Czech
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Sensing and Modeling of Terrain Features using Crawling Robots

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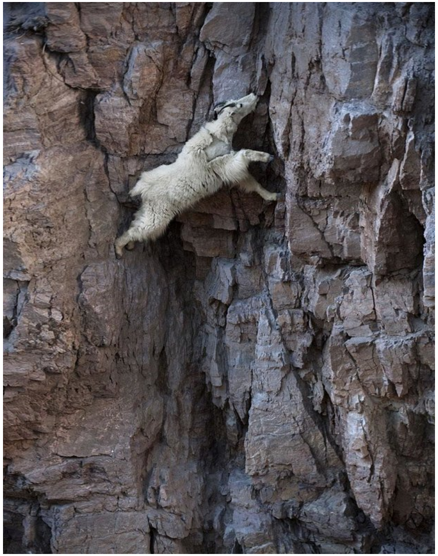
Motivation

Possible scenario : Robots operating autonomously in an unstructured and/or unexplored and/or changing environment

e.g., data collection, surveillance, search-and-rescue, . . .

Why Crawling Robots?

They have much better potential on challenging terrains.
Imagine wheeled robot on such terrain. . .



A lot of technical solutions are inspired from nature. And, no animal has wheels. . .

Cost of Complexity

Wheeled robot

- Left + Right
  (Steering + Accelerating)
- **2 controllable DOFs**

Crawler

- 6 legs, 3 joints each
- **18 controllable DOFs**
- Exact planning in 24 dimensions replaced by walking patterns (gaits)

Walking Pattern – Gait

Traversing rough terrain using predefined (fixed) gait – viz videos:

- Default gait (designed for flat terrain)
- Stairs-traversing gait (designed for specific purpose)

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Desired Gait Properties

- Adaptability to various terrains
- Smooth motion to eliminate bounces (e.g. camera on-board)
- Energy efficiency (avoid damage)

Approaches

Plan each foothold using a terrain map

- Off-line map from external camera system [Kalakrishnan *et al.*, 2011]
- On-board laser scanner [Belter *et al.*, 2011]
- On-board stereo vision [Shao *et al.*, 2012]

Tactile sensing

- Force sensors [Winkler *et al.*, 2014]
- Estimate force at the tip from torque sensor [Walas *et al.*, 2011]
- Add passive servo for measuring ground force [Palmer *et al.*, 2011]

All approaches utilize additional components (increase the complexity of the platform)

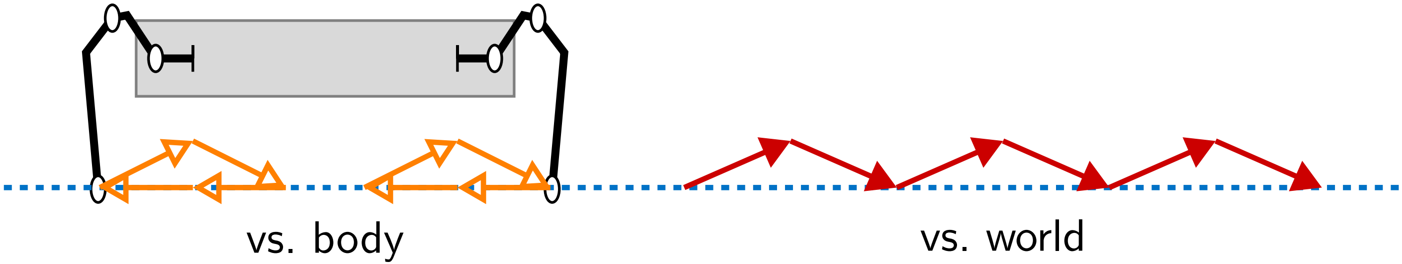
Hexapod Platform

PhantomX Hexapod Mark II

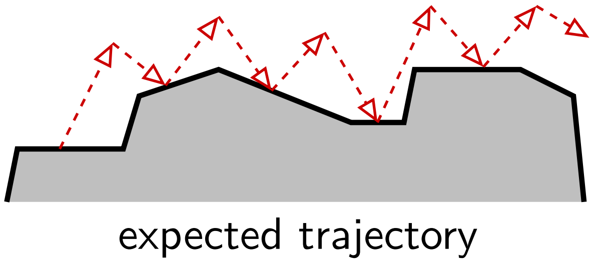
- Mass produced robot
- 18 identical smart servo drives
  - Dynamixel AX-12A
  - Position controlled
  - Can send feedback
- No other sensors – robot is technically **blind**

