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Dynamic Walk of Humanoids: Momentum Compensation Based on the Optimal Pelvic Rotation

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1. Introduction

Biped walking for humanoid robot has almost been achieved through ZMP theory (Takanishi, et al., 1985) (Goswami, 1999) (Kajita, et al., 2002). The research on humanoids has begun to focus on achieving tasks using the arms during walking (Harada, et al., 2003). In order to achieve a stable biped walking, the momentum around the perpendicular axis generated by the swing leg must be counterbalanced. In a normal human walk, the upper body compensates this momentum, i.e., by rotating the thorax (or shoulders) and swinging the arms in an antiphase of the swing leg (van Emmerik & Wagenaar, 1996) (Lamoth, et al., 2002) (LaFiandra, et al., 2003). For humanoid control, some researches have been presented for momentum compensation using the motion of the entire body including the arms (Yamaguchi, et al., 1993) (Kagami, et al., 2000) (Yamane & Nakamura, 2003) (Kajita, et al., 2003). However, momentum compensation by the upper body is undesirable for a humanoid that uses its arms to achieve a task since this type of compensation limits the degree of freedom (DOF) for the task. In addition, the fluctuation of the upper body has a bad effect not only on the task accomplishment, but also on visual processing since most vision systems are attached to the head part. As a result, it is desirable to preserve as many degrees of freedom of the upper body as possible, and to suppress the fluctuation of the body at the same time. The walking action including momentum compensation should be completed only by the lower body, which leads to a simplification of motion planning. Improving the performance of humanoids through observations of humans walk seems natural. Recently, however, in the field of exercise and sports science, a clarification of efficient motion in the human has begun, and this clarification has been accompanied by improvements in the measuring equipments used for this endeavor. Many common features can be observed in the motion of contact sport athletes, i.e., they move so as not to twist their trunks as much as possible. The particular pelvic rotation walk called a trunk-twistless walk has been empirically investigated from the observation of contact sport athletes (Ueda, et al., 2004). The walking action including the momentum compensation is completed only by the lower body. The upper-body DOF can be used for accomplishing a task. It is said that

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this trunk-twistless walk tend to have an advantage in the energy efficiency in humanoids and human athletes. Furthermore, a relative phase of the swing leg and the pelvic rotation tends to be in an anti-phase when compared with the normal walk of humans. However, there seems to be no analysis result to explain these tendencies.

This chapter presents a method of momentum compensation around the perpendicular axis of the stance foot during dynamic walk of humanoid robots. The characteristics of the trunk-twistless walk are described the result of quantitatively investigation from the observation of contact sport athletes and are analyzed by using the mathematical model. The relative phase of the swing leg and the pelvic rotation appears to be in an antiphase when compared with the normal walk of humans. This leads to the possibility of momentum compensation by pelvic rotation, and this characteristic of the pelvic rotation is implemented to a humanoid conducted. A method of determining the optimal rotation of the humanoid's waist is proposed based on a minimization of the momentum around the perpendicular axis. In this chapter, we confirm that the torque around the perpendicular axis is reduced in the humanoid trunk-twistless walk when compared to a standard humanoid walk without the twisting of the trunk or swinging of the arms.

2. Human Walking Measurement

2.1 Methods and Subjects

Three healthy male subjects who are accustomed to the trunk-twistless walk served as subjects. All subjects are contact sport athletes of rugby football, karate, and kendo (the Japanese art of fencing) respectively. All subjects have been coaches. Their mean age, body height, and body weight were 42.6 ± 7.0 years (Mean $\pm$ S.D.), 171.33 ± 1.52 cm, and 79.3 ± 6.02 kg. Subjects were given several minutes to get used to treadmill walking. The treadmill velocity was set to 1.5 km/h, 3.0 km/h and 4.0 km/h. The normal walk and the trunk-twistless walk were measured for 30 seconds.

