Development and implementation dynamic balance algorithms for bipedal robot locomotion

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Final presentation
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June 4, 2015

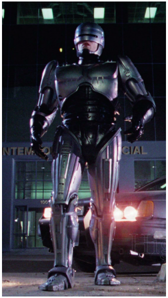
Outline

- Introduction and Motivation
- Problem Overview
- Related work
- Theoretical aspects of bipedal robots control
- Implementation and evaluation
- Future work
- Summary

Introduction and Motivation: the development of robotics in minds

Trends in robotics are near to be developed.

Forbidden planet, 1956

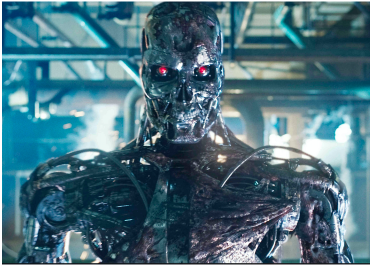


Robocop, 1987

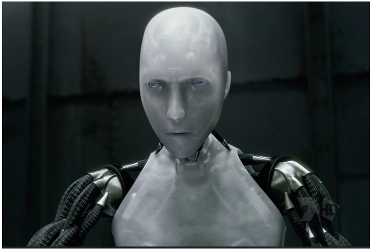
Bicentennial man, 1999

Introduction and Motivation: the development of robotics in minds

Robotics, Cybernetics, Biomechatronics, AI are only several of prospectives that a required to take into account in bipedal robots development.



Terminator, 1984



I, robot, 2004

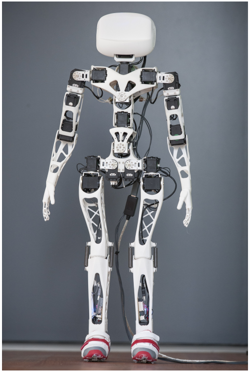
Introduction and Motivation: humanoid robots development

Evolution of Honda humanoids

Introduction and Motivation

Humanoid robot definition

- Mechanism with body structure resembles that of a human: head, torso, legs, arms, hands Hirai et al. (1998)



Humanoid robot

Introduction and Motivation

Why humanoids ?

- Ability to work directly in the same human environment without any modification
- General-purpose workers
- Social integration
- Work with same tools as humans

Introduction and Motivation

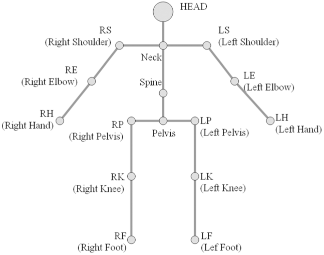
Humanoids Advantages and Disadvantages

- (+) Universal environment
- (+) Natural, human-like
- (+) Uneven terrains
- (-) Difficult locomotion
- (-) Complex design
- (-) Low speed
- (-) Complex control
- (?) Special tasks cannot be performed by general robots as good as by devices that were designed for this proper task.

Problem Overview

Bipedal locomotion difficulties

- Humanoids are underactuated due to inertia frame
- Difficult to solve Inverse Kinematics
- Several kinematic chains
- Requires the robot to plan motions



Human as a kinematic chains, Seo et al. (2011)

Related work

Bipedal locomotion control approaches

- Analytical approach (ZMP based and others)
- Central Pattern Generator approach
- Neural Networks approach
- Hidden Markov Model approach
- Rule based approach

Related work: Analytical approach

Steps required for bipedal locomotion

- Apply stability constraints
- Design a gait algorithm
- Solve remaining Degrees of Freedom

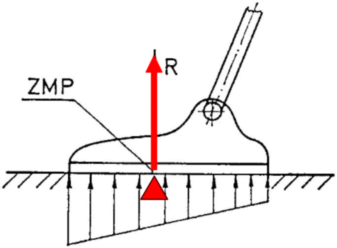
Stability measures

- Zero Moment Point (ZMP)
- Foot Rotation Indicator (FRI)

Related work: Analytical approach

ZMP

- The distributed floor reaction force can be replaced by a single force R acts on Zero Moment Point



Zero Moment Point (ZMP), Vukobratović and Borovac (2004)

Related work: Central Pattern Generator Approach

Human walking process

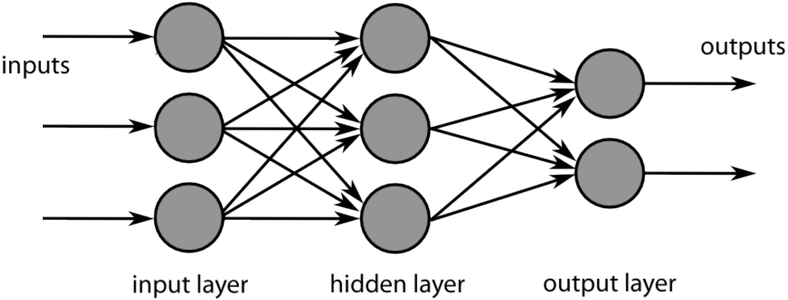
- Rhythm generating
- Control and adaptation mechanism

