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Development of “Bonten-Maru” humanoid robot

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Abstract:

This paper presents the status and research results of the "Bonten-Maru" humanoid robot project. The main contributions of this project are on CORBA based control of humanoid robot, real time optimal gait generation, control of humanoid robot in a long distance using teleoperation system, operation of humanoid robot in emergency environments, and various humanoid robot motions. In order to verify our research results, we developed the "Bonten-Maru" humanoid robot. Another important objective is to cooperate with different researchers on humanoid robots by: (1) making the control platform open; (2) easy to be extended; (3) easy to integrate programs in developed in different programming languages. We present the main results of the "Bonten-Maru" humanoid robot project published in more than 20 papers in international journals and conference proceedings.

1. Introduction

Recently, the research on humanoid robots has attracted many researchers. The research spans from stability and optimal control, gait generation, human-robot and robot-robot communication. In addition, humanoid robots have been also used to understand better human motion. Among humanoid robot prototypes the most well known is Honda humanoid robot (Hirai et. al., 1998)[1)]. This robot has the ability to move forward and backward, sideways to the right or the left, as well as diagonally. In addition, the robot can turn in any direction, walk up and down stairs continuously. The 35 d.o.f. Saika humanoid robot is presented by Inaba et al. (1998)[2)]. The robot can perform a reach-and-grasp motion through coordinating legs and arms. The key idea of the system architecture is a remote brained approach. In addition, the Waseda humanoid robot group has also developed an anthropomorphic dynamic biped walking robot adapting to the humans' living floor (Takanishi et. al., 1990)[3)]. Fujitsu also has developed a commercial humanoid robot for research purposes. The robot’s weight is 7kg and it has 25 d.o.f humanoid robot.

In robotics laboratory of Yamagata University, we initialized the humanoid robot project. The goal of this project was to contribute to the research on humanoid robots. For this reason, we developed the “Bonten-Maru” humanoid robot. During the humanoid robot design, we tried to mimic as much as possible the humans, from the viewpoints of links dimensions, as well as the number and distribution of the dof. The high number of dof help the “Bonten-Maru I” to realize complex motions in even and uneven terrains, like walking, going up and down stairs, creeping, etc.

We were one of the first humanoid robot groups, that proposed a humanoid robot control platform based on CORBA (Takeda et al., 2001)[4]. One of our objectives was to make the control platform open for other researchers to test their results and also to conduct collaborative research. By using a CORBA based control platform, it is easy to add modules developed in different programming languages. In addition, the control of the humanoid robot is made in a distributed environment. Therefore, various humanoid robots in the world can share their own modules with each other via the Internet.

Another direction of our research is the real time generation of humanoid robot optimal gait by using soft computing techniques (Capi et al. 2001)[5]. Genetic Algorithms (GA) was employed to minimize the energy for humanoid robot gait. For a real time gait generation, we used Radial Basis Function Neural Networks (RBFNN), which are trained based on GA data. Until now the walking and going up-stairs modules are created. The main objective of this research is to create an autonomous humanoid robot that can operate in different environments. Based on the information received by the eye system the appropriate module will be simulated to generate the optimal motion.

Control of humanoid robot in a long distance was also another research issue. Our main objective is to create various sophisticated motions and new application fields for humanoid robots. For this reason, we considered accident site operation which are often unknown environments. In our work, we used a teleoperation system to control the humanoid robot through the Internet. We carried out experiments on the teleoperation of the humanoid robot between Deakin University (Australia) and Yamagata University (Japan) (Nasu et al. 2003)[6]. The experimental results verified the good performance of the proposed system and control.

2. “Bonten-Maru I” humanoid robot

The "Bonten-Maru I" humanoid robot is shown in Fig. 1(a). It is 1.2 m high and weights 32 kg, like an 8 years old child. The "Bonten-Maru I" is a research prototype, and as such has undergone some refinement as different research direction are considered. During the design process, some predefined degree of stiffness, accuracy, repeatability, and other design factors have been taken into consideration. The link dimensions are determined such that to mimic as much as possible the humans. In the "Bonten-Maru I" humanoid robot, a DC motor actuates each joint. The rotation motion is transmitted by a timing belt and harmonic drive reduction system. Under each foot are four force sensors, two at the toe and two across the heel. These provide a good indication of both contact with the ground, and the ZMP position. The head unit has two CCD cameras (542x492 pixels, Monochrome), which are connected to PC by video capture board. A Celeron based microcomputer (PC/AT compatible) is used to control the system.

The degrees of freedom of the humanoid robot are presented in Fig. 1(b). The high number of dof gives the "Bonten-Maru I" humanoid robot the possibility to realize complex motions. The hip is a ball-joint, permitting three dof; the knee joint one dof; the ankle is a double-axis design, permitting two. The shoulder has two dof, the elbow and wrist one dof. The DC servomotors act across the three joints of the head, where is mounted the eye system, enabling a total of three dof. The distribution of dof is similar with the dof in human limbs.