A motion capture system with twelve cameras (Vicon Motion Systems Ltd.) was used to measure three dimensional kinematics data (sampling frequency 120Hz) from the reflective markers shown in Figure 1 (a). Two 3-axis accelerometers were attached on both iliac crests to measure the antero-posterior and medio-lateral accelerations of the pelvis. The twisting angle of the trunk was measured using the four markers shown in Figure 1 (b). The thoracic and pelvic rotation around the perpendicular axis, θ_{thorax} and θ_{pelvis} in Figure 2 are measured by the markers on both clavicles and both iliac crests respectively. Both angles are set to 0 when the subject is exactly facing the forward direction. The yaw-axis torque exertion from the stance foot to the floor is defined as τ_{LF} and τ_{RF} for each foot¹. When τ_{LF} increases to positive and exceeds the maximum static friction, the body begins to rotate clockwise due to the slip that occurs at the stance foot.

2.2 Comparison of Trunk Twisting and Pelvic Rotation

For the measurement result, it can be observed that the step width of the athlete's walk is wider than the normal walk, and the posture of the stance feet is in external rotation. In

¹ The foot rotation around the perpendicular axis is the main focus of this chapter. Whenever context permits, we use torque/momentum to the torque around the perpendicular/yaw axis.

addition, the amplitude of pelvic rotation is small, and the relative phase between the swing leg and the pelvis is different compared to the normal walk.

The twisting angle of trunk θ_{twist} is obtained by subtracting θ_{pelvis} from θ_{thorax} :

$$\theta_{twist} = \theta_{pelvis} - \theta_{thorax} \tag{1}$$

Figure 3 shows the typical thorax, pelvis, and twisting angles at 4.0 km/h. The bottom graph shows the stance phase, Left heel Contact (LC) and Right heel Contact (RC). In the trunk-twistless walk, the relative phase between the pelvic and thoracic rotation is smaller, resulting in a smaller twisting angle of trunk than in the normal walk. In comparison to the stance phase, the relative phase between the leg and the thorax is almost the same for both types of walking, but the difference can be found in the pelvic rotation. The counterclockwise rotation of the pelvis is observed for the normal walk when the right leg is in the air, whereas in the trunk-twistless walk, the clockwise rotation is observed in the same period. As a result, the relative phase of the swing leg and the pelvic rotation can be said to be in an antiphase for the trunk-twistless walk compared to the normal walk.

Fig. 3. Twisting Angle of Trunk

2.4 Characteristics of Momentum Compensation of the Trunk-twistless Walk

The trunk-twistless walk was quantitatively investigated from the observation of contact sport athletes (Ueda et al., 2004). The typical characteristics in comparison with the normal walk are:

- (1) Externally rotated posture of the stance feet,
- (2) Wide stance width,
- (3) Small relative phase between the pelvic and thoracic rotation (Small trunk twisting),
- (4) Curved COP trajectory (Torque transmission at the stance foot),
- (5) Antiphase of the swing leg and the pelvic rotation.

In a normal human walk, the momentum is compensated by the upper body, i.e., by rotating the thorax (or shoulder) and swinging the arms in antiphase of the swing leg. This motion leads to canceling the torque at the stance foot and avoiding the rotational slip. However, in contact sports, the upper-body posture should be maintained to the front as much as possible in preparation for contacting against the environments. A similar phenomenon can be observed when the contact increases the intensity of the upper-body exercise. It is assumed that the contact sport athletes perform the trunk-twistless motion for the upper-body exercise. A decreased pelvic and thoracic rotation, similar to the above case, has been observed with a load carriage (carrying a heavy backpack) (LaFiandra, et al., 2003). Without twisting the trunk or swinging the arms, the momentum should be compensated by other methods. The results of the investigation suggest that the momentum is simultaneously compensated passively by the friction at the stance foot and actively by the antiphase pelvic rotation.

