Introduction to Humanoid Robotics

by

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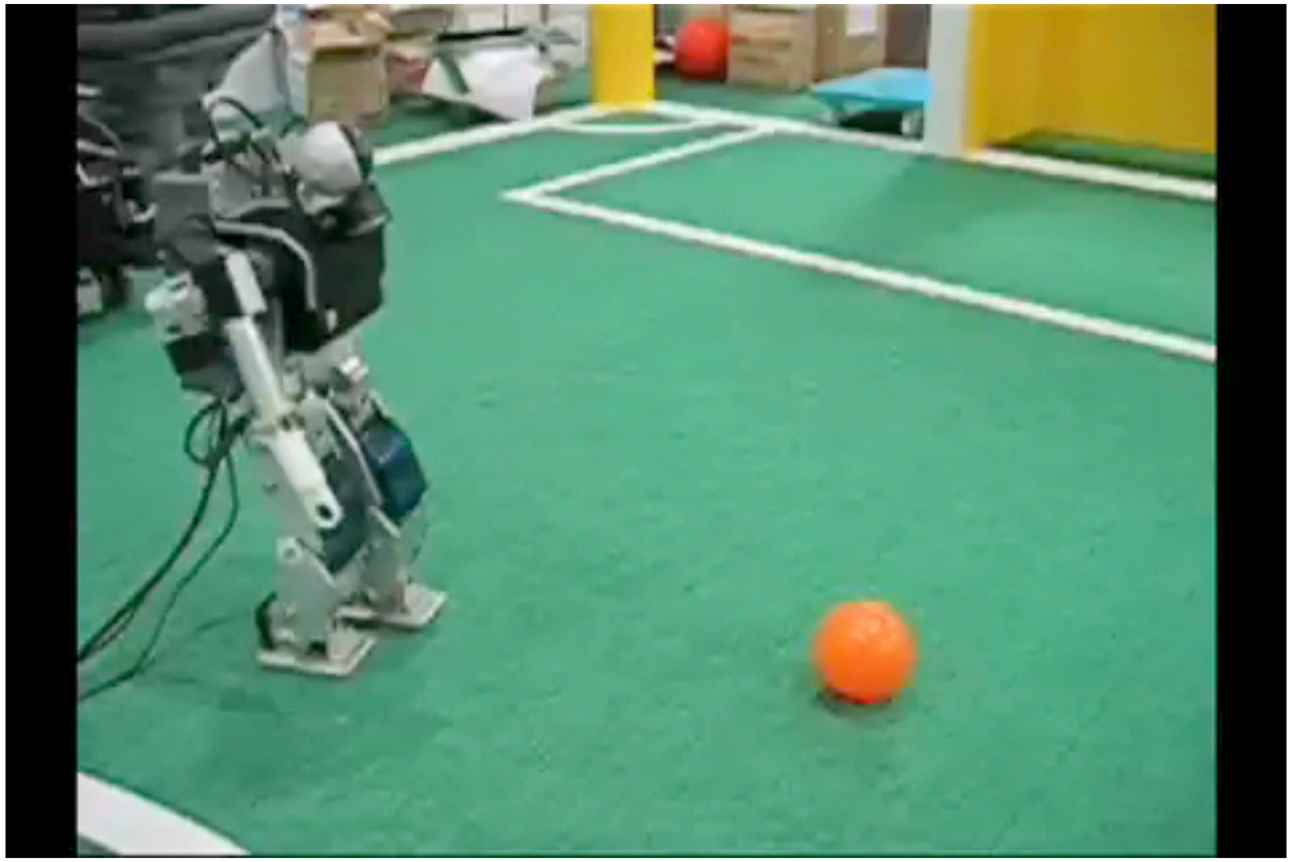
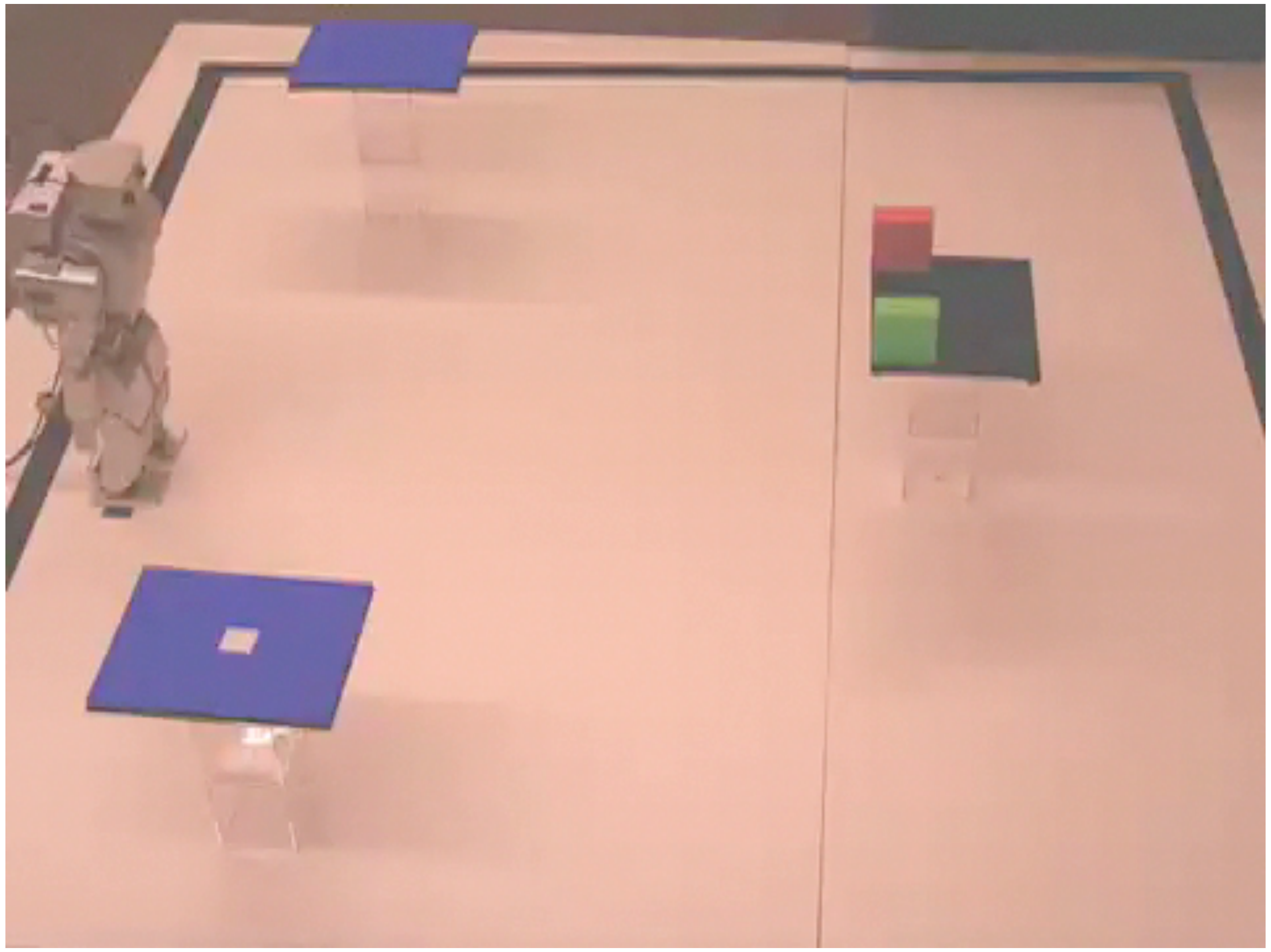
RoboCup soccer



