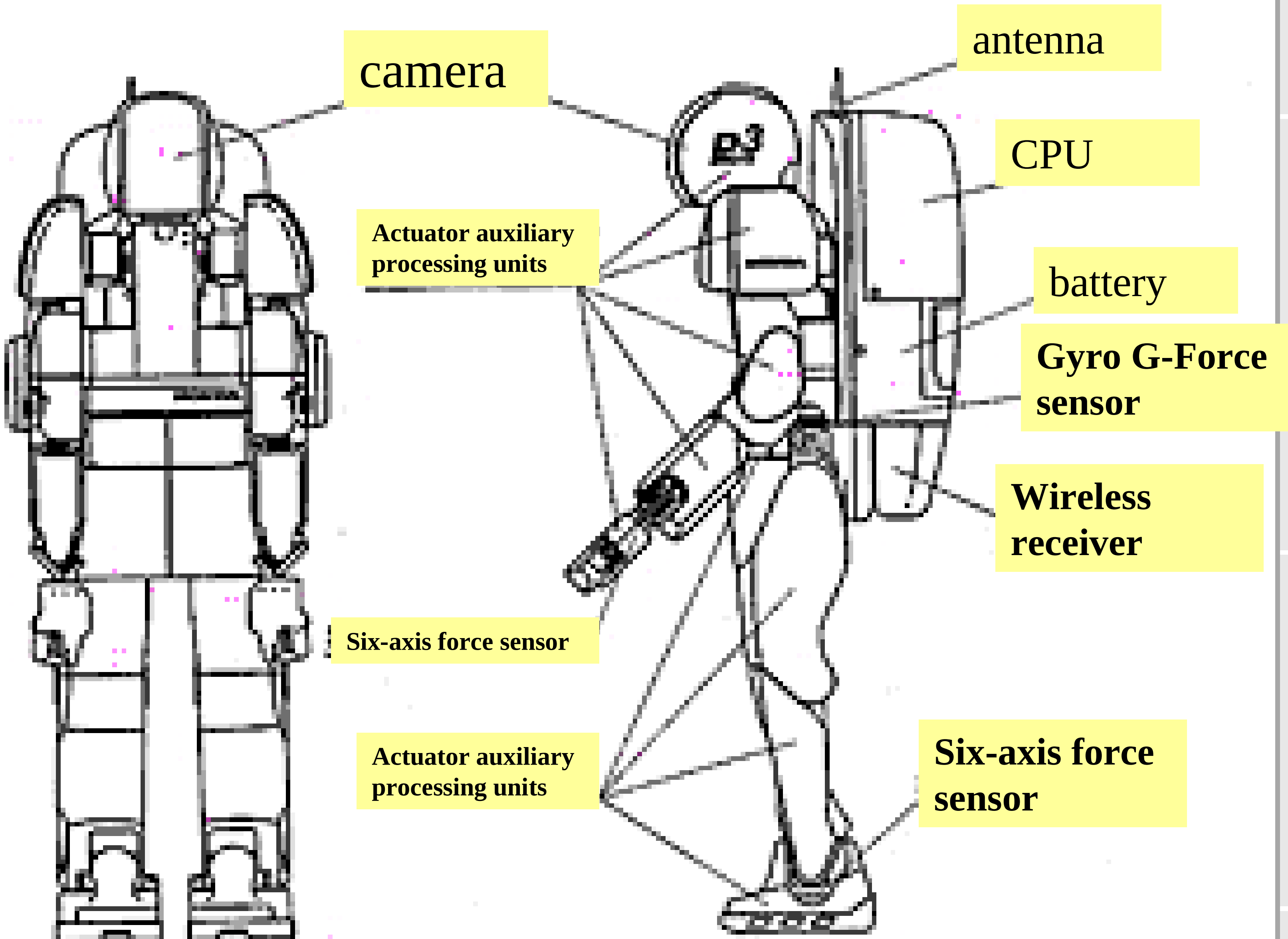
Humanoid Robots

1. Robot puppets: theatres, museums, theme parks, Disneyworld
2. Tele-operated robots: movie industry, military, NASA
3. Kinetic sculptures
4. Autonomous robots
5. Intelligent autonomous robots (Care-bots)

Honda Robot

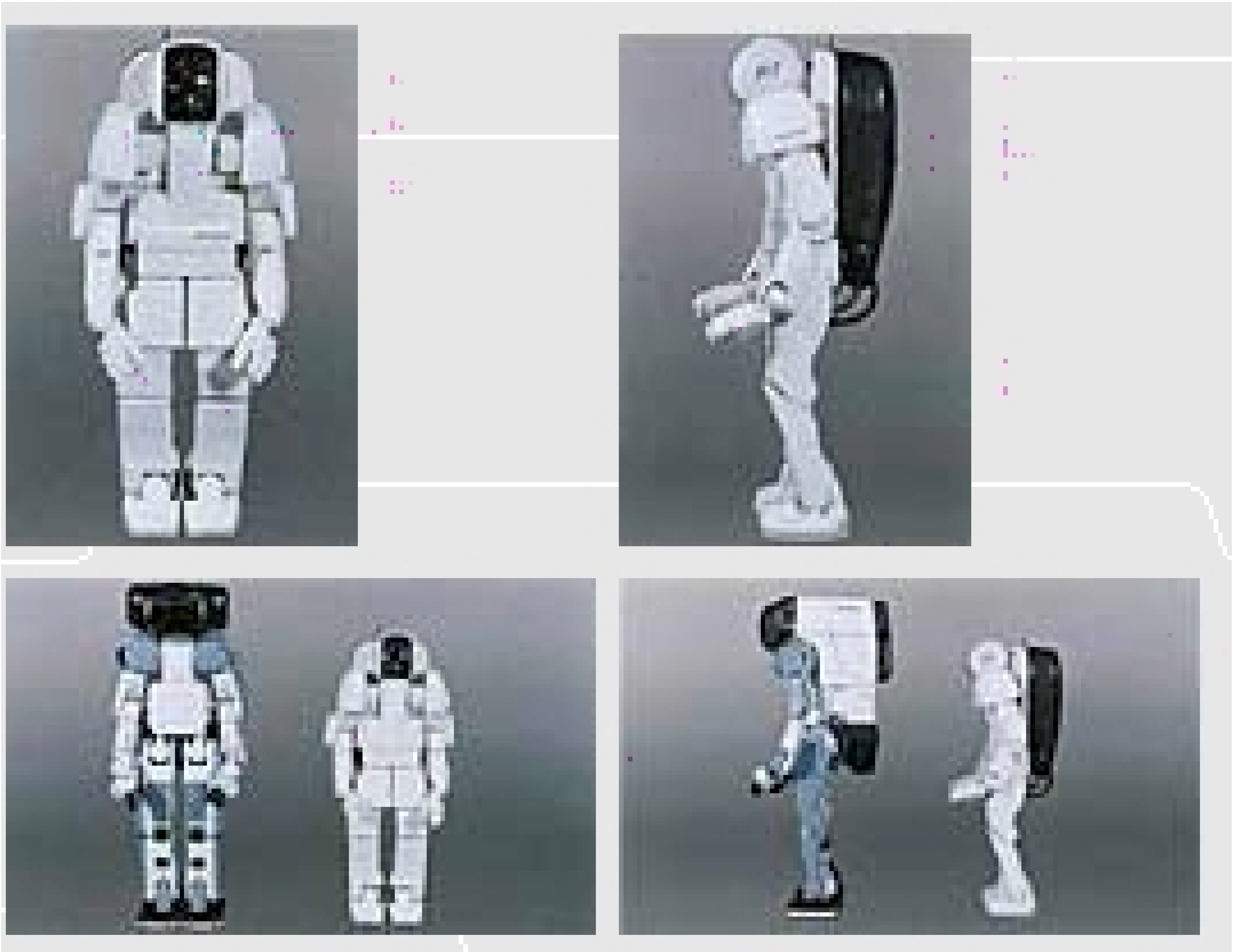
- In 1986, Honda commenced the humanoid robot research and development program.
- Keys to the development of the robot included "intelligence" and "mobility."
- Honda began with the basic concept that the robot "should *coexist and cooperate* with human beings, by doing what a person cannot do and by cultivating a new dimension in mobility to ultimately benefit society."
- This provided a guideline for developing a new type of robot that would be used in daily life, rather than a robot purpose-built for special operations.

Honda Robot



camera
antenna
CPU
Actuator auxiliary processing units
battery
Gyro G-Force sensor
Wireless receiver
Six-axis force sensor
Actuator auxiliary processing units
Six-axis force sensor

P3 front and side views



P2

Specifications	
Max. work weight	5kg per hand
Running time	about 15min.
Weight	210kg
Degree of Freedom (DOF)	Leg's DOF:6x2=12 Arm's DOF:7x2=14 Hand's DOF:2x2=4
Actuators	DC servo motors (+Harmonic Drives)
Sensors	Gyrometers G-sensors Six axis force sensors on wrists and feet Vision cameras
Transmitter	Wireless ethernet modem
Battery	136V7Ah(Ni-Zn)

Bio-Mimetic Principles

- **Joint alignment** was determined to make it "equivalent" to the human skeletal structure.
- **The movable ranges of joints** while walking were defined in accordance with walking test measurements on flat surfaces and stairs.

Dimensions, weights and centers of gravity of each leg and foot part

- The center of gravity of each part was determined by referring to that of the human body.

Torque application to the joints when walking

- Torque acting on the joints was optimized based on the measurements of human joint movement during walking and reaction vectors from the contact surface.