In Figure 2, τ_{LF} increases when the right leg is accelerated and swing forward in the initial part of left leg stance phase. In the normal walk where the leg and the pelvis are in-phase, the momentum due to the increase of θ_{pelvis} also increases τ_{LF} . In this case, the sum of the momentum should be compensated by trunk twisting and arm swinging. On the other hand, in the trunk-twistless walk where the leg and the pelvis are in an antiphase, the decrease of θ_{pelvis} cancels τ_{LF} . Also, the momentum of inertia of the pelvis is not large when compared to the momentum of inertia of the legs; in other words, the total momentum is not compensated only by this active pelvic rotation. However, the twisting action of the trunk seems unnecessary when combined with passive compensation. In this chapter, we focus on this antiphase pelvic rotation, and apply this antiphase rotation to dynamic walking by humanoids.

3. Analysis of Trunk-twistless Walk for Momentum Compensation

3.1 Lower Body Analysis Model

In Section 2, the antiphase pelvic rotation was observed in the trunk-twistless walk of contact sport athletes, and the characteristics of the trunk-twistless walk were described. Then, the effect of the trunk-twistless walk on momentum compensation at the stance foot and energy efficiency is investigated by using a mathematical model. In order to analyze of the trunk-twistless walk, a lower body analysis model is proposed. We especially focus on hip joints of human and pelvic rotation. An upper body rotation is not considered, because the upper body rotation (above the chest) can be cancelled by a chest joint and an analysis

object is trunk-twistless walk. Figure 4 shows a four joints link model which has only two joints as each hip joint. To simplify the analysis, the 2D model as viewed from top of the 3D model is also proposed (Figure 4 (b)). In the Figure 4, J_{pelvis} and J_{leg} are the moment of inertia of pelvis and leg. θ_{st} and θ_{sw} are the pelvic rotation angle of support leg and swing leg respectively. ρ and ϕ are the pitch angle of support and swing legs. τ_{st} and τ_{sw} are the torque of support leg and swing leg pelvic joint. f_{st} and f_{sw} are the load force of support and swing leg. A condition of constraint ($\theta_{st} = -\theta_{sw}$) is added for keeping the direction of foots. p_{st} and p_{sw} are the position of the support leg and swing leg. p_{st} and p_{sw} are given by

Fig. 4. Lower body analysis model

$$p_{st} = r \sin \rho, \quad p_{sw} = r \sin \phi \tag{2}$$

An equation of motion of the proposed model is derived from the Lagrange's equation as follow:

$$L = \frac{1}{2} J_{pelvis} \dot{\theta}_{st}^2 + \frac{1}{2} J_{leg} \dot{\theta}_{sw}^2 + \frac{1}{2} M V_G^2 + \frac{1}{2} m (l \dot{\theta}_{st} + \dot{p}_{st} + \dot{p}_{sw})^2 + \frac{1}{2} m \dot{p}_{st}^2 \tag{3}$$

where V_G is the velocity of center of gravity. The forces and the torques are given by

$$\begin{bmatrix} J_{pelvis} + Mc^2 + ml^2 & 0 & ml - Mc \sin \theta_{st} & ml \\ 0 & J_{leg} & 0 & 0 \\ ml & 0 & m & m \\ ml - Mc \sin \theta_{st} & 0 & M + 2m & m \end{bmatrix} \begin{bmatrix} \ddot{\theta}_{st} \\ \ddot{\theta}_{sw} \\ p_{st} \\ p_{sw} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ -Mc\dot{\theta}_{st}^2 \cos \theta_{st} \end{bmatrix} = \begin{bmatrix} \tau_{st} \\ \tau_{sw} \\ f_{st} \\ f_{sw} \end{bmatrix} \quad (4)$$

where M and m are the mass of body and leg respectively. c is the length from joint to waist position. Therefore, the momentum around the perpendicular axis of the support foot τ_{sf} is given by

$$\tau_{sf} = \tau_{st} + f_{st}l \cos \theta_{st} \quad (5)$$

Fig. 5. Momentums around the perpendicular axis of the support foot

3.2 Verification of the proposed model

In order to evaluate the proposed model, a verification experiment is confirmed comparing the momentums around the perpendicular axis of the support foot, which measured by a force plate and calculated by using the proposed model. Three healthy male subjects served as subjects. The normal walk was measured for ten steps. The motion capture system with twelve cameras was used to measure three dimension kinematics data (sampling frequency

