Humanoid Robots in Waseda University
- Hadaly-2 and WABIAN -

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Abstract. This paper describes two humanoid robots developed in the Humanoid Robotics Institute, Waseda University. Hadaly-2 is intended to realize information interaction with humans by integrating environmental recognition with vision, conversation capability (voice recognition, voice synthesis), and gesture behaviors. It also possesses physical interaction functions for direct contact with humans and behaviors that are gentle and safe for humans. WABIAN is a robot with a complete human configuration that is capable of walking on two legs and it is capable of carrying things as with humans. Furthermore, it has functions for information interactions suite for uses at home.

1 Introduction

It has been a long-standing dream among humans to create a robot that has a configuration similar to that of a human--one that is capable of cohabitation with humans [1].

In 1973, in pursuit of building such a robot, the bioengineering research group at the Science and Engineering Department of the Waseda University (the former body of the current Humanoid Research Group) developed the human-shaped WABOT-1 (Waseda Robot No. 1), the first robot of its kind ever produced [2]. About 10 years later, in 1984, the research group developed WABOT-2, a robot capable of performing on musical instruments with a capability equivalent to that of a professional musician [3]. WABOT-2 was exhibited, and it performed exhibitions within the Japanese Government Pavilion at the Science Exposition held at Tsukuba in 1985. The concept behind and the actual capability of the robot has been widely acclaimed at the world level.

Ever since then, with the coming of the elderly society, the needs for utilizing robots to assist with human activities have grown rapidly. The robot research group at Waseda University further enlarged its activities as it evolved into the humanoid research group, and in 1992 it started the Project Humanoid, a joint project of industry, government, and academia. The Project Humanoid has the ultimate goal of developing a robot that shares information and behavioral space with humans. The research can be divided into the following areas: visual system, brain system, locomotion system, and dialogue system.

In 1995, the Humanoid Project produced a prototype robot in order to realize and evaluate close exchanges of information with humans. The robot is called Hadaly-1 [4]. In fiction, Hadaly is a robot in the form of a superb beauty in the novel, Eve of the Future, by the French writer, Villier de Liradan.

Also in 1995, the Humanoid Project was selected as the proposal type research and development project in the most technologically advanced fields of the New Energy Development Organization (NEDO). Hadaly-2 and WABIAN (WAseda BIpedal humANoid) were developed within this project.

These robots will cohabit with humans developed, and they were developed with the goal of establishing elemental technologies that are necessary if robots are to support humans emotionally and physically in close relationships in the following areas: support for and care of elderly and ill subjects, processing sundry matters at home, and other service areas. The elemental technologies include communications and safety technology.

Hadaly-2 is a robot developed with a totally new concept. It is intended to realize information interaction with humans by integrating environmental recognition with vision, conversation capability (voice recognition, voice synthesis), and gesture behaviors. It also possesses physical interaction functions for direct contact with humans and behaviors that are gentle and safe for humans.

WABIAN is a robot with a complete human configuration that is capable of walking on two legs, and it is capable of carrying things as with humans. Furthermore, it has functions for information interactions, a specification intended for uses at home.

We are convinced that the realizations of Hadaly-2 and WABIAN will greatly contribute to the establishment of key technologies that will allow robots to cohabit with humans. These robots are and will be greatly different from conventional industrial robots.

This paper describes the key technologies developed in the seven laboratories of the Project Humanoid and installed on the total systems, Hadaly-2 and WABIAN.

2 Information Processing Systems

2.1 Environment Recognition System

In order for robots to engage in such activities as moving around and conversations with humans, it is necessary to recognize the environment around them. In this regard, an advanced robot will be the one that is capable of grasping the environment around it in detail, and it must be capable of accurately reflecting the recognition into behavior.

Hashimoto Laboratory has developed an environment recognition system relies upon visual input. Each systems detail is explained below.

(1) Speaker Detection and Tracking: We have been developed a real-time parallel processing system, this system can detect and track a speaker by utilizing the synchronization of image and sound [5].

The outline of this system is shown as Fig.1 The system consists of image processing, sound processing, and integration of these. In the image processing component, low resolution image (wide view processing) and high resolution image (local view processing). This composition is in line with human image processing.

In the system, the dynamic object areas are obtained by detecting movement in images. And based on that the position forecasting of the mouth areas of humans (and their changes) are made. These are integrated with sound source positioning results and average sound pressure data.

By the integration of the image and sound data, it becomes possible to recognize the position and mouth configuration of the speakers within a complex scene, even when a multiple number of humans are present.

The actual processing for these are realized by a group of modules that can be largely categorized into 17 types. In the designing of these modules, the greatest importance is placed on robustness and shortening of processing time. And, in order to have the processing done among these modules in real-time, the hardware system shown in Fig.2 has been produced.

