Walking biped humanoids that perform manual labour

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The Humanoid Robotics Project of the Ministry of Economy, Trade and Industry of Japan realized that biped humanoid robots can perform manual labour. The project developed humanoid robot platforms, consisting of humanoid robot hardware and a package of fundamental software, and explored applications of humanoid robots on them. The applications include maintenance tasks of industrial plants, teleoperation of industrial vehicles, cooperative tasks with a human, guarding the home and office and the care of patients in beds.

Keywords: humanoid robots; biped walking; applications

1. Introduction

The infrastructure of our society is designed for humans. For example, the sizes of doors and the heights of steps on stairs are determined by considering the heights of people and the lengths of their legs. The cockpits of the machines driven by humans are also designed to fit the geometry and kinematics of people. Therefore, we can apply robots to our society without extra investment in the infrastructure if the robots have the human shape. This is our main motivation to develop biped humanoid robots.

The Ministry of Economy, Trade and Industry of Japan promoted the Humanoid Robotics Project (HRP) during 1998 and 2002 to realize that biped humanoid robots can perform manual labour in our society (Inoue et al. 2000, 2001). The project leader of HRP was Hirochika Inoue and the objectives of the HRP include the development of a humanoid robotics platform and the exploration of humanoid robot applications. The platform consists of humanoid robots, teleoperation systems and a package of fundamental software for them. The first version of the humanoid robots was HRP-1 developed by Honda R&D (Inoue et al. 2000, 2001). The controller of HRP-1 for its biped locomotion was also developed by Honda R&D. HRP-1 has been used for investigating the applications of a humanoid robot for the maintenance tasks of industrial plants and guarding the home and office (Inoue & Hirukawa 2001). These applications demand that robots must go up and down stairs, and biped robots can satisfy the demand.

As the next step, the National Institute of Advanced Industrial Science and Technology (AIST) has replaced the control software to have more flexibility for motions (Yokoi et al. 2001). We call the combination of HRP-1 hardware and

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AIST controller HRP-1S. We can control the arms and legs of HRP-1S simultaneously, which was not possible on HRP-1 owing to a restriction of the Honda controller (Inoue & Hirukawa 2001). HRP-1S is applied to the teleoperation of industrial vehicles. The vehicles can be driven by the humanoid robot without the modification of the driver cockpit. HRP-1S is also applied to the care of patients in beds. The patients can feel relaxed since the robot has a human shape.

The dynamics simulator of humanoid robots has also been developed in HRP (Yamane & Nakamura 1999). The software developed on the simulator can be applied to the hardware as it is. We call the package of the simulator and the motion control software Open Architecture Humanoid Robotics Platform (OPENHRP) (Kanehiro et al. 2002).

HRP developed the second hardware platform. It is called HRP-2 whose features include a light weight and compact body. The height of HRP-2 is 1540 mm and the weight is 58 kg, and it does not have a backpack, which HRP-1 needed to enclose the controller. Note that OPENHRP is commonly used as the software platform for HRP-2 and HRP-1S. HRP-2 is applied to a cooperative task with a human. HRP-2 can replace a human partner in a natural way since it has a human shape and can walk.

The rest of the paper is organized as follows. Section 2 describes the detailed specifications of the platforms. Section 3 presents the applications and §4 concludes the paper.

2. Humanoid robotics platforms

(a) Humanoid robot hardware

HRP-1 is 1600 mm in height, 120 kg in weight and has 30 degrees of the freedom (d.f.) consisting of two joints for head, seven joints for each arm, one joint for each hand and six joints for each leg. HRP-1 is an enhanced version of Honda P3. The main difference is its interface for teleoperations. Figure 1 shows the front and side views of HRP-1.
The development of HRP-2 started from the leg module, HRP-2L (Kaneko et al. 2002a), and the arm module, HRP-2A. Figure 2a, b shows HRP-2L and HRP-2A, respectively. HRP-2P, the HRP-2 prototype, was developed after careful examination (Kaneko et al. 2002b). A snapshot of HRP-2P is shown in figure 3a, and the mechanical configuration of HRP-2P is illustrated in figure 3b. As shown in figure 3, HRP-2P has unique configurations. One is that the hip joint of HRP-2P has a cantilever-type structure. The other is that HRP-2P has a waist joint. Table 1 shows the specifications of HRP-2P.

