Development of a Small Biped Entertainment Robot QRIO

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Abstract:

SDR-4X II is the latest prototype model which is a small biped entertainment robot. This is the improved model of SDR-4X. In this paper we report especially about sensing system of this robot which is important and essential for a small biped entertainment robot which will be used in home environment. One technology is the design of motion sensing system. This technology is the inclination sensor system and the force sensor system which obtains the inclination of the trunk and the foot with force. Another technology is the real-world sensing system. One is the touch sensing system. The robot is used in normal home environment, so we should strongly consider the safety for human. Another is the vision sensor system. The configuration and the distance image acquisition are explained. Next is the audio sensor system which obtains the sound and the voice information. The hardware system and the direction recognition are explained. These sensing systems are the key to make the biped robot walking and dynamic motion highly stable and understand the real-world around the robot.

1. INTRODUCTION

When we develop the humanoid type robot which is especially for entertainment robot, the ability of whole body stable motion control and effective sensing of environment 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[4]. 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 [5]. SDR-4X, which was developed in March 2002, is the advanced model and has a capability of a Real-time Integrated Adaptive Motion Control using the enhanced ISA and effective many types of sensors[6][7]. By using real-time adaptive control with effective sensors, SDR-4X can walk on uneven surface and make a adaptive motion control against external forces. Falling- over control of the robot is also realized by real-time adaptive control. In March, 2003, we developed SDR-4X II, which is the improvement model of SDR-4X. The deferent point of the new model is mostly the improvement of reliability and performance of mechanical system, sensor system and control software [8].

Fig.1 Overview of SDR-4X II

In this paper, especially the sensing system of SDR-4X II is proposed. At first we explain sensors for detecting inclination and forces from the outside for the stable motion performance,. As the inclination sensors, we explain the micro accelerometer and the angular rate sensor. These should be small and light for fitting to our small biped robot. We use micro electro mechanical system type sensors which are improved for our suitable specification. As the force sensing system, we use 4 force sensors in each foot and processing the output data to obtain the necessary data like Zero Moment Point position data. As the real-world sensing system, touch sensor system is explained at first. We assume that this robot exists close to human, so the safe interaction with human is indispensable. Many touch sensors are installed around the body. Next the vision sensor system is explained. We use micro CCD cameras as stereo vision system. The hardware system for processing the input image and how to obtain the distance data is explained. The audio sensing system is also explained. As the audio input system, 7 microphones are used. We explain the position of microphones and how to get the direction of sound and clear sound or voice with less noises. The hardware system and the accuracy of the input are also explained. We think sensing technology is one of the key technologies for humanoid robot development.

2. INCLINATION SENSOR SYSTEM

A. Accelerometer Sensor System

The accelerometers which are installed in our robot should be small and light as much as possible. The type of the sensor which we use is micro electro mechanical system. The package size is 5x5x2 mm and the weight is 0.2 g. The principal specification is shown in **Table.1**. It is 2 axis accelerometer and the type is electrostatically driven capacitive accelerometer. The range is plus minus 2G and the sensitivity is 300 mV/G. The resolution is 2mV in 60 Hz Bandwidth and Frequency response is 6 kHz in 3 dB Bandwidth. The output format is PWM. So the processing circuit for PWM transformer is installed in the package.

Table.1 Specification of Accelerometer

Type	2 Axis electrostatically driven
Rang	+/- 2G
Sensitivity	300mV/G
Resolution	2 mG (60 Hz Bandwidth)
Output Format	PWM
Packag	5 x 5 x 2 mm
Frequency Response	6 kHz (3dB Bandwidth)

The locations of accelerometers are shown in **Fig.2**. Two accelerometers are located in the trunk and these are measuring the inclination of trunk with 3 gyroscopes. When the trunk does not move, the output of the accelerometers shows the inclination of the trunk as it is. But normally the trunk is moving and the output of these sensors includes the inertia force. So we are using low pass filter to cut off the moving frequency efficiently. The cut off frequency should be adjusted low enough to cut off the moving frequency.

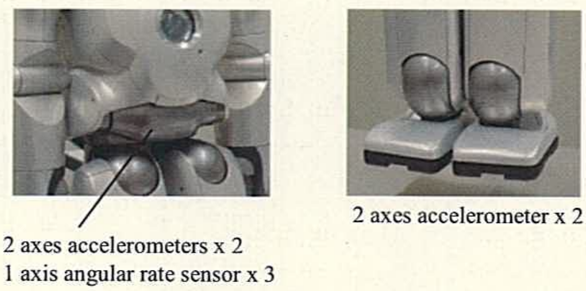


Fig.2 Location of Accelerometers

Accelerometers are also installed in the both feet. This sensor detects the foot inclination angle when the foot is touching the walking surface and does not move. This sensor can detect the surface angle directly, so it is very effective.