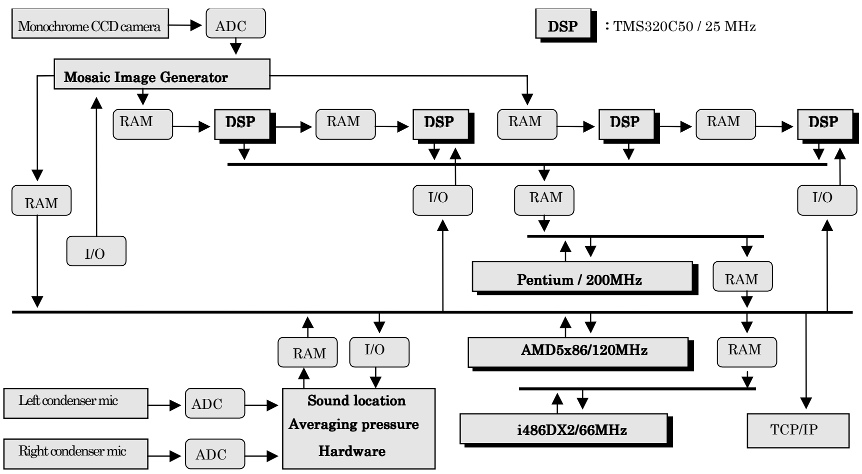

Fig. 1 Outline of the processing

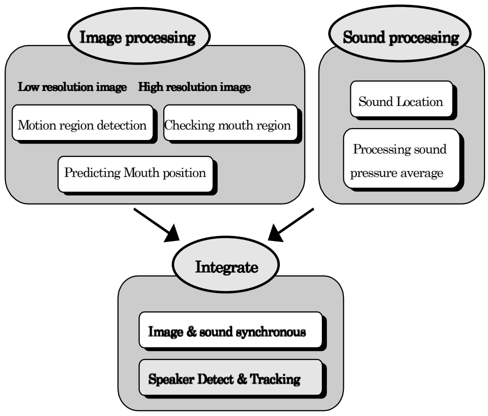

Fig. 2 Hardware system composition

For the processing that are most basic that take the most time, special hardware is produced for images and sound separately. For comparatively basic modules for differential image generation, segmentation, and motion vector induction, four DSP's (TMS320C50/25MHz) are run in parallel. The PC1 (Pentium/200MHz) is allocated with processing functions up to dynamic body area detection, and all the rest of the functions, excluding the processing results display module, are allocated to PC2 (AMD5x86/120MHz). The PC3 (i48dx2/66MHz) is allocated to the dedicated display of processing results.

In addition, as programming logic devices, four Altera EPM7192 and eight EPM7256 are used. With these hardware, real-time recognition processing system of 10 frame/second has been realized.

Hadaly-2 installed with this system will face a person who calls upon it and pursues the speaker with its eyes. Then, if the person talks to it saying "Hello," recognizes the person as a speaker and begins a collaborative behavior with humans with that as a trigger.

(2) Position Detection: When a robot have to do a job upon an object, the positions of the object and the robot itself must be known to the robot.

The system obtains position information by comparing color images from the robot's 'eyes' with modeled computer graphics images of the room environment [6]. In concrete terms, self-position detection is conducted by adjusting position information after moving. Object position measurement is conducted for measuring objects relative to the position of the work object with Hadaly-2. At the same time, the model is updated in response to the environmental change after the work has been done.

When moving itself, the robot may not be able to reach its goal position due to control errors, external forces, friction, and so on. In order to dissolve the accumulation of these types of errors, Self-Position Detection Module is installed in the system.

The model computer graphic (CG) image shown in Fig.3 is created based on the 3D model of the room environment and the viewpoint information of the movement goal position.

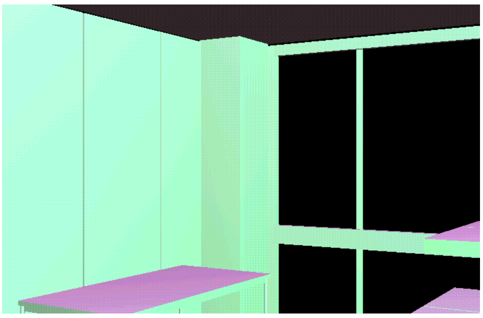

Fig. 3 An Example of the model CG Image

The model CG image is compared with the CCD camera image obtained. When comparisons are performed, the edge contents of the images are extracted, and the edges are compared as shown in Fig.4.

Camera Image Model CG

Fig. 4 Edge image

With the goal movement position in the center, the model CG images are generated from various view points. From among these images, the CG image that is most similar to the CCD camera image is considered as providing the reference for the camera position. From this, the robot position is calculated.

The robot position obtained by the self-position detection module does not have sufficient accuracy for even placing an object in the right position. In order to measure positional relationships between the robot and the object more accurately, Object Position Measurement Module is used.

When the object position is required by the robot, a camera is pointed at an approximate position of the object and the object is searched for. Since the color of the wood block object is known, the specified color of the wood block is searched for in order to specify its position.

(3) Rhythm Generation: The objective of the system is the generation of a dance rhythm which make the biped robot WABIAN dance in accordance with the beat of a conductor's baton.

In order to conduct tempo control for the robot to dance, the tempo is extracted using acceleration sensors [7]. The sensor is made up of piezo-electric elements attached with weights in the XYZ-directions. The acceleration is measured with the position changes of weights.

In conducting, the moment the conductor's baton is extended down, the first beat is recognized, and the time between beats is considered to be the tempo. When correlating tempo with output from the acceleration sensor put at the tip of the conductor's baton, the direction of the baton movement is reversed at the lowest point of the movement. A maximum acceleration value is obtained there. Therefore, by detecting this maximum value, the tempo can be detected.