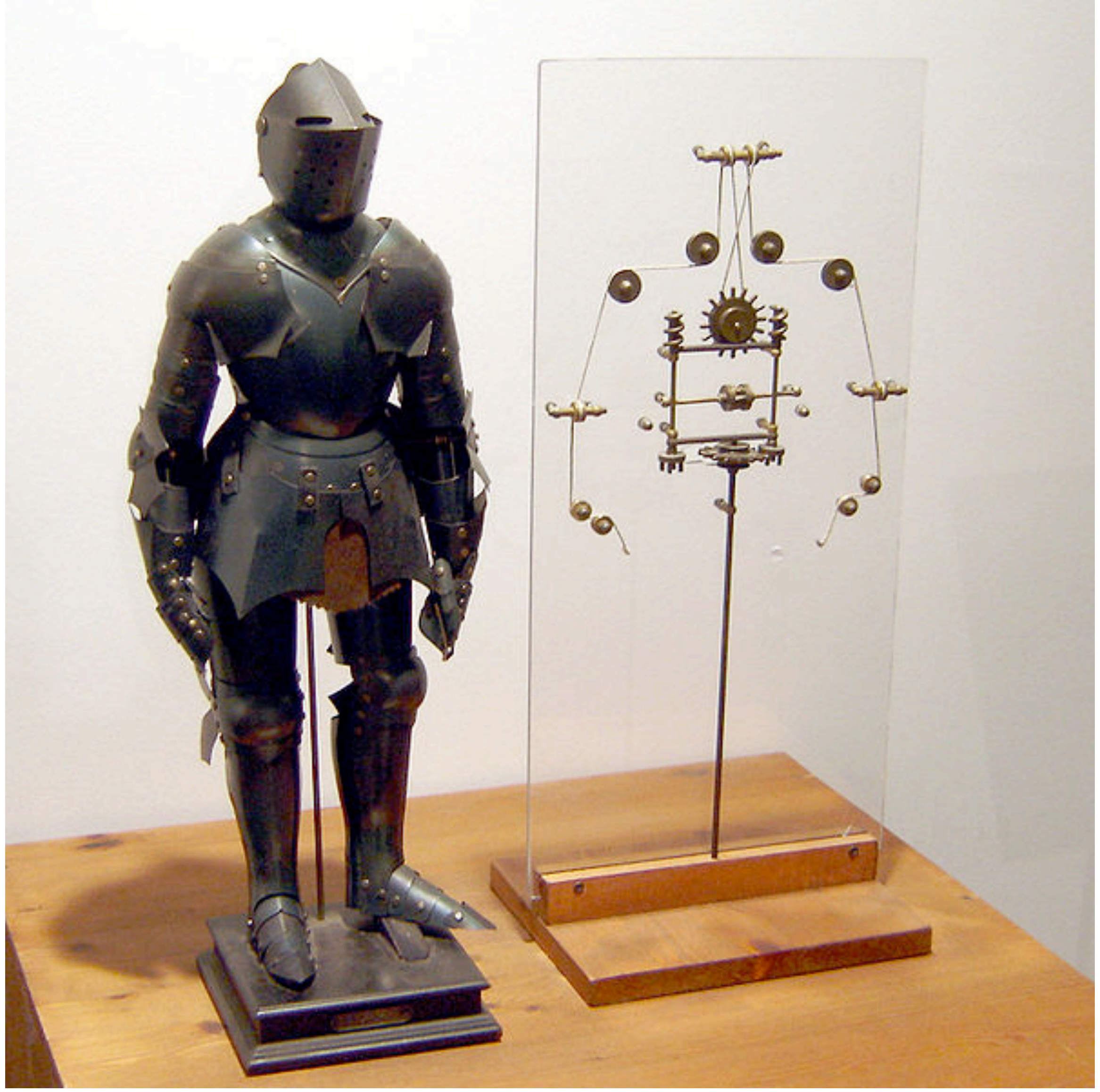
The brain controlled humanoid robot



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



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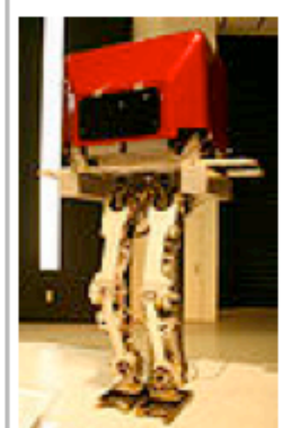
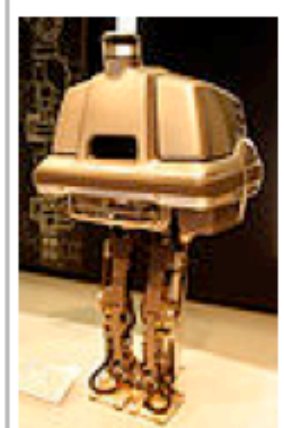
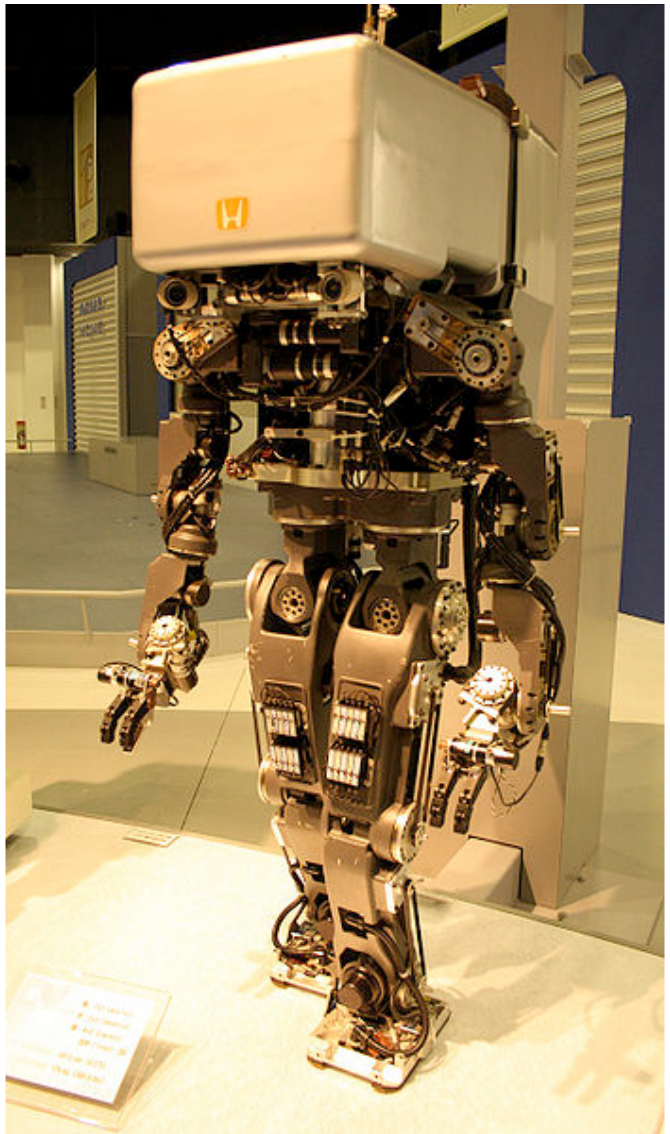
Atomaton: The Japanese tea serving doll