B. Angular Rate Sensor System

The angular rate sensors which are installed should be also small and light as much as possible. The type of the sensor which we use is also micro electro mechanical system. The package size is 7x7x3 mm and the weight is 0.4 g. The principal specification is shown in **Table.2**. It is 1 axis angular rate sensor and the type is electrostatically driven capacitive sensor. The range is plus minus 150 degree and the stability is 0.03 degree/sec. Frequency response is 40 Hz in 3 dB Bandwidth and the sensor resonant frequency is 14 kHz. The output format is analog.

Table.2 Specification of Angular Rate Sensor

Type	Z Axis electrostatically driven
Dynamic Range	+/- 150 deg
Stability (drift)	0.03 deg/sec
Output Format	Analog
Package	7 x 7 x 3 mm BGA
Frequency Response	40 Hz (3dB Bandwidth)
	14 kHz (Sensor Resonant Frequency)

The locations of the angular rate sensors are shown in **Fig.2**. They are located in the trunk and measuring the inclination of trunk. When we use the output of the angular rate sensors, we take the integration and use the output of high pass filter. This output from the high pass filter is added to the output of the low pass filter of the accelerometer. The final added data is used as the inclination of the trunk.

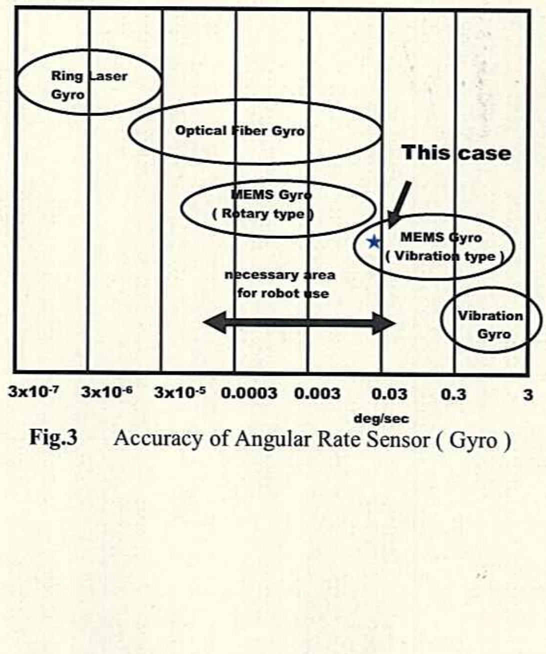


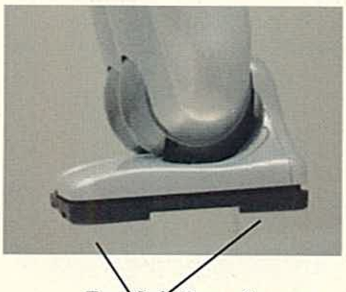
Fig.3 Accuracy of Angular Rate Sensor (Gyro)

There are many types of angular rate sensors. Some of these are shown in **Fig.3**. Currently our sensor is in the type of vibration type MEMS Gyro and has the high spec of that group. But as the ideal angular rate sensor, more stability is required for the robot use. For example, optical fiber gyro or the recent rotary type MEMS Gyro is assumed to be ideal.

3. FOOT SOLE SENSOR SYSTEM

The foot sole force sensor system is very important to stable motion control. Especially the surface of walking or standing is not horizontal or uneven, the robot foot should follow the surface in real-time. And also getting the actual ZMP (Zero Moment Point) is indispensable for stable walking and motion performance.

There are 4 force sensors in the foot sole. The sensors are specially designed diafram type sensor. The measurable range is 0 ~ 5 kg and the resolution is 10 g. The bearable maximum force is 20 kg. The location of these sensors are shown in **Fig.4**. The mechanical stopper for protecting the sensor is installed, so the bearable force from outside of the foot sole is about 50 kg which is good enough to protect.



Foot Sole Force Sensors

Fig.4 Location of Foot Sole Force Sensors

The hardware configuration of these force sensors is shown in **Fig.5**. The output of 4 force sensors are input to AD Converter and the output of ADC is input to satellite DSP. The satellite DSP calculates the position of actual ZMP and sends the ZMP position data and the force data to main CPU through satellite CPU.