Proposed Approach

- Based on the default gait, which generates regular leg trajectories:



- Rough terrain requires irregular gait:

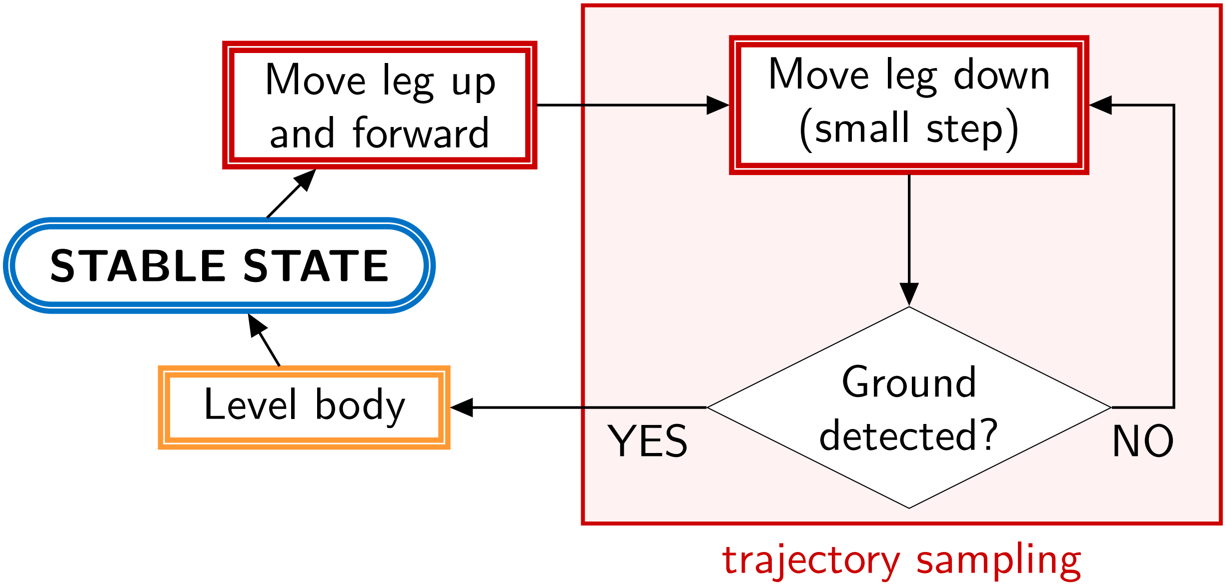


Need to detect the surface contact points

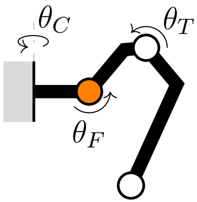
Proposed Approach

- Keep the legs in contact with the ground (avoid bounces)
- Separate leg and body motion

