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Vorlesung

Biorobotik

Unitnummer 473001
Modul 47300 ***Biorobotik***
Prüfungsnummer 47301

Humanoide Laufroboter

inspo

SimTech
Cluster of Excellence

Roboter im Alltag

1. Ein Roboter darf keinen Menschen verletzen oder durch Untätigkeit zu Schaden kommen lassen.
2. Ein Roboter muss den Befehlen eines Menschen gehorchen, es sei denn, solche Befehle stehen im Widerspruch zum ersten Gesetz.
3. Ein Roboter muss seine eigene Existenz schützen, solange dieser Schutz nicht dem ersten oder zweiten Gesetz widerspricht.

Isaac Asimov, "The Naked Sun". Januar 1975: Doubleday

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Humanoide Roboter

1. Definition der Begriffe

Humanoid:

Klassifizierung für alle Lebensformen und Maschinen, die ein menschenähnliches Erscheinungsbild aufweisen. Aus dem lat: „*homo*“ = „*Mensch*“ und altgriechisch: „*eidos*“ = „*Gestalt*“ (http://de.wikipedia.org/wiki/Humanoid)

Roboter:

„*robota*“ = „*arbeiten*“ in den slawischen Sprachen bsp: tschechisch oder polnisch
(Haun, 2007, S. 18)

Definition „Roboter“ nach dem Robot Insitute of America (RIA):

„Ein Roboter ist ein programmierbares Mehrzweck-Handhabungsgerät für das Bewegen von Material, Werkstücken, Werkzeugen oder Spezialgeräten. Der frei programmierbare Bewegungsablauf macht ihn für verschiedenste Aufgaben einsetzbar.“
(http://icd.uni-stuttgart.de/files/robolab/Robolab_Leitfaden.pdf)

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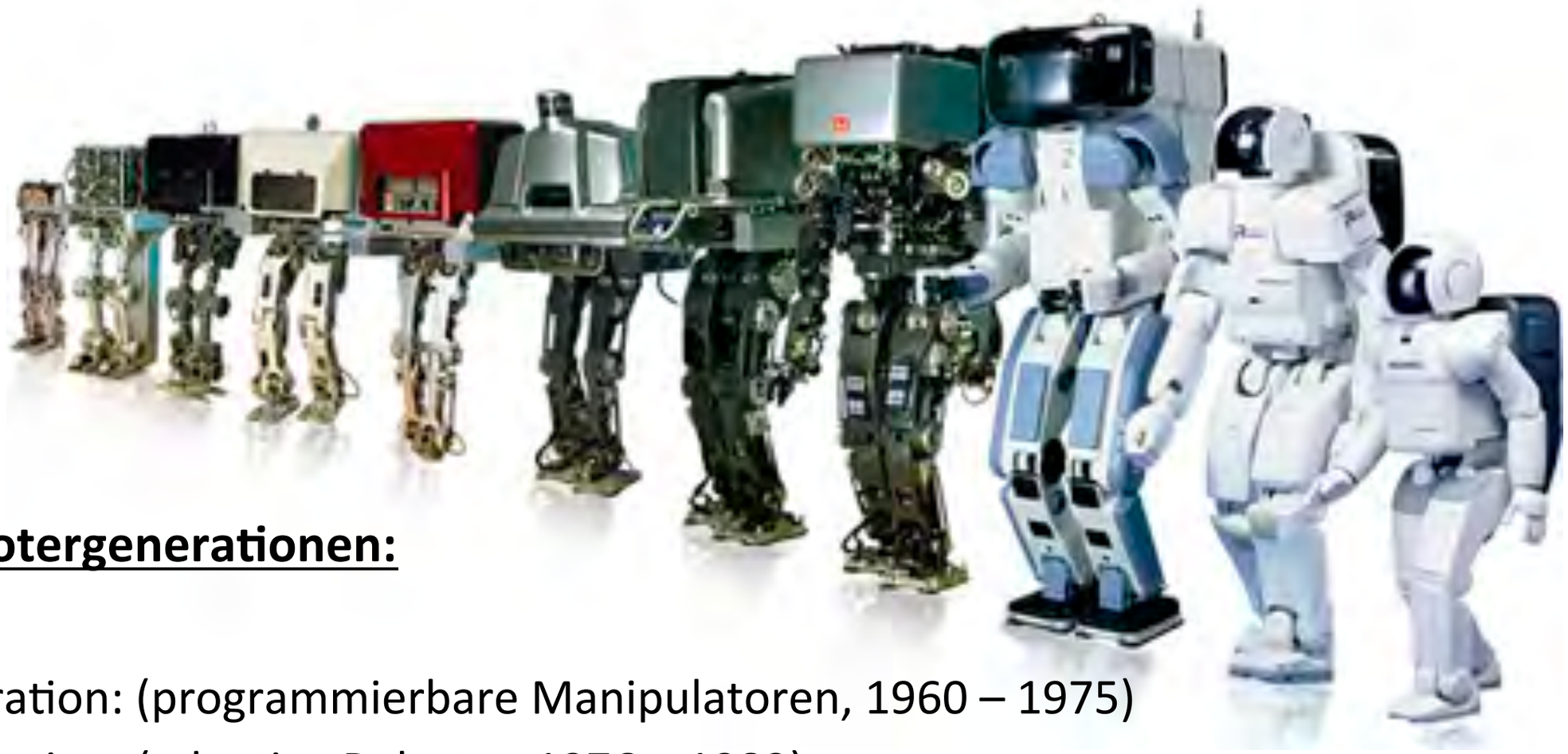
Humanoide Roboter

2. Historische Entwicklung der Roboter



<u>Vier Robotergenerationen:</u>

1. Generation: (programmierbare Manipulatoren, 1960 – 1975)
2. Generation: (adaptive Roboter, 1976 – 1982)
3. Generation: (autonome Roboter, ab 1983)
4. Generation: (humanoide AI-Roboter)

Quelle: I. Einführung in biologisch motivierte Robotersysteme, 2011, F. 10
Grafiken: http://www.apricot.at/wp-content/uploads/2011/11/asimo-history.jpg

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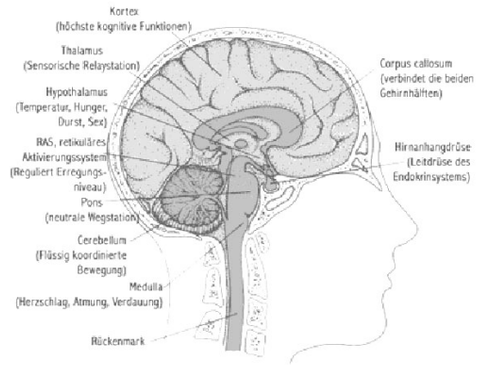
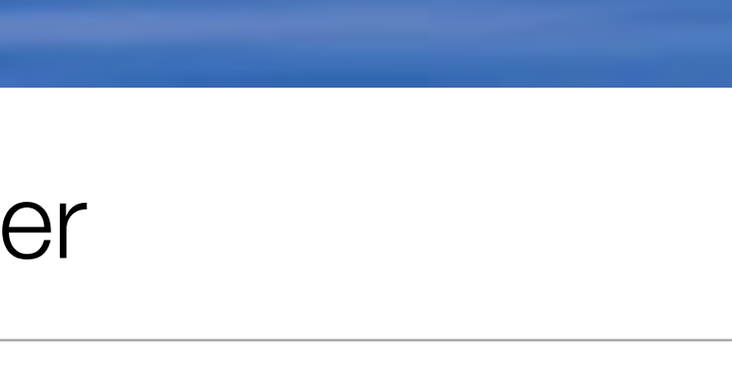
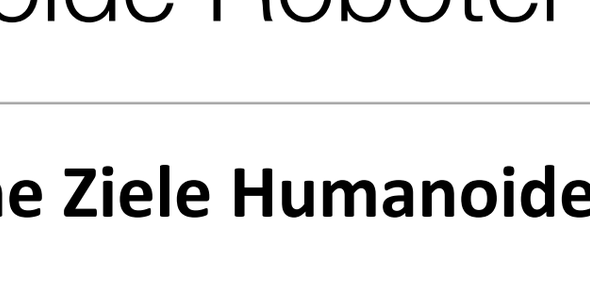
Humanoide Roboter

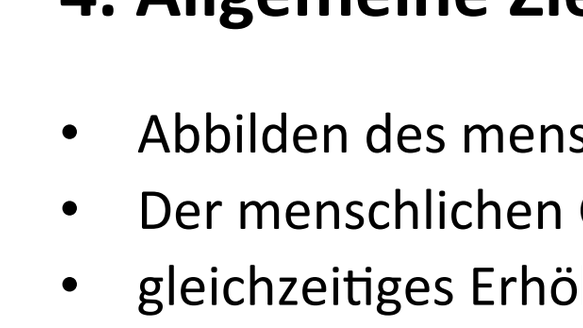
4. Allgemeine Ziele Humanoider Laufroboter

