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Design of Prototype Humanoid Robotics Platform for HRP

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Abstract

This paper presents a prototype humanoid robotics platform developed for HRP-2. HRP-2 is a new humanoid robotics platform, which we have been developing in phase two of HRP. HRP is a humanoid robotics project, which has been lunched by Ministry of Economy, Trade and Industry (METI) of Japan from 1998FY to 2002FY for five years. The ability of the biped locomotion of HRP-2 is improved so that HRP-2 can cope with rough terrain in the open air and can prevent the possible damages to a humanoid robot's own self in the event of tipping over. The ability of whole body motion of HRP-2 is also improved so that HRP-2 can get up by a humanoid robot's own self even tough HRP-2 tips over. In this paper, the mechanisms and specifications of developed prototype humanoid robotics platform, and its electrical system are introduced.

1. Introduction

The traditional robots are typically used for industrial automation and play in environments that are separated from the sphere of human lives and activities. However, the need for robots has recently been changed from industrial automation to human friendly robot system. Coming the increasingly aging societies, robots that assist human activities in human daily environments such as in offices, homes and hospitals are expected. Especially, an emergence of humanoid robots is strongly expected because of anthropomorphism, friendly design, applicability of locomotion, behavior within the human living environments, and so on. To meet these demands, several humanoid robots have been developed in these years.

One of them is WABIAN (WAseda BIpedal humANoid) constructed by Waseda University [1]. WABIAN is succeed by WABOT-1 (WAseda roBOT-1), which is the world's first life-sized humanoid robot constructed in 1973 by late Prof. KATO's laboratory. It is no exaggeration to say that he was a pioneer in the development of humanoid robot and WABIAN is the orthodox humanoid robot. The newest WABIAN: WABIN-RII, which has a total of 43 D.O.F., is 1890 [mm] height, 902 [mm] width, and 131.4 [kg] weight respectively. WABIN-RII has a completely humanoid figure with two legs, two arms, two hands, and two eyes, and is capable of walking and even dancing.

H6 and H7 are humanoid robots constructed by University of Tokyo [2]. H6 is 1370 [mm] height and 590 [mm] width respectively, and has a total of 35 D.O.F. Its weight is 55 [kg], since aircraft technologies were applied to the body frame, which led to a strong and light structure. H6 and H7 can walk up and down 25 [cm] high steps and can also recognize pre-entered human faces.

JOHNNIE is an anthropomorphic autonomous biped robot constructed by Technical University of Munich for realization of dynamically three-dimensional walking and jogging motion [3]. JOHNNIE with 17 D.O.F. is expected to be about 1800 [mm] height and about 37 [kg] weight respectively, while the operating power is supplied by external sources. Since the manufacturing process is in progress, JOHNNIE is just going to walk.

MK.5 is a compact size humanoid robot with 24 D.O.F. constructed by Aoyma Gakuin University, and 356 [mm] height and 1.9 [kg] weight respectively [4]. Its concepts are compact, low-priced, expansible, and mobile humanoid robot. To realize it, all joints are driven by servo modules for radio controlled model like PINO constructed by ERATO [5]. MORPH, that is a succeeding model of MK.5 and is currently constructed by ERATO, will appear with high mobility.

Another compact size humanoid robot is SDR-3X (Sony Dream Robot-3X) [6]. The reason Sony made SDR-3X as small as possible is that the smaller it is, the lower the cost becomes. Its specifications are 500 [mm] height, 220 [mm] width, 5 [kg] weight, and 24 D.O.F. SDR-3X can more than just walk around such as squatting, getting up, and doing synchronized choreography, though it can't go up and down stairs since Sony developed it for entertainment.

