

Adaptive Pick-and-Place Behaviors Based on Parallel Sensor-Motor Modules in a Whole Body Humanoid

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Abstract. The aim of this research is to achieve adaptive carrying behaviors using the whole body of a humanoid robot; in other words, to create humanoid robots' "pick-and-place" behaviors. We developed a small-sized whole-body humanoid robot. The robot's body consists of 22 DOFs, lots of sensors, an onbody micro processor network, and a wireless modem. The robot's brain consists of primitive sensor-motor reflex modules running in parallel as a lower layer and a sequential planner that starts/stops appropriate modules as a higher layer. Using this system the robot can hold, lift up, and put down various objects without knowing its size, hardness or weight. We believe this work will be one of footholds toward achieving various whole-body behaviors of humanoid robots, especially carrying behaviors.

1 Introduction

Whole body humanoid robots that have two arms and two legs are an integration of various technologies[1, 2, 3, 4]. Nowadays there are increasing demands for this type of robot because they have the potential to do numerous kinds of work; in other words, they are not limited to one type of work but are capable of various tasks. Research on whole-body humanoid robots is increasing throughout the world.

In the future, they may work in areas where people live and help humans with various tasks. Among these tasks, one of the most important and most desired would be to carry various objects. The variety of carrying forms must be rich. For instance, moving an object from one room to another may require taking an object out from under a table, carrying it into another room, and placing it on a shelf. Thus, the complexity involved in "pick-and-place" work of humanoid robots will be very different from industrial robots. The humanoid robots must get information about the objects they deal with through their sensors, plan how they carry the objects, and be adaptive and robust against unexpected disturbance during the behaviors. Although there has been some research on pick-and-place by humanoid robots, almost all of them consist of actions not using whole body but using one or both hands, and don't consider the weight of the object.

We aim at achieving various adaptive pick-and-place behaviors using the whole body of a humanoid robot. For this, we developed a small-sized humanoid robot which has many actuators and sensors. It can hold, lift up, and put down an object without knowing its size and weight, in adaptive whole-body behaviors.

2 Pick-and-Place Behaviors in a Whole-Body Humanoid Robot

These are some characteristics and requirements of humanoid robots' "pick-and-place" behaviors.

1. Objects with unknown specification

Usually a humanoid robot will not be told the weight, size, and hardness of an object that it must deal with. In environments such as office or home, there will be various kinds of objects the robot will have to carry. It would be best if the robot acquires the specification by itself.

To do this, the robot must have adequate sensors on its body. Especially, in a whole-body behavior such as dealing with an unknown object, force or torque information is crucial. Humans also make full use of this sort of information in dealing with heavy objects. At the same time, visual information is also important to distinguish the objects, etc. The robot should also have touch sensors and/or force sensors to detect the information about the contact with the objects and the ground. Accelerometers and/or gyroscopes are necessary to know its posture, which cannot be known from model-based calculations when it carries a heavy object.

2. Whole body behavior

Although industrial robots only use their hands or grippers to pick up objects, a humanoid robot can use its whole body if needed. Whole-body actions are the specialty and advantage for humanoid robots. By using the whole body, they would be able to carry quite heavy objects that they cannot carry by using only their hands. To realize whole-body behaviors, an adequate system architecture is needed. We developed a system based on the combination of parallel sensor-motor modules, which makes it possible to create whole-body behaviors relatively easily.

3. Efficiency

The motion and the posture of the robots must be efficient enough to carry comparatively heavy objects. The robot might be unable to carry a heavy object which it could carry in an efficient motion. It is quite difficult for us to search a sufficiently efficient motion by analyzing the dynamics of both the robot and various objects, or by tuning parameters. An autonomous searching or planning method is necessary in conjunction with some learning method. As a result, the robot would have a rich variation of actions.

4. Various situations

There will be various situations where the robot picks up or puts down an object. The object may be under a table, or may have to be put on a shelf. The robot will have to recognize the situation, and plan how it should carry out the task.

5. Mobility

To carry an object, the robot has to walk holding an object. The form of walking should be different depending on the weight, size, or shape of the object. It should have either a variety of walking forms or an ability to acquire the necessary motion automatically.