CPG principle

- Biological CPGs are made from pairs of mutually inhibiting neurons
- Pairs of mutually inhibiting neurons are described by systems of differential equations
- CPG is a neural network working without input

Related work: Neural Networks Approach

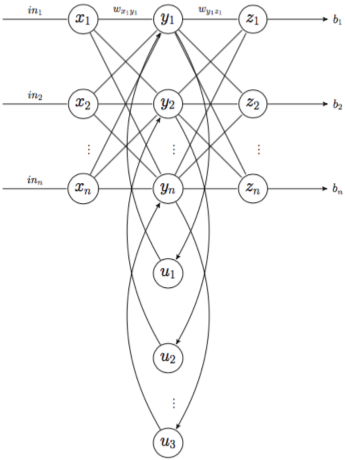
Feed-Forward Networks



Feed Forward Network, Kim et al. (2012)

Related work: Neural Networks Approach

Recurrent networks



Elman Recurrent Network

Related work: Hidden Markov Model Approach

HMM for bipedal locomotion algorithm

- A correspondence between the control signal and controller input
- The control signal depends only on a finite number of previous input signals
- Define a set of patterns
- Set of input signals is mapped to the set of possible control signals
- Train the model by the data describing control signals
- Collect a set of trained models

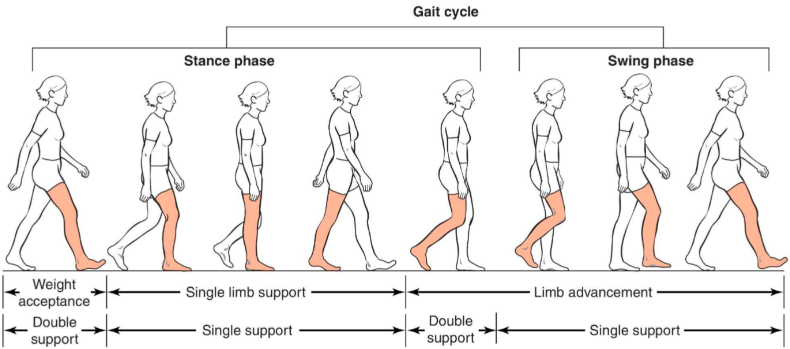
Related work: Rule Based Approach

Rule Based Approach principle

- Divide the set of all possible system configurations into the clusters
- For each cluster assign the control function
- During the work control function will be chosen according to the current robot configuration
- Current configuration defines the possible control function
- Fuzzy logic controller is a perspective approach for solving dynamical stability problem
- Fuzzy logic controller divide all the configuration space into the subspaces
- For each subspace control function is defined in an optimal way

Theoretical aspects of bipedal robots control

Locomotion is a periodic gait cycle.

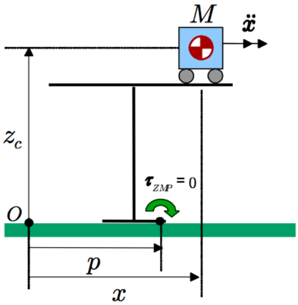


Gait cycle decomposition, Hill (2015)

Theoretical aspects of bipedal robots control

Cart table model

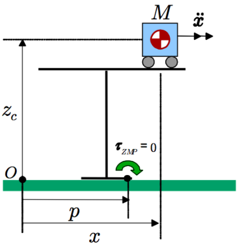
- (+) Easy to understand
- (-) Is not precise



Cart table model, Kajita et al. (2003)

Theoretical aspects of bipedal robots control: cart table model

$$P = x - \frac{Z_c}{g}\ddot{x} \tag{1}$$



Cart table model, Kajita et al. (2003)

Theoretical aspects of bipedal robots control: cart table model

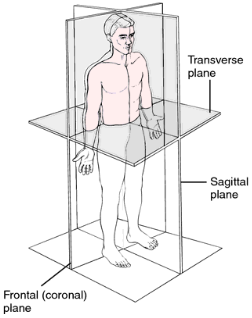
Proper dynamics of cart table model

- $$\frac{d}{dt}\begin{bmatrix} x \\ \dot{x} \\ \ddot{x} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} x \\ \dot{x} \\ \ddot{x} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u \quad (2)$$
- $$p = \begin{bmatrix} 1 & 0 & -\frac{Z_c}{g} \end{bmatrix}\begin{bmatrix} x \\ \dot{x} \\ \ddot{x} \end{bmatrix} \quad (3)$$
- u is the third time derivative of x