The most impressive humanoid robot should be HONDA humanoid robots. When P2, the second prototype HONDA humanoid robot, was revealed in 1996 after ten years secret research, the robotics world was stunned. P2 is the world's first cable-less humanoid robot, which can walk and can go up/down stairs [7]. Downsizing P2 (1820 [mm] height, 600 [mm] width, 210 [kg] weight including batteries, 6 D.O.F./Leg, 7 D.O.F./Arm, 2 D.O.F./Hand), P3 (1600 [mm] height, 600 [mm] width, 130 [kg] weight including batteries, 6 D.O.F./Leg, 7 D.O.F./Arm, 1 D.O.F./Hand) appeared in 1997 with the same mobility as P2 [8]. In 2000, further downsizing P3, ASIMO that stands for Advanced Step in Innovative Mobility appeared with children-size (1200 [mm] height, 450 [mm] width, 43 [kg] weight including batteries, 6 D.O.F./Leg, 5 D.O.F./Arm, 1 D.O.F./Hand, 2 D.O.F./Head) and new walking technology (i-WALK) [9]. The introduction of i-WALK technology allowed ASIMO to walk continuously while changing directions, and gave the robot even greater stability in response to sudden movements. It is no exaggeration to say that the great success of HONDA humanoid robot makes the current research on the world's humanoid robot to become very active area.

The credit for a success of these humanoid robots nearly goes to the zero moment point (ZMP) theory invented by Prof. Vukobratovic [10]. He is also one of the inventors for anthropomorphic mechanisms and biped locomotion. The ZMP theory is effective in making humanoid robots walk with gait stabilization. The more humanoid robots which can walk and can go up/down stairs are developed, the more humanoid robots are expected to perform several application tasks in an actual human living environment. However the application area of humanoid robots has still limited to the amusement and the entertainment.

For research and development of humanoid robot performing application tasks, Ministry of Economy, Trade and Industry (METI) of Japan has launched a humanoid robotics project (HRP) [11]. The project is run from 1998FY to 2002FY for five years, consisting of phase one for the first two years and phase two for the last three years. In phase one (FY 1998-1999), a humanoid robotics platform (HRP-1), a tele-existence cockpit to control humanoid robots, and an equivalent virtual robot including dynamic simulator [12] were developed. In phase two (FY 2000-2002), research and development are carried out on the applications of humanoid robots (maintenance tasks of industrial plants, human care, tele-operations of construction machines, security services of home and office, and cooperative works in the open air) using HRP-1. Improvement and addition of elemental technologies are also carried out in phase two. For R&D of locomotion technology including hardware and software, we have developed a HRP-2L, which is an advanced leg module for HRP [13]. We obtained several experimental results using HRP-2L [14].

This paper presents a HRP-2P, which is a prototype humanoid robotics platform developed for HRP-2 and which was developed using experiences from HRP-2L. HRP-2 is a new humanoid robotics platform, whose manufacturing process is currently in progress in phase two of HRP. HRP-2 has several great peculiarities, which are especially necessary for cooperative works in the open air. One is that the ability of the biped locomotion of HRP-2 is improved so that HRP-2 can cope with rough terrain in the open air. Another is that HRP-2 is designed in order to prevent tipping over easily. Another is that the ability of whole body motion of HRP-2 is also improved so that HRP-2 can get up by a humanoid robot's own self even though it tips over. In this paper, the mechanisms and specifications of developed prototype humanoid robotics platform, and electrical system are also introduced.

2. HRP-2: Humanoid Robotics Platform - 2

HRP-2 is a new humanoid robotics platform, whose manufacturing process is in progress in phase two of HRP. The design concepts of HRP-2 are light, compact, but performable for application tasks like cooperative works in the open air shown in Fig. 1 [15]. As a result, HRP-2 is designed to be feminine size.

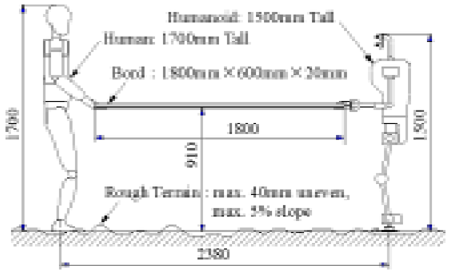

Figure 1. Cooperation Works in the Open Air

In this section, HRP-2P, which is a prototype humanoid robotics platform for HRP-2, is introduced. The details of designs are presented in later sections.

2.1. Specifications of HRP-2P

Figure 2 shows an overview of HRP-2P and Fig. 3 shows the mechanical configuration of HRP-2P, respectively.