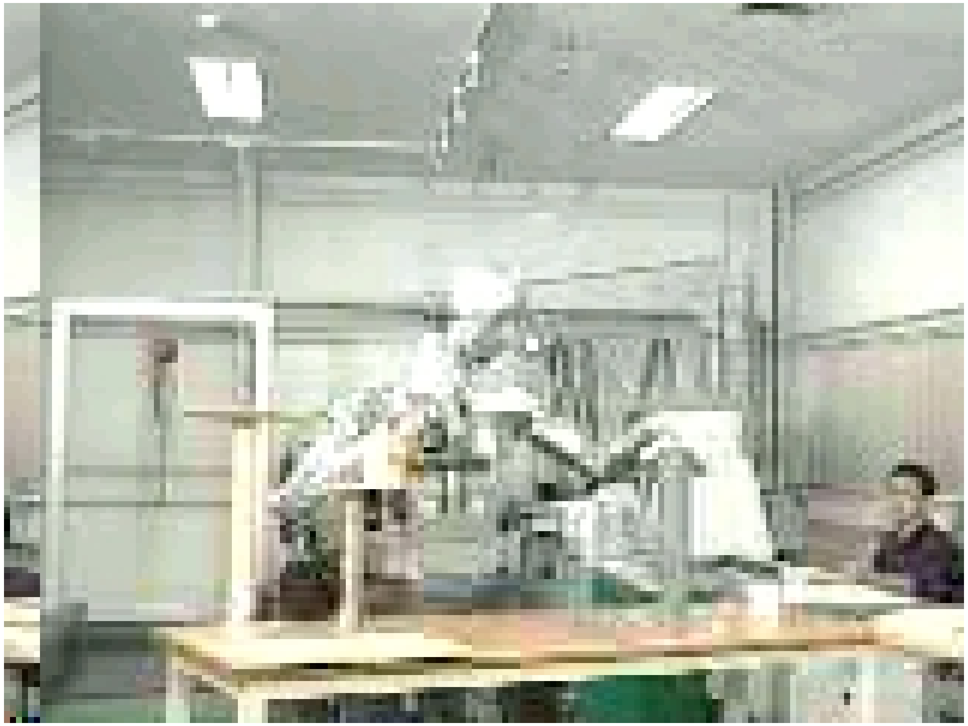
Sensor systems required for walking

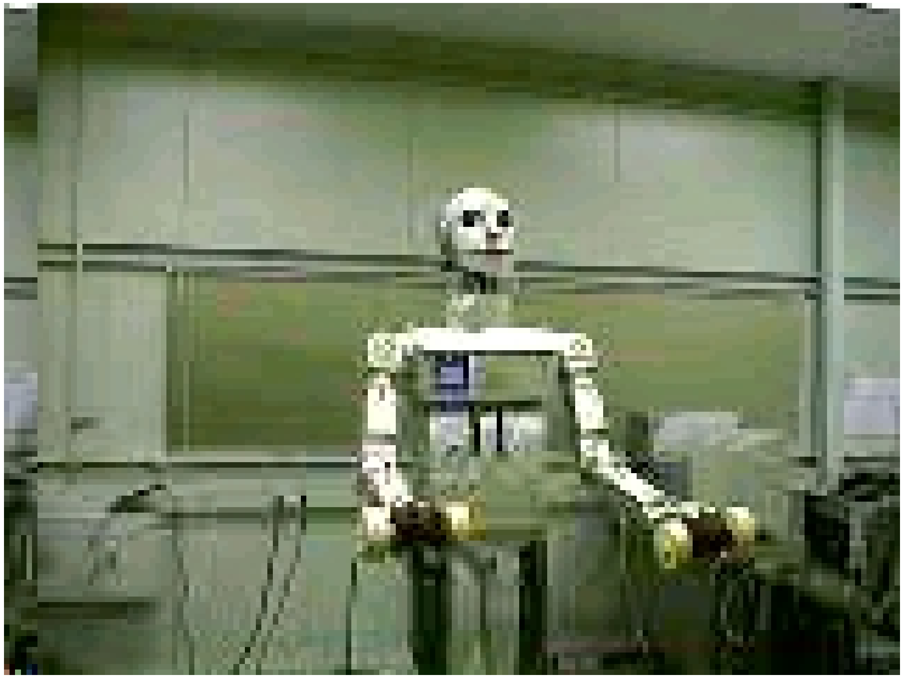
- **The robot system needed to incorporate:**
  - **G-force sensor**
  - **six-axial force sensors**
- **to detect the conditions of legs/feet while walking,**
  - **an inclinometer**
  - **joint-angle sensors**
- **to detect the overall posture.**

Walking

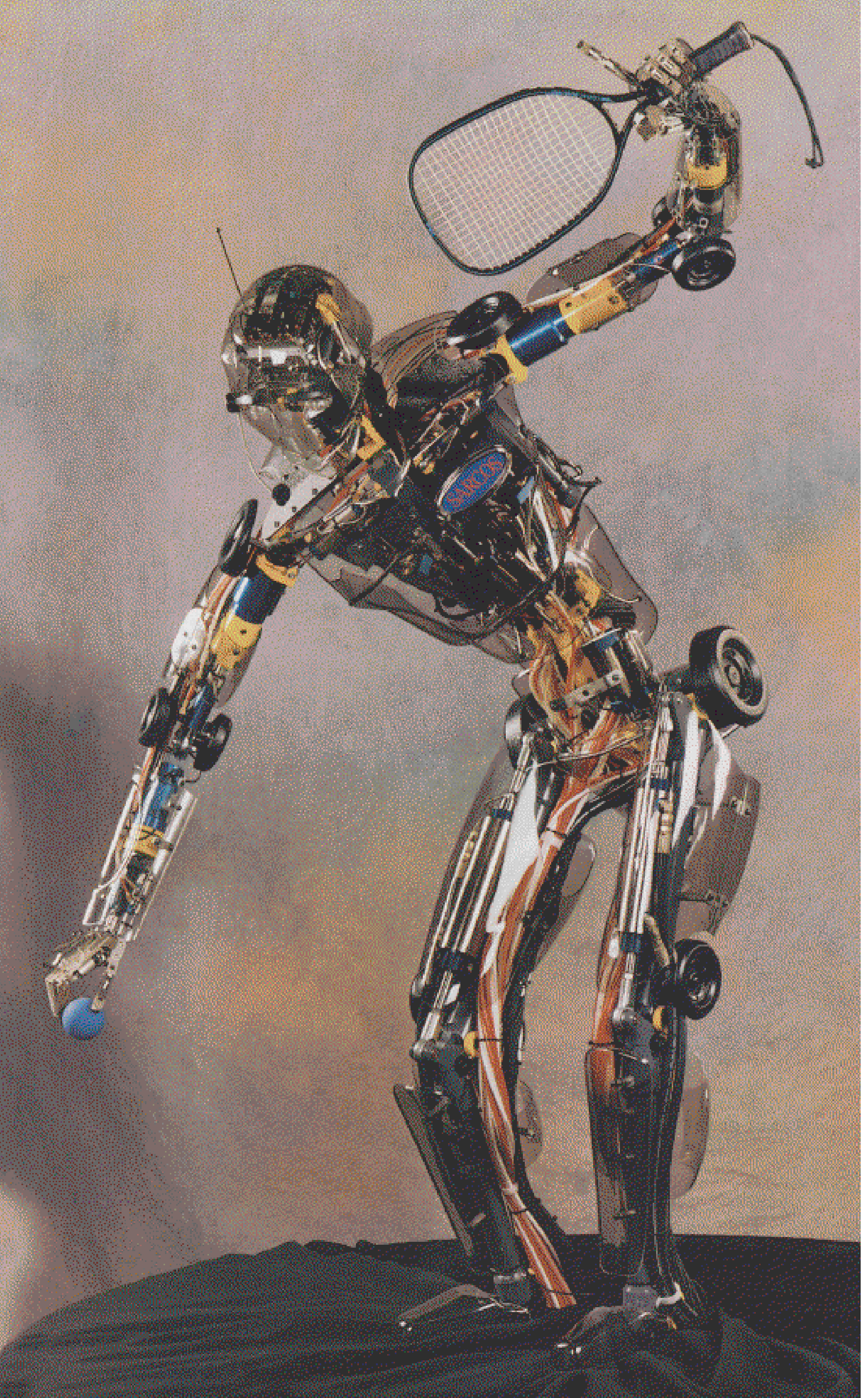
- Stable dynamic two-leg/feet walking operations and, finally, autonomous two-leg/feet walking.
  - (*1) Static walking: The center of gravity is maintained within the supporting leg base area. A smaller footstep and slow speed.
  - (*2) Dynamic walking: The center of gravity is outside the supporting leg base area. A walking maneuver where static balance is intentionally terminated.

