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Whole Body Teleoperation of a Humanoid Robot -Development of a Simple Master Device using Joysticks-

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Abstract

A teleoperation system for whole body motions of a humanoid robot using a simple joystick master device is developed. Humanoid robots are physically similar to human and usually possess a large number of degrees of freedom. Getting hints from the shifting of locus of attention for body motions between the joints of human body during task executions, we propose a switching command based teleoperation system of which the operator selects only the necessary point of the humanoid robot's body for manipulation. In this paper, we present the implementation of this switching command based teleoperation system and the experimental results using this system to teleoperate humanoid robot HRP-1S developed in the Humanoid Robotics Project of the Ministry of Economy, Trade and Industry of Japan

1 Introduction

The tremendous advance in network technologies and robotics have provided us with the infrastructure to transmit not only text, sounds and images but also physical actions. As telephone facilitates human as a tool for extending human voice, humanoid robots with network technologies could be powerful tools for extending human existence. With human-like physical form, humanoid robots are potential tools to function in the real world, which is designed for human[1]. They can be proxies for human to do dangerous or dirty work that would not be done by human if there is a choice, hence providing human with more safety, freedom and time[2].

Projects utilizing teleoperated humanoid robots have begun in search for systems which can do the same work currently done by human in critical environments, for example executing space mission[3], operations of power generation plants, tasks at construction sites and disaster relief missions[4]. There have been reports on humanoid robot teleoperation systems equipped with full master-slave manipulation interface and also systems utilizing teleoperation interface with high autonomy.

During phase one of the Humanoid Robotics Project(HRP) of the Ministry of Economy, Trade and Industry of Japan, a full master-slave teleoperation platform was developed to control a humanoid robot[5]. With its exoskeleton master device and immersive displays, this system enables the operator to control the slave humanoid robot as if the operator has become one to the robot. Although such full master-slave teleoperation systems allow flexible manipulation of the humaniod robot, they require large and complex interface. Moreover, despite being expensive and complicated for being large in system atchitecture, it would not be very comfortable to operate in an exoskeleton device fixed to the body all the time to accomplish all tasks.

There are also projects utilizing Graphical User Interface to teleoperate humanoid robots with higher autonomy[6][7]. Although this kind of highly autonomous, supervisory-control-like teleoperation systems require only simple input devices, they are normally less flexible and can only perform pre-defined motions.

Considering utilizing teleoperated humaoid robots to perform tasks in critical environments and during emergencies, a teleoperation system with the following characteristics will be of great effectiveness.

- A system that is constructed on compact and simple devices that can be carried around easily
- A system that is able to facilitate the operator in teleoperating whole body motions of the slave robot flexibily and in an intuitive manner

This paper describes our endeavour to realize a teleoperation system that can provide flexible master slave commands to manipulate a humamoid robot in a whole body manner using only simple input devices. The paper is organized in the following sequence: Section 2 introduces the conceptual framework of the system. Section 3 describes the implementation of the system on a real humanoid robot. Section 4 reports the experiments done utilizing the system and section 5 concludes the present stage of this research.

2 Whole Body Teleoperation of Humanoid Robots

The construction of an effective communication interface between the operator and the slave robot, and the establishment of an effective teleoperation method to manipulate the complex multi-joint humanoid robot are the two technical challenges for the development of a whole body teleoperation system for humanoid robots.

In order to interact with a remote environment by controlling a remote robot proxy, an effective communication interface, which provides a two-way information link connecting the human operator with the remote robot, is of great importance. An effective interface should be able to provide the following functions.

- Sensor Information Display: function to display the state of the remote environment as being sensed by the sensors of the remote robot
- Robot Information Display: function to display information of the conditions of the remote robot
- Robot Manipulation Command Input: function to transmit physical actions to interact with the remote environment by manipulating the remote robot

The effectiveness of these functions are significant as they affect the operator's perception and performance during teleoperation. An effective interface should be able to extend the operator's sensory perception into remote environment accurately and be able to provide flexible manipulation to teleoperate the remote robot(Figure 1).

