A Humanoid Robot that has Two, Three or Four Feet

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Question of the Sphinx

- Which animal has one voice, but two, three or four feet being slowest on three?
- Oedipus gave the right answer, “Man”.
- This lecture gives another right answer, i.e. “humanoid robot” that can move on two, three or four feet.

Why Humanoids?

- Why not?

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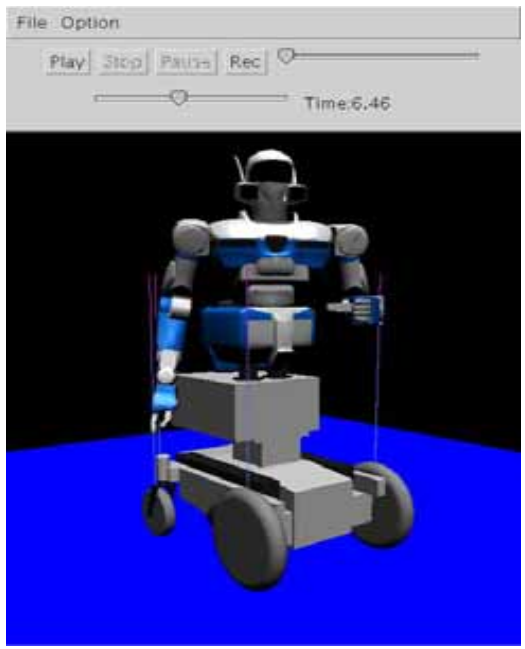


= biped

Why not biped?

- The biped locomotion is more than enough.
  - A wheelchair needs barrier free environment.
- The biped locomotion is unstable.
  - Why don't you crawl every day?
  - ASIMO can run now. The problem will be fixed.
- The biped robot is expensive.
  - Really? It's only a problem of # of motors.

Three Reasons to support Humanoids

- Humanoids have shapes like humans.
- Humanoids can use the tools that are designed for humans.
- Humanoids can move in the environment that is designed for humans.

Humanoids have shapes like humans.

[Kokoro Dreams 2005]

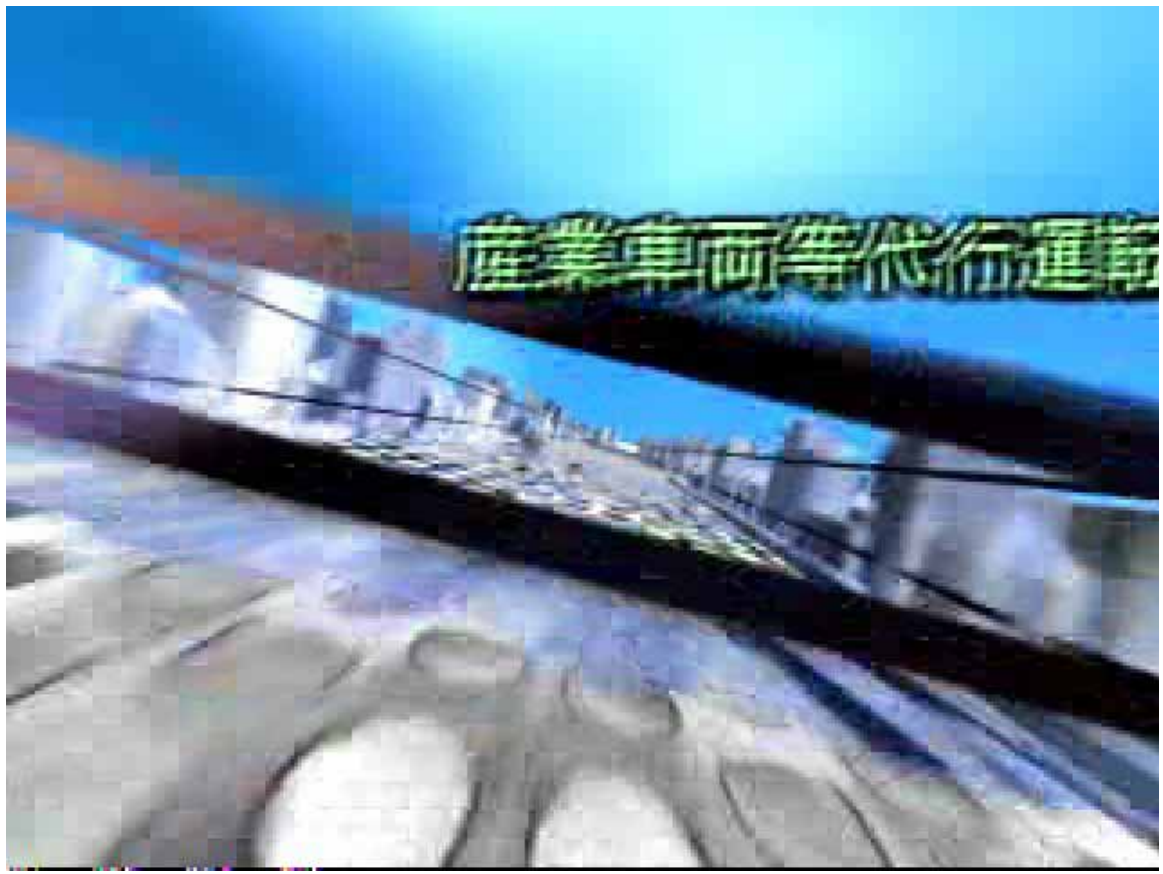
Biped Dinosaur Robot

[AIST & NEDO 2005]

Dinosaur Robot should have the Shape like a Dinosaur!

