Appendix A
Thermodynamic Model

In this section the first order differential equation describing the pressure changes inside the muscle valve system is formulated. The discussion is based on the works of Daerden (104) and Brun (66).

The first law of thermodynamics is applied to a muscle with its valve island of 6 on/off valves. The muscle itself and its tubing until the different input and exhaust valve orifices are taken as control volume V. Figure (A.1) gives a schematic representation where the two inlet valves and the four exhaust valves are respectively depicted as one inlet and one exhaust. The first law is given in its rate form and expresses that the variation of the total energy of an amount of fluid is equal to the sum of the work done by the exerted forces and the net heat transfer with the surrounding. Assuming a uniform thermodynamic state inside the control volume the first law of thermodynamics can be written as follows (variation referred to time):

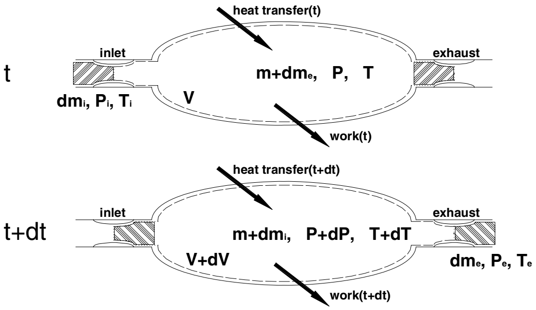


Fig. A.1 Muscle and valves on time step t and $t + dt$.

$$dU + dE_k + dE_p = \delta W + \delta Q \tag{A.1}$$

with:

$dU =$ variation of the fluid's total internal energy
$dE_k =$ variation of the fluid's total kinetic energy
$dE_p =$ variation of the fluid's total potential energy
$\delta W =$ work done by external forces
$\delta Q =$ the net transfer of heat across the boundary

The pressurized air can be regarded as an ideal gas for which the following relations hold:

$$PV = mrT \tag{A.2}$$
$$u = c_v(T - T_0) \tag{A.3}$$
$$h = c_p(T - T_0) \tag{A.4}$$
$$c_p = c_v + r \tag{A.5}$$

with:

$P =$ absolute pressure (A.6)
$V =$ air volume (A.7)
$m =$ air mass (A.8)
$T =$ temperature (A.9)
$r =$ dry air gas constant $= 287Jkg^{-1}K^{-1}$ (A.10)
$u =$ specific internal energy (A.11)
$h =$ specific enthalpy (A.12)
$c_v =$ constant volume specific heat $= 718Jkg^{-1}K^{-1}$ for dry air at $300K$ (A.13)
$c_p =$ constant pressure specific heat $= 1005Jkg^{-1}K^{-1}$ for dry air at $300K$ (A.14)
$T_0 =$ reference temperature which is taken zero (A.15)

To calculate the different variations in equation A.1 for the open muscle-valve system, the constant mass $(m + dm_i + dm_e)$ is studied at two instant time steps t and $t + dt$ as depicted in figure (A.1). At time t, pressurized air with mass dm_i is about to enter the control volume V while mass $m + dm_e$ is inside this volume. At $t + dt$ mass dm_e is leaving while the mass inside the control volume is $m + dm_i$. Evaluating equation A.3 between the two time steps results in:

$$dU = [(m + dm_i)\, c_v\, (T + dT) + dm_e c_v T_e] - [(m + dm_e)\, c_v T + dm_i c_v T_i] \tag{A.16}$$

While neglecting second order terms, equation A.16 leads to:

$$dU = mc_v dT + dm_i c_v (T - T_i) + dm_e c_v (T_e - T) \tag{A.17}$$

Neglecting furthermore the kinetic energy of the air inside the muscle against the kinetic energy of the inlet and exhaust, the variation of kinetic and potential energy becomes:

$$dE_k = dm_e \frac{C_e^2}{2} - dm_i \frac{C_i^2}{2} \tag{A.18}$$

$$dE_p = dm_e g z_e - dm_i g z_i \tag{A.19}$$

The work exchanged with the environment, while assuming reversibility, is expressed as:

$$dW = -PdV + P_i dV_i - P_e dV_e \tag{A.20}$$

with the first term, the work done by the muscle and the other two terms associated with the work needed to transport dm_i and dm_e in and out the muscle volume.

Combining the first law of thermodynamics (A.1) with equations (A.17), (A.18), (A.19) and (A.20) gives:

$$\begin{aligned} mc_v dT + c_v T\left(dm_i - dm_e\right) = {} & -PdV \\ & + dm_i \left(c_v T_i + P_i v_i + \frac{C_i^2}{2} + g z_i\right) \\ & - dm_e \left(c_v T_e + P_e v_e + \frac{C_e^2}{2} + g z_e\right) + \delta Q \end{aligned} \tag{A.21}$$

with v_i and v_e the specific volume of inlet and exhaust. Taking into account conservation of mass and the definition of enthalpy:

$$dm = dm_i - dm_e \tag{A.22}$$

$$h = u + Pv \tag{A.23}$$

Differentiating the perfect gas law (A.2) gives:

$$d\left(PV\right) = PdV + VdP = mrdT + rTdm \tag{A.24}$$

Using (A.24), equation (A.21) can be transformed to:

$$\begin{aligned} \frac{c_v}{r} d\left(PV\right) = {} & -PdV \\ & + dm_i \left(h_i + \frac{C_i^2}{2} + g z_i\right) \\ & - dm_e \left(h_e + \frac{C_e^2}{2} + g z_e\right) + \delta Q \end{aligned} \tag{A.25}$$

Flows through small orifices, such as valves and tubes, are assumed to be adiabatic and since no mechanical work is exchanged with the surroundings, for these situations is stated:

$$h + \frac{C^2}{2} = constant \tag{A.26}$$

Thus for inlet and exhaust can be written:

$$h_i + \frac{C_i^2}{2} = h_s = c_p T_s \tag{A.27}$$

$$h_e + \frac{C_e^2}{2} = h = c_p T \tag{A.28}$$

with h_s and T_s the enthalpy and temperature of the pressurized air supply buffer, h and T are the enthalpy and temperature of the pressurized air inside the muscle volume. For equations (A.27) and (A.28) kinetic energy is neglected since the considered volumes are assumed large enough. Taking into account these two equations and the definition $\gamma = c_p/c_v$ and relation (A.5), the energy balance (A.25) can be rewritten in the following form, if potential energy of the air masses is neglected:

$$dP = -\frac{\gamma}{V}\left(PdV + rT_s dm_i - rTdm_e + (\gamma - 1)\delta Q\right) \tag{A.29}$$

If furthermore an adiabatic process is considered, $\delta Q = 0$, equation (A.29) becomes:

$$dP = \frac{\gamma}{V}\left(-PdV + rT_s dm_i - rTdm_e\right) \tag{A.30}$$

Expression (A.30) is valid for the so called isentropic process, where adiabatic and reversibility conditions are assumed. The non-ideal conditions can be represented in analogy with the polytropic process, by substituting γ with a polytropic coefficient n in equation (A.30) ($n = 1.2$):

$$dP = \frac{n}{V}\left(-PdV + rT_s dm_i - rTdm_e\right) \tag{A.31}$$

with dm_i and dm_e determined by air flows through the different inlet and exhaust valves and dependent on the number of valves that are opened.

Appendix B

Kinematics and Dynamics of the Biped Lucy during a Single Support Phase

B.1 Kinematics

The biped model during a single support phase is depicted in figure B.1. For the following derivations it is supposed that both legs are identical. Hereby assuming all inertial properties and the length of the upper and lower leg to be pairwise equal. l_i, m_i and I_i are respectively the length, mass and moment of inertia with respect to the local COG G_i of link i. The location of the COG's G_i are given by $J_1G_1 = J_6G_5 = \alpha l_1$, $J_2G_2 = J_5G_4 = \beta l_2$ and $J_3G_3 = \gamma l_3$ and for the foot $J_6G_6 = \sigma l_6$ where $0 < \alpha, \beta, \gamma, \sigma < 1$. The position of each link i is given by the angle θ_i, measured with respect to the horizontal axis.

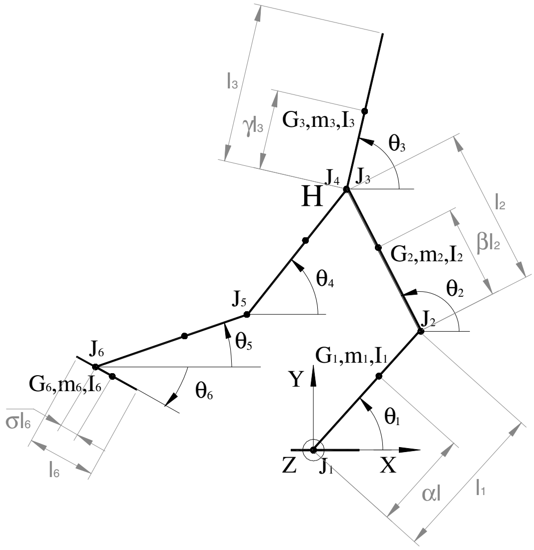


Fig. B.1 Model of the biped during a single support phase.

The hip takes a central position, so the location of the different COG's is calculated with reference to this point.

$$X_H = l_1 \cos\theta_1 + l_2 \cos\theta_2 \tag{B.1a}$$

$$Y_H = l_1 \sin\theta_1 + l_2 \sin\theta_2 \tag{B.1b}$$

The vectors defining the position of the local COG's of each of the five links are calculated as:

$$\overline{OG}_1 = (X_H, Y_H)^T - (1-\alpha)\, l_1 (\cos\theta_1, \sin\theta_1)^T - l_2 (\cos\theta_2, \sin\theta_2)^T \tag{B.2a}$$

$$\overline{OG}_2 = (X_H, Y_H)^T - (1-\beta)\, l_2 (\cos\theta_2, \sin\theta_2)^T \tag{B.2b}$$

$$\overline{OG}_3 = (X_H, Y_H)^T + \gamma l_3 (\cos\theta_3, \sin\theta_3)^T \tag{B.2c}$$

$$\overline{OG}_4 = (X_H, Y_H)^T - (1-\beta) l_2 (\cos\theta_4, \sin\theta_4)^T \tag{B.2d}$$

$$\overline{OG}_5 = (X_H, Y_H)^T - (1-\alpha)\, l_1 (\cos\theta_5, \sin\theta_5)^T - l_2 (\cos\theta_4, \sin\theta_4)^T \tag{B.2e}$$

$$\begin{aligned}\overline{OG}_6 = {} & (X_H, Y_H)^T + \sigma l_6 (\cos\theta_6, \sin\theta_6)^T \\ & - l_1 (\cos\theta_5, \sin\theta_5)^T - l_2 (\cos\theta_4, \sin\theta_4)^T\end{aligned} \tag{B.2f}$$

The position of the global COG of the robot, stance foot not included, is given by:

$$\overline{OG} = (X_G, Y_G)^T \tag{B.3}$$

with:

$$\begin{aligned}X_G = {} & X_H + a_1 \cos\theta_1 + a_2 \cos\theta_2 + a_3 \cos\theta_3 \\ & + a_4 \cos\theta_4 + a_5 \cos\theta_5 + a_6 \cos\theta_6\end{aligned} \tag{B.3a}$$

$$\begin{aligned}Y_G = {} & Y_H + a_1 \sin\theta_1 + a_2 \sin\theta_2 + a_3 \sin\theta_3 \\ & + a_4 \sin\theta_4 + a_5 \sin\theta_5 + a_6 \sin\theta_6\end{aligned} \tag{B.3b}$$

and:

$$\begin{aligned}a_1 &= -(1-\alpha)\,\eta_1 l_1 \\ a_2 &= -\left[\eta_1 + (1-\beta)\,\eta_2\right] l_2 \\ a_3 &= \gamma \eta_3 l_3 \\ a_4 &= -\left[\eta_1 + \eta_6 + (1-\beta)\,\eta_2\right] l_2 \\ a_5 &= -\left[\eta_6 + (1-\alpha)\,\eta_1\right] l_1 \\ a_6 &= \sigma \eta_6 l_6\end{aligned}$$

and:

$$\eta_i = \frac{m_i}{2(m_1 + m_2) + m_3 + m_6}$$

The first and second derivative of (B.3a) and (B.3b), which are required for the derivation of the dynamic model and the ZMP, are straightforward and thus not explicitly listed here.

B.2 Dynamics

With the swing foot included, the robot has 6 DOF during the single support phase if the robot is assumed to move only in the sagittal plane. These degrees of freedom are represented by the 6-dimensional vector:

$$\mathbf{q} = \left[\theta_1 \; \theta_2 \; \theta_3 \; \theta_4 \; \theta_5 \; \theta_6\right]^T \tag{B.4}$$

The dynamics are represented by 6 equations of motion of which the i th equation can be written with the Lagrange formulation as:

$$\frac{d}{dt}\left\{\frac{\partial K}{\partial \dot{q}_i}\right\} - \frac{\partial K}{\partial q_i} + \frac{\partial U}{\partial q_i} = Q_i \quad (i = 1\ldots6) \tag{B.5}$$

with K and U, respectively the total kinetic and gravitational energy of the robot, Q_i are the generalized forces associated with the generalized coordinates q_i.

The total kinetic energy can be found by the summation of the separate kinetic energy values of each link:

$$K = \sum_{i=1}^{6} K_i = \frac{1}{2}\sum_{i=1}^{6}\left(m_i v_{G_i}^2 + I_i \dot{\theta}_i^2\right) \tag{B.6}$$

with $\bar{v}_{G_i} = \left(\dot{X}_{Gi}, \dot{Y}_{Gi}\right)^T$ the velocity of the COG of link i and $\dot{\theta}_i$ the angular velocity. The expression of the total kinetic energy is quite long and is not explicitly listed here.

The gravitational (potential) energy is given by:

$$U = MgY_G \tag{B.7}$$

The generalized forces are the different net torques acting on each link of the robot (see figure B.2):

$$\mathbf{Q} = \tau = \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \\ \tau_5 \\ \tau_6 \end{bmatrix} = \begin{bmatrix} \tau_{K_S} - \tau_{A_S} \\ \tau_{H_S} - \tau_{K_S} \\ -\tau_{H_S} - \tau_{H_a} \\ \tau_{H_a} - \tau_{K_a} \\ \tau_{K_a} - \tau_{A_a} \\ \tau_{A_a} \end{bmatrix} \tag{B.8}$$

The H, K and A stands for “Hip”, “Knee” and “Ankle” respectively, a stands for “air”, and s for “stance”. Expression (B.8) gives the relations between net torques and applied joint torques.

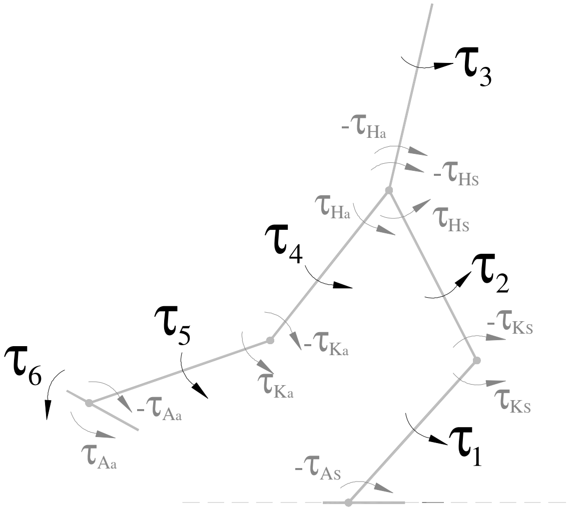


Fig. B.2 Definition of net torques and joint torques.

The 6 equations of motion (B.5) can be written in the following form (376):

$$D(\mathbf{q})\ddot{\mathbf{q}} + C(\mathbf{q},\dot{\mathbf{q}})\dot{\mathbf{q}} + G(\mathbf{q}) = \tau \tag{B.9}$$

with $D(\mathbf{q})$ the inertia matrix, $C(\mathbf{q},\dot{\mathbf{q}})$ the centrifugal/coriolis matrix, $G(\mathbf{q})$ the gravitational torque vector and τ the net torque vector.

The inertia matrix can be calculated with the following relation to the kinetic energy:

$$K = \frac{1}{2}\dot{\mathbf{q}}^T D(\mathbf{q})\dot{\mathbf{q}} \tag{B.10}$$

The elements of the centrifugal/coriolis matrix c_{kj} can be found with the following expression (376):

$$c_{kj} = \sum_{i=1}^{6} c_{ijk}\dot{\theta}_i = \sum_{i=1}^{6} \frac{1}{2}\left\{\frac{\partial d_{kj}}{\partial \theta_i} + \frac{\partial d_{ki}}{\partial \theta_j} - \frac{\partial d_{ij}}{\partial \theta_k}\right\}\dot{\theta}_i \tag{B.11}$$

with c_{ijk} the so called Christoffel symbols and d_{ij} the elements of the inertia matrix $D(\mathbf{q})$. The elements of the gravitational torque vector g_i are given by:

$$g_i = \frac{\partial U}{\partial q_i} \tag{B.12}$$

As a result all the parameters of the dynamic model are given below:

- Inertia matrix $D(\mathbf{q})$:

$$
\begin{aligned}
d_{11} &= I_1 + l_1^2\left[\left(1+\alpha^2\right)m_1 + 2m_2 + m_3 + m_6\right]\\
d_{12} &= l_1 l_2\left[m_1 + (1+\beta)\,m_2 + m_3 + m_6\right]\cos(\theta_1-\theta_2) = d_{21}\\
d_{13} &= l_1 l_3 \gamma m_3 \cos(\theta_1-\theta_3) = d_{31}\\
d_{14} &= l_1 l_2\left[(\beta-1)\,m_2 - m_1 - m_6\right]\cos(\theta_1-\theta_4) = d_{41}\\
d_{15} &= l_1^2\left[(\alpha-1)\,m_1 - m_6\right]\cos(\theta_1-\theta_5) = d_{51}\\
d_{16} &= l_1 l_6 m_6 \sigma \cos(\theta_1-\theta_6) = d_{61}\\
d_{22} &= I_2 + l_2^2\left[m_1 + \left(1+\beta^2\right)m_2 + m_3 + m_6\right]\\
d_{23} &= l_2 l_3 \gamma m_3 \cos(\theta_2-\theta_3) = d_{32}\\
d_{24} &= l_2^2\left[(\beta-1)\,m_2 - m_1 - m_6\right]\cos(\theta_2-\theta_4) = d_{42}\\
d_{25} &= l_1 l_2\left[(\alpha-1)\,m_1 - m_6\right]\cos(\theta_2-\theta_5) = d_{52}\\
d_{26} &= l_2 l_6 m_6 \sigma \cos(\theta_2-\theta_6) = d_{62}\\
d_{33} &= I_3 + \gamma^2 l_3^2 m_3\\
d_{34} &= 0 = d_{43}\\
d_{35} &= 0 = d_{53}\\
d_{36} &= 0 = d_{63}\\
d_{44} &= I_2 + l_2^2\left[m_1 + (1-\beta)^2 m_2 + m_6\right]\\
d_{45} &= l_1 l_2\left[(1-\alpha)\,m_1 + m_6\right]\cos(\theta_4-\theta_5) = d_{54}\\
d_{46} &= -l_2 l_6 m_6 \sigma \cos(\theta_4-\theta_6) = d_{64}\\
d_{55} &= I_1 + l_1^2\left[m_1(1-\alpha)^2 + m_6\right]\\
d_{56} &= -l_1 l_6 m_6 \sigma \cos(\theta_5-\theta_6) = d_{65}\\
d_{66} &= I_6 + l_6^2 m_6 \sigma^2
\end{aligned}
$$

