

Dynamically Stable Walking For Humanoid Bipedal Robots Based On Walking Patterns

Bachelor Thesis

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Outline

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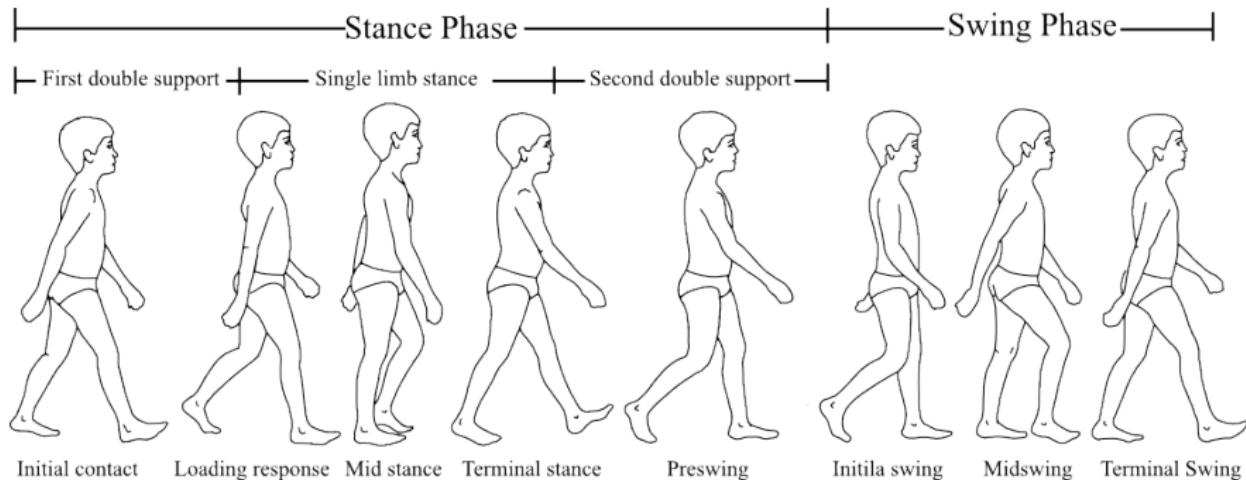
4 Push recovery

Why bipedal walking?

- Robots should be able to navigate in environments made for humans:
 - Little space
 - Obstacles
- ⇒ Wheeled base not flexible enough.
- **Problem:** How do you guarantee stability during walking?

The Human Gait

- Of primary interest for stability: Number of feet that are in contact with ground
- **Walking:** Dual support phase and single support phase.
- **Running:** Single support and no ground contact



Source: Dynamics of Human Gait

Application to robots?

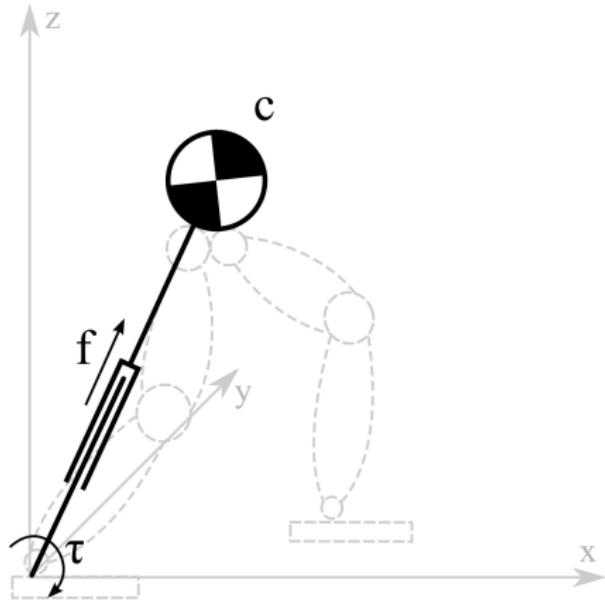
- ➊ Adapt recorded human motions to robot:
 - Kinematic structure different: Not clear how to map to robot
 - Dynamic properties (weight, inertia) different

→ Might not yield dynamically stable walking at all
- ➋ Derive stable trajectories from dynamic models of the robot:
 - Most popular: 3D-Linear Inverted Pendulum Model and ZMP
 - Simplification: Height of the CoM is constant with respect to ground
(only approximately true for humans see Orendurff et al. [5])

This work is build on the second approach.