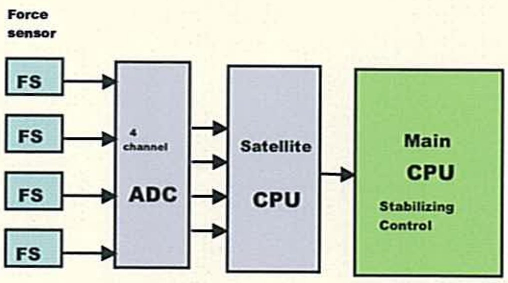
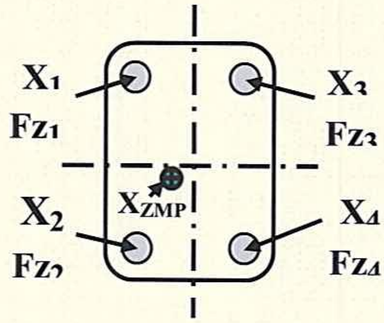


Fig.5 The Hardware configuration of force sensors

The position of force sensors is shown in **Fig.6**. In the figure, assumed variables like the positions, X1~X4, the forces, Fz1~Fz4. are shown.



Xn : Position of force sensor n
Fzn : Force applied to force sensor n
XZMP : Position of ZMP

Fig.6 Position of force sensors

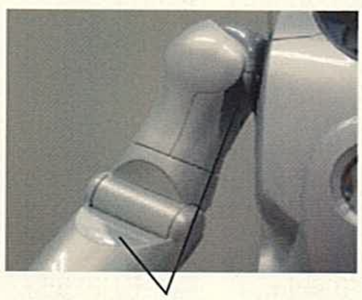
The position of ZMP is obtained from the following equation.

$$\sum_{n=1}^{4} Fz_n(X_n - X_{ZMP}) = 0$$

$$\therefore \quad X_{ZMP} = \frac{\sum_{n=1}^{4} X_n Fz_n}{\sum_{n=1}^{4} Fz_n}$$

4. TOUCH SENSOR SYSTEM

SDR-4X II 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 touches 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.7**) 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. Currently the total sensors number is 19.



Touch Sensors against the trap

Fig.7 Location of Touch Sensors

These sensors are sheet type tactile sensors which material is polyethylene printed by carbon. 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.

5. VISION SENSOR SYSTEM

As the real-time and real-world vision sensor system, we developed a micro stereo vision system with obstacle detection. **Fig. 8** shows a head view with the stereo vision system. The hardware configuration of the stereo vision system is shown in **Fig.9**. We use two color CCD cameras with about 110,000 pixels, whose baseline is about 5cm. The disparity is computed by FPGAs, where block-matching based algorithm is implemented. The disparity image is further transferred a range data using mechanical information of SDR-4X II. The range data and a normal color image sequences are transferred to a main CPU via a high speed bus named LVDS (Low Voltage Differential Signaling). The programs for the FPGAs can be down-loaded from a main CPU via OPEN-R BUS.

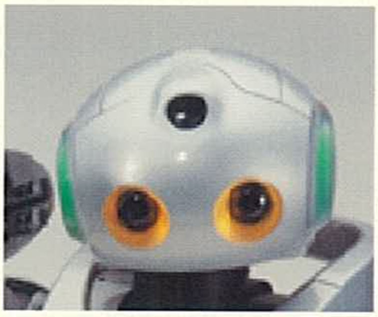


Fig.8 Vision sensor system inside the head

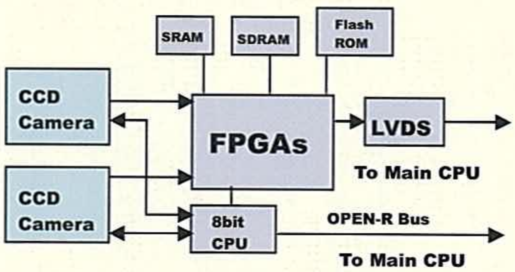


Fig.9 Hardware Diagram of a Micro Stereo Vision System

The method which we obtained the distance by using two CCD camera is described as follows. **Fig.10** shows the situation which base camera and detection camera are observing the 3 dimensional scene. If the point P is observed as point Vb by the base camera and also as point Vd by the detection camera, the 3 dimensional position of point P is obtained.