2.1 Whole Body Teleoperation Using Simple Input Device

A young boy immerses himself into the virtual game environment feeling the sense of becoming one to the human form game character only by controlling his gamepad. Using the simple input device, he manipulates the game character following pre-defined motion generation rules. His perception on the motions of the game character in the virtual world fits the expected effects of the actions he performs using the gamepad. The existence of this continuing

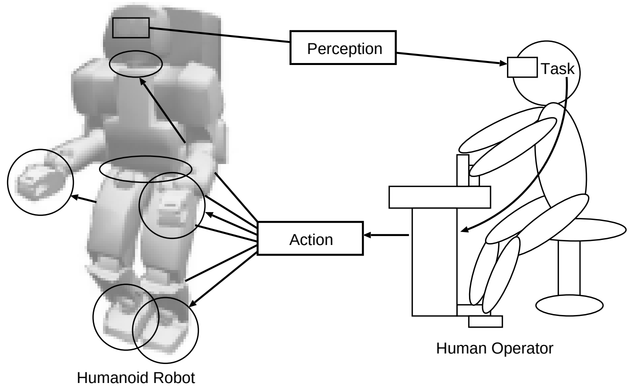

Figure 1: *Perception-action loop between a human operator and a remote humanoid robot*

perception-action loop enables him to develop the sense of becoming one to the virtual character.

A humanoid robot is human-like in physical form and is expected to move in a human-like manner. By constructing a teleoperation system of a humanoid robot with motion generation rules similar to that of a human, human operators should be able to manipulate the slave humanoid robot stablely and safely.

With the above observations, by constructing a system which generates whole body motions following simple operation rules, we are aiming at realizing a whole body teleoperation system for humanoid robots using only simple input devices like a joystick or a gamepad.

2.2 A Switching Command Based Whole Body Teleoperation

Humanoid robots are highly-complex structures that possess degrees of freedom far exceeding the number of input for a joystick or a gamepad that we are using to construct a whole body teleoperation system.

Human has only one locus of attention, we can only conciously attend to one object or idea at a time[8]. Despite having possess a large number of joints in our physical body, we carry out a specific task with our locus of attention focusing only on some specific points of our body. Depending on the desired task, the points on which we execute motor command differ. For example, during a task to reach out to a bottle on a table in front, our locus of attention is on our hand to accomplish the task. When we try to lean down, our locus of attention is on our torso to give command to our body to go downward. When we try to kick a ball, our locus of attention shifts on to the leg.

Human motions are generated with a mixture of conscious motion generations and subconscious motion generations. Conscious motion generations are triggered and supervised by concious executions of motor command on specific points of the body, which are the locus of attention of the motion, to accomplish the desired force or position of the targeted points. Subconscious motion generations provide automatic, reflective motions to ensure the stability and safety of the body, such as legs movements for maintaining body balance and reflective motions to prevent injury, which are generated without the supervision of the conscious mind.

Getting hints from these characteristics of human motor command and motion generations, we have designed a teleoperation system to manipulate humanoid robots in a similar manner. As the locus of attention shifts between points of the body during task executions, we propose a switching command based method of which the operator selects only the necessary target points of the robot's body to teleoperate(Figure 2). Like the motion generation of human, which is a mixture of conscious and subconscious generations, we have designed a motion generation architecture in which the configurations for the degrees of freedom necessary to realize the desired positon and orientation of the targeted points are calculated based on the input command, and then the configuration for other redundant joints are generated automatically based on a set of pre-defined rules to obtain stability and task performance.

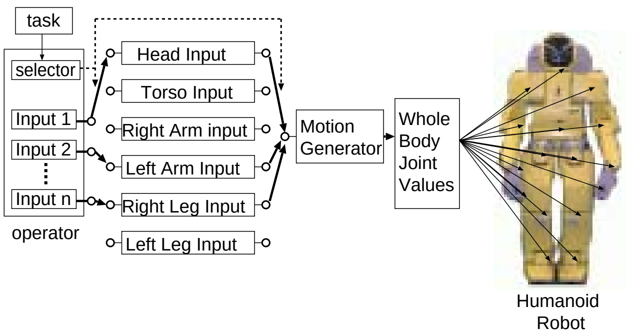

Figure 2: *A Switching Command Based Teleoperation System*

3 Implementation on Humanoid Robot HRP-1S

The following subsections describe the design and the implementation of the proposed switching command based teleoperation system in details. The whole body teleoperation system was first implemented on a virtual robot model and tested using a simulator, OpenHRP, which is developed in the HRP[10]. Having confirm the effectiveness of the algorithms, we implemented the system on a real humanoid robot, HRP-1S, also developed in the HRP[11].

3.1 Humanoid Robot HRP-1S

HRP-1S shown in Figure 3 is a humanoid robot 1600[mm] in height, 600[mm] in width, and 99[kg] in weight excluding batteries. It has 30 degreess of freedom(DOF), with 6 DOFs in each leg, 8 DOFs in each arm including a 1 DOF hand gripper, and 2 DOFs in the head.

The torso is equipped with an inclination sensor consists of gyroscopes and G-force sensors. Each foot and wrist is equipped with a force/torque sensor. The head is equipped with two video cameras.