3D Linear Inverted Pendulum Model

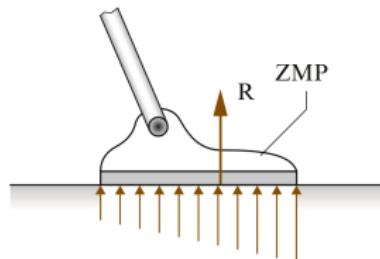
- Simplified dynamic description of robot
- Reduce robot to pendulum with massless rod and point contact
- *Linear actuator* in rod of pendulum
- Mass of robot gets reduced to the *CoM* (the head of the pendulum)
- To make the dynamics *linear* we constrain the head of the pendulum to a constant height



Zero Moment Point

If all contact forces are in the same plane, we can define the *Center of Pressure* as:

$$p := \begin{pmatrix} p_x \\ p_y \\ p_z \end{pmatrix} = \frac{\sum_{i=1}^N p_i f_{iz}}{\sum_{i=1}^N f_{iz}}$$



- Torque around x and y axis at this point is zero
- Thus we can call this point the *Zero Moment Point*.

Why is the ZMP interesting?

- ① Describes the *foot-floor contact dynamics* in case of flat ground contact
- ② Can be used to derive a *condition to ensure dynamically stable pose*: If the ZMP is **strictly inside the support polygon**, the foot-floor contact will be preserved.

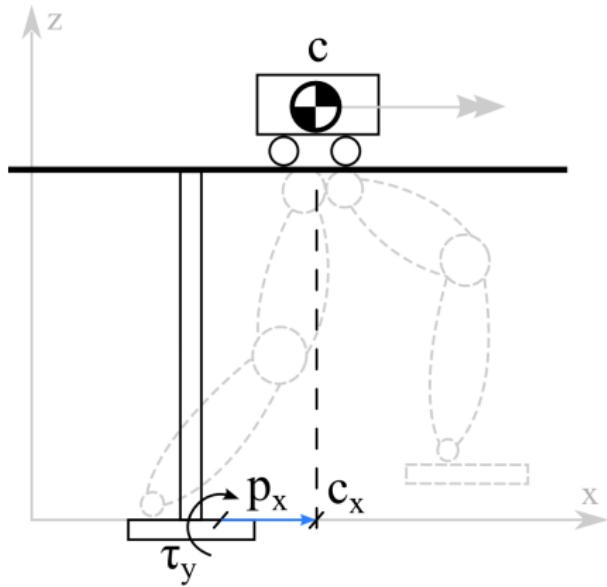
We will use 2. to derive dynamically stable trajectories by constraining the ZMP to the support polygon.

Cart-Table-Model

- Simple model to compute the ZMP
- Does not require knowledge about contact forces
- For each dimension: Cart on massless table
- Cart represents the CoM of the robot
- Foot of the table corresponds to the support polygon

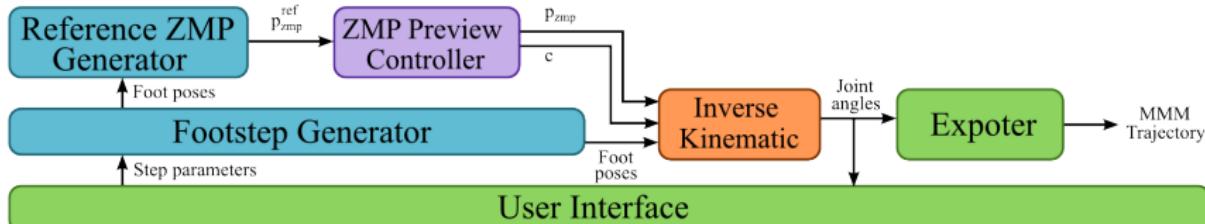
Resulting ZMP:

$$p_x = c_x - \frac{z_c}{g} \ddot{c}_x \quad (1)$$



Pattern generation as control problem

- **Idea:** Formulate dynamic walking as a control problem
- **Goal:** Realize given reference ZMP position
- **Result:** Array of system states (position, velocity, acceleration of the CoM and realized ZMP position)
- **Implementation:** Uses a Preview Controller (Kajita et al. 2003 [1]) that utilizes knowledge about the future trajectory