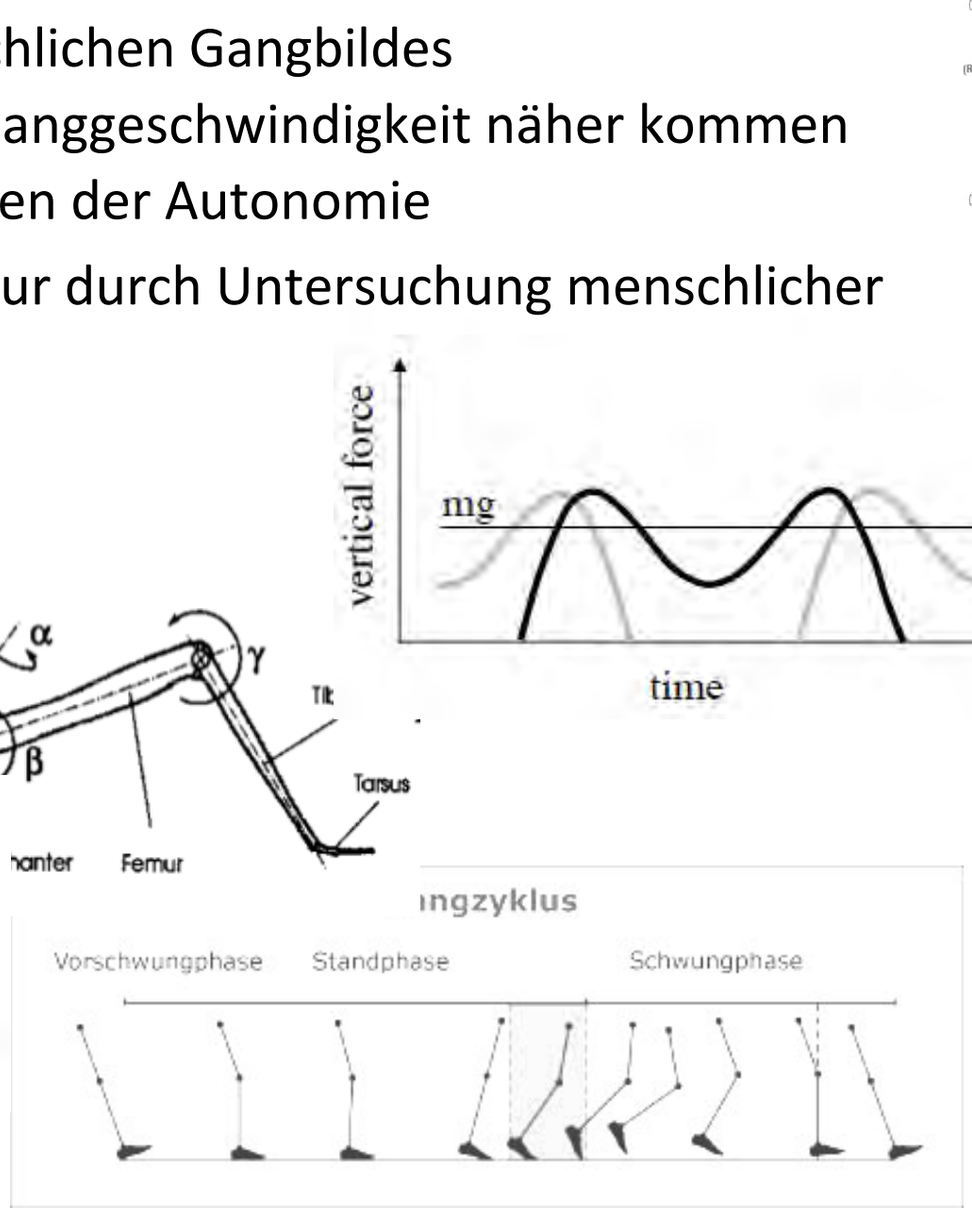
- Abbilden des menschlichen Gangbildes
- Der menschlichen Ganggeschwindigkeit näher kommen
- gleichzeitiges Erhöhen der Autonomie
- Verständnis der Natur durch Untersuchung menschlicher Eigenschaften











Quelle: Ulbrich, Buschmann, Favot, Lohmeier & Schwienbacher, 2011, S. 2
Grafiken: Blickhan, Seyfarth, Geyer, Grimmer, Wagner & Günther, 2007; http://img179.imageshack.us; www.solamed.de; www.sonic.net; II. Biomechanik als Konstruktionsvorbild, 2011b F. 32

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Humanoide Roboter

5. Komponenten Robotersystem ←→ Menschliches Systems

Sensorik:

Formen der Wahrnehmung:

- Wahrnehmung der Außenwelt (5 Sinne)
  → Info über Reizintensität, -dauer, -lokalisation
- Wahrnehmung des eigenen Körpers (Propriozeption etc.)

Funktion:

- Einstellen auf Umwelt; adaptiv sein
- Bewegungsplanung
- Krafteinsatz

→ Interaktion Mensch ↔ Umwelt

Quelle: Lugmair, 2006, S. 22 & S. 139
Grafiken: www.werbung-out-of-the-box.de

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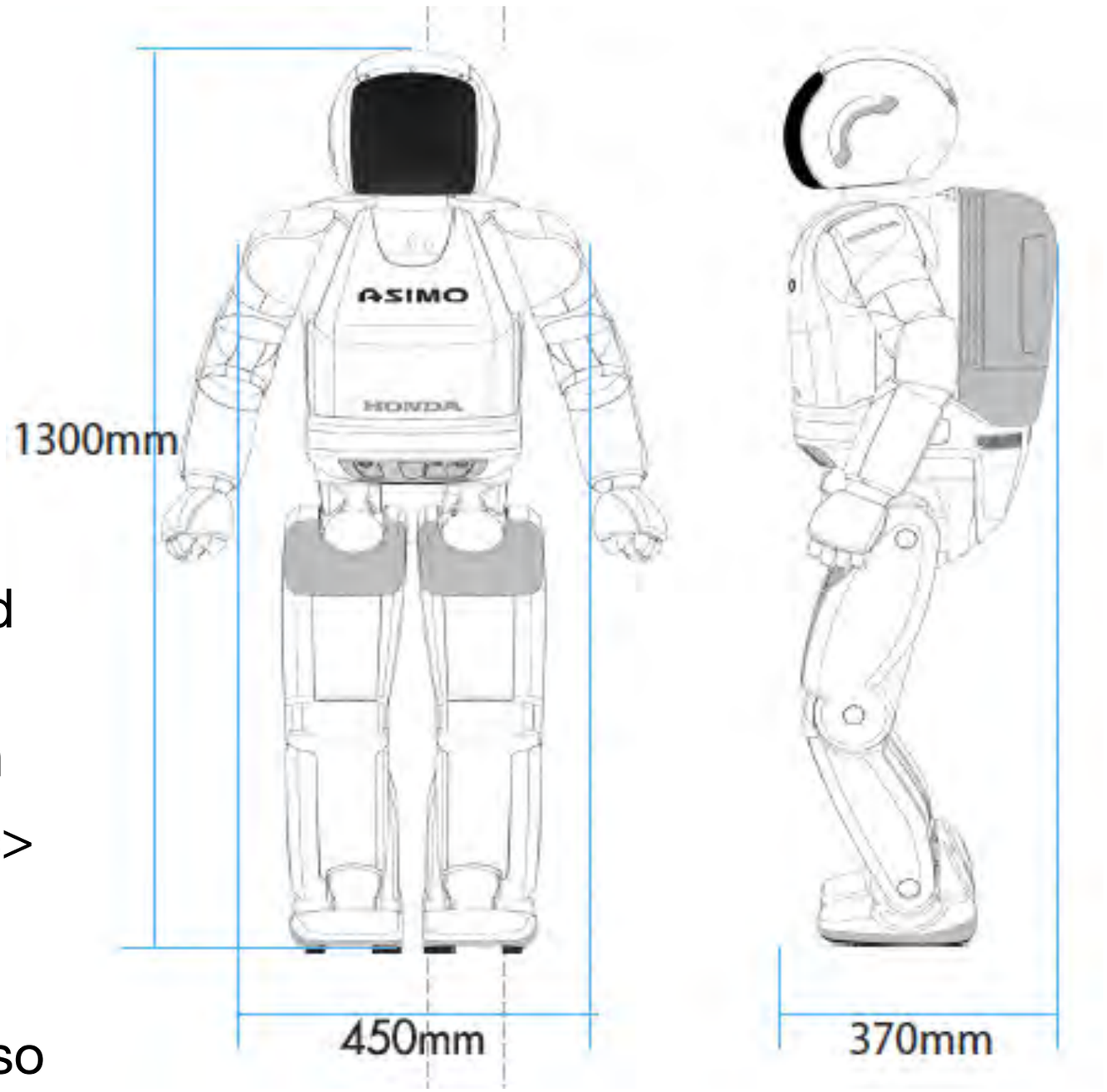
ASIMO (**A**dvanced **S**tep in **I**nnovativ **Mo**bility)

- Baujahr: 2004 (V.1)
- Gewicht: 43 kg
- Frei von externen Kabeln
- Akku bis zu 1 Stunde
- Gang wird gesteuert durch Ablauf- und Schrittanpassung
- Antrieb über Servomotor, harmonischer Geschwindigkeitsreduzierer und Antriebseinheit
- Kabellose Übertragung möglich
- 6-Achsen-Fußbereich-Sensor => Fußsensorik
- Gyroskop und Beschleunigungssensor => Torso