Centaur Robot from Korea





Sarcos Robots

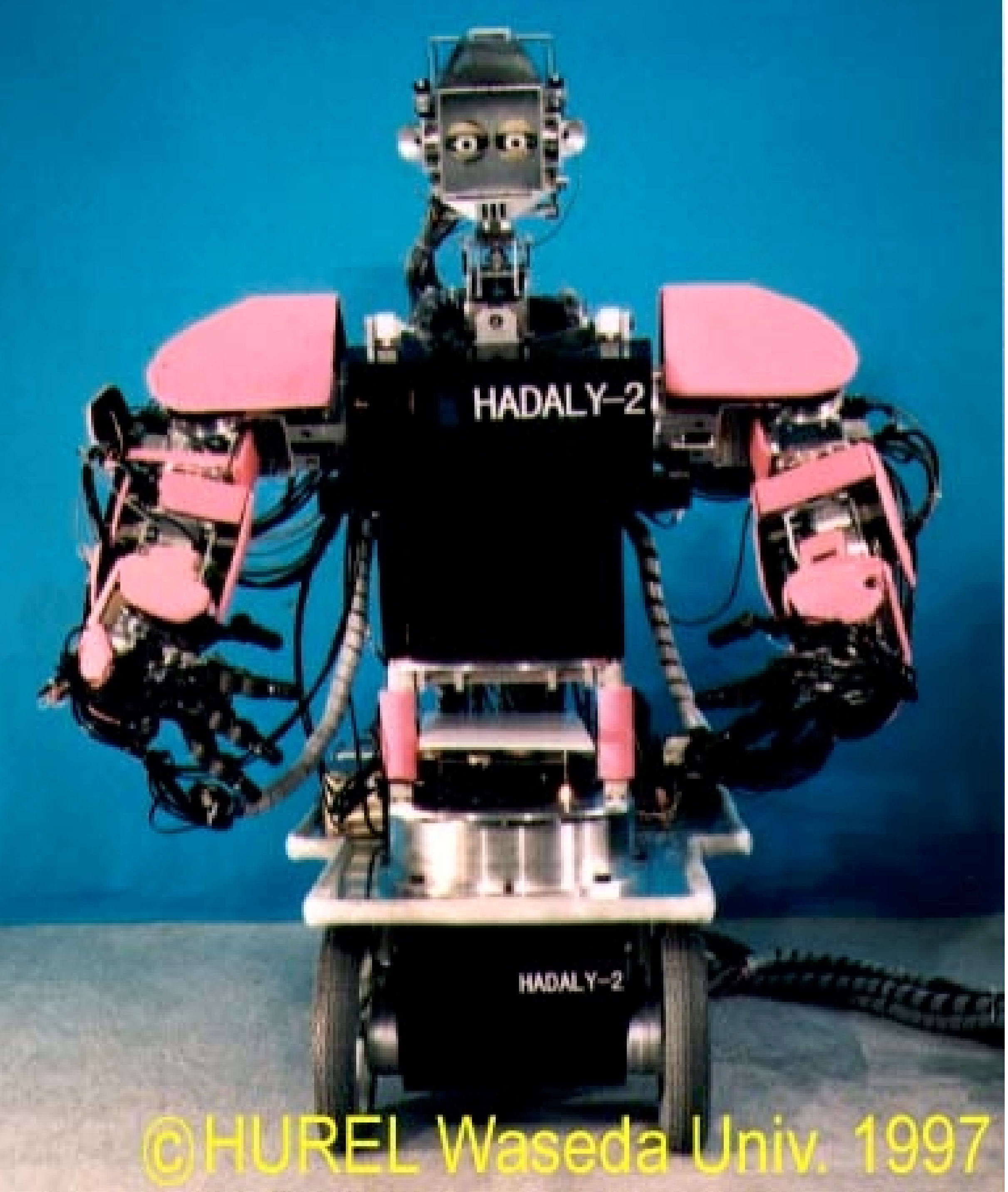


Sarcos

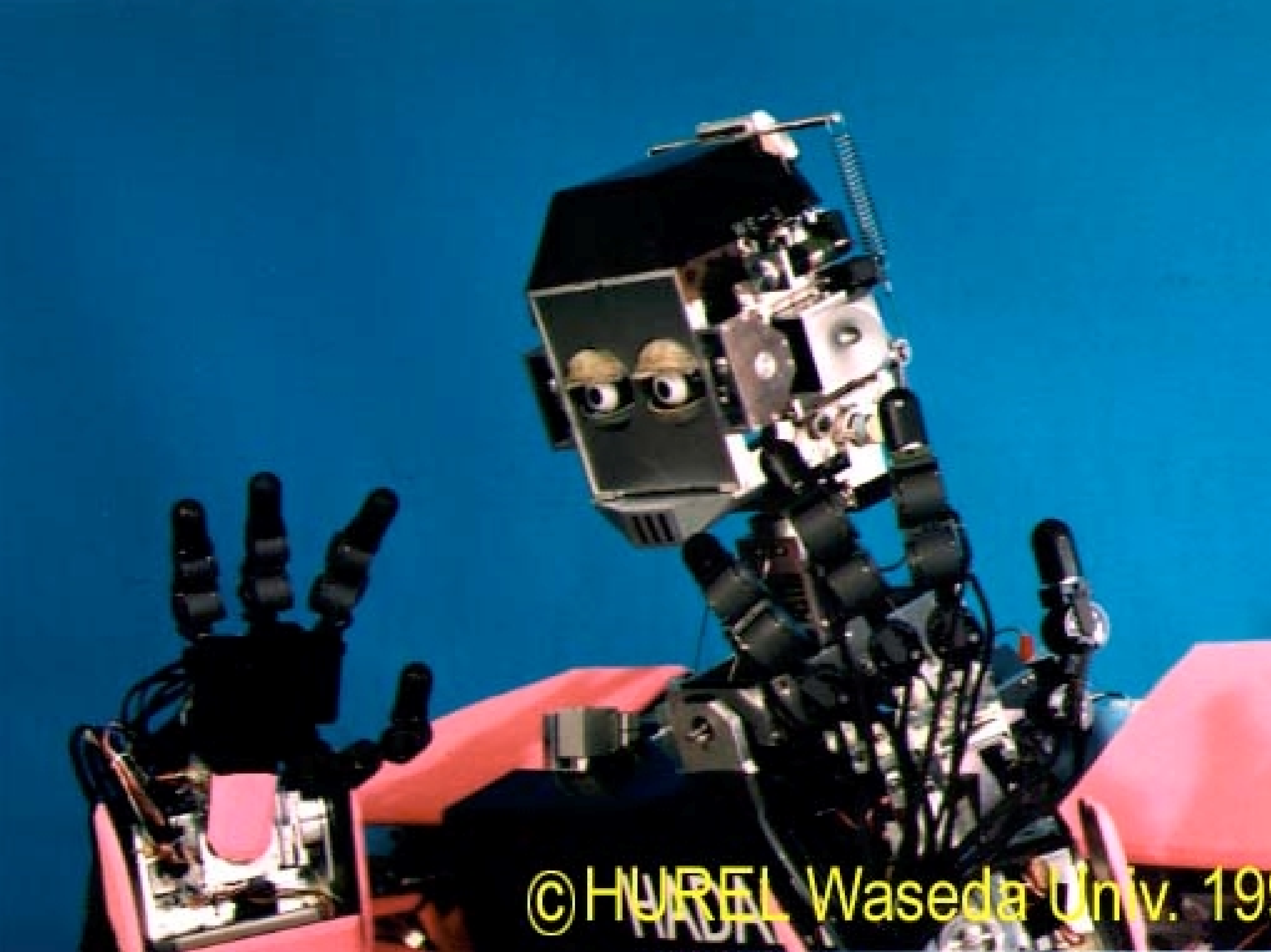
- Research and entertainment robot used by several U.S. universities and research institutions

Humanoid Robot Hadaly-2

- Hadaly-2 is a new concept Humanoid Robot to realize interactive communication with human.
- Hadaly-2 has:
  - environment recognition system by its vision,
  - conversation system by voice generation and recognition,
  - compliant motion system by mechanically compliant arm and
  - mobile system by electric wheel.



