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# Mechanical System of a Small Biped Entertainment Robot

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## Abstract

SDR-4X is the latest prototype model which is a small humanoid type robot. We reported the outline of this robot last year. In this paper we discuss more about mechanical system which is important and original for a small biped entertainment robot which will be used in home environment. One technology is the design of actuators alignment in the body which enables dynamic motion performance. Another technology is the actuator technology which we originally developed named Intelligent Servo Actuator ( ISA ) . We explain the specification and the important technical points. Next technology is the sensor system which supports the high performance of the robot, especially the detection of outside objects, ability of stable walking motion and safe interaction with human. The robot is used in normal home environment, so we should strongly consider the falling-over of the robot. We propose the ideas against falling-over which makes the robot as safe as possible.

## 1 Introduction

For the humanoid type robot which is especially for entertainment robot, whole body motion should be considered. Formerly some important studies about whole body cooperative motion control for humanoid robots have been proposed[1][2][3]. After these studies, we proposed a small biped entertainment robot SDR-3X ( Sony Dream Robot, a prototype ) in November, 2000. That robot realized the dynamic and elegant motion performances using the small high performance robot actuator ISA ( Intelligent Servo Actuator ) and the Whole Body Cooperative Dynamic Motion Control [4][5][6]. SDR-4X is the advanced model and has a capability of a Real-time Integrated Adaptive Motion Control using the enhanced ISA and sensors. By using real-time adaptive control SDR-4X can walk on uneven suface and make a adaptive motion control against external forces. Falling- over control of the robot is also realized by real-time adaptive control.

In this paper, especially the mechanical system of SDR-4X is proposed. At first the main body mechanical system is explained. The important location of degree of freedoms and other original points are descrived. Next, the chactarictics of ISA, which is the most important part element, is explained. Then the sensor systems which make the robot high performance such as camera, microphone, accelerometer, gyro sensor, force sensor and so on are explained. We should think over the falling-over of the robot. So the means against falling-over are descrived. The former paper descrived the control system specifically, so in this paper we touch upon the robot system from the mechanical system point of view. We think the mechanical system is the basis of realizing the high performance system. Especially in case of humanoid robot, the accutuators number is very huge and the space is really limited. But the moving angle area of actuators are requested to be as wide as possible. Also the weight is better to be as light as possible. From this point we think the discuss on mechanical system is really important.

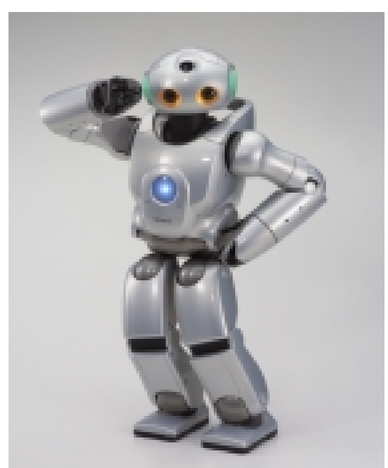

**Fig.1** Outview of SDR-4X

## 2 Dynamic Mechanical System

**Table.1** shows the configuration of SDR-4X. The height of SDR-4X is 58cm and the weight is 6.5 kg. It has 28 degrees of freedom (DOF) as major joints. In details, each leg has 6 DOF which is enough for taking all postures. Trunk has 2 DOF which is not enough for all postures. Yaw axis is omitted because of lack of space. Each arm has 5 DOF which is not enough for all postures. The position of elbow can be taken freely but the wrist needs 2 more DOF for taking all postures which is good for variety of expressions. The neck has 4 DOF which is good for emotional expressions. It has 5 independent driving fingers in each hand which is just for expressions. These fingers can not grasp objects in this stage because of lack of power and sensors. It has 38 DOF as total.

**Table.1** Configuration of SDR-4X

| | |
|---|---|
| Height | 580 [mm] |
| Weight | 6.5 [kg] |
| Joints | 38 DOF |
| Head | 4 DOF |
| Body | 2 DOF |
| Arms | 5 DOF x 2 |
| Legs | 6 DOF x 2 |
| Fingers | 5 DOF x 2 |

SDR-4X can bend the upperbody at the trunk, and it is very useful for sitting and standing-up motions. And it also enables more emotional performance of motions. It can be realized by the axis of the trunk. There are 2 axes which are roll axis and pitch axis. We contrived the location of pitch axis as shown in **Fig.2**. The pitch axis is not located in the same line on the center line of the leg, but it is shiftted just a little foreside of it. By taking this location the bending angle of the upperbody can take wider area of bending motion. **Fig.3** shows the sitting pose and it shows the natural bending posture as you can see.

