Introduction to Humanoid Robotics

by

Dr. Rawichote Chalodhorn (Choppy)

Humanoid Robotics Lab, Neural System Group, Dept. of Computer Science & Engineering, University of Washington.
RoboCup soccer
The brain controlled humanoid robot
Outline

- History of humanoid robots
- Humanoid robots today
- Androids
- Analytical approaches of bipedal locomotion
- Learning to walk through imitation
- Future of humanoid robotics
Atomaton: Leonardo's robot
Atomaton: The Japanese tea serving doll

18th century to 19th century
# Honda E series

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Weight</td>
<td>16.5 kg</td>
<td>72 kg</td>
<td>67.7 kg</td>
<td>86 kg</td>
<td>150 kg</td>
<td>150 kg</td>
<td>150 kg</td>
</tr>
<tr>
<td>Height</td>
<td>101.3 cm</td>
<td>128.8 cm</td>
<td>132 cm</td>
<td>136.3 cm</td>
<td>159.5 cm</td>
<td>170 cm</td>
<td>174.3 cm</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>6</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

## Image

![E0](image1.png) ![E1](image2.png) ![E2](image3.png) ![E3](image4.png) ![E4](image5.png) ![E5](image6.png) ![E6](image7.png)
Honda P series

- P1: 1993
- P2: 1996
- P3: 1997
Androids

• A robot that closely resembles a human
• Human robot interaction

Prof. Hiroshi Ishiguro
Zero-Moment Point (ZMP)

We can maintain balance as long as the ZMP is staying within the support polygon.

[ZMP (Zero Moment Point)]

[Image of ZMP]

[Vukobratovic et al. 1972]
Derivation of the ZMP

\[ \sum_{i}^{n} \left\{ m_i (r_i - p) \times (\ddot{r}_i + g) \right\} + T - \sum_{j} M^j - \sum_{k} \left\{ s^k - p \right\} \times F^k \right\} = 0 \]

- \( P = [x_p, y_p, 0]^T \): position vector of P
- \( T = [T_x, T_y, T_z]^T \): total torque acting at P
- \( M^j = [M^j_x, M^j_y, M^j_z]^T \): external moment j
- \( F^k = [F^k_x, F^k_y, F^k_z]^T \): external force k
- \( s^k = [s^k_x, s^k_y, s^k_z]^T \): position where \( F^k \) is acting

Vectors of a walking mechanism
Derivation of the ZMP

ZMP equations with external forces and moments

\[
x_{ZMP} = \frac{\sum_i^n m_i \{x_i (\ddot{z}_i + g_z) - (\ddot{x}_i + g_x)z_i\} + \sum_j M_y^j + \sum_k [s^k \times F^k]^y}{\sum_i^n m_i (\ddot{z}_i + g_z) - \sum_k F^k_z}
\]

\[
y_{ZMP} = \frac{\sum_i^n m_i \{x_i (\ddot{z}_i + g_z) - (\ddot{x}_i + g_x)z_i\} + \sum_j M_x^j + \sum_k [s^k \times F^k]^x}{\sum_i^n m_i (\ddot{z}_i + g_z) - \sum_k F^k_z}
\]

A simplified version of ZMP equations

\[
x_{ZMP} = \frac{\sum_i^n m_i \{x_i (\ddot{z}_i + g_z) - (\ddot{x}_i + g_x)z_i\} - I_{iy} \omega_{iy}}{\sum_i^n m_i (\ddot{z}_i + g_z)}
\]

\[
y_{ZMP} = \frac{\sum_i^n m_i \{y_i (\ddot{z}_i + g_z) - (\ddot{y}_i + g_y)z_i\} - I_{ix} \omega_{ix}}{\sum_i^n m_i (\ddot{z}_i + g_z)}
\]

[Takanishi et al., 1989]

[Huang et al., 2001]
ZMP Jacobian Compensation

\[ p_{ZMP} \equiv p_{ZMP}(q) \]

\[ dp_{ZMP} = \frac{\partial p_{ZMP}}{\partial q} dq \]

\[ \dot{p}_{ZMP} = J_{ZMP}(q) \cdot \dot{q} \]

\[ \dot{q} = J_{ZMP}^\#(q) \cdot \dot{p}^H_{ZMP} \]

\[ J_{ZMP}(q) = \begin{bmatrix} \frac{\partial p_{ZMP}}{\partial q_1} & \cdots & \frac{\partial p_{ZMP}}{\partial q_n} \end{bmatrix} \]

\[ J_{ZMP}(q) = \begin{bmatrix} \frac{\partial p^H_{ZMP}}{\partial q_1} & \cdots & \frac{\partial p^H_{ZMP}}{\partial q_n} \end{bmatrix} \begin{bmatrix} \frac{\partial x_Z}{\partial q_1} & \cdots & \frac{\partial x_Z}{\partial q_n} \\ \frac{\partial y_Z}{\partial q_1} & \cdots & \frac{\partial y_Z}{\partial q_n} \end{bmatrix} = \begin{bmatrix} \frac{\partial x_Z}{\partial q_1} & \cdots & \frac{\partial x_Z}{\partial q_n} \\ \frac{\partial y_Z}{\partial q_1} & \cdots & \frac{\partial y_Z}{\partial q_n} \end{bmatrix} \]
The Cart-Table Model

\[
\tau_{zmp} = mg(x - p_x) - m\ddot{z}_c = 0
\]

The ZMP of the Cart-Table Model

\[
\begin{align*}
p_y &= y - \frac{z_c \ddot{y}}{g} \\
p_x &= x - \frac{z_c \dddot{x}}{g}
\end{align*}
\]

Dynamics equations

\[
\begin{align*}
\ddot{y} &= \frac{g}{z_c} y - \frac{1}{m z_c} \tau_x \\
\dddot{x} &= \frac{g}{z_c} x + \frac{1}{m z_c} \tau_y
\end{align*}
\]

ZMP

\[
\begin{align*}
p_y &= \frac{\tau_x}{mg} \\
p_x &= -\frac{\tau_y}{mg}
\end{align*}
\]
ZMP Model-based Feedback controller configuration

Balancer Module

- Gyro
- Accelerometer
- Force/torque sensor
- Encoder

Kalman filter

Body inclination

ZMP calculator

Joint servo

References of Joint angles, body inclination and ZMP
Learning Approach

Learning to walk through imitation

[Chalodhorn et al. 2006]
Dimension reduction

Gaussian process latent variable model

[Grochow et al. 2004]
Learning through low-dimensional spaces

![Graphs showing gyroscope signals](image)

[Chalodhorn et al. 2005]
Learning by imitation results
Learning by imitation results
Intrinsically low-dimensional humanoid motion
Conclusion

• Humanoid robots are used as a research tool in several scientific areas.

• Although the initial aim of humanoid research was to build better orthosis and prosthesis for human beings.
Future of Humanoid robots

Near-Optimal Graphs for Compact Character Controllers

Submission id 0656
(with audios)
THANK YOU