Experimental Study of Biped Locomotion of Humanoid Robot HRP-1S

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Abstract. We have developed a humanoid robot HRP-1S that can be controlled its whole body motion. In phase one of Humanoid Robotics Project (HRP) of METI of Japan, Honda R&D Co. Ltd. has produced humanoid robots HRP-1 as humanoid research platforms to establish good applications of humanoid robots in phase two of HRP. However HRP-1 is controlled its legs and arms separately, and it is not suitable for some applications. By modifying the control hardware of HRP-1 and implementing our own control software on it, we made HRP-1S. In this paper, we present several experimental results of HRP-1S.

1 Introduction

Recently research on a humanoid robot has become very active area. Not only academia [2][3][14][15][25][17], but several industryies produce humanoid robots [5][10]. However the application area of humanoid robots has been still limited to the amusement and the entertainment.

Ministry of Economy, Trade and Industry (METI) of Japan has launched as R&D project on humanoid robotics from 1998FY[9]. The project is run on a new scheme, called a platform-based approach, in which a platform is developed at phase one and it is utilized by contributors of the project as an infrastructure for R&D at phase two. The main mission of phase two is finding a promising application of humanoid robots that can initialize a mass production spiral of humanoid robot industry.

Honda R&D Co. Ltd. has produced the humanoid robot platform HRP-1 in phase one of HRP. However the legs and arms of HRP-1 can be controlled separately, and it is not suitable for establishing some applications of humanoid robot in phase two. We have developed a humanoid robot HRP-1S whose whole body motions can be controlled. HRP-1S is made by replacing the main control CPU and the software of HRP-1.

The rest of the paper is organized as follows. In Section 2, we present the hardware specification of HRP-1S. The control software of HRP-1S is described in Section 3. Section 4 shows experimental results. We conclude the paper in Section 5.

2 Humanoid Robot HRP-1S

HRP-1S has 1600 [mm] height, 600 [mm] width, and 99 [kg] weight excluding batteries. The mechanical hardware is identical with HRP-1[8]. It has 12 d.o.f. in two legs and 16 d.o.f in two arms including hands with 1 d.o.f. grippers.

Each joint is actuated by a brushless DC servo motor with a harmonic-drive reduction gear. Brushless DC servo amplifiers, a Ni-Zn battery, a wireless Ethernet modem are embedded in the body.

The body is equipped with an inclination sensor that consists of gyroscopes and G-force sensors. Each foot and wrist is equipped with a force/torque sensor, respectively. Two video cameras are mounted in the head.

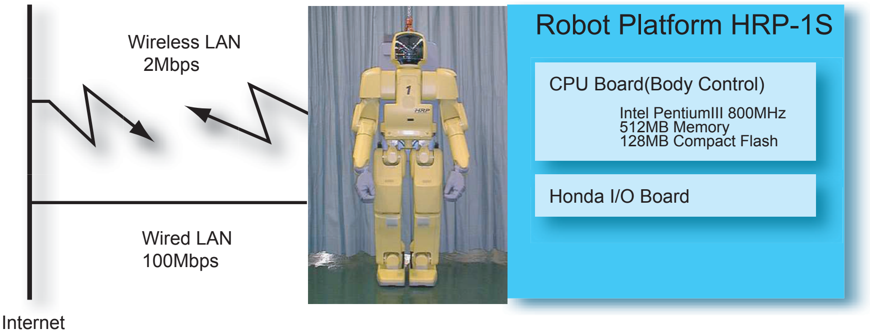

Fig. 1. Minimum Set of Control Hardware System of HRP-1S

Figure 1 shows the minimum set of the control hardware system of HRP-1S. The real-time controller runs on the CPU board in the backpack of HRP-1S, whose operating system is ART-Linux[11]. ART-Linux enables the execution of real-time processes at the user level so that users can implement real-time applications as if they are non-real-time ones. This feature of ART-Linux is very helpful for realizing the identical controller for the simulator and the real robot[16].