The extracted tempo is used as information for the playing of music and to assist in the robot's walking. Fig.5 shows the system composition as a whole.

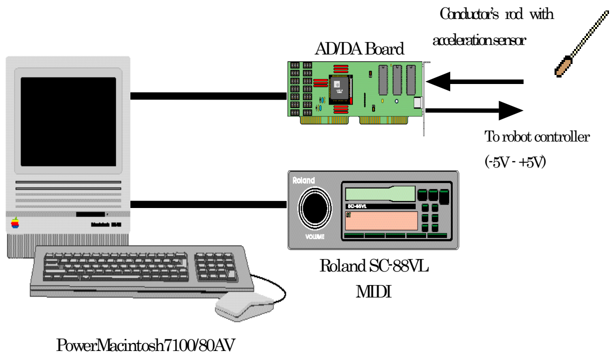

Fig. 5 Tempo control system

The information for playing music uses the Standard MIDI File (SMF) format, which is commonly used for computer music. In the information captured for playing music in SMF format, events such as on/off of keyboard touches and tones are written in accordance with time with the quarter note serving as the time standard. Therefore, the tempo control in the information for playing music can be obtained with the following formula.

$$dT_{next\_evt} = T_{tempo} \times (dT_{midi} / Div_{qtr}) \tag{1}$$

Where, dT_{next_evt} is the transmission time for the next event, T_{tempo} is the tempo extracted for the previous beat, dT_{midi} is the time between events based on the division number of the quarter tempo, and Div_{qtr} is the division number of quarter notes. The same tempo information is sent to the movement controls of WABIAN, and dance movements are effected in line with the music.

2.2 Spoken Dialogue System

Shirai Laboratory and Kobayashi Laboratory are in charge of the research on the speech conversation system for robot, in order to realize natural communications between human and robots, we need to build a spoken dialogue system that is capable of recognizing a continuous speech that comprise a sentence, not just isolated words [8].

Sentences that can be conveyed in speech are described by finite state automaton which has phonemes as nodes. Sentence Speech recognition is done by the most appropriate paths on the automaton. Real-time sentence speech recognition are achieved by using recognition algorithm called one-pass algorithm, which are of a time-synchronous type.

The phoneme which are to be nodes are expressed in acoustic models, such as the Hidden Markov Model (HMM). When using a large amount of speech data in HMM, it is possible to build acoustic models of phoneme that can reflect fluctuations among speakers and contexts.

The dialogue control section can be considered as the brain of Hadaly-2. She comprehends instructions from humans through speech and image recognition and decides upon the next Hadaly-2's.

This module issues most of the instructions for the robot's actions (such as the content for speech, gestures for mechanical systems such as arms and transport mechanism, and instructions for actions such as going to fetch building blocks). The dialogue to be conducted by the robot is controlled as transitions in states, and based on words spoken by humans and image data, decisions are made on conditions at the time. The system determines the next action according to the results of speech recognition, and it issues instructions to the speech output sections and the mechanical systems. Also, in order to be able to respond in a more natural manner to human speech, responses will be made by the use of dialogue history so as to respond to speech which includes indications such as "that" and "previous." Also, the dialogue control section attempts to have adaptability in using objects of humans by having information on simple building block information such as positions, configuration, and color. (Fig.6, Fig.7)

Fig. 6 Captured image of the gesture "No"

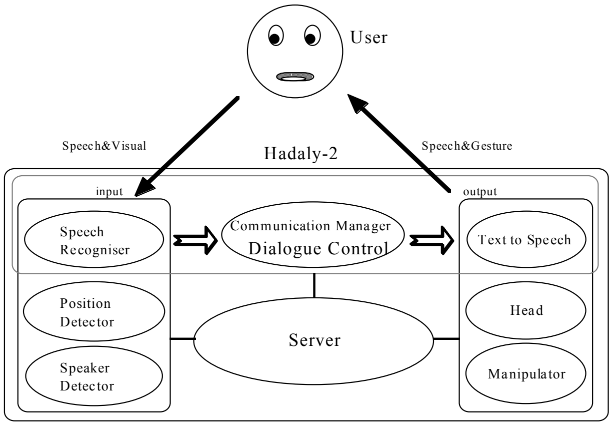

Fig. 7 Module composition of Hadaly-2

2.3 Visual information system of WABIAN

Kobayashi Laboratory developed a gesture recognition system that processes moving pictures. The system is to installed on the biped robot WABIAN [9], and the control section of the visual system is in the head section of WABIAN.

Through the automatic recognition of human gestures, a simple means of communication between humans and robots has been realized. Especially, through realization of communication by image processing, which is vision in human beings, the means have been demonstrated for the possibility of natural communications between man and robots through the use of language and vision.

Using vision system mentioned above, WABIAN can also recognize hand gestures of human. In the current stage, she can recognize 7 types of gestures: "Thank you," "Hello," "Good bye," "Yes," "No," "Come here," "Go away." We can communicate with her using these gestures. We don't need any special devices for the communication.