- Centrifugal/coriolis matrix $C(\mathbf{q},\dot{\mathbf{q}})$:

$$
\begin{aligned}
c_{11} &= 0 = c_{22} = c_{33} = c_{44} = c_{55} = c_{66}\\
c_{12} &= l_1 l_2\left[m_1 + (1+\beta)m_2 + m_3 + m_6\right]\sin(\theta_1-\theta_2)\,\dot{\theta}_2\\
c_{13} &= l_1 l_3 \gamma m_3 \sin(\theta_1-\theta_3)\,\dot{\theta}_3\\
c_{14} &= -l_1 l_2\left[m_1 + (1-\beta)m_2 + m_6\right]\sin(\theta_1-\theta_4)\,\dot{\theta}_4\\
c_{15} &= -l_1^2\left[(1-\alpha)\,m_1 + m_6\right]\sin(\theta_1-\theta_5)\,\dot{\theta}_5\\
c_{16} &= l_1 l_6 m_6 \sigma \sin(\theta_1-\theta_6)\,\dot{\theta}_6\\
c_{21} &= -l_1 l_2\left[m_1 + (1+\beta)m_2 + m_3 + m_6\right]\sin(\theta_1-\theta_2)\,\dot{\theta}_1\\
c_{23} &= l_2 l_3 \gamma m_3 \sin(\theta_2-\theta_3)\,\dot{\theta}_3\\
c_{24} &= -l_2^2\left[m_1 + (1-\beta)m_2 + m_6\right]\sin(\theta_2-\theta_4)\,\dot{\theta}_4
\end{aligned}
$$

$$
\begin{aligned}
c_{25} &= -l_1 l_2 \left[(1-\alpha) m_1 + m_6\right] \sin(\theta_2 - \theta_5)\, \dot{\theta}_5 \\
c_{26} &= l_2 l_6 m_6 \sigma \sin(\theta_2 - \theta_6)\, \dot{\theta}_6 \\
c_{31} &= -l_1 l_3 \gamma m_3 \sin(\theta_1 - \theta_3)\, \dot{\theta}_1 \\
c_{32} &= -l_2 l_3 \gamma m_3 \sin(\theta_2 - \theta_3)\, \dot{\theta}_2 \\
c_{34} &= 0 = c_{35} = c_{43} = c_{53} = c_{63} = c_{36} \\
c_{41} &= l_1 l_2 \left[m_1 + (1-\beta) m_2 + m_6\right] \sin(\theta_1 - \theta_4)\, \dot{\theta}_1 \\
c_{42} &= l_2^2 \left[m_1 + (1-\beta) m_2 + m_6\right] \sin(\theta_2 - \theta_4)\, \dot{\theta}_2 \\
c_{45} &= l_1 l_2 \left[(1-\alpha) m_1 + m_6\right] \sin(\theta_4 - \theta_5)\, \dot{\theta}_5 \\
c_{46} &= -l_2 l_6 m_6 \sigma \sin(\theta_4 - \theta_6)\, \dot{\theta}_6 \\
c_{51} &= l_1^2 \left[(1-\alpha) m_1 + m_6\right] \sin(\theta_1 - \theta_5)\, \dot{\theta}_1 \\
c_{52} &= l_1 l_2 \left[(1-\alpha) m_1 + m_6\right] \sin(\theta_2 - \theta_5)\, \dot{\theta}_2 \\
c_{54} &= -l_1 l_2 \left[(1-\alpha) m_1 + m_6\right] \sin(\theta_4 - \theta_5)\, \dot{\theta}_4 \\
c_{56} &= -l_1 l_6 m_6 \sigma \sin(\theta_5 - \theta_6)\, \dot{\theta}_6 \\
c_{61} &= -l_1 l_6 m_6 \sigma \sin(\theta_1 - \theta_6)\, \dot{\theta}_1 \\
c_{62} &= -l_2 l_6 m_6 \sigma \sin(\theta_2 - \theta_6)\, \dot{\theta}_2 \\
c_{64} &= l_2 l_6 m_6 \sigma \sin(\theta_4 - \theta_6)\, \dot{\theta}_4 \\
c_{65} &= l_1 l_6 m_6 \sigma \sin(\theta_5 - \theta_6)\, \dot{\theta}_5
\end{aligned}
$$

- Gravitational torque vector $G(\mathbf{q})$:

$$
\begin{aligned}
g_1 &= \left[(\alpha+1) m_1 + 2m_2 + m_3 + m_6\right] g l_1 \cos\theta_1 \\
g_2 &= \left[m_1 + (\beta+1) m_2 + m_3 + m_6\right] g l_2 \cos\theta_2 \\
g_3 &= \gamma m_3 g l_3 \cos\theta_3 \\
g_4 &= \left[-m_1 + (\beta-1) m_2 - m_6\right] g l_2 \cos\theta_4 \\
g_5 &= \left[(\alpha-1) m_1 - m_6\right] g l_1 \cos\theta_5 \\
g_6 &= g l_6 m_6 \sigma \cos\theta_6
\end{aligned}
$$

Appendix C
Details of the Electronics

C.1 Joint Micro-controller Board

Figure C.1 gives a detailed overview of the micro-controller board which is provided for each modular unit. This micro-controller board regulates muscle pressure with the bang-bang control structure. Furthermore, it handles sensory inputs originating from two pressure sensors and an encoder, and provides a buffered interface between the central PC and the local micro-controller. The same board architecture is also used for an extra micro-controller, which handles additional sensory information such as absolute robot position, supply pressure conditions, ground reaction forces and control of the treadmill.

The core of the joint controller board is the MC68HC916Y3 micro-controller of Motorola. It has a 16 bit central processor unit, CPU, and a separate processor, TPU, which is designed to handle sensory input and control output without disturbing the CPU.

The micro-controller unit can be debugged and programmed via the serial SDI interface which is a commercially available device. A 10 pin connector is provided to link the essential pins to the SDI debugger module. This interface has only been used during the development of the micro-controller board. Currently, the micro-controllers are programmed via the 16-bit communication interface.

This interface is created with a dual ported RAM unit. This unit provides a buffered structure which communicates with the Cypress micro-controller communication interface board (see C.7). Two dual ported ram chips IDT7130SA (8 bit wide) are used to create the 16-bit parallel bus interface. Each chip has $1 Kbyte$ of memory, the first chip is used to store the lowest byte of the 16-bit data, while the other stores the highest byte. The memory is physically divided into a read data block and a write data block by connecting the $R/\overline{W}$ signal to address line number 8 of the dual ported RAM memory. The highest address line is not used, which means that two memory storage places are provided for 256 $16 bit$ wide data. Due to the divided structure into a read and write block, it is never possible to access a memory place from both sides simultaneously, therefore the BUSY and INT pins of the dual ported RAM units are not used.

The connector to the USB interface board redirects the pins of port PF which can be used to generate interrupts on the CPU (MC68HC916Y3) and give acknowledge signals to the communication master. E.g. the Cypress USB micro-controller, which is the communication master controlling the communication sampling rate, generates an interrupt on the CPU of all the Motorola micro-controllers each communication sample. Furthermore these pins are used to reset all the Motorola CPUs and in the other direction, to acknowledge to the communication master that the specific Motorola CPU is ready for a read or write action.

One connector is provided for the interface to the sensors and the valves. These valves are controlled by several TPU signals. The micro-controller board provides 6 separate signals to control the 6 valves of a valve island, but currently only 4 of them are used since three exhaust valves are switched together. The 3 incremental encoder channels are also connected with the TPU, which presents a position signal to the CPU without demanding any processor time. Additionally, one of the two main channel of the encoder are linked with a secondary TPU pin in order to estimate angular joint rotation speed. This speed is determined by a time measurement between two neighboring encoder flanks. The 12-bit digital signals of the two pressure sensors are linked to the micro-controller via the serial SPI interface. Finally, port G is connected with 8 LEDs which are used to visualize the different operation modes of the robot.

Resetting the controller can be done by a local button on the micro-controller board or by the USB micro-controller via the dual ported RAM units. The local reset and micro-controller initialization scheme uses an AND-port (chip 4023) structure as clearly explained in the data sheets. Furthermore are provided an oscillation circuit to generate the clock for the CPU, two RS232 interfaces and a flash EEPROM programming circuit, all described in the data sheets.

The communication software is programmed into the flash EEPROM and works with two essential modes: program and run mode. These modes are selected by the first word of the communication data block, which come with $32bytes$ each sample. Program mode is selected to load the micro-controller with the specific low-level controller program, such as e.g. the bang-bang controller, and in the run mode this downloaded program is executed while exchanging necessary control data with the central PC. So there is no fixed controller design programmed in the controller but it is downloaded each time the robot is initialized. This creates a fast and flexible experimental low-level control board for which different controller strategies can be implemented easily.

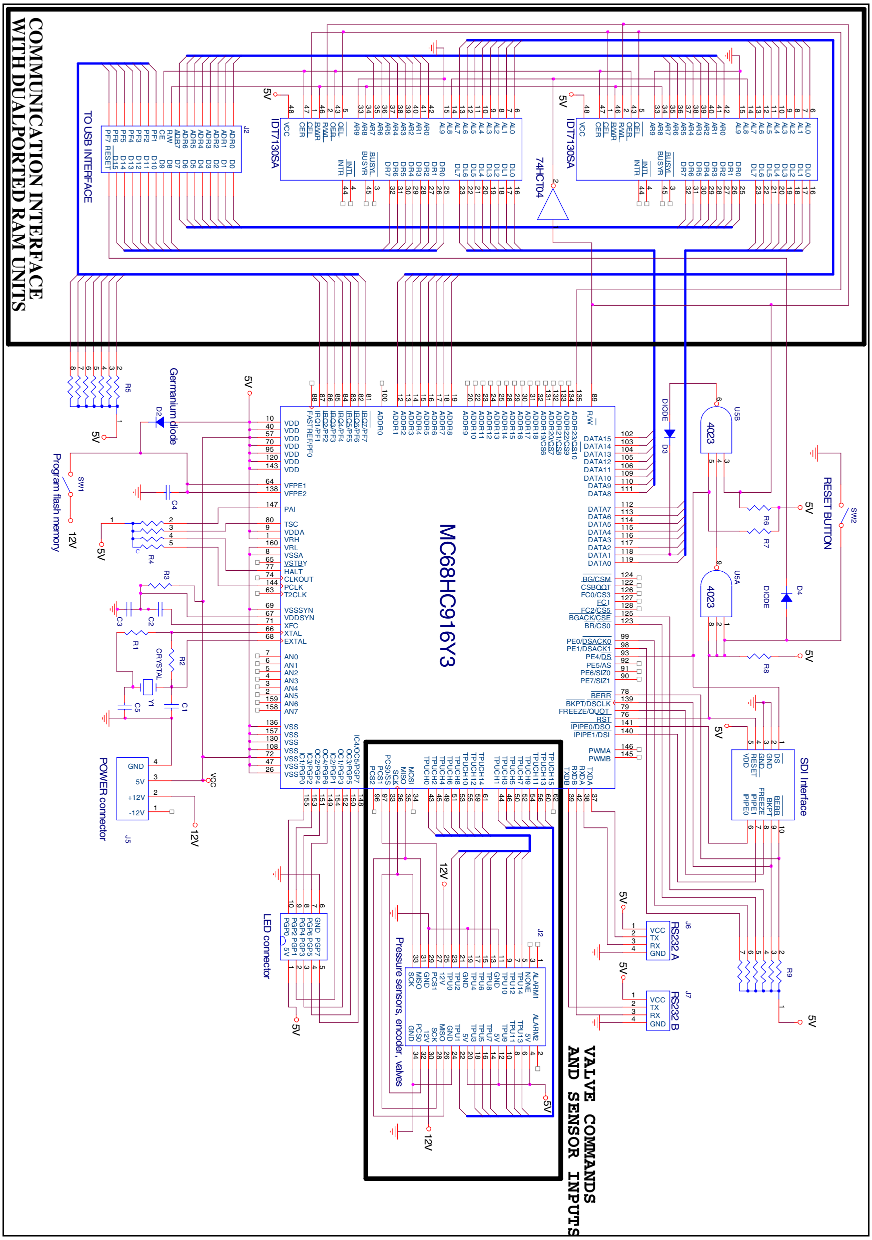


Fig. C.1 Electronic scheme of joint micro-controller board.

C.2 Speed-up Circuitry

In order to enhance the opening time of the Matrix valves, the manufacturer proposes a speed-up in tension circuitry. With a temporal $24V$ during a period of $2.5ms$ and a remaining $5V$ the opening time of the valves is said to be $1ms$. But during practical tests more than double values for the opening time were recorded. The opening tension is therefore increased to $36V$, but the time during which this voltage is applied is decreased to the actual opening time of $1ms$, such that the valves do not get overheated.

Figure C.2 gives the complete electronic scheme of the speed-up circuitry. Four identical schemes are provided, two for inlet and two for exhaust valves, of which one circuit commands three exhaust valves to open and close simultaneously. For each circuitry two LED's are provided in order to visualize valve action, one of them only lights up when the increased voltage is applied. These LEDs are important to check if the pressure control block is properly working. For each circuitry, the micro-controller commands a valve via discrete $5V$ on/off signals. These signals directly activate mosfet Q1 (IRF530) in order to apply $5V$ over the valve. The same signal passes parallel through a one-shot (74LS123) in order to increase the applied voltage over the valve during the first $1ms$ of valve activation. The output of the one-shot therefore temporally activates mosfet Q2 (IRF610) which on its turn commands mosfet Q3 (IRF9540) to branch the $36V$ supply to a valve. Whenever the micro-controller commands a valve to close, by disabling mosfet Q1, the discharge path is connected to the increased supply source via diode D2. This provides a fast discharge of the electromagnetic energy stored in the valve, which results in a faster closing time.

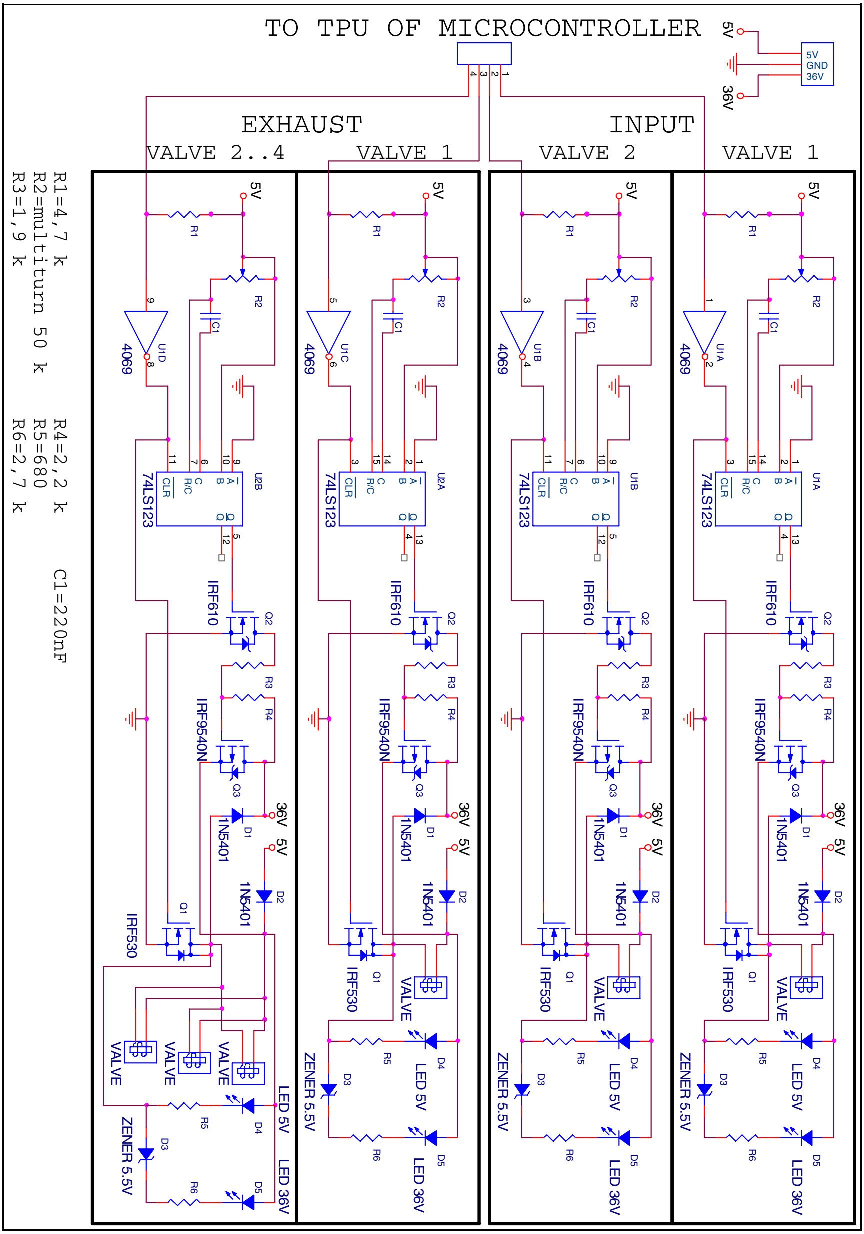


Fig. C.2 Electronic scheme of the speed-up circuitry.

C.3 Pressure Sensor

Figure C.3 depicts the electronic scheme which conditions the pressure sensor signal. The most important component is the absolute pressure sensor, CPC100AFC, from Honeywell. This sensor measures absolute pressure values up to $100psi$ ($6.9bar$) and has an accuracy of about $20mbar$. Approximately $100mV$ for each $100psi$ is generated, meaning $14.5mV$ for $1bar$. The output of the pressure sensor is amplified by a differential amplifier. The gain of this amplifier is approximately 63.2. In order to avoid as much as possible noise generation, the amplified pressure signal (V_0) is immediately digitized by a $12bit$ analog to digital converter. A stable reference voltage for this converter is locally generated by a cascade circuit of two zener diodes. The negative input (-IN) of the AD-converter is augmented with a fixed voltage to roughly compensate atmospheric pressure. The AD-converter chip communicates with the micro-controller unit by a serial SPI interface, which is typically used for communication between chips and micro-controllers. A comparator $LM324$ is provided to generate an alarm signal in order to protect the muscle against pressure overload. This signal is not treated by the micro-controller, but immediately acts on the central pressure supply valve (see 2.7.1.2). Whenever the muscle gauge pressure exceeds approximately $4.2bar$, the pressure supply is cut-off. The pressure sensor circuit is calibrated each time the robot is initialized. This calibration is performed via an other pneumatic calibration circuit with an additional pressure sensor. In order to pass through the entrance of a muscle, the diameter of the sensor and its electronics is made small ($12mm$).

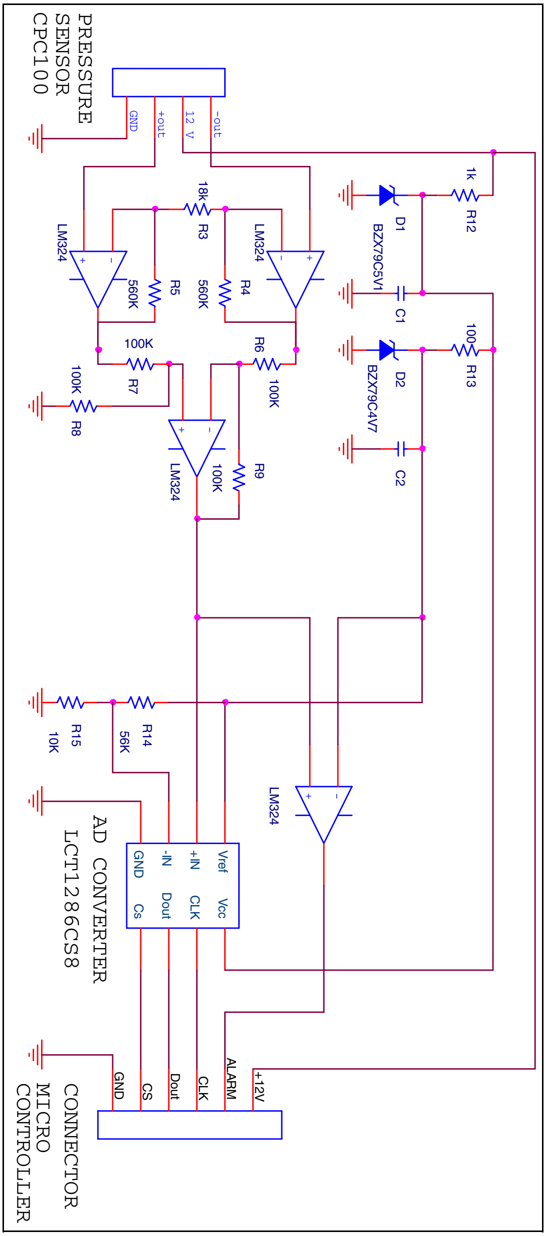


Fig. C.3 Electronic scheme of the pressure sensor.