120Hz) for calculating the momentum around the perpendicular axis by using the proposed model. The floor reactive force and moment was also measured concurrently by using the force plate (Kistler Co Ltd.). The momentums around the perpendicular axis of the support foot at one step are shown in Figure 2. The both moment peaks of each subject are around 0.1 second. The sharp of the lines is almost same. The mean square error is less than 5%. The calculated results are qualitatively and quantitatively in agreement with the experimental results. Then, the proposed model can be use for analyzing the trunk-twistless walk.

3.3 Effect on Momentum Compensation and Energy Efficiency

The moment at the support foot and energy consumption are calculated by the proposed model when the pelvic rotation only changed. In order to analysis of the trunk-twistless walk, the pseudo-trunk-twistless walk is generated by using the measured 3D motion capture data as following steps. First, the motion captures system was used to measure three dimensional kinematics data. All subjects were given several minutes to set used. The treadmill velocity was set to 1.5 km/h, 3.0 km/h and 4.0 km/h. The normal walk was measured for 30 seconds. Second, the pelvic rotation trajectory θ_{st} and the pitch angle of the support leg ρ are calculated from the measured 3D motion capture data. Last, to generate the pseudo-trunk-twistless walk, the ρ is fixed, and the θ_{st} is forcibly changed to produce the phase difference between the pelvic rotation and the swing leg (from 0 to 360 [deg]). Note that all patterns have the same trajectory, velocity, posture, and landing positions for the foot in the air by using the redundancy of the waist and leg part. As a result, the walking velocity, step length, and step width are the same. The only difference is the pelvic rotation. Figure 6 shows typical examples of the walking posture of the normal walk and the pseudo-trunk-twistless walk (anti-phase). From Figure 6, the anti-phase pelvic rotation can be observed in the pseudo-trunk twistless walk, and the posture of the support feet is in external rotation. In addition, the relative phase between the swing leg and the pelvis is different compared to the normal walk. Then, the generated pseudo-trunk-twistless walk is applied to the proposed model to calculate the momentums around the perpendicular axis of the support foot and energy consumption. The energy consumption $E(t)$ is given by

$$E(t) = \int U dt \tag{6}$$

where U is the kinetic energy. The each parameter is defined in table 1 from the anatomical insight.

Parametar	Description	Value
M	Weight of waist	10.32[kg]
m	Weight of leg	10.08 [kg]
L	Length of waist	0.5[m]
c	Center of waist	0.25[m]
r	Length of leg	0.68[m]
J_{pelvis}	Moment of inertia of waist	0.98[kgm ²]
J_{leg}	Moment of inertia of leg	0.23[kgm ²]

Table 1. Parameter value of the model

Fig. 6. Generated Pseudo-Trunk-Twistless Walking (P-TTW) Motion

Results of one subject are shown in Figure 7 and Figure 8. Figure 7 shows the energy consumption when the phase difference of the pelvic rotation is only changed. Figure 8 shows the momentums around the perpendicular axis when the waking velocity is 4.0 km/h. Table 2 shows the phase differences of normal walk, minimum energy consumption and minimum moment perk, and also shows averages of reduction rate of energy consumption and moment perk when comparing of the normal walking. The phase difference of normal walking is in an angle around 33.7 [deg]. However, the phase difference of minimum energy consumption and minimum moment perk is in an angle around π . The momentum perk around the perpendicular axis is reduced 33.6 [%] and the energy consumption is also reduced 45.6 [%] when compared to the normal walking. The antiphase pelvic rotation was observed in the trunk-twistless walk. The phase difference of around π is the antiphase pelvic rotation. The trunk-twistless walk can be reduced the moment perk and energy consumption. These results are suggested that the possibility of improving efficiency of momentum compensation and energy consumption to change the phase difference between the pelvic rotation and the swing leg at the normal walking pattern. This result strongly supports the previous investigation (Ueda et al., 2004).