- Hadaly-2 communicates with human not only informationally, but also physically.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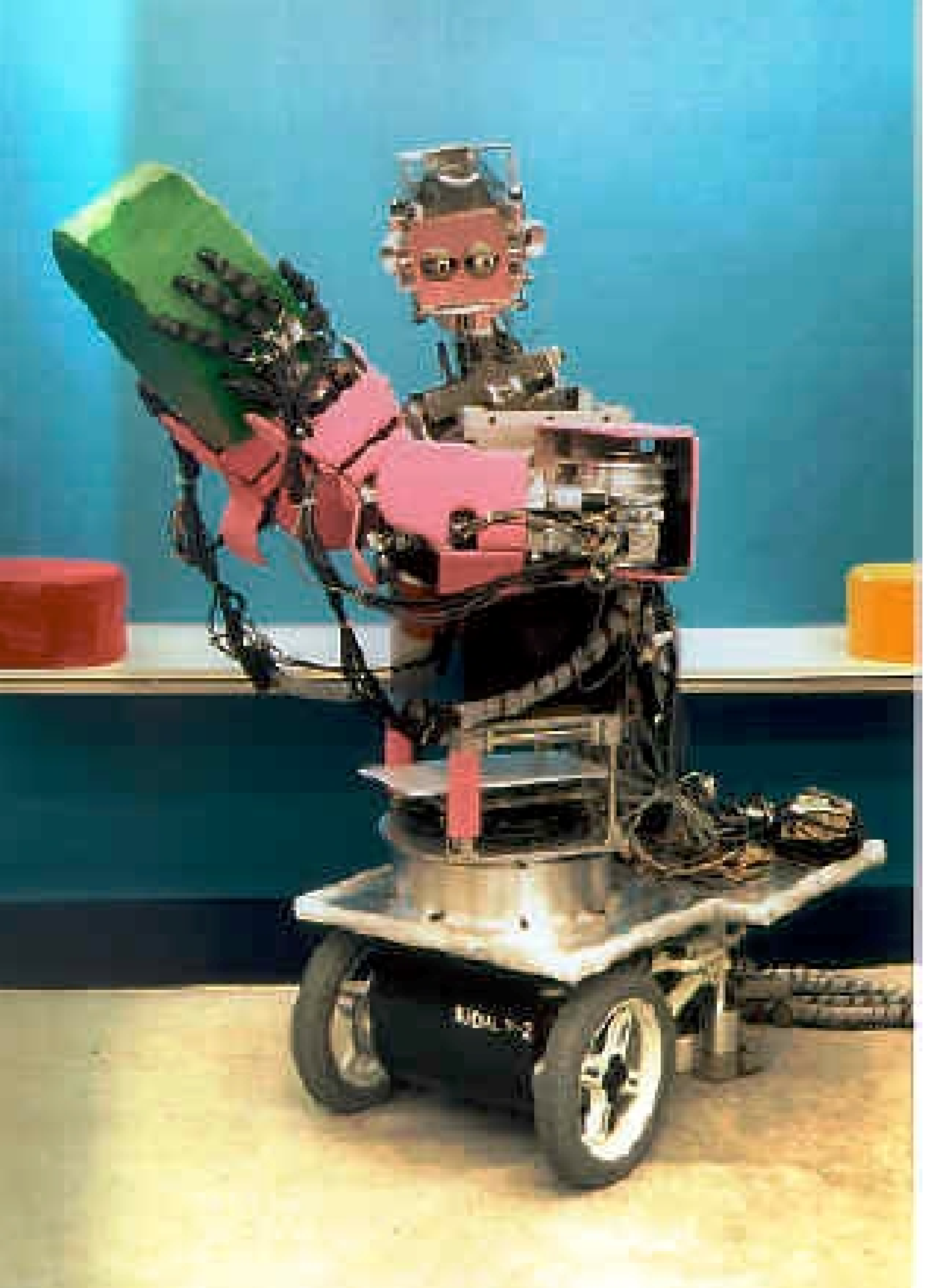
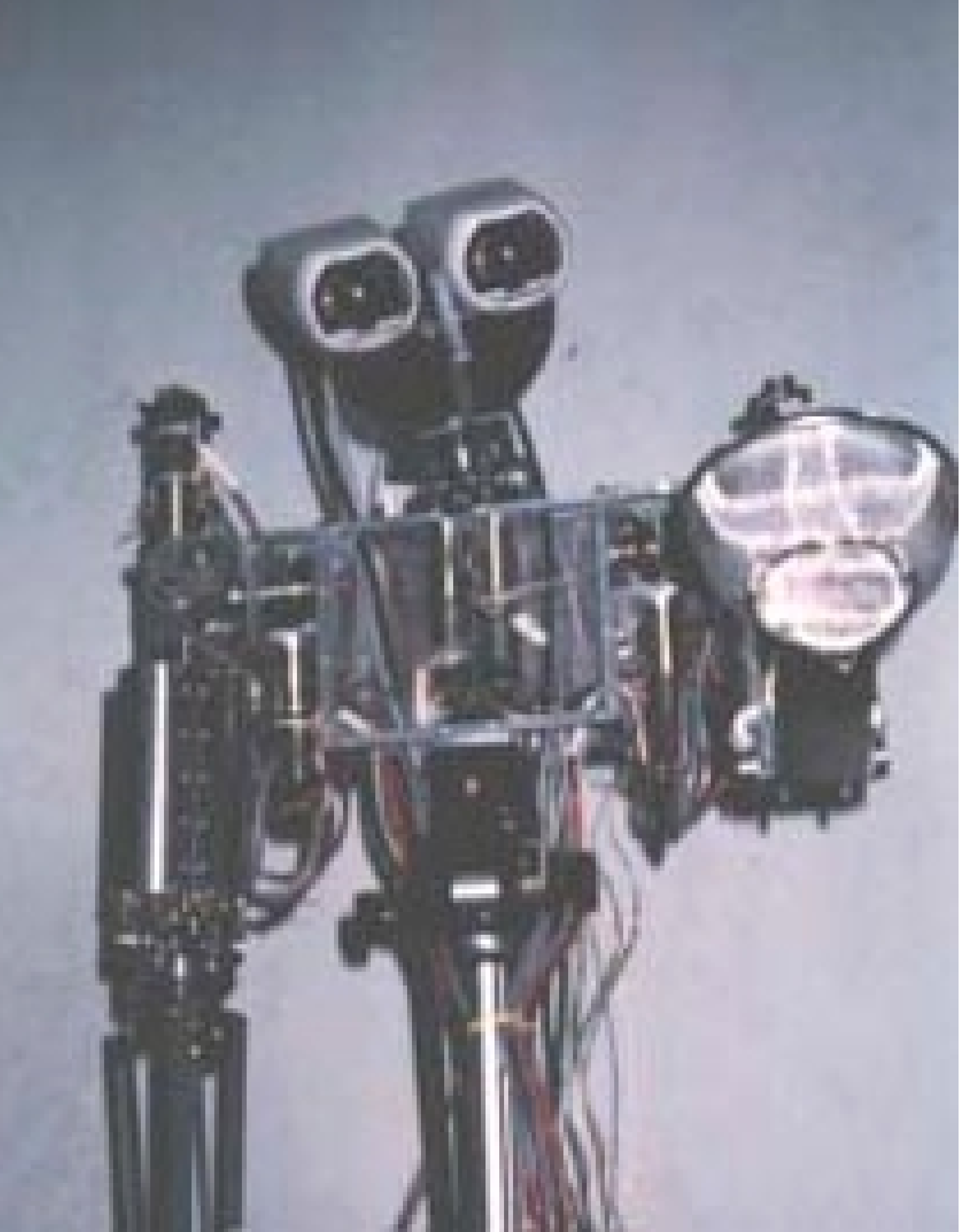
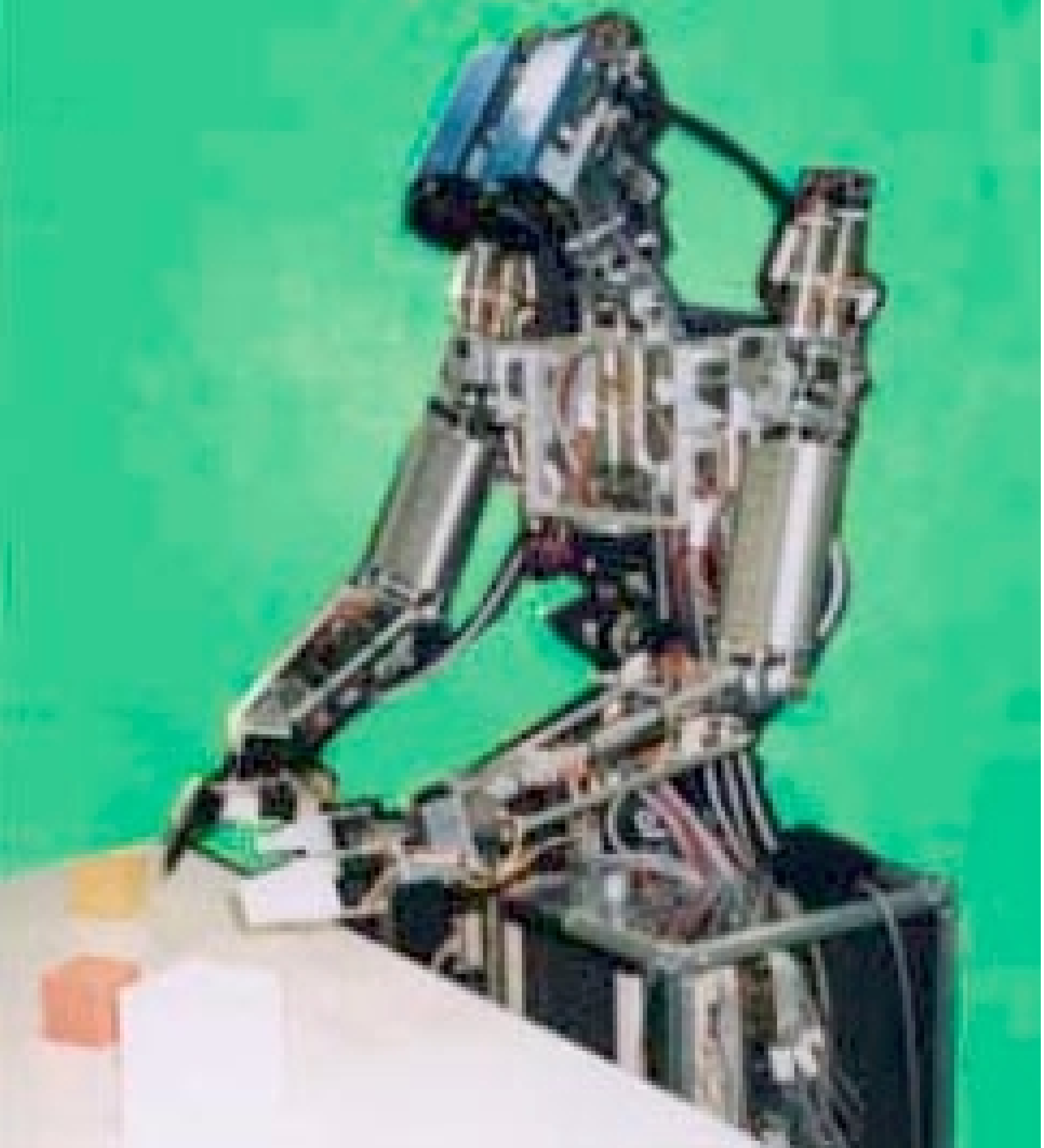




Other Japanese humanoid robots

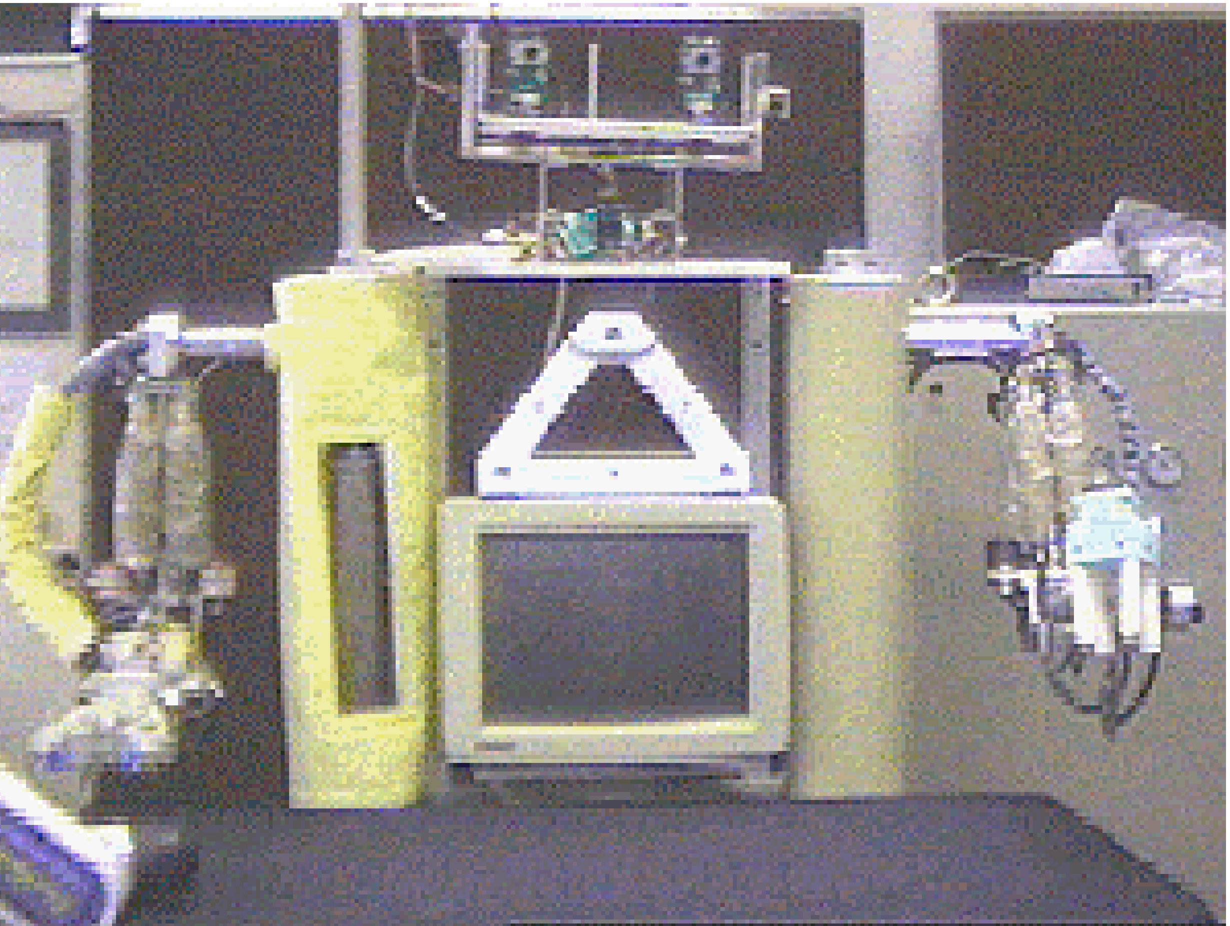
Project Saika

- Modularized to reduce the developing cost and to make maintenance easy, the total weight of the head, the neck, the two upper arms and the torso is only eight kilograms and most of the motors are installed inside the arms and the torso.
- **Three** kinds of skillful **manipulations** are studied as examples of behavior-based movement control:
  - hitting a bounding ball
  - grasping unknown objects by groping
  - catching a thrown ball



- A light-weight, human-size and low-cost developing humanoid robot
- The humanoid robot is named Saika (``outstanding intelligence" in Japanese).
- Two-DOF neck, dual five-DOF upper arms, a torso and a head.
- Several types of hands and forearms are developed.
- They are chosen depending upon the tasks to perform.