C.4 Foot Measurement Board

An electronic scheme of the foot measurement board is shown in figure C.4. The ground reaction forces are measured by load cells of Transducer Techniques (THA-250-Q). A commercial strain gauge amplifier of RS-components (846-171) is used to amplify the signal of the full bridge circuit. The chip requires also a negative supply voltage of $-10V$. To avoid the necessity of a new power supply a DC/DC-converter of Traco Power (TEN 10-2422) is used which makes out of $24V$ $+/-12V$. The foot board has one such DC/DC-converter for the gauge amplifiers of the rear and front load cell. The amplified force signal is digitized by a 12 bit AD-converter (LTC 1286). A stable reference voltage for this converter is locally generated by zener diodes. The AD-converter chip communicates with the micro-controller unit by a serial SPI interface. Each foot has also a mechanical switch to detect if the foot

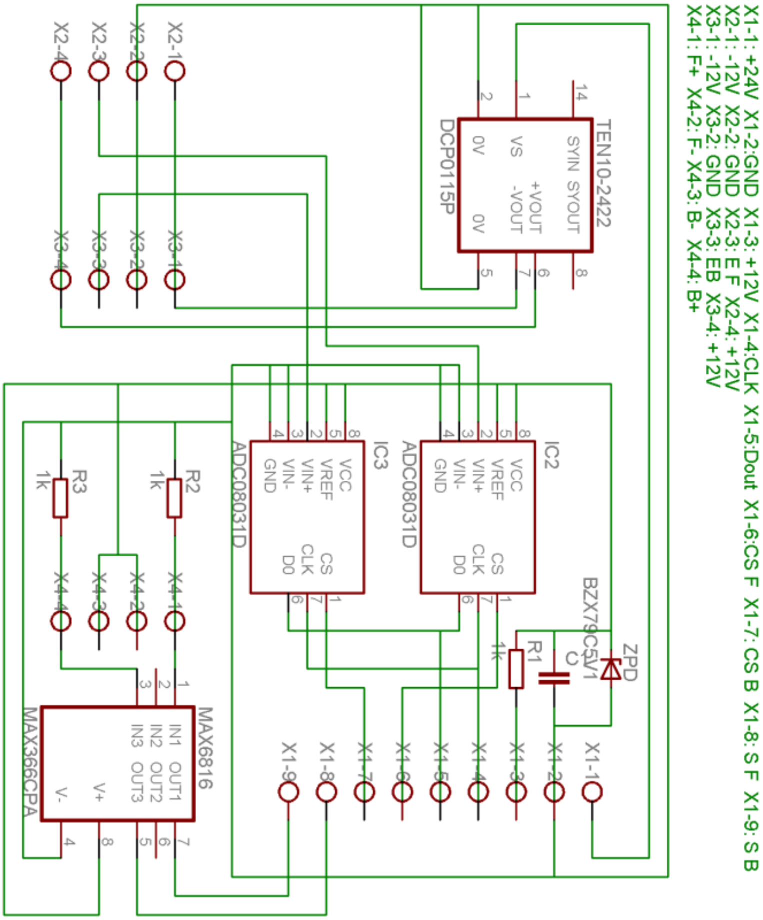


Fig. C.4 Electronic scheme of the foot measurement board.

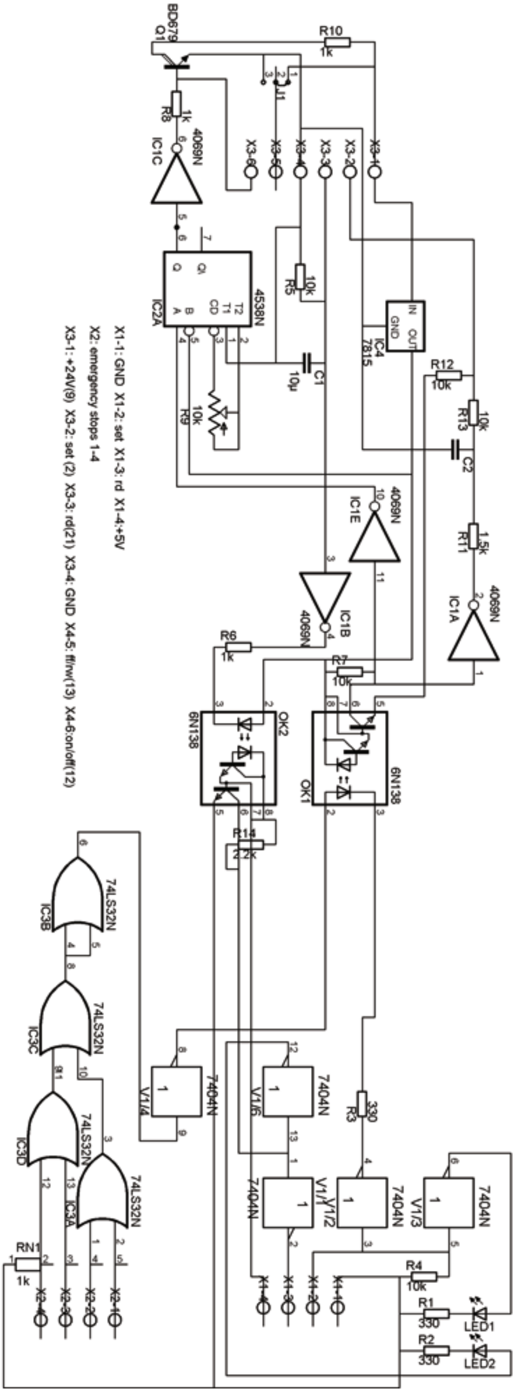
is on the ground or not. To provide a clean interface with the digital system switch debouncers (MAX6816) are used.

C.5 Treadmill Control Board

The treadmill is powered by a 3 phase synchronous AC Motor controlled by the frequency inverter ACS 350 from ABB. This motor drive contains a vector control to provide enough torque at low rotation speeds. The steering signal and the measured rotation speed of the motor are treated by a separate electrical board which can be seen in figure C.5 This board contains opto-couplers so in case of a fault like an overvoltage on one side, the other side is not corrupted, especially to protect the low voltage electronics of the robot. This board is also connected to the emergency buttons: if an emergency button is pressed the treadmill stops automatically.

The treadmill control board (figure C.5) connects the 7th micro-controller with the frequency inverter ACS 350, which controls the motor of the treadmill. Essential are the opto-couplers 6N139 for galvanic separation of the robot electronics and the frequency inverter. A PWM signal coming from the TPU unit of the 7th micro-controller represents the speed signal. This signal is inverted (74HCT04) and feeds a LED and the opto-coupler 6N139. 4 emergency stops can be connected to this board. These signals are merged by OR-gates and if one of the emergency stops is pressed the power supply to the opto-coupler is turned off. After the opto-coupler a first order filter, formed by a capacity and resistor, makes an analogues signal between 0-10V for the frequency inverter. MC14538B is a monostable multivibrator. When there are no pulses the output is driven so the Darlington transistor is low and the frequency inverter is stopped. When pulses occur they are lengthened by the multivibrator so they form a continuous high signal and the frequency inverter is started. The drive has one programmable transistor output. In this application the frequency inverter is programmed to give the speed signal. Through an opto-coupler the signal is sent to the TPU unit of the 7th micro-controller. A manual switch makes it possible to reverse the rotation speed.

The part of the frequency inverter is fed by the frequency inverter itself. The board is designed so it consumes less than 200mA, the maximum current it can supply.



X1-1: GND X1-2: set X1-3: rd X1-4:+5V

X2: emergency stops 1-4

X3-1: +24V(9) X3-2: set (2) X3-3: rd(21) X3-4: GND X4-5: ff/rw(13) X4-6:on/off(12)

Fig. C.5 Electronic scheme of the treadmill control board.

C.6 Safety Board

The safety board is provided in order to control the supply pressure flow. It will cut-off the supply pressure in case an emergency situation is met. It can also select a lower calibration supply pressure required for the calibration of the 12 muscle pressure sensors. Figure C.6 shows the electronic scheme of the safety board. There are three valves which control the supply pressure. Opening valve 1 connects the robot to the high supply pressure and valve 2 introduces a lowered calibration pressure. Both valves are activated by a transistor circuit for which signals S1 or S2 have to be logic zero in order to open valve 1 or valve 2 respectively. If these signals are high, than valve 3 is opened in order to depressurize the robot. This happens when the robot is not working or when a pressure alarm or emergency stop is activated. A pressure alarm is induced by the pressure sensors in the muscles, whenever the pressure exceeds approximately $4.5 bar$ gauge pressure. In this case a rising flank on the alarm signal switches the output of a D flip-flop to low logic state. The flip-flop is used to remember this emergency state and close the pressure valve until a manual reset is given on the safety board. All alarm signals have their own flip-flop structure with an additional LED such that is can be easily detected in which muscle the alarm signal was generated. An OR structure on all the flip-flop outputs in combination with 4 mechanical emergency stops depressurizes the robot whenever one of them alerts for a dangerous situation. Selection between the high or initialization pressure is done by two external signals, which are commanded by the extra micro-controller.

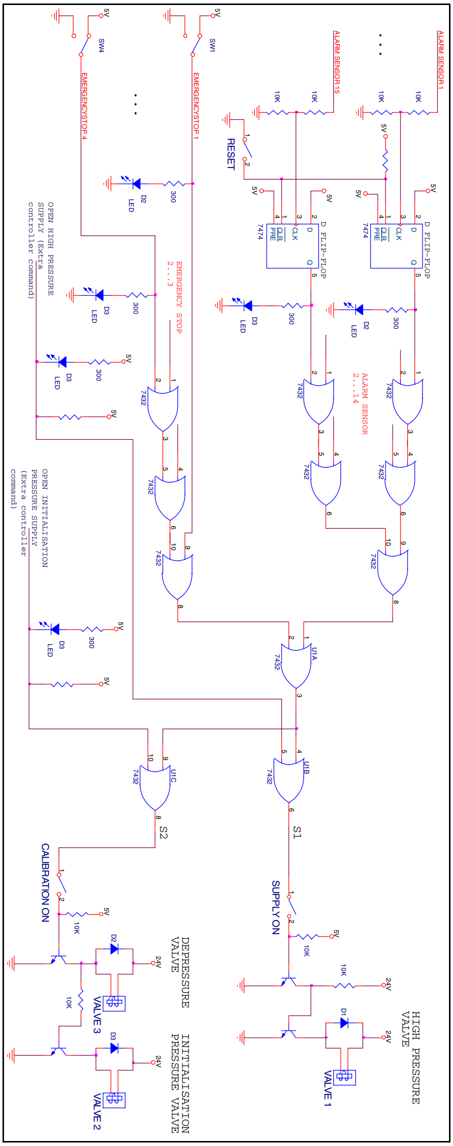


Fig. C.6 Electronic scheme of the safety board.

C.7 Cypress Communication Interface

C.7.1 Why USB 2.0?

Since a lot of extensive calculations are required due to the model based control algorithms, a central PC is used. Therefore a fast communication line between PC and robot hardware is provided. A fast communication line could be an extension of the PC bus by means of a parallel data communication, but this kind of communication is only suitable for short distance applications. For larger distances (several meters) serial communication protocols are preferable. This section will deal about the electronics needed to make the connection and the design choices made to handle the communication between the central PC and the 7 micro-controllers. This section will not deal about how the USB protocol works. For more information (25; 35; 28) is suggested.

Table C.1 shows an overview of some common interfaces.

RS-232 is not fast enough, FireWire is limited too much in allowable distance. For this application it was chosen to use a USB 2.0 communication interface, which has a data transfer rate of $480 Mbit/s$.

Other advantages for choosing an USB protocol are:

- A USB device can be plugged in anytime, even while the PC is turned on.
- When the PC detects that a USB device has been plugged in, it automatically interrogates the device to learn its capabilities and requirements. From this information, the PC automatically loads the devices driver into the operating system. When the device is unplugged, the operating system automatically logs it off and unloads its driver.
- USB devices do not use DIP switches, jumpers, or configuration programs. There is never an IRQ, DMA, memory, or I/O conflict with a USB device. USB expansion hubs make the bus simultaneously available to dozens of devices.
- Single connector type, the USB defines a single connector used to attach any USB device. Additional connectors can be added with USB hubs.

Table C.1 Comparison between different interfaces

Interface	Type	max # peripherals	transmission speed	max distance
USB	serial	127	USB 1.0: 1.5Mbits/s, low speed USB 1.1: 12Mbits/s, full speed USB 2.0: 480Mbits/s, high speed	5m (with hubs up to 30m)
RS-232	serial	2	20 - 115kbit/s	15-20m
IEEE-1394 (FireWire)	serial	64	400Mbit/s IEEE-1394b: 3.2Gbit/s	4m
Ethernet	serial	1024	10Mbit/s 1Gbit/s 100Mbit/s	4m

C.7.2 EZ-USB FX2

Since the local Motorola controllers (6 joint controllers+1 extra controller) have a 16*bit* parallel communication bus via the dual ported RAM units, the serial USB bulk communication data blocks have to be divided into 7 blocks of 16*bit* parallel data. Therefore an extra micro-controller, EZ-USB FX2 from Cypress Semiconductors, is provided to act only as data transfer agent. The main reasons to choose the EZ-USB FX2 were:

- An integrated, high-performance CPU based on the industry-standard 8051 processor.
- A soft (RAM-based) architecture that allows unlimited configuration and upgrades. Full USB throughput. USB devices that use EZ-USB chips are not limited by number of endpoints, buffer sizes, or transfer speeds.
- Automatic handling of most of the USB protocol.
- No external power supply, The $3.3V$ power supply can be delivered by the 5V power available at the USB connector (which the USB Specification allows to be as low as $4.4V$).

This controller runs at $48Mhz$ and is able to transfer the serial data block of $226bytes$ to the peripheral 16*bit* data bus in less than $50\mu s$. Additional to the Cypress development board, an electronic interface has been created to connect the peripheral bus of the Cypress micro-controller to the different dual ported RAM units. Figure C.7 gives the electronic scheme of the interface. Since the Cypress controller works at $3V$ supply voltage level and the dual ported RAM units at $5V$, all lines connecting both parts are buffered via octal supply translating transceiver chips, 74LVC4245. These have a tristate when not enabled, this is important especially for connecting the data lines FD[i] of the Cypress controller to data lines D[i] of the dual ported RAM units. Two chips, U1 and U2, are foreseen for the 16 bit data lines, which work in both directions. The address lines are buffered with U3 which only translates in one direction as is the same for chip U4. The latter connects port PE of the Cypress controller to the other micro-controllers in order to give communication commands. These are: selection of a specific dual ported RAM unit by means of the line decoder chip U6, directing the R/W signal, global reset by software via pin PE5 and two extra general purpose control pins connected to PF1 and PF2 of the Motorola controller. These PF port pins can be controlled interrupt driven. In the other direction, pins PF3 of all the Motorola micro-controllers are connected separately to port PA of the Cypress controller. The pins PF4 of all Motorola controllers are connected together via an AND gate to pin PA7. These signals are used as communication acknowledgement signals, knowing that the Cypress controller is the bus master. Furthermore, a dip switch is provided to act on pin PF5 in order to select between two working modes. Finally, a general purpose interrupt can be generated manually on pin PF7 of all controllers and a manual global reset button is provided also.

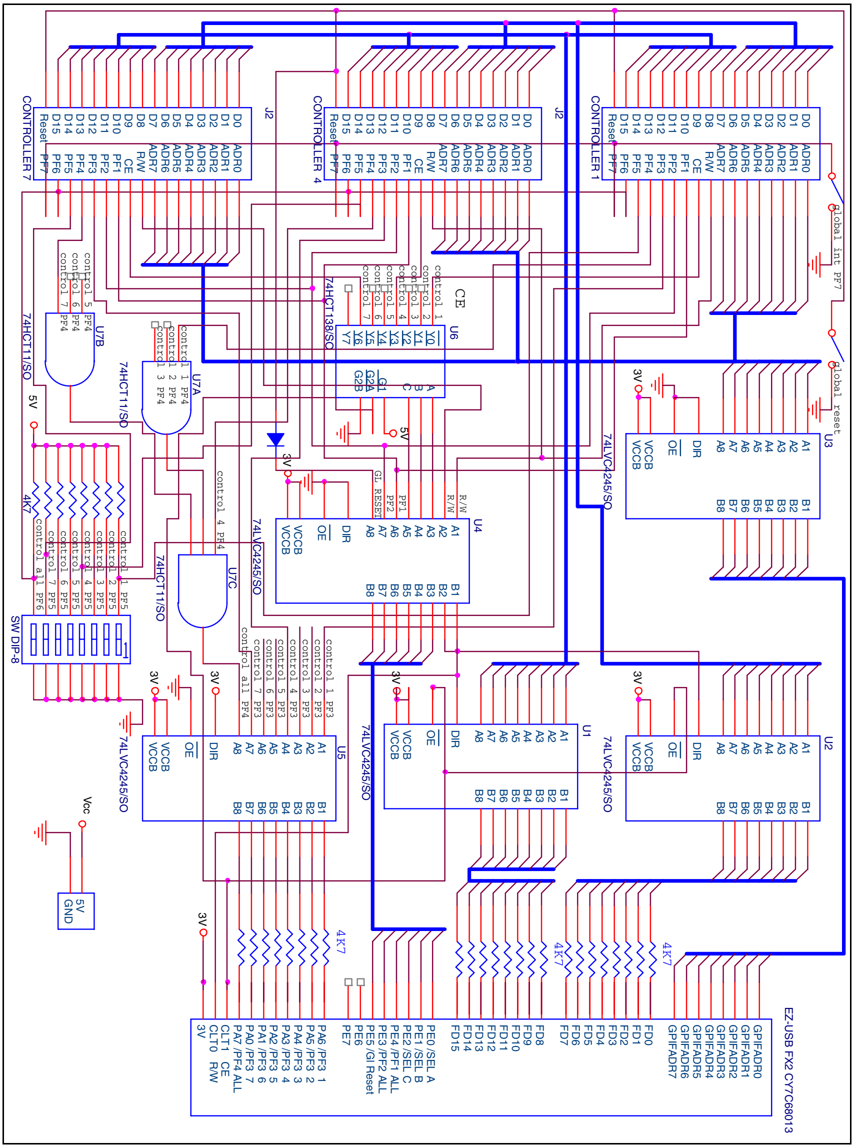


Fig. C.7 Electronic scheme of the cypress communication interface.

C.7.3 USB Transfer Types

USB defines four transfer types. These match the requirements of different data types delivered over the bus.

- Bulk Transfers
- Interrupt Transfers
- Isochronous Transfers
- Control Transfers

The EZ-USB FX2 is configured as Bulk Transfer for the robot application. Bulk data is bursty, traveling in packets of $512 bytes$ at high speed. The most important reason to choose for this type is that it has guaranteed accuracy, due to an automatic retry mechanism for erroneous data. The host schedules bulk packets when there is available bus time.

C.7.4 EZ-USB FX2 Architecture

The FX2 packs all the intelligence required by a USB peripheral interface into a compact integrated circuit. As figure C.8 illustrates, an integrated USB transceiver connects to the USB bus pins D+ and D-. A Serial Interface Engine (SIE) decodes and encodes the serial data and performs error correction, bit stuffing, and the other signaling-level tasks required by USB. Ultimately, the SIE transfers parallel data to and from the USB interface.

The high-level USB protocol is not bandwidth-critical, so the FX2s CPU is well-suited for handling host requests over the control endpoint. However, the data rates offered by USB 2.0 are too high for the CPU to process the USB data directly. For this reason, the CPU is not in the high bandwidth data path between endpoint FIFOs and the external interface. Instead, the CPU simply configures the interface, then “gets out of the way” while the unified FX2 FIFOs move the data directly between the USB and the external interface. To do this the General Programmable Interface (GPIF) is used. This internal FX2 timing generator serves as an internal master, interfacing directly to the FIFOs and generating user-programmed control signals for the interface to external logic.