HRP-2 was completed by improving HRP-2P in the following points. HRP-2 can walk for 60 min at the speed of 1.25 km h⁻¹ by the battery on the robot, whereas HRP-2P could walk for 20 min at 0.675 km h⁻¹. The improvement was realized using more powerful motors for the legs, introducing a cooling system for...
them and employing a better battery. HRP-2 can walk more stably than HRP-2P, since the rigidity of the mechanism of HRP-2 was improved from that of HRP-2P. Figure 4 shows a snapshot of HRP-2. HRP-2 has been used as a platform robot for the research and development of humanoid robotics after HRP was completed.

(b) Software platform OPENHRP

Since humanoid robots demand various kinds of software, the architecture of the software must have a modular structure. Stasse & Kuniyoshi (2000) developed PredN that has a modular structure and can operate with multi-thread on ATM and the Ethernet (Stasse & Kuniyoshi 2000). Oka et al. (1996) investigated an asynchronous parallel system.

OPENHRP is implemented as a distributed object system on CORBA (Common Object Request Broker Architecture). A user can implement a controller using an arbitrary language on an arbitrary operating system if it has a CORBA binding. OPENHRP consists of several CORBA servers. Each server can be replaced with another implementation if it has the same interface defined by the interface definition language (IDL). The users of OPENHRP can replace a server of OPENHRP or add a new server to examine their contributions while using the remaining part of OPENHRP. In the sense, the users can concentrate their effort to the point where they have their interests. Using the language independence feature of CORBA, some of the servers are implemented using JAVA and JAVA3D, the others are implemented using C and C++. Currently, OPENHRP supports WINDOWS 2000/XP/98/Me and LINUX (Ishiwata & Matsui 1998). Each server consists of a CORBA interface part, a native language interface part and a core logic part. A realtime routine uses native interface and a non-realtime routine does CORBA interface. As a result, a lot of codes are shared between the simulator and the controller, which can make the development more efficient.

Table 1. Specifications of HRP-2P.

<table>
<thead>
<tr>
<th>d.f.</th>
<th>head: 2 d.f. (pitch, yaw) = 2 d.f.</th>
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<tbody>
<tr>
<td></td>
<td>arms: 6 d.f. (shoulder: 3, elbow: 2, wrist: 1 × 2 = 12 d.f.</td>
</tr>
<tr>
<td></td>
<td>hands: 1 d.f. (open/close) × 2 = 2 d.f.</td>
</tr>
<tr>
<td></td>
<td>waist: 2 d.f. (pitch, yaw) = 2 d.f.</td>
</tr>
<tr>
<td></td>
<td>legs: 6 d.f. (hip: 3, knee: 1, ankle: 2) = 12 d.f.</td>
</tr>
<tr>
<td></td>
<td>total: 30 d.f.</td>
</tr>
<tr>
<td>dimensions</td>
<td>height: 1549.6 (mm)</td>
</tr>
<tr>
<td></td>
<td>width: 654.0 (mm)</td>
</tr>
<tr>
<td></td>
<td>depth: 337.7 (mm)</td>
</tr>
<tr>
<td></td>
<td>upper arm length: 250.0 (mm)</td>
</tr>
<tr>
<td></td>
<td>lower arm length: 250.0 (mm)</td>
</tr>
<tr>
<td></td>
<td>upper leg length: 300.0 (mm)</td>
</tr>
<tr>
<td></td>
<td>lower leg length: 300.0 (mm)</td>
</tr>
<tr>
<td>weight</td>
<td>head: 1.2 (kg) = 1.2 (kg)</td>
</tr>
<tr>
<td></td>
<td>arms: 5.4 (kg arm⁻¹) × 2 = 10.8 (kg)</td>
</tr>
<tr>
<td></td>
<td>bodies: 26.9 (kg) = 26.9 (kg)</td>
</tr>
<tr>
<td></td>
<td>legs: 7.6 (kg/leg) × 2 = 15.2 (kg)</td>
</tr>
<tr>
<td></td>
<td>total: 54.1 (kg)</td>
</tr>
</tbody>
</table>
A simulation is controlled by a CORBA client that has a graphical interface shown in figure 5, which is called the integrated simulation environment (ISE). ISE uses services provided by four CORBA servers, i.e. collision checker, model parser, dynamics and view simulator. The model parser loads a virtual reality modelling language (VRML) file describing the geometric models and dynamics parameters of robots and their working environment, and provides these data to other servers. The collision checker finds the interference between two sets of triangles is inspected, and the position, normal vector and the depth of each intersecting point are found. The dynamics server computes the forward dynamics of the robots. The view simulator generates the field of view from cameras on a humanoid.

