Proceedings of the 2006 IEEE/RSJ
International Conference on Intelligent Robots and Systems
October 9 - 15, 2006, Beijing, China

Design of Android type Humanoid Robot Albert HUBO

Jun-Ho Oh — *Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea* — *jhoh@kaist.ac.kr*

David Hanson — *Hanson Robotics Inc, Dallas, TX, USA* — *David@HansonRobotics.com*

Won-Sup Kim — *Division of Industrial Design, Ewha Womans University, Seoul, Korea* — *kimws@ewha.ac.kr*

Il Young Han — *Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea* — *Nyoung1@kaist.ac.kr*

Jung-Yup Kim — *Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea* — *Kirk1@mclab3.kaist.ac.kr*

Ill-Woo Park — *Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea* — *mrquick@mclab3.kaist.ac.kr*

Abstract

To celebrate the 100th anniversary of the announcement of the special relativity theory of Albert Einstein, KAIST HUBO team and hanson robotics team developed android type humanoid robot Albert HUBO which may be the world's first expressive human face on a walking biped robot. The Albert HUBO adopts the techniques of the HUBO design for Albert HUBO body and the techniques of hanson robotics for Albert HUBO's head. Its height and weight are 137cm and 57Kg. Albert HUBO has 66 DOFs(31 for head motions and 35 for body motions) And head part uses 'Fubber' materials for smooth artificial skin and 28 servo motors for face movements and 3 servo motors for neck movements are used for generating a full range of facial expressions such as laugh, sadness, angry, surprised, etc. and body is modified with HUBO(KHR-3) introduced in 2004 to join with Albert HUBO's head and 35 DC motors are embedded for imitating various human-like body motions.

Index Terms - Humanoid robot, HUBO, KHR-3, KHR-2 Dynamic Walking

I. INTRODUCTION

The research of humanoid robot is diverging into the various categories such as the artificial intelligence, robot hardware development, realization of biped locomotion and human-robot interaction[1-4]. As these researches make progress many researchers have started to make their focus on the human friendly robots, which is partially inspired by the rapid growth of technology. AI equipped humanoid robots with bi-pad walking mechanism having characteristics of human differed from animals, were showed possibilities of the use for new applications in human life space.

The objective of Albert HUBO project is the experiment to make narrow two research areas of android robot and humanoid robot, each system has different mechanism and structure clearly till now. The head of android and the body of humanoid, two aspects of Albert HUBO, are still remains incompletely. But, the combination of these two factors brought an unexpected result from the mutual effect.

The body of Albert HUBO is based on humanoid robot 'HUBO' introduced in 2004[5]. HUBO, the human scale humanoid robot platform with simple structure, can bi-pad walking and independent self stabilize controlling. The head of Albert HUBO is made by hanson robotics team and the techniques of low power consumptions and full facial expressions are based on famous, worldwide recognized, Philip K. Dick android. The skin of Albert HUBO' head is used of a sponge-like elastomer material that moves more like facial soft-tissues. These materials, which we call "Frubber"(a contraction of *flesh* and *rubber*), wrinkle, crease, and amass, much more like skin than do animatronics materials. It also consumes very little power—less than 10W when affecting a full range of facial expressions.

In terms of Albert HUBO design, we used the merits of HUBO platform design, there was no great difficulty in development of Albert HUBO project. Most serious problems of this project were 'who is a hero (or heroine) of this robot?' and 'how to join with a face and a body harmoniously?' The 2005 year is the 100th anniversary of the announcement of the special relativity theory of Albert Einstein. And everyone in the world recognizes the Albert Einstein face. Therefore, we choose an Albert Einstein as a robot shape.

HUBO team for body robot and hanson robotics team for head robot are joined to develop Albert HUBO. It was very hard to decrease head size due to the complicate head robot structure and fully operation of mechanisms for the real human facial express. We decided that we expand the HUBO body platform in considering the design of Albert HUBO and its functionality. To apply the parts of HUBO platform as maximum, project team minimized modification range and searched new styling concept. The design concept of Albert HUBO was "Return of Einstein." This concept contained the resurrection of Einstein's and his comeback from the outer space. A space suit of astronaut Einstein was effective to hind inner mechanical devices and controllers and to connect various sub-systems. And unchanged parts of HUBO platform - arms and legs - were well matched with a space suit image.