Video of pattern based walking



Motivation

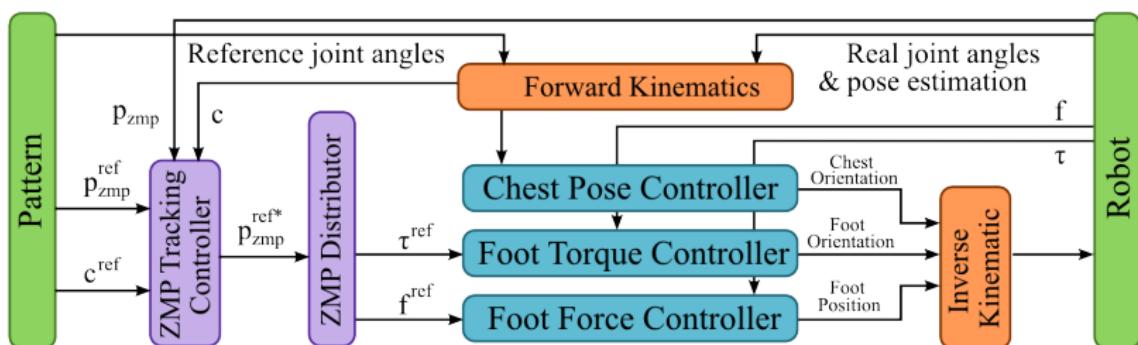
Walking Pattern Generation

Walking Stabilization

Push recovery

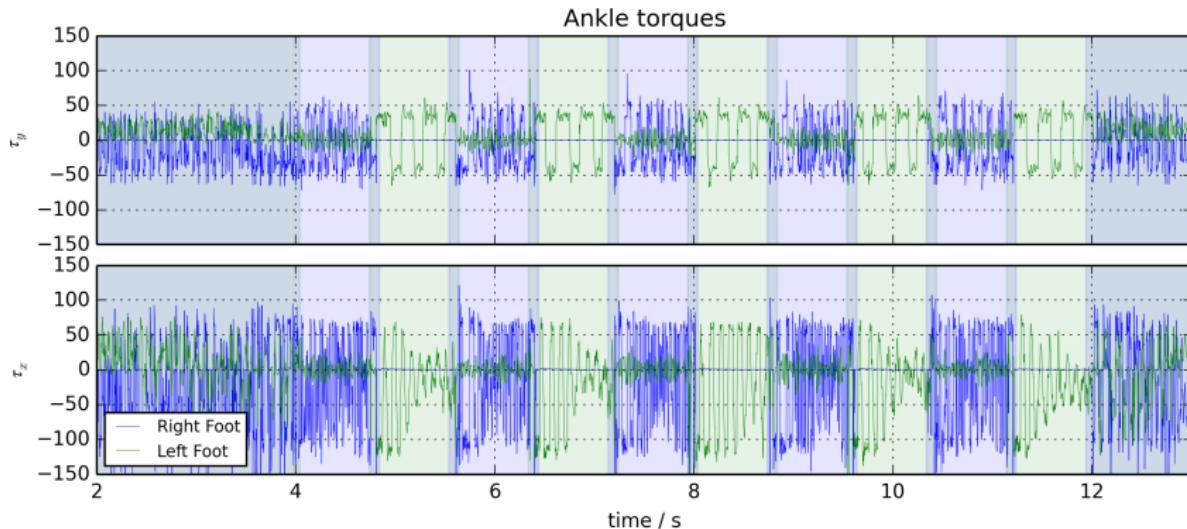
Stabilizer

- **Problem:** Disturbances cause instabilities (even though the pattern is dynamically stable!)
- **Solution:** Adapt pattern to disturbances → stabilizer
- **Implemented:** Stabilizer based on Kajita et al. 2010 [3]. Adapts frames in Cartesian space (no torque control needed).



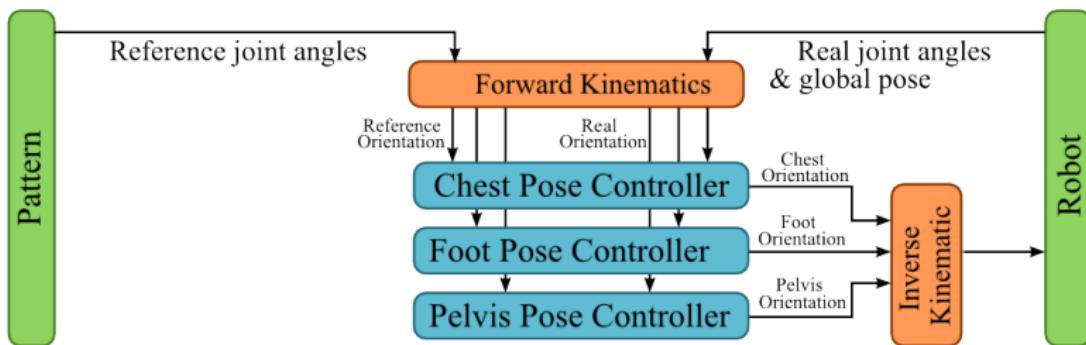
Ankle torques

Problem: Needs accurately measured torques. Bullet does not provide realistic torques.



