Outline

Outline (cont.)

Motivation

- Enabling locomotion in difficult terrain
- Legs can be used for other things
- Necessary to integrate robots in a human environment


[3]


[4]

[3] http://1.bp.blogspot.com/-MhFnvPPR5V4/UmifTu4r_OI/AAAAAAAAFtI/FvJqeWu9Ahc/s1600/13-pictures-of-crazy-goats-on-cliff-transparent.png

[4] https://www.allposters.com

Problems

- Stability
- Energy consumption
- Hardware costs
- Complex control

[5]

[5] https://www.wikihow.com/Recognize-the-Signs-of-Intoxication

Types of Walking

- Static - Dynamic
- Passiv - Active
- 2,4,6,8,... legged
- Open loop - closed loop
- This lecture: active bipedal walking, no running


6


7

[6] https://3c1703fe8d.site.internapcdn.net/newman/gfx/news/hires/2017/1-sixleggedrob-transparent.png
[7] https://asl.ethz.ch/research/legged-robots.html

Types of Implementing Walking

- Control Theory
- Neural Networks
- Central Pattern Generators
- Evolutional Computing
- Expert Solution

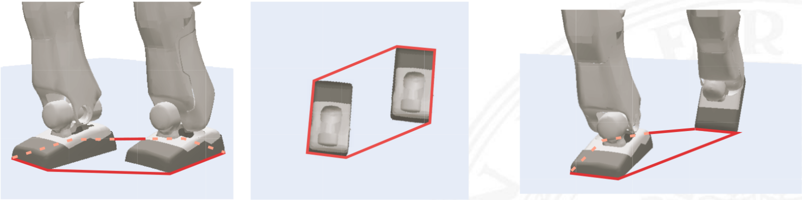
[8]

[8] https://de.wikipedia.org/wiki/Spline-Interpolation

Important Words

- Support leg/foot
- Flying leg/foot
- Torso / trunk
- Step / double step
- Sagittal / lateral

- Convex hull of all ground contact points

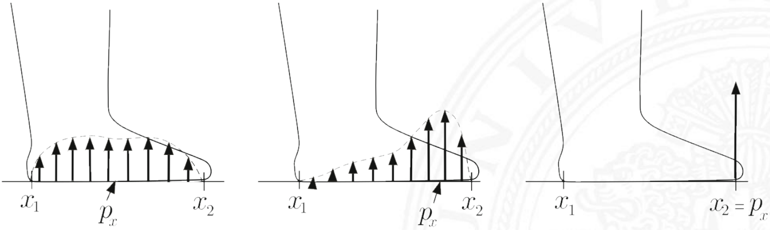


(a) Full contact of both feet (b) Partial contact [9]

[9] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Center of Pressure (CoP)

- Center of ground reaction forces
- Those can also be horizontal
- Moment becomes zero
- Equals the zero moment point (ZMP)

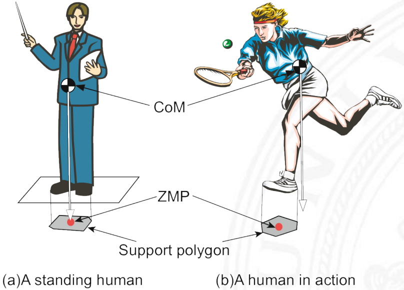


(a)Almost flat (b)Biased distribution (c)Concentrate at tiptoe [10]

[10] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Zero Moment Point (ZMP)

- When standing, projection of CoM coincides with ZMP
- When dynamic, CoM outside of support polygon
- ZMP is always inside support polygon

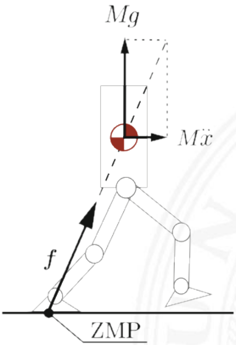


[11]

[11] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

ZMP

- Forces of the robot define position of ZMP
- Can it get outside of the support polygon?



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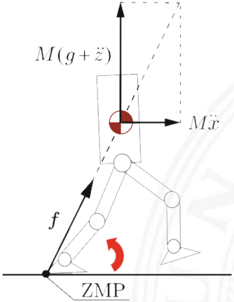
12 Introduction to Humanoid Robotics, Shuuji Kajita, 2015

- No! The ZMP is always in the support polygon
- If it is on an edge, the robot rotates



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[13] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Limitations of ZMP

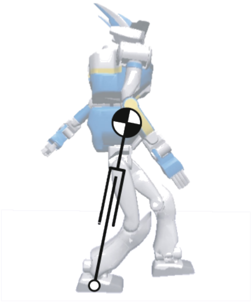
- Sole slips on ground
- Other parts of the robot are in contact with environment
- Ground is not perfectly level

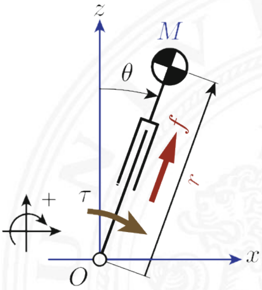
[14]