1-4244-0259-X/06/$20.00 ©2006 IEEE

As a result, the new icon, the android type humanoid robot Albert HUBO which may be the world's first expressive human face on a walking biped robot was created through the interdisciplinary research between different contents. It is unveiled at the APEC summit Nov. 2005 in Busan, Korea, the Albert HUBO greeted world leaders, schoolchildren, the public at large, and the press media over the span of 5 days of presentations. Resoundingly, the Albert HUBO was the hit of the show at the APEC summit [U.S. News, CNN, and MSNBC, Nov. 2005].

II. Albert hubo: Overall Description

Albert HUBO is our latest android type humanoid robot shown in Fig. 1. Its height and weight are 137cm and 57Kg. The robot has been upgraded from HUBO (KHR-3) platform. The body frame and the cover of KHR-3 platform are modified to connect with android robot head. The joint controller, motor drive, battery, sensors and main controller (PC) are designed to be installed in the robot itself. The specifications of the robot is given in Table I and the DOF of Albert HUBO is given in Table II.

Fig. 1 Android type humanoid robot Albert HUBO

TABLE I
SPECIFICATION OF ALBERT HUBO

Research term		2005.3 ~ 2005.11
Weight		57Kg
Height		1.37m
Walking Speed		1.25Km/h
Walking Cycle, Stride		0.95sec/step, 32cm/step
Grasping Force		0.5Kg/finger
Actuator		DC Servo Motor + Harmonic Reduction Gear Unit
Control Unit		Walking Control Unit Servo Control Unit, Communication Unit
Sensors	Foot	3-Axis Force Torque Sensor, Inclinometer
	Torso	Rate Gyro & Inclination Sensor
Power Section	Battery	6V-10A for servo motors in robot head Li-Polymer 24V-2h for motors and circuits in robot body
	External Power	12V, 24V (Battery and External Power Supply Changeable)
Operation Section		Laptop computer with wireless LAN
Operating System (OS)		Windows XP and RTX
Degrees of Freedom		66 D.O.F (Face and Neck parts: 31 D.O.F, Body part: 35 D.O.F)

TABLE II
DEGREE OF FREEDOM OF ALBERT HUBO

Head	Torso	Arm	Hand	Leg	Total
28/Face 3/ Neck	1/Torso (Yaw)	3/Shoulder 1/Elbow	5/Hand 2/Wrist	3/Hip 1/Knee 2/Ankle	
31 DOF	1 DOF	8 DOF	14 DOF	12 DOF	66 DOF

A. Explanation about Albert HUBO's head.

Sociable robotics emulate human facial expressions to provide a more intuitive interface between humans and robots [6]. The actuation specifications required to emulate facial expressions are less restricted than those of locomotion or manipulation, but historically have been outside the range of mobile robots. In the past, sociable robotics has used technologies of entertainment robotics (or "animatronics") for its expressive skin materials[7-9]. Animatronic figures are biomimetic, electro-mechanical puppets that populate numerous themeparks and feature films.

Animatronics tend to be expensive to design and build (restricting research and creativity), limited in expressivity (the faces don't make a full range of humanlike expressions), and power hungry (limiting mobility and fusion with expressive humanoid bodies like Hubo). Altogether, the limitations of animatronics technology prevent expansive use in social robotics, and generally limit usefulness outside niche applications of films and theme parks.

Animatronics' problems of costliness, low expressivity, and power consumption all result from the physical dissimilarity of the "skins" materials relative to natural human facial soft tissues. The rubber/elastomer materials used in animatronics do not wrinkle, fold, or crease like human facial tissues. This means that animatronics can't affect a natural looking smile, frown, etc, unless the face is sculpted (and hence frozen) in such an expression. Moreover, the elastomers used in animatronics and other social robots require hundreds of watts to affect a full range of expressions.

To interact with people in real-world applications, robotic interactions should be lifelike, real-time, and portable [10].

To resolve these issues, author David Hanson and Victor White demonstrated a series of methods for making sponge-like elastomer materials that move more like facial soft-tissues [11]. In particular, these techniques allow the structuring of pore-walls in elastomer foams, so that the elastomer foam elongates much further than conventional foams, with much lower forces than equivalent solid elastomers. The resulting materials, called "Frubber" (a contraction of flesh and rubber), wrinkle, crease, and amass, much more like skin than do animatronics materials (see figure 2). They also consume very little power—less than 10W when affecting a full range of facial expressions and speech-related mouth motions. In early tests, the material required less than 1/22nd the force and energy of animatronic materials[8].

The reduced energy consumption enables use with battery-powered biped walking. Being a porous, Frubber also weighs much less—also a benefit for untethered walking robots. This technololgy enables this first demonstration of walking, facially expressive humanoid robotics.