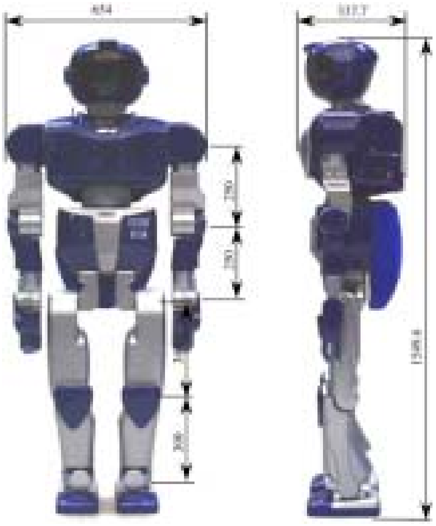

Figure 2. Prototype Humanoid Robotics Platform for HRP-2

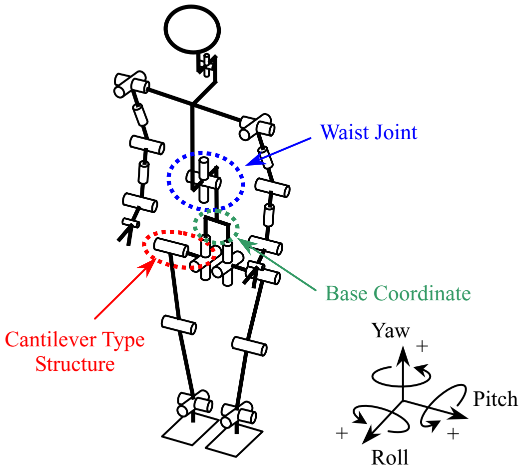

Figure 3. Configuration of HRP-2P

As shown in Fig. 2 and Fig.3, HRP-2P has unique configurations. One is that the hip joint of HRP-2P has a cantilever type structure as well as HRP-2L. The other is that HRP-2P has a waist joint. The reason we designed so will be explained later.

Table 1 shows the specifications of HRP-2P.

Table 1. Specifications of HRP-2P

D.O.F.	Head: 2 D.O.F (Pitch, Yaw)	= 2 D.O.F.
	Arms: 6 D.O.F./Arm × 2 (Shoulder: 3, Elbow: 2, Wrist: 1)	= 12 D.O.F.
	Hands: 1 D.O.F./Hand × 2 (Open/Close)	= 2 D.O.F.
	Waist: 2 D.O.F. (Pitch, Yaw)	= 2 D.O.F.
	Legs: 6 D.O.F./Leg × 2 (Hip: 3, Knee: 1, Ankle: 2)	= 12 D.O.F.
	Total:	30 D.O.F.
Dimension	Height:	1,549.6 [mm]
	Width:	654.0 [mm]
	Depth:	337.7 [mm]
	Upper arm length:	250.0 [mm]
	Lower arm length:	250.0 [mm]
	Upper leg length:	300.0 [mm]
	Lower leg length:	300.0 [mm]
Weight	Head: 1.2 [kg]	= 1.2 [kg]
	Arms: 5.4 [kg/arm]×2 [arms]	= 10.8 [kg]
	Bodies: 26.9 [kg]	= 26.9 [kg]
	Legs: 7.6 [kg/leg]×2 [legs]	= 15.2 [kg]
	Total:	54.1 [kg]

Looking at Fig. 2 and Table 1, we can observe that the light and compact humanoid robot was completed. Its detail design will be presented in the followings sections.

2.2. Movable Range of Each Joint

This section explains how we designed the movable range of each joint for HRP-2P.

First, we designed that to be about the same as that of standard human so that a humanoid robot performs human tasks as well as human. Table 2(a) shows the data on movable range of head, right arm, right hand, waist, and right leg of standard human [16].