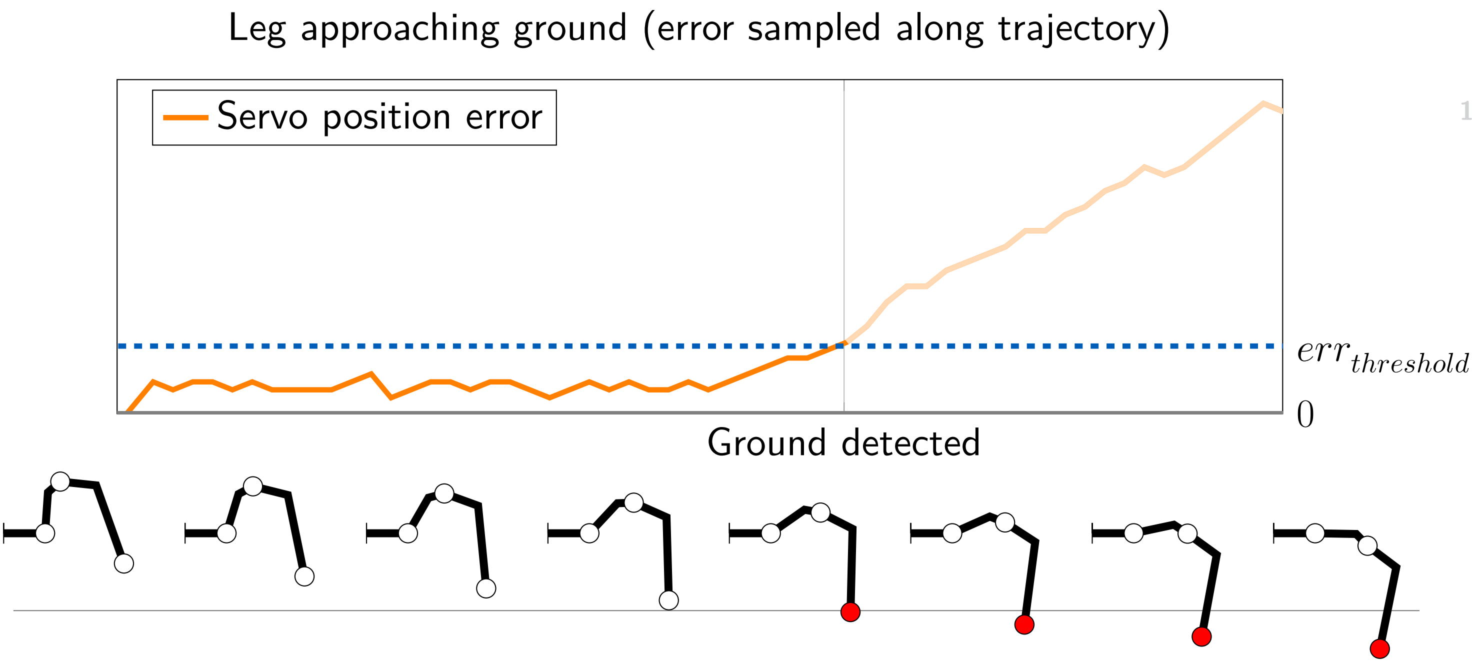
Do not move the body until new footholds are reached



Ground Detection



Using middle joint (θ_F) servo drive position error to emulate tactile sensor



Body Motion

- We assume the environment satisfies the robot's construction limits
- Keep the legs inside their working space (avoid awkward configurations)

New body posture is computed using only the foot positions (relative to the body)

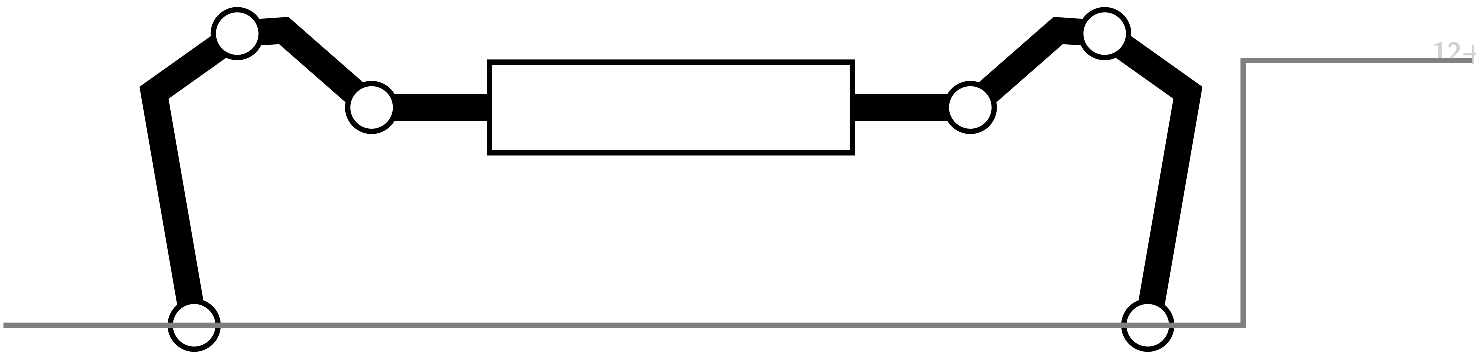
1) Compute an approximated ground plane (footholds linear regression) $(z = ax + by + c)$
2) Rotate the body parallel to the plane (z)
3) Shift the body to:
   - keep the same height above the ground
   - the "center" of the foot positions