It is not so easy to decide that the observed point Vb by the base camera is the same point of the observed point Vd by the detection camera. As you see in **Fig.10**, the point Vd exists on the line where the plane fixed by the both optical center and the observed point Vb by the base camera crosses the image plane of the detection camera. This line is called epipolar line.

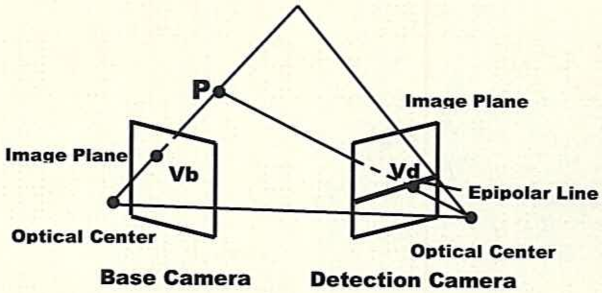


Fig.10 Corresponding points and Epipolar Line

The corresponding point is found by searching on this line. We use the template-matching method to obtain the corresponding point. Some area on the epipolar line is compared with the image of Vb and the most similar image is obtained. After repeating this comparison, the corresponding point is obtained. If the whole part of the image plane of the base camera is repeated to obtain the distance data of each part, the depth image can be obtained.

We further implement plane extractor using range data. As **Fig.11** shows, in the short distance like 50 mm, it is possible to estimate the plane with about plus/minus 10 mm distribution, but in the long distance like 100 mm, it is about plus/minus 30 mm distance.

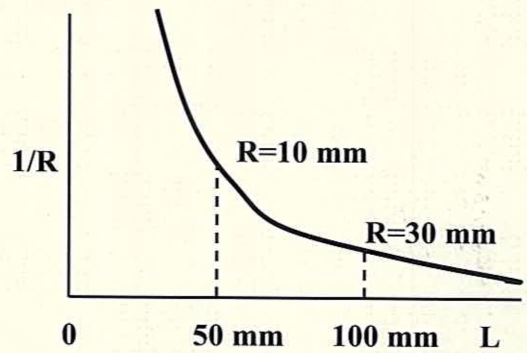


Fig.11 Resolution of plane estimation

From theoretical estimation, the resolution of the image sensors and the base-line distance result in about 80mm resolution, however, the error distribution must be evaluated as vertical distance error from the estimated plane, whose value must be multiplied by sin(theta). Thus, the estimated error of the plane extractor is not so bad for "plane estimation" purpose.

Currently the range of visible area of CCD camera is 50 degree which is not so wide. So if the robot wants to find something, it has to rotate the head some area very often. That takes time to find the necessary object. We think the wider range of camera is more useful for the robot purpose.

6. AUDIO SENSOR SYSTEM

For the real-time audio sensor system, we developed a multi-microphone system. **Fig.12** shows a head view with the multi-micro phone system. We use 7 microphones and the location of these microphones are shown in **Fig.13**. As is shown in that figure, two microphones are located at right and left side of the head. The fifth microphone is located at backside and the sixth is located at frontside. The last one is located in the head.

The reason which two microphones are used in one side is to control the direction for gathering the sound. Currently the direction is adjusted a little bit foreside. The backside and frontside microphones are not only to get the sound from that direction, but also to distinguish the vertical direction of the sound. These microphones are shifted a little from the plane of the right and left side microphones. The microphone in the head is used to cancel the noise which occurs in the head by motors.

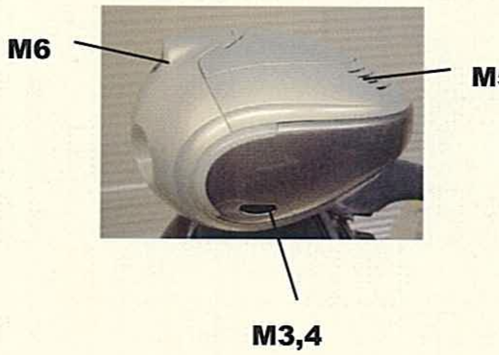


Fig.12 Audio Sensor System

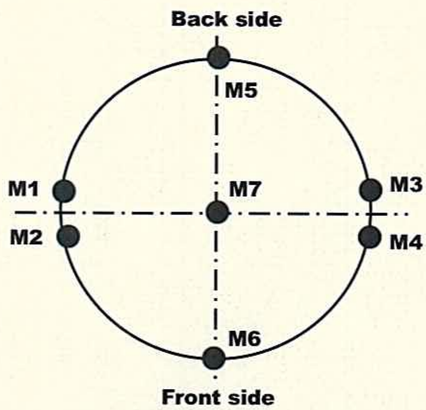


Fig.13 Location of Microphones

From this alignment of 7 microphones, the resolution of the sound direction is shown in **Fig.14**. Horizontally the accuracy of the observed direction of the sound is plus minus 15 degrees. That means 30 degrees width. The front side is a little bit better than the back side, but in the software we assume the same resolution. For vertical resolution, the accuracy of the direction is also plus minus 15 degrees and that means 30 degrees width. In this case the accuracy in the upper half side is a little better than that of in the lower side.