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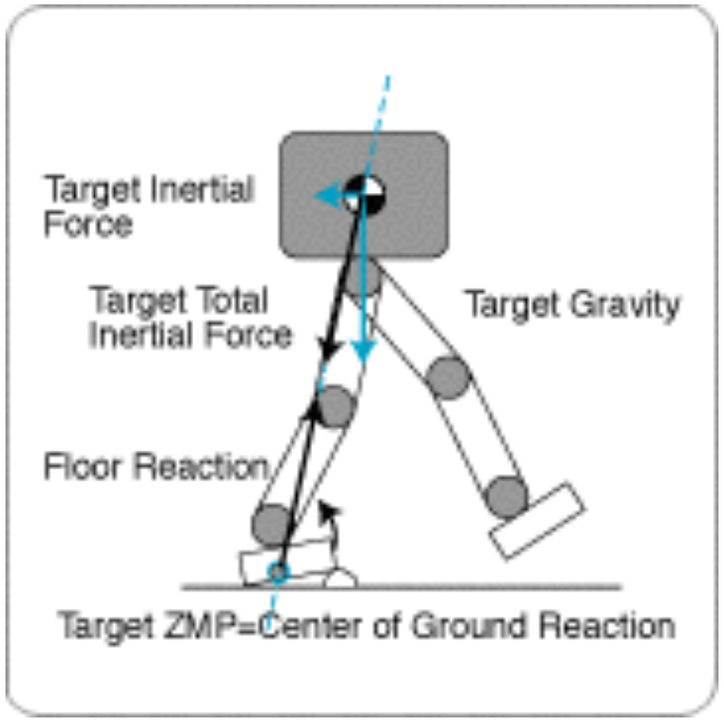
ASIMO (**A**dvanced **S**tep in **I**nnovativ **Mo**bility)

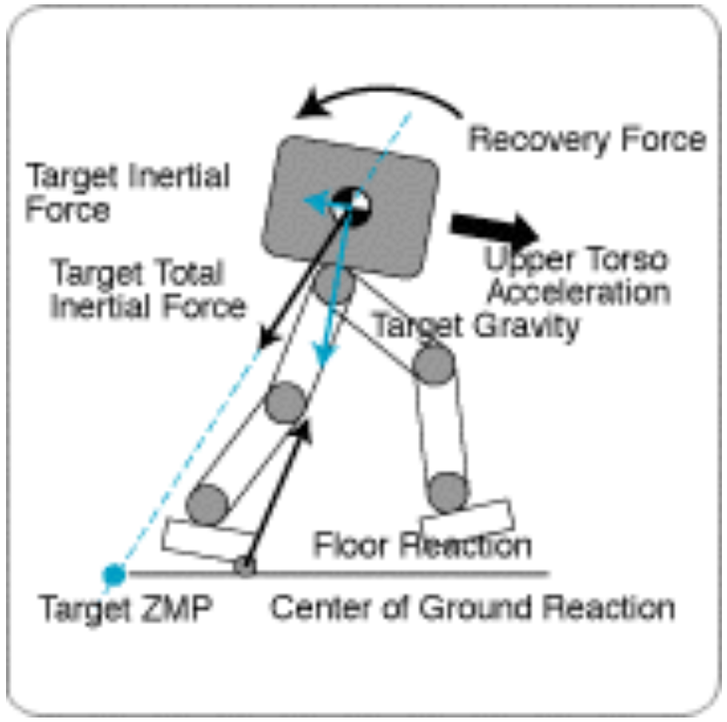
Floor Reaction Control

Target MP Control

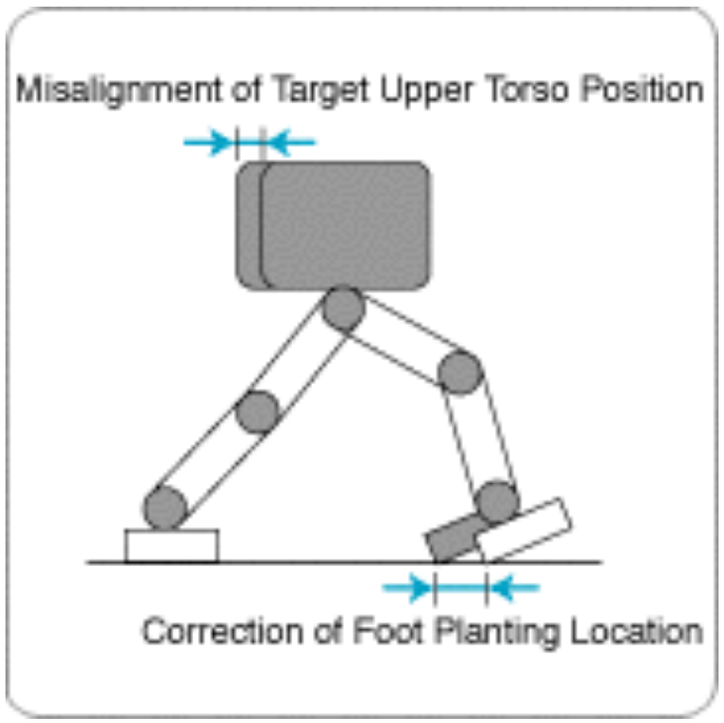
Foot Planting Location Control



Floor Reaction Control



Target ZMP Control



Foot Planting Location Control

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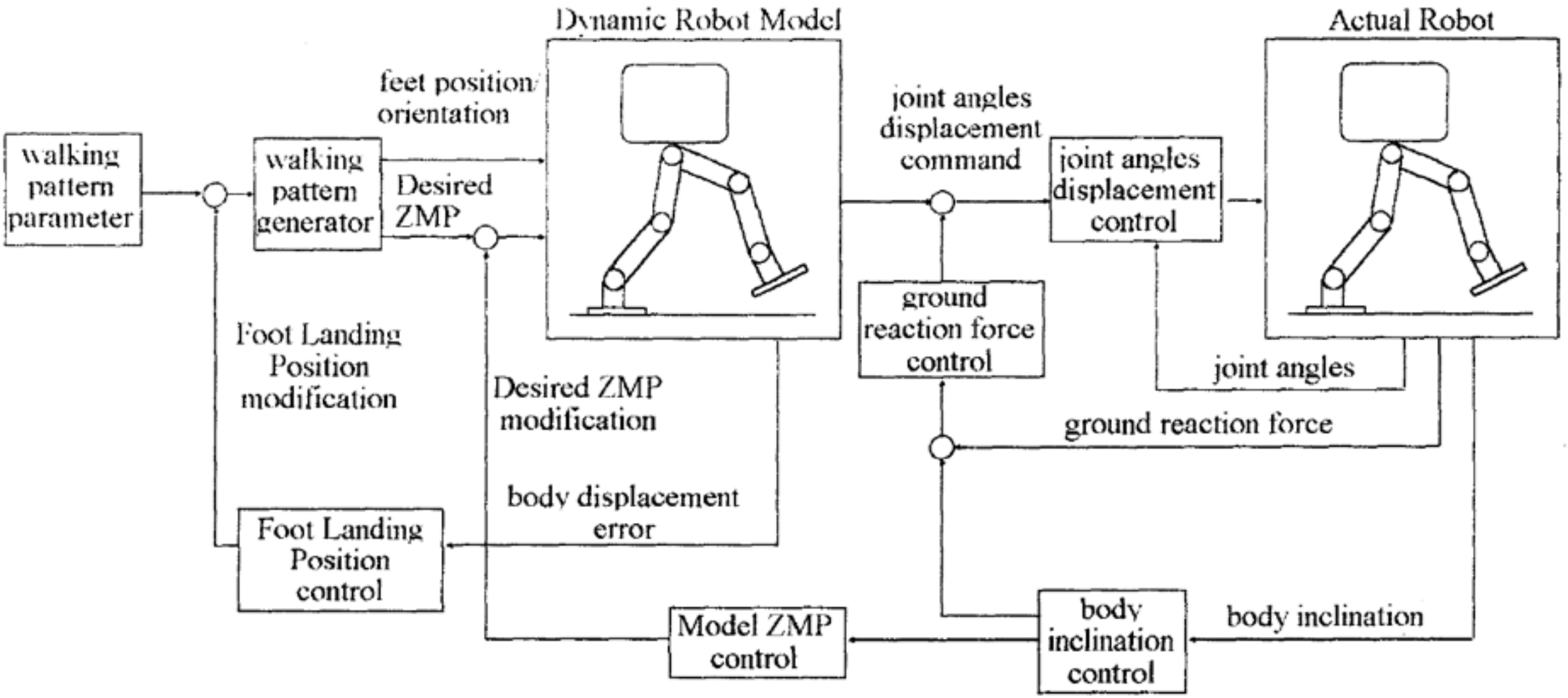
ASIMO (**A**dvanced **S**tep in **I**nnovativ **Mo**bility)