$$\bar{R} = \begin{bmatrix} 1 & -ab & -a \\ 0 & a^2+1 & -b \\ a & b & 1 \end{bmatrix}$$

$$\vec{t} = \begin{bmatrix} \frac{\vec{R}_x}{6||\vec{R}_x||} \sum \vec{x} \\ \frac{\vec{R}_y}{6||\vec{R}_y||} \sum \vec{x} \\ \frac{c}{||\vec{R}_z||} - h \end{bmatrix}$$

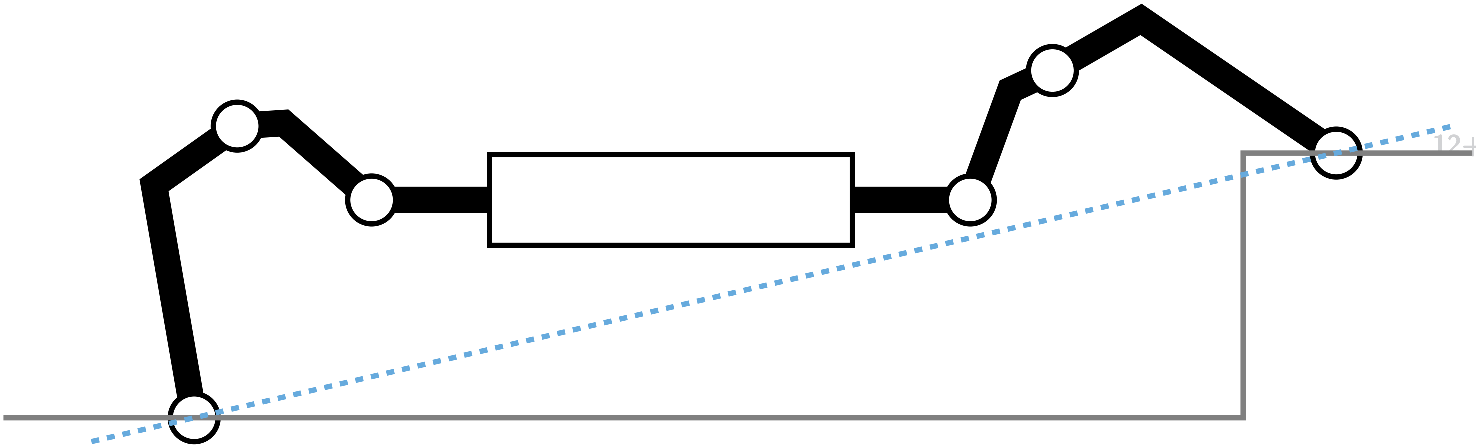
Body Motion

- Default position



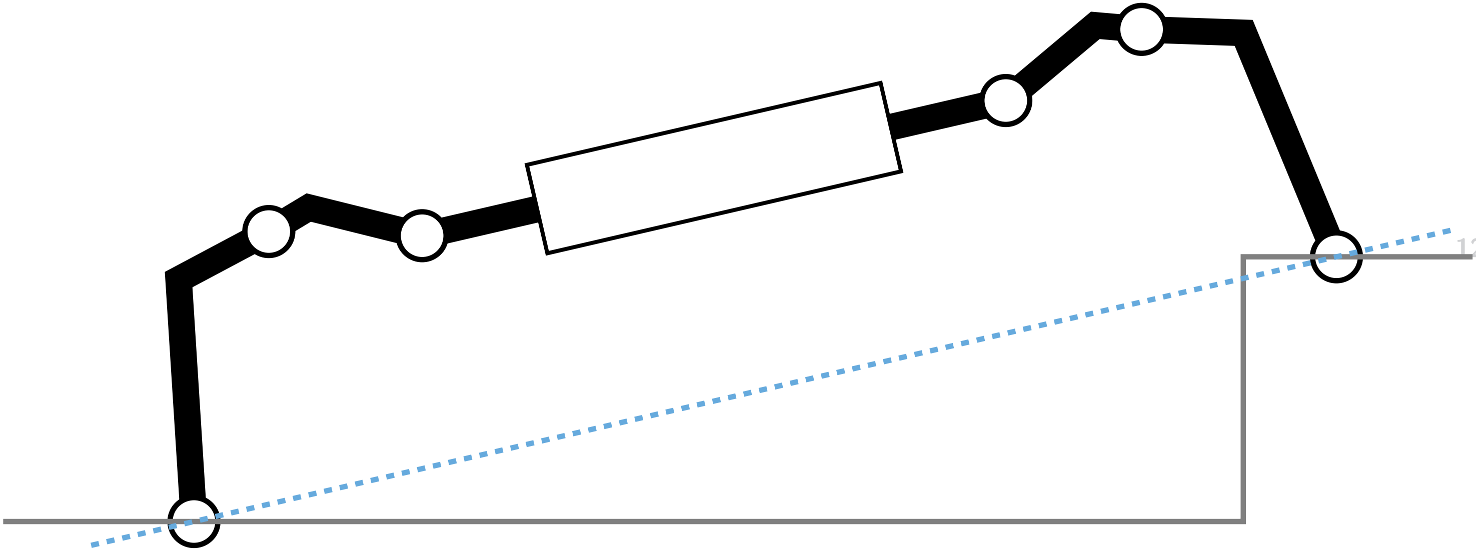
Body Motion

- After leg motion



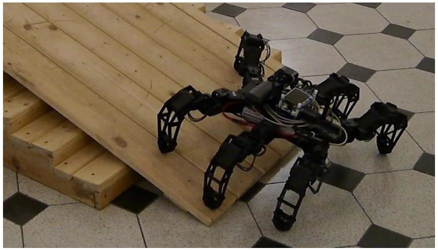
Body Motion