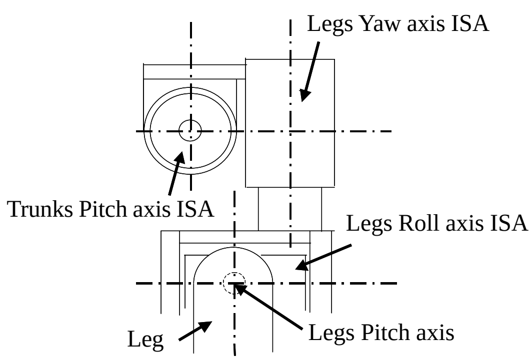


**Fig.2** Axis location

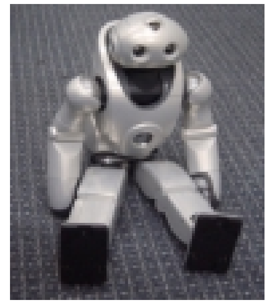

**Fig.3** Sitting pose

As you can see in **Fig.2**, the yaw axis of leg is offset from the center line of the leg. That is the idea of having wider turn angle which you can see in **Fig.4**. If the yaw axis is not shiftted and on the center line of the leg, the edge of foot makes collision to another foot easily as shown in that figure. In case of axis offset the foot can turn more angle until the edge of the foot contacts another foot.
That means SDR-4X can make more dynamic turn motion. Currently it can make 180 degree turn by one motion by using the bend of pitch axes of the leg additionally.

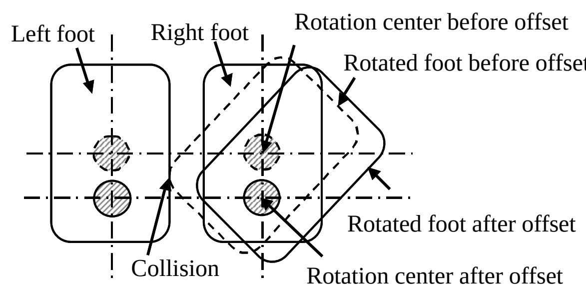


**Fig.4** Wider turn angle by axis offset

We made the idea which is shown in **Fig.5** in the design of foot system for more stable walking. The foot assembly is devided into two pieces which are upper side and lower side. There are some space and lower side is movable. In between there are 4 force sensors. By calculating with these output data the center of actual zero moment point can be found. It is used for stabilizing the walking motion, so the preciseness of the output of these sensors are very important. These sensors are protected mechanically.

**Fig.5** Foot system

## 3 Intelligent Servo Actuator

SDR-4X has 24 intelligent servo actuators (ISA) which are used at the axes which need high torque and high accuracy such as the axes of leg, arm and trunk. ISAs are developped originally for SDR robot. The point is high torque, high accuracy and the electrical control sysytem is installed inside the motor. The gear is also originally developed and assembled with the motor in one system. The specification of the rated torque are designed from the necessary torque when the leg is bending as shown in **Fig.6**. The necessary torque is known by multiplying 6.5kg and 7cm that is about 2.1 Nm torque for each leg knee axis.

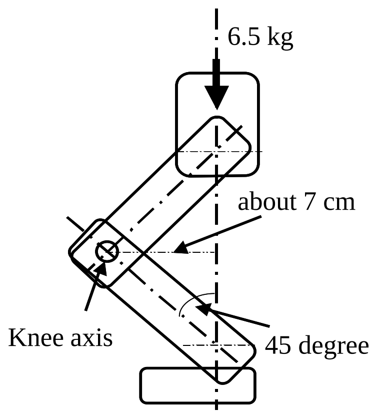


**Fig.6** Necessary rated torque

The necessary accuracy for leg actuators should be considered. If the configuration of the robot is defined as shown in **Fig.7**, in case of d degree is very small, the deviation of the head D is roughly calcurated as follows.

$$D = L1 \tan d + L2 \tan 2d + L3 \tan 3d$$

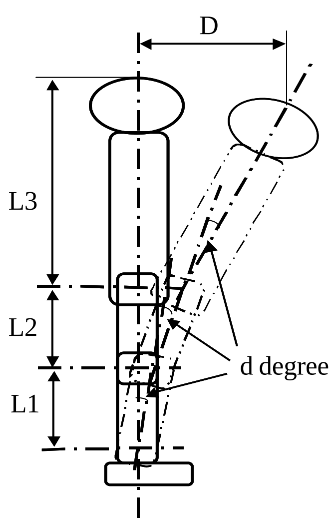


**Fig.7** Deviation caused by accuracy

In case of SDR-4X, if we assume that D should be less than 10 mm, d should be around less than 0.5 degree. Of course it depends on how the robot is controlled and how to define D, but the basic accuracy which is needed should be thought about. When we develop the actuator, we consider this point.