Heuristic Stabilizer

- Works very similar to stabilizer proposed by Kajita
- Instead of torque feedback, we use the pose of error of the frames
- **Problem:** Accurately measuring pose error for each frame not possible in reality



Stabilized walking in a circle

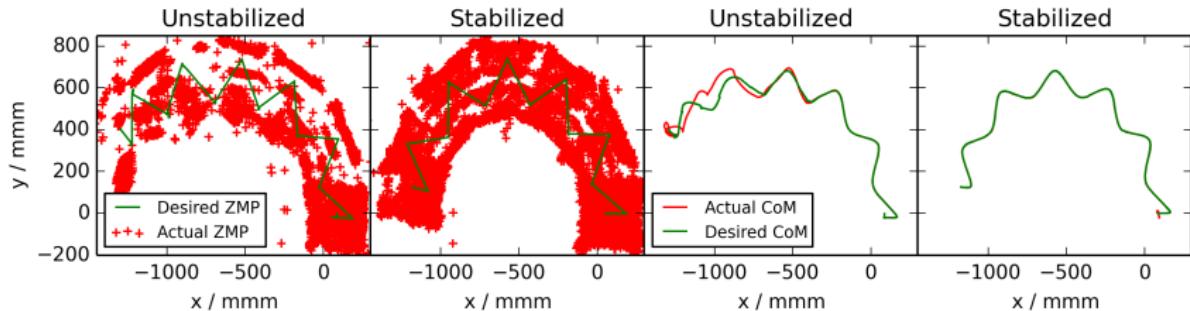


Figure: Walking in a half-circle.

Walking with disturbances

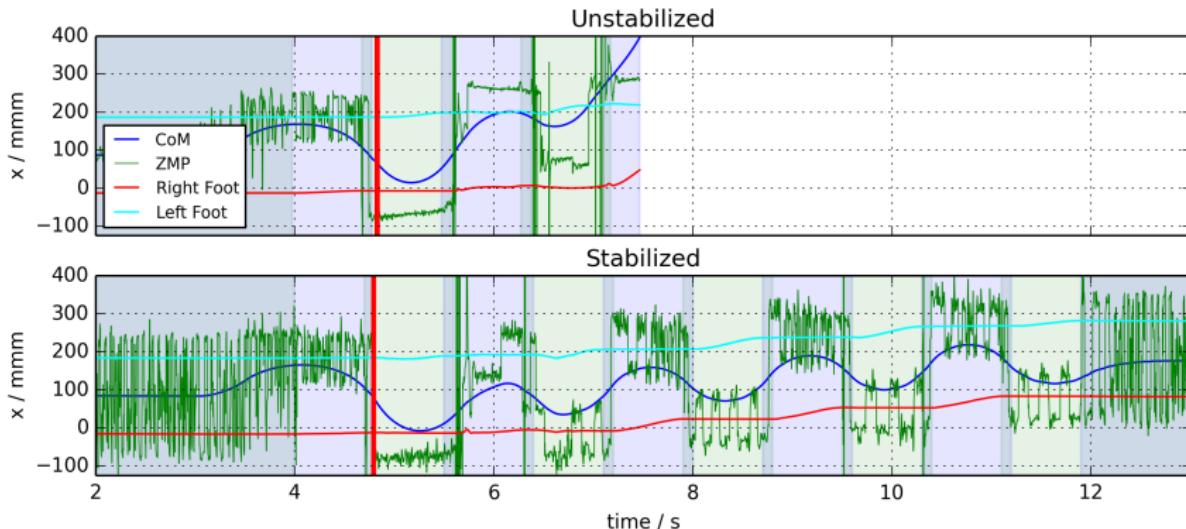
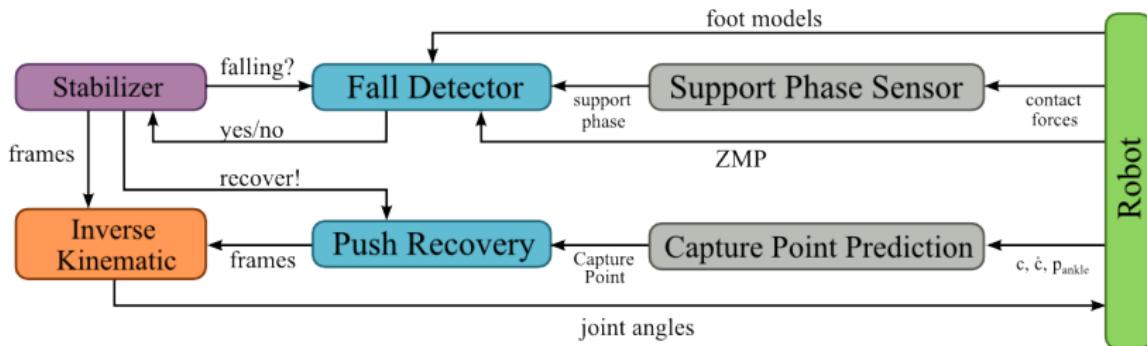