Dual-Arm Humanoid Project

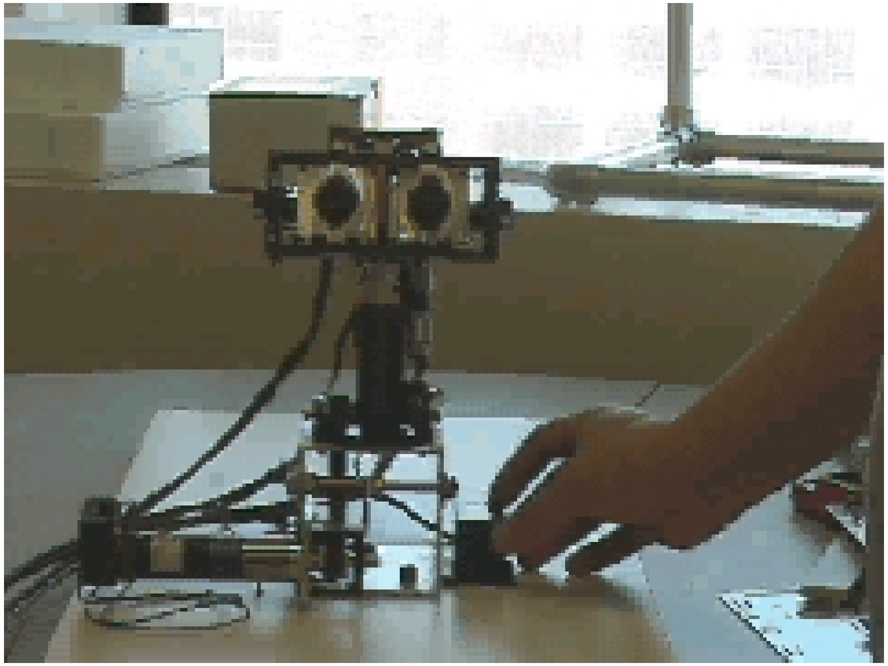


- The goal of the Dual-Arm Humanoid project is to create a service robot for use in intelligent manufacturing and to aid the elderly and the disabled.

Dual-Arm Humanoid Project

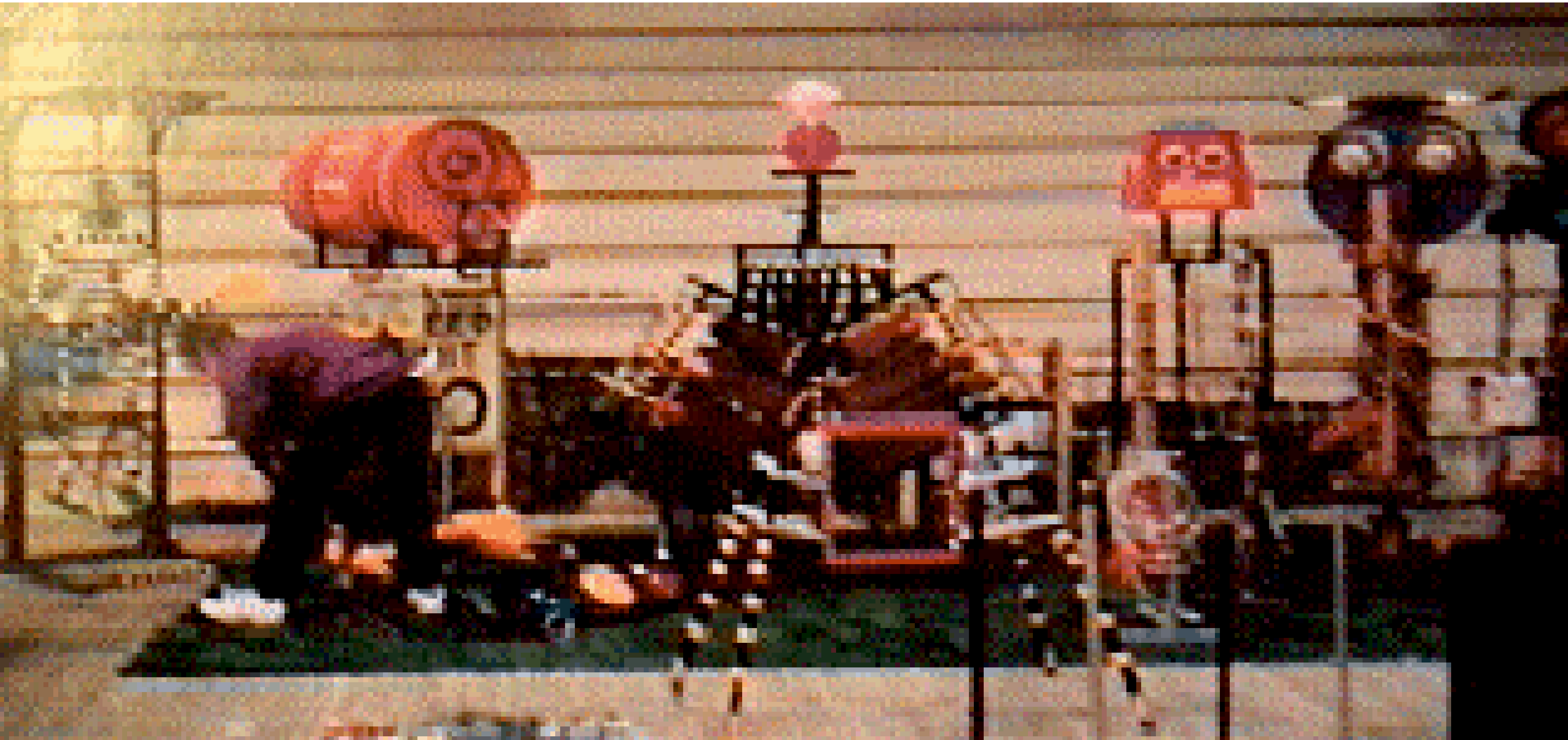
- Makes use of two rubbertuator-based robot arms from Bridgestone.
- A *stereo pan/tilt camera system* and video capture board, both developed in house, provide **intelligent vision capabilities.**
- The dual-arm system also provides a test-bed to develop new technologies for user-to-robot and robot-to-user communications
- They include audio, visual, and **gestural** methods.

Eye tracking movement

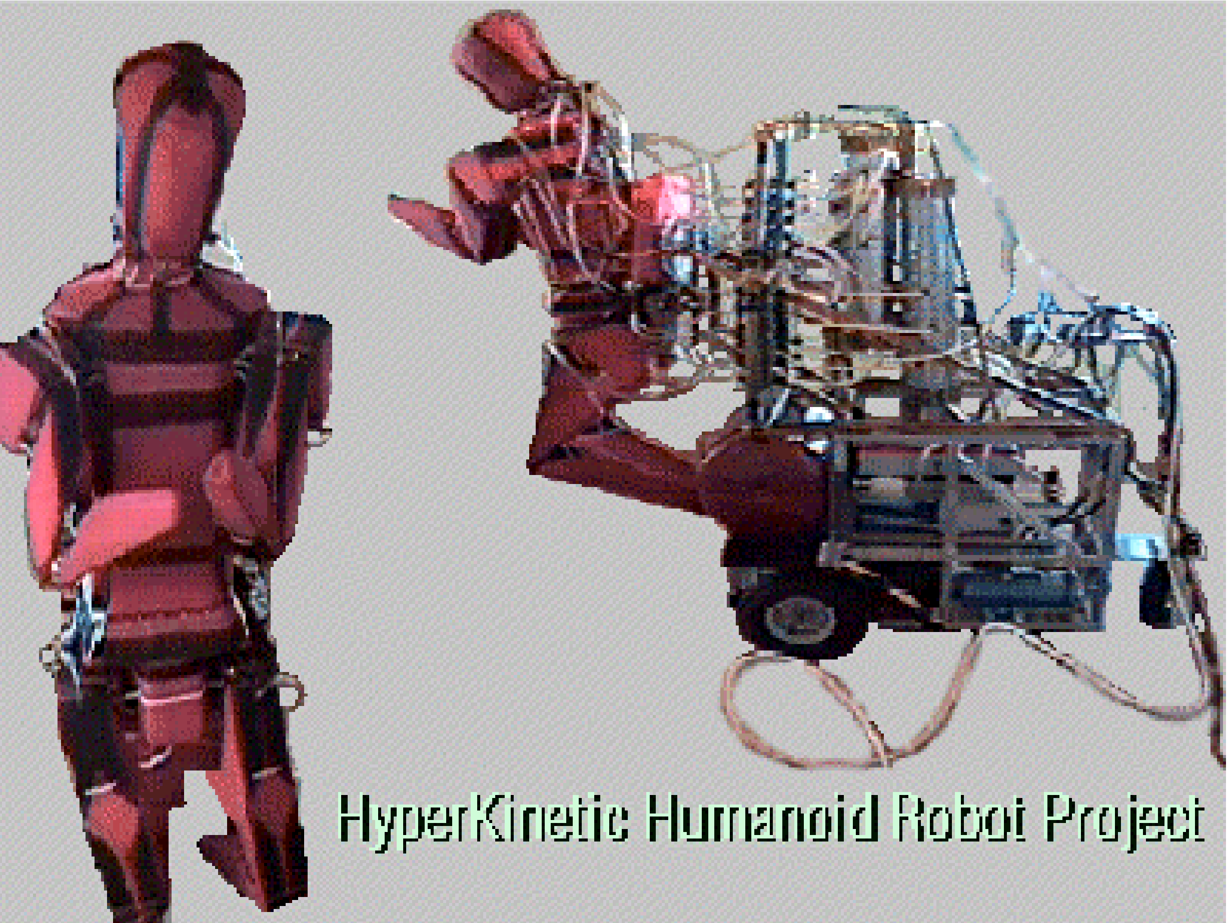


The Robot Band

- Craig and Charlene Sainsott, early members of the Robot Group, created the famous Robot Band over a period of several years.
- It was a popular attraction at several Robofests.