18th century to 19th century

Honda E series

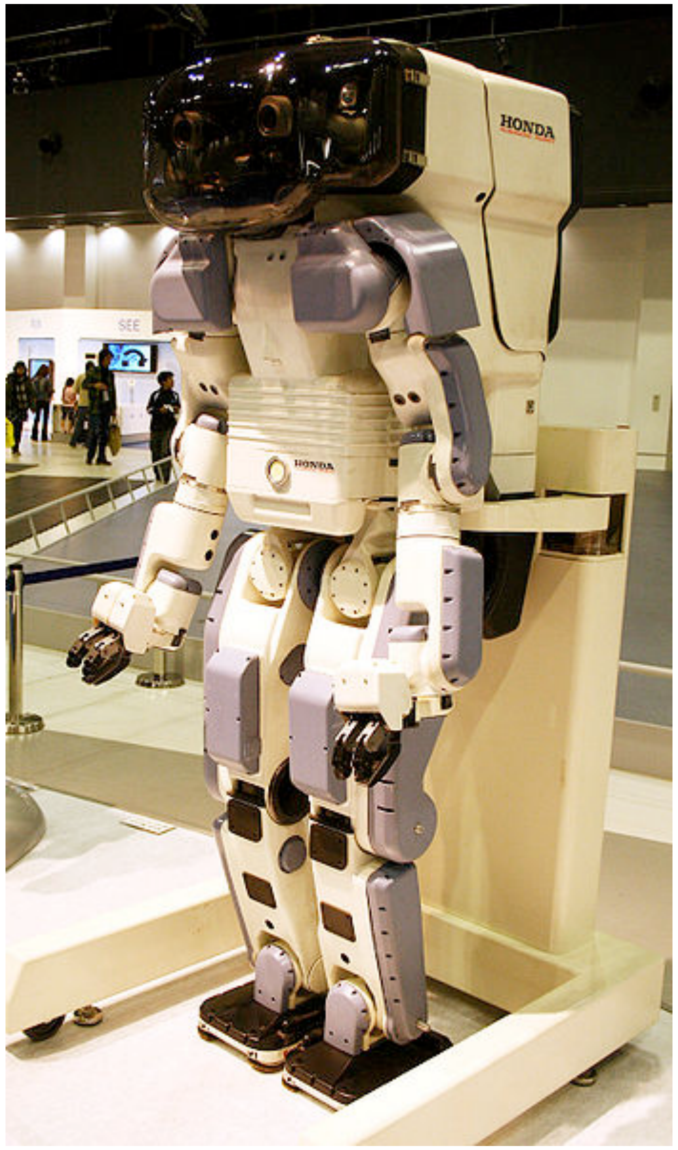
	E0 (1986)	E1 (1987)	E2 (1989)	E3 (1991)	E4 (1991)	E5 (1992)	E6 (1993)
Weight	16.5 kg	72 kg	67.7 kg	86 kg	150 kg	150 kg	150 kg
Height	101.3 cm	128.8 cm	132 cm	136.3 cm	159.5 cm	170 cm	174.3 cm
Degrees of freedom	6	12	12	12	12	12	12
Image							

Honda P series



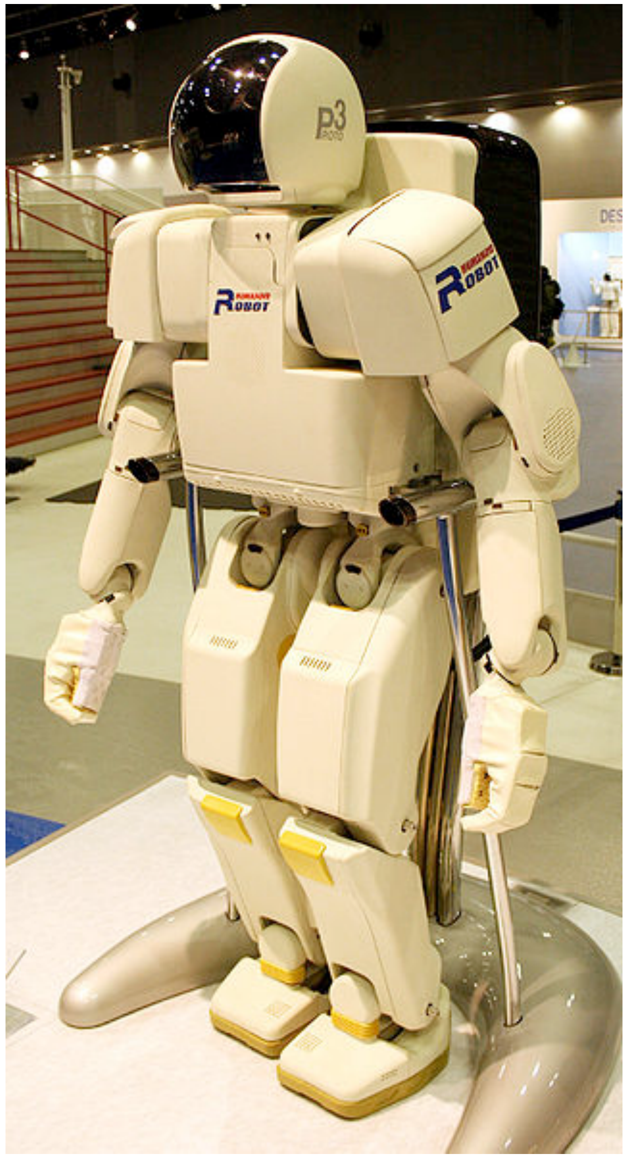
P1

1993



P2

1996



P3

1997

AIST / Kawada Industries : HRP series

HRP-4C

Androids

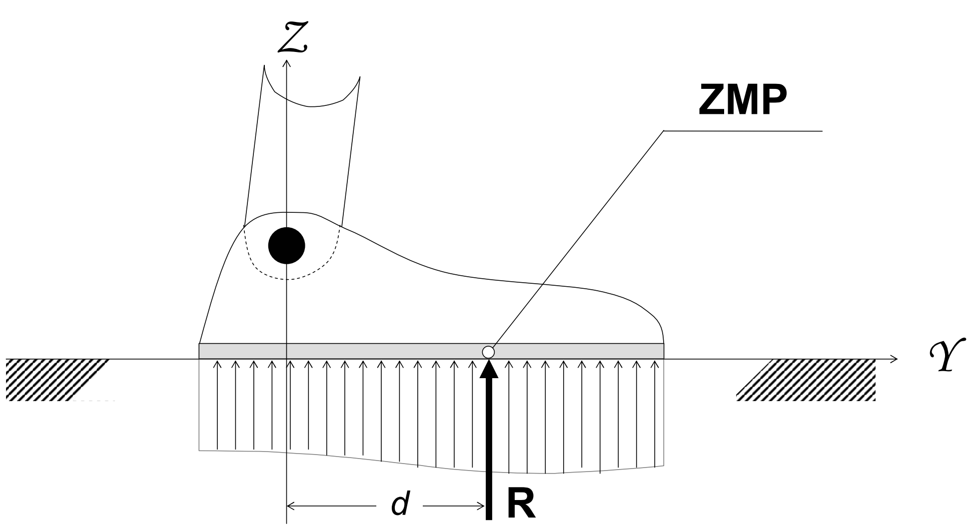
Prof. Hiroshi Ishiguro

- **A robot that closely resembles a human**
- **Human robot interaction**

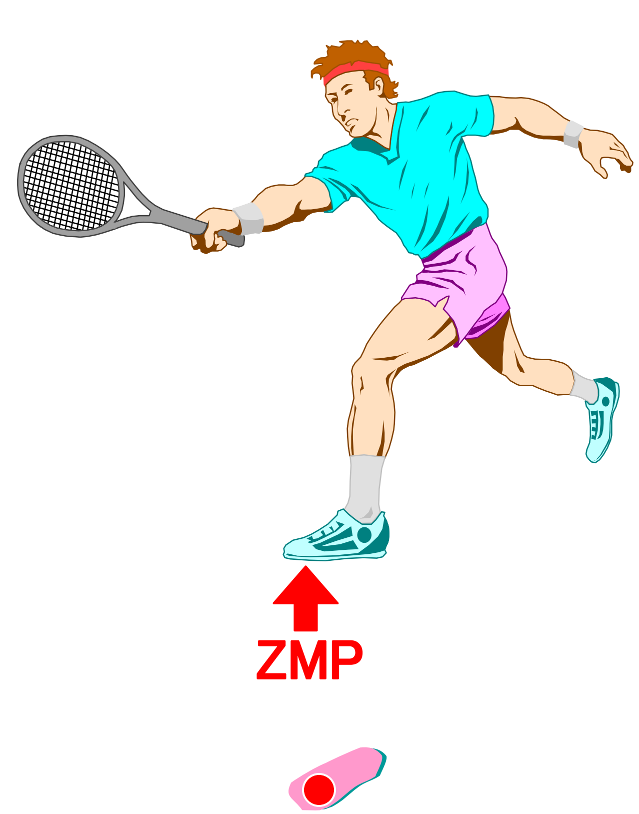
Zero-Moment Point (ZMP)

