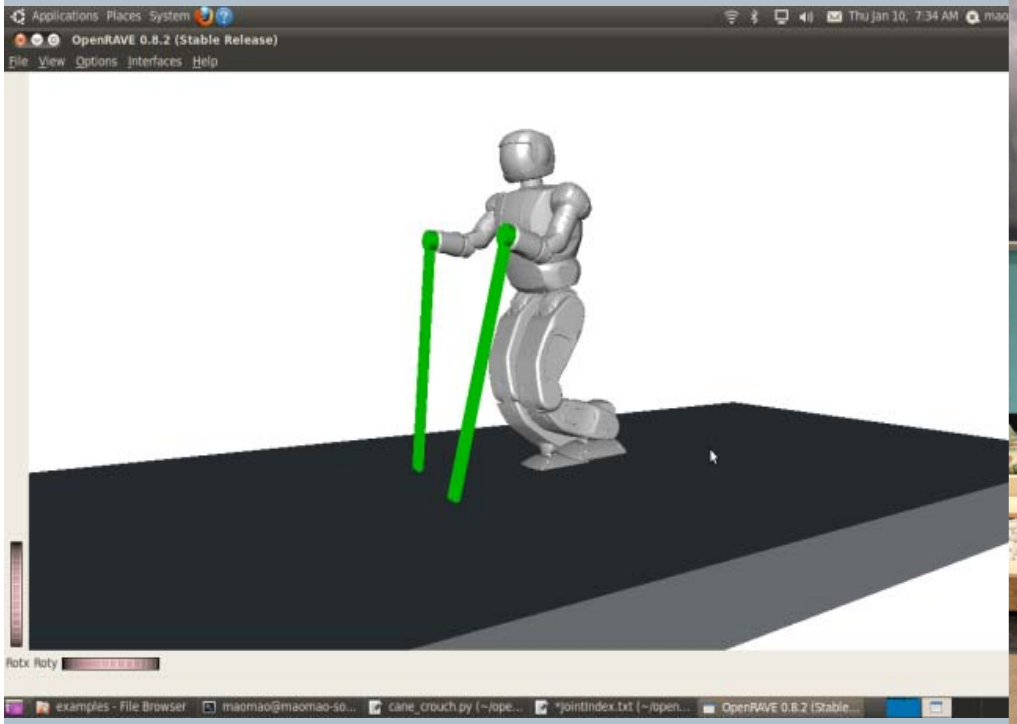
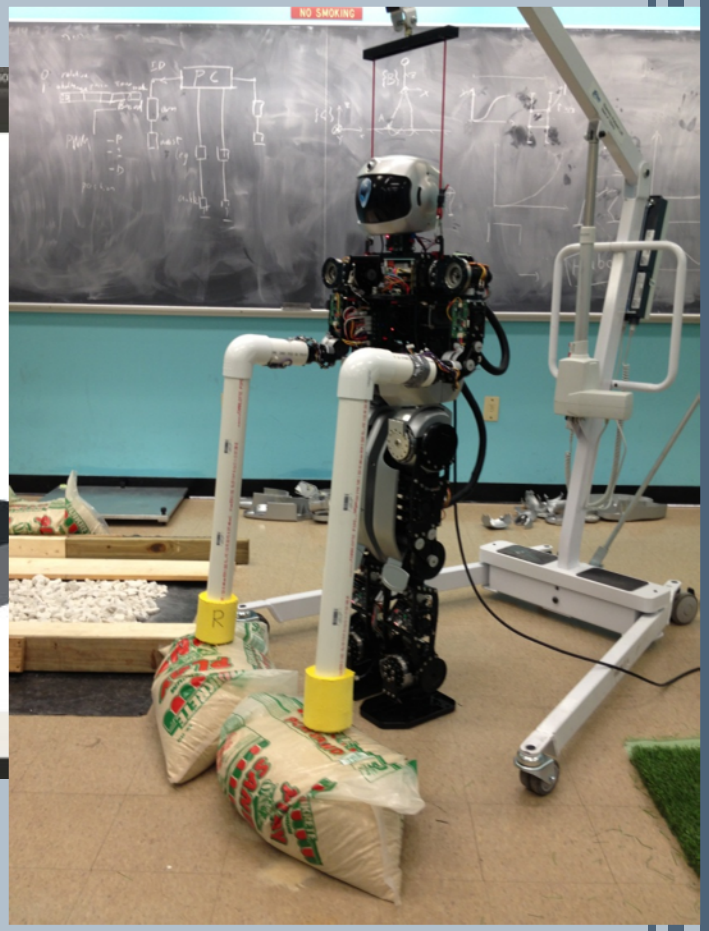
Design Ski-Type Quadruped Gait Walking

- Design the canes - openRAVE
- Install the canes – on Hubo





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Simulation Video

- A number of ski-type quadruped walking gaits developed
- The gaits have been simulated by Matlab
- OpenRAVE is difficult to simulate the ski gait.

test-0010.mpeg

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Modifications Needed to Hubo

- Turn an originally designed biped robot to a qua-druped robot is a challenge
- Strong shoulder and elbow joints so that the arms can support the weight of the body
- To lift the canes, the elbow and should joints need to be stronger
- Increase the compliance capability of the feet so that the feet can adapt to different kinds of rough surface
- Need vision system to find the best spot for foot - holds.

Future Plan and Related Work to do

- Apply the Ski-type quadruped gait to Hubo
  - Understand and modify the control software
  - Implemented simulation-proved gaits on the Hubo robot
- Build a compliance control scheme in Hubo using sensory feedback and apply it to Step-over and Ski-type quadruped gaits

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Thank you!

Questions Please

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