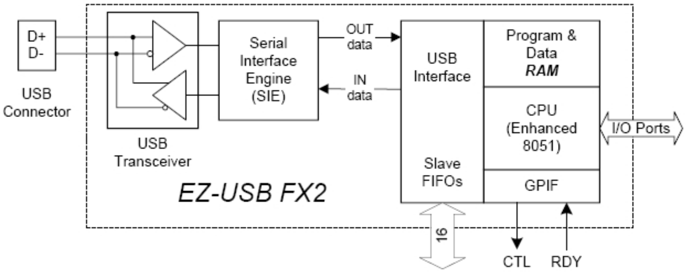


Fig. C.8 FX2 Simplified Block Diagram (28).

C.7.5 FX2 Endpoint Buffers

The USB Specification defines an endpoint as a source or sink of data. Since USB is a serial bus, a device endpoint is actually a FIFO which sequentially empties or fills with USB data bytes. The host selects a device endpoint by sending a 4-bit address and a direction bit. Therefore, USB can uniquely address 32 endpoints, IN0 through IN15 and OUT0 through OUT15.

From the FX2s point of view, an endpoint is a buffer full of bytes received or held for transmission over the bus. The FX2 reads host data from an OUT endpoint buffer, and writes data for transmission to the host to an IN endpoint buffer. The terms "IN" and "OUT" are from the viewpoint of the PC, because the PC is always the master in a USB system. USB devices respond to host requests. USB devices cannot send information among themselves, as they could if USB were a peer-to-peer topology.

EP0 is the default CONTROL endpoint, a bidirectional endpoint that uses a single 64-byte buffer for both IN and OUT data.

Endpoints 2, 4, 6 and 8 are the large, high bandwidth, data moving endpoints. In this application the endpoint 2 is used as OUT endpoint and 6 as IN endpoint.

C.7.6 Firmware

Because the FX2s configuration is soft, one chip can take on the identities of multiple distinct USB devices. The functionality of the controller, called the firmware, isn't stored in the memory of the chip itself, but on the central PC. This has as advantage that it is easily adapted. When first plugged into USB, the FX2 enumerates automatically and downloads firmware and USB descriptor tables over the USB cable. Next, the FX2 enumerates again, this time as a device defined by the downloaded information. This patented two-step process, called ReNumeration^{TM}, happens instantly when the device is plugged in. The new programmed FX2 is visible in the "Device manager".

C.7.7 Driver

To communicate between the FX2 and the PC the proper device driver has to be installed. A device driver is the software that Windows or a Windows based application uses to interact with a piece of hardware. As a result the application doesn't need to bother about protocols, physical connections, signals and can stay platform independent.

Because the FX2 is not a standard piece of hardware, a class driver can't be used. Examples of class drivers are the human interface device (HID) class, which supports devices like mice, joysticks, and keyboards. Another is the monitor class, which controls image position, size, and alignment on video displays. Custom drivers are an alternative to class drivers.

Because we didn't want to write our own driver with for example Driver Developer's Kit (DDK), the generic driver "WinRT for USB" of BSQUARE is used. Using this, developers can write application-level Win32 hardware control programs for USB hardware and eliminate the need for device driver toolkits or custom device driver development.

Communicating with the FX2 is then possible with easy to understand functions as for example "WinRTBulkTransfer" and "FindBulkEndpoints".

Appendix D
Publication List Related to Lucy

- Trajectory Planning for the Walking Biped ’Lucy’
  VERMEULEN Jimmy, VERRELST Bjorn, VANDERBORGHT Bram, LEFEBER Dirk
  International Journal of Robotics Research, Vol. 25, No. 9, 2006, pp. 867-887
- Controlling a Bipedal Walking Robot Actuated by Pleated Pneumatic Artificial Muscles
  VANDERBORGHT Bram, VERRELST Bjorn, VAN HAM Ronald, LEFEBER Dirk
  Robotica, Vol. 24, No. 4, July 2006, pp. 401-410
- Second Generation Pleated Pneumatic Artificial Muscle and Its Robotic Applications
  VERRELST Bjorn, VAN HAM Ronald, VANDERBORGHT Bram, LEFEBER Dirk, DAERDEN Frank, VAN DAMME Michael
  Advanced Robotics, Vol. 20 No. 7, 2006, pp. 783-805
- Exploiting Natural Dynamics to Reduce Energy Consumption by Controlling the Compliance of Soft Actuators
  VANDERBORGHT Bram, VERRELST Bjorn, VAN HAM Ronald, VAN DAMME Michael, LEFEBER Dirk, MEIRA Y DURAN Bruno, BEYL Pieter
  International Journal of Robotic Research, Vol. 25, No. 4, April 2006, pp. 343-358
- A real-time joint trajectory planner for dynamic walking bipeds in the sagittal plane
  VERMEULEN Jimmy, VERRELST Bjorn, LEFEBER Dirk, KOOL Patrick, VANDERBORGHT Bram
  Robotica, Vol. 23, No. 06, November 2005, pp. 669-680
- Control Architecture for the Pneumatically Actuated Dynamic Walking Biped ’Lucy’
  VERRELST Bjorn, VANDERBORGHT Bram, VERMEULEN Jimmy, VAN HAM Ronald, NAUDET Joris, LEFEBER Dirk
  Mechatronics, Vol. 15, No. 6, July 2005, pp. 703-729

- The Pneumatic Biped 'LUCY' Actuated with Pleated Pneumatic Artificial Muscles
  VERRELST Bjorn, VAN HAM Ronald, VANDERBORGHT Bram, DAERDEN Frank, LEFEBER Dirk, VERMEULEN Jimmy
  Autonomous robots, Vol. 18, No. 2, March 2005, pp. 201-213
- Motion Generation and Control for the Pneumatic Biped "Lucy"
  VERRELST Bjorn, VERMEULEN Jimmy, VANDERBORGHT Bram, VAN HAM Ronald, NAUDET Joris, LEFEBER Dirk, DAERDEN Frank, VAN DAMME Michael
  International Journal of Humanoid Robotics (IJHR), Vol. 3, No. 1, 2006, pp. 1-35
- Fast and Accurate Pressure Control Using On-Off Valves
  VAN HAM Ronald, DAERDEN Frank, VERRELST Bjorn, VANDERBORGHT Bram, LEFEBER Dirk
  International Journal of Fluid Power, No. 6, 2005, pp. 53-58
- Treadmill walking of the pneumatic biped Lucy: Walking at different speeds and step-lengths Authors: VANDERBORGHT Bram, VERRELST BJORN, VAN HAM Ronald, VAN DAMME Michael, VERSLUYS Rino, LEFEBER DIRK Reference: International Applied Mechanics, vol. 44, n. 7, 2008, pp. 134 - 142
- Objective locomotion parameters based inverted pendulum trajectory generator Authors: VANDERBORGHT Bram, VERRELST BJORN, VAN HAM Ronald, VAN DAMME Michael, LEFEBER DIRK Reference: Robotics and Autonomous Systems, vol. 56, n. 9, 2008, pp. 738 - 750
- Development of a compliance controller to reduce energy consumption for bipedal robots Authors: VANDERBORGHT Bram, VERRELST BJORN, VAN HAM Ronald, VAN DAMME Michael, BEYL Pieter, LEFEBER DIRK Reference: Autonomous Robots, vol. 15, n. 6, 2008, pp. 419 - 434
- Overview of the Lucy Project: Dynamic Stabilization of a Biped Powered by Pneumatic Artificial Muscles Authors: VANDERBORGHT Bram, VAN HAM Ronald, VERRELST BJORN, VAN DAMME Michael, LEFEBER DIRK Reference: Advanced Robotics, vol. 22, n. 10, 2008, pp. 1027 - 1051
- Dynamically Walking over Large Obstacles by a Humanoid Robot Authors: STASSE Olivier, VERRELST BJORN, VANDERBORGHT Bram, YOKOI Kazuhito Reference: IEEE Transactions on Robotics, vol. 25, n. 4, 2009, pp. 960 - 967
- Comparison of Mechanical Design and Energy Consumption of Adaptable, Passive-compliant Actuators Authors: VANDERBORGHT Bram, VAN HAM Ronald, LEFEBER DIRK, Sugar Thomas, Hollander Kevin Reference: International Journal of Robotics Research, vol. 28, n. 1, 2009, pp. 90 - 103

For a publication list including conference papers please visit
http://mech.vub.ac.be/bram.htm

References

[1] http://support.sony-europe.com/aibo/2_0_news.asp?news=13
[2] Aldebaran robotics, http://www.aldebaran-robotics.com/
[3] Anybots, http://anybots.com
[4] Biped robot entertainment robo-one official site, http://www.robo-one.com/
[5] Development of a humanoid robot based on technical transfer from AIST, http://www.aist.go.jp/aist_e/latest_research/2006/20060713/20060713.html
[6] Development of waseda robot -the study of biomechanisms at (the late) kato laboratory, http://www.humanoid.waseda.ac.jp/booklet/katobook.html
[7] The federation of international robot-soccer association (FIRA), http://www.fira.net
[8] Festo ag & co., http://www.festo.com/
[9] Hitachi medical corporation, http://www.hitachimedicalsystems.com/
[10] Hitec robotics, http://www.hitecrobotics.com/
[11] KineoWorks is a software development kit dedicated to motion planning and marketed by kineo CAM, http://www.kineocam.com/
[12] Kondo Kagaku Co., Ltd. KHR-1, http://www.kondo-robot.com
[13] Merlin robotics, http://www.merlinrobotics.co.uk/
[14] Modular controller architecture version2 (mca2), http://www.mca2.org/
[15] Network based humanoid robot - mahru, ahra, http://humanoid.kist.re.kr/eng/
[16] Nuvo - the first humanoid robot in the world ”for home use”, http://nuvo.jp/nuvo_home_e.html
[17] Official home page of honda’s humanoid robot. http://world.honda.com/ASIMO/
[18] Overview of the partner robots of toyota, http://www.toyota.co.jp/en/special/robot/
[19] Pal technology, http://www.pal-robotics.com/reem.html
[20] Population division of the department of economic and social affairs of the united nations secretariat, world population prospects: The 2004 revision and world urbanization prospects: The 2003 revision, http://esa.un.org/unpp
[21] Press release: World’s first running humanoid robot, http://www.sony.net/SonyInfo/News/Press/200312/03-060E
[22] Robocup, http://www.robocup.org
[23] Sarcos, http://www.sarcos.com

[24] Shadow robot company, `http://www.shadowrobot.com/`

[25] Universal serial bus specification version 2.0, `http://www.usb.org`

[26] ZMP Inc., `http://www.zmp.co.jp/`

[27] Summary report on technology strategy for creating a ”robot society” in the 21st century. Tech. rep., Japan Robot Society (2001)

[28] EZ-USB FX2 Technical Reference Manuel. Cypress Semiconductor (2003)

[29] Adamczyk, P.G., Collins, S.H., Kuo, A.D.: The advantages of a rolling foot in human walking. Journal of Experimental Biology 209, 3953–3963 (2006)

[30] Ahn, C.K., Lee, M.C., Go, S.J.: Development of a biped robot with toes to improve gait pattern. In: IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2003), vol. 2, pp. 729–734 (2003)

[31] Albert, A., Gerth, W.: New path planning algorithms for higher gait stability of a bipedal robot. In: 4th International Conference on Climbing and Walking Robots (CLAWAR 2001), pp. 521–528 (2001)

[32] Alexander, R.M.: Exploring Biomechanics: Animals in Motion. Scientific American Library (1992)

[33] Alexander, R.M.: Human elasticity. Physics Education 29, 358–362 (1994)

[34] Alexander, R.M.: Physiology: Enhanced: Walking made simple. Science 308(5718), 58–59 (2005)

[35] Anderson, D., Dzatko, D.: Universal Serial Bus System Architecture. Addison-Wesley, Reading (2001)

[36] Anderson, F.C., Pandy, M.G.: Dynamic optimization of human walking. Journal of Biomechanical Engineering 123(5), 81–390 (2001)

[37] Aoi, S., Tsuchiya, K.: Locomotion control of a biped robot using nonlinear oscillators. Autonomous Robots 19(3), 219–232 (2005)

[38] Aristotle: De Anima (On the soul), vol. 1 406b15-22 (350 BC)

[39] Aristotle: The Politics, vol. 1253b33-1254a1 (350 BC)

[40] Asimov, I.: I, Robot. Doubleday & Company, New York (1950)

[41] Asimov, I.: Robots and Empire. Grafton Books, London (1985)

[42] Azevedo, C., Andreff, N., Arias, S.: BIPedal walking: from gait design to experimental analysis. Mechatronics 14/6, 639–665 (2004)

[43] Azevedo, C., Poignet, P., Espiau, B.: Artificial locomotion control from human to robots. Robotics and Autonomous Systems 47/4, 203–223 (2004)

[44] Baillie, J.C.: URBI: towards a universal robotic low-level programming language. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), pp. 820–825 (2005)

[45] Bares, J.E.: Dante II: Technical description, results, and lessons learned. The International Journal of Robotics Research 18(7), 621–649 (1999)

[46] Basmajian, J., De Luca, C.: Muscles alive: their function revealed by electromyography, p. 1964 (1985)

[47] Basmajian, J.V., Tuttle, R.: EMG of locomotion in gorilla and man. In: Control of Posture and Locomotion, pp. 599–609. Plenum Press, New York (1973)

[48] Bauby, C.E., Kuo, A.D.: Active control of lateral balance in human walking. Journal of Biomechanics 33, 1433–1440 (2000)

[49] Behnke, S., Müller, J., Schreiber, M.: Toni: A Soccer Playing Humanoid Robot. LNAI, pp. 59–70. Springer, Heidelberg (2006)

[50] Behnke, S., Schreiber, M., Stückler, J., Renner, R., Strasdat, H.: See, walk, and kick: Humanoid robots start to play soccer. In: IEEE-RAS International Conference on Humanoid Robots, pp. 497–503 (2006)

[51] Beletskii, V., Berbyuk, V., Samsonov, V.: Parametric optimization of motions of a bipedal walking robot. Mechanics of Solids 17(1), 24–35 (1982)

[52] Berns, K., Braun, T.: Design concept of a human-like robot head. In: IEEE-RAS International Conference on Humanoid Robots, pp. 32–37 (2005)

[53] Beyl, P., Naudet, J., Vanderborgt, B., Van Damme, M., Van Ham, R., Verrelst, B., Lefeber, D.: Mechanical design of a step rehabilitation robot prototype: Dimensioning of compliant actuators. In: International Conference on Climbing and Walking Robots (CLAWAR 2006), pp. 454–460 (2006)

[54] Beyl, P., Van Damme, M., Van Ham, R., Vanderborght, B., Lefeber, D.: Design and control of a lower limb exoskeleton for robot-assisted gait training. Applied Bionics and Biomechanics 6(2), 229–243 (2009)

[55] Bicchi, A., Tonietti, G.: Fast and soft arm tactics: Dealing with the safety-performance trade-off in robot arms design and control. IEEE Robotics and Automation Magazine 11, 22–33 (2004)

[56] Bicchi, A., Tonietti, G., Bavaro, M., Piccigallo, M.: Variable stiffness actuators for fast and safe motion control. In: Int. Symposium Robotics Research, pp. 100–110 (2003)

[57] Blajer, W., Schiehlen, W.: Walking without impacts as a motion/force control problem. Journal of Dynamic Systems, Measurement and Control 114, 660–665 (1992)

[58] Bluethmann, W., Ambrose, R., Diftler, M., Askew, S., Huber, E., Goza, M., Rehnmark, F., Lovchik, C., Magruder, D.: Robonaut: A robot designed to work with humans in space. Autonomous Robots 14(2-3), 1573–7527 (2003)

[59] Bluethmann, W., Ambrose, R., Diftler, M., Huber, E., Fagg, A., Rosenstein, M., Platt, R., Grupen, R., Breazeal, C., Brooks, A., Lockerd, A., Peters, R., Jenkins, O., Mataric, M., Bugajska, M.: Building an autonomous humanoid tool user. In: IEEE/RAS International Conference on Humanoid Robots, pp. 402–421 (2004)

[60] Breazeal, C.: Emotion and sociable humanoid robots. International Journal of Human computer Studies 59(1-2), 119–155 (2003)

[61] Breazeal, C.: Designing Sociable Robots. The MIT Press, Cambridge (2004)

[62] Breazeal, C., Buchsbaum, D., Gray, J., Gatenby, D., Blumberg, B.: Learning from and about others: Towards using imitation to bootstrap the social understanding of others by robots. Artificial Life 11(1-2), 31–62 (2005)

[63] Brooks, A., Kaupp, T., Makarenko, A., Williams, S., Oreback, A.: Towards component-based robotics. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), pp. 163–168 (2005)

[64] Brooks, R.: Prospects for human level intelligence for humanoid robots. In: International Symposium on Humanoid Robots (HURO 1996) (1996)

[65] Brown, R.H., Schneider, S.C., Mulligan, M.G.: Analysis of algorithms for velocity estimation from discreteposition versus time data. IEEE Transactions on Industrial Electronics 39(1), 11–19 (1992)

[66] Brun, X.: Commendes linéaires et non linéaires en electropneumatique, méthodologies et applications. Ph.D. thesis, Institut National des Science Appliquees de Lyon (1999)

[67] Bruyninckx, H.: Open robot control software: the OROCOS project. In: IEEE International Conference on Robotics and Automation (ICRA 2001), vol. 3 (2001)

[68] Bruyninckx, H., Soetens, P., Koninckx, B.: The real-time motion control core of the orocos project. In: IEEE International Conference on Robotics and Automation (ICRA 2003), vol. 2, pp. 2766–2771 (2003)

[69] Buehler, M., Playter, R., Raibert, M.: Robots step outside. In: Int. Symp. Adaptive Motion of Animals and Machines (AMAM), Ilmenau, Germany, pp. 1–4 (2005)

[70] Burkhard, H., Duhaut, D., Fujita, M., Lima, P., Murphy, R., Rojas, R.: The road to RoboCup 2050. IEEE Robotics & Automation Magazine 9(2), 31–38 (2002)

[71] Buschmann, T., Lohmeier, S., Ulbrich, H., Pfeiffer, F.: Modeling and simulation of a biped robot. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 2673–2678 (2006)

[72] Caballero, R., Akinfiev, T., Montes, H., Manzano, C., Armada, M.: Design of the SMART actuated ROBICAM biped robot. In: International Conference on Climbing and Walking Robots (CLAWAR 2002), pp. 409–416 (2002)

[73] Caballero, R., Alarcon, P., Armada, M.: Development and experimental evaluation of sensorial system for SILO-2 biped robot. In: International Conference on Climbing and Walking Robots (CLAWAR 2006), pp. 386–395 (2006)

[74] Caballero, R., Armada, M.A., Akinfiev, T.: Robust cascade controller for nonlinearly actuated biped robots: Experimental evaluation. The International Journal of Robotics Research 23(10-11), 1075–1095 (2004)

[75] Cabas, L., Cabas, R., Staroverov, P., Arbulu, M., Kaynov, D., Pérez, C., Balaguer, C.: Challenges in the design of the humanoid robot R.H.1. In: International Conference on Climbing and Walking Robots (CLAWAR 2006), pp. 318–323 (2006)

[76] Cabodevilla, G., Chaillet, N., Abba, G.: Energy-minimized gait for a biped robot. In: Proceedings Fachgespräch Autonome Mobile Systemer, pp. 90–99 (1995)

[77] Caldwell, D., Medrano-Cerda, G., Bowler, C.: Investigation of bipedal robot locomotion using pneumatic muscle actuators. In: IEEE International Conference on Robotics and Automation (ICRA 1997), pp. 799–804 (1997)

[78] Caldwell, D., Medrano-Cerda, G., Goodwin, M.: Control of pneumatic muscle actuators. IEEE Control Systems Magazine 15(1), 40–48 (1995)

[79] Caldwell, D., Tsagarakis, N., Badihi, D., Medrano-Cerda, G.: Pneumatic muscle actuator technology: a light weight power system for a humanoid robot. In: IEEE International Conference on Robotics and Automation (ICRA 1998), vol. 4, pp. 3053–3058 (1998)

