Generalized Biped Walking Control - Coros et Al 2010

Group 9

Jousson Kento

De Nuccio Luca

André Masi Marius

École polytechnique fédérale de Lausanne

Novembre 2024

Main idea

- Develop a tool that simplifies the creation of realistic, physics-based motions in animation/video games.
- Strong control generalized for different gaits, types of motion, character proportions and more
- Real time control
- No tuning required
- Stable under perturbations

Figure 1: *Real-time physics-based simulation of walking. The method provides robust control across a range of gaits, styles, characters, and skills.*
Motions are easily authored by novice users.

“Generalized biped walking control” (2010)

https://dl.acm.org/doi/10.1145/1778765.1781156

Key aspects

- Simulation of biped bodies
  - Different types of morphologies, doesn't have to be realistic of symmetric
- Performed tasks
  - Lifting and moving a crate
  - Navigation over and under obstacles
  - Climbing stairs
- Design method
  - Mathematical model and hand tuned

Key aspects

- Control
  - PD controllers tracks target trajectories provided by motion generator
  - Gravity compensation models adds torque compensation
  - Inverted pendulum model for foot placement
  - Jacobian transpose for balance adjustments

- Gait type
  - Wide range of different dynamically-simulated gaits
  - Different parameters such as character proportions, forwards or backwards walking, turns, idling, stop behavior etc

Control Framework

- Control
  - PD controllers tracks target trajectories provided by motion generator
  - Gravity compensation models adds torque compensation
  - Inverted pendulum model for foot placement
  - Jacobian transpose for balance adjustments

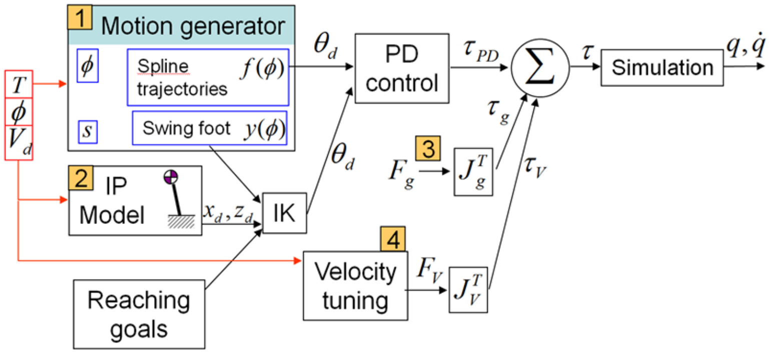


Figure 2: *System Overview. Key components of the model are: (1) a motion generator for producing desired trajectories; (2) an inverted pendulum model for predictive foot placement; (3) a gravity compensation model for all links; and (4) velocity tuning for fine balance corrections.*

Motion Generator

- **Characteristics**
  - Relative to parent joint or character coordinate frame
  - Model function of the phase step : $\phi \in [0, 1)$
  - Catmull-Rom splines
  - Input of the PD controller :
    - Tracking torque
    - Easy to compute
    - Exact position
- **Robustness**
  - All angles equal zero
  - Stance hip and Swing leg can be 0
  - Swing foot height : $y(\phi) \neq 0$
- **Implementation**
  - $\phi = t/T$, with T the period
  - Next step : foot strike or t > T

Inverted Pendulum Foot Placement

- **Calculations with the constance of the energy sum**
  - Desired stepping point : (x_d, z_d)
  - d = distance from the future point of support = $v\sqrt{h/g + v^2/(4g^2)}$
  - v = velocity, h = height
  - L = h’ = $\sqrt{h^2 + d^2}$
    $d' = d - \alpha V_d$
  - v = 0 for next step, shorter step, velocity becomes more than zero
- **Specific case**
  - Can ignore 2 steps
  - Impossible results : d = 0.6L, need of few steps of recovery
- **Results**
  - $y(\phi)$ = height of the step
  - $x(\phi) = (1 - \phi)x_0 + \phi x_d$ and $z(\phi) = (1 - \phi)z_0 + \phi z_d$

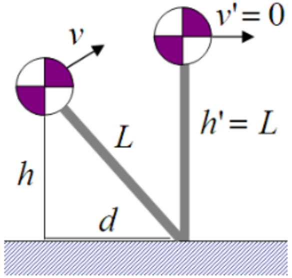


Figure 4: *Left: Inverted pendulum model.*

Velocity Tuning and Gravity Compensation

- **Velocity Tuning**
  - Control with ground forces reaction and location of the center of pressure (zero moment point)
    - COP closer to toe, speed decrease
    - Balance feedback
  - Virtual forces in the two planes : $F_V = k_V(V_d - V)$
  - Force total : $\tau_V = J_V^T F_V$, Jacobian of the center of mass
- **Gravity Compensation**
  - Lower PD gain
  - Virtual force : $F_i = -m_i g$
  - Jacobian on every link : $\tau_i = J_i^T F_i$
- **Turning and Limb Guidance**

  $\omega_{max} = 2\,\mathrm{rad/s}$

  $\phi \in [0, 1)$
  - Cartesian space trajectory to guide
  - Risk of collision regulated