There are three types of ISA which are small size, middle size and large size. Small size ISA is used mainly for arm axes. Middle size ISA are used for trunk and leg axes. Large size ISA are used for leg knee especially which needs high torque. The specification of each ISA are shown in **Table.2**. In this table rated torque are listed. The start-up torque is about 3 to 4 times of rated torque .

**Table.2** Specification of ISA

| | rated torque | weight |
|---|---|---|
| ISA-4S | 0.5 [Nm] | 80[g] |
| ISA-4M | 1.1 [Nm] | 130[g] |
| ISA-4MH | 2.1 [Nm] | 150[g] |

ISA has about 2 times higher torque compared with existed actuators without thinking of inner control system weight contribution. One of the original design is high density wiring for core parts. Another is the design of core parts itself. Very high power magnet is also adopted.

The reduction gear is also developed originally. Normally harmonic drive type gear is used for accurate robot axes, but in ISA that type of gear is not used because of size and cost . The normal plain flat gear is mainly used, but the accuracy of gear parts are very high.

The main reason which we use plain flat gear is that we put the strong concern on back-drivability of gears.
When the robot is pushed by the external force, the robot should have the adaptive motion quickly. Also in case of falling-over the robot arms or legs should have compliant motion at once. For these needs ISA could be rotated from outside torque easily. We call the easiness of rotating the gears from the outside as the back-drivability. Our ISA has a very high back-drivability that enables very good adaptive control.

**Fig.8** Actuator ISA

## 4 Sensor System

**Fig.9** shows the head part which has eye and ear sensors. Two small CCD color cameras with about 110,000 pixels, whose baseline is about 5 cm, are used for stereo image recognition detecting the distance between itself and an object. In the distance of about 50 cm, the distribution is about 10 mm. More than 100 cm distance the distribution is about 30 mm. By using this obstacle detection, SDR can walk avoiding obstacles.

As ears 7 microphones are installed inside the head. By using these SDR-4X can detect the direction of a sound source. The area of the possible direction of detection is 360 degrees horizontally and some area is possible vertically. The reason which we use 7 microphones is not only to detect the direction in wide area but also to reduce the influence of the noise which is generated by the actuators in the head. These microphones also recognize an indivisual speaking.

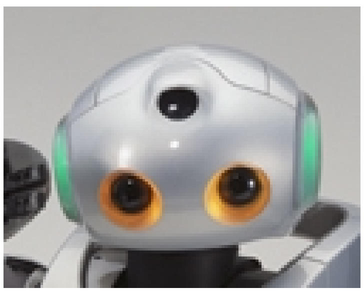

**Fig.9** Sensors inside the head

SDR-4X has been designed not to injure human as much as possible because the purpose of this robot is to be used in home environment and human touchs it very often. Therefore it has the safe design including a joint structure that does not trap hands and fingers in between joints. And touch sensors are installed in everywhere(**Fig.10**) to detect these traps when these happen. For example, the sensors are installed inside the shoulder joints, elbow joints, trunk joints, leg joints and foot joints. These sensors are sheet type tactile sensors and if these are activated, the main control system stops the actuators motion and change the control to release the force which is happened by that trap.

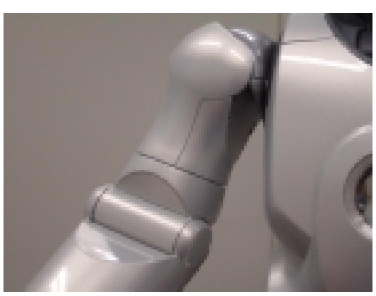

**Fig.10** Sensors agaist the trap

**Fig.11** Sensors agaist the trap inside the legs

For the motion stabilizing control some typical sensors are used. They are 3 axes accelerometers and gyro sensors in the trunk. The required specification is high in the point of resolution, response frequency and low drift performance. And also these must be small and light. From these points we use micro electro mechanical system type sensors and added necessary controls.

**Fig.12** Inclination sensors inside the trunk

Inside the foot we use not only forse sensors but also accelerometer in each. The purpose of this sensor is to detect the angle of the plain which the foot is walking on. By using the forse sensors the foot follows the plain under the foot and after the foot contacts the plain, the accelerometer detects the plain angle and sends the data to stabilizing control system. These data is important because the robot can understand the plain angle directly. For the stability, both data from the trunk and foot accelerometers are used.