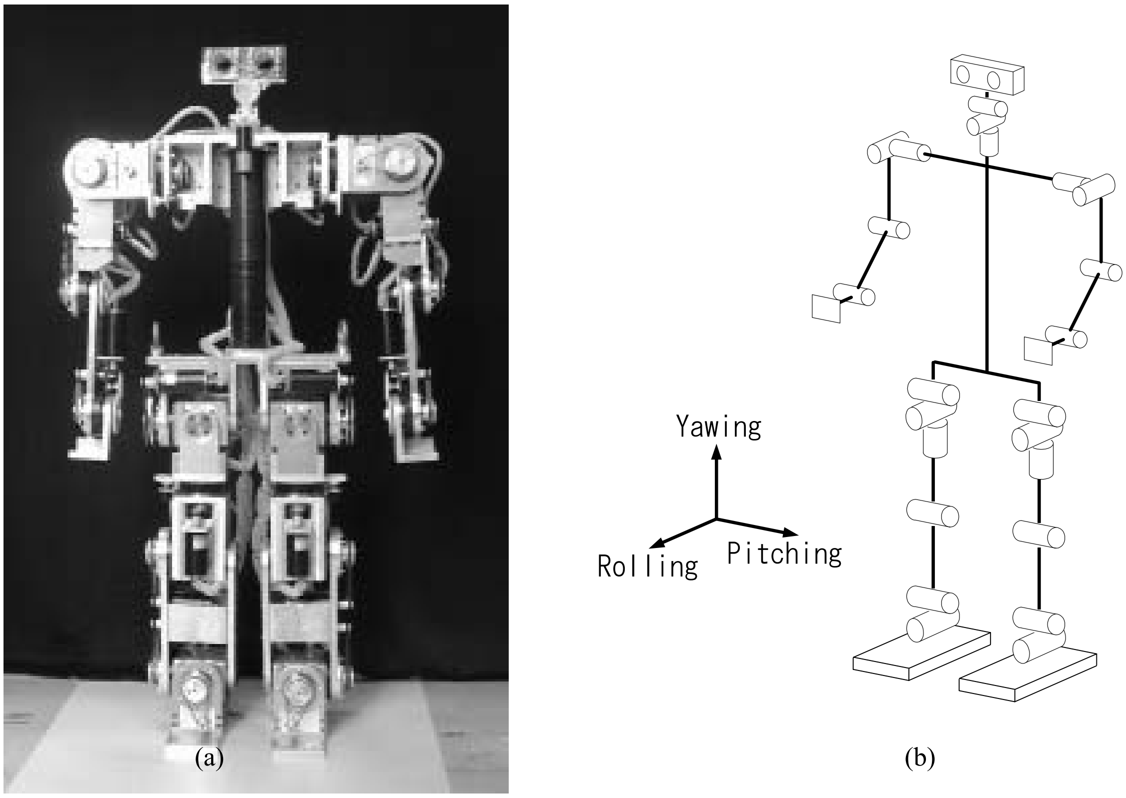

(a)
(b)

Fig. 1 The” Bonten-Maru Ⅰ “ Humanoid robot.

2.1 CORBA control platform

The humanoid robot must attain many sophisticated motions such as walking, going up and down stairs, obstacle overcoming, creeping, etc. Therefore, the control architecture must be implemented in parallel or distributed programming architecture. The control modules should be developed independently and integrate easily to the system. For this reason, CORBA is a good platform for humanoid control system architecture. CORBA is a specification of message exchange among objects, which is specified by Open Management Group (OMG). CORBA is a useful distributed application platform, which can make the cooperation among distributed applications very easy. Also, CORBA is independent on a specific programming language or OS. The Humanoid Robot Control Architecture (Takeda et al., 2001)[4] is proposed to integrate the desired modules developed by many researchers individually to control the motion of humanoid robot through the Internet. The HRCA can share many modules among many users or researchers from remote distance through any computer by the Internet communication. Fig. 2 shows a basic concept of proposed HRCA. The HRCA design is based on the Unified Modeling Language (UML), which includes the Use Case Diagram (UCD) and Class Diagram (CD).

We have upgraded the humanoid robot control architecture (HRCA) to apply to the teleoperation of the humanoid robot in an accident site through the Internet. We have implemented the following main modules: DTCM, MCM, JTM, GSM, JAM, FCM, CCM, VCM and UIM in this figure. Each module corresponds to “Data Transmission”, “Target Position”, “Angle Trajectory Calculation”,