Table 2. Movable Range of Each Joint

Joint			(a) Standard Human	(b) HRP-2P
Head		R	-50 deg. to 50 deg.	no existence.
		P	-50 deg. to 60 deg.	-20 deg. to 55 deg.
		Y	-70 deg. to 70 deg.	-45 deg. to 45 deg.
Right Arm	Shoulder	R	-90 deg. to 0 deg.	-95 deg. to 30 deg.
		P	-180 deg. to 50 deg.	-180 deg. to 60 deg.
		Y	-90 deg. to 90 deg.	-90 deg. to 90 deg.
	Elbow	P	-145 deg. to 0 deg.	-135 deg. to 0 deg.
		Y	-90 deg. to 90 deg.	-90 deg. to 90 deg.
	Wrist	R	-55 deg. to 25 deg.	no existence
		P	-70 deg. to 90 deg.	-90 deg. to 90 deg.
Right	Hand	P	0 deg. to 90 deg.	-16.5deg. to 60 deg.
Waist		R	-50 deg. to 50 deg.	no existence
		P	-30 deg. to 45 deg.	-5 deg. to 60 deg.
		Y	-40 deg. to 40 deg.	-45 deg. to 45 deg.
Right Leg	Hip	R	-45 deg. to 20 deg.	-35 deg. to 20 deg.
		P	-125 deg. to 15 deg.	-125 deg. to 42 deg.
		Y	-45 deg. to 45 deg.	-45 deg. to 30 deg.
	Knee	P	-0 deg. to 130 deg.	-0 deg. to 150 deg.
	Ankle	R	-20 deg. to 30 deg.	-20 deg. to 35 deg.
		P	-20 deg. to 45 deg.	-75 deg. to 42 deg.

R: Roll axis, P: Pitch axis, Y: Yaw axis

However, as shown in Table 2(b) which shows the designed movable range of HRP-2P, some movable ranges of humanoid joint should be extended or reduced by following reasons.

The reasons to extend are as follows. One of them is that we request the humanoid robot to perform the motions that are impossible for human. For example, the movable range of knee joint and that of ankle pitch joint are extended, since we request HRP-2P to sit on the floor in Japanese style. Since we also request HRP-2P to be lithe in build such as setting-up exercise and getting up, the positive movable range of waist pitch joint is extended. The other reason is that the kinematical design of HRP-2P is not same as human. Further, the humanoid robot does not have limber motions that exist in a human. After simulating the humanoid robot that performs basic motions in human daily environments, we decided the extended joint angles.

The movable ranges of head joint of HRP-2P are reduced by a light and compact design of head part. Although they are reduced, they are enough for our purpose. As shown in Fig. 1, our final goal is a development of humanoid robot doing cooperative tasks with a human in the open air. The head part with a stereo camera is used for measuring a panel grasp point and for detecting walking surface topology [15]. The designed movable ranges of head part satisfy our purpose.

Some movable ranges, such as that of hip yaw joint and that of hip roll joint, are slightly reduced in HRP-2P, though they were same as that of standard human in HRP-2L. The reason to reduce come from the experiments using HRP-2L. We decided that we should rather design a high stiff structure than ensure their movable ranges [14].

The joints which do not exist in HRP-2P are related with I/O control system explained in Section 4.1.

3. Mechanical Design

As mentioned in former section, the design concepts of HRP-2 are light, compact, but performable for application tasks like cooperative works in the open air. To realize HRP-2, several distinctive mechanisms are employed. In this section, the details of mechanical design are introduced.

3.1. Cantilever Type Structure in Hip Joint

The humanoid robot tends to tip over easily, since the area of foot sole that supports the whole body is so small and limited. The motion of not only body but also arms during tasks also makes it easy to throw the humanoid robot off balance. The mechanism for prevention of tipping over is a very important achievement to realize a humanoid robot.

The tipping over easily occurs when the target ZMP is outside of the support polygon made by supported legs (and/or leg) [13]. Since it is so hard to recover tipping over when the target ZMP is outside of the support polygon, our approach to prevent tipping over is to construct the mechanism, which easily enables to make the target ZMP to be inside of the support polygon.

A mechanism, which enables to have a wide sphere of landing point for swinging leg, would be one solution for our approach. The reason is that we can appropriately shape the support polygon for the phase of double supported legs by selecting the landing point of swing leg. By shaping the support polygon for the phase of double supported legs immediately, the tipping over would be prevented, even if humanoid robot begins to tip over. Especially, crossing legs further enables to make the support polygon to be on the opposite side of supported leg. To realize a wide sphere of landing point for swinging leg, the hip joint of HRP-2L has a cantilever type structure as shown in Fig. 2. Because the cantilever type structure enables to have less collision between both inside upper-limbs and also enables to cross legs [13].