Theoretical aspects of bipedal robots control

Human planes intersting for locomotion

- Sagittal plane
- Frontal plane

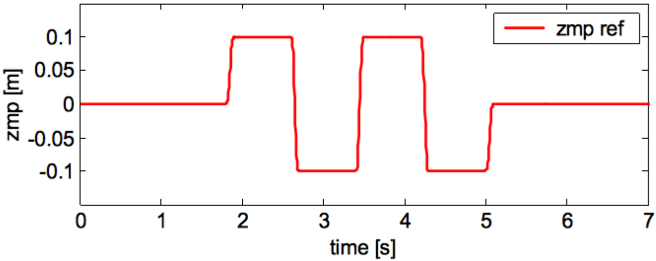


Human planes, Stedman (2015)

Theoretical aspects of bipedal robots control

Control principle

- Find ZMP pattern that corresponds to wanted robot locomotion direction
- Calculate the cart trajectory to realize the given ZMP pattern
- Apply correction to robot in order to follow pattern



ZMP desired trajectory in frontal plane, Kajita et al. (2003)

Theoretical aspects of bipedal robots control

Control principle

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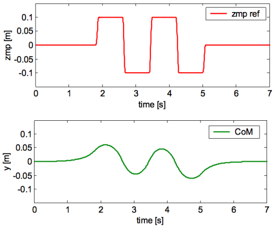
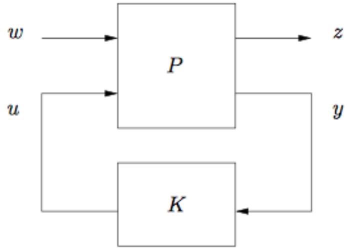


Inverse control principle, Kajita et al. (2003)

Theoretical aspects of bipedal robots control

Optimal Control

- State space model
- Transfer function
- Transfer function measures



Generalized regulator, Hazell (2008)

Theoretical aspects of bipedal robots control: Optimal Control

Optimal Control

- State space model

$$\begin{aligned} x(k+1) &= Ax(k) + Bu(k) \\ y(k) &= Cx(k) + Du(k) \end{aligned} \tag{4}$$

- Transfer function

$$G(Z) = C(ZI - A)^{-1}B + D \tag{5}$$

Where Z is Z transform variable

Theoretical aspects of bipedal robots control: Optimal Control

Optimal Control

- Transfer function measures

$$||G(Z)||_2 = Tr\{B^T XB + D^T D\} \tag{6}$$

- X should satisfy:

$$X = A^T XA + C^T C \tag{7}$$

- Physical meaning is a gain in power from input to output, assuming that the input signal is white noise.

Theoretical aspects of bipedal robots control: Optimal Control

Optimal Control

- Transfer function measures

$$||G(Z)||_\infty = \sup_\omega \frac{||z||_2}{||\omega||_2} \tag{8}$$

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$$z = G\omega \tag{9}$$

- ω is assumed to be a realization of a unit power, Gaussian, white noise process and z is the real values vector of input
- Physical meaning is a maximum possible gain in power from input to output, assuming that the input signal is white noise.

Theoretical aspects of bipedal robots control: Preview Control

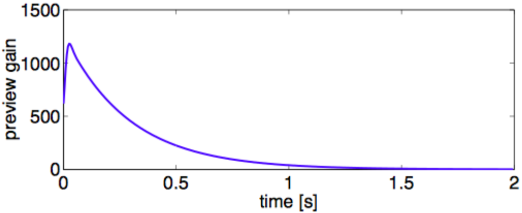
Preview Control

- Look forward for N discrete steps
- Predict the desirable value of controlled signal
- Katayama et al. (1985) proved the theorem that optimal control signal has the followong form:

$$u(k) = -G_I \sum_{i=0}^{k} e(i) - G_x x(k) - \sum_{l=1}^{N} G_d(l) y_d(k+l) \quad (10)$$

Theoretical aspects of bipedal robots control: Preview Control

It makes sense to find critical number of important future steps.



Preview Gain dependency from the time Kajita et al. (2003)

Implementation and Evaluation

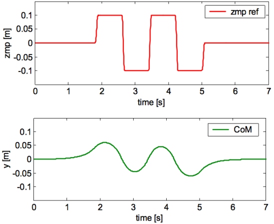
What was done?

- Implementation of cart table model
- Implementation of PID controlled cart table model
- Implementation of preview controlled cart table model
- Comparison of preview and PID control result
- Preview control was applied to robot model

Implementation and Evaluation:

Controller

- PID controller
- Preview controller



Inverse control principle, Kajita et al. (2003)

Summary

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Thanks for the attention

Now it's time for your questions

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