6. Adaptability and autonomy

Although this point has been discussed, one of the most important features of this type of humanoid robot is the mechanism which makes the robot adaptive, autonomous, and robust against disturbance. For the robot will have to deal with various unknown objects and may get various unexpected disturbance during a task.

We developed a humanoid robot to satisfy some of these requirements. It has 22 degrees of freedom, 22 torque sensors, four force sensors on each sole of a foot, a three-axes accelerometer and a CCD camera. Its system has adaptability, autonomy, and robustness based on the combination of parallel sensor-motor modules. It satisfies the requirements 1., 2., and 6., and has a structure that can integrate other requirements.

3 The Robot's Body

The 22 DOFs consist of five DOFs at each leg, five at each arm, and two at the head. The height is about 44[cm] and the weight is about 4.1[kg]. All actuators are radio control servo modules. The module has a geared motor and proportional position servo circuit inside. We can see the approximate torque the motor outputs, by watching motor driving signal (PWM format) in the circuit. The signal is almost proportional to torque as show in Figure 1 . Thus we can obtain torque information of all actuators, without attaching any other components.

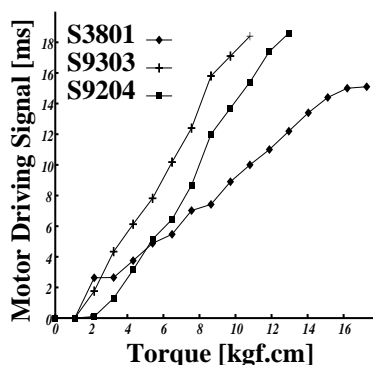


Figure 1: The relation between torque and motor driving signal

Four force sensors are attached on the sole of each foot, to detect the reaction force from the ground and the center of the force, which are used to detect the zero moment point. A three-axes accelerometer are attached on the chest, to detect the direction of gravity. A CCD color camera is attached on the head. To deal with data of actuators and sensors, we constructed an onbody micro processor network[5], which consists of six 8-bit micro processors (Hitachi H8/3334YF-ZTAT). This micro processor has many digital/analogue I/Os and timers to control actuators and measure sensors, and it has two types of serial communication interfaces. One is the I²C(InterIC) bus[6] designed by Philips (400[kbps] at the maximum), which is used for communication in the onbody network. Thanks to the property of the bus, we can easily add extra micro processors or ICs, and communication between any two points is possible. The other serial interface is for communication between the onbody network and a remote brain through radio link

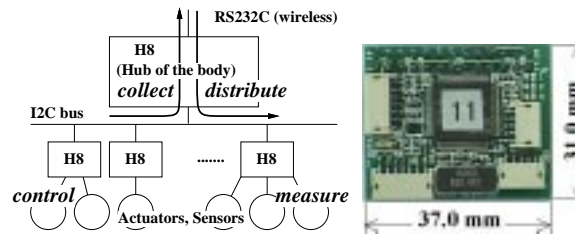


Figure 2: The structure of onbody micro processor network, and one of micro processor boards we designed

(153.6[kbps] at the maximum). These micro processors, embedded in various parts of the body, have connections with local actuators and sensors, and control the actuators and get sensor information.

Figure 2 shows the structure of the network and one of the small boards we designed so that they can be embedded in various parts on the body.

4 The Robot's Brain

We take remote-brained approach[7] where the brain of the robot is separated from the body conceptually and actually. The brain receives all sensor information through both radio modem and video transmitter, and sends all actuator information through radio modem. Using this approach, we can develop the brain without thinking of various restriction the body may impose.

To realize adaptive autonomous robust pick-and-place behaviors, we made our system based on parallel sensor-motor modules. Since Brooks suggested the subsumption architecture[8], there have been various proposals for realizing intelligence based on the combination or network of reactive modules[9, 10].