Fig. 7. Energy Consumption and Phase Difference (3.0km/h)

Fig. 8. Momentums in Each Phase Difference (4.0 km/h)

Walking velocity [km/h]	1.5	3.0	4.0	Average
Phase difference of normal walking (Ave.)[deg]	31	34	36	33.7
Phase difference of minimum moment perk (Ave.) [deg]	210	210	150	190
Phase difference of minimum energy consumption (Ave.) [deg]	197	180	217	198
Reduction rate (moment perk) (Ave.) [%]	32.3	32.3	36.3	33.6
Reduction rate (energy consumption) (Ave.) [%]	49.6	32.3	55.0	45.6

Table 2. Phase Differences and Reduction Rate of Energy Consumption and Moment Per

4. Moment Compensation for Humanoids using Waist Rotation

4.1 Humanoid Robot: HRP-2

Figure 9 shows the overview and the actuator configuration of the humanoid HRP-2 (Inoue, 2000) used in this chapter. Its height is 154cm and weight is 58kg, which are close the height and weight of a human. HRP-2 has 30 DOF in total. One characteristic of the HRP-2 is a joint around the perpendicular axis between the chest and the waist (called “chest joint”). Along with the hip joints, the chest part and the waist part rotate independently around the perpendicular axis as shown in Figure 9 (a). The pelvic rotation can be implemented to HRP-

2 by correlating the robot's waist to a human's pelvis and its chest to a human's thorax. A simulation software, Open HRP (Hirukawa, et al., 2001), is also available.

Fig.9. Humanoid Robot HRP-2

4.2 From Athlete Measurements to Humanoids

In Section 2, the antiphase pelvic rotation was observed in the trunk-twistless walk of contact sport athletes. The advantages of the application to humanoids are as follows: One goal of the research on humanoids is to achieve a task where the humanoid carries a load or interacts with environments (Harada, et al., 2003) using its upper body. The use of the upper body for walking itself, however, is undesirable for this purpose. The walking action including momentum compensation should be completed only by the lower body in order to preserve the freedom of the upper body. In general, humanoids have larger feet for static stability; hence the maximum friction torque of the sole is larger than the human's. The rotational slip was not generated without considering the momentum in a low-speed walking pattern; however, this slip becomes a problem when the walking velocity is increased. In this case, the trunk-twistless walk preserves the upper body's DOF by waist rotation. As a secondary effect, the trunk-twistless

walk provides the humanoids with an easy visual processing using a vision system attached to the head part.

4.3 Evaluation of Humanoid Walk

The walking pattern with swinging arms and twisting trunk, which is common to the majority of people, cannot be regarded as a humanoid's standard walk. In this chapter, we apply the antiphase pelvic rotation of athletes to humanoids. First, the standard walk of a humanoid is defined to make clear the effects on momentum compensation without using the upper body. Note that we use "standard" for a humanoid walk to distinguish this walk from the "normal" walk of humans. In the standard walk of a humanoid, the upper body (above the chest) is not twisted and is planned to facing the forward direction. The swinging of arms is not performed; therefore, the walking action is completed only by the lower body. The waist rotation is set in-phase of the swing leg for the humanoid's standard walk, the same as in a human's normal walk. In contrast, the antiphase rotation of the waist is performed for the proposed walk of the humanoid, and is calculated by Equation (9) presented in the following section. The step width is set equal to the shoulder's width for all patterns by applying the result of the step width, which allows us to use a standard pattern generator (Kajita, et al., 2002). Note that all patterns have the same trajectory, velocity, posture, and landing positions for the foot in the air by using the redundancy of the waist and leg part. As a result, the walking velocity, step length, and step width are the same. The only difference is the pelvic rotation.