**Fig.13** Sensors inside the foot

## 5 Means against falling-over

SDR-4X is basically designed to allow some lebel of falling-over because it is used in normal home environment and falling-over can happen occasionally. As is already explained, there are force sensors in foot and from the calculation of these force data the zero moment point(ZMP) position can be obtained. When the robot is pushed, the ZMP moves toward the edge of foot space. To prevent fallng-over the robot steps to the direction of ZMP motion. If the external force is strong and the step motion cannot reach the speed of ZMP, the robot takes the falling-over motion control and get into the pose which can adopt and secure against contacting with environment.
When the falling-over direction is front side, the robot moves the hand forward and contact the edge of the hand to the ground. As is shown in **Fig.14**, the edge of the hand is round and slightly soft. It protects the fingers not to be damaged.

**Fig.14** Outview of hand

When the direction of falling-over is backword, the robot bends the legs quickly and takes the shock by the back. On the back there is a handle for lifting-up and this handle also reduce the falling-over shock because it is covered slightly soft material ( **Fig.15** ).

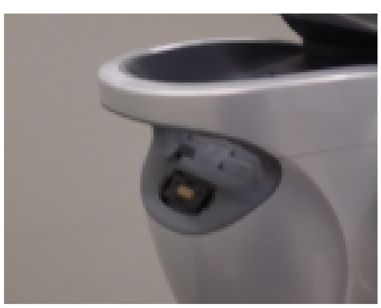

**Fig.15** Handle and backsideview

The direction of falling-over is rightside or leftside of the robot, the robot takes the form of bending the legs and make the contact part to the back as much as possible. If the contact part happens to be shoulders, it is not so safe for mechanism, so the robot takes the back as the contact area as much as possible.

## 6 Balance of weight

To have more stability of walking, the balance of weight should be discussed. The center of grabity of the whole body should be upperside as much as possible because the robot can have more time until the falling-over. From this point heavy parts are located as upperside as possible. For example the heavy battery is located in the chest ( **Fig.16**) .
Legs are better to be as light as possible for quick motion and the center of grabity point of view.

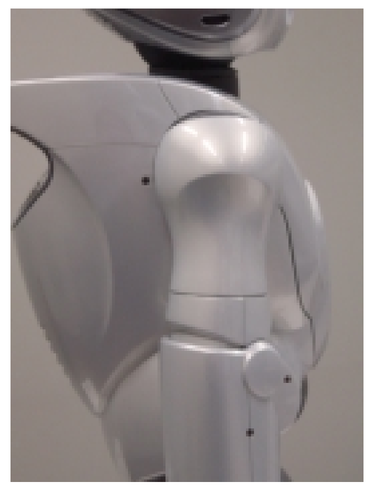

**Fig.16** Battery weight location

Weight balance of rightside and leftside, and also foreside and backside is really important for stable motion. If these balances are not good, it affects the stability calculation accuracy and also causes unnecessary power for actuators.
Therefore when the robot is designed, the parts location is carefully decided not to make unbalanced position.

But still totally the whole weight of this robot is heavier than expected. Especially the heavy battery is still used because of necessary power consumption. The next task for this robot is to reduce the weight as much as possible including the actuator weight reduction.

## 7 Summary and Conclusion

We descrived the main technologies about SDR-4X mechanical system. At first the main body mechanical system is explained. The important location of degree of freedoms and other original points are descrived. Especially the location of pitch axis of the trunk and the yaw axis of the leg is explained. Next, the chactarictics of ISA, which is the most important part element, is explained. Especially the idea of high torque and high precision and also the importance of back-drivability are descrived. Then the sensor system which makes the robot high performance such as CCD camera, microphone, accelerometer, gyro sensor, force sensor and so on are explained. For the safety for human the sensors in between the joints are descrived. We should think over the falling-over of the robot. So the means against falling-over are descrived. The several ways of falling-over are explained. And also the mechanical proposal for reducing the shock which happens on falling-over.

The former paper descrived the control system specifically, so in this paper we touch upon the robot system from the mechanical system point of view. We think the mechanical system is the basis of realizing the high performance system. Especially in case of humanoid robot, the actuators number is very large and the space for mechanical elements is really limited. But the moving angle area of actuators are requested to be as wide as possible. Also the body weight is requested to be as light as possible. From this point we think the discuss on mechanical system is really important.

Currently SDR-4X can perform a high-tempo dancing and a cappella chorus performance using the descrived core-technologies of mechanical system and control system.

## 8 Acknowledgement

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