3 Control Systems of HRP-1S

Figure 2 shows an overall block diagram of the control system of HRP-1S. We generate a dynamically consistent motion pattern off-line by using two kinds of motion generators. The motion pattern consists the desired trajectories of all joints and the desired ZMP trajectory. In order to keep a balance of the robot, HRP-1S controller modifies the suitable joints trajectories according to the various sensor data getting from Honda I/O board and commands them to Honda I/O board every 5 [msec]. Motor drivers, which are built in the body, charge the control of joint angles.

3.1 Motion Generator

A lot of researchers proposed a biped walking pattern generation[7][19][23].

We introduce two types of motion generation algorithm. One is developed by Hitachi and Waseda University[18] under phase one of HRP, and the other is developed by AIST[12].

Hitach/Waseda's Motion Generator ZMP is the one of the most important measure to keep the stable motion planned by the motion generator[22]. The algorithm of Hitach/Waseda's motion generator can compute the whole body motion that compensates for all axes moments on the preset ZMP before the robot begins walking. Its basic algorithm was proposed by [25].

With this programming library, complex locomotion can be realized as adequateness of these basic motion patterns. The linking motion between the basic motions of the robot is also automatically generated for the continuous motion patterns.

AIST's Motion Generator AIST's motion generator is based on a new dynamic modeling method named *Three-Dimensional Linear Inverted Pendulum Mode (3D-LIPM)* [12]. When a biped robot is supporting its body on one leg, its dominant dynamics can be represented by a single inverted pendulum that connects the supporting foot and the robot's centre of gravity. By applying constraints to limit the motion of the humanoid robot as an inverted pendulum moving in a plane, it allows a separate controller design for the sagittal (x-z) and the lateral (y-z) motions and simplifies a walking pattern generation a great deal. This merit makes real-time walk generation possible.

3.2 Stabilizer of HRP-1S

The absorption of the landing-impact force is very important for practical biped robots[24]. HRP-1S has impact absorption mechanisms in its feet quite similar to Honda P2[4]. It is effective in reducing the transmission of impact forces, however it makes a rotational compliance between the ankle and the ground.

In the motion generator, it is very hard to consider this compliance effect because of its high nonlinearity and construct perfect models of the robot and the working environment. This leads to the necessity of a reflex controller to maintain the stability of HRP-1S, even if the joint servo controllers were perfect. There are many reflex control method of humanoid and biped robots [1][4][6][13][20][21][24]. We have introduced the following three control subsystem to achieve the stable motion of HRP-1S.

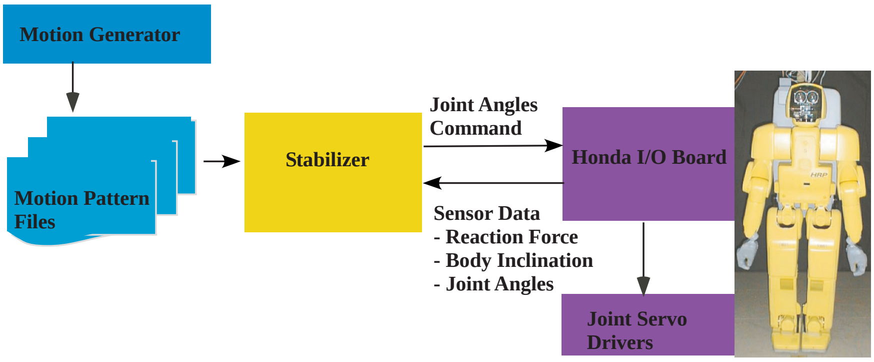

Fig. 2. Motion Control System of HRP-1S

Body Inclination Control By adjusting each foot's desired position and orientation according to the difference between the desired body posture and the actual body posture, the robot can be regarded as an inverted pendulum, and its inclination is able to be recovered. Here the desired body posture is given by the motion generators. The actual body posture is estimated by Kalman filter from the data of the body inclination sensor which consists of gyroscopes and G-force sensors. During the single support phase, the orientation of the supporting foot is controlled around the desired ZMP given by the motion generator. It makes the back section of the supporting foot lower when the robot's body tips backward. On the other hand, orientation and position of both feet are controlled around the desired ZMP during the double support phase.