Honda P2

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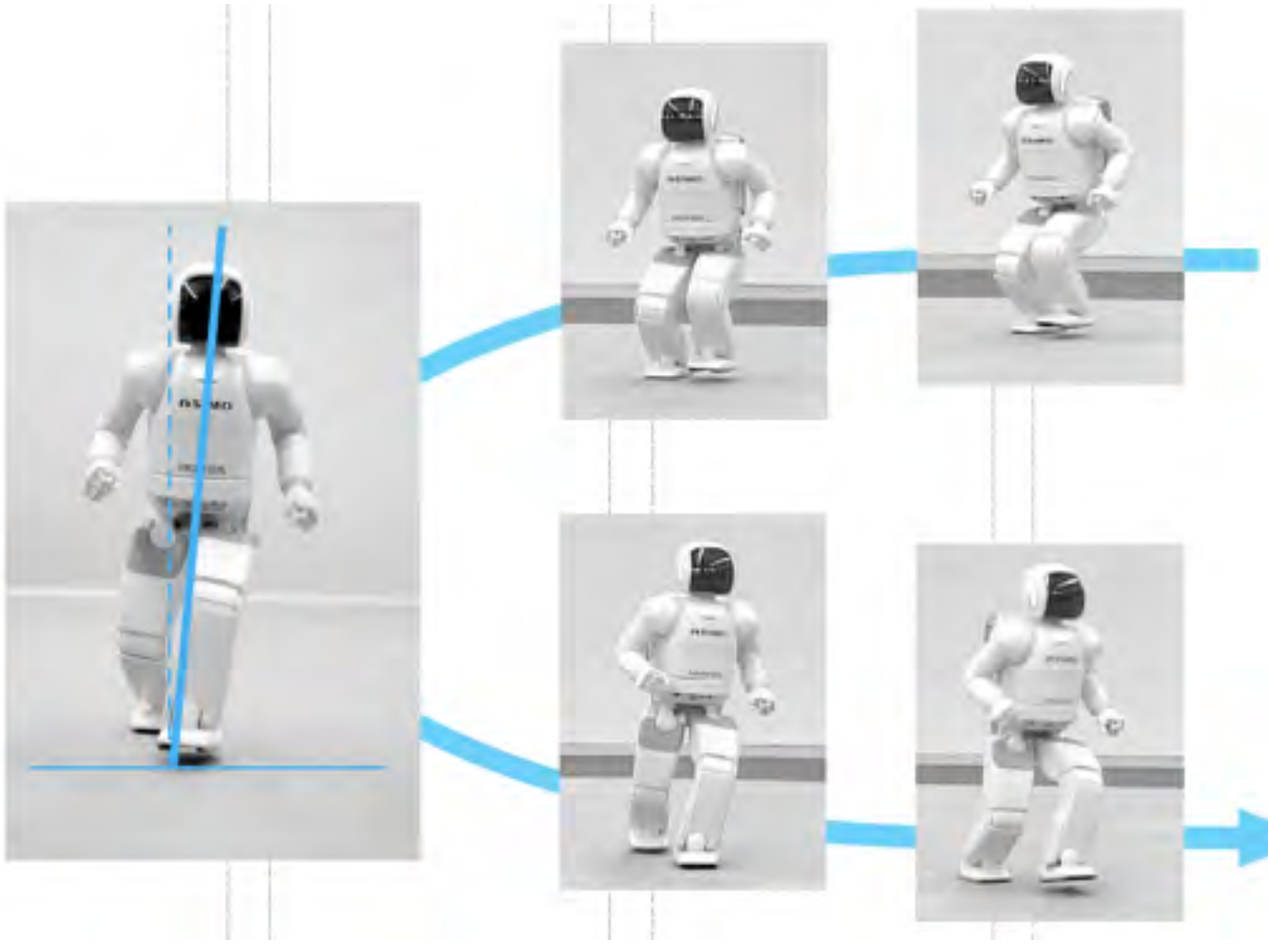
ASIMO (**A**dvanced **S**tep in **I**nnovativ **Mo**bility)

Kurven Rennen (r= 2,5 m): 5 km/h



Normales Gehen: 2,7 km/h

Laufen und Tragen eines Gegenstandes (1kg): 1,6 km/h

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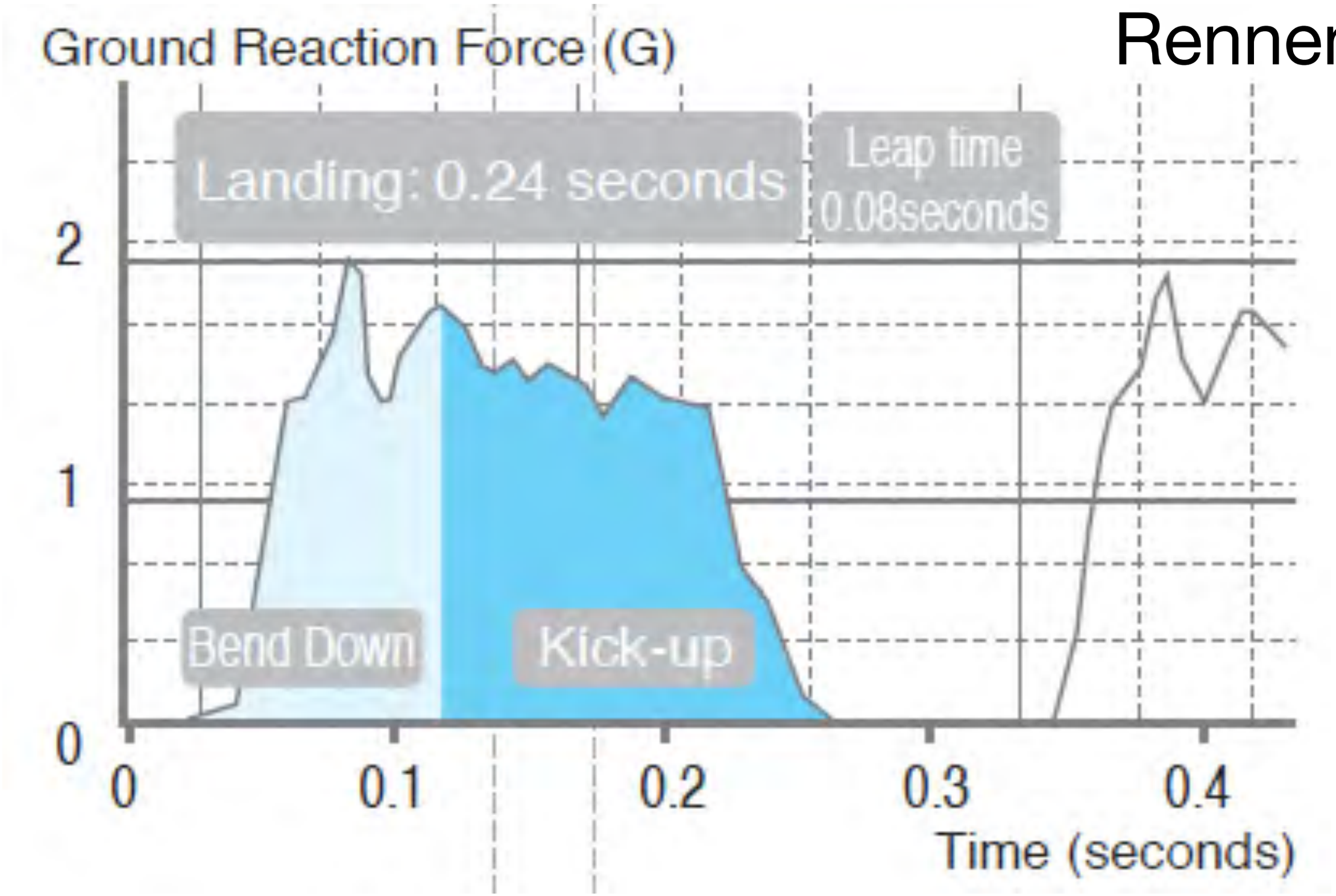
ASIMO (**A**dvanced **S**tep in **I**nnovativ **Mo**bility)



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Johnnie (TU München)

- Baujahr: 2003
- TU München
- Größe: 180 cm
- Gewicht: 49 kg
- Max. Geschwindigkeit: 2,4 km/h
- Schrittlänge 55 cm
- 18 Gelenke

- Besonderheiten:
  - Erkennt Hindernisse
  - Übersteigt und umgeht Hindernisse
  - Kann Schrittlänge entsprechend anpassen
  - Sensorik, Elektronik und Rechner auf Roboter montiert
  - ABER: Externe Energiezufuhr (=> Kabel)

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Johnnie (TU München)

- Gang:
  - Autonom durch Sichtsystem
  - Passt Gangmuster an aktuelle Umweltgegebenheiten an
  - Ständige Messung der Gelenkpositionen, -geschwindigkeiten, Bodenaufstandskräfte
  - Orientierungssensor: Misst Abweichungen der idealen Trajektorie
- Bewegungsregelung:
  - Allgemeine Gangkoordination
    - Übergang zwischen den programmierten Gangmustern
    - Berechnet Ausgleichsbewegungen der Gelenke
  - Regelt die Bewegung der Gelenke
    - Unabhängig von der ersten Ebene
    - Regelt die zeitgleichen einzelnen Bewegungen der Gelenke