The other factor throwing the humanoid robot off balance is caused from rolling motion of gait. The mechanism, which makes the trajectory of the center of gravity (COG) of upper body smooth with less rolling motion, is also effective in the prevention of tipping over. To reduce rolling motion of gait, the cantilever type structure also plays an important. Since the cantilever type structure can make the length between hip joints shorter, this structure enables to make the length between landing points of pitch axis shorter too [13].

From these discussions, we designed the cantilever type structure to achieve the mechanism for prevention of tipping over. This structure enables to cross legs as well as to make a protector between legs for minimal damage in the event of tipping over.

3.2. Waist Joint

HRP-2P would not be able to avoid tipping over, even though HRP-2P has the cantilever type structure as explained in Section 3.1. When HRP-2P tips over during cooperative tasks in open air, we request HRP-2P to get up by a humanoid robot's own self. To realize such a humanoid, a waist joint with 2 D.O.F. (pitch axis and yaw axis) is necessary for HRP-2P.

The waist joint brings several advantages. One is that HRP-2P can be lithe in build. The more lithe the upper body is, the smoother its gait is. Another is that the moment generated in the yaw axis of HRP-2P can be suppressed by using waist motion. This compensation will be done in the near future. Furthermore, the waist joint makes a working space of arm extended. Although HRP-2P has 6 D.O.F. in each arm and 1 D.O.F. in each hand, waist motion gives a redundancy to the arm motion.

3.3. Structural Design for Light Weight

The weight of the structural parts is quite significant. From a design experience [17], the proportion of structure weight to total weight of humanoid is more than 60 [%]. The weight of screws is also significant, since 20 [%] of the overall weight are due to screws [3]. A shortcut to make humanoid robot lighter can be achieved by reducing the weight of structural parts. An approach to realize a structural design for light weight is carried out by casting several links. From this point of view, we cast several links in magnesium alloy for HRP-2L. The reason we had selected magnesium alloy is that its specific gravity of magnesium alloy is 68 [%] of that of aluminum alloy. However, it was so hard to cast them in magnesium alloy. The cast links had blow holes sometimes.

This experience decided us to cast several links in aluminum alloy for HRP-2P. Although its specific gravity is heavier than that of magnesium alloy, a modification of link form kept them to be light weight.

4. Electrical Design

In the electrical design for HRP-2P, several efforts for light weight and realization of compact body were adopted. In this section, the details of electrical design are introduced.