ZMP Dumping Control In order to reduce the error between the desired ZMP trajectory given by the motion generators and the actual ZMP calculated from contact force/torque information measured by 6 axes force/torque sensor integrated within the each foot of the robot, the horizontal position of the torso is adjusted. When the actual ZMP is forward of the desired ZMP, the torso is accelerated forward. This control makes the actual ZMP smooth as connecting a sky-hook dumper to the torso. Actually, the motion of the torso is produced by the opposite movement of the support foot.

Foot Adjusting Control In order to move on an uneven terrain with bumps and dents, each foot can be adjusted the inclination of the ground. The body inclination control mentioned above shifts the desired ZMP to an appropriate position that we call the modified ZMP. Even if the ground surface is inclined, the force/torque sensors in the feet detect changes in the ground reaction force. Using these changes, the actual ZMP is controlled to the modified ZMP by rotating each supporting foot.

Finally, the desired angles of all joints are calculated from the planned motion of the whole body by the pattern generator and the modified feet position and orientation using inverse kinematics.

4 Experiments

In order to confirm the performance of the controller of HRP-1S, we did several experiments.

Figure 3 through 4 show the scenes and the data while HRP-1S was walking 6 steps on the flat floor according to the same generated motion pattern by Hitachi/Waseda's motion generator. The step length is 0.2 [m/step] and the step period is 0.8 [sec/step].

Figure 3 shows body inclinations and ground reaction forces while HRP-1S was walking without the stabilizer. In this experiment, the body inclined 0.1 [deg] around a roll axis and 3.4 [deg] around a pitch axis when HRP-1S started walk at 12 [sec] as shown in Fig. 3. The body inclinations were increasing step by step. HRP-1S walked 3 steps, and it tipped back over after around 16 [sec]. The body inclinations recovered after 16.4 [sec], because the body was hanging up by a crane.

Even if the impact absorption mechanisms are install in the feet, it was hard to reduce the impact caused by such huge unexpected inclinations. Consequentially, the maximum ground reaction force was over 200 [kgf] that is 1.7 times as heavy as the weight of HRP-1S.

Figure 4 shows the results while HRP-1S was walking with the stabilizer. In this experiment, the body inclined about 1 [deg] around a pitch axis when HRP-1S started walking. While it was walking, the body inclination around the roll axis was stable in the region of -0.4 [deg] through +0.6 [deg] and that around the pitch axis was a stable in the region of +0.2 [deg] through +1.2 [deg]. The maximum ground reaction force was about 131 [kgf] that is only 1.1 times of the weight of HRP-1S.

Figure 5 shows the experimental results walking on an unknown rigid rough ground with a height of 20 [mm] or less and a gradient of 5 [%] or less. HRP-1S can stably walk on the unknown and uneven terrain with the step length 0.2 [m/step] and the step period 0.8 [sec/step].

Figure 6 shows the experimental results turning on a flat floor with the step length about 0.2 [m/step], the step period 0.8 [sec/step], and the turning angle 15 [deg/step]. In this experiment, we used AIST's Motion Generator that can generate more flexible walking pattern.

As shown in these figures, we could successfully control Honda humanoid robot by our own software.