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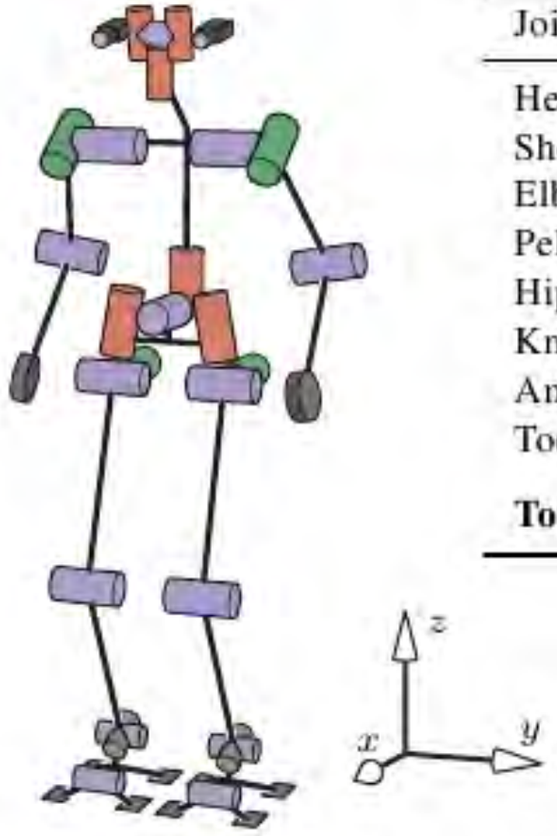
LOLA (TU München)

- Eckdaten:
  - Größe: 180 cm
  - Gewicht: 55 kg
  - Gehgeschwindigkeit: 3.34 km/h
  - Freiheitsgrade: insgesamt 25

Lola



Joint	DoF
Head	3
Shoulder	2
Elbow	1
Pelvis	2
Hip	3
Knee	1
Ankle	2
Toe	1
Total	**25**

- Zero Moment Point (ZMP)
- Foot Rotation Indicator (FRI)
- Zero Rate of Change of Angular Momentum (ZRAM)

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Vergleich LOLA vs. ASIMO

LOLA	ASIMO
Gebaut um die menschliche Bewegung nachzuvollziehen	*Gebaut um als Service Roboter zu wirken*
Geringe Anzahl an Funktionen	*Hohe Anzahl an Funktionen*
Höchstgeschwindigkeit 3,34 km/h	*Höchstgeschwindigkeit 9 km/h*
ZMP Control	*ZMP Control*
FRI und ZRAM	*Floor Reaction Control, Foot Planting Location Control*
180 cm und 55 kg	*130 cm und 48 kg*
Stockender Gang	*Relativ flüssiger gleichmäßiger Gang*
25 Freiheitsgrade	*57 Freiheitsgrade*
Wird über Kabel mit Energie versorgt, Antrieb durch Motoren	*Hat einen Akku, Antrieb durch Motoren*

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Vergleich Mensch, ASIMO, LOLA

Gelenk	Mensch	Asimo	Lola
Schulter	*Kugelgelenk, 3 Freiheitsgrade, Anteversion/Retroversion, Abspreizung/Anlegen, Innen-/ Außenrotation*	*3 Freiheitsgrade,*	*2 Freiheitsgrade*
Hüft-Bein-Gelenk	*3 Freiheitsgrade, Beugung, Streckung, Abspreizen und Wiederanlegen, Rotation*	*3 Freiheitsgrade*	*3 Freiheitsgrade*
Knie	*2 Freiheitsgrade, Beuge- und Rotationsachse*	*1 Freiheitsgrad*	*1 Freiheitsgrad*
Fußgelenk	*2 Freiheitsgrade, Beuge- und Rotationsachse*	*2 Freiheitsgrade*	*2 Freiheitsgrade*

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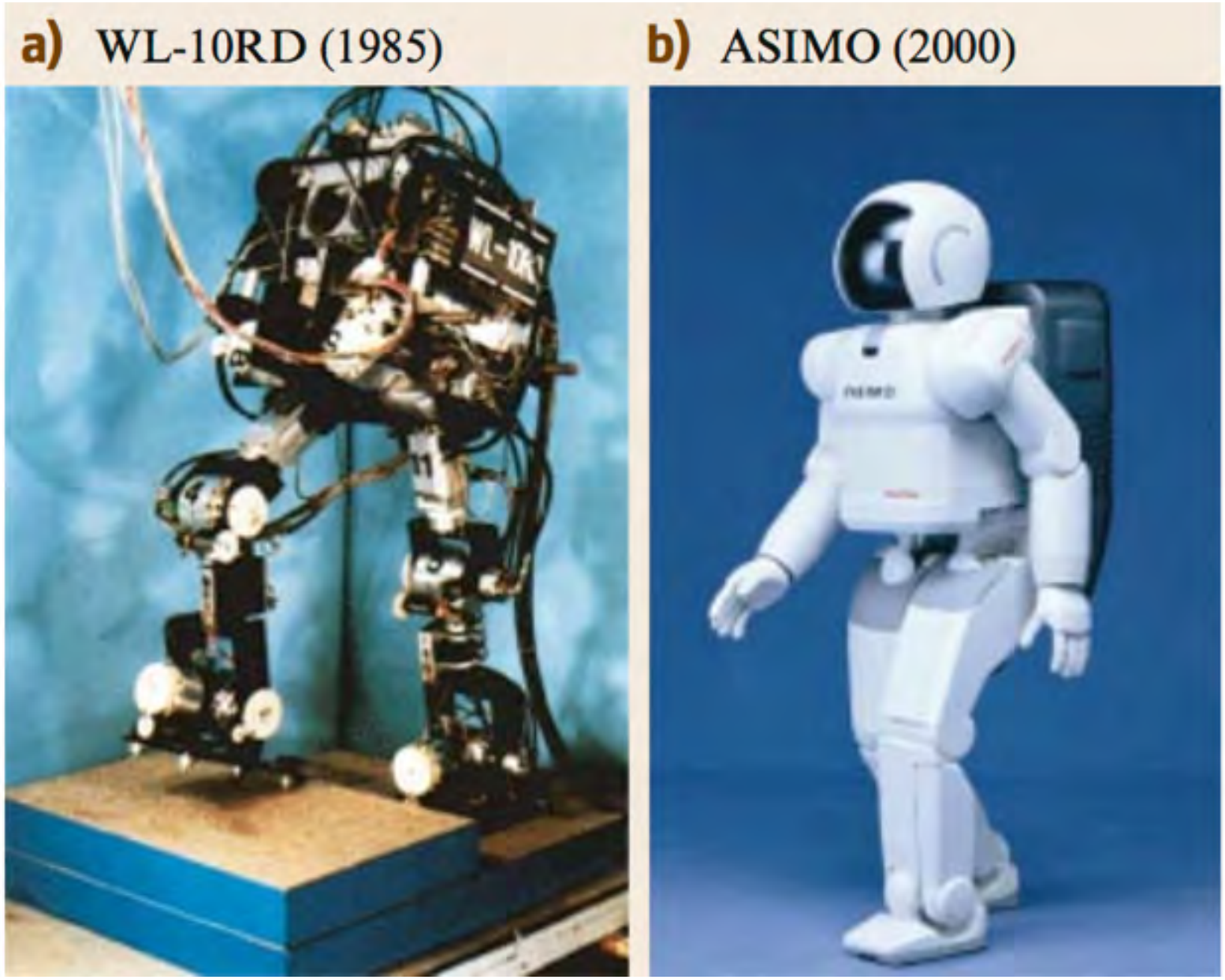
„Klassische“ Humanoide Roboter



WL-10RD, developed by Takanishi and Kato, the first ZMP-based robot. It is a 12-degree-of-freedom (DOF) biped, 1.43m high and weighing 84.5 kg, and driven by hydraulic actuators.

ASIMO, a 26-DOF humanoid robot developed by Honda Motor Co. in 2000.

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Einschub: Zero-Moment Point (ZMP)

Abbildung 16.9 zeigt ein Beispiel einer Kraftverteilung unterhalb des Fußes. Da die Kraft überall an der Oberfläche das gleiche Vorzeichen hat, kann sie zur resultierenden Kraft R reduziert werden. Der Kraftangriffspunkt wird dann der Zero-Moment Point genannt oder kurz ZMP.