4.4 Generation of Optimal Pelvic Rotation

In section 3, the pseudo-trunk-twistless walk is generated by forcibly producing the phase difference. In this section, the optimal pelvic rotation is determined by using the proposed mathematical model based on a minimization of the momentum around the perpendicular axis as following equation:

$$J = \int_0^T \tau_{sf}^2 dt \rightarrow \min \quad (7)$$

where τ_{sf} is the momentum around the perpendicular axis of support foot. A perturbed trajectory $\theta_{st}(t) + \delta\theta_{st}(t)$ is considered. A functional of the perturbed trajectory is given by

$$\begin{aligned} \tilde{J} &= \int_0^T f(\theta_{st} + \delta\theta_{st}, \dot{\theta}_{st} + \delta\dot{\theta}_{st}, \ddot{\theta}_{st} + \delta\ddot{\theta}_{st}, t) dt \\ &= \int_0^T f(\theta_{st}, \dot{\theta}_{st}, \ddot{\theta}_{st}, t) dt + \int_0^T \left(\frac{\partial f_{st}}{\partial \theta_{st}} \delta\theta_{st} + \frac{\partial f_{st}}{\partial \dot{\theta}_{st}} \delta\dot{\theta}_{st} + \frac{\partial f_{st}}{\partial \ddot{\theta}_{st}} \delta\ddot{\theta}_{st} \right) dt \\ &\quad + o(\delta\theta_{st}^2, \delta\dot{\theta}_{st}^2, \delta\ddot{\theta}_{st}^2) \\ &= J + \delta J \end{aligned} \quad (8)$$

A necessary condition is Equation (9) calculated based on Euler-Poisson equation.
(9pt)

$$\frac{\partial f_{st}}{\partial \theta_{st}} - \frac{d}{dt} \left(\frac{\partial f_{st}}{\partial \dot{\theta}_{st}} \right) + \frac{d^2}{dt^2} \left(\frac{\partial f_{st}}{\partial \ddot{\theta}_{st}} \right) = 0 \quad (9)$$

The optimal pelvic rotation is generated based on the motion capture data and Equation (9). We confirmed that the peak momentum around the perpendicular axis is reduced by 42% on an average in the optimal pelvic rotation walk when compared to the normal walk measured by the motion capture system.

Fig. 10. Perpendicular Axis Momentum

5. Dynamic Walking of Humanoid

The effect of the waist rotation for reducing the support foot torque is confirmed. The antiphase waist rotation is realized in the proposed walk. We apply the optimal pelvic rotation to humanoid robot HRP-2 (Figure 5). The standard walk of a humanoid is defined that a single supporting time is 0.7[s], a double supporting time is 0.1[s], a step width is 0.25[m], the phase difference is in-phase, and without arm swing. The momentums around the perpendicular axis are shown in Figure 10. The peak momentum around the perpendicular axis of the proposed walk decrease in 13% is observed, and the amount of integration of the momentum is also reduced by 18% when compared to the standard walk. The validity of the proposed walk can be observed not only in the peak torque but also in the average torque.

6. Conclusion

In this chapter, the trunk-twistless walk of contact sport athletes was described from a motion measurement and the trunk-twistless walk was analyzed by using the mathematical model. The proposed optimal relative phase of the swing leg and the pelvic rotation was applied to the walk of humanoid HRP-2. The walking action including the momentum compensation was completed only by the lower body, so that the upper body DOF can be used for accomplishing a task. Using the proposed walk, the stance foot torque and the energy consumption were both reduced.

The future work includes an evaluation of the energy efficiency of the trunk-twistless walk, both in humanoids and human. An optimization program for an efficient walking pattern should be investigated. The authors wish to thank Kenji Shirae and Atsutoshi Ikeda of Nara Institute of Science and Technology for the data processing required for this research.