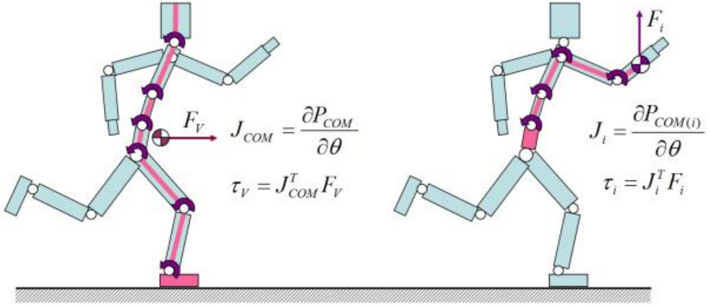


Figure 3: *Jacobians used for velocity tuning (left) and gravity compensation (right).*

Implementation

- **No need to tune**
  - Kp and Kd scale to mass
  - Friction = 0.8
  - No need of torque limit

Results

- ❖ **Generalization across gait parameters**
  - ➢ Demonstrated capabilities :
    - ■ Forward and backward walking
    - ■ Adjustable walking speeds and step frequencies
  - ➢ Application to varied characters
  - ➢ Stop and start as a function of speed Vd
- ❖ **Generalization across styles**
  - ➢ Styles created by adjusting parameters like body tilt, knee movement, arm style
  - ➢ Interactive parameter modification
- ❖ **Generalization across characters**
  - ➢ Generalizes across a variety of character dimensions and proportions
  - ➢ Dynamically balanced motion generated immediately

Figure 7: *Interactive editing of character proportions and the resulting walking gait.*

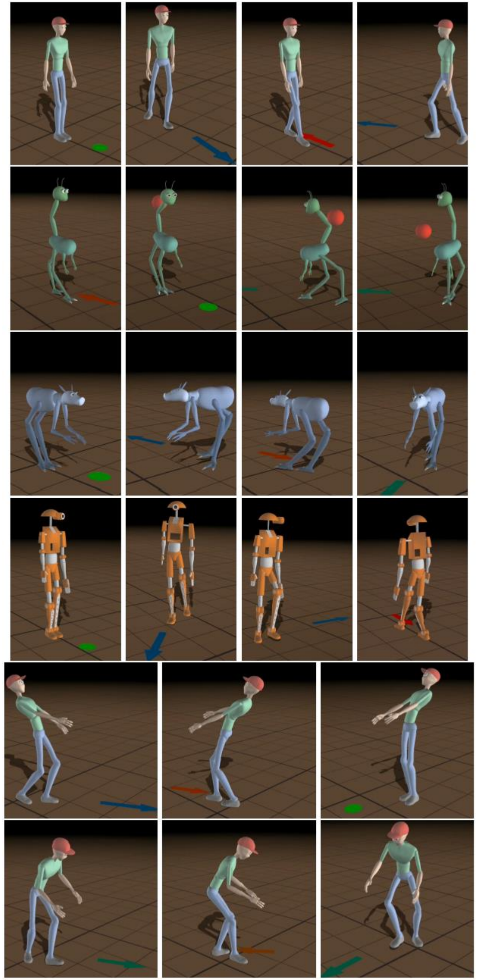


Figure 5: *Direction Following*

Results

- **Generalization across tasks**
  - **Reaching:** Picking up objects at varying heights/positions
  - **Pushing/pulling crates**
  - **Lifting/carrying**
  - **Navigation**
  - **Stairs**
  - **Crowd simulation**

Figure 8: *Reaching for objects*

Figure 13: *A dancing crowd with 16 characters.*

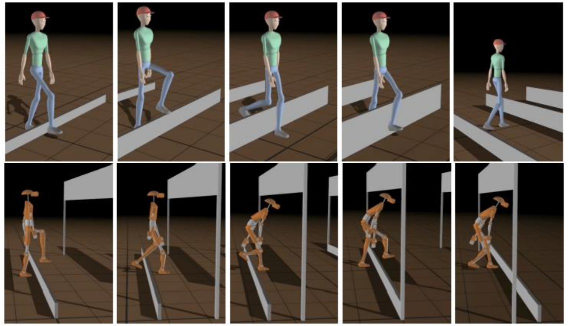


Figure 11: *Navigating over and under obstacles. Top: Stepping over a sequence of obstacles of up to 45cm in height. Bottom: Stepping over a sequence of obstacles combined with ducking under obstacles, with varying offsets.*

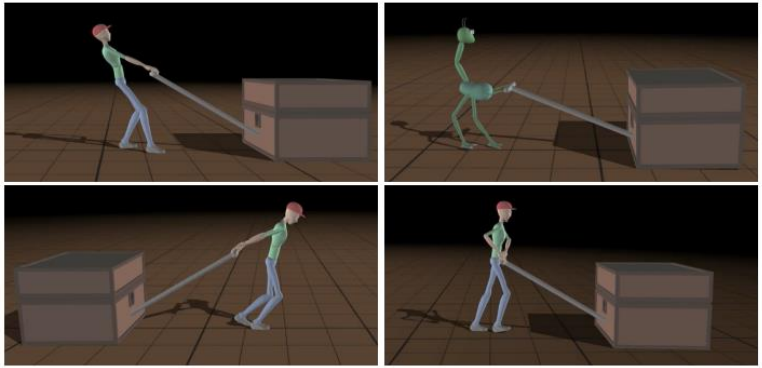


Figure 9: *Pulling and pushing a crate. Top: Pulling to the left. Bottom: Pulling and pushing to the right.*