Commercial: The Hyperkinetic Humanoid (H2-X) Robot Project



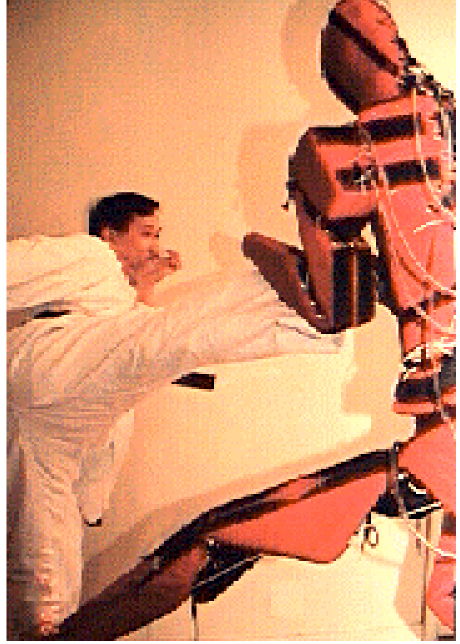
- THE WORLD'S MOST ADVANCED MARTIAL ARTS ROBOT IS ALSO A MAJOR PERFORMANCE ARTIST

- **The machine is *faster and tougher than a human,* yet is surprisingly safe.**
- **H2 is expressing its general potential to do human feats ranging from common tasks to performance arts such music, dance, and theatre.**

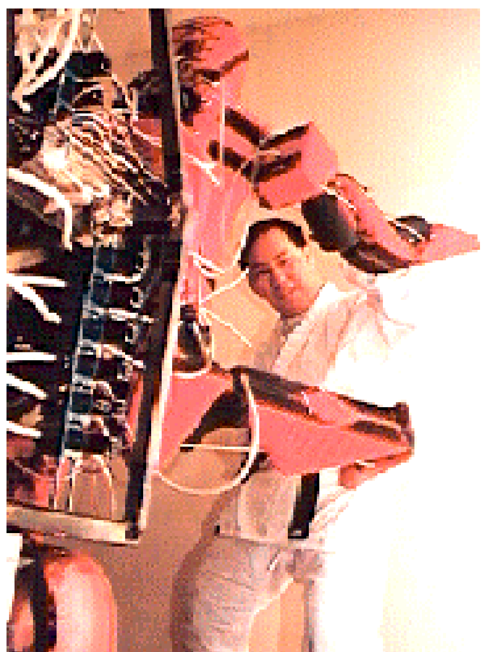
- At 24 "degrees of freedom" H2's kinematic complexity rivals the most advanced industrial and academic robots.
- It is the fastest humanoid robot ever.
- Safety is achieved by use of light weight foams and fabric and a comprehensive set of safety features and operational procedures.
- H2-X is scheduled to complete a long list of proof of concept tasks as well as mix with the public as a sort of celebrity.
- H2s cost around 50 K each.
- H2-X graces Austin area events for 1 K a pop.

- **The H2 robot is a design/build project of Faustex Systems Corporation as part of an overall humanoid robotics technology development effort.**
- **Commission your own custom robot.**
- **You're invited on over to Faustex to find out more about the company that develops some of the coolest robots ever.**

- The Austin American Statesman described the early prototype as "a reasonable imitation of a karate expert."
- Ongoing performance and control improvements will focus the robot's superhuman speed into greater agility.

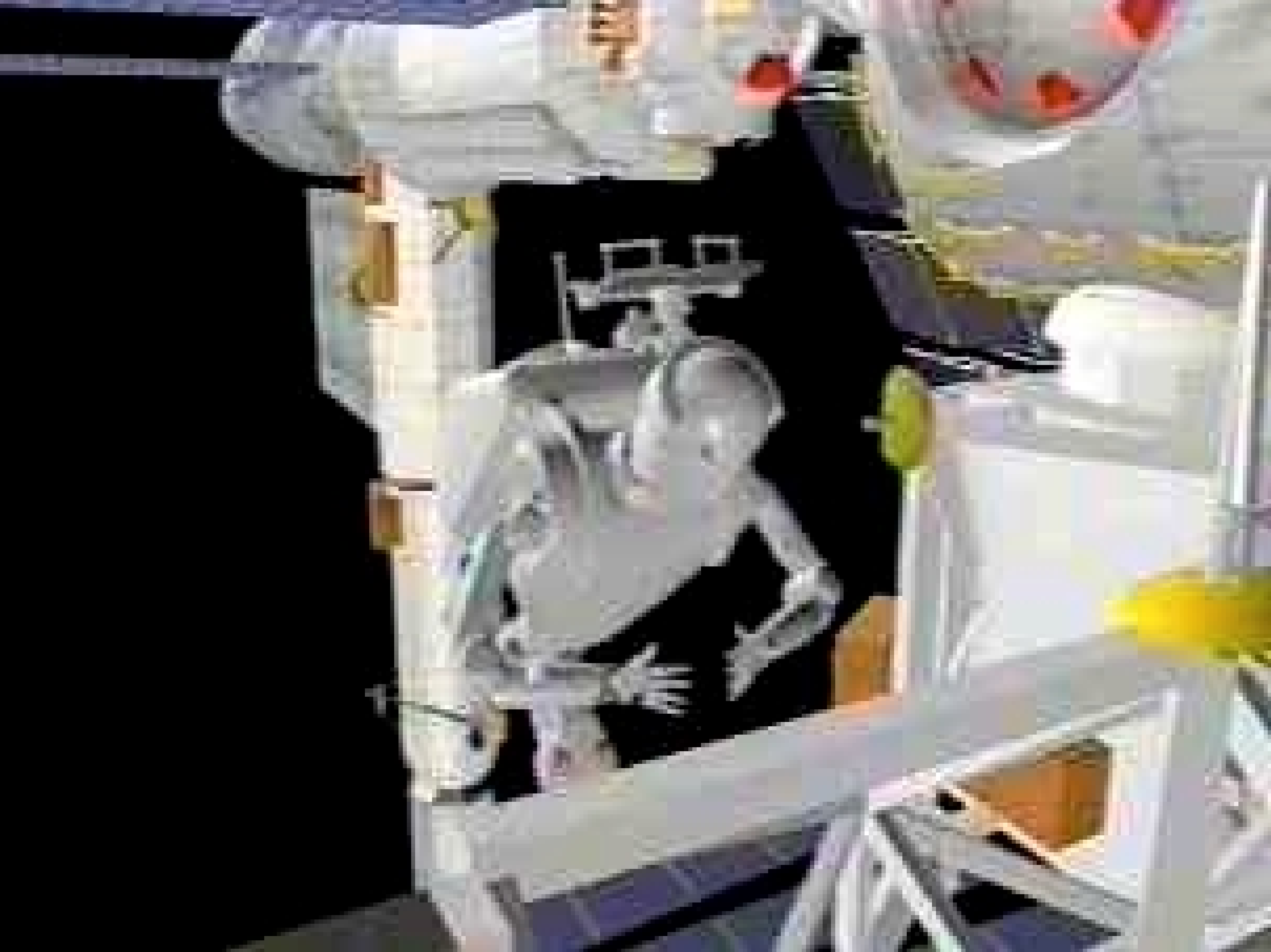

- Just as Kasparov beat Big Blue, after a struggle, Wan-Yik won the first ever martial arts bout with a machine

The next human to sparr the machine may well lose on a point score basis.

ROBONAUT of NASA

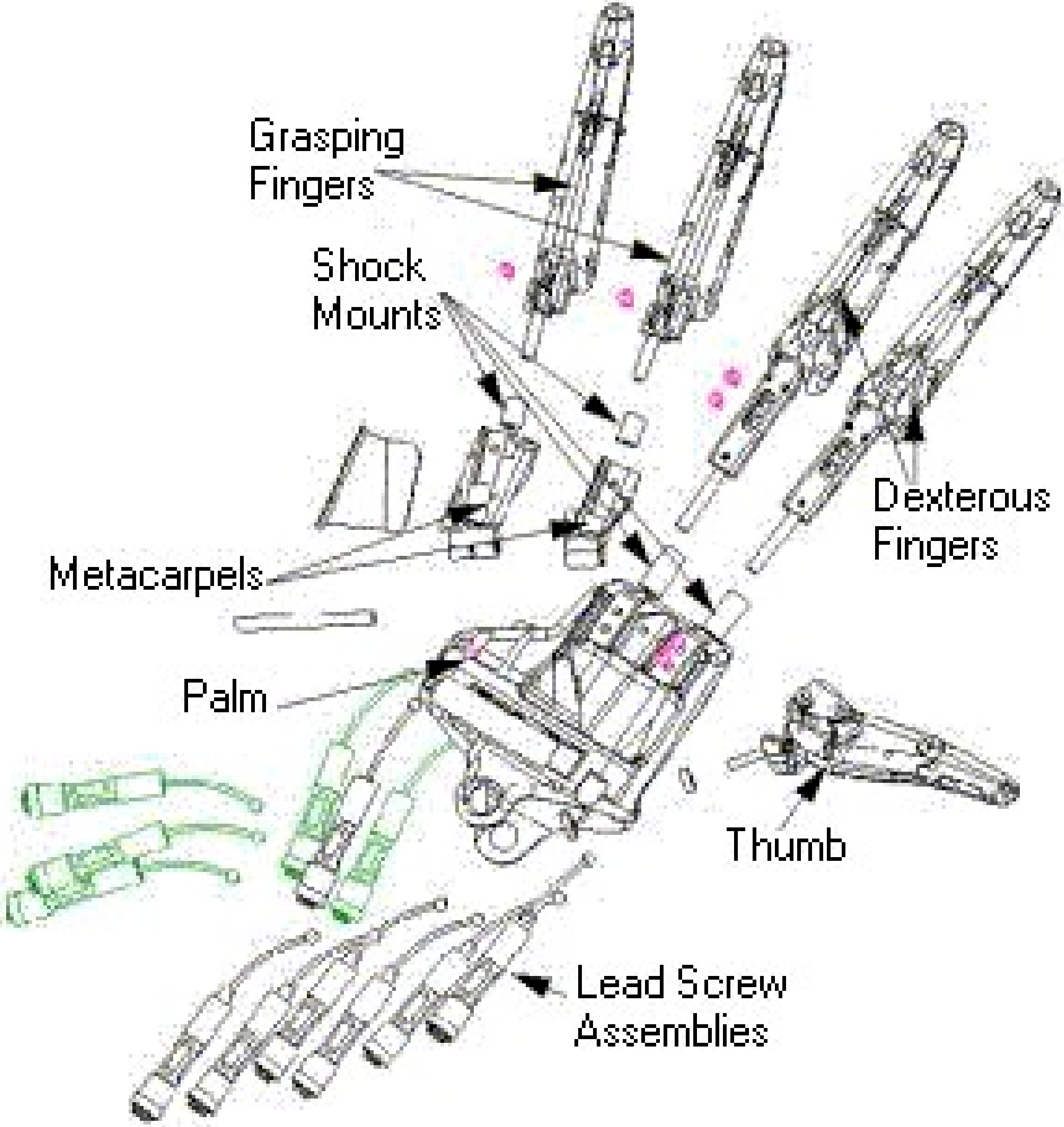
NASA is building an advanced humanoid system called Robonaut, currently under development at the Johnson Space Center.