[14] https://www.reddit.com/r/rickandmorty/comments/70t45i/anyone_else_wish_heshe_could_experience_true_level/

Inverted Pendulum

- Simplest model for walking robot or human
- Point mass at end of massless telescopic leg
- f: kick force, tau: torque

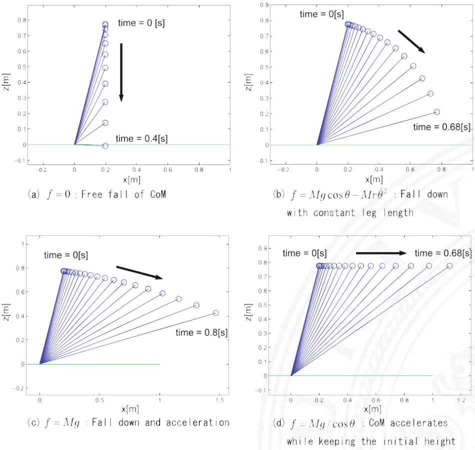




[15]

[15] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Inverted Pendulum

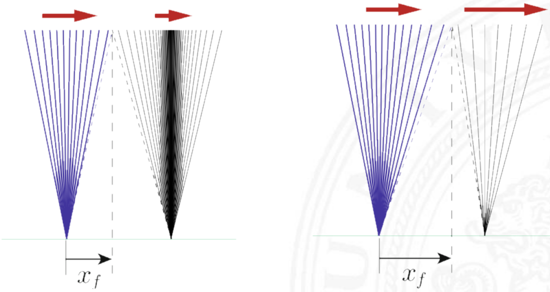


[16]

[16] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Support Leg Exchange

- Considering fixed step length
- Earlier touchdown of the next step results slow down
- Later touchdown of the next step results speed ups



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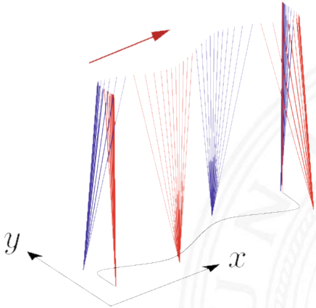
[17] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

3D Support Leg Exchange

- Transfer to 3D
- Introduction of lateral movement

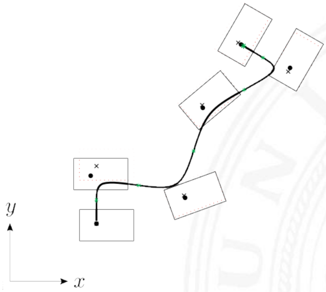


[18]

[18] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Omni-directional Walking

- Forward (x)
- Sideward (y)
- Turn (yaw)



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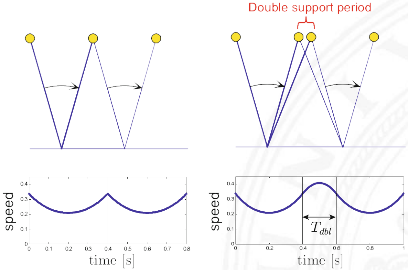
[19] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Double Support Phase

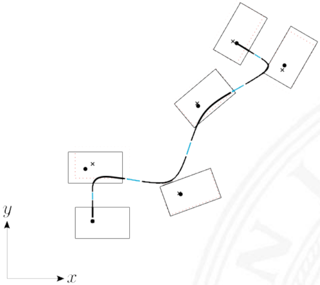
- Accelerations are extreme on support change
- Not feasible in reality
- Introduction of a double support phase



[20]

[20] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Double Support



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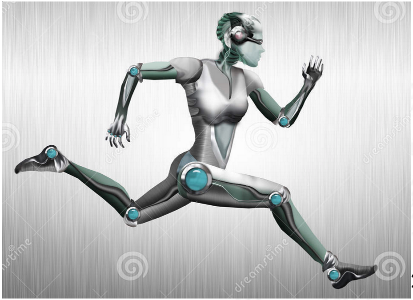
[21] Introduction to Humanoid Robotics, Shuuji Kajita, 2015

Zero Support


[22]

[22] https://thumbs.dreamstime.com/z/running-robot-27653003-transparent.png

?

- Why are we not finished yet?

Detecting Instability

Which senses do you think humans use for walking?

Detecting Instability

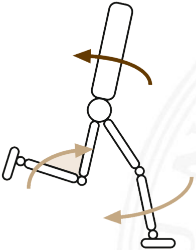
- Sensors
  - IMU(s)
  - Force sensors on foot sole
  - 6 axis force/torque sensor in ankle
  - Joint Torques
  - Camera
- Model
  - Joint positions
  - Link masses and inertia
  - Rigidity of links (especially foot soles)

Stabilizing Approaches

- Simple stopping
- Counter movements with the arms/torso
- Change of step position (capture steps)

Counter Movements with Upper Body

- Rotation around edge of support polygon
- Introduce counter force with arms/torso or flying leg
- Flying leg is mostly not usable



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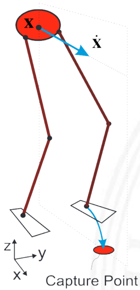
[23] Springer Handbook of Robotics, Bruno Siciliano, 2016