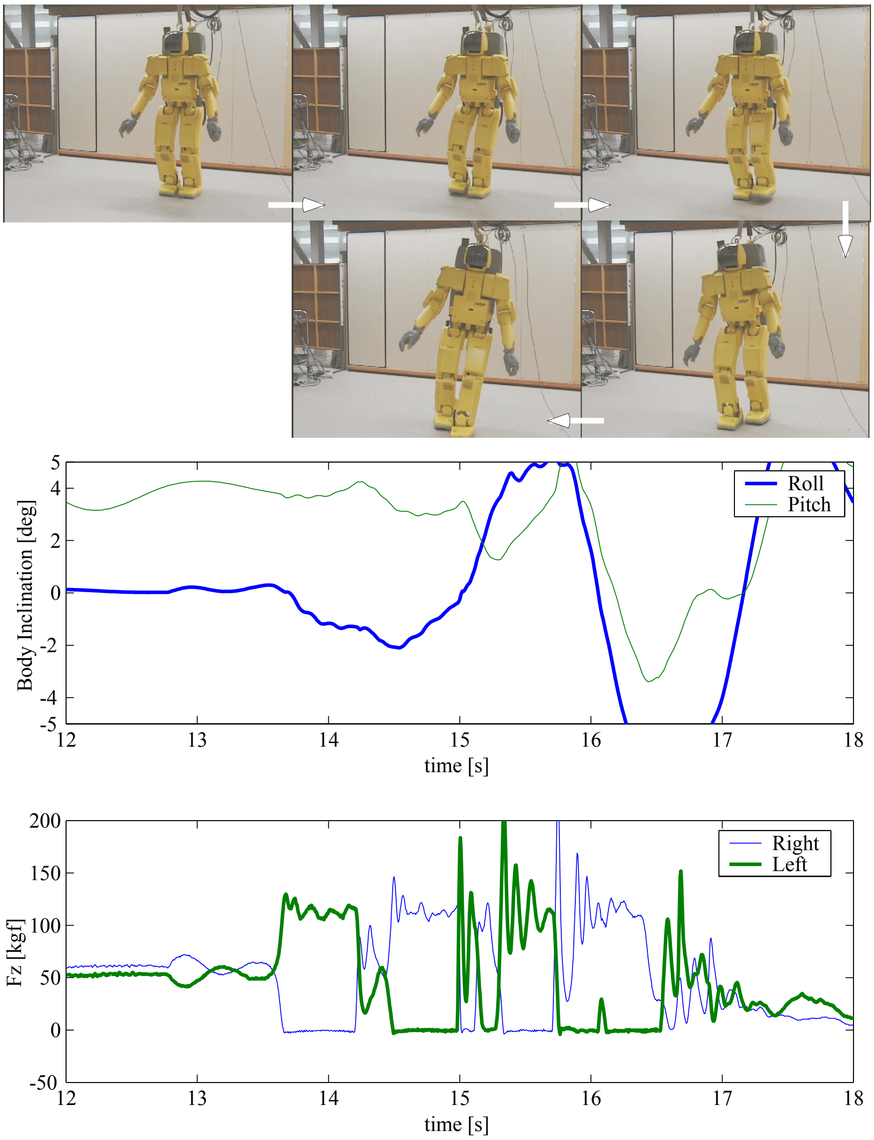

Fig. 3. Experimental Results: HRP-1S walks without stabilizer

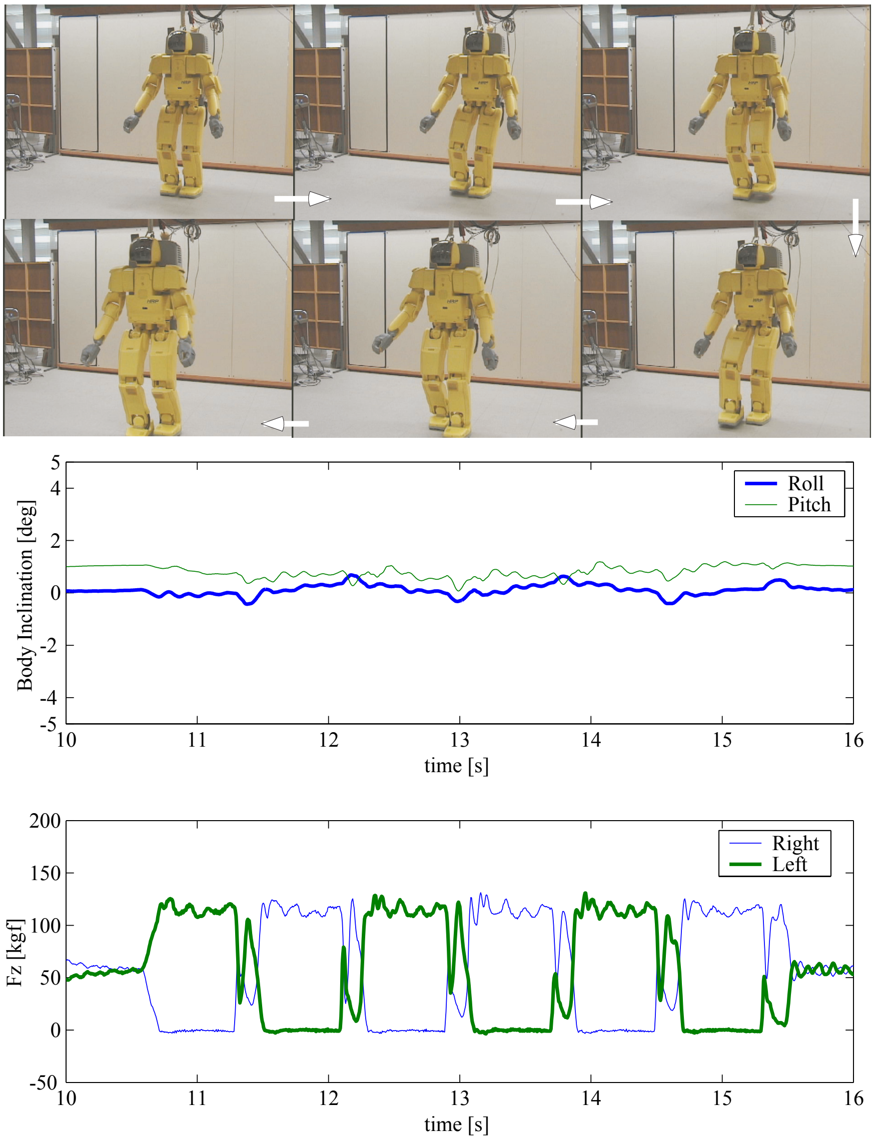

Fig. 4. Experimental Results: HRP-1S walks with stabilizer

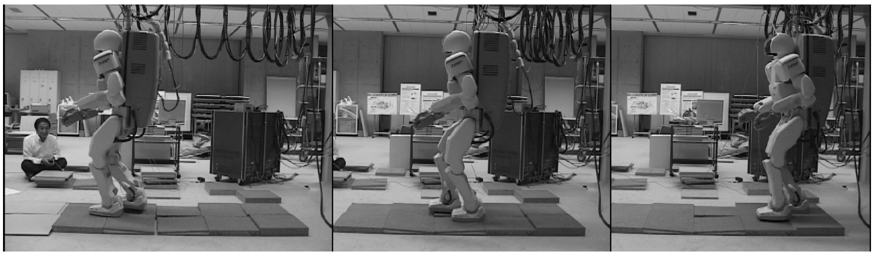

Fig. 5. Straight forward walking of HRP-1S on unknown rough terrain

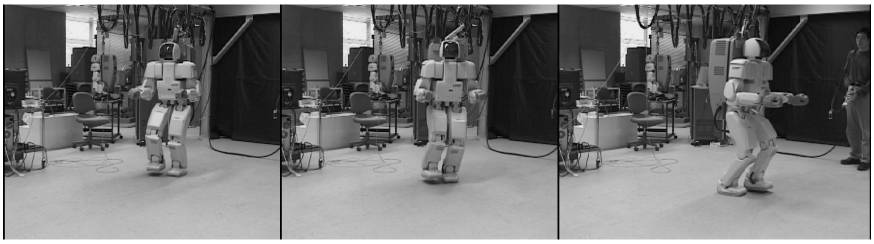

Fig. 6. Turning of HRP-1S

5 Conclusions

This paper presented how we can control a Honda's humanoid robot without Honda's control software.

Future works include the development of a real-time whole body motion generator and a more stable balance controller to adapt more rough terrain. The implementation of the real time collision checker is also imperative to avoid a self destruction.

References

1. Azevedo, C., Poignet, P., Espiau, B. (2001) Moving horizon control for biped robots without reference trajectory. Proc. IEEE Int. Conf. Robotics and Automation 2762–2767
2. Espiau, B., Sardain, P. (2000) The anthropomorphic biped robot BIP2000. Proc. IEEE Int. Conf. Robotics and Automation 3997–4002
3. Gienger, M., Löffler, K., Pfeiffer, F. (2001) Towards the design of a biped jogging robot. Proc. IEEE Int. Conf. Robotics and Automation 4140–4145
4. Hirai, K., Hirose, M. t al. (1998) The development of Honda humanoid robot. Proc. IEEE Int. Conf. Robotics and Automation 1321–1326
5. Hirose, M., Haikawa, Y., et al. (2001) Development of humanoid robot ASIMO. Proc. Workshop on Explorations towards Humanoid Robot Applications of IEEE/RSJ International Conference on Intelligent Robots and Systems