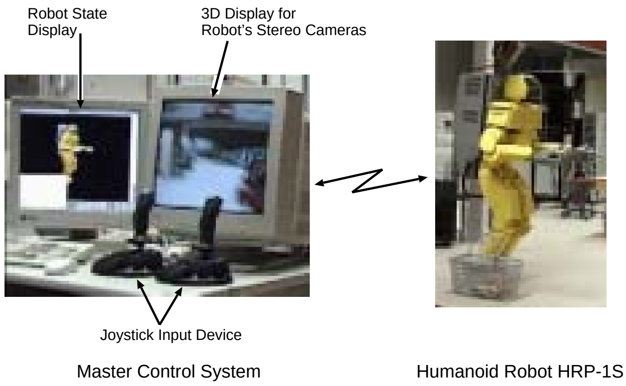

Figure 3: *Whole Body Teleoperation System of HRP-1S*

3.2 Hardware System

The hardware for the proposed master control system (Figure 3) is constructed using a 3D display, a robot state display and two joysticks.

The 3D display provides real images captured by the stereo video cameras on board of HRP-1S. The robot state display aids the operator for a more effective teleoperation by presenting the information of the slave robot using a visual simulator and a text console. The visual simulator provides a 3D simulation displaying current configuration of the robot, which is simulated based on the data of all joints of the robot. The text console displays the data of the inclination sensors and force/torque sensors of the robot, and the real ZMP value calculated based on the data of the force sensors equipped on each foot.

We use two 3 DOFs joysticks, Microsoft Sidewinder Precision 2^{TM}, as the input interface for manipulating target points of the humanoid robot. Buttons are allocated for the selection of eight target points: head, right/left hand, right/left wrist, torso and right/left foot. Input for the target points can be made either in the coordinate frames fixed on the

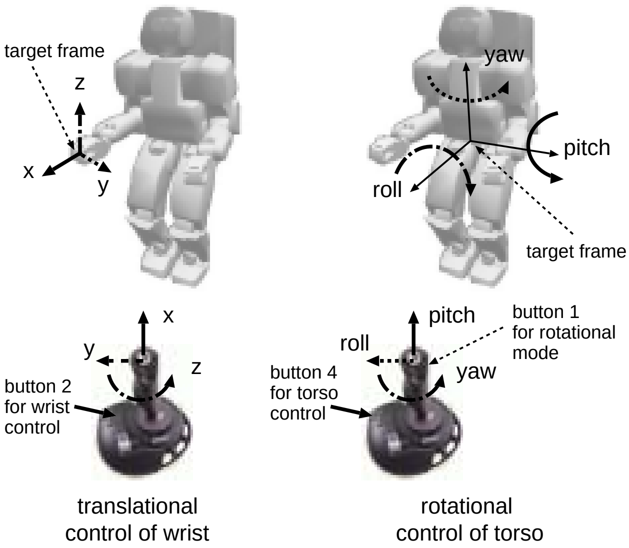

Figure 4: *Translational and Rotational Controls using Joystick*

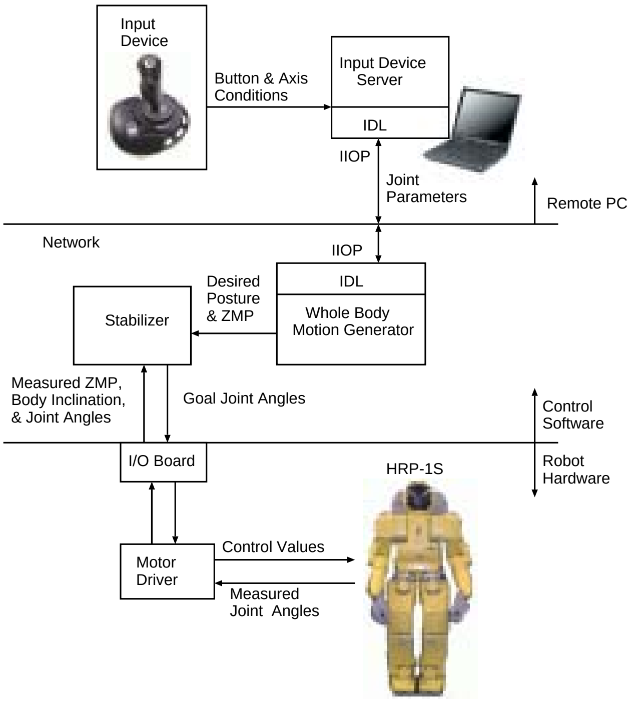

Figure 5: *Software System Overview*

torso, or, in the coordinate frames fixed on the selected target point, by selecting the allocated button for the respective mode. As the joysticks have only 3 DOFs, the desired displacements for the position and the orientation of the target point are being input seperately. The translational control of the right wrist, and the rotational control of the torso using joystick are shown in Figure 4.