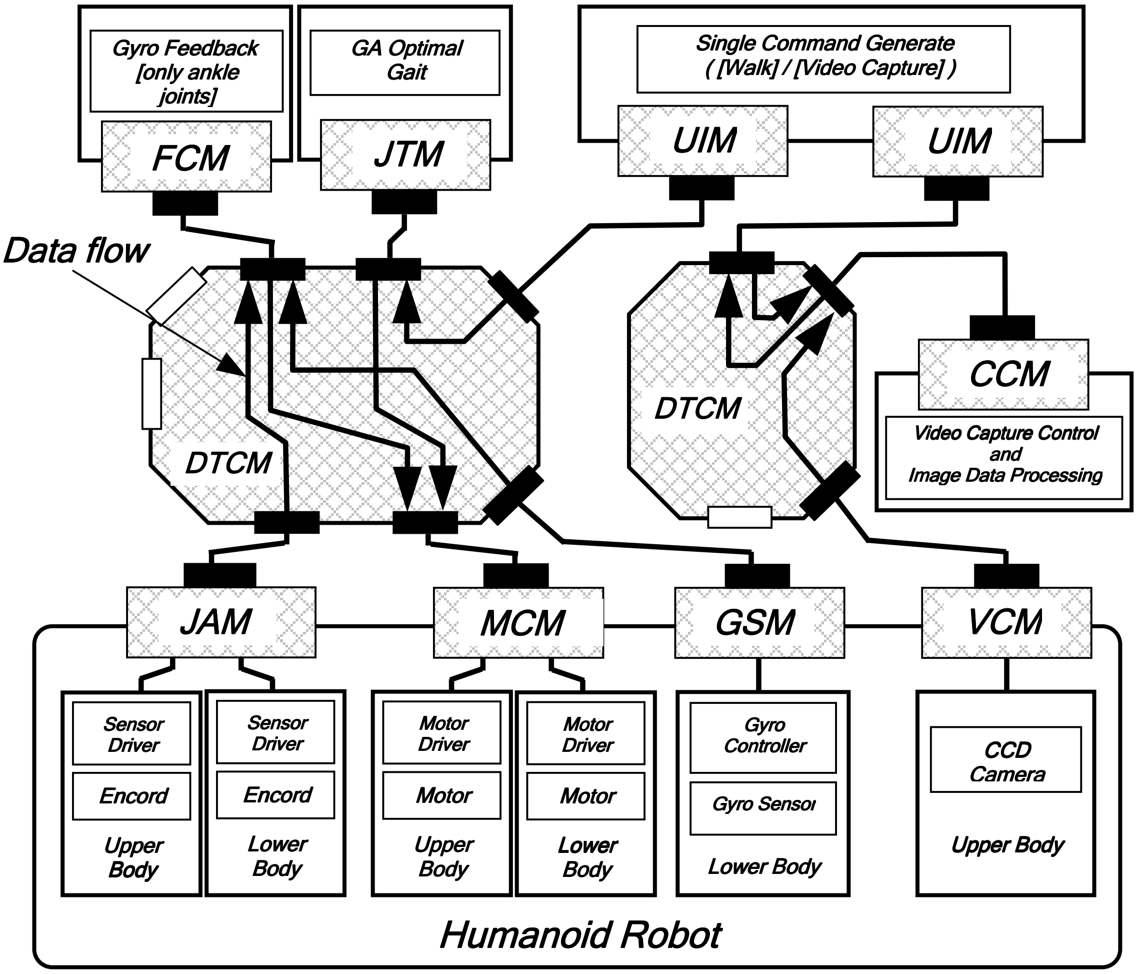


Fig. 2. The HRCA for Bonten-MaruII humanoid robot.

"Sensor", "Position", "Feedback Control", "CCD Camera", "Video Capture Control" and "Command Generator", respectively. To implement CORBA servers and client, the Inter-Language Unification (ILU) is use, which has been proposed by XEROX PARC. ILU supports many programming languages, such as C++, ANSI C, Python, Java, Common Lisp, Modula-3, Guile Scheme, and Perl 5. In this HRCA, the DTCM controls the data flow of the modules. The one DTCM communicates with MCM, JTM, GSM, JAM, and FCM by using their functions, and other DTCM communicates with VCM and CCM. Both DTCM communicate with UIMs by their own function. The UIMs are simple, which are able to command "WALK", "SIDE-STEP", "SQUAT", "STAND","CREEP", " NECK-ROTATE" and "VIDEO CAPTURE".

3. Real Time Gait Generation Method

We considered minimum CE as criterion for humanoid robot gait generation, because autonomous humanoid robots make difficult to use external power supply. In order to have a long operation time when a battery actuates the motors, the energy must be minimized. For minimum CE cost function, it can be assumed that the energy to control the position of the robot is proportional to the integration of the square of the torque with respect to the time. Because the robot joints are driven by torque, then the unit of torque, Nm, is equal to the unit of energy, joule. During walking, the arms of the humanoid robot will be fixed on the chest. It can be considered as a five-link biped robot in the sagigtal plane, as shown in Fig. 3.

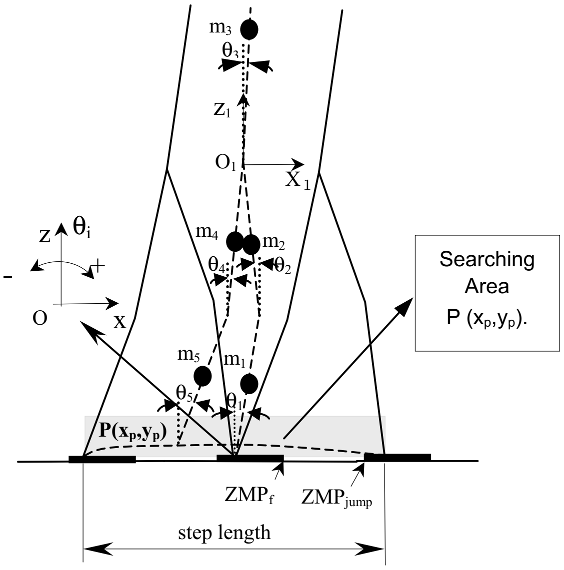


Fig.3 Five-link biped robot.