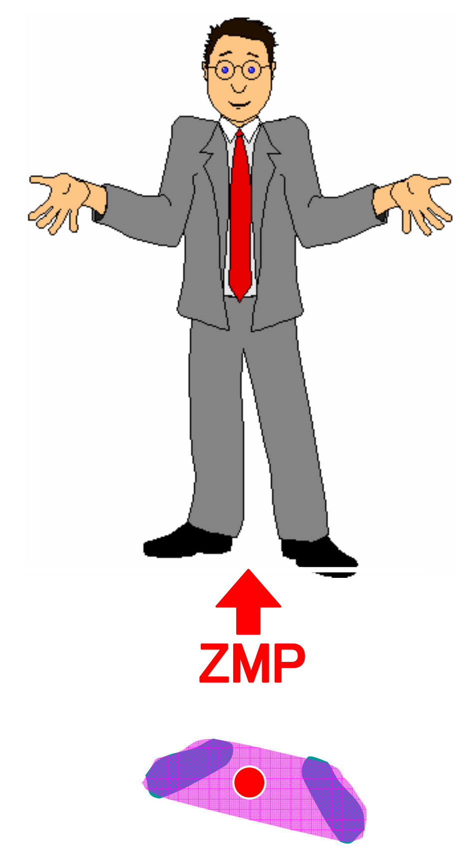
[Vukobratovic et al. 1972]

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



Zero-moment point

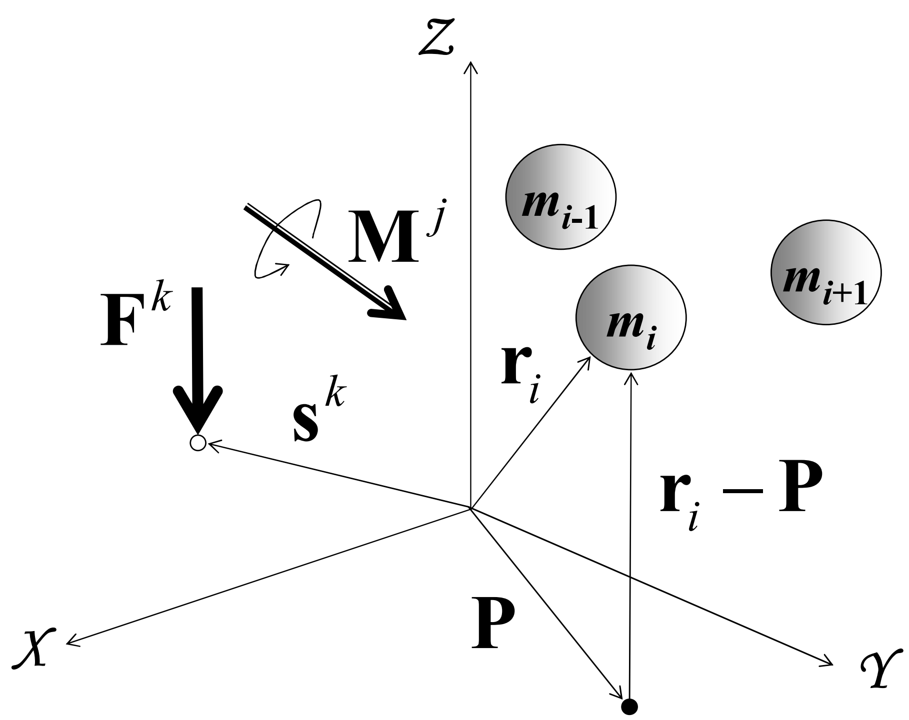




Derivation of the ZMP

[Takanishi et al., 1989]

$$\sum_{i}^{n}\{m_i(\mathbf{r}_i-\mathbf{p})\times(\ddot{\mathbf{r}}_i+\mathbf{g})\}+\mathbf{T}-\sum_{j}\mathbf{M}^j-\sum_{k}\{(\mathbf{s}^k-\mathbf{p})\times\mathbf{F}^k\}=\mathbf{0}$$



Vectors of a walking mechanism

$\mathbf{P}=[x_p \quad y_p \quad 0]^T$: position vector of **P**

$\mathbf{T}=[T_x \quad T_y \quad T_z]^T$: total torque acting at **P**

$\mathbf{M}^j=[M_x^j \quad M_y^j \quad M_z^j]^T$: external moment j

$\mathbf{F}^k=[F_x^k \quad F_y^k \quad F_z^k]^T$: external force k

$\mathbf{s}^k=[s_x^k \quad s_y^k \quad s_z^k]^T$: position where $\mathbf{F}^k$ is acting

Derivation of the ZMP

ZMP equations with external forces and moments

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

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

[Takanishi et al., 1989]

A simplified version of ZMP equations

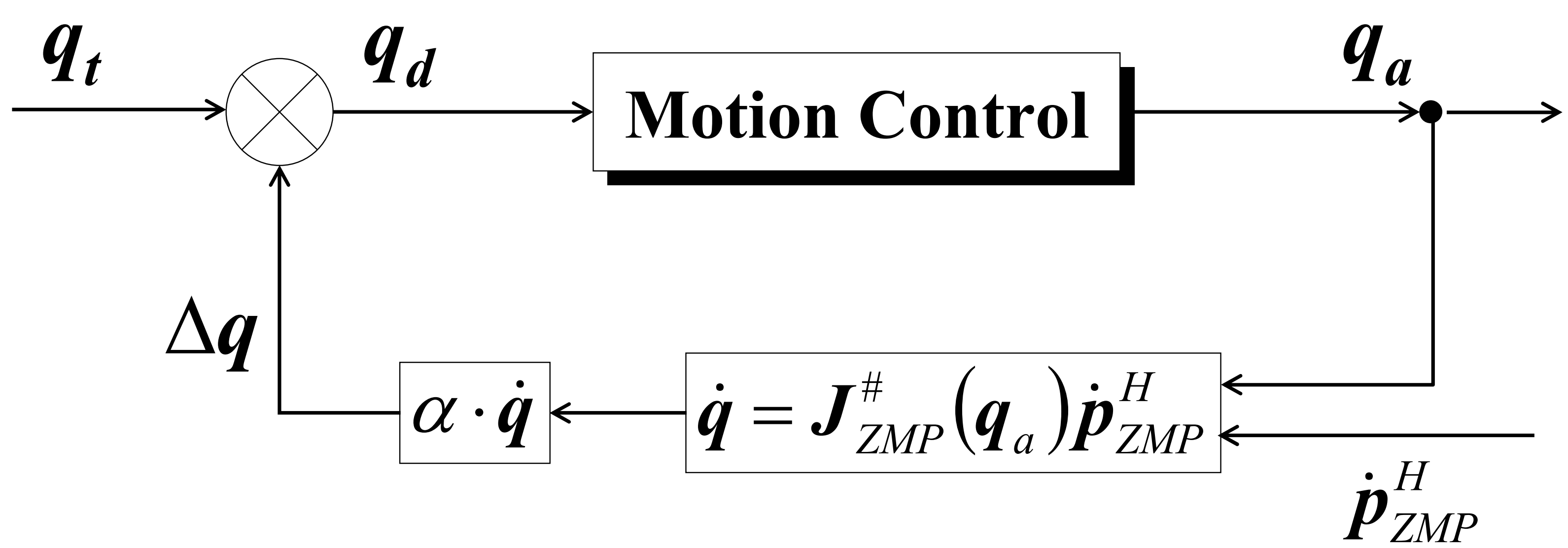
$$x_{ZMP} = \frac{\sum_i^n m_i \{x_i(\ddot{z}_i + g_z) - (\ddot{x}_i + g_x) z_i\} - I_{iy}\omega_{iy}}{\sum_i^n m_i (\ddot{z}_i + g_z)}$$