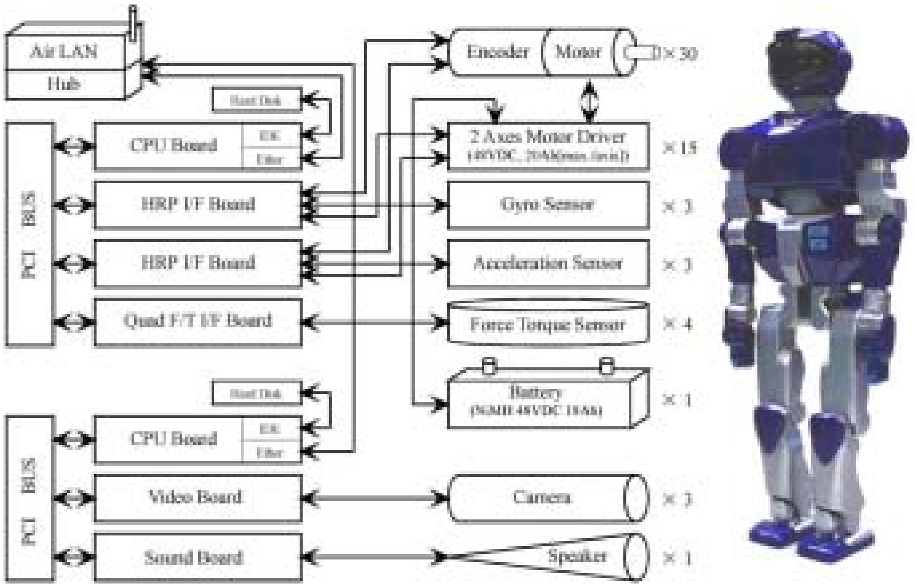

Figure 5. Electrical System of HRP-2P

4.1. I/O Control System

Recently, PCI bus becomes the most popular bus in industrial field. However, employing PCI bus brings an issue. It is that PCI bus accepts only four or less PCI boards without a bus-bridge. This is an important issue for constructing a humanoid robot. Because, several kinds of function such as DA, AD, counter, and Digital Input/Output, and multi-channels are necessary for control the humanoid robot. In the case of HRP-2P with 30 D.O.F., 30 DC motors, 30 encoders, 3 gyro sensors, 3 acceleration sensors, and 4 force/torque sensors should be controlled using PCI boards occupied within four slots of PCI bus. To overcome this issue, the function boards on the market are not sufficient. We then developed a HRP interface board and a quad force sensors interface board [13]. Table. 3 shows the specifications of HRP interface board. Using these developed boards, we could complete a compact I/O control system as shown in Fig. 5.

Table 3. Specifications of HRP Interface Board

Bus Type	PCI
DA	16 Channel 12-Bit
AD	12 Channel 12-Bit
Counter	16 Channel 24-Bit Up/Down Counter
DIO	16 Channel Input, 16 Channel Output
Size (L×W×H)	176 [mm] × 99 [mm] × 22 [mm]
Weight	160 [g]

4.2. Servo Driver Module

To realize humanoid robot using electrical actuators, servo drivers are necessary. Since the humanoid robot has high D.O.F., the volume of servo drivers is significant issue for construction of compact humanoid. To overcome this issue, we have developed a compact servo driver module for HRP-2L [13]. Its volume and weight were almost 15 [%] and 33[%] of smaller servo drivers on the market, respectively. For making smaller and more efficient, we re-developed it by surface mount technology (SMT). Figure 6 shows three modules of new DC motor driver module for HRP-2P. Since one module enables to control two DC motors independently, 15 modules are employed for control 30 DC motors of HRP-2P.

Figure 6. “DC Motor Driver Module for 2-Axes” × 3 Modules

4.3. Stereo Camera System

HRP-2P has a vision system to be used in the robot to generate a 3D terrain map of the worksite, and detect ground topology for walking, as well as panel grip points and panel placement points in our final goal. This system consists of three camera units. Its 3D image is processed by the VVV software system [18].

4.4. Computer System

As shown in Fig. 5, HRP-2P has two CPU boards (Pentium III, 1 [GHz]) in the body. One of them is utilized for the realtime controller of whole body motion, while the other is utilized for the VVV software system.

The operating system is ART-Linux [19]. ART-Linux enables the execution of realtime processes at the user level so that users can implement realtime applications as if they are non-realtime ones. This feature of ART-Linux is essential for realizing the identical controller for the simulation and the real robot [20].

5. Conclusions

This paper presented how we developed the prototype humanoid robotics platform for HRP-2, which has a ability to cope with rough terrain in the open air, to prevent tipping over, and to get up get up by a humanoid robot's own self. Several distinctive mechanisms such as mechanism for prevention of tipping over and mechanism for lithe motion are employed for HRP-2P. This paper also presented the detail of mechanism design, electrical design, specifications of movable ranges.

Future works include more walking experiments in the open air. The developments of a cooperation controller between arms and legs, whole body controller, a more stable balance controller, and an integration of vision system will also be investigated in the future.

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References

[1] J. Yamaguchi, E. Soga, S. Inoue, and A. Takanishi, "Development of a Bipedal Humanoid Robot – Control Method of Whole Body Cooperative Dynamic Biped Walking," Proc. IEEE Int. Conference on Robotics and Automation, pp. 368-374, 1999.

[2] K. Nishiwaki, T. Sugihara, S. Kagami, F. Kanehiro, M. Inaba, and H. Inoue, "Design and Development of Research Platform for Perception-Action Integration in Humanoid Robot: H6," Proc. Int. Conference on Intelligent Robots and Systems, pp. 1559-1564, 2000.

[3] M. Gienger, K. Löffler, and F. Pfeiffer, "Towards the Design of Biped Jogging Robot," Proc. IEEE Int. Conference on Robotics and Automation, pp. 4140-4145, 2001.

[4] T. Furuta, Y. Okomura, and K. Tomiyama, "Design and Construction of a Series of Compact Humanoid Robots and Development of Biped Walk Control Strategies," CD-ROM Proc. IEEE-RAS Int. Conference on Humanoid Robots, 84.pdf, 2000.