Figure: Push without stabilization

Figure: Push with stabilization.

Capture Point

- The (immediate) Capture Point is defined as the point on the floor, where by placing the base of the pendulum there, the CoM would come to a rest. [4]
- Problem:** The base needs to be moved instantaneously to the Capture Point, but foot would at least need t_{min} seconds.
- Solution:** Predict the future position of the immediate Capture Point in t_{min}

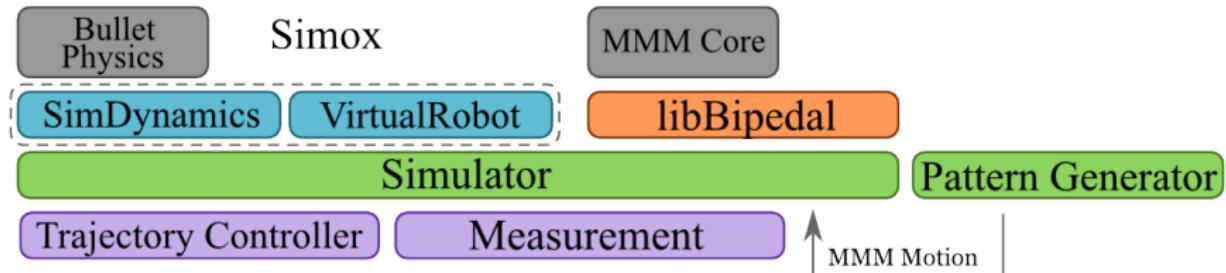


Capture Point Video

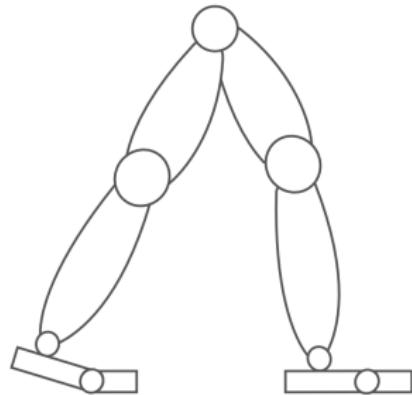
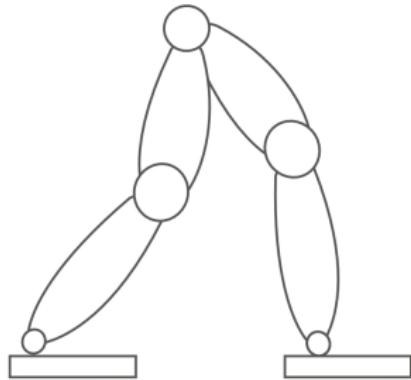
Figure: Push recovery, standing on left leg.

Implementation

- All algorithms implemented independent of the physical simulation (libBipedal): <https://github.com/TheMarex/libbipedal>
- Simulator using Simox with SimDynamics: <https://i61wiki.itec.uka.de/git/simdynamicsviewer.git>
- All C++11, needs Simox, MMMCore and Bullet 2.82 with double support



Future Work



- **Problem:** Constant CoM height requires knees to be bend: looks somewhat unnatural.
- **Solution:** Add additional DoF in the toe: foot can rotate forward without loosing ground contact
- Used successfully in WABIAN or HRP-4C.
- Needs adapted stabilizer and pattern generator [2]

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