Walking on the Sarcos Humanoid Robot

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Inverse Dynamics

Stack up many equations:

- Dynamics
- Kinematics (foot accel.)
- CoM Acceleration
- CoP
- Torso rotation
- Regularization

$$\mathbf{A}x = b$$

Where x contains:

- Contact Forces
- Joint Torques
- Joiint Accelerations

Convert to Quadratic Program

$$x^T \mathbf{A}^T \mathbf{A}x - b^T \mathbf{A}x = 0$$

With Constraints:

- Joint torque limits
- Joint kinematic limits
- Zero Moment Point
- Friction Cone

Inverse Kinematics

Get actual desired velocity of features:

- CoM
- Feet
- Torso Angle

$$\tilde{\dot{q}}_d = \dot{q}_d + K_p(q_d - q)$$

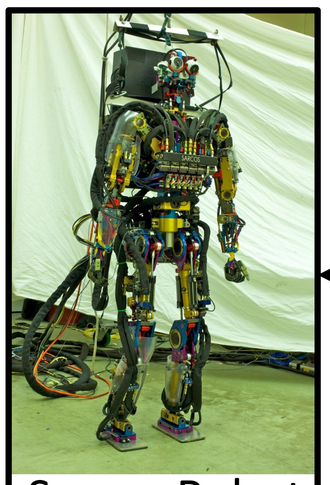
Stack up all equations

- Velocity of all features
- Reference pose
- Regularization

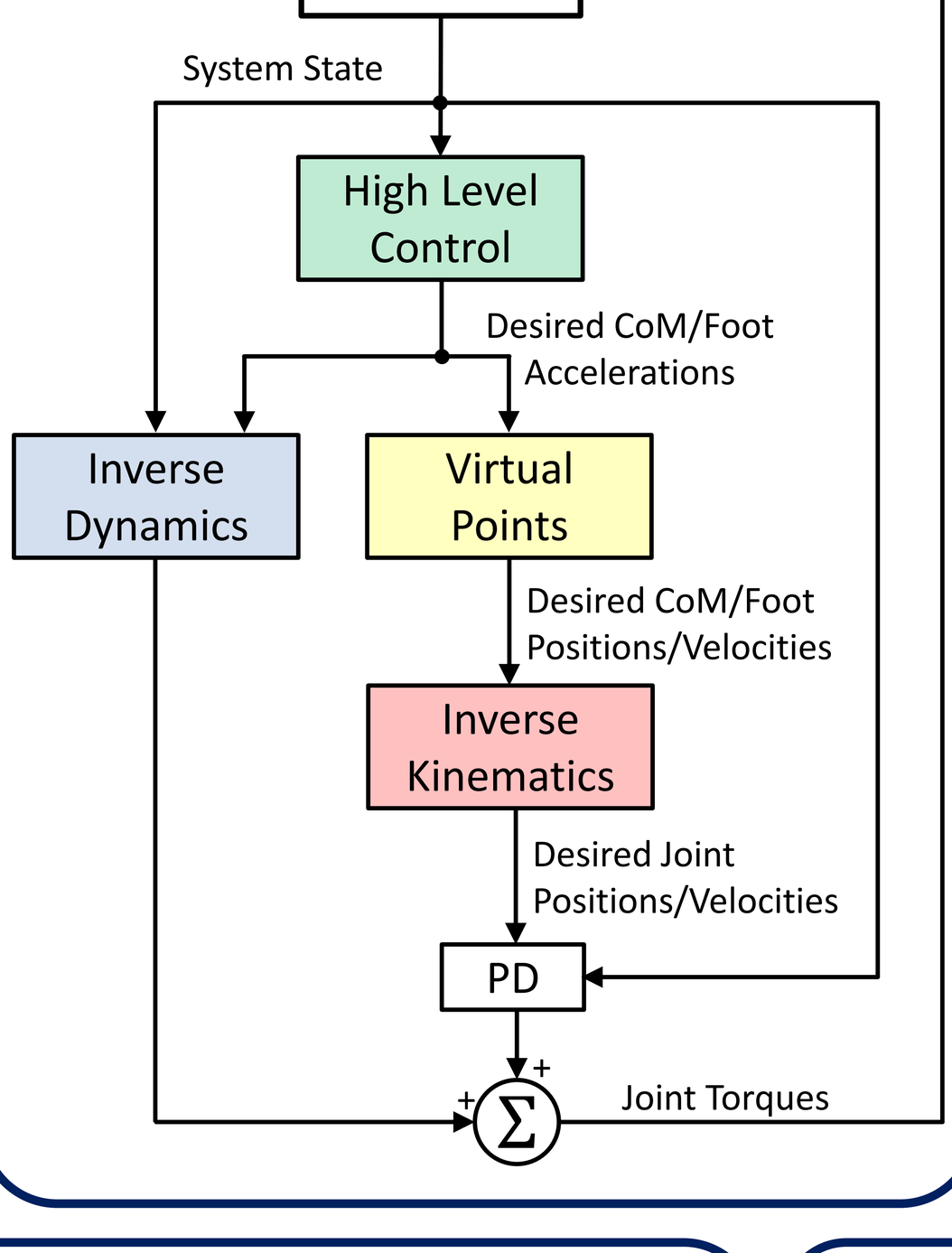
$$\mathbf{A}x = b$$

Where x contains joint velocities
Convert to QP form
Add kinematic constraints

Overall Architecture



Sarcos Robot



High Level Control

Consider 3D LIPM and fully controllable swing leg