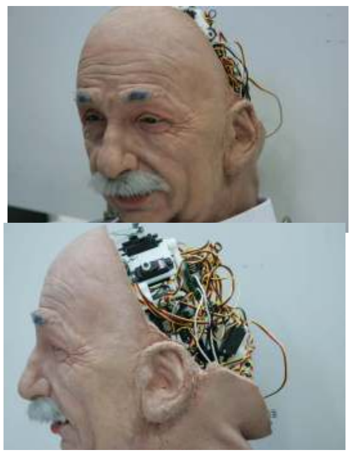

Fig. 2 The head of Albert HUBO

As shown in Fig. 2, Frubber is used for Albert HUBO's skin. And 28 servo motors for face movements and 3 servo motors for neck movements are used for generating a full range of facial expressions such as laugh, sadness, angry, surprised, etc. Servomotors are linked with the various points of Albert HUBO's face through Teflon-coated nylon strings. Therefore, the face motions are generated by drawing or releasing the strings which are linked with achors at various face points such as brows, eyes, Jaw, lips, Frown, and etc on Albert HUBO's face.

To control the 31 servomotors, we use the serial servo controller (mini SSC II, Scott Edwards Electronics). So, main controller sends the positions data through RS232 signals to the serial servo controller. Then, it converts RS232 signals to PWM signals for driving the 31 servomotors. Serial servo controller just sends the PWM signals to servomotors without feedback because Servomotor has feedback control circuits in its system.

B. Explanations of Albert HUBO' body

1) Actuator (Reduction Gear and DC Motor)

We divided the reduction gears into 2 types as its application. First type is planetary gear. We used this gear for small error (e.g. backlash) allowable joints such as finger, wrist-pan, neck-pan and eyeball joints. Finger and wrist-pan joint error can not affect the whole body stability and overall motion of arms and legs. Second type is harmonic gear. We used it for the major joints such as leg and arm joints. It is used in neck-tilt, wrist-tilt also. Since the harmonic gear has little backlash on its output side, it is used in leg joints whose error can affect the whole system stability and joint position repeatability.

Brushed 24V DC motors are used. It is relatively simple to develop motor drivers than the other type motors (e.g. brushless DC motor and AC motor), which we can design its size, shape and wiring. They also have suitable thermal property. When we drive them in harsh condition such as high speed and torque, generated heat from them is not so much compared to that of brushless DC motors.

2) Weight Distribution

Main controller (PC), speakers, battery and servo controllers/drivers for upper body are in torso as shown in Fig. 3. The mass except for actuators is concentrated on torso, since we need to reduce the load which is inflicted to the actuators in frequently moving parts such as arms and legs and we want to have large inertia of upper body for small amplitude fluctuation of the trunk also.

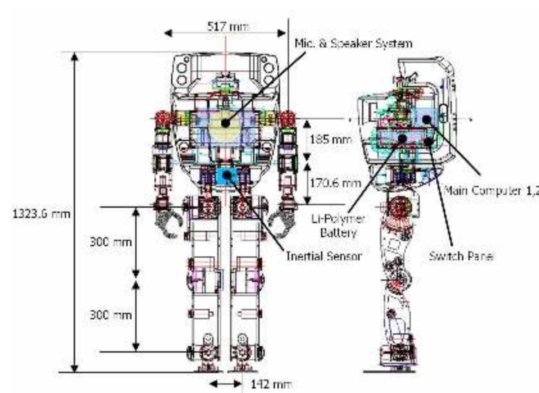

Fig. 3 The design of Albert HUBO

III. System Integration

A. Distributed Control System

There are many peripheral devices for Albert HUBO such as wireless LAN and CAN module, etc. By using distributed control architecture, calculation burden on the main computer was decreased in the expense of having to develop sub-controllers and communication bus lines between main computer and sub controllers. In addition, we have to realize real-time capability in Windows environment because Windows OS is not a real-time OS. We used RTX HAL extension commercial software for realizing the real-time control capability in Windows environment. The RTX allows making an interrupt with highest priority, which has maximum latency of only 12usec.

B. Main Controller

We use a commercial single board computer (PCM-3370, Advantech Co.) as the main controller because it has various peripheral interfaces, easy and fast programming environment and also a good graphic user interface (GUI). Selecting criterions are fast CPU speed, low power consumption, compact size and expansion interface. CPU performance of the main computer is about Pentium III 900 MHz.