The process of gesture recognition is as follows. Firstly, the gestures are captured as a sequence of pictures. Then, the right hand position and the head position are extracted from each frame of pictures using color information. Basically, the biggest skin color area is decided as face, and the biggest moving skin color area is decided as hand. The hand movements are expressed by the time series of the relative positions of the right hand against the head. These time series data are used as the feature parameters for the pattern matching. As for the pattern matching, HMM which is widely and successfully used for the speech recognition is used. The HMM decide which pattern in the 7 gestures is the closest to the captured unknown gesture. We achieved 90% of accuracy in this 7 categories gesture recognition task. Through the experiments, it has been demonstrated the possibility of natural communications between human and robot through the combined use of spoken language and visual information.

2.4 Remote control system

Narita Laboratory, which had the goal of producing a network compatible humanoid robot as shown in Fig.8, is in charge of operating the robot by remote control. In recent years, we have seen remarkable progress in robotic and telecommunications technologies.

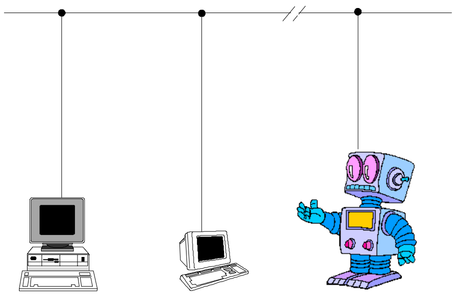

Fig. 8 Network compatible humanoid robot

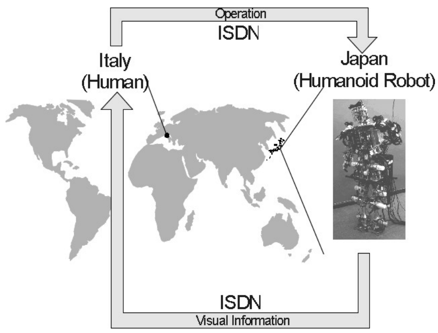

Fig. 9 Remote control of the humanoid robot

Our expectations for applied uses of these technologies are increasing day by day. As far as robots are concerned, interests are stronger for research areas that will assist in maintaining the independent status of many people who are subject to social welfare activities, individuals such as the handicapped and elderly. This concern is in line with the view that our society is shifting toward an elderly society. On the other hand, as far as telecommunications technologies are concerned, it will be important to consider how to achieve the better use of networks that cover the entire globe, as represented by telephone networks.

Therefore, our project has the goal of showing the possibilities for realizing a humanoid type of robots that is compatible with a welfare society, robots that can operate by remote control over high-speed circuits that are accessible in general households. For example, by placing nursing humanoid robots in the homes of elderly citizens, the goals would be to provide elderly subjects with dietary support and to allow conversations with elderly subjects via the remote controls of the robot.

(1) System Composition: In concrete terms, as shown Fig.9, the humanoid robot, WABIAN, in Japan is to be remote controlled from Italy through Integrated Services Digital Network (ISDN), which is rapidly becoming popular within Japanese homes. On the Italian side, Prof. Paolo Dario's research group participated. Prof. Dario is one of the members of the advisory group for the Humanoid Project and is a professor at the Advanced Robotics Technology and Systems (ARTS) of the Scuola SuperioreS. Anna. The following are the concrete parts that make up the system composition [10].

(2) User Interface: Fig.10 shows the screen content of the screen for controlling the eyes of the robot. The screen is composed of five major areas. On the upper left corner is a picture of the robot. The operator will be able to tell intuitively the kind of robot that is being controlled. On the lower left corner of the screen is a cursor in the shape of a cross-cursor. The user can control the eye direction in the vertical and horizontal directions by dragging the cursor. On the upper right corner of the screen, the horizontal and vertical angles of the eyes are displayed from time to time. In the right middle section of the screen are the connection and communication conditions with the eye-controlling computer. By looking at these, the operator can know the type of communication that is taking place between the robot and the computer. In the lower right corner, the connection with the eye computer is conducted.

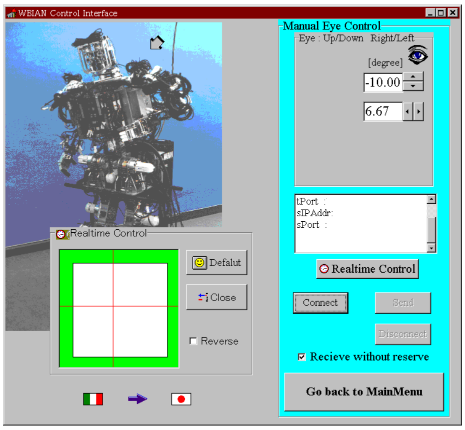

Fig. 10 WABIAN controlling screen

2.5 Communication system

Kasahara Laboratory were in charge of consulting for the selection of software and a network interface; the provision of a software interface which can be accessed easily by user software; and the generation of model code for communications.

The library provided functions are follows.

<Low Level Library Functions>

tcplib_open_server(): Communication channel port is prepared (on the receiving end)
teplib_accept ( ): Accept port connection
tcplib_connect( ): Establish communication channel to the receiving end.
tcplib_close( ): Close the communication channel.
tcplib_write( ): Send byte data to the communication channel.
tcplib_read ( ): Receive byte data from the communication channel. Also, in order to remove communication problems, the following high-level functions were also prepared.
readline ( ): Read data until a carriage return code is found. When a sender keeps on sending data to a port, buffering is conducted at the port. This will cause the data to be stringed together when the receiving end accesses the data. By confirm the data with carriage returns, the receiver ends reading by finding the carriage return and one group of data was received. Also, in TCPI/IP communications, the transmission order of the data is secured, but it may not be that the number of bytes specified by the argument is read in at a time. Therefore, even in cases when only part of the data is read, it is possible to receive correct data as it tries to read to the carriage return.
timeout_read ( ): Wait for the data for the number of seconds specified by the argument. We have developed read-functions with timeout functions. Since there is a possibility for data to be sent after a time out, it is necessary to be able to jump to a certain point in the data when reading from the port the next time by using the return value from the timeout.