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

[Huang et al., 2001]

ZMP Jacobian Compensation

[Sobota et al., 2003; Wollherr et al., 2003]



$$\boldsymbol{p}_{ZMP} \equiv \boldsymbol{p}_{ZMP}(\boldsymbol{q})$$

$$d\boldsymbol{p}_{ZMP} = \frac{\partial \boldsymbol{p}_{ZMP}}{\partial \boldsymbol{q}} d\boldsymbol{q}$$

$$\dot{\boldsymbol{p}}_{ZMP} = \boldsymbol{J}_{ZMP}(\boldsymbol{q}_a) \cdot \dot{\boldsymbol{q}}$$

$$\boldsymbol{J}_{ZMP}(\boldsymbol{q}_a) = \left[\frac{\partial \boldsymbol{p}_{ZMP}}{\partial q_1} \quad \cdots \quad \frac{\partial \boldsymbol{p}_{ZMP}}{\partial q_n} \right]_{\boldsymbol{q}=\boldsymbol{q}_a}$$

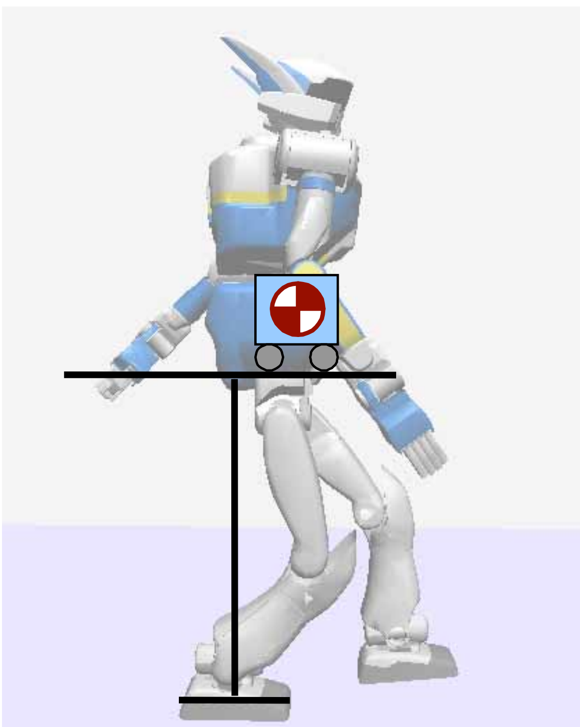
$$\dot{\boldsymbol{q}} = \boldsymbol{J}^{\#}_{ZMP}(\boldsymbol{q}_a) \cdot \dot{\boldsymbol{p}}^{H}_{ZMP}$$

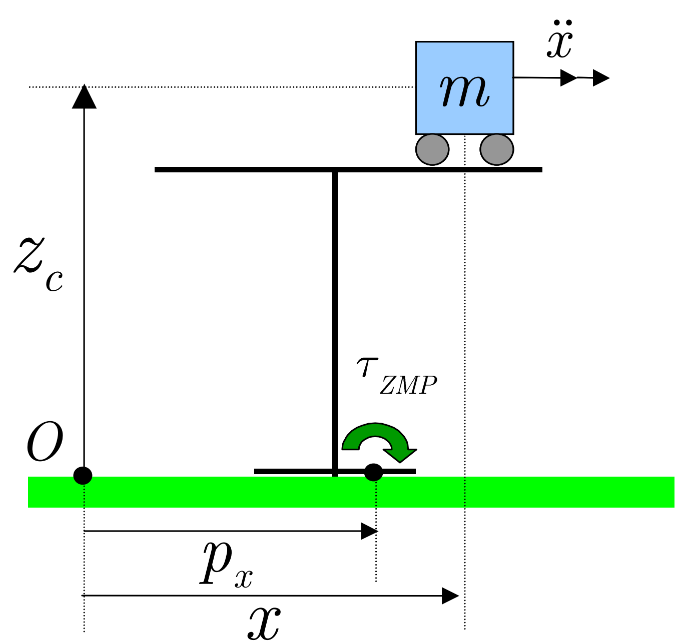
$$\boldsymbol{J}_{ZMP}(\boldsymbol{q}_a) = \left[\frac{\partial \boldsymbol{p}^{H}_{ZMP}}{\partial q_1} \quad \cdots \quad \frac{\partial \boldsymbol{p}^{H}_{ZMP}}{\partial q_n} \right]_{\boldsymbol{q}=\boldsymbol{q}_a} = \begin{bmatrix} \frac{\partial x_Z}{\partial q_1} & \cdots & \frac{\partial x_Z}{\partial q_n} \\ \frac{\partial y_Z}{\partial q_1} & \cdots & \frac{\partial y_Z}{\partial q_n} \end{bmatrix}_{\boldsymbol{q}=\boldsymbol{q}_a}$$

The Cart-Table Model

[Kajita et al. 2003]