C. Communication

The communication bus line between the main computer and the sub controllers is the means for the main computer to transmit instructions to sub controllers, or to receive data. The communication speed should be fast enough to handle many sub controllers concurrently. Therefore we use CAN (Controller Area Network) protocol, which assures a high speed serial communication up to 1Mbit/s. In CAN protocol, just two lines are needed for data transmission, therefore, it is very simple to extend to other sub controllers.

D. Sub Controllers

There are two kinds of sub controllers; the joint motor controller (JMC), and the inertia sensor. We developed all sub controllers and their MPUs (Micro Processor Units) to be identical except the serial servo controller on its head. This MPU has a CAN module and communicates with a main computer. Each controller also has several A/D converters, so we can easily add sensors to them. Table V shows the specification of sub-controllers.

TABLE III
SPECIFICATION OF SUB-CONTROLLERS

JMC	Type 1 (head, hand)	CAN Module 16 bit micro controller 7 ch DC motor driver (48W/ch) 5 ch A/D converter 2 ch Digital output
	Type 2	CAN Module 16 bit micro controller 2 ch DC motor driver (400W/ch) 2 ch A/D converter
3-Axis F/T sensor		CAN Module 16 bit micro controller 1 normal force (up to 1000 N), 2 moments(up to 30 Nm) Strain gage amp circuit Auto balancing function
Inertia sensor		CAN Module 16 bit micro controller 7 ch A/D converter (2 ch for 2-axis acceleration sensor 2ch for 2-axis rate gyro sensor 1 ch for temperature sensor) Measurable range : -15 ~ 15 deg in each axis

IV. MOTION CONTROL

Albert HUBO has 35 DC motors and 31 servomotors. 14 joint motor controllers for the DC motors of body part and 1 controller for the servomotors of head part are embedded in Albert HUBO. Since Albert HUBO has the distributed control architecture, the main computer sends the reference position data to the joint motor controllers constantly in exactly 10msec intervals (the system control frequency is 100 Hz). This frequency allows sufficient calculating time for the main computer. On the other hand, the joint motor controller divides the reference position into ten time slices because the control frequency of the joint motor control is 1 kHz (Fig. 3).

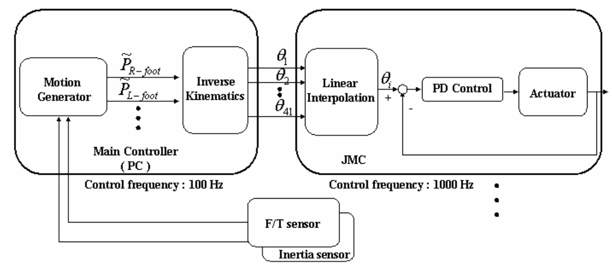

Fig. 3 Motion control

V. BODY STYLING DESIGN

Albert HUBO is the first application model using HUBO platform. It was modified body frame and cover to connect with android robot head. 'HUBO FX-1' is another model applying HUBO platform mechanism and technology.

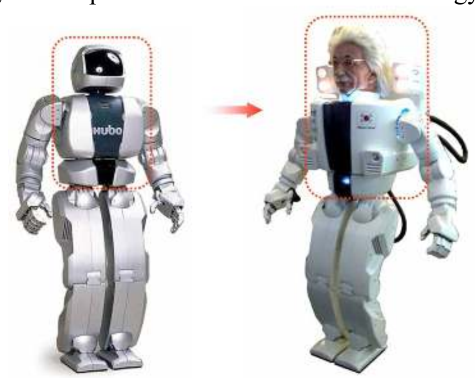

Fig. 4 Modifying parts of HUBO Platform

The objective of the development of HUBO and its former version KHR-2 [12] is the use for bi-pad walking humanoid robot platform to develop further excellent intelligent model. KHR-2 had no chances to use as the object because it was upgraded to HUBO directly without any other minor change process. HUBO was designed as best condition for humanoid robot platform which is settled the problems occurred in development process of KHR-2 and removed unnecessary parts in operation.

The main design problem of Albert HUBO project was how to connect machine shaped body and realistic Einstein's head naturally. The modifying of body and the making of head were progressed concurrently. In design process, these were had to expect and consider some errors that could be occur in final stage of assembly process. But there is no much room for layout design in size and space, because its base platform was designed accurately. So, body layout was designed based on

CAD and image data of head mechanism excluded skin. Minimum modification parts were chest body to exchange old head of platform for new android head. In this process, finding the best solutions was needed to show the well-balanced robot because android's head was much bigger than that of HUBO.