Notwithstanding, when using Ethernet as the network interface, complete real-time communication cannot be realized since Ethernet is basically a shared media based on CSMA/CD. However, as is our case this time, when the network is relatively independent of other networks and when the network is not so crowded, it is possible to conduct real-time control accordingly. However, since we used TCP/IP as the communication protocol, and since the TCP is a sequential stream protocol, the delay will be larger compared to protocols handling packets directly.

Therefore, it is considered that controls in the 0.1 second order are only possible. On the other hand, since most of workstations in general do not have real-time modules, finer controls of less than 0.01 seconds are not performed by the internal clocks and process schedulers. So we think there will not be a major problem.

3 Mechanical System

3.1 Head-Eye System

Takanishi Laboratory is in charge of the research on the anthropomorphic head-eye robot. Vision is one of the most important senses that humans utilize in collecting environmental information. Motion plays important role when the human generate the visionary space with eyes and various objects.

For humanoids, when it is necessary to respond to constantly changing unknown space (and not only to a limited and already known environment), it is considered indispensable to have wide-ranging visual information including information obtained by tracking moving objects. In order to cope with such information, a humanoid needs a flexible vision function that actively changes viewing positions.

At the same time, in order for humanoids to be active in society, communication with humans will be important. From this point of view, it is necessary for the humanoids to have quick movements of the eye as do humans, an ability which has not existed previously. Therefore, to develop anthropomorphic head-eye system, Takanishi Laboratory has the goal of elucidating human vision system from an engineering point of view and to develop a new human communication system based on the information and knowledge obtained. In 1996, in the "Development of an anthropomorphic Head-Eye System adjust to brightness, Using an Eyelid Mechanism," eyelids were installed on WE-3 as mechanical hardware. On WE-3, adaptation in the retina and adjustment of the pupil diameter within the iris were realized in software [11]. Coordinated movement among these were realized in Waseda Eye No.3 Refined (WE-3R). This head-eye system is installed on Hadaly-2.

The retina and adjustment of the pupil diameter within the iris were realized in software [11]. Coordinated movement among these were realized in Waseda Eye No.3 Refined (WE-3R). This head-eye system is installed on the Hadaly-2. Fig.11 presents the total view, and Fig.12 shows the assembly drawing of the anthropomorphic head-eye system WE-3R that has been developed. The robot has eyeball and neck parts.

(1) Eye part: In this study, the goal specification was that the robot needed to have movement velocity that is equivalent to or better than that of a human being. This meant that it was necessary to develop the eyeball part with high-speed movement capability. The human eyeball has 3 DOF: horizontal movement (the yew axis), vertical movement (the pitch axis), and rolling movement (the roll axis).

The robot that was to be developed needed to have the first two movements, excluding the rolling movement. From among various ideas about possible mechanisms, we chose to develop the eyeball mechanism with a tendon-driven gimbals mechanism. With the wire drive, it was possible to make the camera drive lighter in weight. Also, by making one side of the opposing wire a spring mechanism, it was possible to make the eyeball part as a whole lighter in weight without allowing backlash. For the distance between the right and left pupil, we had the typical distance for a human or 62 mm as the goal distance. The maximum angular velocity is about 600 deg/s, which is almost equivalent to that of a human.

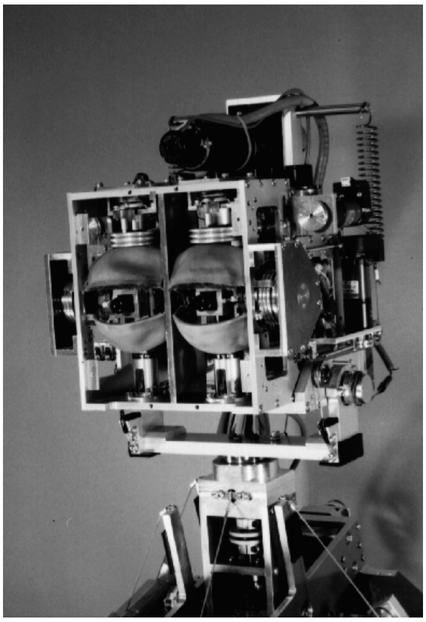

Fig. 11 Total view of WE-3R

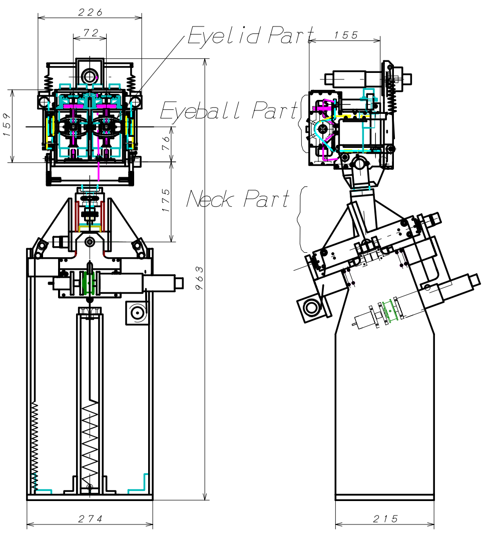

Fig. 12 WE-3R assembly chart

(2) Neck part: In order to realize pursuing motion in the depth direction, it was necessary to give the neck motion mechanism a degree of freedom that is equivalent to that of humans. For example, the following motions are required:

1) From looking downward to further looking directly below.
2) From looking upward to further looking directly above.