Design Philosophy of NASA

- The depth and breadth of human performance is beyond the current state of the art in robotics
- NASA targeted the reduced dexterity and performance of a suited astronaut as Robonaut's design goals
- Specifically:
  - using the work envelope,
  - ranges of motion,
  - strength and endurance capabilities of space walking humans.

Robonaut uses a flexible, five-fingered hand.



Grasping Fingers
Shock Mounts
Dexterous Fingers
Metacarpels
Palm
Thumb
Lead Screw Assemblies

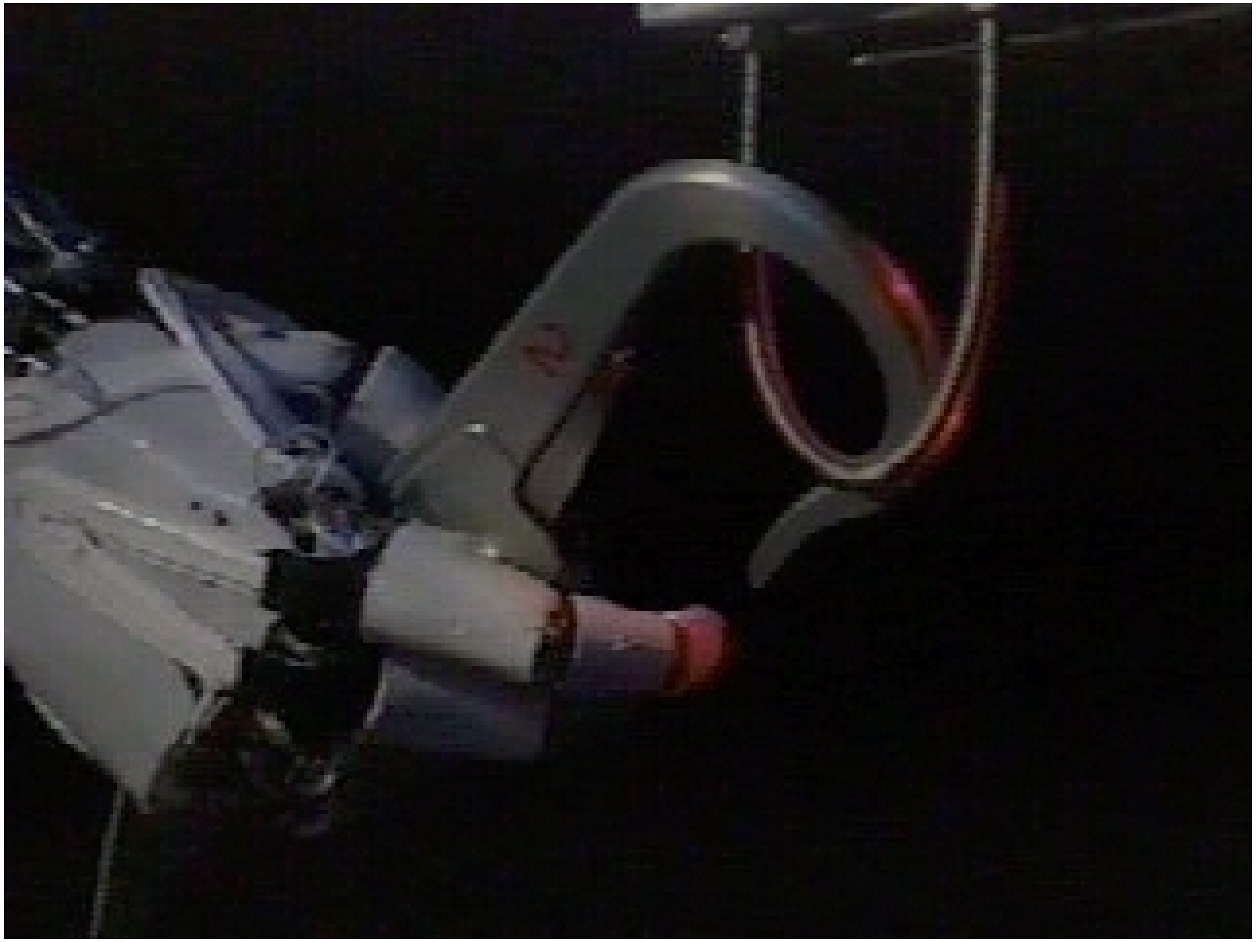
Robonaut uses a flexible, five-fingered hand.

- Dexterous robot hands make it possible for a robot manipulator to grasp and manipulate objects that are not designed to be robotically compatible. While several grippers have been designed for space use and some even tested in space, no dexterous robotic hand has been flown to space
- The Robonaut Hand is one of the first under development for space use and the closest in size and capability to a suited astronaut’s hand.
- Robonaut Hand will be able to fit into all the required places.
- Joint travel for the wrist pitch and yaw is designed to meet or exceed the human hand in a pressurized glove. The hand and wrist parts are sized to reproduce the necessary strength to meet maximum crew requirements.
- Parts made of different materials are toleranced to perform acceptably under the extreme temperature variations.

The Robonaut Hand has a total of fourteen degrees of freedom.

It consists of a forearm which houses the motors and drive electronics, a two degree of freedom wrist, and a five finger, twelve degree of freedom hand.

The forearm, which measures four inches in diameter at its base and is approximately eight inches long, houses all fourteen motors, 12 separate circuit boards, and all of the wiring for the hand



Robonaut has two arms designed to be equivalent to human strength, scale, reach and dexterity.

- The arm has a dense packaging of joints and avionics developed with the mechatronics philosophy.
- The endoskeletal design of the arm houses thermal vacuum rated motors, harmonic drives, fail-safe brakes and 16 sensors in each joint.
- Custom lubricants, strain gages, encoders and absolute angular position sensors were developed in house to make the dense packaging possible.

- The Roll-Pitch-Roll-Pitch-Roll-Pitch-Yaw kinematic tree is covered in a series of synthetic fabric layers
- They form a skin that provides protection from contact and extreme thermal variations in the environment of space.
- Two of these arm joints have already been tested in a thermal vacuum chamber, where they performed well as the temperature was varied from -25C to 105C.

- The arms were designed using software developed as part of Dr. Ambrose's Ph.D. dissertation at the University of Texas at Austin
- The combined design of the arms, body and leg (tail) for the microgravity applications was also performed using custom analysis techniques, where load sharing and compliance require an understanding of serial, parallel and bifurcating chain kinetics
- Arm requirements for advanced applications such as climbing in microgravity and integration with surface mobility systems (rovers) are now being explored.

The Robonaut head has two eyes and a neck with two degrees of freedom -- the ability to nod up and down and shake left and right.

- The existing system includes an articulated neck that allows the teleoperator to point Robonaut's face.
- The head holds two small color cameras that deliver stereo vision to the operator's helmet display, yielding a form of depth perception.
- The interocular spacing of the cameras is matched to typical human eye spacing, with a fix vergence at arm's reach.
- The neck drives are commanded using a 6 axis Polhemus sensor mounted on the teleoperator's helmet, and can track the velocities of typical human neck motions.

- Like the arms, the neck's endoskeleton is covered in a fabric skin, which is fitted into and under the helmet.
- The helmeted approach is unusual in the robotics world, where cameras are typically mounted in exposed locations on pan-tilt-verge units.

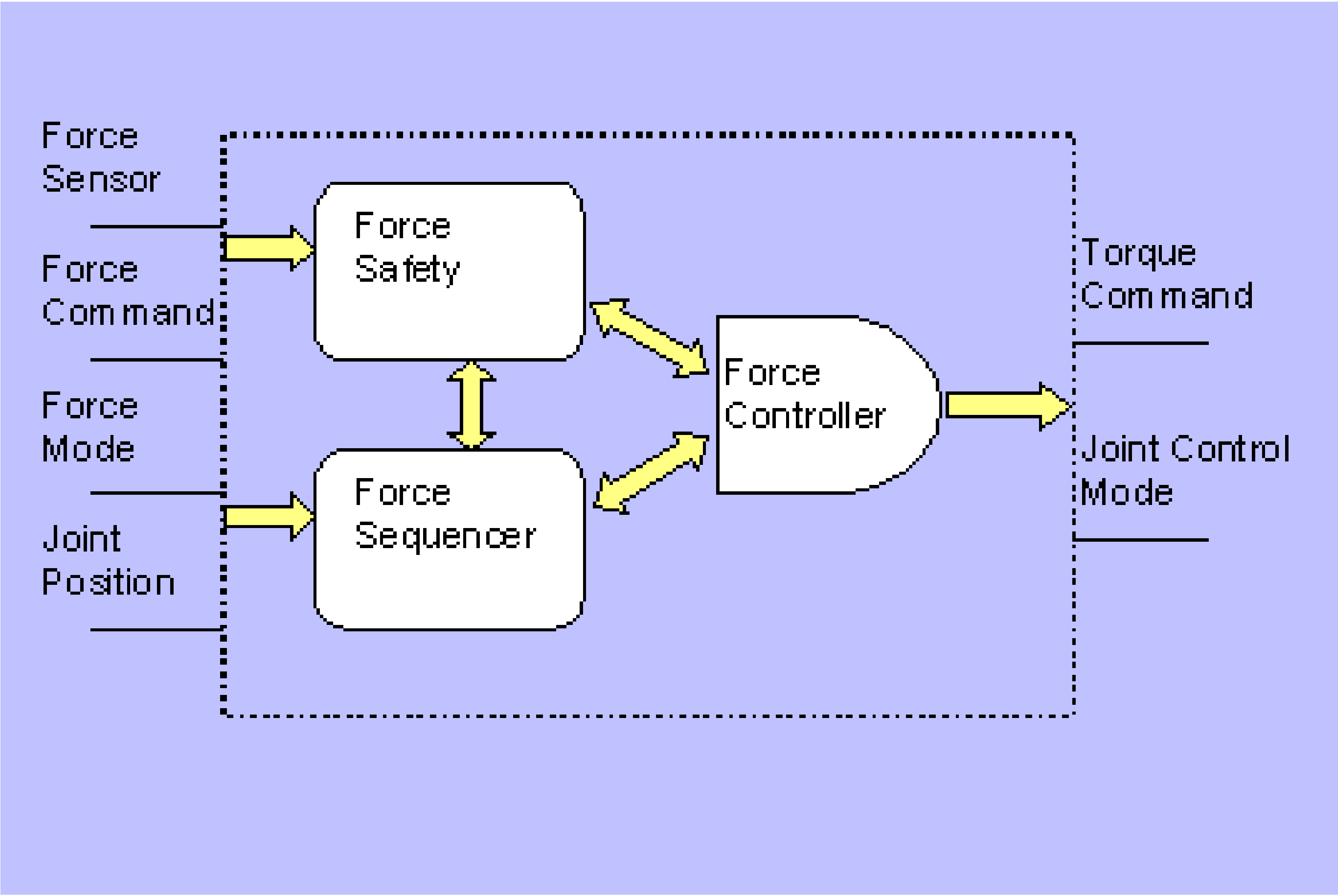
- Robonaut's requirements for a rugged design, working with astronauts in cluttered environments drove the design towards a better protection system, such as the helmets that humans where here on Earth.
- The helmet is made of an epoxy resin, "grown" using a stereo lithography machine.
- The design was inspired by Centurian armor, giving Robonaut some attitude.