[80] Caldwell, G.: Natural and artificial muscle elements as robot actuators. Mechatronics 3(3), 269–283 (1993)

[81] Capi, G., Nasu, Y., Barolli, L.K.M.: Real time gait generation for autonomous humanoid robots: A case study for walking. Robotics and Autonomous Systems 42(2), 107–116 (2003)

[82] Cavagna, G., Thys, H., Zamboni, A.: The sources of external work in level walking and running. Journal of Physiology 262, 639–657 (1976)

[83] Cavagna, G.A., Saibene, F.P., Margaria, R.: Mechanical work in running. Journal of Applied Physiology 19, 249–256 (1964)

[84] Chakarov, D.: Some approaches for passive compliance realization for precize opperation manipulators. In: Bulgarian Conference on Bionics, Biomechanics and Mechatronics, pp. 88–91 (2004)

[85] Channon, P., Hopkins, S., Pham, D.: Derivation of optimal walking motion for a bipedal walking robot. Robotica 10, 165–172 (1992)

[86] Cheng, G., Hyon, S.H., Jun Morimoto, A.U., Colvin, G., Scroggin, W., Jacobsen, S.C.: CB: A humanoid research platform for exploring neuroscience. In: IEEE-RAS International Conference on Humanoid Robots, pp. 182–187 (2006)

[87] Cherfas, J.: The difficulties of darwinism. New Scientist 102, 29 (1984)

[88] Chestnutt, J., Kuffner, J., Nishiwaki, K., Kagami, S.: Planning biped navigation strategies in complex environments. In: IEEE International Conference on Humanoid Robots (2003)

[89] Chevallereau, C., Abba, G., Aoustin, Y., Plestan, F., Westervelt, E., Canudas-De-Wit, C., Grizzle, J.: RABBIT: a testbed for advanced control theory. IEEE Control Systems Magazine 23(5), 57–79 (2003)

[90] Chevallereau, C., Aoustin, Y.: Optimal running trajectories for a biped. In: International Conference on Climbing and Walking Robots (CLAWAR 1999), pp. 559–570 (1999)

[91] Chevallereau, C., Aoustin, Y.: Optimal reference trajectories for walking and running of a biped robot. Robotica 19, 557–569 (2001)

[92] Chew, C., Pratt, G.: Frontal plane algorithms for dynamic bipedal walking. Robotica 22(01), 29–39 (2004)

[93] Chew, C.M., Pratt, G.A.: Frontal plane algorithms for dynamic bipedal walking. In: IEEE lnternational Conference on Robotics & Automation (ICRA 2003), pp. 45–50 (2003)

[94] Cho, D.: Wrestle a robot. New Scientist 191(2564), 39 (2006)

[95] Choi, C., Tsao, T.C.: H_∞ preview control for discrete-time systems. Journal of Dynamic Systems, Measurement, and Contro 123(1), 117–124 (2001)

[96] Clarke, R.: Asimov's laws of robotics: implications for information technology-part I. Computer 26(12), 53–61 (1993)

[97] Clarke, R.: Asimov's laws of robotics: implications for information technology-part II. Computer 27(1), 57–66 (1994)

[98] Colbrunn, R., Nelson, G., Quinn, R.: Design and control of a robotic leg with braided pneumaticactuators. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001), vol. 2, pp. 992–998 (2001)

[99] Collins, S., Ruina, A.: A bipedal walking robot with efficient and human-like gait. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 1983–1988 (2005)

[100] Collins, S.H., Ruina, A., Tedrake, R., Wisse, M.: Efficient bipedal robots based on passive-dynamic walkers. Science 18(307), 1082–1085 (2005)

[101] Colon, E.: CoRoBa, a multi mobile robot control and simulation framework. Ph.D. thesis, Vrije Universiteit Brussel - Koninklijke Militaire School (2006)

[102] Cote, C., Letourneau, D., Michaud, F., Valin, J.M., Brosseau, Y., Raievsky, C., Lemay, M., Tran, V.: Code reusability tools for programming mobile robots. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), vol. 2, pp. 1820–1825 (2004)

[103] Cupec, R., Lorch, O., Schmidt, G.: Vision-guided humanoid walking - concepts and experiments. In: Workshop on Robotics in Alpe-Adria-Danube Region (RAAD 2003), Cassino, Italy (2003)

[104] Daerden, F.: Conception and realization of pleated pneumatic artificial muscles and their use as compliant actuation elements. Ph.D. thesis, Vrije Universiteit Brussel (1999)

[105] Daerden, F., Lefeber, D.: Pneumatic artificial muscles: actuators for robotics and automation. European Journal of Mechanical and Environmental Engineering 47(1), 11–21 (2002)

[106] Daerden, F., Lefeber, D., Verrelst, B., Van Ham, R.: Pleated pneumatic artificial muscles: compliant robotic actuators. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001), vol. 4, pp. 1958–1963 (2001)

[107] Dasgupta, A., Nakamura, Y.: Making feasible walking motion of humanoid robots from human motion capture data. In: IEEE International Conference on Robotics and Automation (ICRA 1999), Detroit, USA, vol. 2, pp. 1044–1049 (1999)

[108] David, A., Bruneau, O.: Dynamic stabilization of an under-actuated robot using dynamic effects of the legs and the trunk. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 898–903 (2006)

[109] Davis, S., Canderle, J., Artrit, P., Tsagarakis, N., Caldwell, D.: Enhanced dynamic performance in pneumatic muscle actuators. In: IEEE International Conference on Robotics and Automation (ICRA 2002), vol. 3, pp. 2836–2841 (2002)

[110] Davis, S., Tsagarakis, N., Canderle, J., Caldwell, D.G.: Enhanced modelling and performance in braided pneumatic muscle actuators. The International Journal of Robotic Research 22(22), 213–227 (2003)

[111] De Schutter, J.: A study of active compliant motion control methods for rigid manipulators based on a generic scheme. In: IEEE International conference on Robotics and Automation (ICRA 1987), pp. 1060–1065 (1987)

[112] Denk, J., Schmidt, G.: Synthesis of walking primitive databases for biped robots in 3D-environments. In: IEEE International Conference on Robotics and Automation (ICRA 2003), vol. 1, pp. 1343–1349 (2003)

[113] Dertien, E.: Dynamic walking with dribbel. IEEE Robotics & Automation Magazine 13(3), 118–122 (2006)

[114] Dickinson, M.H., Farley, C.T., Full, R.J., Koehl, M.A.R., Kram, R., Lehman, S.: How animals move: An integrative view. Science 288, 100–106 (2000)

[115] Djoudi, D., Chevallereau, C.: Feet can improve the stability property of a control law for a walking robot. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 1206–1212 (2006)

[116] Donelan, J.M., Kram, R., Kuo, A.D.: Mechanical work for step-to-step transitions is a major determinant of the metabolic cost of human walking. The Journal of Experimental Biology 205, 3717–3727 (2002)

[117] Einstein, J., Pawlik, G.: Feasibility of bipedal locomotion in robotic systems: Pneumatics vs. electronics. In: Proceedings 5th International Symposium on Measurement and Control in Robotics, Smolenice, Slovakia, pp. 453–458 (1995)

[118] Elftman, H.: The function of arms in walking. Human Biology 11, 529–535 (1939)

[119] Endo, G., Morimoto, J., Nakanishi, J., Cheng, G.: An empirical exploration of a neural oscillator for biped locomotion control. In: IEEE International Conference on Robotics and Automation (ICRA 2004), vol. 3, pp. 3036–3042 (2004)

[120] English, C., Russell, D.: Mechanics and stiffness limitations of a variable stiffness actuator for use in prosthetic limbs. Mechanism and Machine Theory 34(1), 7–25 (1999)

[121] Fallis, G.T.: Walking toy (improvement in walking toys). U. S. Patent, No. 376, 588 (1888)

[122] Farley, C., Gonzalez, O.: Leg stiffness and stride frequency in human running. Journal of Biomechanics 29(2), 181–186 (1996)

[123] Farley, C.T., Houdijk, H.H.P., Van Strien, C., Louie, M.: Mechanism of leg stiffness adjustment for hopping on surfaces of different stiffnesses. Journal of Applied Physiology 85(3), 1044–1055 (1998)

[124] Fernández, R., Hespanha, J., Akinfiev, T., Armada, M.: Nonlinear control for the dual smart drive using backstepping and a time-optimal reference. Autonomous Robots 19(3), 233–255 (2005)

[125] Fernández-Madrigal, J.A., Galindo, C., González, J., Cruz-Martín, E., Cruz-Martí, A.: A software engineering approach for the development of heterogeneous robotic applications. Robotics and Computer-Integrated Manufacturing (2007) (in press)

[126] Ferris, D.P., Farley, C.T.: Interaction of leg stiffness and surface stiffness during human hopping. Journal of Applied Physiology 82(1), 15–22 (1997)

[127] Festo: Information brochure Fluidic Muscle DMSP with pressed-on connections

[128] Figliolini, G., Ceccarelli, M.: Walking programming for an electropneumatic biped robot. Mechatronics 9(8), 941–964 (1999)

[129] Figliolini, G., Ceccarelli, M.: Climbing stairs with EPWAR2 biped robot. In: IEEE International Conference on Robotics and Automation (ICRA 2001), pp. 4116–4121 (2001)

[130] Figliolini, G., Ceccarelli, M.: EP-WAR3 biped robot for climbing and descending stairs. Robotica 22, 405–417 (2004)

[131] Fujiwara, K., Kajita, S., Harada, K., Kaneko, K., Morisawa, M., Kanehiro, F., Nakaoka, S., Hirukawa, H.: Towards an optimal falling motion for a humanoid robot. In: IEEE-RAS International Conference on Humanoid Robots, pp. 524–529 (2006)

[132] Fujiwara, K., Kanehiro, F., Kajita, S., Hirukawa, H.: Safe knee landing of a human-size humanoid robot while falling forward. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), pp. 503–508 (2004)

[133] Fujiwara, K., Kanehiro, F., Saito, H., Kajita, S., Harada, K., Hirukawa, H.: Falling motion control of a humanoid robot trained by virtual supplementary tests. In: IEEE International Conference on Robotics and Automation (ICRA 2004), pp. 1077–1082 (2004)

[134] Gates, B.: A robot in every home. Scientific American 296(1), 58–65 (2007)

[135] Geng, T., Porr, B., Florentin, W.: Fast biped walking with a sensor-driven neuronal controller and real-time online learning. International Journal of Robotics Research 25(3), 243–259 (2006)

[136] Gerecke, M., Albert, A., Hofschulte, J., Strasser, R., Gerth, W.: Towards an autonomous, bipedal service robot. In: Tagungsband 10 Jahre Fraunhofer IFF, Magdeburg, pp. 163–168 (2002)

[137] Geyer, H., Seyfarth, A., Blickhan, R.: Compliant leg behaviour explains basic dynamics of walking and running. Proceedings of the royal society B 273(1603), 2861 (2006)

[138] Ghan, J., Kazerooni, H.: System identification for the berkeley lower extremity exoskeleton (BLEEX). In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 3477–3484 (2006)

[139] Goddard, R., Hemami, H., Weimer, F.: Biped side step in the frontal plane. IEEE Transactions on Automatic Control 28(2), 179–187 (1983)

[140] Gorce, P., Guihard, M.: On dynamic control of pneumatic bipeds. Journal of Robotic Systems 15(7), 421–433 (1998)

[141] Goswami, A.: Postural stability of biped robots and the foot-rotation indicator (FRI) point. The International Journal of Robotics Research 18(6), 523–533 (1999)

[142] Gould, S.J.: The Panda's Thumb (1980)

[143] Spampinato, G., Muscato, G.: Control architecture and walking strategy for a pneumatic biped robot. In: International Conference on Climbing and Walking Robots, CLAWAR 2005 (2005)

[144] Guan, Y., Neo, E., Yokoi, K., Tanie, K.: Stepping over obstacles with humanoid robots. IEEE Transactions on Robotics 22(5), 958–973 (2006)

[145] Guccione, S., Muscato, G., Spampinato, G.: A human inspired robotic leg: Design, control and mechanical realization. In: IEEE International Conference on Humanoid Robots (2003)

[146] Guizzo, E., Goldstein, H.: The rise of the body bots [robotic exoskeletons]. IEEE Spectrum 42(10), 50–56 (2005)

[147] Gutmann, J.S., Fukuchi, M., Fujita, M.: A modular architecture for humanoid robot navigation. In: IEEE-RAS International Conference on Humanoid Robots, pp. 26–31 (2005)

[148] Habumuremyi, J.C., Kool, P., Doroftei, I., Baudoin, Y.: Method to find dynamic parameters of a system using neuro-fuzzy techniques and its application to a pantograph-based leg of a robot AMRU5. In: International Symposium on Measurement and Control in Robotics (2005)

[149] Hansen, A., Childress, D., Miff, S., Gard, S., Mesplay, K.: The human ankle during walking: implications for design of biomimetic ankle prostheses. Journal of Biomechanics 37(10), 1467–1474 (2004)

[150] Harada, K., Hirukawa, H., Kanehiro, F., Fujiwara, K., Kaneko, K., Kajita, S., Nakamura, M.: Dynamical balance of a humanoid robot grasping an environment. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), vol. 2, pp. 1167–1173 (2004)

[151] Harada, K., Kajita, S., Kaneko, K., Hirukawa, H.: ZMP analysis for arm/leg coordination, pushing manipulation by humanoid considering two-kinds of ZMPs. In: International Conference on Intelligent Robots and Systems (IROS 2003), pp. 75–81 (2003)

[152] Hardt, M., Kreutz-Delgado, K., Helton, J., Stryk, O.V.: Obtaining minimum energy biped walking gaits with symbolic models and numerical optimal control. In: Workshop - Biomechanics Meets Robotics, Modelling and Simulation of Motion (1999)

[153] He, J., Kram, R., McMahon, T.: Mechanics of running under simulated low gravity. Journal of Applied Physiology 71(3), 863–870 (1991)

[154] Hemami, H., Wyman, B.: Modelling and control of constrained dynamic systems with application to biped locomotion in the frontal plane. IEEE Transactions on Automatic Control 24(4), 526–535 (1979)

[155] Hemker, T., Sakamoto, H., Stelzer, M., von Strykpp, O.: Hardware-in-the-loop optimization of the walking speed of a humanoid robot. In: International Conference on Climbing and Walking Robots (CLAWAR 2006), pp. 614–623 (2006)

[156] Hildebrand, M.: Walking and running. In: Functional Vertebrate Morphology, pp. 38–57. Belknap, Harvard Univ. Press, Cambridge (1985)

[157] Hildebrandt, A., Sawodny, O., Neumann, R., Hartmann, A.: Cascaded control concept of a robot with two degrees of freedom driven by four artificial pneumatic muscle actuators. In: American Control Conference, vol. 1, pp. 680–685 (2005)

[158] Hirai, K.: The honda humanoid robot: development and future perspective. Industrial Robot 26(4), 260–266 (1999)

[159] Hirai, K., Hirose, M., Haikawa, Y., Takenaka, T.: The development of honda humanoid robot. In: IEEE International Conference on Robotics and Automation (ICRA 1998), vol. 2, pp. 1321–1326 (1998)

[160] Hirose, S., Yokota, S., Torii, A., Ogata, M., Suganuma, S., Takita, K., Kato, K.: Quadruped walking robot centered demining system - development of TITAN-IX and its operation. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 1284–1290 (2005)

[161] Hirukawa, H.: Humanoid robotics projects in japan. In: Workshop ICRA 2006, Understanding Humanoid Robots (2006)

[162] Hirukawa, H., Hattori, S., Harada, K., Kajita, S., Kaneko, K., Kanehiro, F., Fujiwara, K., Morisawa, M.: A universal stability criterion of the foot contact of legged robots - adios ZMP. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 1976–1983 (2006)

[163] Hirukawa, H., Kanehiro, F., Kajita, S., Fujiwara, K., Yokoi, K., Kaneko, K., Harada, K.: Experimental evaluation of the dynamic simulation of biped walking of humanoid robots. In: IEEE International Conference on Robotics and Automation (ICRA 2003), vol. 2, pp. 1640–1645 (2003)

[164] Hirukawaa, H., Kanehiroa, F., Kanekoa, K., Kajitaa, S., Fujiwaraa, K., Kawaia, Y., Tomitaa, F., Hiraia, S., Taniea, K., Isozumib, T., Akachib, K., Kawasakib, T., Otab, S., Yokoyamac, K., Handac, H., Fukased, Y., Ichiro Maedad, J., Nakamurae, Y., Tachie, S., Inoue, H.: Humanoid robotics platforms developed in HRP. Robotics and Autonomous Systems 48(4), 165–175 (2004)

[165] Hobbelen, D., de Boer, T., Wisse, M.: System overview of bipedal robots flame and tulip: Tailor-made for limit cycle walking. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2008), pp. 2486–2491 (2008)

[166] Hobbelen, D., Wisse, M.: Active lateral foot placement for 3D stabilization of a Limit Cycle Walker prototype. International Journal of Humanoid Robotics (IJHR) 6(1), 93–116 (2009)

[167] Hodgins, J., Koechling, J., Raibert, M.: Running experiments with a planar biped. In: Giralt, G. (ed.) Proceedings 3rd International Symposium on Robotics Research, pp. 349–355. MIT Press, Cambridge (1986)

[168] Hodgins, J., Raibert, M.: Biped gymnastics. International Journal of Robotics Research (Special Issue on Legged Locomotion) 9(2), 115–132 (1990)

[169] Hofschulte, J., Seebode, M., Gerth, W.: Parallel manipulator hip joint for a bipedal robot. In: International Conference on Climbing and Walking Robots (CLAWAR 2004), pp. 601–609 (2004)

[170] Höhn, O., Gacnik, J., Gerth, W.: Detection and classification of posture instabilities of bipedal robots. In: International Conference on Climbing and Walking Robots (CLAWAR 2005), pp. 409–416 (2005)

[171] Höhn, O., Gerth, W.: Probabilistic balance monitoring for bipedal robots. In: International Conference on Climbing and Walking Robots (CLAWAR 2006), pp. 435–442 (2006)

[172] Hollander, K., Sugar, T.: Concepts for compliant actuation in wearable robotic systems. In: US-Korea Conference on Science, Technology and Entrepreneurship, UKC 2004 (2004)

[173] Hollander, K., Sugar, T., Herring, D.: Adjustable robotic tendon using a ”jack spring”^{TM}. In: 9th International Conference on Rehabilitation Robotics (ICORR 2005), pp. 113–118 (2005)

[174] Hollerbach, J., Hunter, I., Ballantyne, J.: A comparative analysis of actuator technologies for robotics. The Robotics Review 2, 299–342 (1991)

[175] Honda Motor Co., Ltd., New asimo - running at 6km/h (2005), `http://world.honda.com/HDTV/ASIMO/New-ASIMO-run-6kmh/`

[176] Hood, M.: Running against the wind [sports prosthetics]. IEEE Spectrum 42(6), 13–14 (2005)

[177] Hornyak, T.: Android science, pp. 32–34. Scientific American (2006)

[178] Hosoda, K., Takuma, T., Ishikawa, M.: Design and control of a 3D biped robot actuated by antagonistic pairs of pneumatic muscles. In: International Symposium on Adaptive Motion in Animals and Machines (2005)

[179] Hosoda, K., Takuma, T., Nakamoto, A.: Design and control of 2D biped that can walk and run with pneumatic artificial muscles. In: IEEE-RAS International Conference on Humanoid Robots, pp. 284–289 (2006)

[180] Hosoda, K., Takuma, T., Nakamoto, A., Hayashi, S.: Biped robot design powered by antagonistic pneumatic actuators for multi-modal locomotion. Robotics and Autonomous Systems 56(1), 46–53 (2007)

[181] Huang, Q., Kajita, S., Koyachi, N., Kaneko, K., Yokoi, K., Arai, H., Komoriya, K., Tanie, K.: High stability, smooth walking pattern for a biped robot. In: IEEE International Conference on Robotics and Automation (ICRA 1999), vol. 1, pp. 65–71 (1999)