The controller server is the controller of a robot, which is usually developed by the users of OpenHRP. A walking pattern generator is a part of the controller and outputs dynamically stable walking patterns (Kajita et al. 2001). Another building block of the controller, is a feedback controller which stabilizes the motions.

When the software has been examined on the simulator, it can be applied to a hardware platform as it is. That is, the binary compatibility between the software on the simulator and that on the robot is kept under the assumption that the identical processor is used for the simulator and the robot. The compatibility is realized by the introduction of the common adapter at the application programming interface of the controller and synchronization mechanism between the simulator and the robot. After the required software has been downloaded to a robot, the behaviour of the robot can be initiated by sending a script to the robot.

Figure 6 shows the snapshots of HRP-2P walking. HRP-2P can also get up from the floor (Kanehiro et al. 2003). HRP-2P is the first human-size humanoid robot that can get up from the floor (figure 7; Kanehiro et al. 2002). HRP-2P can also lie down on the floor (Kanehiro et al. 2003). Besides these motions, a
controlled falling motion that minimizes the damage to the robot was realized using HRP-2P (Fujiwara et al. 2002). A snapshot of the motion is shown in figure 8. The realization of falling down and getting up is very important. Some people may claim that a humanoid robot is useless since the robot stops to operate when it falls down. It is true that a novel technology cannot be accepted by society if it comes with a weak point. The falling down and getting up motions have been studied to overcome this weak point.

3. Explorations of applications

Must robots walk instead of moving on wheels? Must robots look like humans? We believe that a biped humanoid robot can be justified if any of the following characteristics of the robot makes sense in the applications.
(i) The robot can move in the environment that is designed for humans.
(ii) The robot can operate a machine without the modification of the cockpit.
(iii) The robot has a human shape with two arms and two legs.

The current artificial environment is designed for humans. For example, the width of a corridor is determined by the size of humans, and the height of steps on stairs by the length of a human leg. Therefore, a robot can move in the current environment without re-investment to the environment when the kinematics of the robot is compatible with that of humans.

Some tasks in the hazardous environment can be executed by industrial machines whose cockpits are equipped with mechanism for teleoperation. For example, a backhoe with such a mechanism has been teleoperated and used for restoration works in disaster areas. We claim that a humanoid robot can be used to teleoperate it without the modification of the cockpit.

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The last characteristic is important for entertainment applications. People have shown enthusiasm for walking humanoid robots on two legs. Besides, patients in beds may feel more relaxed when a robot with a human shape takes care of them.

Considering these characteristics, HRP explored five applications of humanoid robots (Inoue et al. 2001). The maintenance tasks of industrial plants and guarding the home and office were investigated to confirm the first characteristic. The teleoperation of industrial vehicles was studied to use the second one. The care of patients in beds and cooperative tasks with a human were examined for the first and third ones. Brief results are described as follows.

(a) Maintenance tasks of industrial plants

Industrial plants can be run without a break if teleoperated robots are able to maintain them, including hazardous areas. Besides, we can expect that the plants do not need remodelling when the maintenance robots are humanoid robots. The operator of the humanoid robot for the maintenance task may feel as if he/she is in a remote plant. Besides, a biped humanoid robot can go up and down stairs. HRP-1 can go up and down stairs whose step height is no more than 200 mm. An industrial plant may have a step with a height of up to 300 mm, therefore more improvement is required to apply the robot to a real plant.

HRP-1 was used to investigate the application. A snapshot of the experiments is shown in figure 9. We found a navigator to lead the robot to the destination through corridors and up stairs using RFID. The maintenance tasks included the inspection of instrumentation devices and the manipulation of handles in the plants, which were executed by teleoperation. A simple teleoperation cockpit was developed for the purpose.

(b) Guarding the home and office

Since the environment of the standard home has a critical size for humans, i.e. the sizes of doors and the widths of corridors are minimum for humans to move, biped humanoid robots have the maximum chance to move around in the environment. We connected the humanoid robot to a cellular phone and let the robot serve as a home sitter from the observation.