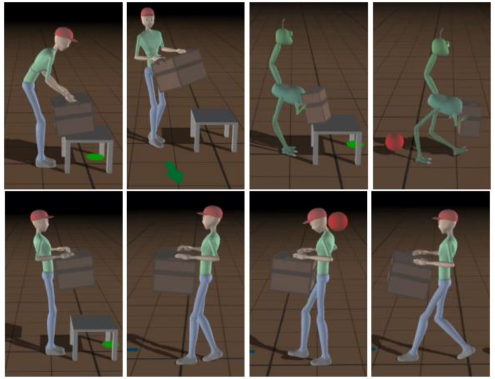


Figure 10: *Lifting and moving heavy crates.*

Figure 12: *Walking to a crate, picking it up, climbing steps, stepping over obstacles, and coming to a stop.*

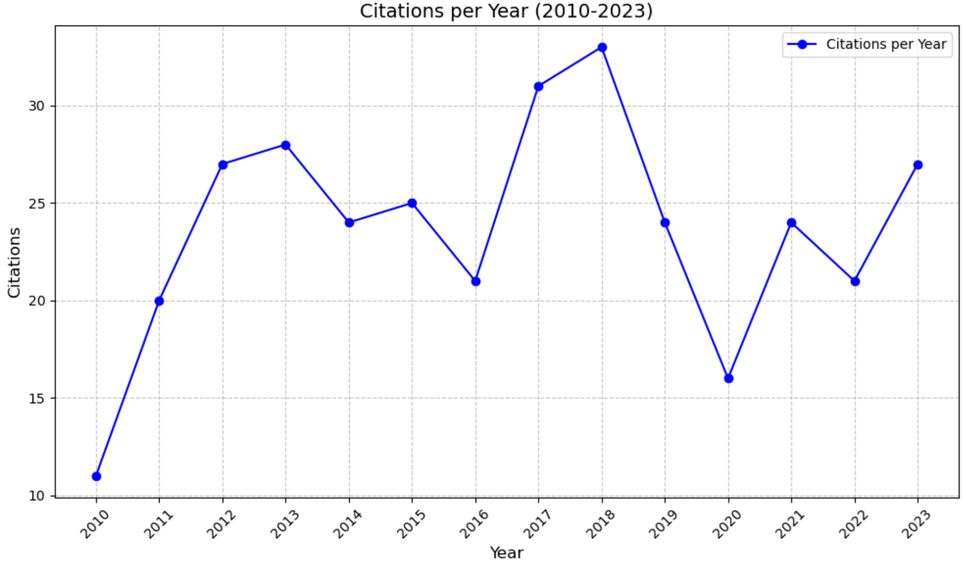
Article citations

Citations in Scopus : 144

FWCI (Field-Weighted citation impact) : 5.28

Citations in Google Scholar : 353

Google Scholar



Article citations

Article : Resolving Collisions in Dense 3D Crowd Animations, 06 September 2024, ACM Transactions on Graphics, Volume 43, Issue 5, Gonzalo Gomez-Nogales and Al.

- “Forward dynamics methods compute joint torques and apply them to synthesize realistic movements [Hodgins et al. 1995; Coros et al. 2010; Yin et al. 2007], but they typically struggle with scenarios with multiple contacts.”

Article : Imprecise dynamic walking with time-projection control, 9 novembre 2018, Salman Faraji, A.J. Ijspeert

- Concept taken up by the Atlas robot, for example: Implementation of CoP control and swing-hip joints tracking the desired footstep locations.

Pros and cons

- **Pros**
  - Robust generalization
    - Wide range of gait parameters, motion styles, and character proportions
    - Supports diverse tasks
  - Integrated and adaptive control
    - Combines multiple control strategies
    - Simplifies configuration using approximate models, avoiding complex dynamic inversion calculations
  - Ease of use for novice animators
    - Interactive interface allows users to modify character proportions and motion styles
  - Robustness
    - Tolerates external disturbances, such as pushes

- **Cons**
  - Limitations in dynamic movements
    - Better suited for slow and balanced motions
  - Inter-limb collisions
    - Occasional issues with leg intersections (swing/stance) in complex scenarios
  - Limited generalization on complex terrain
    - Hasn't been tested on irregular terrains or highly realistic environments
  - Lack of demonstration for non-biped morphologies

Possible exam questions

- What are the main components of the control framework proposed in the article, and how do they contribute to achieving generalized biped walking? (slide 6)
- What are the limitations of the generalized walking control approach presented in the paper? (slide 15)

References

❖ Figures 1-13 : Generalized Biped Walking Control, 2010, University of British Columbia, Stelian Coros and Al