[182] Huang, Q., Nakamura, Y.: Sensory reflex control for humanoid walking. IEEE Transactions on Robotics 21(5), 977–984 (2005)

[183] Huang, Q., Yokoi, K., Kajita, S., Kaneko, K., Arai, H., Koyachi, N., Tanie, K.: Planning walking patterns for a biped robot. IEEE Transactions on Robotics and Automation 17(3), 280–289 (2001)

[184] Hunter, I., Lafontaine, S.: A comparison of muscle with artificial actuators. In: IEEE Solid-State Sensor and Actuator Workshop, pp. 178–185 (1992)

[185] Hurst, J.W., Chestnutt, J., Rizzi, A.: An actuator with mechanically adjustable series compliance, CMU-RI-TR-04-24 (2004)

[186] Hurst, J.W., Chestnutt, J., Rizzi, A.A.: An actuator with physically variable stiffness for highly dynamic legged locomotion, new orleans, usa. In: IEEE International Conference on Robotics and Automation (ICRA 2004), pp. 4662–4667 (2004)

[187] Hurst, J.W., Rizzi, A.: Physically variable compliance in running. In: International Conference on Climbing and Walking Robots (CLAWAR 2004), pp. 123–134 (2004)

[188] Hurst, J.W., Rizzi, A.A.: Series compliance for robot actuation: Application on the electric cable differential leg. IEEE Robotics & Automation Magazine 15(3), 2008 (2008)

[189] Hyon, S., Abe, S., Emura, T.: Development of a biologically-inspired biped robot KenkenII. In: Japan-France Congress on Mechatronics & 4th Asia-Europe Congress on Mechatronics, pp. 404–409 (2003)

[190] Hyon, S., Emura, T., Mita, T.: Dynamics-based control of one-legged hopping robot. Journal of Systems and Control Engineering 217(2), 83–98 (2003)

[191] Hyon, S.H., Cheng, G.: Gravity compensation and full-body balancing for humanoid robots. In: IEEE-RAS International Conference on Humanoid Robots, pp. 214–221 (2006)

[192] Ikemata, Y., Sano, A., Fujimoto, H.: A physical principle of gait generation and its stabilization from mechanism of fixed point. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 836–841 (2006)

[193] Inaba, Kagami, Nishiwaki: Robot Anatomy, ISBN4-00-011247-3

[194] Inoue, H., Hirukawa, H.: Explorations of humanoid robot applications. In: IEEE-RAS International Conference on Humanoid Robots (2001)

[195] International Standard ISO6358: Pneumatic fluid power - method of test - determination of flow rate characteristics of components using compressible fluids (1989)

[196] Ishida, T., Kuroki, Y., Yamaguchi, J.: Mechanical system of a small biped entertainment robot. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003), vol. 2, pp. 1129–1134 (2003)

[197] Ishida, T., Kuroki, Y., Yamaguchi, J., Fujita, M., Doi, T.: Motion entertainment by a small humanoid robot based on OPEN-R. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001), vol. 2, pp. 1079–1086 (2001)

[198] Ishiguro, H., Asada, M., Shapiro, S.C., Thielscher, M., Breazeal, C., Mataric, M.J., Ishida, H.: Trends and controversies: Human-inspired robots. IEEE Intelligent Systems 21(4), 74–85 (2006)

[199] Itoh, K., Miwa, H., Matsumoto, M., Zecca, M., Takanobu, H., Roccella, S., Carrozza, M., Dario, P., Takanishi, A.: Various emotional expressions with emotion expression humanoid robot WE-4RII. In: IEEE Technical Exhibition Based Conference on Robotics and Automation (TExCRA 2004), pp. 35–36 (2004)

[200] Iwata, H., Hoshino, H., Morita, T., Sugano, S.: A physical interference adapting hardware system using MIA arm and humanoid surface covers. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 1999), vol. 2, pp. 1216–1221 (1999)

[201] Jalón, J.G., Bayo, E.: Kinematic and Dynamic Simulation of Multibody Systems The Real-Time Challenge. Springer, Heidelberg (1994)

[202] Japan Robot Society: Summary report on technology strategy for creating a robot society in the 21st century

[203] Jezernik, S., Colombo, G., Keller, T., Frueh, H., Morari, M.: Robotic orthosis lokomat: A rehabilitation and research tool. Neuromodulation 6(2), 108–115 (2003)

[204] Jha, R.K., Singh, B., Pratihar, D.K.: Online stable gait generation of a two-legged robot using a genetic-fuzzy system. Robotics and Autonomous Systems 53(1), 15–35 (2005)

[205] Jung, H., Seo, Y., Ryoo, M., Yang, H.: Affective communication multimodality for the humanoid robot AMI. In: IEEE-RAS/RSJ International Conference on Humanoid Robots (2004)

[206] Kagami, S., Kitagawa, T., Nishiwaki, K., Sugihara, T.M.I., Inoue, H.: A fast dynamically equilibrated walking trajectory generation method of humanoid robot. Autonomous Robots 12(1), 71–82 (2002)

[207] Kagami, S., Mochimaru, M., Ehara, Y., Miyata, N., Nishiwaki, K., Kanade, T., Inoue, H.: Measurement and comparison of human and humanoid walking. In: IEEE International Symposium on Computational Intelligence in Robotics and Automation (ICRA 2003), vol. 2, pp. 918–922 (2003)

[208] Kagami, S., Nishiwaki, K., Kuffner, J., Kuniyoshi, Y., Inaba, M., Inoue, H.: Online 3D vision, motion planning and bipedal locomotion control coupling system of humanoid robot: H7. In: IEEE/RSJ International Conference on Intelligent Robots and System (IROS 2002), vol. 3, pp. 2557–2562 (2002)

[209] Kagami, S., Nishiwaki, K., Kuffner, J.J., Kuniyoshi, Y., Inaba, M., Inoue, H.: Online 3d vision, motion planning and bipedal locomotion control coupling system of humanoid robot: H7. In: IEEE/RSJ International Conference on Intelligent Robots and System (IROS 2002), vol. 3, pp. 2557–2562 (2002)

[210] Kagami, S., Nishiwaki, K., Sugihara, T., Kuffner, J., Inaba, M., Inoue, H.: Design and implementation of software research platform for humanoid robotics: H6. In: IEEE International Conference on Robotics and Automation (ICRA 2001), vol. 3, pp. 2431–2436 (2001)

[211] Kajita, S.: and Kanehiro, F., Kaneko, K., Fujiwara, K., Yokoi, K., Hirukawa, H.: A realtime pattern generator for biped walking. In: IEEE International Conference on Robotics and Automation (ICRA 2002), vol. 1, pp. 31–37 (2002)

[212] Kajita, S., Kanehiro, F., Kaneko, K., Fujiwara, K., Harada, K., Yokoi, K., Hirukawa, H.: Biped walking pattern generation by using preview control of zero-moment point. In: IEEE International Conference on Robotics and Automation (ICRA 2003), vol. 2, pp. 1620–1626 (2003)

[213] Kajita, S., Kaneko, K., Harada, K., Kanehiro, F., Fujiwara, K., Hirukawa, H.: Biped walking on a low friction floor. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), vol. 4, pp. 3546–3552 (2004)

[214] Kajita, S., Matsumoto, O., Saigo, M.: Real-time 3D walking pattern generation for a biped robot with telescopic legs. In: IEEE International Conference on Robotics and Automation (ICRA 2001), pp. 2299–2306 (2001)

[215] Kajita, S., Nagasaki, T., Kaneko, K., Yokoi, K., Tanie, K.: A hop towards running humanoid biped. In: IEEE International Conference on Robotics and Automation (ICRA 2004), pp. 629–635 (2004)

[216] Kajita, S., Nagasaki, T., Kaneko, K., Yokoi, K., Tanie, K.: A Running Controller of Humanoid Biped HRP-2LR. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 616–622 (2005)

[217] Kajita, S., Nagasaki, T., Yokoi, K., Kaneko, K., Tanie, K.: Running pattern generation for a humanoid robot. In: IEEE International Conference on Robotics and Automation (ICRA 2002), vol. 3, pp. 2755–2761 (2002)

[218] Kajita, S., Tani, K.: Study of dynamic biped locomotion on rugged terrain - derivation and application of the linear inverted pendulum mode. In: Proceedings 1991 IEEE International Conference on Robotics and Automation, Sacramento, California, USA, pp. 1405–1411 (1991)

[219] Kanda, T., Miyashita, T., Osada, T., Haikawa, Y., Ishiguro, H.: Analysis of humanoid appearances in human-robot interaction. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), pp. 899–906 (2005)

[220] Kanehira, N., Kawasaki, T., Ohta, S., Ismumi, T., Kawada, T., Kanehiro, F., Kajita, S., Kaneko, K.: Design and experiments of advanced leg module (HRP-2L) for humanoid robot (HRP-2) development. In: IEEE/RSJ International Conference on Intelligent Robots and System (IROS 2002), vol. 3, pp. 2455–2460 (2002)

[221] Kanehiro, F., Hirukawa, H., Kajita, S.: OpenHRP: Open architecture humanoid robotics platform. The International Journal of Robotics Research 23(2), 155–165 (2004)

[222] Kanehiro, F., Hirukawa, H., Kaneko, K., Kajita, S., Fujiwara, K., Harada, K., Yokoi, K.: Locomotion planning of humanoid robots to pass through narrow spaces. In: IEEE International Conference on Robotics and Automation (ICRA 2004), vol. 1, pp. 604–609 (2004)

[223] Kaneko, K., Harada, K., Kanehiro, F., Miyamori, G., Akachi, K.: Humanoid robot hrp-3. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2008), pp. 2471–2478 (2008)

[224] Kaneko, K., Kanehiro, F., Kajita, S., Hirukawa, H., Kawasaki, T., Hirata, M., Akachi, K., Isozumi, T.: Humanoid robot hrp-2. In: IEEE International Conference on Robotics and Automation (ICRA 2004), vol. 2, pp. 1083–1090 (2004)

[225] Kaneko, K., Kanehiro, F., Kajita, S., Morisawa, M., Fujiwara, K., Harada, K., Hirukawa, H.: Slip observer for walking on a low friction floor. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), pp. 634–640 (2005)

[226] Kaneko, K., Kanehiro, F., Kajita, S., Morisawa, M., Fujiwara, K., Harada, K., Hirukawa, H.: Motion suspension system for humanoids in case of emergency real-time motion generation and judgment to suspend humanoid. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 5496–5501 (2006)

[227] Kaneko, K., Kanehiro, F., Morisawa, M., Miura, K., Nakaoka, S., Kajita, S.: Cybernetic human hrp-4c. In: IEEE-RAS International Conference on Humanoid Robots (Humanoids 2009), pp. 7–14 (2009)

[228] Kanzaki, S., Okada, K., Inaba, M.: Bracing behavior in humanoid through preview control of impact disturbance. In: IEEE-RAS International Conference on Humanoid Robots, pp. 301–306 (2005)

[229] Katayama, T., Itoh, T., Ogawa, M., Yamamoto, H.: Optimal tracking control of a heat exchanger with change in load condition. In: Proceedings of the 29th IEEE Conference on Decision and Control, vol. 3, pp. 1584–1589 (1990)

[230] Katayama, T., Ohki, T., Inoue, T., Kato, T.: Design of an optimal controller for a discrete time system subject to previewable demand. Int. J. Control 41, 677–699 (1985)

[231] Kato, I.: Development of WABOT 1. Biomechanism 2, 173–214 (1973)

[232] Kato, I., Mori, Y., Masuda, T.: Pneumatically powered artificial legs walking automatically under various circumstances. In: Proceedings of the 4th International Conference on External Control of Human Extremities, pp. 458–470 (1972)

[233] Kawamoto, H., Sankai, Y.: Power assist method based on phase sequence and muscle force condition for hal. Journal Advanced Robotics 19(7), 717–734 (2005)

[234] Kawamura, S., Yamamoto, T., Ishida, D., Ogata, T., Nakayama, Y., Tabata, O., Sugiyama, S.: Development of passive elements with variable mechanical impedance for wearable robots. In: IEEE International Conference on Robotics and Automation (ICRA 2002), vol. 1, pp. 248–253 (2002)

[235] Kazerooni, H., Steger, R., Huang, L.: Hybrid control of the berkeley lower extremity exoskeleton (bleex). The International Journal of Robotics Research 25, 561–573 (2006)

[236] Kearney, R., Hunter, I.: System identification of human joint dynamics. Critical reviews in biomedical engineering 18(1), 55–87 (1990)

[237] Kerscher, T., Albiez, J., Zoellner, J.M., Dillmann, R.: Biomechanical inspired control for elastic legs. In: International conference on Climbing and Walking Robots (CLAWAR 2006), pp. 592–597 (2006)

[238] Kho, J.W., Lim, D.C., Kuc, T.Y.: Implementation of an intelligent controller for biped walking robot using genetic algorithm. In: IEEE International Symposium on Industrial Electronics, pp. 49–54 (2006)

[239] Khraief, N., M'Sirdi, N., Spong, M.: Nearly passive dynamic walking of a biped robot. In: European Control Conference (2003)

[240] Kikuuwe, R., Fujimoto, H.: Proxy-based sliding mode control for accurate and safe position control. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 25–30 (2006)

[241] Kim, J.H., Oh, J.H.: Walking control of the humanoid platform khr-1 based on torque feedback control. In: IEEE International Conference on Robotics and Automation (ICRA 2004), vol. 1, pp. 623–628 (2004)

[242] Kim, J.Y., Park, I.W., Lee, J., Kim, M.S., Cho, B.K., Oh, J.H.: System design and dynamic walking of humanoid robot KHR-2. In: IEEE International Conference on Robotics & Automation (ICRA 2005), pp. 1443–1448 (2005)

[243] Kingsley, D.A., Quinn, R.D., Ritzmann, R.E.: A cockroach inspired robot with artificial muscles. In: Proceedings of the International Symposium on Adaptive Motion of Animal and Machines, Kyoto, Japan (2003)

[244] Komatsu, T., Usui, M.: Dynamic walking and running of a bipedal robot using hybrid central pattern generator method. In: IEEE International Conference Mechatronics and Automation (ICMA 2005), vol. 2, pp. 987–992 (2005)

[245] Komi, P., Fukashiro, S., Jarvinen, M.: Biomechanical loading of achilles tendon during normal locomotion. Clinics in sports medicine 11(3), 521–531 (1992)

[246] Komura, T., Leung, H., Kudoh, S., Kuffner, J.: A feedback controller for biped humanoids that can counteract large perturbations during gait. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 1989–1995 (2005)

[247] Konczak, J.: On the notion of motor primitives in humans and robots. In: International Workshop on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems, pp. 47–53 (2005)

[248] Kram, R., Domingo, A., Ferris, D.: Effect of reduced gravity on the preferred walk-run transition speed. Journal of Experimental Biology 200, 821–826 (1997)

[249] Krishna, M., Bares, J., Mutschler, E.: Tethering system design for dante II. In: IEEE International Conference on Robotics and Automation (ICRA 1997), vol. 2, pp. 1100–1105 (1997)

[250] Kudoh, S., Komura, T.: C2 continuous gait-pattern generation for biped robots. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003), vol. 2, pp. 1135–1140 (2003)

[251] Kuitunen, S., Komi, P., Kyrolainen, H.: Knee and ankle joint stiffness in sprint running. Medicine & Science in Sports & Exercise 34(1), 166–173 (2002)

[252] Kuo, A.D., Donelan, J.M., Ruina, A.: Energetic consequences of walking like an inverted pendulum: step-to-step transitions. Exercise and sport sciences reviews 33(2), 88–97 (2005)

[253] Kurazume, R., Tanaka, S., Yamashita, M., Hasegawa, T.: Straight legged walking of a biped robot. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), pp. 3095–3101 (2005)

[254] Kuroki, Y., Blank, B., Mikami, T., Mayeux, P., Miyamoto, A., Playter, R., Nagasaka, K., Raibert, M., Nagano, M., Yamaguchi, J.: Motion creating system for a small biped entertainment robot. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003), vol. 2, pp. 1394–1399 (2003)

[255] Kuroki, Y., Fujita, M., Ishida, T., Nagasaka, K., Yamaguchi, J.: A small biped entertainment robot exploring attractive applications. In: IEEE International Conference on Robotics and Automation (ICRA 2003), vol. 1, pp. 471–476 (2003)

[256] Kurzweil, R.: The Age of Intelligent Machines. The MIT Press, Cambridge (1990)

[257] Kusuda, Y.: The humanoid robot scene in japan. Industrial Robot 29(5), 412–419 (2002)

[258] Kusuda, Y.: How japan sees the robotics for the future: observation at the world expo 2005. Industrial Robot 33(1), 11–18 (2006)

[259] Lee, J.: Developement of a human-riding humanoid robot HUBO FX-1. In: SICE - ICASE International Joint Conference 2006 (2006)

[260] Lee, S.H., Song, J.B.: Acceleration estimator for low-velocity and low-accelerationregions based on encoder position data. IEEE/ASME Transactions on Mechatronics 6(1), 58–64 (2001)

[261] Liu, Q., Huang, Q., Zhang, W., Wang, X., Wu, C., Li, D., Li, K.: Manipulation of a humanoid robot by teleoperation. In: Fifth World Congress on Intelligent Control and Automation (WCICA 2004), vol. 6, pp. 4894–4898 (2004)

[262] Cabas, L.M., Torre, S., Cabas, R., Kaynov, D., Arbulú, M., Staroverov, P., Balaguer, C.: Mechanical design and dynamic analysis of the humanoid robot Rh-0. In: International Conference on Climbing and Walking Robots, CLAWAR 2005 (2005)

[263] Löffler, K., Geinger, M., Pfeiffer, F.: Sensors and control concept of walking ”johnnie”. The International Journal of Robotics Research 22(3-4), 229–239 (2003)

[264] Loffler, K., Gienger, M., Pfeiffer, F.: Sensor and control design of a dynamically stable biped robot. In: IEEE International Conference on Robotics and Automation (ICRA 2003), vol. 1, pp. 484–490 (2003)

[265] Loffler, K., Gienger, M., Pfeiffer, F., Ulbrich, H.: Sensors and control concept of a biped robot. IEEE Transactions on Industrial Electronics 51(5), 972–980 (2004)

[266] Lohmeier, S., Buschmann, T., Ulbrich, H., Pfeiffer, F.: Modular joint design for performance enhanced humanoid robot LOLA. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 88–93 (2004)

[267] Lohmeier, S., Buschmann, T., Ulbrich, H., Pfeiffer, F.: Modular joint design for performance enhanced humanoid robot LOLA. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 88–93 (2006)

[268] Lorch, O., Albert, A., Denk, J., Gerecke, M., Cupec, R., Seara, J., Gerth, W., Schmidt, G.: Experiments in vision-guided biped walking. In: IEEE/RSJ International Conference on Intelligent Robots and System (IROS 2002), vol. 3, pp. 2484–2490 (2002)

[269] Manoonpong, P., Geng, T., Wörgötter, F.: Exploring the dynamic walking range of the biped robot RunBot with an active upper-body component. In: IEEE-RAS International Conference on Humanoid Robots, pp. 418–424 (2006)

[270] Mao, Y., Wang, J., Jia, P., Li, S., Qiu, Z., Zhang, L., Han, Z.: A reinforcement learning based dynamic walking control. In: IEEE International Conference on Robotics and Automation, ICRA 2007 (2007)

[271] Mao, Y., Wang, J., Li, S., Han, Z.: Energy-efficient control of pneumatic muscle actuated biped robot joints. In: 6th World Congress on Intelligent Control and Automation, pp. 8881–8885 (2006)

[272] Matsubara, T., Morimoto, J., Nakanishi, J., Aki Sato, M., Doya, K.: Learning CPG-based biped locomotion with a policy gradient method. Robotics and Autonomous Systems 54(11), 911–920 (2006)

[273] Matsui, T., Hirukawa, H., Ishikawa, Y., Yamasaki, N., Kagami, S., Kanehiro, F., Saito, H., Inamura, T.: Distributed real-time processing for humanoid robots. In: IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA 2005), pp. 205–210 (2005)