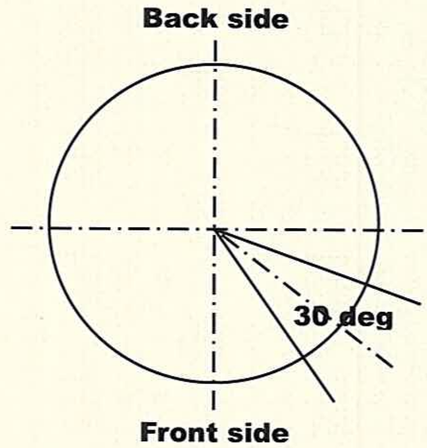


Fig.14 Accuracy of detecting direction

The hardware configuration of the audio sensor system is shown in **Fig.15**. The analog output of 7 microphones are input to the 8 channel AD converter. The output of AD converter are input to the Satellite Digital Signal Processor. The roll of the DSP is to processing the data of 7 microphones. There are many points of processing. For example, one is to adjust the direction of gathering the sound more from the front side using the output of the M1,M2 and M3,M4 microphones. The other is to obtain the direction of the sound source using all 7 microphones. More the other is to cancel noises from the outside as much as possible. For canceling the noise which is occurred inside the head by motors, the M7 microphone's output is useful. After processing the all microphones output by DSP, the data of processed more clear sound or voice and the other data like the direction of the sound source are sent to the Satellite CPU. The Satellite CPU sends those data to main CPU through USB bus.

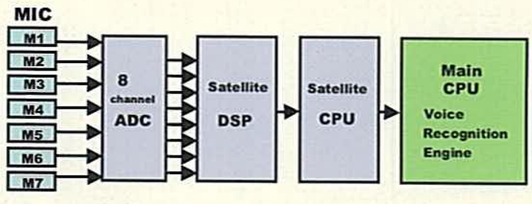


Fig.15 Hardware Diagram of a Audio Sensor System

Then the main CPU firstly distinguish the sound data to speech data or non-speech data. The data which is distinguished as speech data is decoded. Then the decoder find out the recognized words, recognition confidence speaker identification and so on. Those data are used for the next main speech recognition process.

Currently the sampling rate of the sound is 16 kHz, so the sound of 8 kHz can be detected. That is normally enough for the speech recognition. The sensitivity of the sound input is automatically changed from the environment situation.

7. SUMMARY AND CONCLUSIONS

We described the essential technologies about SDR-4X II sensing system. At first, for the stable motion performance, sensors for detecting inclination and forces from the outside are explained. As the inclination sensors, we explain the micro accelerometer and the angular rate sensor. These should be small and light for fitting to our small biped robot. We use micro electro mechanical system type sensors which are improved for our suitable specification. Our system specification is explained. For the angular rate sensor, the recent other types of sensors are described and our system level is shown. Force sensor is also explained. We use 4 force sensors in each foot and process the output data to obtain the necessary data like Zero Moment Point position data. How to calculate the actual ZMP position data is also described. Next, touch sensor system is explained. We assume that this robot exists close to human, so the safe interaction with human is indispensable. 19 sheet type touch sensors are installed around the body. As real-world sensing system, the vision sensor system is explained. We use two micro CCD cameras as stereo vision system. The hardware configuration for processing the input image and how to obtain the distance data is explained. The resolution level of this system is also described. Next, the audio sensing system is explained. As the audio input system, 7 microphones are used. We explain the position of microphones and how to get the direction of sound and clear sound or voice with less noises. The resolution of the direction detection is measured. The hardware system for processing the sound input data is also explained. All these sensing system makes SDR-4X II to have a very high level stable walking and dynamic motion performance. And also these are supporting SDR-4X II's high level of communication capability with human. We think sensing technology is one of the most key technologies for humanoid robot development.

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