Therefore, the cost function, J, can be defined as follows:

$$J = \frac{1}{2}\left(\int_0^{t_f} \tau^T \tau dt + \Delta\tau_{jump}^2 \Delta t + \int_0^{t_f} C dt \right) \qquad (1)$$

where: t_f is the step time, τ is the torque vector, $\Delta\tau_{jump}$ and Δt are the addition torque applied to the body link to cause the ZMP to jump and its duration time, and C is the constraint function. The torque vector is calculated from the inverse dynamics of five-link biped robot[7)] as follows:

$$J(\theta)\ddot{\theta} + X(\theta)\dot{\theta}^2 + Y\dot{\theta} + Z(\theta) = \tau \qquad (2)$$

where $J(\theta)$ is the (5x5) mass matrix, $X(\theta)$ is the (5x5) matrix of centrifugal coefficients, Y is the (5x5) matrix of Coriolis coefficients, $Z(\theta)$ is the (5x1) vector of gravity terms, τ is the (5x1) generalized torque vector, and $\theta, \dot{\theta}, \ddot{\theta}$ are (5x1) vectors of joint variables, joint angular velocities and joint angular accelerations, respectively.

To determine the humanoid robot optimal gait, a real-value GA was employed in conjunction with the selection, mutation and crossover operators. The GA generates randomly the first population, where every individual of the population presents a possible humanoid robot gait. According to the formula (1), the minimum CE cost function is calculated and attached to every individual of the population. The GA moves from generation to generation, selecting parents and producing offspring until the termination criterion (maximum number of generations GN_{max}) is met. In our method, we used normalized geometric ranking as a selection function. Based on the GA results, the minimum CE gait is obtained. In our simulations, GA needs about 10 minutes to determine the optimal gait.

In order to generate in real time the humanoid robot optimal gait we considered creating different RBFNN modules. Every module presents a humanoid robot task. The creation of modules is carried out off time and separately for each task because the number of variables optimized by GA and searching spaces are different. GA generates the optimal gaits for a wide range of motion parameters, like step length and step time during walking, or step depth, step rise and step time during going up-stairs, which are used to teach the RBFNNs. Up to now, we have created the walking and going up-stairs modules. In Fig. 4 is shown the schematic diagram of real time gait generation by walking module. The CCD cameras transmit the image information to image recognition module. After the image is analyzed, the RBFNN module and input variables are determined.

4. Teleoperation System

Fig.5 shows the teleoperation schematic diagram. The operator uses this system as a CORBA client and commands several kinds of motions, i.e. walking, crouching, creeping,