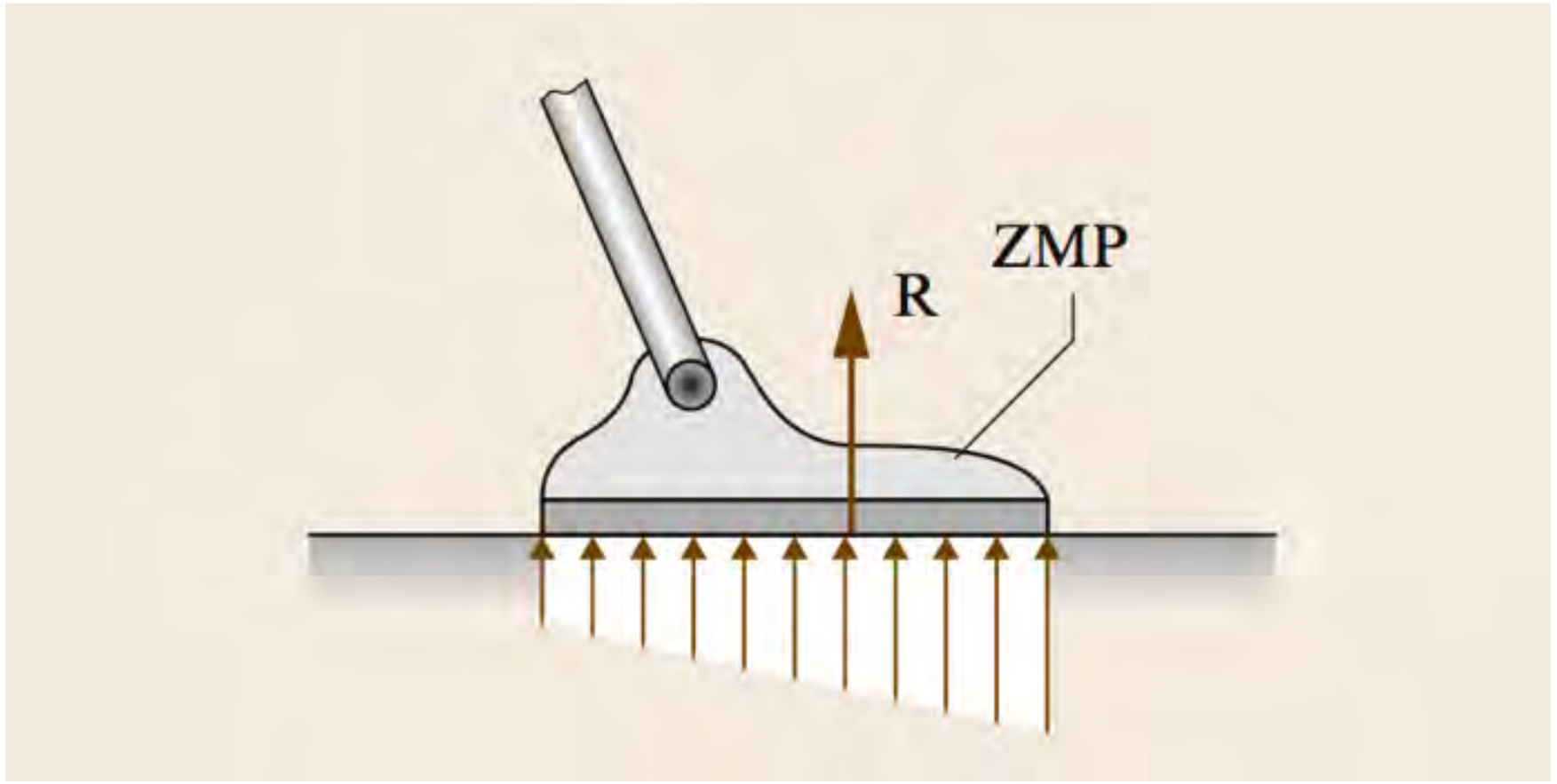

Fig. 16.9 Vukobratovic´ and Stepanenko in 1972

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Zero-Moment Point (ZMP) Control

For the further discussion, let us discuss detailed floor reaction force in three dimensions, as shown in Fig. 16.10.

Suppose that the floor reaction force is acting on a finite number of contact points $\boldsymbol{p}_i (i = 1, \ldots, N)$ and that each force vector is of the form

$$\boldsymbol{f}_i := [f_{ix}\, f_{iy}\, f_{iz}]^\top ,$$

where f_{ix}, f_{iy}, and f_{iz} are the force components in the x, y, and z directions in the coordinate system fixed to the ground, respectively. The ZMP can be calculated as

$$\boldsymbol{p} := \frac{\sum_{i=1}^{N} \boldsymbol{p}_i f_{iz}}{\sum_{i=1}^{N} f_{iz}} . \tag{16.12}$$

It can also be written as

$$\boldsymbol{p} = \sum_{i=1}^{N} \alpha_i \boldsymbol{p}_i , \tag{16.13}$$

$$\alpha_i := f_{iz} / f_z , \tag{16.14}$$

$$f_z := \sum_{i=1}^{N} f_{iz} . \tag{16.15}$$

Since an ordinary walking robot cannot generate adhesive force on its soles,

$$f_{iz} \geq 0 \qquad (i = 1, \ldots, N) . \tag{16.16}$$

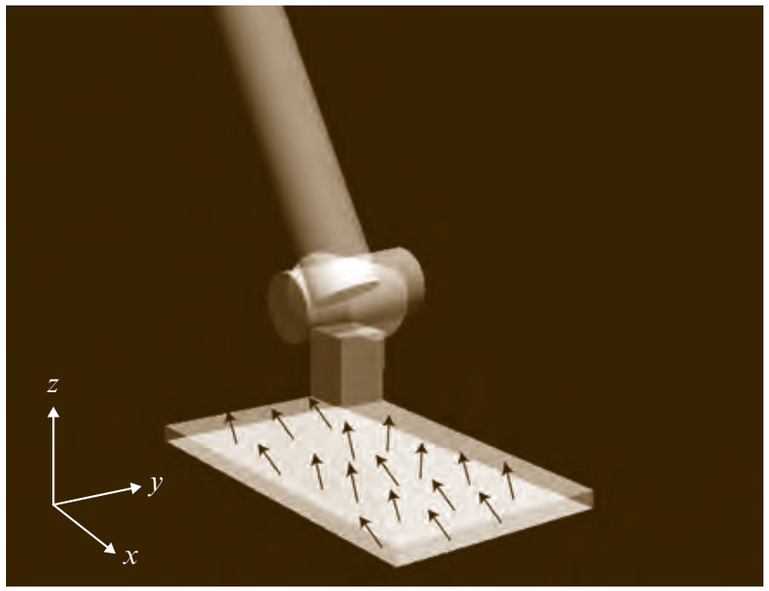

Fig. 16.10 Floor reaction force in three dimensions

Then we can say,

$$\begin{cases} \alpha_j \geq 0 & (i = 1, \ldots, N) , \\ \sum_{i=1}^{N} \alpha_i = 1 . \end{cases} \tag{16.17}$$

The points that satisfy (16.13) and (16.17) form the *support polygon*, the convex hull of the contacting point. Thus, we can conclude that the ZMP always exists in the support polygon. In other words, *the ZMP never leaves the support polygon* as the result of the unilateral constraint on the floor reaction force.

Now let us calculate the torque around the ZMP:

$$\boldsymbol{\tau} = \sum_{i=1}^{N} (\boldsymbol{p}_i - \boldsymbol{p}) \times \boldsymbol{f}_i . \tag{16.18}$$

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Zero-Moment Point (ZMP) Control

This equation can be rewritten in terms of vector components as

$$\boldsymbol{\tau}_x = \sum_{i=1}^{N}(p_{iy} - p_y) f_{iz} - \sum_{i=1}^{N}(p_{iz} - p_z) f_{iy} \,, \quad (16.19)$$

$$\boldsymbol{\tau}_y = \sum_{i=1}^{N}(p_{iz} - p_z) f_{ix} - \sum_{i=1}^{N}(p_{ix} - p_x) f_{iz} \,, \quad (16.20)$$

$$\boldsymbol{\tau}_z = \sum_{i=1}^{N}(p_{ix} - p_x) f_{iy} - \sum_{i=1}^{N}(p_{iy} - p_y) f_{ix} \,, \quad (16.21)$$

where p_{ix}, p_{iy}, p_{iz} are the components of the position vector $\boldsymbol{p}_i$ and p_x, p_y, and p_z are the components of the ZMP.

When the floor is horizontal, we have $p_{iz} = p_z$ for all i, thus, the second term of (16.19) and the first term of (16.20) become zero. Moreover, by substituting (16.12) into (16.19) and (16.20), we obtain

$$\boldsymbol{\tau}_x = \boldsymbol{\tau}_y = 0 \,. \quad (16.22)$$

This is the reason why $\boldsymbol{p}$ was named as *zero-moment* point. Nevertheless, one must note that the frictional force creates a nonzero vertical moment (16.21) in the general case.

$$\boldsymbol{\tau}_z \neq 0 \,. \quad (16.23)$$

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Berechneter Zero-Moment Point (ZMP)