Capture Step

- Capture point is where the robot comes to a complete stop
- Multiple capture steps may be necessary
- You can completely base your walking on this



[24]

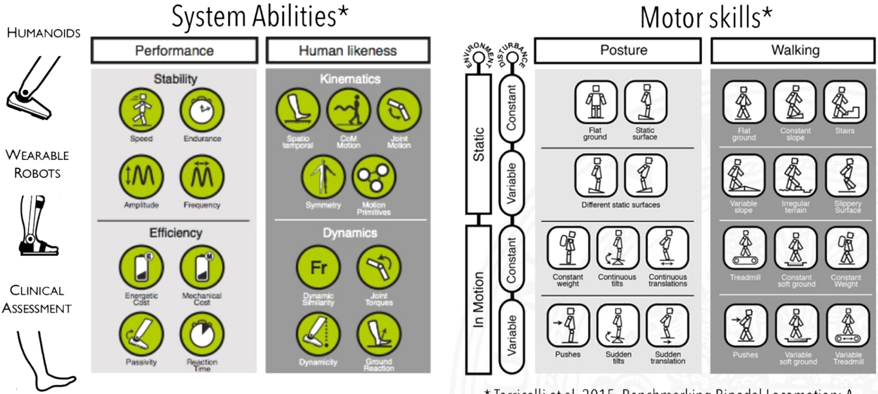
[24] https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6094435

Machine Learning

- We will not cover machine learning
- If you are interested join my lecture in "Intelligent Robotics" in the winter term
- General approaches are:
  - Learning parameter of a walking pattern generator (e.g. double support length)
  - Learning neural networks from scratch
  - Learning from demonstration
  - Artificial central pattern generators

Current State of the Art

- Some very expensive robot manage to solve the problem (at least most of the time) using control theory
- Cheaper robots still struggle to achieve really stable walking
- Machine learning approaches still mostly only work in simulation (reality gap)
- Working on better comparison between approaches, e.g. EuroBench

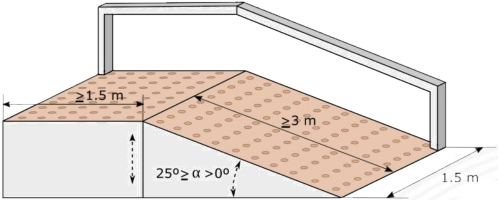


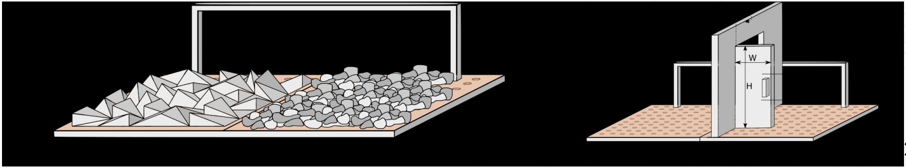
www.benchmarkinglocomotion.org

* Torricelli et al. 2015, Benchmarking Bipedal Locomotion: A Unified Scheme for Humanoids, Wearable Robots, and Humans

[25]

[25] http://eurobench2020.eu/abstract/motivation-background/





[26]

[26] Eurobench Guide for Applications

Full Body Motion

- Small overview of full body motions
- Examples are: walking with hand on handrail or standing up
- Higher complexity since all limbs are involved
- Breaks assumptions that are often made for normal walking
- Motions can be periodic or non periodic

Walking with Hand Contacts

- Using handrail, pushing cart, opening door, holding hands, using walking stick, collaborative carrying
- Introduces additional forces on the robot
- Support polygon maybe totally different
- More complex models have to be used
- Currently mostly used approach: quadratic programming
  - Solve problem of optimizing a quadratic function with multiple linear constrains
  - Use rigid body dynamics together with a model
  - Problems
    - Model is not perfect
    - If caring an object, you need a model of it
    - Robot is maybe not perfectly rigid

Non Periodic Motions

- Simpler due to known start and end
- Examples
  - Standing up
  - Kicking
  - Grasping
  - Waving

Implementing Non Periodic Motions

- Keypoint teach in
  - Put robot into key positions manually
  - Save joint positions at these points
  - Interpolate
  - Useful for simple motions (e.g. waving) or static robots
- Learning from demonstration
  - Either demonstrate on the robot itself or by using motion capture
  - Normally more than one demonstration
  - Not just simply replaying
- Cartesian splines
  - Define trajectories of the limbs with Cartesian splines manually
  - Comparably easy to do for humans (much better than joint space)
  - Splines configurable with few parameters
  - Use inverse kinematics to compute joint goals
  - Optionally use additional goals in the IK solver to keep balance

Implementing Non Periodic Motions

- DeepLearning
  - Just let it learn in simulation till it works
  - Put it on the robot and hope for the best
  - Reality gap
- Control Theory
  - Have an open loop trajectory, e.g. from teach in
  - Use a stability criterion, e.g. ZMP
  - Adjust joint goals with controller, e.g. PID
- More on the learning aspect in the intelligent robotics lecture

Questions

Questions?

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