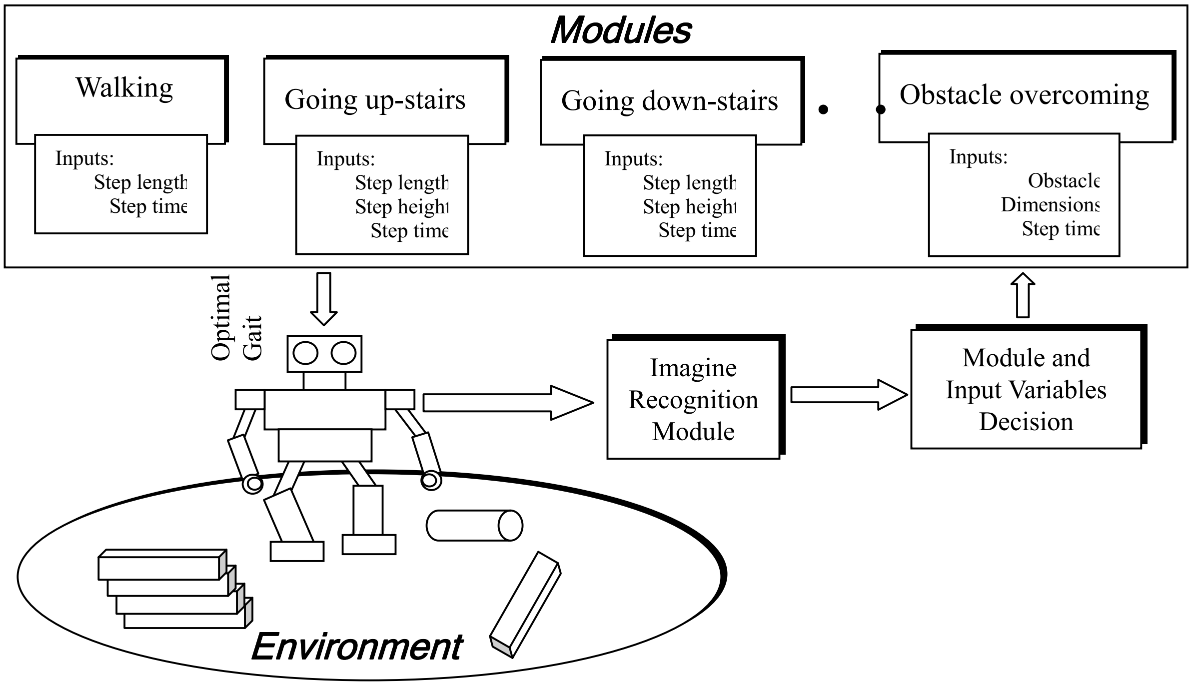


Fig. 4. Real time optimal gait generation

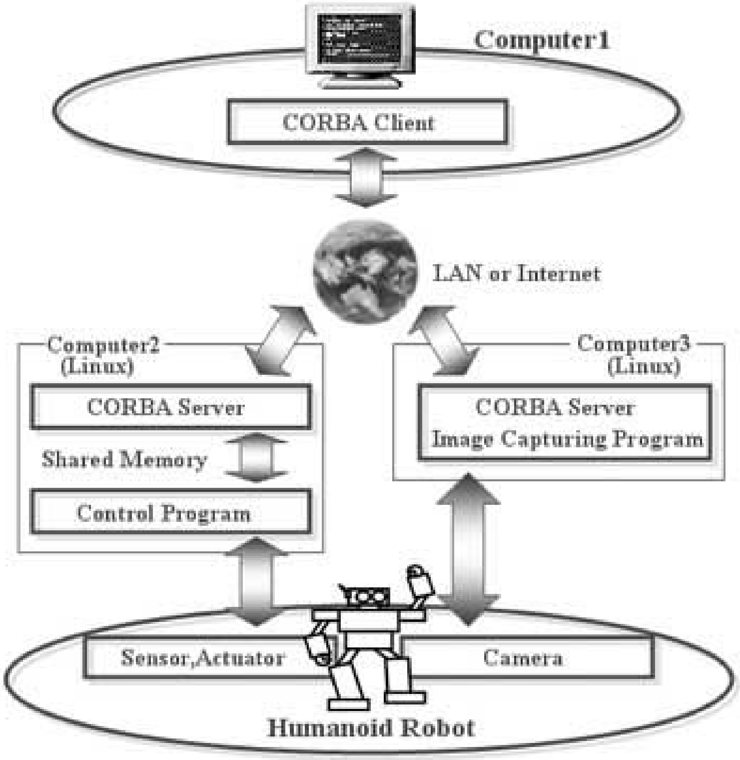


Fig. 5. Teleoperation concept

standing up, etc.Up to now, the operator can command the number of steps and humanoid robot walking direction. The operator receives the camera image mounted in humanoid robot's head and based on the data displayed in PC1, measures the distance between the robot and objects. PC2 is used to read and manipulate the sensor data and send output commands to the actuators. PC3 is used to capture the CCD camera image.

A notebook type computer with a Pentium Ⅲ,700MHz processor running Red Hat Cygwin on the Windows XP was used as the client computer (Computer1) PC1. Two different type computers were used as server computers: (Computer2) PC2 (Celeron, 433MHz), (Computer3) PC3 (Pentium Ⅱ , 200MHz) running Red Hat Linux7.3.

CORBA server program receives a motion command from CORBA client and writes it on the shared memory of PC2. Sending and receiving the data between CORBA server program and control program are executed by using shared memory feature of UNIX OS. Among all programs on the LINUX, the control program OS implemented in accordance to highest-priority due to keep the control execution period. CORBA server program is implemented at default value.

When the operator watches the camera image, PC1 and PC2 are used. When the operator executes CORBA client program of PC1, the image data, which is captured in PC3, is imported to PC1. The operator can use it to measure the object distance, to recognize the environment condition and make decision of the optimal motion. First, we measured the image capturing job time through the Internet. The typical job time averaged about 13 sec to a few minutes, because there are many communication traffic loads in the both universities LANs.

Second, using the humanoid robot, we have carried out two types of teleoperation obstacle avoidance experiments between Australia and Japan. The operator executed teleoperation program from Deakin University (Australia) through the internet.

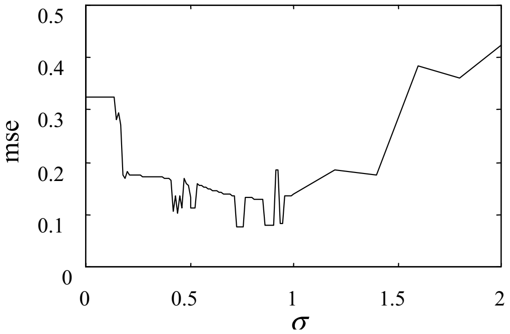


Fig. 6. mse vs. the width σ .

5. Results

5.1 Real time gait generation

In our RBFNN, the centers of Gaussian function are the same with training data and the width σ is considered the same for all hidden neurons. Determining the best value of the width σ is important in order to minimize the overall training error. The goal is to select σ in such way to minimize the overlapping of nearest neighbors, as well as maximize the generalization ability. The width selection depends on the distance between the two neighbor vectors. In our case, the width σ is the same for all neurons, because the distances between the centers are the same. In Fig. 6 is shown the mse versus the width σ . The minimal value of mse is for σ =0.73.