[274] McGeer, T.: Powered flight, child's play, silly wheels, and walking machines. In: IEEE International Conference on Robotics and Automation (ICRA 1989), pp. 1592–1597 (1989)

[275] McGeer, T.: Passive bipedal running. Proceedings Royal Society of London: Biological Sciences, 107–134 (1990)

[276] McGhee, R.B., Frank, A.A.: On the stability properties of quadruped creeping gaits. Journal of Mathematic Biosciences 3, 331–351 (1968)

[277] McMahon, T.A., Valiant, G., Frederick, E.C.: Groucho running. Journal of Applied Physiology 62(6), 2326–2337 (1987)

[278] Merlin Systems Corp. Ltd.: Flow-Controlled Air Muscle Datasheet v1.0

[279] Metta, G., Fitzpatrick, P., Natale, L.: YARP: yet another robot platform. International Journal on Advanced Robotics Systems 3(1), 43–48 (2006)

[280] Mianzo, L., Peng, H.: Lq and h_∞ preview control for a durability simulator. In: Proceedings of the American Control Conference, vol. 1, pp. 699–703 (1997)

[281] Mianzo, L., Peng, H.: A unified framework for LQ and H_∞ preview control algorithms. In: Proceedings of the 37th IEEE Conference on Decision and Control, vol. 3, pp. 2816–2821 (1998)

[282] Michel, P., Chestnutt, J., Kuffner, J., Kanade, T.: Vision-guided humanoid footstep planning for dynamic environments. In: IEEE-RAS International Conference on Humanoid Robots, pp. 13–18 (2005)

[283] Migliore, S.A., Brown, E.A., DeWeerth, S.P.: Biologically inspired joint stiffness control. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 4519–4524 (2005)

[284] Minato, T., Shimada, M., Itakura, S., Lee, K., Ishiguro, H.: Does gaze reveal the human likeness of an android? In: The 4nd International Conference on Development and Learning, pp. 106–111 (2005)

[285] Mita, T., Yamaguchi, T., Kashiwase, T., Kawase, T.: Realization of a high speed biped using modern control theory. International Journal of Control 40(1), 107–119 (1984)

[286] Mitobe, K., Capi, G., Nasu, Y.: A new control method for walking robots based on angular momentum. Mechatronics 14, 163–174 (2004)

[287] Miwa, H., Itoh, K., Matsumoto, M., Zecca, M., Takanobu, H., Roccella, S., Carrozza, M., Dario, P., Takanishi, A.: Effective emotional expressions with emotion expression humanoid robot WE-4RII. In: IEEE/RSJ International Conference on Intelligent RObots and Systems (IROS 2004), pp. 2203–2208 (2004)

[288] Miyakoshi, S., Taga, G., Kuniyoshi, Y., Nagakubo, A.: Three dimensional bipedal stepping motion using neural oscillators-towards humanoid motion in the real world. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 1998), vol. 1, pp. 84–89 (1998)

[289] Morimoto, J., Endo, G., Nakanishi, J., Hyon, S., Cheng, G., Bentivegna, D., Atkeson, C.: Modulation of simple sinusoidal patterns by a coupled oscillator model for biped walking. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 1579–1584 (2006)

[290] Morisawa, M., Kajita, S., Harada, K., Fujiwara, K., Kanehiro, F., Kaneko, K., Hirukawa, H.: Emergency stop algorithm for walking humanoid robots. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), pp. 2109–2115 (2005)

[291] Morisawa, M., Kajita, S., Kaneko, K., Harada, K., Kanehiro, F., Fujiwara, K., Hirukawa, H.: Pattern generation of biped walking constrained on parametric surface. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 2405–2410 (2005)

[292] Morita, T., Sugano, S.: Development of a new robot joint using a mechanical impedance adjuster. In: IEEE International Conference on Robotics and Automation (ICRA 1995), vol. 3, pp. 2469–2475 (1995)

[293] Morris, B., Westervelt, E., Chevallereau, C., Buche, G., Grizzle, J.W.: Achieving bipedal running with rabbit: six steps towards infinity. In: Fast Motions in Biomechanics and Robotics, Heidelberg, Allemagne (2005)

[294] Nadjar-Gauthier, N., Cherrid, H., Cadiou, J.C.: A new second order sliding mode control for the experimental walking of an electro-pneumatic biped robot. In: Proceedings of the 5th International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines, Paris, France, pp. 93–100 (2002)

[295] Nagasaka, K., Inaba, M., Inoue, H.: Stabilization of dynamic walk on a humanoid using torso position compliance control. In: Proceedings of 17th Annual Conference on Robotics Society of Japan, pp. 1193–1194 (1999) (in Japanese)

[296] Nakanishi, J., Morimoto, J., Endo, G., Cheng, G., Schaal, S., Kawato, M.: learning from demonstration and adaptation of biped locomotion. Robotics and Autonomous Systems 47(2-3), 79–91 (2004)

[297] Napoleon, N.S., Sampei, M.: Balance control analysis of humanoid robot based on zmp feedback control. In: IEEE/RSJ International Conference on Intelligent Robots and System (IROS 2002), vol. 3, pp. 2437–2442 (2002)

[298] Nishiwaki, K., Kagami, S.: High frequency walking pattern generation based on preview control of ZMP. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 2667–2672 (2006)

[299] Nishiwaki, K., Kagami, S., Kuniyoshi, Y., Inaba, M., Inoue, H.: Online generation of humanoid walking motion based on a fast generation method of motion pattern that follows desired ZMP. In: IEEE/RSJ International Conference on Intelligent Robots and System (IROS 2002), vol. 3, pp. 2684–2689 (2002)

[300] Nishiwaki, K., Kagami, S., Kuniyoski, Y., Inaba, M., Inoue, H.: Toe joints that enhance bipedal and fullbody motion of humanoid robots. In: IEEE International Conference on Robotics and Automation (ICRA 2002), pp. 3105–3110 (2002)

[301] Nishiwaki, K., Sugihara, T., Kagami, S., Kanehiro, F., Inaba, M., Inoue, H.: Design and development of research platform for perception-actionintegration in humanoid robot: H6. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2000), pp. 1559–1564 (2000)

[302] Nonami, K.: Development of mine detection robot COMET-II and COMET-III. In: Proceedings of the 41st SICE Annual Conference (SICE 2002), vol. 1, pp. 346–351 (2002)

[303] Nonami, K., Ikedo, Y.: Walking control of COMET-III using discrete time preview sliding mode controller. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), vol. 4, pp. 3219–3225 (2004)

[304] Nunez, V., Nadjar-Gauthier, N.: Humanoid vertical jump with compliant contact. In: International Conference on Climbing and Walking Robots (CLAWAR 2005), pp. 457–464 (2005)

[305] Ogura, Y., Aikawa, H., Shimomura, K., Kondo, H., Morishima, A., Lim, H.-O., Takanishi, A.: Development of a new humanoid robot WABIAN-2. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 76–81 (2006)

[306] Ogura, Y., Lim, H.-o., Takanishi, A.: Stretch walking pattern generation for a biped humanoid robot. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003), vol. 1, pp. 352–357 (2003)

[307] Ogura, Y., Kataoka, T., Aikawa, H., Shimomura, K., Lim, H.-o., Takanishi, A.: Evaluation of various walking patterns of biped humanoid robot. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 603–608 (2005)

[308] Ogura, Y., Kataoka, T., Shimomura, K., Lim, H.-O., Takanishi, A.: A novel method of biped walking pattern generation with predetermined knee joint motion. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), vol. 3, pp. 2831–2836 (2004)

[309] Ogura, Y., Shimomura, K., Kondo, H., Morishima, A., Okubo, T., Momoki, S., Lim, H.-O., Takanishi, A.: Human-like walking with knee stretched, heel-contact and toe-off motion by a humanoid robot. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 3976–3981 (2006)

[310] Oh, J.H., Hanson, D., Kim, W.S., Han, I.Y., Kim, J.Y., Park, I.W.: Design of android type humanoid robot Albert HUBO. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 1428–1433 (2006)

[311] Oh, Y., Choi, Y., You, B.J., Oh, S.R.: Development of a biped humanoid robot: BabyBot. In: International Conference on Mechatronics and Information Technology (ICMIT 2003), pp. 690–695 (2003)

[312] Okada, K., Ogura, T., Haneda, A., Inaba, M.: Autonomous 3D walking system for a humanoid robot based on visual step recognition and 3D foot step planner. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 623–628 (2005)

[313] Okumura, Y., Tawara, T., Endo, K., Furuta, T., Shimizu, M.: Realtime ZMP compensation for biped walking robot using adaptive inertia force control. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003), vol. 1, pp. 335–339 (2003)

[314] Olaru, I., Krut, S., Pierrot, F.: Novel Mechanical Design of Biped Robot SHERPA Using 2 DOF Cable Differential Modular Joints. In: IEEE/RSJ International Conference on Intelligent RObots and Systems (IROS 200), pp. 4463–4468 (2009)

[315] Ono, K., Liu, R.: Optimal biped walking locomotion solved by trajectory planning method. Transactions of the ASME Journal of Dynamic Systems, Measurement and Control 124, 554–565 (2002)

[316] Park, I.W., Kim, J.Y., Lee, J., Oh, J.H.: Mechanical design of humanoid robot platform KHR-3 (KAIST humanoid robot - 3: HUBO). In: IEEE-RAS International Conference on Humanoid Robots, pp. 321–326 (2005)

[317] Park, I.W., Kim, J.Y., Lee, J., Oh, J.H.: Online free walking trajectory generation for biped humanoid robot KHR-3(HUBO). In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 1231–1236 (2006)

[318] Park, I.W., Kim, J.Y., Park, S.W., Oh, J.H.: Development of humanoid robot platform KHR-2 (KAIST humanoid robot-2). In: IEEE-RAS International Conference on Humanoid Robots, vol. 1, pp. 292–310 (2004)

[319] Park, J.: Fuzzy-logic zero-moment-point trajectory generation for reduced trunk motions of biped robots. Fuzzy Sets and Systems 134(1), 189–203 (2003)

[320] Park, J., Kim, K.: Biped robot walking using gravity-compensated inverted pendulum mode and computed torque control. In: IEEE International Conference on Robotics and Automation (ICRA 1998), vol. 4, pp. 3528–3533 (1998)

[321] Park, J., Rhee, Y.: ZMP trajectory generation for reduced trunk motions of biped robots. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 1998), vol. 1, pp. 90–95 (1998)

[322] Park, J.H., Cho, H.C.: An online trajectory modifier for the base link of biped robots to enhance locomotion stability. In: IEEE International Conference on Robotics and Automation (ICRA 2000), vol. 4, pp. 3353–3358 (2000)

[323] Park, J.H., Chung, H.: ZMP compensation by online trajectory generation for biped robots. In: IEEE International Conference on Systems, Man, and Cybernetics (SMC 1999), vol. 4, pp. 960–965 (1999)

[324] Park, N.C., Yang, H.S., Park, H.W., Park, Y.P.: Position/vibration control of two-degree-of-freedom arms having one flexible link with artificial pneumatic muscle actuators. Robotics and Autonomous Systems 40(15), 239–253 (2002)

[325] Paynter, H.M.: Hyperboloid of revolution fluid-driven tension actuators and methods of making. US Patent No. 4 721 030 (1988)

[326] Peng, Z., Huang, Q., Zhao, X., Xiao, T., Li, K.: Online trajectory generation based on off-line trajectory for biped humanoid. In: IEEE International Conference on Robotics and Biomimetics (ROBIO 2004), pp. 752–756 (2004)

[327] Pfeiffer, F., Lffler, K., Gienger, M.: Humanoid robots. In: International Conference on Climbing and Walking Robots (CLAWAR 2003), pp. 505–516 (2003)

[328] Pfeiffer, F., Loffler, K., Gienger, M.: The concept of jogging johnnie. In: IEEE International Conference on Robotics and Automation (ICRA 2002), vol. 3, pp. 3129–3135 (2002)

[329] Playter, R., Raibert, M.: Control of a biped somersault in 3D. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 1992), Raleigh, NC, USA, pp. 582–589 (1992)

[330] Plestan, F., Grizzle, J., Westervelt, E., Abba, G.: Stable walking of a 7-dof biped robot. IEEE Transactions on Robotics and Automation 19(4), 653–668 (2003)

[331] Pratt, G.: Legged robots at mit: what's new since raibert? IEEE Robotics & Automation Magazine 7(3), 15–19 (2000)

[332] Pratt, G., Williamson, M.M., Dilworth, P., Pratt, J., Wright, A.: Stiffness isn't everything. In: International Symposium on Experimental Robotics (ISER 1995), Stanford, California, pp. 253–262 (1995)

[333] Pratt, G.A., Williamson, M.M.: Series elastic actuators. In: IEEE International Workshop on Intelligent Robots and Systems (IROS 1995), Pittsburg, USA, pp. 399–406 (1995)

[334] Pratt, J.: Virtual model control of a biped walking robot. Master's thesis, Massachusetts Institute of Technology (1995)

[335] Pratt, J.: Exploiting inherent robustness and natural dynamics in the control of bipedal walking robots. Ph.D. thesis, Massachusetts Institute of Technology (2000)

[336] Pratt, J., Carff, J., Drakunov, S., Goswami, A.: Capture point: A step toward humanoid push recovery. In: IEEE-RAS International Conference on Humanoid Robots, pp. 200–207 (2006)

[337] Pratt, J., Chew, C.M., Torres, A., Dilworth, P., Pratt, G.: Virtual model control: An intuitive approach for bipedal locomotion. The International Journal of Robotics Research 20, 129–143 (2001)

[338] Pratt, J., Krupp, B.: Design of a bipedal walking robot. In: Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, vol. 6962, p. 44 (2008)

[339] Quinn, R.D., Nelson, G., Bachmann, R., Kingsley, D., Offi, J., Ritzmann, R.E.: Insect designs for improved robot mobility. In: International Conference on Climbing and Walking Robots (CLAWAR 2001), pp. 69–76 (2001)

[340] Raibert, M.: Legged robots. Communications of the ACM 29, 499–514 (1986)

[341] Raibert, M.: Legged Robots That Balance. MIT Press, Cambridge (1986)

[342] Raibert, M.: Running with symmetry. International Journal of Robotics Research 5(4), 45–61 (1986)

[343] Raibert, M., Brown, H.J.: Experiments in balance with a 2D one-legged hopping machine. Journal of Dynamic Systems, Measurement and Control 106, 75–81 (1984)

[344] Raibert, M., Brown, H.J., Chepponis, M.: Experiments in balance with a 3D one-legged hopping machine. International Journal of Robotics Research 3(2), 75–92 (1984)

[345] Raibert, M., Chepponis Jr., M.H.B.: Running on four legs as though they were one. IEEE Transactions on Robotics and Automation 2(2), 70–82 (1986)

[346] Rao, C., Mitra, S.: Generalized Inverse of Matrices and its Applications. John Wiley & Sons, Inc., New York (1971)

[347] Rebula, J., Canas, F., Pratt, J., Goswami, A.: Learning capture points for humanoid push recovery. In: IEEE/RAS International Conference on Humanoid Robots (Humanoids 2007), pp. 65–72. Citeseer (2007)

[348] Ridderström, C.: Legged locomotion control - a literature study. Tech. rep., Mechatronics Lab, Department of Machine Design, Royal Institute of technology, Stockholm, Sweden (1999)

[349] Ridderström, C.: Legged locomotion control - a literature study. Tech. Rep. 27, Mechatronics Lab, Departement of Machine Design, Royal Institute of Technology, Stockholm, Sweden (1999)

[350] Righetti, L., Ijspeert, A.J.: programmable central pattern generators: an application to biped locomotion control. In: IEEE International Conference on Robotics and Automation (ICRA 2006), pp. 1585–1590 (2006)

[351] Ritter, H., Haschke, R., Koiva, R., Rothling, F., Steil, J.: A layered control architecture for imitation grasping with a 20-DOF pneumatic anthropomorphic hand. Internal report University of Bielefeld (2005)

[352] Rose, J., Gamble, J.: Human walking. Lippincott Williams & Wilkins (2006)

[353] Rosheim, M.E.: Leonardo's Lost Robots. Springer, Heidelberg (2006)

[354] Sabourin, C., Bruneau, O., Buche, G.: Control strategy for the robust dynamic walk of a biped robot. The International Journal of Robotics Research 25(9), 843–860 (2006)

[355] Sakagami, Y., Watanabe, R., Aoyama, C., Matsunaga, S., Higaki, N., Fujimura, K.: The intelligent asimo: System overview and integration. In: IEEE/RSJ International Conference on Intelligent Robots and System (IROS 2002), vol. 3, pp. 2478–2483 (2002)

[356] Sakka, S., Yokoi, K.: Humanoid vertical jumping based on force feedback and inertial forces optimization. In: IEEE International Conference on Robotics and Automation (ICRA 2005), pp. 3752–3757 (2005)

[357] Saldien, J., Goris, K., Yilmazyildiz, S., Verhelst, W., Lefeber, D.: On the design of the huggable robot probo. Journal of Physical Agents 2(2) (2008)

[358] Sandini, G., Metta, G., Vernon, D.: RobotCub: an open framework for research in embodied cognition. In: IEEE-RAS International Conference on Humanoid Robots, vol. 1, pp. 13–32 (2005)

[359] Schaal, S., Peters, J., Nakanishi, J., Ijspeert, A.: Learning movement primitives. In: International Symposium on Robotics Research (ISRR 2003). Springer, Heidelberg (2004)

[360] Schroder, J., Erol, D., Kawamura, K., Dillman, R.: Dynamic pneumatic actuator model for a model-based torque controller. In: IEEE International Symposium on Computational Intelligence in Robotics and Automation (CIRA 2003), vol. 1, pp. 342–347 (2003)

[361] Schuitema, E., Hobbelen, D., Jonker, P., Wisse, M., Karssen, J.: Using a controller based on reinforcement learning for a passive dynamic walking robot. In: IEEE-RAS International Conference on Humanoid Robots, pp. 232–237 (2005)

[362] Schuitema, E., Hobbelen, D., Jonker, P., Wisse, M., Karssen, J.: Using a controller based on reinforcement learning for a passive dynamic walking robot. In: IEEE-RAS International Conference on Humanoid Robots, pp. 232–237 (2005)

[363] Seara, J.F., Strobl, K.H., Schmidt, G.: Path-Dependent Gaze Control for Obstacle Avoidance in Vision Guided Humanoid Walking. In: IEEE International Conference on Robotics and Automation (ICRA 2003), Taipei, Taiwan, vol. 1, pp. 887–892 (2003)

[364] Seilacher, A.: Arbeitskonzept zur konstruktionsmorphologie. Lethaia 3, 393–396 (1970)

[365] Seilacher, A.: Self-organizing mechanisms in morphogenesis and evolution. In: Constructional Morphology and Evolution, pp. 251–271. Springer, Heidelberg (1991)

[366] Sekiguchi, A., Atobe, Y., Kameta, K., Tsumaki, Y., Nenchev, D.N.: A walking pattern generator around singularity. In: IEEE-RAS International Conference on Humanoid Robots, pp. 270–275 (2006)

[367] Sellaouti, R., Stasse, O., Kajita, S., Yokoi, K., Kheddar, A.: Faster and smoother walking of humanoid HRP-2 with passive toe joints. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 4909–4914 (2006)

[368] Shan, J., Nagashima, F.: Neural locomotion controller design and implementation for humanoid robot HOAP-1. In: Annual Conference of the Robotics Society of Japan (2002)

[369] Sheridan, T.: Three models of preview control. IEEE Transaction on Human Factors in Electronics HFE 7(2), 91–102 (1966)

[370] Shih, C.L.: Gait synthesis for the SD-2 biped robot to climb stairs. Robotica 15, 599–607 (1997)

[371] Shih, C.L., Gruver, W.: Control of a biped robot in the double-support phase. IEEE Transactions on Systems, Man and Cybernetics 22(4), 729–735 (1992)

[372] Slatter, R., Koenen, H.: Lightweight harmonic drive gears for service robots. Harmonic Drive AG

[373] Slotine, J.J.E., Li, W.: Applied Nonlinear Control. Prentice-Hall, Cambridge (1991)