Considering these architectures, we decided to make the “brain” divided to two layers. The lower layer of the brain is based on the combination of primitive sensor-motor modules running in parallel. Each module inputs some sensor information, calculates using a certain formula, and outputs differentials of some joint-angles. Each output is added to the current joint angle. These sensor-motor modules have primitive reflex functions, i.e. balancing, force adjusting, etc. The upper layer of the brain sends start/stop commands, lists of sensors and joints, and a formula, to the lower layer. By activating the appropriate modules with the appropriate parameters at the appropriate time, a whole-body behavior is realized. This architecture is shown in the left side of Figure 3. The system is implemented using multi thread programming, and communication between the threads (modules) depends on global variables with mutual exclusion locks.

By using this architecture, we can make each primitive function without having to consider other functions the robot should have, and when a new function is needed we can just make the function individually and add it to the system. Because whole body behaviors of a humanoid robot often consist of combinations of many primitive functions, we can build the behaviors by making each function and combining them. There can be some way to derive the expression of each function. We developed adaptive whole-body pick-and-place behaviors based on this architecture. In this paper we derive the expressions by analyzing and parameter tuning. When the efficiency or optimization is considered, learning methods are effective.

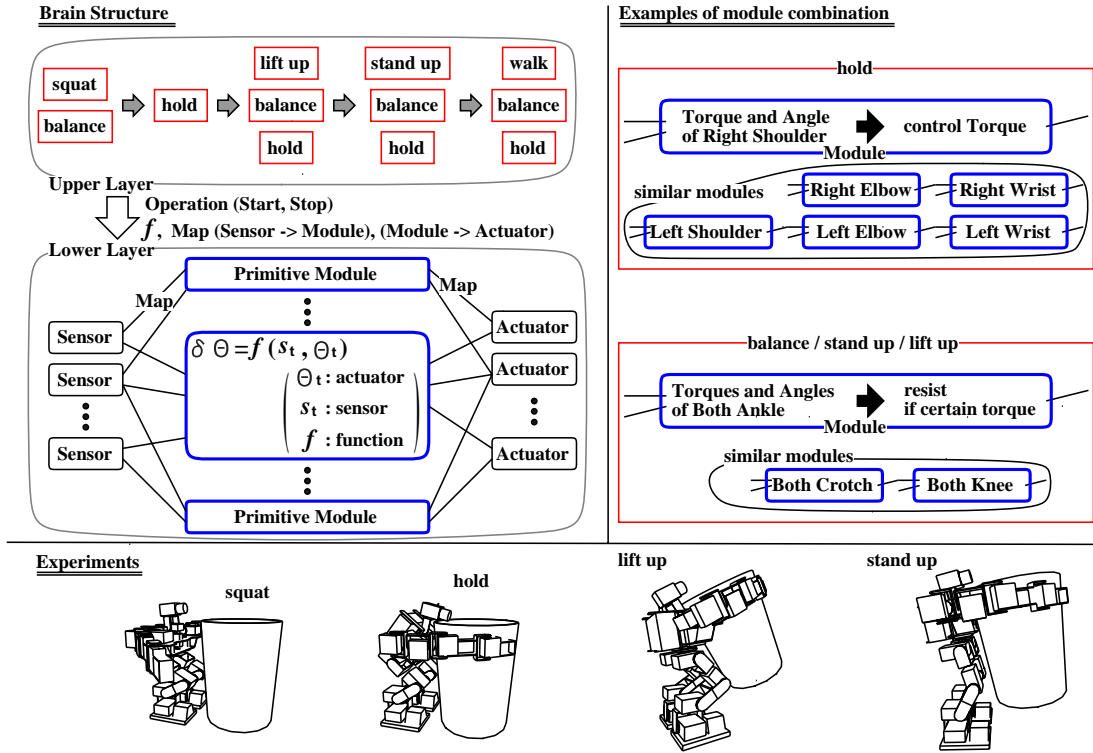


Figure 3: How to realize pick-and-place behaviors: The left side shows the brain structure. The right side shows the modules which are used by the experiment.

5 Experiment

To develop adaptive pick-and-place behavior using whole-body, we made some necessary functions. Two types of the functions are explained below.

hold The module watches the torque (τ_i) of a specified joint i and outputs differential angle ($\delta\theta_i$) to keep specified torque (r_i). The calculation is carried out using the formula:

$$\delta\theta_i = -G_i(\tau_i - r_i)$$

where G_i is the gain (positive value).