[5] F. Yamasaki, T. Matsui, T. Miyashita, and H. Kitano, "PINO The Humanoid that Walks," CD-ROM Proc. IEEE-RAS Int. Conference on Humanoid Robots, 80.pdf, 2000.

[6] Y. Kuroki, T. Ishida, J. Yamaguchi, M. Fujita, and T. Doi, "A Small Biped Entertainment Robot," Proc. IEEE-RAS Int. Conference on Humanoid Robots, pp. 181-186, 2001

[7] K. Hirai, "Current and Future Perspective of Honda Humanoid Robot," Proc. IEEE/RSJ Int. Conference on Intelligent Robots and Systems, pp. 500-508, 1997.

[8] K. Hirai, M. Hirose, Y. Haikawa, and T. Takenaka, "The Development of Honda Humanoid Robot," Proc. IEEE Int. Conference on Robotics and Automation, pp. 1321-1326, 1998.

[9] M. Hirose, Y. Haikawa, T. Takenaka, and K, Hirai, "Development of Humanoid Robot ASIMO," Proc. Int. Conference on Intelligent Robots and Systems, Workshop2 (Oct. 29, 2001), 2001.

[10] M. Vukobratovic and D. Juricic, "Contribution to the Synthesis of Biped Gait," IEEE Tran. On Bio-Medical Engineering, Vol. 16, No. 1, pp. 1-6, 1969.

[11] H. Inoue, S. Tachi, Y. Nakamura, K. Hirai, N. Ohyu, S. Hirai, K. Tanie, K. Yokoi, and H. Hirukawa, "Overview of Humanoid Robotics Project of METI," Proc. the 32nd Int. Symposium on Robotics, pp. 1478-1482, 2001.

[12] Y. Nakamura, et al., "V-HRP: Virtual Humanoid Robot Platform," CD-ROM Proc. IEEE-RAS Int. Conference on Humanoid Robots, 86.pdf, 2000.

[13] K. Kaneko, S. Kajita, F. Kanehiro, K. Yokoi, K. Fujiwara, H. Hirukawa, T. Kawasaki, M. Hirata, and T. Isozumi, , "Design of Advanced Leg Module for Humanoid Robotics Project of METI," Proc. IEEE Int. Conference on Robotics and Automation, (to be appeared), 2002.

[14] N. Kanehira, T. Kawasaki, S. Ota, K. Akachi, T. Isozumi, F. Kanehiro, and K. Kaneko, and S. Kajita, "Design and Experiment of Advanced Leg Module (HRP-2L) for Humanoid Robot (HRP-2) Development," Proc. Int. Conference on Intelligent Robots and Systems, (Submitted paper), 2002.

[15] K. Yokoyama, J. Maeda, T. Isozumi, and K. Kaneko, "Application of Humanoid Robots for Cooperative Tasks in the Outdoors," Proc. Int. Conference on Intelligent Robots and Systems, Workshop2 (Oct. 29, 2001), 2001.

[16] Y. Kagawa., "Bio-Engineering Technical Terms Dictionary," Japanese Standards Association, ISBN 4-542-20125-2, (in Japanese).

[17] K. Kaneko, S. Kajita, K. Yokoi, V. Hugel, P. Blazevic, and P. Coiffet., "Design of LRP Humanoid Robot and its Control Method," Proc. IEEE Int. Workshop on Robot-Human Interactive Communication, pp. 556-561, 2001.

[18] Y. Sumi, Y. Kawai, T. Yoshimi, and F. Tomita, "3D Object Recognition in Cluttered Environments by Segment-Based Stereo Vision," International Journal of Computer Vision, 46, 1, pp.5-23, 2002..

[19] Y. Ishiwata and T. Matsui, "Development of Linux which has Advanced Real-Time Processing Function," Proc. RSJ Annual Conf., pp. 355-356, 1998 (in Japanese).

[20] F. Kanehiro, N. Miyata, S. Kajita, K. Fujiwara, H. Hirukawa, Y. Nakamura, K. Yamane, I. Kohara, Y. Kawamura, and Y. Sankai, "Virtual Humanoid Robot Platform to Develop Controllers of Real Humanoid Robots without Porting," Proc. Int. Conference on Intelligent Robots and Systems, pp. 1093-1099, 2001.