3.3 Software System

The proposed teleoperation system is being implemented as a distributed server system using CORBA. The overview of the whole system is shown in Figure 5. The distributed server system consists of an input device server, a whole body motion generator, a stabilizer, and the I/O board of the robot.

The input device server is contructed and implemented on a remote Linux PC. The whole body motion generator and the stabilizer are implemented on a realtime operating system, ART-Linux, on board the slave robot. Motor commands to the I/O board are sent every 5[msec], with all the processes and communications between all servers being done within this control cycle.

Input Device Server. We have designed a set of joystick operation rules for whole body manipulation and walking pattern generation of the slave humanoid robot. The input device server receives input from the joystick devices and interpret the axis and button conditions of the joystick devices to register them as parameters for target point manipulation and walking pattern generation. The parameters for each target points and walking patterns are described in Table1. Parameters are registered as zero if there are no joystick inputs. The parameters are being accessed every 5[msec] by the realtime control software on the remote robot for the generation of whole body motions. In order to maintain standing stability, the input device server limits the maximum values of the displacement of the torso and the wrists.

Table 1: *Whole Body Teleoperation Parameters*

Target Frame	Torso Frame, Target Point Frame
Target Point	Output Parameter
Head	Orientation: pitch, yaw angle
Torso	Translation: Δx, Δy, Δz
Right/left wrist	Orientation: Quaternion
Right/left foot	ΔQZ, ΔQY,ΔQZ, ΔQW
Right/left hand	Mode: close, open Grasping force
Walk	Mode: start, stop Walking direction: yaw angle Step distance: Δx, Δy Maximum step height: Z Distance between two feet: L

Whole Body Motion Generation. For tasks that do not require changes in foot position, the joint configurations for both legs are generated first in order to realize the target displacement of the position and the orientation of the torso. And then the joint angles for both arms, the head and both hands are calculated based on the target values provided by the input device server.

For example, manipulating the humanoid robot to pick up a bottle on the floor in front of the robot using its right wrist requires simultaneous manipulations of the right wrist and the torso. When the target displacements of the torso $\Delta\overrightarrow{torso}$ and the right wrist $\Delta\overrightarrow{Rwrist}$ are being input, the whole body joint configuration are being calculated by first calculating the joint configuration of the legs $\overrightarrow{\theta_{Rleg}}$, $\overrightarrow{\theta_{Lleg}}$ and then the joint configuration of the right arm $\overrightarrow{\theta_{Rarm}}$ using equations in the following sequence every sampling time:

$$\overrightarrow{torso_{target}} = \overrightarrow{torso_{current}} + \Delta\overrightarrow{torso}, \quad (1)$$

$$\overrightarrow{\theta_{Rleg}} = IK_{rfw}(\overrightarrow{Rfoot_{current}}, \overrightarrow{torso_{target}}), \quad (2)$$

$$\overrightarrow{\theta_{Lleg}} = IK_{lfw}(\overrightarrow{Lfoot_{current}}, \overrightarrow{torso_{target}}), \quad (3)$$

$$\overrightarrow{Rwrist_{target}} = \overrightarrow{Rwrist_{current}} + \Delta\overrightarrow{Rwrist}, \quad (4)$$

$$\overrightarrow{\theta_{Rarm}} = IK_{wrw}(\overrightarrow{torso_{target}}, \overrightarrow{Rwrist_{target}}). \quad (5)$$

where $\overrightarrow{torso_{current}}$ and $\overrightarrow{torso_{target}}$ denote the current and the target configuration of the torso, $\overrightarrow{Rwrist_{current}}$ and $\overrightarrow{Rwrist_{target}}$ denote them of the right wrist, $\overrightarrow{Rfoot_{current}}$ and $\overrightarrow{Lfoot_{current}}$ denote the current configuration for right foot and left foot, and IK_{rfw} and IK_{lfw} denote the inverse kinematics functions for joints from right foot to torso and from left foot to torso, and, IK_{wrw} denotes the inverse kinematics function for joints from torso to right wrist, respectively.

For manipulating the humanoid robot to perform tasks that require walking motions, we are using walking patterns generated using the biped walking pattern generator developed by AIST based on the Three-Dimensional Linear Inverted Pendulum Mode(3D-LIPM)[9]. We realize whole body configurations for simultaneous manipulation of arms during walking by using a mixture of walking pattern generations and upper body motion generations.