The GA and RBFNN results for different sets of step lengths and step times are shown in Fig. 7. These sets are different from the training data, for which the RBFNN and GA results are the same. This figure shows that RBFNN outputs are very near with the optimal data generated by GA. The difference between the GA and RBFNN angle trajectories for the step length

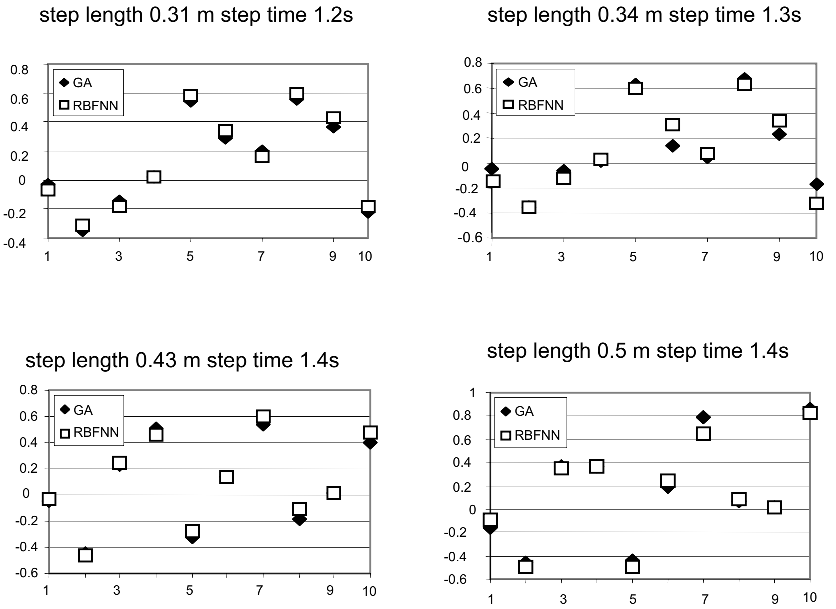


Fig. 7. GA and RBFNN results.

0.45m and step time 1.2s is very small, as shown in Fig. 8. During the simulations, we see that the difference between RBFNN and GA angle trajectories is small for θ_2, θ_3, θ_4. The difference is larger for θ_1 and θ_5.

5.2 Obstacle avoidance by walk

We set a box on the floor in front of humanoid robot. The operator recognized it in the image data from the humanoid robot BT-2. Fig. 9 shows a series of the obstacle avoidance walking motions and image data of the humanoid robot eyes. The humanoid robot received the following motion commands:

1) Walk front (or back)

2) Side step to left (or right)

3) Spin left (or right)

The operator measures the distance between the robot and the obstacle, and plans a walk trajectory to avoid the obstacle. Because the measured obstacle data is not precious, the motion command is not always the best. However, the operator can correct the walking trajectory by using the image information easily.