6. Huang, Q., Nakamura, Y., Inamura, T. (2001) Humanoids walk with feedforward dynamic pattern and feedback sensory reflection, Proc. IEEE Int. Conf. Robotics and Automation 4220–4225
7. Huang, Q., Kajita, S., et al. (1999) A high stability smooth walking pattern for a biped robot Proc. IEEE Int. Conf. Robotics and Automation 65–71
8. Inoue, H., Tachi, S. et al. (2000) HRP: Humanoid Robotics Project of METI. Proc. IEEE-RAS Int. Conf. Humanoid Robots
9. Inoue, H., Tachi, S. et al. (2001) Overview of humanoid robotics project of METI, Proc. Int. Symp. Robotics 1478–1482
10. Ishida, T., Kuroki, Y. (2001) Motion entertainment by a small humanoid robot based on Open-R. Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems
11. Ishiwata, Y., Matsui, T. (1998) Development of Linux which has advanced real-time processing function. Proc. RSJ Annual Conf. 355–356
12. Kajita, S., Kanehiro, et al. (2001) The 3D Linear Inverted Pendulum Mode: A simple modeling for a biped walking pattern generation. Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems 239–246
13. Kagami, S., Nishiwaki, K., et al. (2000) A fast generation method of a dynamically stable humanoid robot trajectory with enhanced ZMP constraint. Proc. IEEE-RAS Int. Conf. Humanoid Robots
14. Kagami, S., Nishiwaki, K., et al. (2001) Design and implementation of software research platform for humanoid robotics : H6 Proc. IEEE Int. Conf. Robotics and Automation 2431–2436
15. Kanehiro, F., Inaba, M., Inoue, H. (1996) Development of a two-armed bipedal robot that can walk and carry objects, Proc. IEEE/RSJ Int. Conf. Intelligent Robot and Systems 23–28
16. Kanehiro, F., Miyata, N. et al. (2001) Virtual humanoid robot platform to develop controllers of real humanoid robots without porting. Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems
17. Lorch, O., Seara, J. F., et al. (2002) Perception errors in vision guided walking: analysis, modeling, and filtering. Proc. IEEE Int. Conf. Robotics and Automation 2048–2053
18. Nemoto, Y., Hattori, S., et al. (2001) Development of a basic motion control library for humanoid. Proc. Int. Symp. Robotics 1489–1490
19. Nishiwaki, K., Sugihara, T., et al. (2001) Online mixture and connection of basic motions for humanoid walking control by footprint specification. Proc. IEEE Int. Conf. Robotics and Automation 4110–4115
20. Park, J. H., Kwon, O. (2001) Reflex control of biped robot locomotion on a slippery surface. Proc. IEEE Int. Conf. Robotics and Automation 4134–4139
21. Pratt, J., Pratt, G., (1998) Intuitive control of a planar bipedal walking robot. Proc. IEEE Int. Conf. Robotics and Automation 2014–2021
22. Vukobratović, M., Stepanenko, J. (1972) On the stability of anthropomorphic systems. Mathematical Biosciences **15**, 1–37
23. Yagi, M. and Lumelsky, V. (1999) Biped robot locomotion in scenes with unknown obstacles. Proc. IEEE Int. Conf. Robotics and Automation 375–380
24. Yamaguchi, J., Kinoshita, N., et al. (1996) Development of a dynamic biped walking system for humanoid - development of a biped walking robot adapting to the humans' living floor -. Proc. IEEE Int. Conf. Robotics and Automation 232–239

25. Yamaguchi, J., Soga, E. (1999) Development of a bipedal humanoid robot - control method of whole body cooperative dynamic biped walking. Proc. IEEE Int. Conf. Robotics and Automation 368–374
26. Zheng, Y.F., Shen, J. (1990) Gait Synthesis for the SD-2 Biped Robot to Climb Sloping Surface. IEEE Trans. Robotics and Automation **6-1**, 86–96