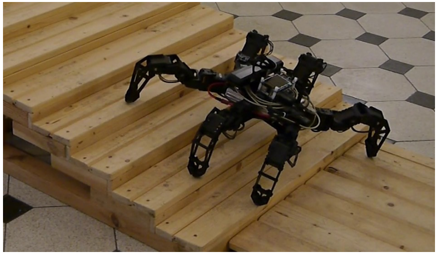
- Body leveled (applied transformation on all legs)

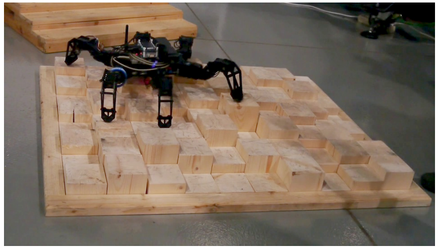


Videos

- Adaptive gait experimentally tested on:
  - inclined plane
  - stairs
  - wooden blocks of various height





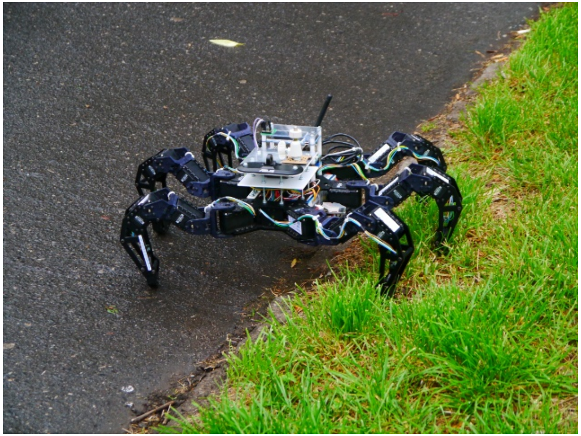


- Adaptive gait is able to deal with various terrains
- Slower, but smoother motion
- Prevents servo overloading on challenging terrain
- Easily applicable on various regular gaits (tripod, ripple,. . .)