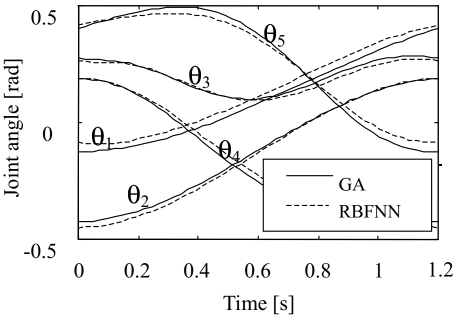
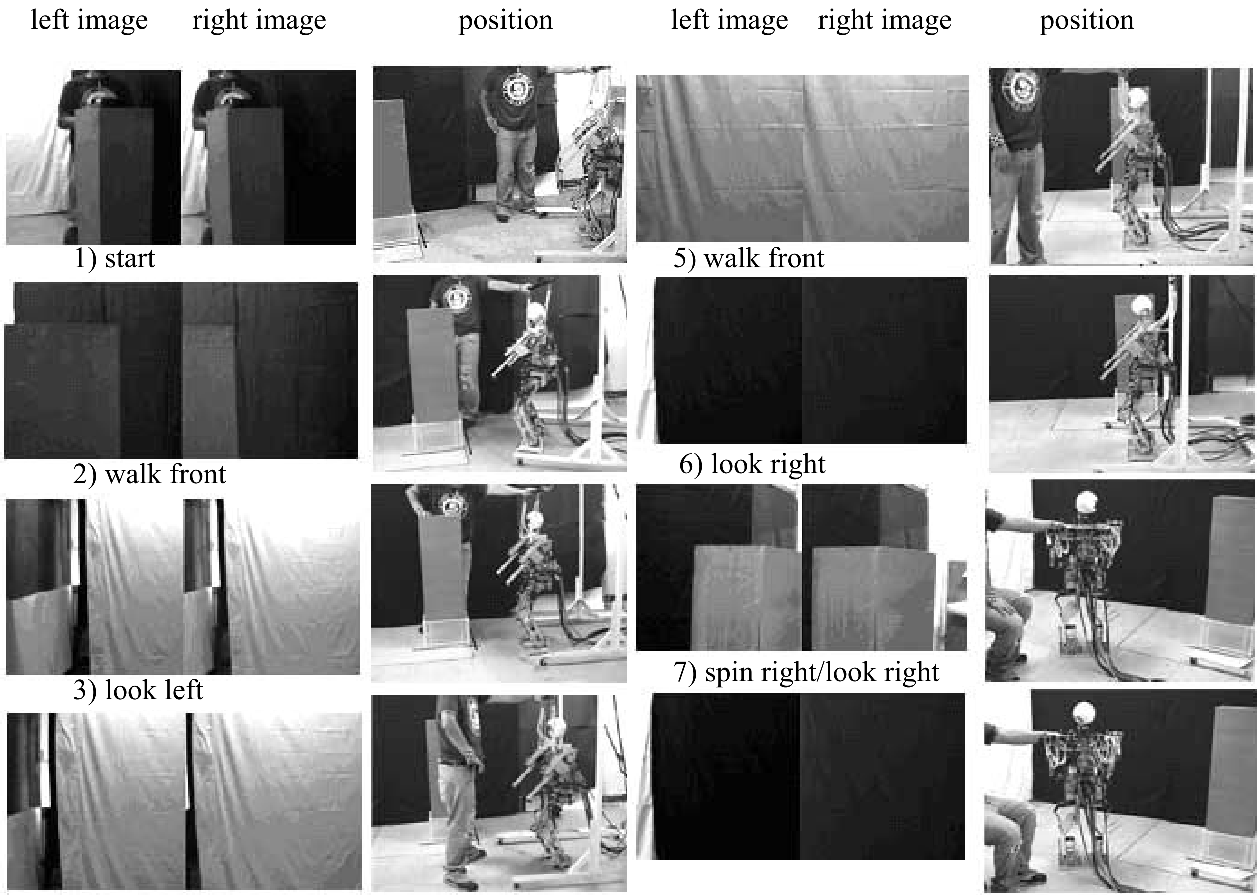


Fig. 8. GA and RBFNN angle trajectories

5.3 Sneaking through a low ceiling gate

At second, we set a low ceiling gate in front of the humanoid robot. The operator recognized it in the captured images data from the humanoid robot and judged that humanoid robot could not go through the gate having the body in upright position. Fig. 10 shows a series of the sneaking through a low ceiling gate (obstacle). The client commanded the following motion; 1) look front, 2) squat, 3) creep start, 4)-8) creep, 9) stand up, and 10) look front. The humanoid robot could go through the gate successfully.



1) start

2) walk front

3) look left

4) side step left

5) walk front

6) look right

7) spin right/look right

8) look front

Fig. 9. Walking and obstacle avoidance.

6. Conclusions

In this paper, we gave an overview of the Bonten-Maru humanoid robot project, some of the research objectives and results. The main contributions of this project on humanoid robot research have been on application of CORBA as on open platform for humanoid robot control; application of intelligent algorithms for humanoid robot gait generation; control of humanoid robot in a long distance by using the teleoperation system. In addition, experiments were conducted on the possible application of humanoid robot on in danger and rescue environments. The simulation and experimental results showed a good performance of the developed algorithms with an impact on humanoid robot research. In the future, we will realize of more sophisticated motion modules of humanoid robot for obstacle overcoming. For example, Fig.11 shows a high step overcoming using its arms and legs.

Furthermore, a new teleoperation system for a humanoid robot is developed as shown in Fig.12. The system has a virtual reality user interface using ultrasonic sensor net[8].

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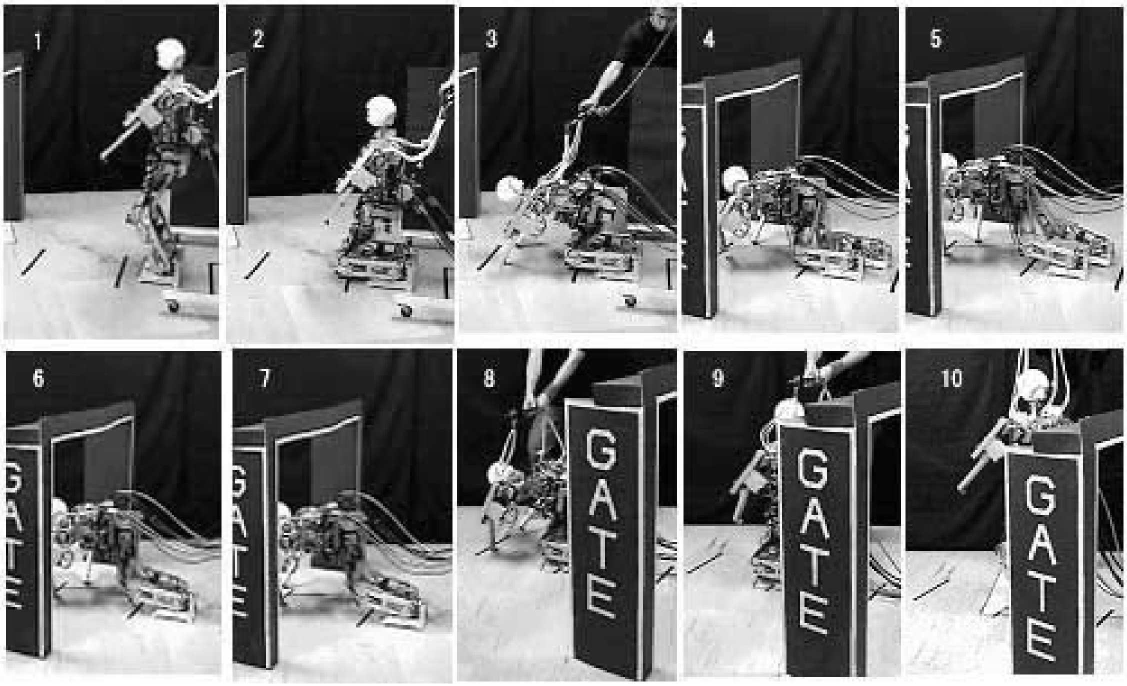