Break into 5 Instantaneously Coupled subsystems

- Sagittal stance
- Coronal stance
- Swing X
- Swing Y
- Swing Z

Augment subsystems with coordination variables

- Time until transition (touchdown or liftoff)
- Position of touchdown (x & y)

Use Dynamic Programming to generate controllers for each subsystem

Pick optimal coordination variables by minimizing the combined value function

Look up optimal action for each subsystem

Eric C. Whitman and Christopher G. Atkeson. "*Control of Instantaneously Coupled Systems Applied to Humanoid Walking*." Proc. of Humanoids 2010, Nashville.

Virtual Points

Provide desired CoM/foot positions/velocities for the Inverse Kinematics

- Apply desired acceleration (from High Level Control
- Return to measured position (proportional gain)

$$p_{i+1} = k_I T p_{\text{meas},i} + (1 - k_I T)(p_i + v_i T + 1/2 a_{\text{des},i} T^2)$$

$$v_{i+1} = k_I T v_{\text{meas},i} + (1 - k_I T)(v_i + T a_{\text{des},i}),$$

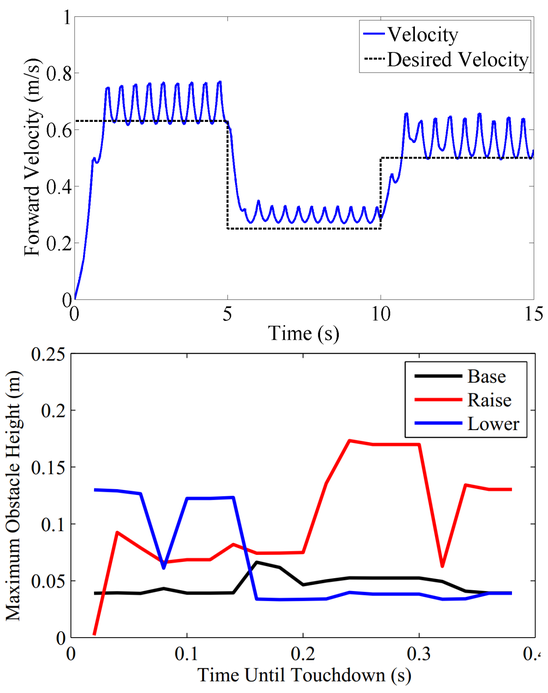
Simulation Results

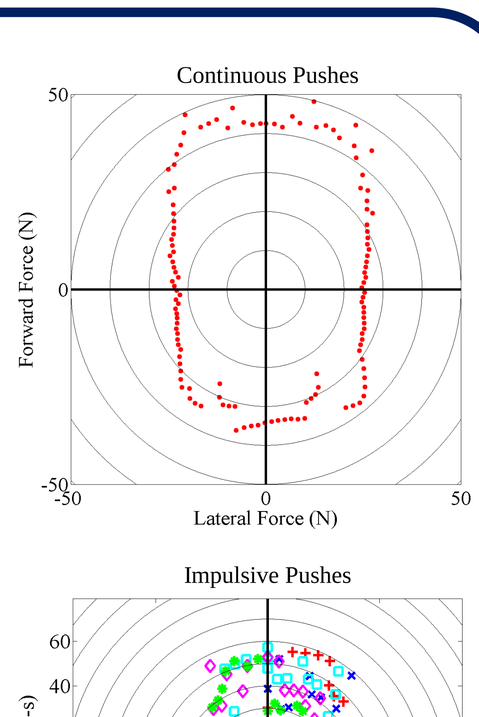
Capabilities:

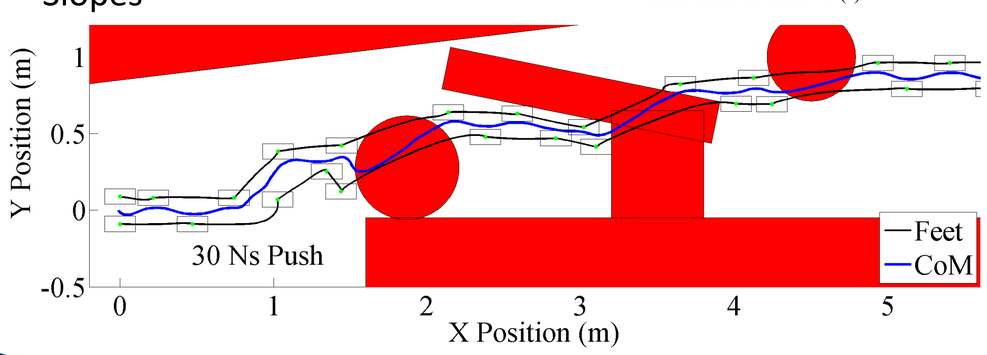
- Start from rest (top)
- Desired speed (top)
- Stop
- Turn
- Avoid Obstacles (bottom)

Robustness to:

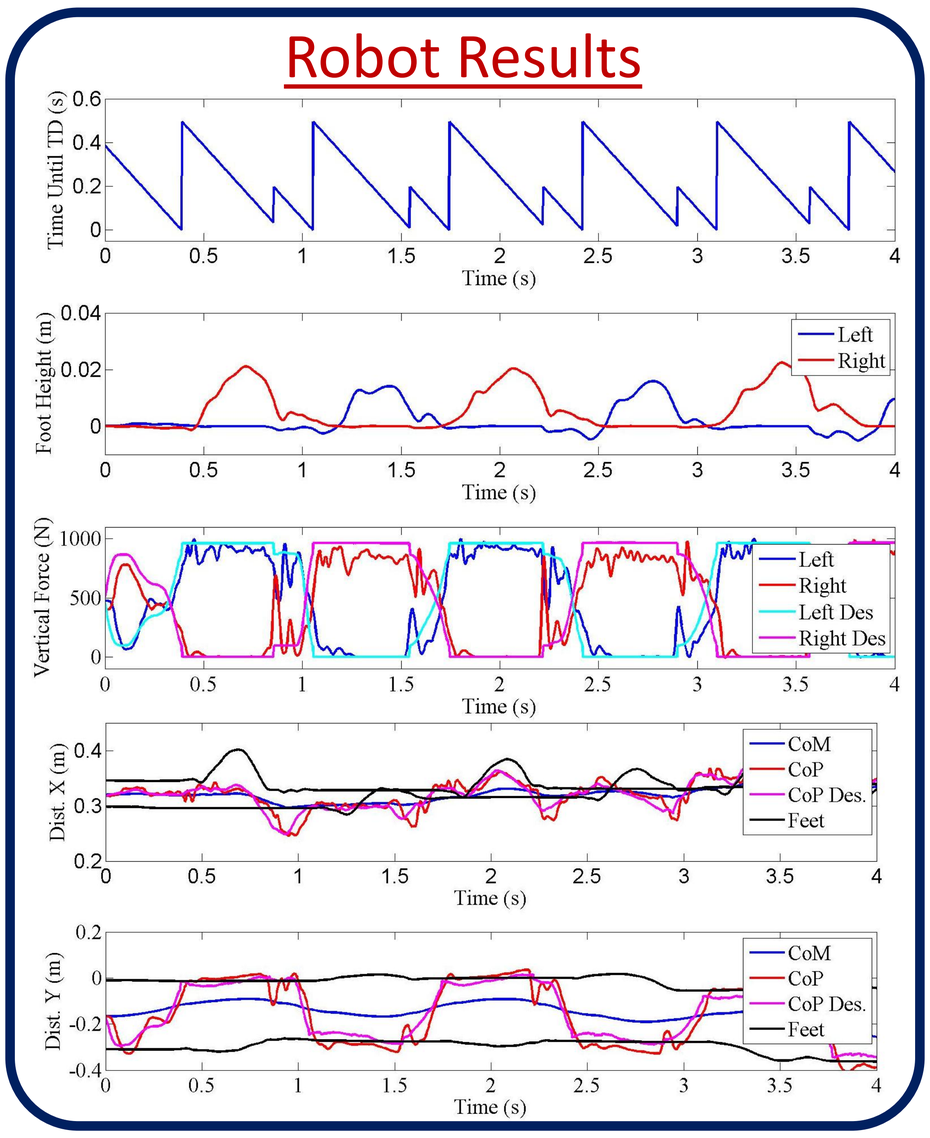
- Pushes (right/bottom)
- Trips (center)
- Step up/down
- Low friction
- Slopes







Robot Results



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