Terrain Classification

Recognized terrain class is another useful information for:

- Planning
- Localization
- Mapping
- Gait selecting



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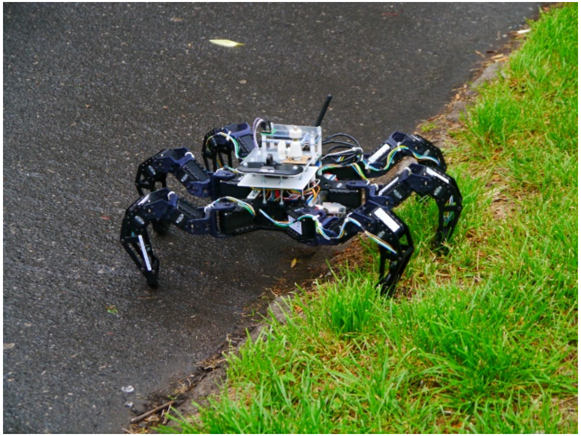


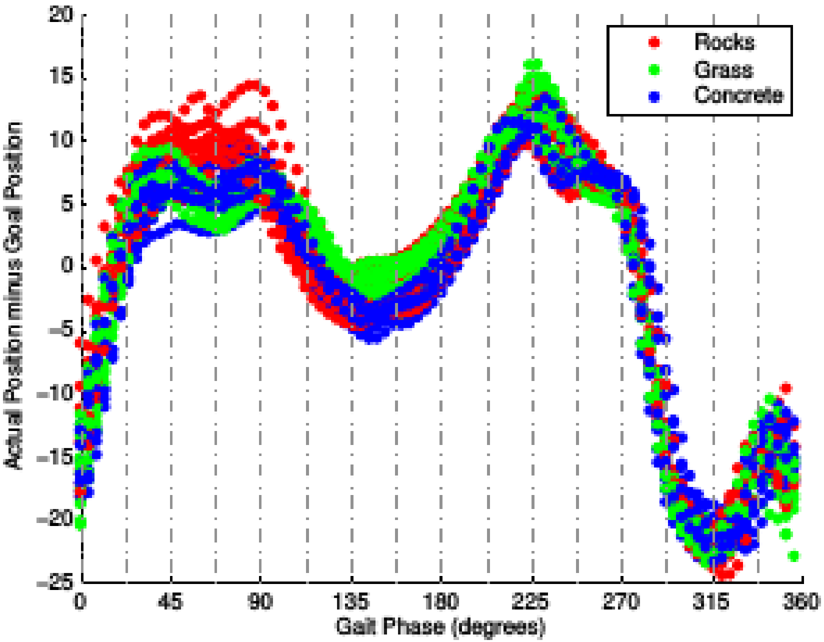
Additional sensors increase complexity

Most of the terrains are not flat – focus on rough

Default Gait Analysis

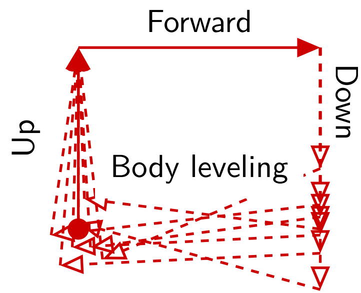
[Best et al., *2013] „Terrain classification using a hexapod robot"*