To carry out “holding”, the upper layer starts the modules giving this type of formula, in the joints of shoulders, elbows, and wrists.

balance The module watches the torque (τ_i) of a specified joint i (crotch, knee, or ankle) and outputs differential angle ($\delta\theta_i$) to keep balance. The calculation is carried out using the formula:

$$\delta\theta_i = \begin{cases} 0 & (|\tau_i| \leq T_i) \\ G_i \cdot \tau_i & (T_i < |\tau_i|) \end{cases}$$

where G_i is the gain.

Consequently, the center of gravity of the upper part than the joint i (including the held object) comes to right above the axis of the joint (Figure 5). In the

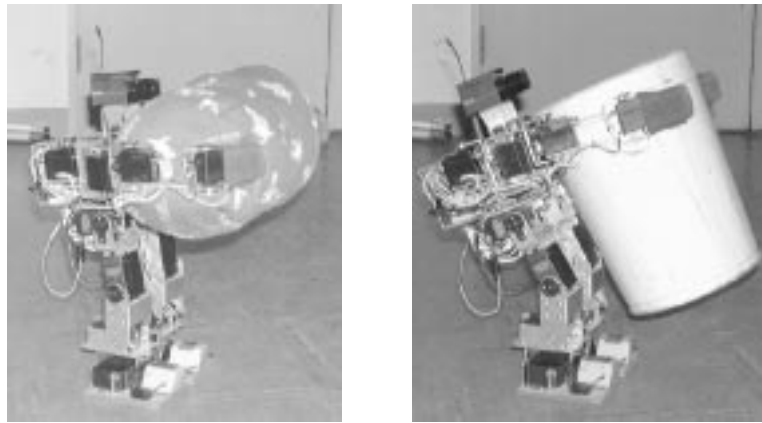


Figure 4: Holding objects of various size, hardness and weight

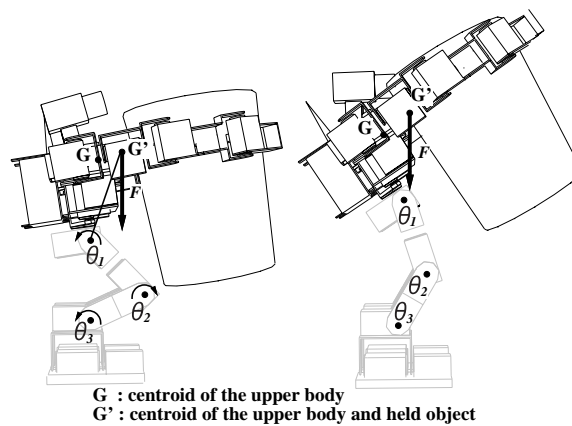


Figure 5: Balancing by legs during holding an object

figure, the center of gravity of the upper part of the robot (upper than the axis of θ_i) is **G'**, while that including the object is **G**.

The upper layer starts the modules giving this type of formula, in the joints of crotches, knees, and ankles.

Whole-body behaviors are organized in this way by various primitive modules running in parallel (“hold”, “balance”, “lift up”, and “stand up”, appropriately), as shown in the right side of Figure 3. As a result, the humanoid robot can squat, hold an object without knowing the size and weight, lift it up, and stand up. These are the pick-and-place behaviors of whole-body humanoid robot.

Figure 4 shows two scenes where the robot has lifted up two objects of different size, hardness and weight, using the same program. In the photographs the robot is bending backward at a different angle, to balance with the weights of the objects. In the left it holds a soft cushion (100[g]) and in the right it holds a trash can (500[g]). The robot weighs about 4.1[kg].

6 Conclusion and Future Work

We developed a humanoid robot that has adaptive pick-and-place behaviors based on the combination of reflex sensor-motor modules running in parallel. It can hold and lift up an object of unknown properties, and put it down, with adaptability, autonomy, and robustness, during the actions.

We are trying to develop more variations of behaviors, to achieve various carrying form. There are still lots of problems to be solved; walking while holding an object, working out strategies for picking or holding, etc. We believe this work will be one of foothold toward these subjects.

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