3) Move the head forward and backward in the depth direction.

In order to satisfy such requirements, we have modeled the neck part to 4 DOF from an anatomical and functional point of view, using the human head structure as a reference. This allowed for comparatively free pursuing motion which is almost at the human level. In the upper pitch axis, we chose a tendon-driven mechanism of the wire using motor and spring which makes it possible for the mechanism to be compact. Also, on the lower pitch and roll axes, as with the eyeball part, a tendon-driven gimbals mechanism wire has been adopted of wire using motor and spring, in order to reduce the amount of inertia. On the yew axis, a harmonic drive motor was used, which completely prevents backlash. Moreover, as the gravity-cancel spring at the center of the robot pulls the gimbals centerline with a wire, the gravity generated by the head is canceled.

3.2 Manipulator system

Sugano Laboratory has developed hands, arms, mobile mechanisms, and body sections of Hadaly-2. All throughout the design and the development of the Hadaly-2, the greatest importance has been placed on making Hadaly-2 a system that can collaborate with humans. This means that Hadaly-2 will come in direct contact with humans, and it has functions that allow it to work in collaboration with human. This means that maintenance of safety is most important in working with humans, and it was necessary to realize motion controls that work in Human-machine collaboration. From these remarks, various specifications for Hadaly-2 had been determined so as to make informational as well as physical interaction possible.

We started to develop the hand and the arm subsystem (WAM-10) for Hadaly-2 in 1993. In WAM-10, all of the seven joints employ a passive compliance adjustment mechanism (MIA: Mechanical Impedance Adjuster), and the subsystem composes a manipulator that secures safety and workability under a coexisting environment with humans [12].

In 1994, a prototype with one degree of freedom using MIA was completed, and in 1996 the whole right arm with seven DOF (WAM-10R) was completed. Also, in 1996, we set out to develop a hand with four fingers and 13 DOF. In 1997, we completed development of hands with four fingers and 13 DOF (right and left hand), the left arm (WAM-10L), the body, and the mobile mechanism. This completed the development of the Hadaly-2 system. Below is an outline of the systems developed.

(1) Hand section: The hand is an anthropomorphic robot hand with four fingers and 13 DOF. The thumb has four DOF, which is the same as the human thumb, and the other fingers have three DOF, abbreviating the DIP joint. For the actuator that drives the 13 DOF finger joint, an AC servomotor has been used. At the base of each fingers are six-axes force/torque sensors for whole finger compliance control. By this, physical interactions with humans, such as shaking hands and handing objects over, is possible.

(2) Arm section: The configuration and the placement of the DOF for the arm have been determined with reference to the human arm. The arm has seven DOF as is also the case with a human arm. Therefore, the total DOF for WAM-10 (including the fingers) is 20 per each arm. WAM-10 is equipped with a mechanism for adjusting joint compliance and viscosity mechanically. By conducting compliant motion using this mechanism, it is possible to realize collaboration with human while securing safety.

For driving the upper arm and the forearm, AC motors and DC motors are used. Furthermore, for the adjustment of compliance and viscosity, DC motors, and electromagnetic brakes are used. This means that each joint has three actuators. For designing the motion speed of the hand, the general movement speed of adult men is referenced, which is about 1.0 (m/s). If the joint compliance is set to maximum, an approximate weight of 500 grams can be held while maintaining an extended arm position.

Table 1 Hadaly-2 specifications (excluding head)

Configuration	Anthropomorphic Upper Body, And Lower Body with Wheels
Degree of Freedom	Finger 13 x 2, Arm 7 x 2 Body 1, Vehicle 2
Dimension	Height Approx. 170 cm Body Width Approx. 40 cm Total Width Approx. 130 cm
Weight	Hand Approx. 2 kg Arm Approx. 25kg Transport Approx. 50kg Total Weight: 150kg
Structural Material	Duralumin
Actuator	DC motor, AC motor
Sensor	Rotary Encoder (hand, arm, body, wheel) Six-Axes Force/Torque Sensor (Hand)

(3) Body and Mobile Mechanism: Hadaly-2 uses a wheel-type mobile mechanism. By controlling and driving the two front wheels, the mobile mechanism achieves back and forth movement and the ability to turn around. The transport speed is 6 km/h at the maximum pace. The body has one degree of freedom, which makes it possible to twist the upper body when the mobile mechanism is stopped. Table 1 shows the specifications of each section.

(4) Control System: The hand, arm, and body sections of Hadaly-2 are composed of a total of 71 actuators with 43 DOF. In order to efficiently control, this large-scale system, a distributed control computer system was built.