- Used a default gait (walking pattern) – **can walk only on flat surfaces**



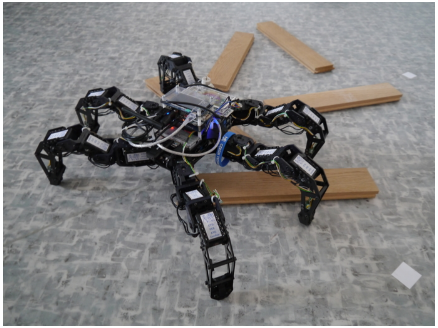
Adaptive Gait Analysis

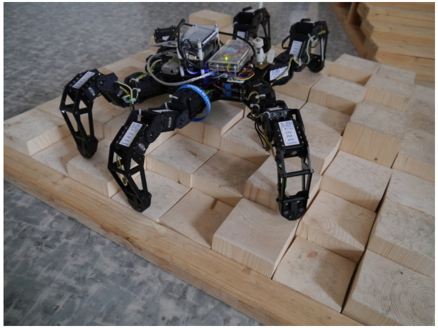
- The gait is no longer regular
- Data = servo drive position error (desired minus actual position)
- 1 cycle of adaptive gait has 8 phases (4 per each leg triplet)
- Data in respective phases are gathered during last 3 cycles
- Basic statistics are computed (min, max, avg, std, median)
- 2 front legs * 3 servos * 8 phases * 5 values = 240 features
- 1 feature vector after each gait cycle
- Multi-class linear SVM is trained (7 classes)



Experimental Results

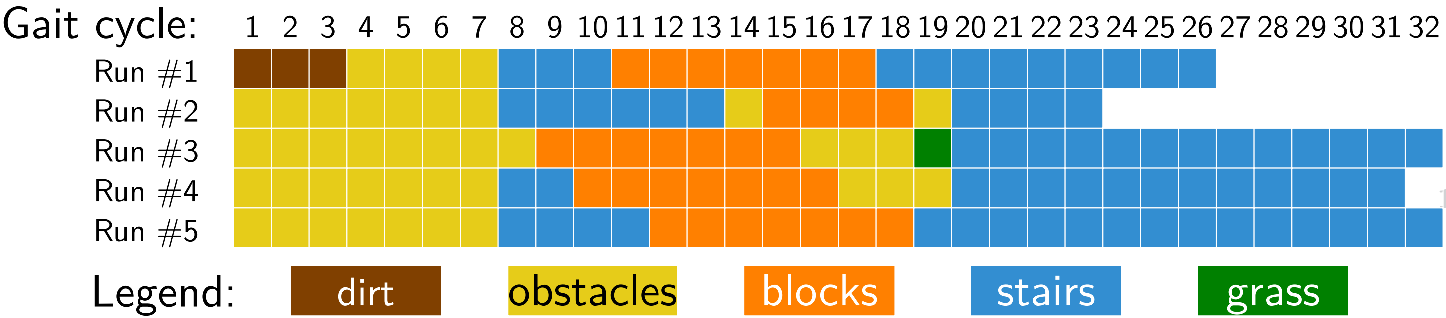
- 4 flat terrains (asphalt, dirt, grass, office floor)
- 3 rough terrains





- 100% accuracy when cross-validating training datasets

Testing Scenario



Classification-based Control

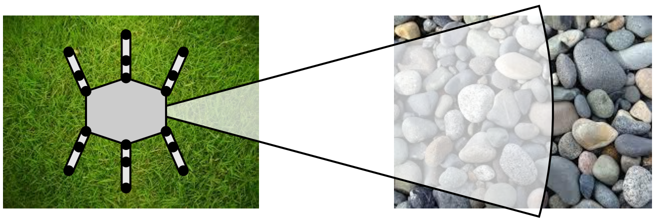
Courtesy of Martin Stejskal

Cost-based Planning

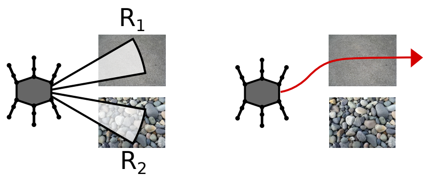
The "real" cost of the motion (e.g., energy consumption) cannot be usually seen from the terrain shape.

We need to associate the cost with known terrain features.

- Robot walking through environment and collecting data from all sensors
- Analysing data and computing both specific terrain features and cost of motion (traversability cost)
- Feature-Cost Mapping combining exteroceptive and proprioceptive sensors



Proprioceptive   Exteroceptive



$C_e \to C_p \to \mathrm{cost}(r_1) < \mathrm{cost}(r_2)$

Thank you for your attention

Questions?