Fig.10　Creeping to avoid obstacle.

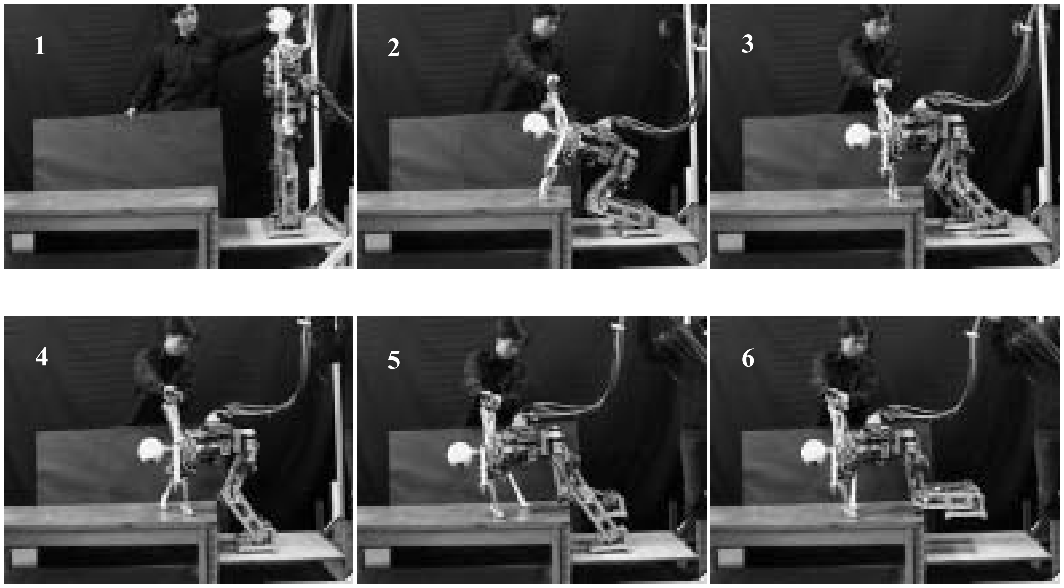

Fig.11　Step overcoming

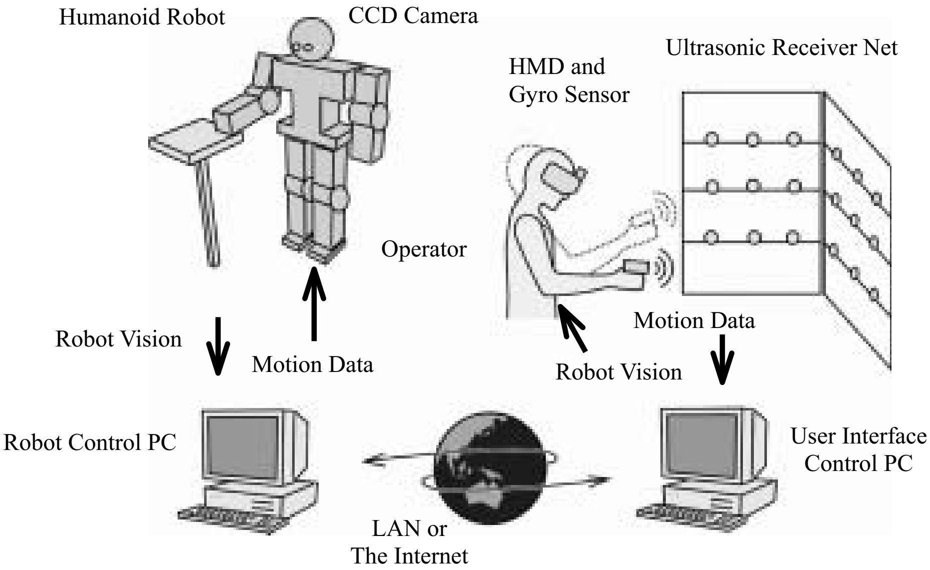

Fig.12 Schema of teleoperation system

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