Some design alternatives about styling factors were proposed for this problem. The first design alternative was an inverted triangle shape of body applying the perspective effect. Artists of renaissance used perspective to express image more really, and modern artists distort in their art work using perspective to present an extra effective. As ordinary people are good at the perspective view, they do not recognize little distortion about depth of perspective unless exchange a lot. And as modern people are familiar with camera view or screen through the movie camera, they recognize naturally the distortion from lens, too. A standard adult looks down Albert HUBO from the high view point, because he is taller than robot. In this case, viewer can see upper body more wide and lower body more narrow. This effect is appears more clearly as closing the distance between viewer and robot and as raising the point of eye level. If the perspective image obtained from the high view point is applied to the styling, an inverted triangle robot shape will be appeared (Fig. 5).

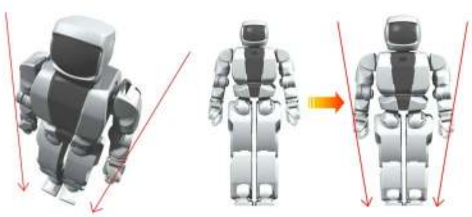

Fig. 5 Distorted image from perspective view and its application

In spite of various points of view, people remind shape from the view of camera through the high view level. This case is natural situation (Fig. 6).

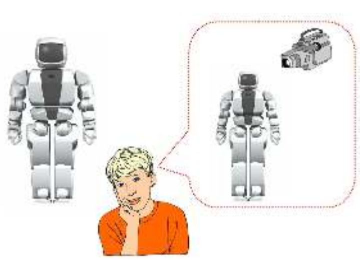

Fig. 6 Seeing the distorted robot, people to image shape from the view of camera

For expansion of upper body, arm parts were moved about 45mm to the outside from body center. To minimize the amount of moving distance of arm parts, body cover was cut round not to interfere with shoulder (Fig. 7).

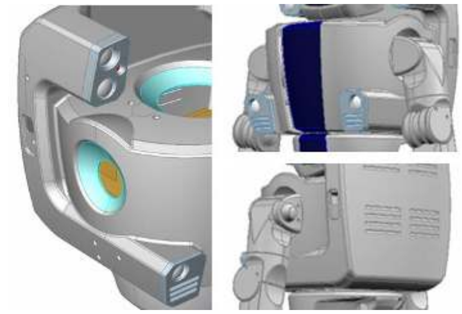

Fig. 7 Design of shoulder connection

The pelvis parts were needed to modify for the balance of proportion and volume of whole body. Through the design modification the figure of Albert HUBO was looks good.

The second design alternative was reducing the frequency of exposure relatively except face witch is the best important part in this project. To shading the back of head, the backpack of astronaut was expanded to the middle of head. The backpack supports protection of head from outer impact, room for inner mechanic parts and controllers, and base to attach various equipments (Fig. 8).

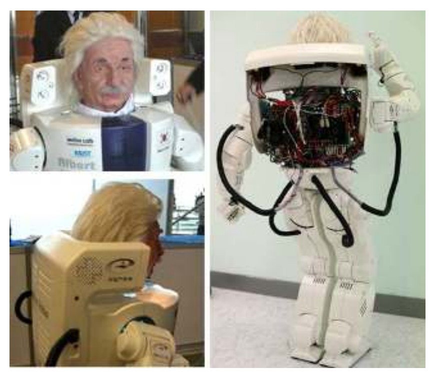

Fig. 8 The backpack of Albert HUBO

The third design alternative was application of effective lighting (Fig. 9). The side lights of head were dispersed spectator's sight concentrated on head. These powerful halogen lights make dramatic effect when the robot present on the stage in the artificial fog. Additional blue LED light in the neck and the shoulder connection will be reminds feeling of a mystique or fantastic mood. Specially LED light in the neck makes shade the gap in connection between head and body, and drive spectator's sight to the face.

Fig. 9 The light of head around, shoulder connection, and the front waist

Maintenance and convenience factors in robot operating were added in styling design process. The access mode to standby was changed from cap type cover to hinge style. It made shorten ready time to operate. The Spacious inner room of body was chocked up with head mechanisms and controllers. Wiring problem in HUBO platform was made easy using backpack side and rear pelvis. It was very hard to wiring in HUBO platform. Albert HUBO has room to assemble as moving apart wiring position from near arms and legs joints(Fig. 10).