One may suppose that networked cameras are enough for the purpose, but we claim that the robot can do more than cameras. For example, the robot can manipulate objects to remove occlusion and to turn off a switch if the switch was unexpectedly on. Figure 10 shows the robot turning off the switch of an oven when a fire in the oven was found by the robot. The robot has to execute such tasks autonomously since the master controller is a cellular phone. A vision system for the autonomous navigation and manipulation was developed for the purpose.

(c) Teleoperations of construction machines

Construction machines play an important role in rescue activities, but sometimes the environments are too hazardous to approach. If a humanoid robot can drive a construction machine and it can be operated from a remote site, the
construction machine can work in a dangerous place. This humanoid robot operator has two advantages over a automated construction machine. It is much easier to carry the robot to a disaster site than moving the special construction machine. Besides, the robot may be less expensive than developing the special automated machine whose required number is relatively small.

This application was investigated using HRP-1S. At first, the robot must get on a construction machine. This is very difficult because drivers’ cockpits in most construction machines are very narrow. The second task is the operation of the machine by the foot of the robot. The last one includes an easy-to-use operator’s cockpit including foot pedals to control the foot of the robot. A snapshot of the backhoe with the humanoid driver is shown in figure 11 and that of the teleoperation cockpit in figure 12. Note that HRP-1S wears a water-proof suit to operate in the open air.

Figure 9. Maintenance task of an industrial plant (Mitsubishi Heavy Industries).

Figure 10. HRP-1 turning off a fire in an oven (Fujitsu Ltd and Alsok (Sohgo Security Services Co., Ltd)).
Care of patients in beds

It is very significant if humanoid robots can replace some parts of tasks for taking care of elderly/handicapped people. The advantages of applying humanoid robots to the care of humans are threefold: the daily environments do not need to be modified; people may feel familiar with the robots owing to the human-like shape; and the robots do not need a break.

To test the application, we enhanced humanoid robot HRP-1 at the following points. We developed a special tool to let the robot pick up small objects. The robot wears soft clothes to avoid dangerous collision with surrounding people. A small portable controller has been developed to enable the operator to use the robot easily. A snapshot of the robot taking care of people in a bed is shown in figure 13.
Considering cooperative works in the open air, we can see that many tasks can be carried out by an expert and a novice. For example, we need two people to carry a piece of wood, but only one person should be an expert when the piece is mounted on a house. It is more realistic for a humanoid robot to be a novice partner of an expert human, and we can then save a labour force. We developed the following technologies to test the application. A small portable/wearable controller of the robot was developed for the human partner. The arms are under compliance control to help the robot work cooperatively with the human. The ability of the biped locomotion of the robot was enhanced to cope with rough surface in the open air. A stereo vision was also used to locate the position of the hand relative to the target object (Sumi et al. 2002). These enhancements were implemented on HRP-2. A snapshot of HRP-2 carrying a panel with a human partner is shown in figure 14 and assembling it in figure 15.

Figure 13. HRP-1S taking care of people (Hitachi, Matsushita Electric Works).

Figure 14. HRP-2 carrying a panel with a human (Yaskawa Electric, Shimizu Corporation, Kawada Industries, AIST).

(e) Cooperative works in the open air

Considering cooperative works in the open air, we can see that many tasks can be carried out by an expert and a novice. For example, we need two people to carry a piece of wood, but only one person should be an expert when the piece is mounted on a house. It is more realistic for a humanoid robot to be a novice partner of an expert human, and we can then save a labour force. We developed the following technologies to test the application. A small portable/wearable controller of the robot was developed for the human partner. The arms are under compliance control to help the robot work cooperatively with the human. The ability of the biped locomotion of the robot was enhanced to cope with rough surface in the open air. A stereo vision was also used to locate the position of the hand relative to the target object (Sumi et al. 2002). These enhancements were implemented on HRP-2. A snapshot of HRP-2 carrying a panel with a human partner is shown in figure 14 and assembling it in figure 15.
4. Conclusions

This paper overviews the results of HRP. HRP developed HRP-2 as a hardware platform and OpenHRP as a software platform, which have been used in the research of humanoid robotics after HRP was completed.

HRP also investigated several applications of humanoid robots and proved that humanoid robots have advantages in the applications described here. It is true that humanoid robots need more time to be applied in real society on a large scale, but we have already started approaching the goal with a rapid speed.

We believe that biped humanoid robots have a good chance of being the largest product of this century.

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References