[374] Song, S.M., Waldron, K.: Machines That Walk: The Adaptive Suspension Vehicle. MIT Press, Cambridge (1989)

[375] Spampinato, G., Muscato, G.: DIEES biped robot: A bio-inspired pneumatic platform for human locomotion analysis and stiffness control. In: IEEE-RAS International Conference on Humanoid Robots, pp. 478–483 (2006)

[376] Spong, M., Vidyasagar, M.: Robot Dynamics and Control. John Wiley and Sons, Inc., Chichester (1989)

[377] Stankevich, L.A.: Intellectual robots in russia: experience of development and robocup participation. In: SPECOM 2004, pp. 615–620 (2004)

[378] Stasse, O., Verrelst, B., Davison, A., Mansard, N., Vanderborght, B., Esteves, C., Saidi, F., Yokoi, K.: Integrating vision and walking to increase humanoid autonomy. In: IEEE International Conference on Robotics and Automation (ICRA 2007), Roma, Italia, pp. 2272–2273 (2007)

[379] Stasse, O., Verrelst, B., Vanderborght, B., Yokoi, K.: Dynamically walking over large obstacles by a humanoid robot. IEEE Transactions on Robotics 25(4), 960–967 (2009)

[380] Stilman, M., Kuffner, J.: Navigation among movable obstacles: Real-time reasoning in complex environments. International Journal of Humanoid Robotics 2(4), 479–504 (2005)

[381] Microsoft Robotics Studio, `http://msdn.microsoft.com/robotics`

[382] Sugahara, Y., Ohta, A., Hashimoto, K., Sunazuka, H., Kawase, M., Tanaka, C., Lim, H.-O., Takanishi, A.: Walking up and down stairs carrying a human by a biped locomotor with parallel mechanism. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), pp. 1489–1494 (2005)

[383] Sugihara, T., Nakamura, Y., Inoue, H.: Realtime humanoid motion generation through ZMP manipulation based on inverted pendulum control. In: IEEE International Conference on Robotics and Automation, ICRA 2002 (2002)

[384] Sulzer, J., Peshkin, M., Patton, J.: MARIONET: An exotendon-driven, rotary series elastic actuator for exerting joint torque. In: International Conference on Robotics for Rehabilitation (ICORR 2005), pp. 103–108 (2005)

[385] Swevers, J., Ganseman, C., Tukel, D., de Schutter, J., Van Brussel, H.: Optimal robot excitation and identification. IEEE Transactions on Robotics and Automation 13(5), 730–740 (1997)

[386] Tabata, O., Konishi, S., Cusin, P., Ito, Y., Kawai, F., Hirai, S., Kawamura, S.: Microfabricated tunable bending stiffness device. In: The Thirteenth Annual International Conference on Micro Electro Mechanical Systems (MEMS 2000), pp. 23–27 (2000)

[387] Taga, G.: A model of the neuro-musculo-skeletal system for human locomotion i: Emergence of basic gait. Biological Cybernetics 73(2), 97–111 (1995)

[388] Taga, G.: A model of the neuro-musculo-skeletal system for human locomotion II: Real-time adaptabilty under various constraints. Biological Cybernetics 73(2), 113–121 (1995)

[389] Taga, G., Yamaguchi, Y., Shimizu, H.: Self-organized control of bipedal locomotion by neural oscillators in unpredictable environment. Biological Cybernetics 65, 147–159 (1991)

[390] Tajima, D., Honda, D., Suga, K.: Fast Running Experiments Involving a Humanoid Robot. In: IEEE International Conference on Robotics and Automation (ICRA 2009), pp. 1571–1576 (2009)

[391] Tajima, R., Suga, K.: Motion having a flight phase: Experiments involving a one-legged robot. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 1726–1731 (2006)

[392] Takaba, K.: A tutorial on preview control systems. In: SICE 2003 Annual Conference, vol. 2, pp. 1388–1393 (2003)

[393] Takahashi, T., Kawamura, A.: Posture control using foot toe and sole for biped walking robot ”ken”. In: International Workshop on Advanced Motion Control, pp. 437–442 (2002)

[394] Takanishi, A., Ogura, Y., Itoh, K.: Some issues in humanoid robot design. In: International Symposium of Robotics Research, ISRR 2005 (2005)

[395] Takuma, T., Hosoda, K., Ogino, M., Asada, M.: Controlling walking period of a pneumatic muscle walker. In: International Conference on Climbing and Walking Robots (CLAWAR 2004), pp. 757–764 (2004)

[396] Takuma, T., Hosoda, K., Ogino, M., Asada, M.: Stabilization of quasi-passive pneumatic muscle walker. In: IEEE-RAS International Conference on Humanoid Robots, pp. 627–639 (2004)

[397] Tanaka, T., Takubo, T., Inoue, K., Arai, T.: Emergent stop for humanoid robots. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 3970–3975 (2006)

[398] Tang, Z., Zhou, C., Sun, Z.: Balance of penalty kicking for a biped robot. In: IEEE Conference on Robotics, Automation and Mechatronics, vol. 1, pp. 336–340 (2004)

[399] Tawara, T., Okumura, Y., Furuta, T., Shimizu, M., Shimomura, M., Endo, K., Kitano, H.: Morph: A desktop-class humanoid capable of acrobatic behavior. The International Journal of Robotics Research 23, 1097–1103 (2004)

[400] Tedrake, R.L.: Applied optimal control for dynamically stable legged locomotion. Ph.D. thesis, MIT (2004)

[401] Tellez, R., Ferro, F., Garcia, S., Gomez, E., Jorge, E., Mora, D., Pinyol, D., Oliver, J., Torres, O., Velazquez, J.: et al.: Reem-B: An autonomous lightweight human-size humanoid robot. In: IEEE-RAS International Conference on Humanoid Robots (Humanoids 2008), pp. 462–468 (2008)

[402] Tomizuka, M., Rosenthal, D.: On the optimal digital state feedback controller with integral and preview actions. Transactions of ASME, Journal of Dynamic Systems, Measurement and Control 101, 172–178 (1979)

[403] Tsagarakis, N., Sinclair, M., Becchi, F., Metta, G., Sandini, G., Caldwell, D.G.: Lower body design of the iCub a human-baby like crawling robot. In: IEEE-RAS International Conference on Humanoid Robots, pp. 450–455 (2006)

[404] Tsusaka, Y., Ota, Y.: Wire-driven bipedal robot. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 3958–3963 (2006)

[405] Tzafestas, S., Raibert, M., Tzafestas, C.: Robust sliding-mode control applied to a 5-link biped robot. Journal of Intelligent and Robotic Systems 15, 67–133 (1996)

[406] Ulaby, F.: The Legacy of Moore's Law. Proceedings of the IEEE 94(7), 1251–1252 (2006)

[407] University Archives and Records Center, University of Pennsylvania: Eadweard Muybridge Collection

[408] Utz, H., Sablatnog, S., Enderle, S., Kraetzschmar, G.: Miro - middleware for mobile robot applications. IEEE Transactions on Robotics and Automation 18(4), 493–497 (2002)

[409] Van Damme, M., Beyl, P., Vanderborght, B., Versluys, R., Van Ham, R., Vanderniepen, I., Daerden, F., Lefeber, D.: The safety of a robot actuated by pneumatic muscles - a case study. International Journal of Social Robotics (2010) (accepted for publication)

[410] Van Damme, M., Vanderborght, B., Verrelst, B., Van Ham, R., Daerden, F., Lefeber, D.: Proxy-based sliding mode control of a planar pneumatic manipulator. International Journal of Robotics Research 28(2), 266–284 (2009)

[411] Van Damme, M., Beyl, P., Vanderborght, B., Van Ham, R., Innes, V., Dirk, L.: Modeling hysteresis in pleated pneumatic artificial muscles. In: IEEE International Conferences on Robotics, Automation & Mechatronics (RAM), pp. 471–476 (2008)

[412] Van Ham, R.: Compliant actuation for biologically inspired bipedal walking robots. Ph.D. thesis, Vrije Universiteit Brussel (2006)

[413] Van Ham, R., Thomas, S., Vanderborght, B., Hollander, K., Lefeber, D.: Compliant actuator designs: Review of actuators with passive adjustable compliance/controllable stiffness for robotic applications. IEEE Robotics and Automation Magazine 16(3), 81–94 (2009)

[414] Van Ham, R., Vanderborght, B., Van Damme, M., Verrelst, B., Lefeber, D.: MACCEPA, the Mechanically Adjustable Compliance and Controllable Equilibrium Position Actuator: Design and Implementation in a Biped Robot. Robotics and Autonomous Systems 55(10), 761–768 (2007)

[415] Van Ham, R., Verrelst, B., Daerden, F., Vanderborght, B., Lefeber, D.: Fast and accurate pressure control using on-of valves. International Journal of Fluid Power 6(1), 53–58 (2005)

[416] Vandenhoudt, J.: PWM-sturing van een antagonistisch paar pneumatische artificile spieren. Master's thesis, Vrije Universiteit Brussel (2002)

[417] Vanderborght, B., Tsagarakis, N., Semini, C., Van Ham, R., Caldwell, D.: MACCEPA 2.0: Adjustable Compliant Actuator with Stiffening Characteristic for Energy Efficient Hopping. In: IEEE International Conference on Robotics and Automation (ICRA 2009), pp. 544–549 (2009)

[418] Vanderborght, B., Verrelst, B., Van Ham, R., Van Damme, M., Lefeber, D., Y Duran, M.B., Beyl, P.: Exploiting natural dynamics to reduce energy consumption by controlling the compliance of soft actuators. The International Journal of Robotics Research 25(4), 343–358 (2006)

[419] Vaughan, R., Gerkey, B., Howard, A.: On device abstractions for portable, reusable robot code. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003), vol. 3, pp. 2421–2427 (2003)

[420] Verlinde, P., Acheroy, M., Baudoin, Y.: The belgian humanitarian demining project (hudem) and the european research context. European journal of mechanical and environmental engineering 46(2), 96–98 (2001)

[421] Vermeulen, J.: Trajectory generation for planar hopping and walking robots: An objective parameter and angular momentum approach. Ph.D. thesis, Vrije Universiteit Brussel (2004)

[422] Vermeulen, J., Verrelst, B., Lefeber, D., Kool, P., Vanderborght, B.: A real-time joint trajectory planner for dynamic walking bipeds in the sagittal plane. Robotica 23(6), 669–680 (2005)

[423] Verrelst, B., Stasse, O., Yokoi, K., Vanderborght, B.: Dynamically stepping over obstacles by the humanoid robot HRP-2. In: IEEE-RAS International Conference on Humanoid Robots, pp. 117–123 (2006)

[424] Verrelst, B., Van Ham, R., Vanderborght, B., Daerden, F., Lefeber, D.: The pneumatic biped LUCY actuated with pleated pneumatic artificial muscles. Autonomous Robots 18, 201–213 (2005)

[425] Verrelst, B., Van Ham, R., Vanderborght, B., Lefeber, D., Daerden, F., Van Damme, M.: Second generation pleated pneumatic artificial muscle and its robotic applications. Advanced Robotics 20(7), 783–805 (2006)

[426] Verrelst, B., Vanderborght, B., Stasse, O., Yokoi, K.: Stepping over large obstacles by the humanoid robot hrp-2. In: International Conference on Climbing and Walking Robots (CLAWAR 2006), pp. 747–754 (2006)

[427] Verrelst, B., Vermeulen, J., Vanderborght, B., Van Ham, R., Naudet, J., Lefeber, D., Daerden, F., Van Damme, M.: Motion generation and control for the pneumatic biped lucy. International Journal of Humanoid Robotics 25(4), 343–358 (2006)

[428] Verrelst, B., Yokoi, K., Stasse, O., Arisumi, H., Vanderborght, B.: Mobility of humanoid robots: Stepping over large obstacles dynamically. In: International Conference on Mechatronics and Automation (ICMA 2006), pp. 1072–1079 (2006)

[429] Versluy, R., Lenaerts, G., Van Damme, M., Jonkers, I., Desomer, A., Vanderborght, B.: Successful preliminary walking experiments on a transtibial amputee fitted with a powered prosthesis. Prosthetics and Orthotics International 33(4), 368–377 (2009)

[430] Versluys, R.: Study and development of articulated transtibial prostheses with adaptable compliance and push-off properties. Ph.D. thesis, Vrije Universiteit Brussel (2009)

[431] Versluys, R., Desomer, A., Lenaerts, G., Pareit, O., Vanderborght, B., Perre, G., Peeraer, L., Lefeber, D.: A biomechatronical transtibial prosthesis powered by pleated pneumatic artificial muscles. International Journal of Modelling, Identification and Control 4(4), 394–405 (2008)

[432] Veruggio, G.: The EURON roboethics roadmap. In: IEEE-RAS International Conference on Humanoid Robots, pp. 612–617 (2006)

[433] Visser, L., Carloni, R., Stramigioli, S.: A port-based comparison of variable stiffness actuators. In: IEEE International Conference on Robotics and Automation (ICRA 2010), accepted for publication (2010)

[434] Vukobratovic, M.: Legged Locomotion Robots and Anthropomorphic Mechanisms. Mihailo Pupin Institute, Beograd (1975)

[435] Vukobratovic, M., Borovac, B.: Zero-moment point - thirthy five years of its life. International Journal of Humanoid Robotics 1, 157–173 (2004)

[436] Vukobratovic, M., Borovac, B., Potkonjak, V.: Towards a unified understanding of basic notions and terms in humanoid robotics. Robotica 25(1), 87–101 (2005)

[437] Vukobratovic, M., Stepanenko, J.: On the stability of anthropomorphic systems. Mathematical Biosciences 15, 1–37 (1972)

[438] Wakimoto, S., Suzumori, K., Kanda, T.: Development of intelligent mckibben actuator. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2005), pp. 487–492 (2005)

[439] Walker, R.: Using air muscles for compliant bipedal and many-legged robotics. In: IEE Colloquium on Information Technology for Climbing and Walking Robots, pp. 3/1–3/3 (1996)

[440] Wang, L., Yu, Z., Meng, Q., Zhang, Z.: Influence analysis of toe-joint on biped gaits. In: International Conference on Mechatronics and Automation (ICMA 2007), pp. 1631–1635 (2006)

[441] Whittington, B., Silder, A., Heiderscheit, B., Thelen, D.: Passive elastic joint moments during humand walking. In: Dynamic Walking (2006)

[442] Wieber, P.B.: Trajectory free linear model predictive control for stable walking in the presence of strong perturbations. In: IEEE-RAS International Conference on Humanoid Robots, pp. 137–142 (2006)

[443] Wisse, M.: Essentials of dynamic walking: Analysis and design of two-legged robots. Ph.D. thesis, Technische Universiteit Delft (2004)

[444] Wisse, M., Hobbelen, D.G., Rotteveel, R.J., Anderson, S., Zeglin, G.J.: Ankle springs instead of arc-shaped feet for passive dynamic walkers. In: IEEE-RAS International Conference on Humanoid Robots, pp. 110–116 (2006)

[445] Wisse, M., Schwab, A., van der Linde, R., van der Helm, F.: How to keep from falling forward: elementary swing leg action for passive dynamic walkers. IEEE Transactions on Robotics and Automation 21(3), 393–401 (2005)

[446] Wisse, M., Schwab, A.L.: Skateboards, bicycles, and three-dimensional biped walking machines: Velocity-dependent stability by means of lean-to-yaw coupling. International Journal on Robotic Research 24(6), 417–429 (2005)

[447] Wisse, M., Schwab, A.L., Van Der Helm, F.C.T.: Passive dynamic walking model with upper body. Robotica 22(6), 681–688 (2004)

[448] Wisse, M., van Frankenhuyzen, J.: Design and construction of mike; a 2D autonomous biped based on passive dynamic walking. In: 2nd International Symposium on Adaptive Motion of Animals and Machines (2003)

[449] Xiao, T., Huang, Q., Li, J., Zhang, W., Li, K.: Trajectory calculation and gait change on-line for humanoid teleoperation. In: IEEE International Conference on Mechatronics and Automation (ICMA 2006), pp. 1614–1619 (2006)

[450] Yamaguchi, J., Nishino, D., Takanishi, A.: Realization of dynamic biped walking varying joint stiffness using antagonistic driven joints. In: IEEE International Conference on Robotics and Automation (ICRA 1998), vol. 3, pp. 2022–2029 (1998)

[451] Yamaguchi, J., Takanishi, A.: Design of biped walking robot having antagonistic driven joint using nonlinear spring mechanism. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 1997), pp. 251–259 (1997)

[452] Yamaguchi, J., Takanishi, A.: Development of a biped walking robot having antagonistic driven joints using nonlinear spring mechanism. In: IEEE International Conference on Robotics and Automation (ICRA 1997), pp. 185–192 (1997)

[453] Yamakita, M., Kamamichi, N., Kozuki, T., Asaka, K., Luo, Z.W.: Control of biped walking robot with ipmc linear actuator. In: IEEE/ASME International Conference on Advanced Intelligent Mechatronics (ICMA 2005), pp. 48–53 (2005)

[454] Yamasaki, F., Miyashita, T., Matsui, T., Kitano, H.: PINO the humanoid that walk. In: IEEE-RAS International conference on Humanoid Robots, CD ROM (October 2000)

[455] Yang, H.S., Seo, Y.H., Chae, Y.N., Jeong, I.W., Kang, W.H., Lee, J.H.: Design and development of biped humanoid robot, AMI2, for social interaction with humans. In: IEEE-RAS International Conference on Humanoid Robots, pp. 352–357 (2006)

[456] Yang, J.S.: Adaptive control for a biped locomotion system. In: Proceedings of the 36th Midwest Symposium on Circuits and Systems, vol. 1, pp. 657–660 (1993)

[457] Yi, K.Y.: Walking of a biped robot with compliant ankle joints:implementation with kubca. In: IEEE Conference on Decision and Control, vol. 5, pp. 4809–4814 (2000)

[458] Yokoi, K., Kanehiro, F., Kaneko, K., Fujiwara, K., Kajita, S., Hirukawa, H.: A honda humanoid robot controlled by AIST software. In: IEEE/RAS International Conference on Humanoid Robots, Tokyo, Japan, pp. 259–264 (2001)

[459] Yokoi, K., Kanehiro, F., Kaneko, K., Kajita, S., Fujiwara, K., Hirukawa, H.: Experimental study of humanoid robot HRP-1S. The International Journal of Robotics Research 23(4-5), 351–362 (2004)

[460] Yoshida, E., Belousov, I., Esteves, C., Laumond, J.P.: Humanoid motion planning for dynamic tasks. In: IEEE-RAS International Conference on Humanoid Robots, pp. 1–6 (2005)

[461] Yoshida, E., Esteves, C., Sakaguchi, T., Laumond, J.P., Yokoi, K.: Smooth collision avoidance: Practical issues in dynamic humanoid motion. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2006), pp. 827–832 (2006)

[462] Yoshimi, T., Kawai, Y., Fukase, Y., Araki, H., Tomita, F.: Measurement of ground surface displacement using stereo vision and mechanical sensors on humanoid robots. In: IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI 2003), pp. 125–130 (2003)

[463] Zarrugh, M., Radcliffe, C.: Computer generation of human gait kinematics. Journal of biomechanics 12(2), 99–111 (1979)

[464] Zecca, M., Endo, N., Momoki, S., Itoh, K., Takanishi, A.: Design of the humanoid robot KOBIAN-preliminary analysis of facial and whole body emotion expression capabilities. In: IEEE-RAS International Conference on Humanoid Robots (Humanoids 2008), pp. 487–492 (2008)

[465] Zheng, Y., Hemami, H.: Mathematical modeling of a robot collision with its environment. Journal of Robotic Systems 2(3), 289–307 (1985)

[466] Zinn, M., Roth, B., Khatib, O., Salisbury, J.: A new actuation approach for human friendly robot design. The International Journal of Robotics Research 23(4-5), 379–398 (2004)

[467] Zinn, M., Khatib, O., Roth, B., Salisbury, J.: Playing it safe [human-friendly robots]. IEEE Robotics & Automation Magazine 11(2), 12–21 (2004)

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