In the upper control level, a personal computer with a 200 MHz Pentium processor is used for handling TCP/IP communications with the voice and the vision stems, for motion planning of the manipulator, and control of the body and the mobile mechanisms. The lower control level consists of two control systems for the right and the left manipulator. Each uses a 200 MHz Pentium PC and interface boards for motion control. C-Language has been used for the software. Fig.13 shows the motion control system of Hadaly-2.

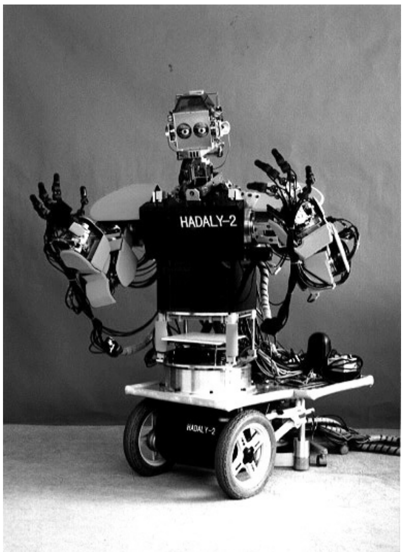

Fig. 13 Overview of Hadaly-2

3.3 Biped walking system

In recent years, we have come to see much more research on humanoid robots. However, we have seen no case of humanoid robot which is about the size and weight of humans, which performed stable dynamic biped walking in the human habitat and has two arms and communicates with humans. Takanishi Laboratory has been in charge of the research on the biped walking mechanism [13].

In our project, we set it as our goal development of a prototype of humanoid robot that will conduct support work for humans involving walking in the human habitat. As its first step, we have developed a biped humanoid robot WABIAN (WAseda BIpedal humANoid). WABIAN is approximately the size of humans and has a head that is equipped with a mechanism for acquiring audio-visual information.

Prior to setting out on development of WABIAN, a bipedal humanoid robot, we set the following guidelines.

1) In view of collaborative work with humans, the robot size would be decided with reference to the average measurement of adult Japanese women.
2) External connection of the robot will be limited to power supply through household alternating current outlet. The robot control computer and motor drive circuit will be on board the robot.
3) The robot should be capable of biped walking at approximate human speed, in forward and backward directions.
4) The robot will have human-type seven DOF arm.
5) The robot will have a head that is equipped with a mechanism for acquiring audio-visual information, for making bi-directional communication with humans. It could be possibly equipped with voice communication capability through the use of external computers.
6) In view of uses in a human habitat, electric servomotors will be used as actuators.
7) For the walking control method, the control method for dynamic biped walking, proposed by the author and others in 1992, will be used. In this method, the biped walking will consider to compensate for pitch, roll, and yaw axes moment by trunk motion.

Based on the above guidelines, biped walking humanoid robot WABIAN was developed. The robot stands at standstill condition 1662 mm and the total weight is 107 kg, It has weight carrying capacity of 30 kg on the shoulder and 1.5 kg on the hand. The total picture is shown in Fig.14, and Fig.15 shows the assembly drawing. The features of the mechanical model are: head with audio-visual information acquisition function; hand-arm system that also contributes to walking stabilization; and biped walking with all control equipment on-board, excluding the power source. (Household alternate current is used as the power source.). As far as the head is concerned, head-eye robot WE-3, developed by the author and other in 1995, is modified and installed. As a result, it is also possible for the robot to have audio-visual and audio-dialogue capabilities.

The DOF for different sections of the robot are distributed in the following manner: two DOF each on the pitch and roll axes in the eyeball and neck sections; seven DOF in the arm section, the same as humans; three DOF in the hand section; one degree of freedom each on pitch, roll, and yaw axes on the trunk; in the lower limb section, one degree of freedom on the pitch axis at ankle joint, knee joint, and hip joint; and the foot mechanism has passive DOF (four DOF for X, Z-axes, pitch and roll axes for each foot. Thus, there are 43 DOF on the whole.

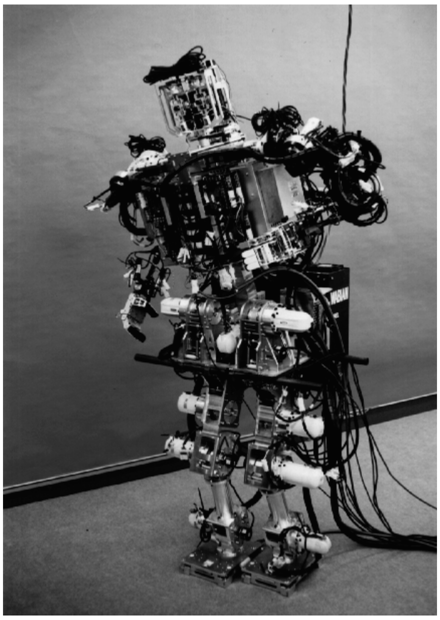

Fig. 14 WABIAN

As for the driving method for the DOF, antagonistic driving method is sued for the hip joint, the same method used by humans, in order to make efficient driving possible by using potential energy. This makes it possible to vary the stiffness of joints on a wide-ranging bases. As far as the other joints are concerned, one actuator drives for one degree of freedom through a reduction gear. The extra super duralumin is used to enhance the stiffness of the skeleton as a whole and mechanical precision in combination with fit and bolt fastening.