Calculation for Desired ZMP. After the whole body motions are being generated by the motion generator, the desired motions are tested for stability. We use Zero-Moment Point(ZMP) as the criterion to determine stability. By limiting the maximum values of target joint displacements to values small enough to ignore dynamic effects, we use the ground projection of the center of mass(GCoM) as the approximity for ZMP. The desired ZMP(in our case the GCoM) is being calculated after the desired motions are being generated in each control cycle. When the desired ZMP calculated is out of the support polygon of both feet, the current motion commands are ignored with the former commands being resumed.

Stabilizer for HRP-1S. As humanoid robots are biped machines that are dynamically unstable by nature, it is necessary to maintain the stability of the motions generated. HRP-1S has a reflex controller(stabilizer) to maintain the stability of the motions generated using three control subsystems which controls the body inclination, ZMP, and foot adjustment of the robot respectively[11].

After the whole body motions are generated by the motion generator, the desired torso orientation and the desired ZMP calculated are sent to the stabilizer. The actual body posture(torso orientaion) is estimated using body inclination datas of gyroscopes and G-force sensors, and the actual ZMP is being estimated using datas of the foce/torque sensor in the feet. Using this estimated values, the error between the actual and the desired body posture(torso orientation), as well as the error between the actual and the desired ZMP are reduced by modifying the orientation and position of both feet.

Using these modified position and orientation of the feet and the planned body configuration generated by the motion generator, the desired angles of all joints are calculated using inverse kinematics. These desired angles are then sent to the motor controller of the robot for motor command executions.

4 Experiments

Using the teleoperation sytem described above, experiments controlling HRP-1S to pick up a basket on the floor utilizing whole body were performed to confirm the effectiveness of the system. Snapshots taken during the experiments are shown in Figure 6. The operator switched the target point for manipulation in the following sequence.
(1)Selecting the head as the target point to search for the basket.
(2)Switching the target point to the right wrist and the torso simultaneously to reach for the basket.
(3)Switching the target point to the right hand to grap the basket.
(4)Switching the target point to the right wrist to raise up the basket.
(5)Swithcing the target point to the torso to raise up the body.

Having set the maximum input for the translational displacement as 0.5[mm] and the maximum input for the rotational displacement as 0.00175[rad] for one sampling time(5[msec]), we succeeded in teleoperating HRP-1S to pick up a basket on the floor in 1[min].

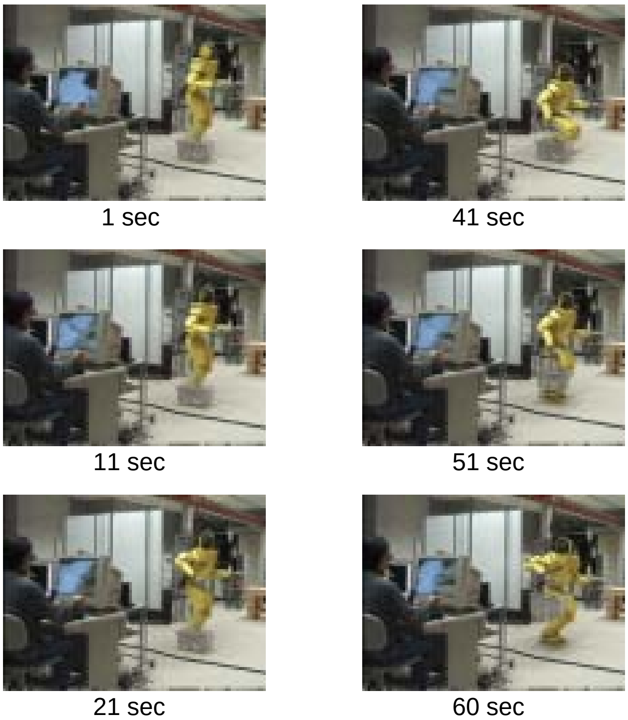

Figure 6: *Snapshots of experiment teleoperating Humanoid Robot HRP-1S to pick up a basket on the floor*

5 Conclusions

This paper described a whole body teleoperation of a humanoid robot using simple joystick interface as input device. Experiments teleoperating a real humanoid robot HRP-1S are carried out to confirm the effectiveness of the system developed.

As the proposed interface does not provide tactile and force feedbacks, the operator detects physical contacts and collisions between the robot and the environment visually from the robot's stereo camera images, which is rather difficult. Difficulties also exist in monitoring collisions between the environment and body parts which are out of the camera image range. We hope to cope with these difficulties by enhancing the autonomy of the robot in the future.

Other future works include the extention of the present realtime whole body motion generator with the inclusion of stability and task performance criterion and the implementation of the present system using 6 DOF input device.

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