$$\tau_{zmp} = mg(x - p_x) - m\ddot{x}z_c = 0$$





The ZMP of the Cart-Table Model

$$p_y = y - \frac{z_c}{g}\ddot{y}$$

$$p_x = x - \frac{z_c}{g}\ddot{x}$$

Dynamics equations

$$\ddot{y} = \frac{g}{z_c}y - \frac{1}{mz_c}\tau_x$$

$$\ddot{x} = \frac{g}{z_c}x + \frac{1}{mz_c}\tau_y$$

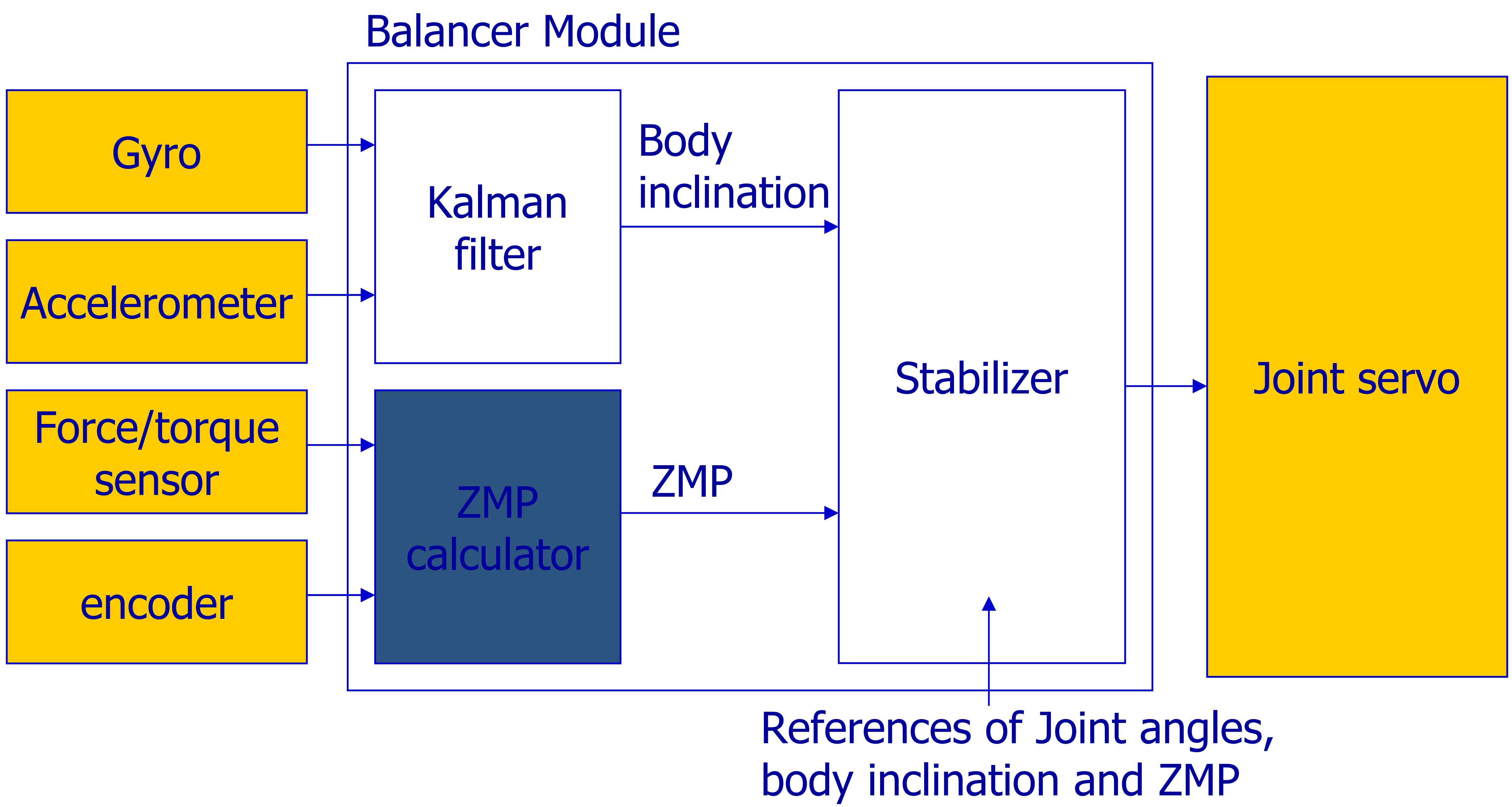
ZMP

$$p_y = \frac{\tau_x}{mg}$$

$$p_x = -\frac{\tau_y}{mg}$$

ZMP Model-based Feedback controller configuration

[Kajita et al. 2003]

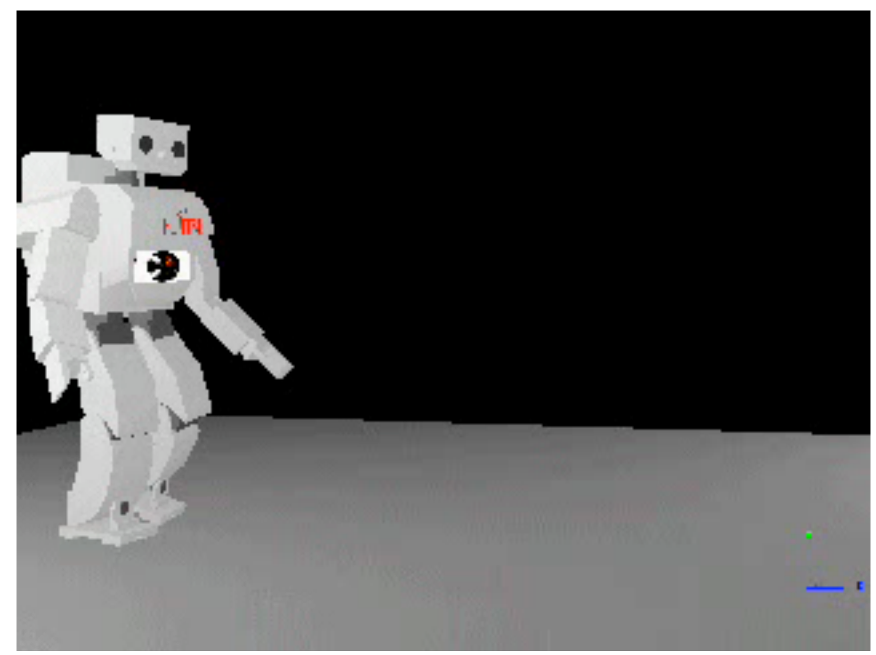


Learning Approach

[Chalodhorn et al. 2006]

Learning to walk through imitation

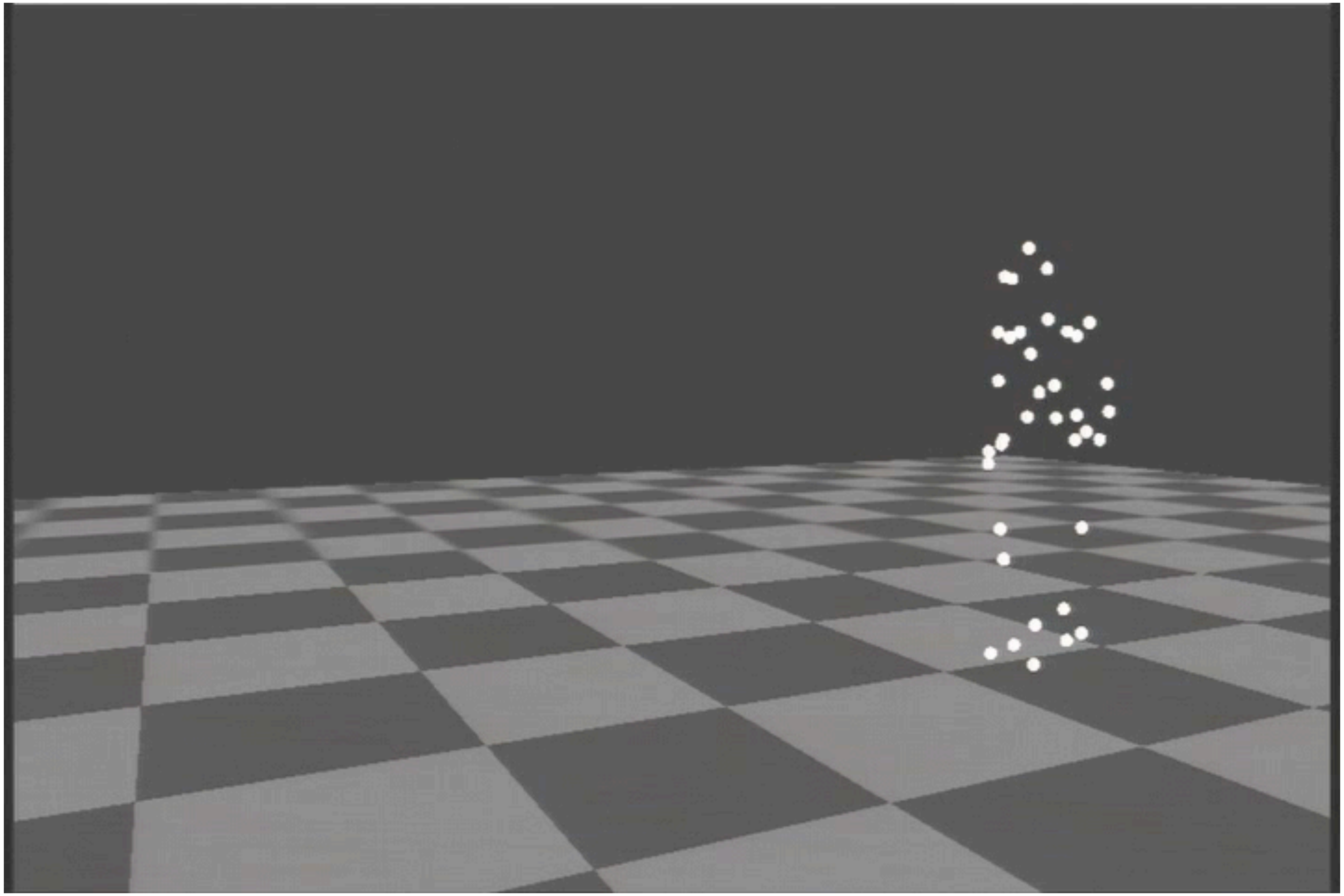
QuickTime™ and a
decompressor
are needed to see this picture.