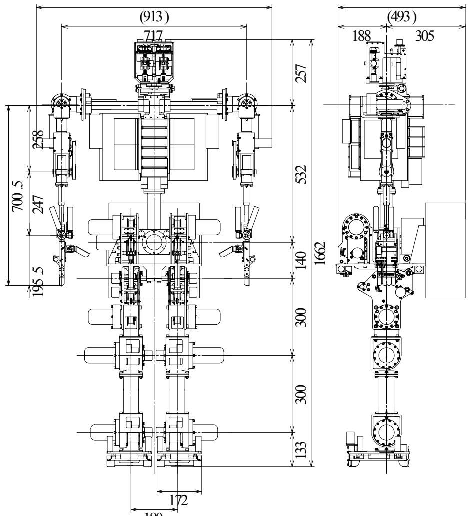

Fig. 15 Assembly drawing

As for the control system, 15 AC servomotors, 16 DC servomotors are centrally controlled via IO board by the PC/AT CPU board having Pentium processor by INTEL. As I/O boards, two D/A conversion boards, one A/D conversion board, two counter boards, and one Ethernet board are used, total of 6 ISA bus expansion boards. The control system is installed at the back of the robot. Also, the motor drive circuits are installed on the upper part of the trunk, playing the role of weight for moment compensation as well.

4 Conclusions

The Project of Waseda University Humanoid is now in the second phase of research to realize an emotional man-machine-environment interaction using vision, audition and haptics. Although a lot of works are required on information processing systems, mechanical systems and total architecture designs to realize practical humanoid, we can find great possibilities in it. Because humanoid is a machine with human-like configurations, human-like functions, human-like behavioral patterns and human-like "mind", which will open a new epoch of human machine relationship in the aged society.

For the future works, Waseda University Humanoid Robotics Institute (HRI) are planning to create a humanoids that have intension, mind, will, consciousness, and brain. For example, Prof. Takanishi's Group has developed a new version of WABIAN that can show various emotional intentions in walking; happy walk, sad walk and etc. They also developed a head-eye system that have four senses to react emotionally to the environmental sound, view, smell and touch. Prof. Sugano's group is continuing the research for artificial emotion machine "WAMOEBA" as well as the flexible body robot "WENDY" that can break egg and cut cucumber with a knife to help the kitchen works. Prof. Kobayashi's group is now training the communication robot "ROBITA" that can make a speech conversation with two human partners by using vision to recognize the speaker and his face orientation. Prof. Narita's group is now making a virtual humanoid simulator to assist the robot design and to examine the effect of the data transmission delay for the networked humanoid. Prof. Hashimoto's group is now developing a dance partner robot that can move around with human partner with visual and auditory senses as well as haptic and gesture interface for artistic performance.

All these specialized researches will be integrated to more sophisticated humanoid robot in a few years. Some of these current works will be presented in the Humanoids Conference 2000.

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References

1. Kato. I.: Conception of living and life support robot, Jour-nal of the Robotics Society of Japan, Vol. 11, No. 5 (1993) 14-17
2. Kato. I., et al.: Pneumatically Powered Artificial Legs Walking Automatically Under Various Circumstances, Proc. of 4th Int. Symposium in External Control of Human Extremities (1972)
3. Kato. I., et al.: Wabot-2: Autonomous Robot with Dexterous Finger-Arm, Proc. of IEEE Robotics and Automation, Vol.5 No.2 (1987)
4. S. Hashimoto, et al.: Humanoid Robot-Development of an Information Assistant Robot Hadaly-, RO-MAN'97 (1997) 106-111
5. T. Kurata, Dingding Chang, S. Hashimoto: Multimedia sensing system for robot, Proc. of the 4th IEEE Intl. Workshop on Robot and Human Communication (1995) 83-88
6. T. Noguchi, S. Hashimoto: Recognition Environment by Active Searching, Proc.of the conference of the Information Processing Society of Japan (1998)
7. H. Sawada, S. Hashimoto: Gesture Recognition Using an Acceleration Sensor and Its Application to Musical Performance Control, Electronics and Communication in Japan, Part 3 Vol.80, No. 5 (1997) 452-259
8. K.Shirai: Spoken Dialogue in Multimodal Human Interface, ICSP 97 Proc.Vol.1 (1997) 13-20
9. T. Kobayashi, S. Haruyama: Partly-Hidden Markov and Its Application to Gesture Recognition, Proc.of Intl. Conference on Acoustics, Speech, and Signal Proc. (ICASSP97), Vol. 4 (1997) 3081-3084
10. H. Takanobu et al: Japan-Italy Joint Research on Interaction between Humans and Remote Environments, No. 15 Proc of the conference of the Robotics Society of Japan (1997) 789-790
11. Atsuo Takanishi, Tadao Matsuno, Isao Kato: Development of an Anthropomorphic Head-Eye Robot with Two Eyes-Coordinated Head-Eye Motion and Pursuing Motion in the Depth Direction-, IROS97 (1997) 799-804
12. T. Morita, S. Sugano: Development of an Anthropomorphic Force-Controlled Manipulator WAM 10, 8th Intl. Conference on Advanced Robotics (1997) 701-706
13. J. Yamaguchi, A. Takanishi: Design of Biped Walking Robot Having Antagonistic Driven Joint Using Nonlinear Spring Mechanism, IROS'97 (1997) 251-259