7. References

- Takanishi, A.; Ishida, M.; Yamazaki, Y. & Kato, I. (1985). The realization of dynamic walking by biped walking robot WL-10RD, *Proceedings of International Conference on Advanced Robotics*, pp. 459-466, Tokyo, Japan, September, 1985.
- Goswami, A. (1999). Postural Stability of Biped Robots and the Foot Rotation Indicator (FRI) Point, *International Journal of Robotics Research*, Vol.18, No.6, pp. 523-533.
- Kajita, S.; et al. (2002). A Realtime Pattern Generator for Biped Walking, *Proceedings of 2002 International Conference on Robotics and Automation*, Washington DC, May, 2002, pp. 31-37.
- Harada, K.; Kajita, S.; Kaneko, K. & Hirukawa, H. (2003). ZMP Analysis for Arm/Leg Coordination, *Proceedings of 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Las Vegas, Nevada, October, 2003, pp.75- 81.
- van Emmerik, R. E. A.; Wagenaar, R. C. (1996). Effects of walking velocity on relative phase dynamics in the trunk in human walking, *Journal of Biomechanics*, Vol. 29, No. 9, pp. 1175-1184, 1996.
- Lamoth, C.J.C.; Beek, P.J. & Meijer, O.G. (2002). Pelvis-thorax coordination in the transverse plane during gait, *Gait & Posture*, Vol. 16, No. 2, pp. 101-114, 2002.
- LaFiandra, M.; Wagenaar, R.C.; Holt, K.G. & J.P. Obusek. (2003). How do load carriage and walking speed influence trunk coordination and stride parameters?, *Journal of Biomechanics*, Vol. 36, No. 1, pp. 87-95, 2003.
- Yamaguchi, J.; Takanishi, A. & Kato, I. (1993). Development of a biped walking robot compensating for three-axis moment by trunk motion, *Proceedings of 1993 International Workshop on Intelligent Robotics and Systems*, Yokohama, Japan, pp. 561-566.
- Kagami, S.; Kanehiro, F.; Tamiya, Y.; Inaba, M. & Inoue, H. (2000). AutoBalancer: An Online Dynamic Balance Compensation Scheme for Humanoid Robots, *Proceedings of 4th International Workshop on Algorithmic Foundation on Robotics*, pp. 329-340, 2000.
- Yamane K. & Nakamura, Y. (2003). Dynamics Filter-Concept and Implementation of On-line Motion Generator for Human Figures, *IEEE Transactions on Robotics and Automation*, Vol.19, No.3, pp.421-432, 2003.

- Kajita, S.; Kanehiro, F.; Kaneko, K.; Fujiwara, K.; Harada, K.; Yokoi, K. & Hirukawa, H. (2003). Resolved Momentum Control: Humanoid Motion Planning based on the Linear and Angular Momentum, *Proceedings of 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 1644-1650.
- Ueda, J.; Shirae, k.; Matsumoto, Y.; Oda, S. & Ogasawara, T. (2004). Momentum Compensation for the Fast Dynamic Walk of Humanoids based on the Pelvic Rotation of Contact Sport Athletes, *Proceedings of IEEE/RSJ International Conference on Humanoid Robots*.
- Inoue, H., et al., (2000). HRP, Humanoid Robotics Project of MITI, *Proceedings of IEEE/RAS International Conference on Humanoid Robots*.
- Hirukawa, H.; Kanehiro, F. & Kajita, S. (2001). OpenHRP, Open Architecture Humanoid Robotics Platform, *Proceedings of 2001 International Symposium on Robotics Research*.

Climbing and Walking Robots: towards New Applications

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With the advancement of technology, new exciting approaches enable us to render mobile robotic systems more versatile, robust and cost-efficient. Some researchers combine climbing and walking techniques with a modular approach, a reconfigurable approach, or a swarm approach to realize novel prototypes as flexible mobile robotic platforms featuring all necessary locomotion capabilities. The purpose of this book is to provide an overview of the latest wide-range achievements in climbing and walking robotic technology to researchers, scientists, and engineers throughout the world. Different aspects including control simulation, locomotion realization, methodology, and system integration are presented from the scientific and from the technical point of view. This book consists of two main parts, one dealing with walking robots, the second with climbing robots. The content is also grouped by theoretical research and applicative realization. Every chapter offers a considerable amount of interesting and useful information.

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