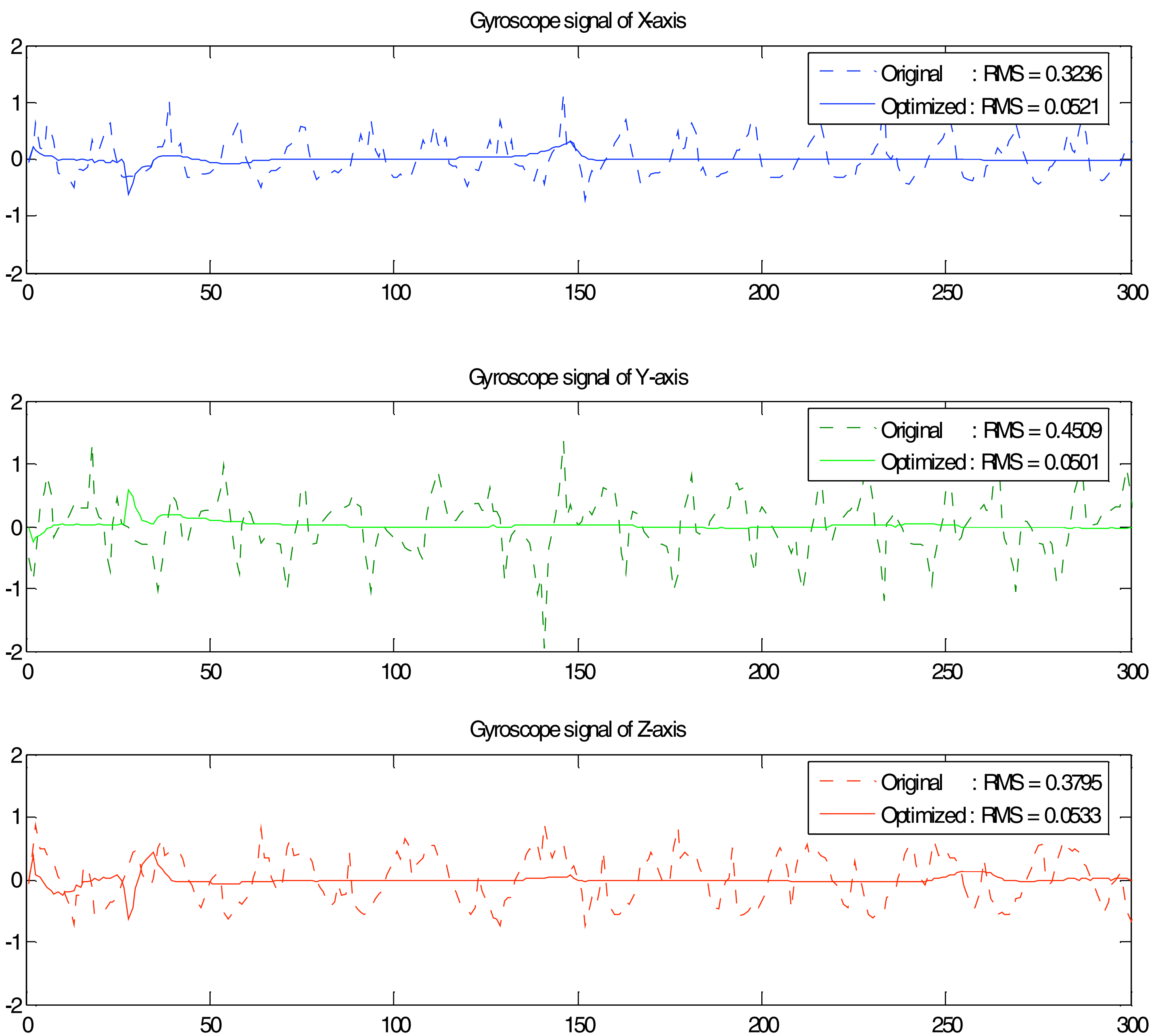
Dimension reduction

Gaussian process latent variable model

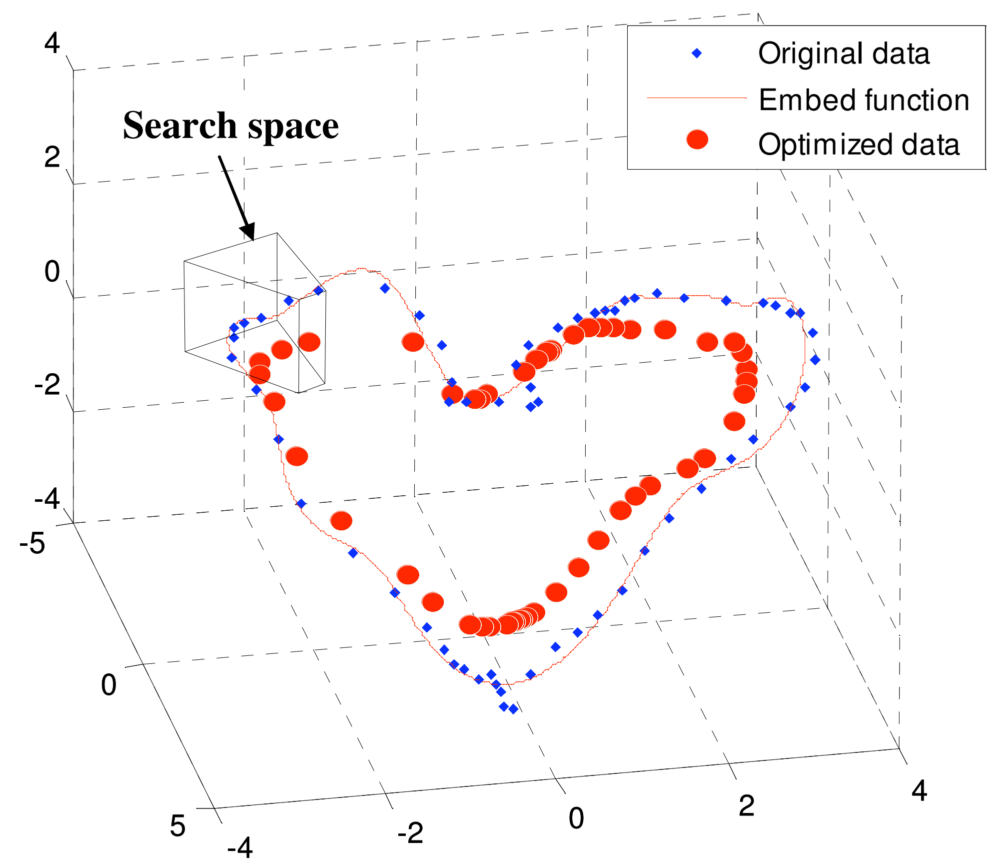
[Grochow et al. 2004]