- The neck joints are similar to the joints and are controlled with the same real-time control system.
- Their kinematics is based on a pan-tilt serial chain, with the first rotation about Robonaut's spine, and then a pitch motion about a lateral axis.
- The pitch motion axis does not pass through the camera sensors, but is instead 3 inches below, like the Atlas joint in the human neck.
- This offset (actually a D-H link length) allows the cameras to translate forward, letting Robonaut see down over its chest.

Architecture

The Robonaut control system combines operator commands, force data and kinematic algorithms with safety rules to provide real-time joint control for Robonaut.

- The overall control architecture is being developed around the concept of creating sub-autonomies which are used to build the main system.
- These autonomies each combine controllers, safety systems, low-level intelligence, and sequencing.
- As a result, each is a self contained, peer system which interacts with the other peers.



Force Sensor
Force Command
Force Mode
Joint Position
Force Safety
Force Sequencer
Force Controller
Torque Command
Joint Control Mode

Computing environment

- The computing environment chosen for the Robonaut project includes several state-of-the-art technologies.
- The PowerPC processor was chosen as the real-time computing platform for its performance and its continued development for space applications.
- The computers and their required I/O are connected via a VME backplane.
- The processors run the VxWorks real-time operating system.

- The software for Robonaut is written in C and C++.
- ControlShell, a software development environment for object oriented, real-time software development, is used extensively to aid in the development process.
- ControlShell provides a graphical development environment which enhances the understanding of the system and code reusability.

- The functions that the FPGA motor control provides are six step commutation of the three phase brushless DC motors using the hall sensor feedback, pulse width modulation (PWM) to control the six switches in the driver, open loop PWM or velocity loop control of the motor using the motor shaft incremental encoder feedback, over temperature monitoring and shutdown using thermostat feedback, velocity and

Data Aquisition

- The Robonaut I hand/wrist module contains 42 sensors for feedback and control, 28 of which are analog and require signal conditioning and digitization.
- The arm module contains a similar number of sensors with similar requirements.
- To perform this function a modular, compact, ruggedized data acquisition system (DAS) was specified to meet environmental test conditions.

Data Aquisition

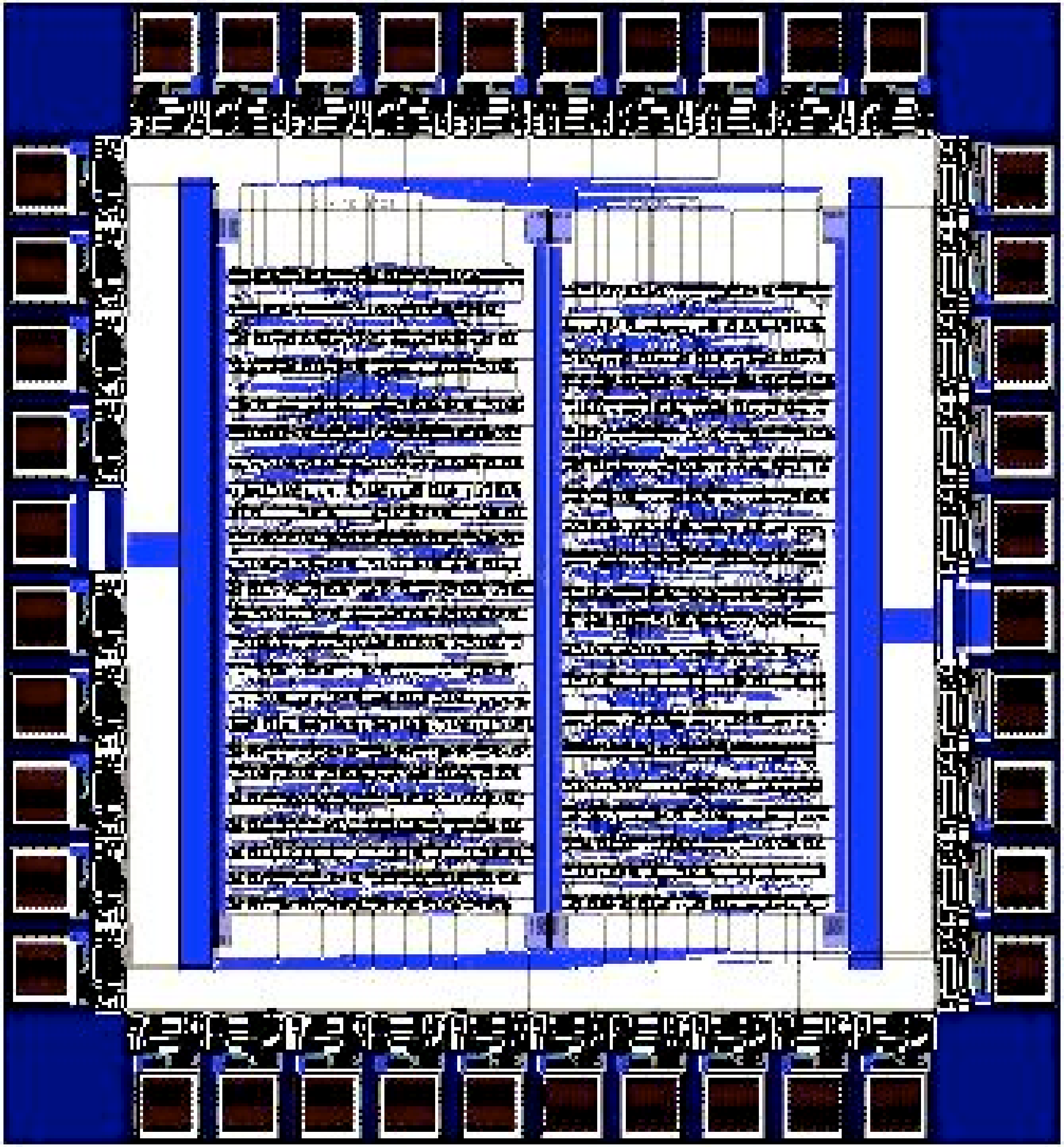
- A thorough investigation of COTS DAS's was performed to determine the feasibility of using existing systems versus designing and building a custom DAS for the Robonaut.
- Several vendors produce DASs certified to MIL-STD-810B for military, and aerospace applications which meet many of the Robonaut requirements.
- A DAS produced by Acra Controls and distributed in the U.S. by Nicolet was selected as best meeting the size, modularity and environmental requirements of Robonaut. The DAS has been delivered and integrated with the sensors and VME computer system which provides Robonaut's primary control. The DAS is currently configured to accept 24 channels of strain gage input, 24 channels of programmable 0-5V analog input, 64 channels of fixed 0-5V analog input, and 15 channels of thermocouple data. The data is encoded, packetized, and transmitted in an IRIG-106-93 PCM format.

Smart Motor Controller Chip for Brushless DC Motor

- The Smart Motor Controller Chip for Brushless DC Motor (SmartChip) project is a collaborative effort between JSC and JPL and funded by HQ code S.
- It is a new start in FY99 building on previous work.
- The goals of the SmartChip project are to reduce by an order of magnitude the control and power electronics associated with small brushless DC motors of 1" and smaller in diameter, and enabling integrated packaging of the electronics with the motor.

Smart Motor Controller Chip for Brushless DC Motor

- The focus of the first year's effort was on building component technology for bench level testing.
- JPL has expertise in Micro Electro-Mechanical Systems (MEMS) switches for motor commutation and is adapting this technology for a miniature custom encoder.
- JSC is combining Field Programmable Gate Array (FPGA) based motor control expertise with radiation tolerant Application Specific Integrated Circuit (ASIC) design to produce a miniature motor control ASIC which can be combined with JPL's MEMS encoder and commutation components.



Telepresence

- **Robonaut uses several novel techniques for establishing remote control of its subsystems and enabling the human operator to maintain situation awareness.**

- AR&SD surveyed a number of potential technologies for tracking the waist-up posture (together with arm and head positions) of a human.
- These technologies include: directly placing mechanical, or magnetic sensors on the body joints of interest; visual tracking of body markers; non-contact methods such as sonar, structured light, and machine vision; etc..

- There are advantages and disadvantages to all of them for telepresence.
- For example, several of these techniques offer impressive tracking accuracy.
- However, very few of these operate fast enough (i.e., in real-time) for teleoperating Robonaut.
- Also, to meet the challenges of a space environment and the NASA thrust for less costly space systems some additional characteristics in the selected technology are required, such as: highly intuitive and unobtrusive interfaces to minimize crew training and system operations, use of COTS components, safe operation in a spacecraft, compact stowage requirements, low power consumption, etc.