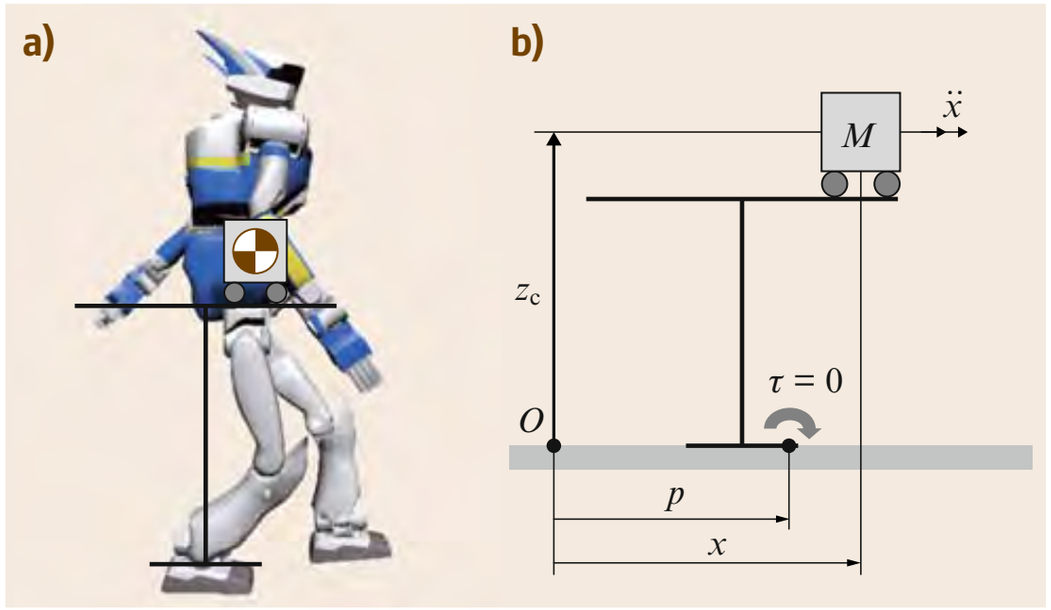

Fig. 16.11a,b Cart–table model [16.37]

Simple Case

Let us start with an extremely simple mechanism. Figure 16.11a illustrates a walking robot and its simplified model, which consists of a running cart on a massless table. The cart has mass M and its position is (x, z_c) corresponds to the center of mass of the robot (Fig. 16.11b). Also, the table is assumed to have the same support polygon as the robot.

In this case, the torque τ around the point p is given by

$$\boldsymbol{\tau} = -Mg(x-p) + M\ddot{x}z_c \,, \tag{16.24}$$

where g is the acceleration due to gravity. Using the zero-moment condition of $\boldsymbol{\tau} = 0$, the computed ZMP of this cart–table model is obtained as

$$p = x - \frac{z_c}{g}\ddot{x} \,. \tag{16.25}$$

From this equation, we can observe two fundamental facts about the computed ZMP.

1. When the acceleration of the cart is zero, the ZMP corresponds to the projection of the CoM: $p = x$.
2. The computed ZMP is not bounded by the support polygon. In fact, we can easily determine x and $\ddot{x}$ to give any specified value of p.

The second fact is explained in Fig. 16.12a. When the cart acceleration is too large, the computed ZMP goes outside of the support polygon. This happens since (16.25) does not consider the support polygon and the unilateral constraint (16.16). In other words, (16.25) assumes that the foot is glued to the floor. If the unilateral constraint is properly considered, we have the state of

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Berechneter Zero-Moment Point (ZMP)

Fig. 16.12b. Since the table is no longer upright, the computed ZMP must be calculated by

$$p = x - \frac{z}{g + \ddot{z}} \ddot{x} \,, \tag{16.26}$$

which gives the computed ZMP on the edge of support polygon.

In much of the literature, states like Fig. 16.12b are not explicitly discussed, but the computed ZMP is allowed to leave the support polygon under the implicit assumption of the glued foot on the floor. In this case, a computed ZMP outside of the support polygon implies that the robot might not maintain its feet in full contact with the ground and that the walking motion will not be performed as planned.

When the computed ZMP is inside the support polygon, it guarantees the full foot-ground contact under the unilateral constraint, while it tells us nothing about *stability* in the context of control theory.

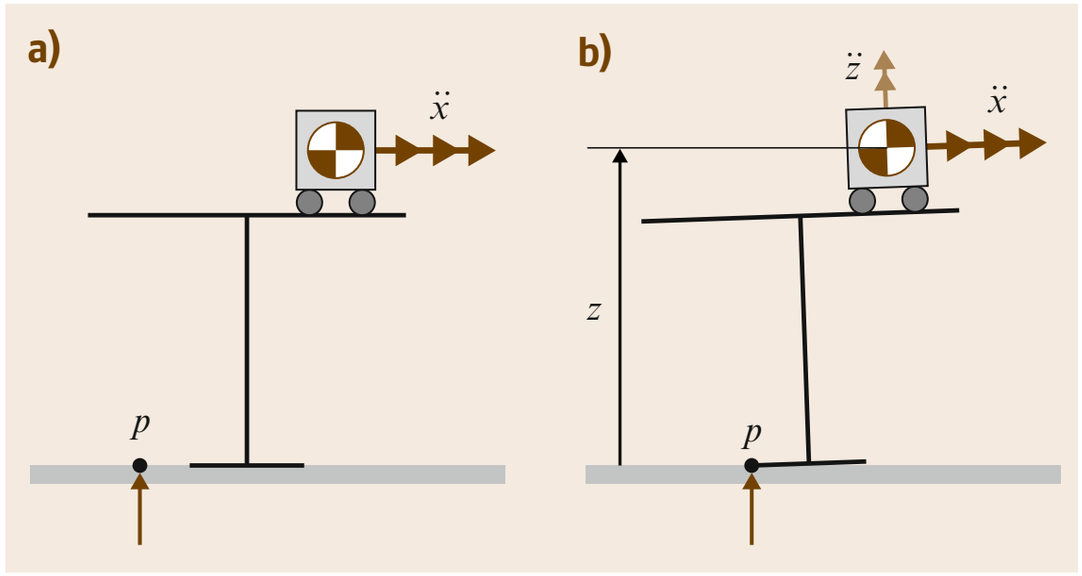

Fig. 16.12a,b Computed ZMP (a) fictitious case (b) correct result

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Einschub: Zero-Moment Point (ZMP) Control