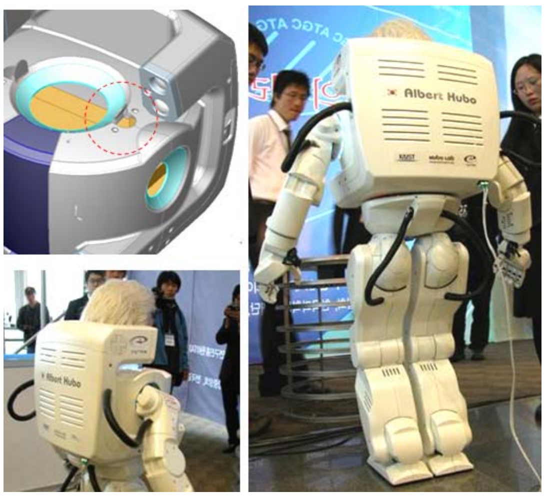

Fig. 10 Services for hanging and wiring

In this project, serious mechanic problems or engineering feedback were not occurred because there were no change in arms and legs having complicated mechanism and structure than others.

VI. CONCLUSION

KAIST HUBO team and hanson robotics team developed android type humanoid robot Albert HUBO which may be the world's first expressive human face on a walking biped robot. The Albert HUBO adapts the techniques of the HUBO design for Albert HUBO body and the technique of hanson robotics for Albert HUBO's head. Its height and weight are 137cm and 57Kg. Albert HUBO has 66 DOFs(31 for head motions and 35 for body motions) And head part uses 'Fubber' materials for smooth artificial skin and 28 servo motors for face movements and 3 servo motors for neck movements are used for generating a full range of facial expressions such as laugh, sadness, angry, surprised, etc. and body is modified with HUBO(KHR-3) introduced in 2004 to join with Albert HUBO's head and 35 DC motors are embedded for imitating various human-like body motions.

ACKNOWLEDGMENT

This research is mainly supported by MOCIE(Ministry of Commerce, Industry and Energy) and partly supported by b BK-21(Brain Korea –21) project.

REFERENCES

[1] K. Hirai, M. Hirose, Y. Haikawa, and T. Takenaka, "The Development of Honda Humanoid Robot", in *Proc. IEEE Int. Conf. on Robotics and Automations*, pp.1321-1326, 1998.

[2] J. Yamaguchi, A. Takanishi, and I. Kato, "Development of a biped walking robot compensating for three-axis moment by trunk motion", in *Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pp.561–566, 1993.

[3] Y. Sakagami, R. Watanabe, C. Aoyama, S. Matsunaga, N. Higaki, and K. Fujimura, "The intelligent ASIMO: System overview and integration", in *Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pp. 2478-2483, 2002.

[4] K. Nishiwaki, T. Sugihara, S. Kagami, F. Kanehiro, M. Inaba, and H. Inoue, "Design and Development of Research Platform for Perception-Action Integration in Humanoid Robot: H6", in *Proc. IEEE/RJS Int. Conf. on Intelligent Robots and Systems*, pp.1559-1564, 2000.

[5] Ill-Woo Park, Jung-Yup Kim, Jungho Lee, and Jun-Ho Oh, "Mechanical Design of Humanoid Robot Platform KHR-3", in Proc. *IEEE-RAS International Conference on Humanoid Robot*, pp.321-326, 2005.

[6] Breazeal, C. "Designing Sociable Robots", MIT press, 2001.

[7] Bar-Cohen, Y and Breazeal, C. (Ed.) "Biologically Inspired Intelligent Robotics.", SPIE, 2003.

[8] Hanson, D. Rus, D., Canvin, S., Schmierer, G., "Biologically Inspired Robotic Applications", in Biologically Inspired Intelligent Robotics, SPIE Press, 2003

[9] Landon, R., "Entertainment Robotics", in Biologically Inspired Intelligent Robotics, SPIE Press, 2003

[10] Hanson, D, Olney, A, Zielke, M, Pereira, A. "Upending the Uncanny Valley", AAAI conference proceedings, 2005

[11] Hanson D., White V. "Converging the Capabilities of ElectroActive Polymer Artificial Muscles and the Requirements of Bio-inspired Robotics", *Proc. SPIE's Electroactive Polymer Actuators and Devices Conf., 10TH Smart Structures and Materials Symposium*, San Diego, USA, 2004.

[12] Jung-Yup Kim, Ill-Woo Park, Jungho Lee, Min-Su Kim, Baek-Kyu Cho and Jun-Ho Oh, "System Design And Dynamic Walking Of Humanoid Robot KHR-2", *IEEE International Conference on Robotics & Automation*, 2005.