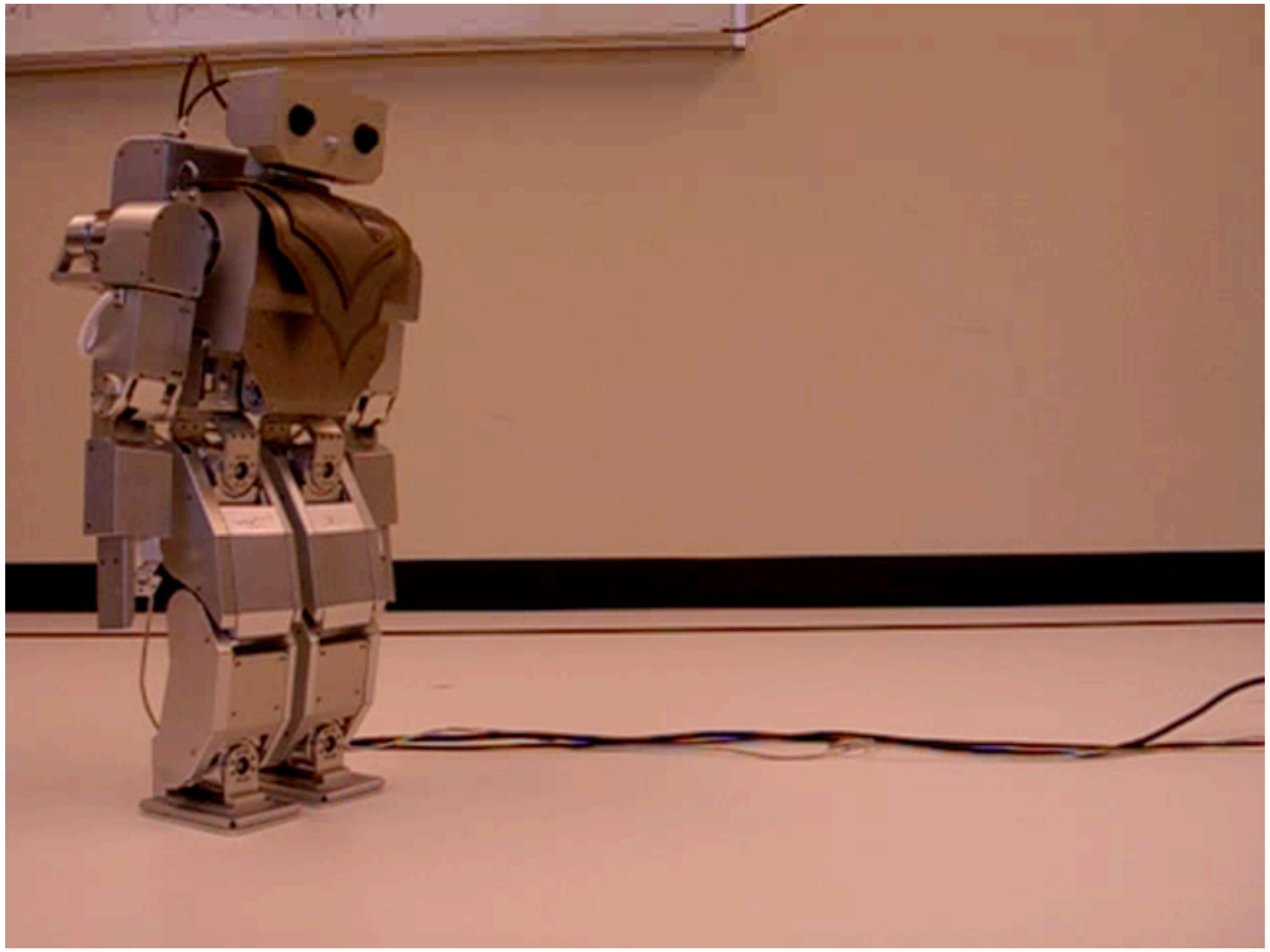
Learning through low-dimensional spaces



[Chalodhorn et al. 2005]



Learning by imitation results



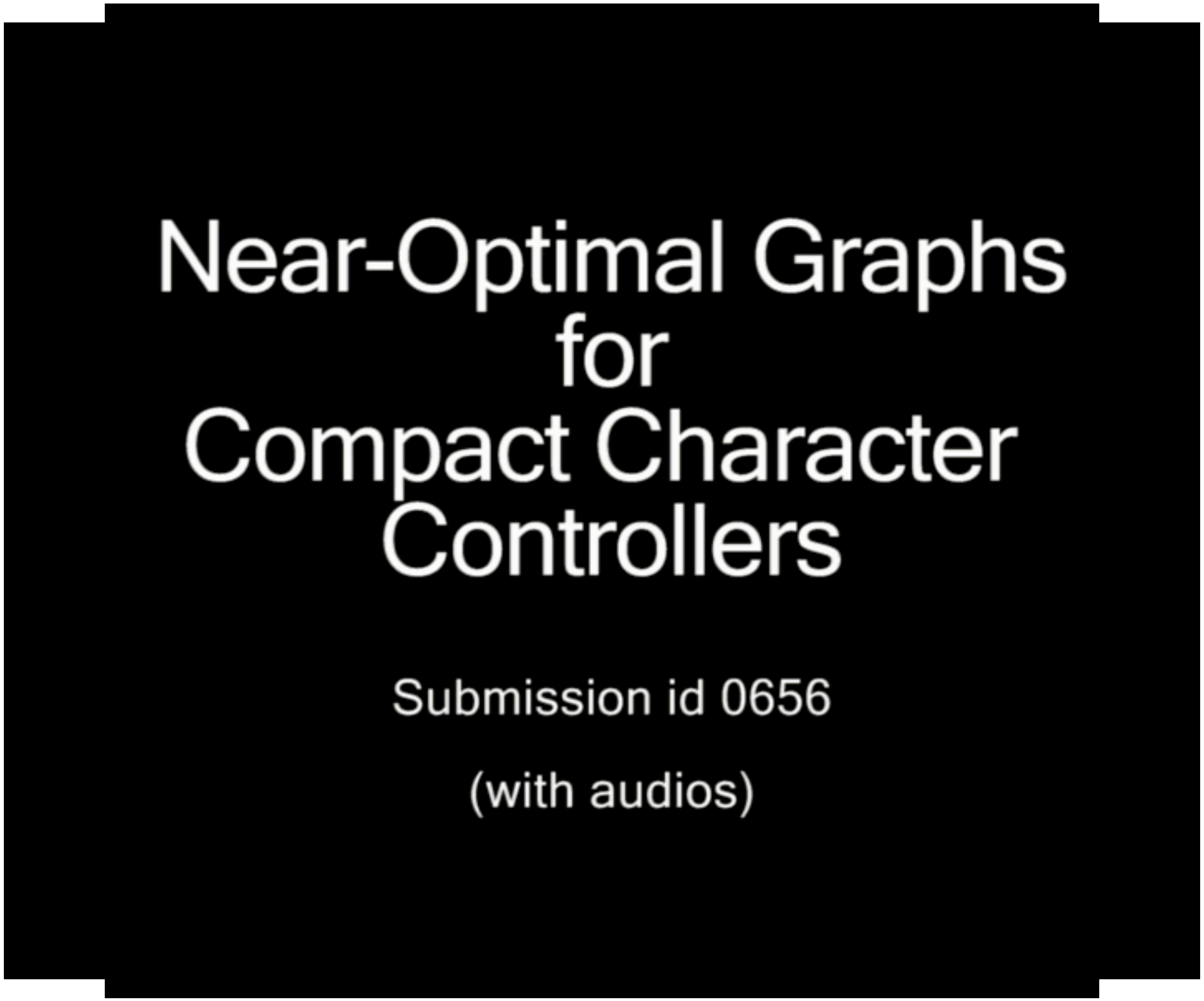
Learning by imitation results

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



THANK YOU