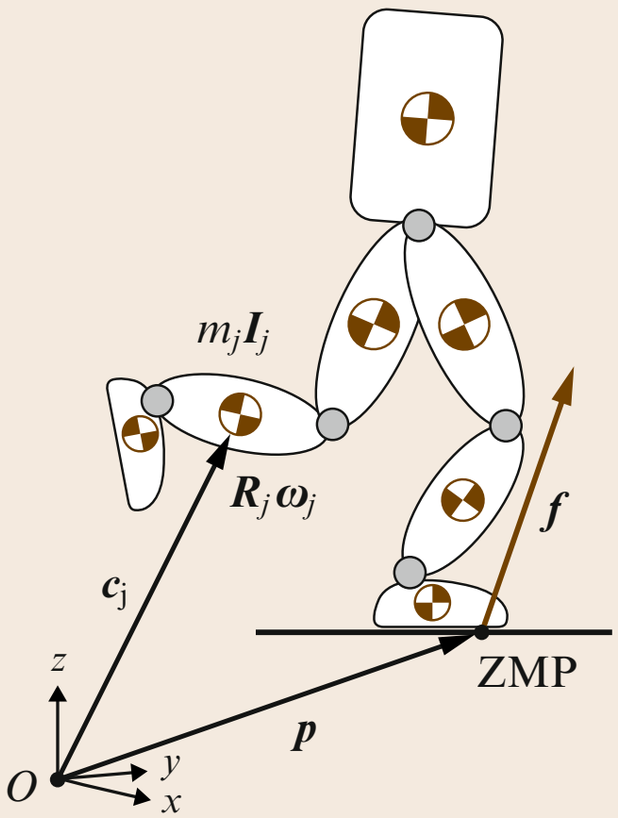


Fig. 16.13 Robot model and ZMP in three dimensions

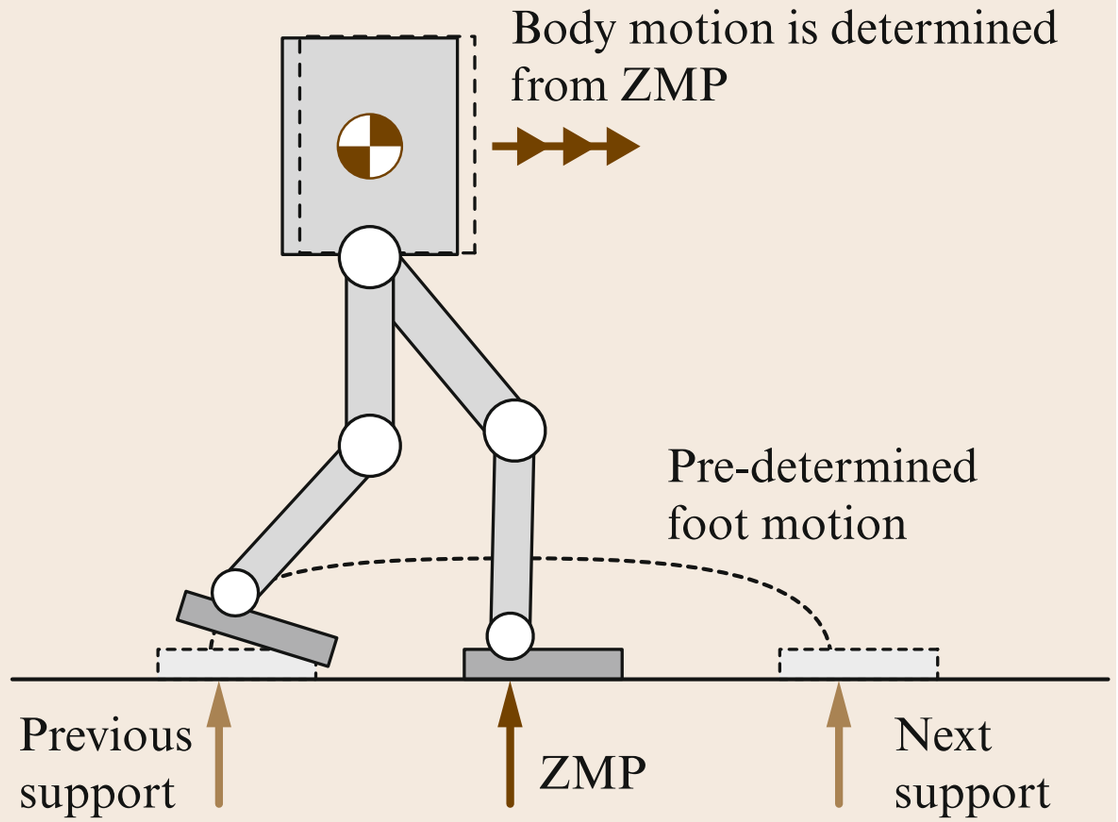
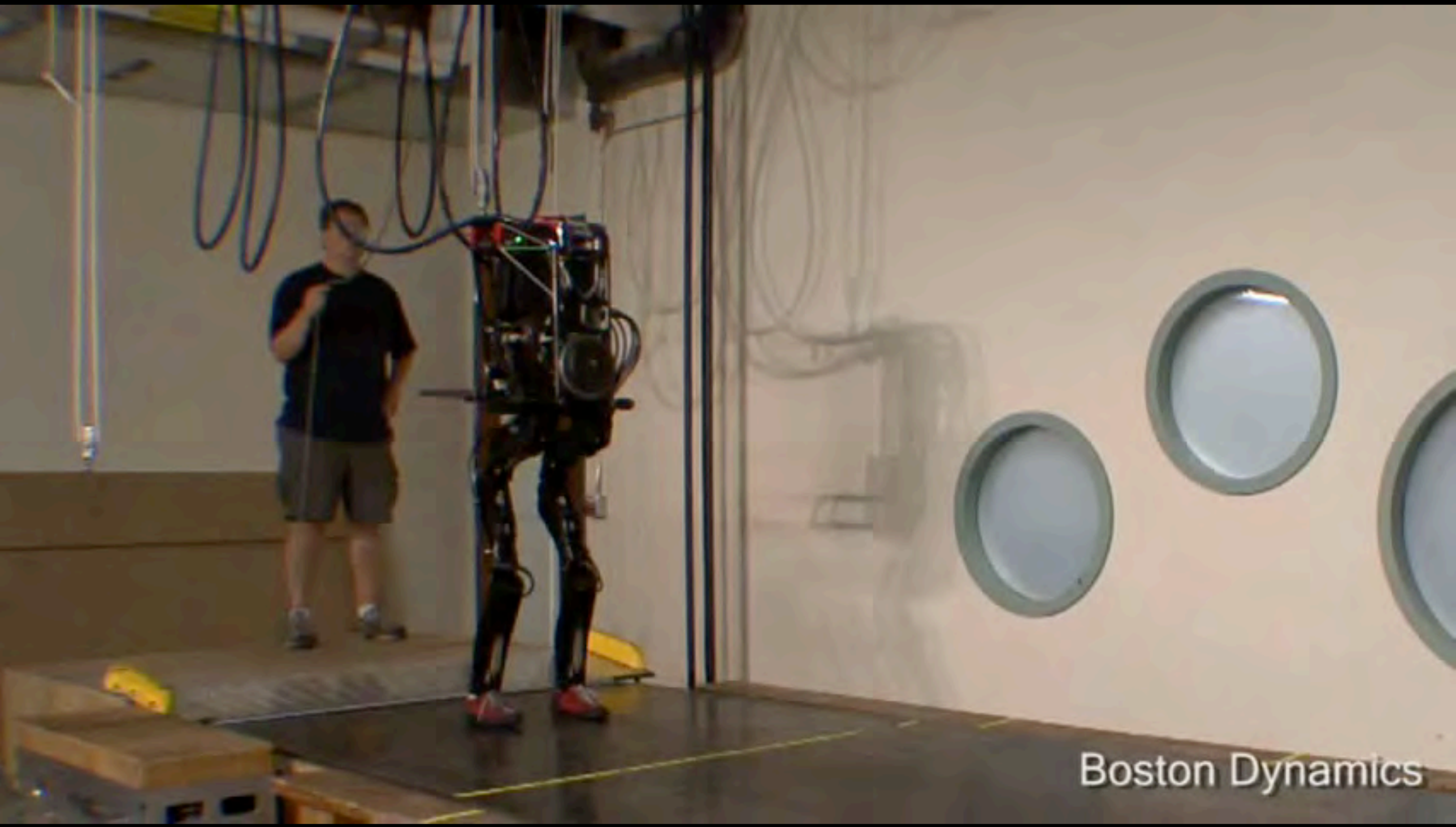
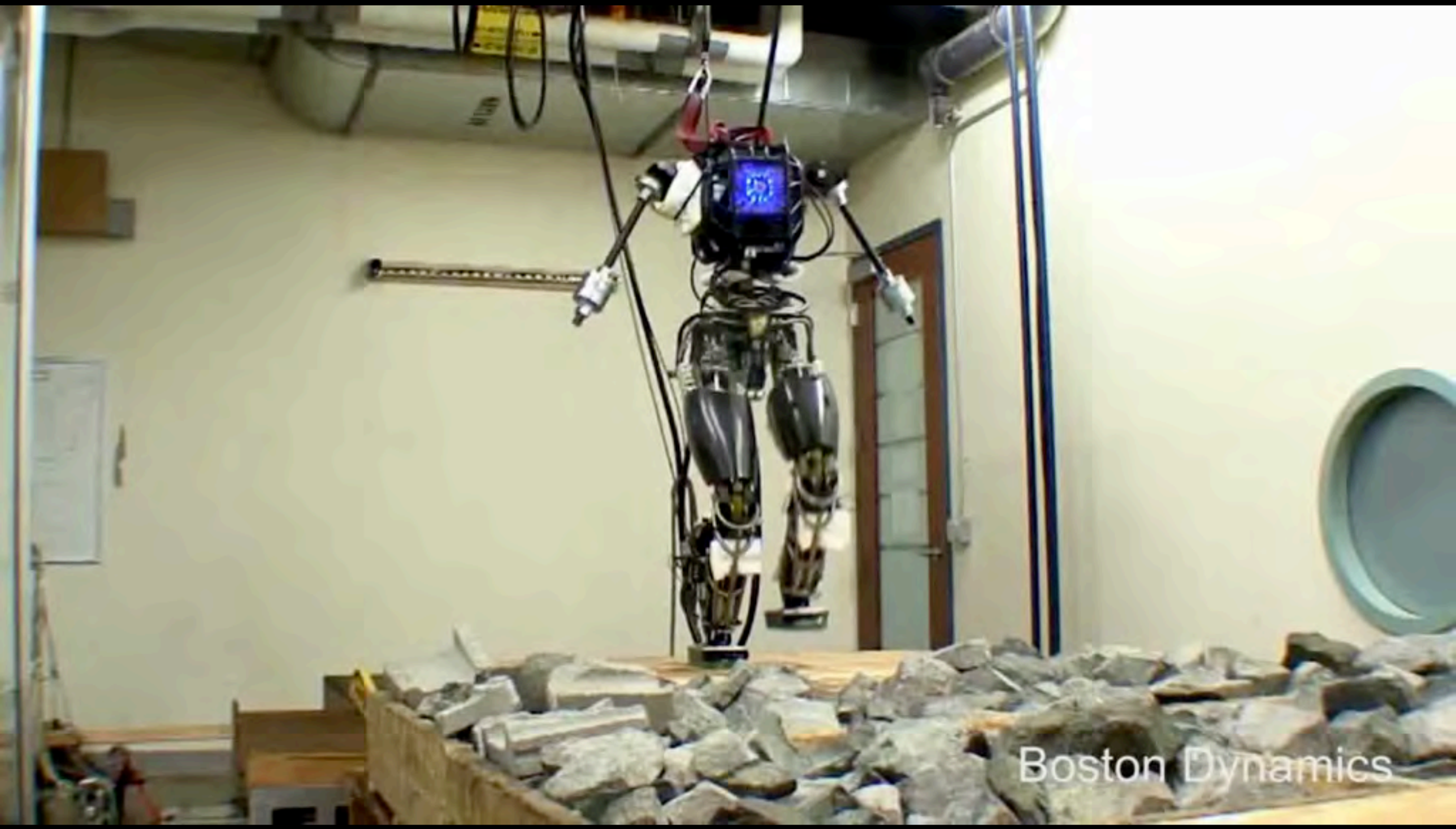


Fig. 16.15 Modern implementation of the ZMP scheme


Boston Dynamics


Boston Dynamics

THE UNIVERSITY OF TOKYO

Athlete Robot: Sprint Running

1st report, December 2010.

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