[AIST & NEDO 2005]

Humanoid Driver



[KHI, Tokyu Construction, AIST 2003]

Humanoids can move the environment for humans

[Mitsubishi Heavy Industries, 2003]

Humanoids can move in the environment for humans

- Implies that
  - Walking on a flat floor and rough terrain
  - Going up and down stairs and ladders
  - Lying down, crawling and getting up
  - Falling down safely and getting up
  - Opening and closing doors

- Humanoids move on two, three or four feet.

HRP-2 walks on a Rough Terrain

Gap < ±20 mm Slope < 5%

Going up stairs while catching a handrail (Three feet)

[Harada et al. 2004]

Lying down and Getting up

[Kanehiro et al. 2003]

Crawling to go through a narrow space (Four feet)

[Harada et al. 2004]

Ukemi: Falling Motion Control

[Fujiwara et al. 2003]

Humanoids can move the environment for humans

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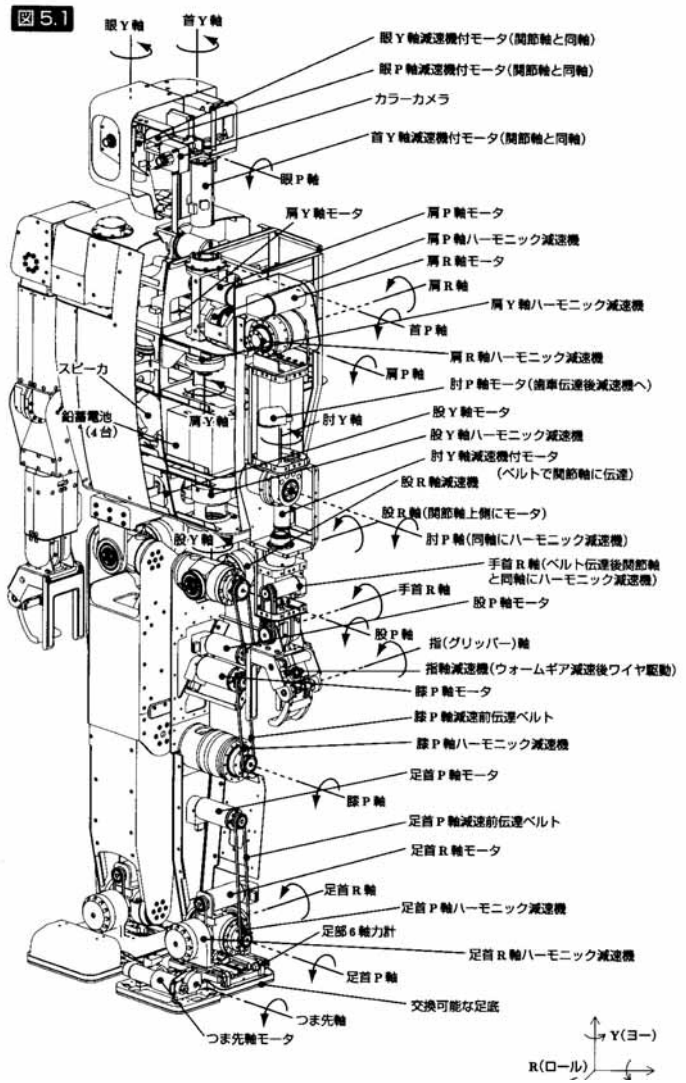
- Humanoids move on two, three or four feet.

How were the motions realized?

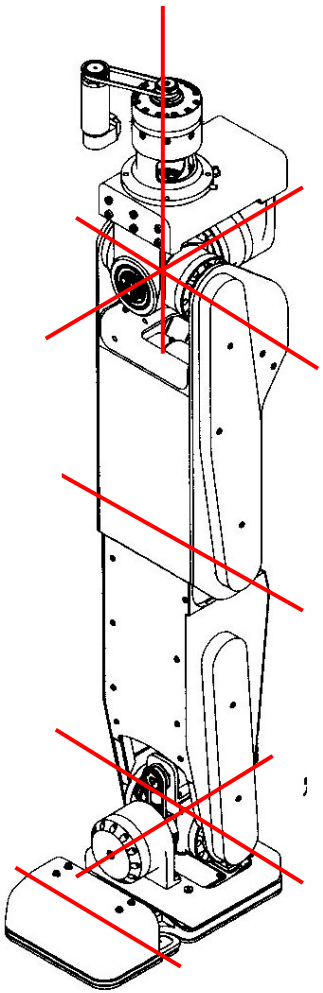
- Mechanism
- Sensors
- Design
- Control (the Second Class)

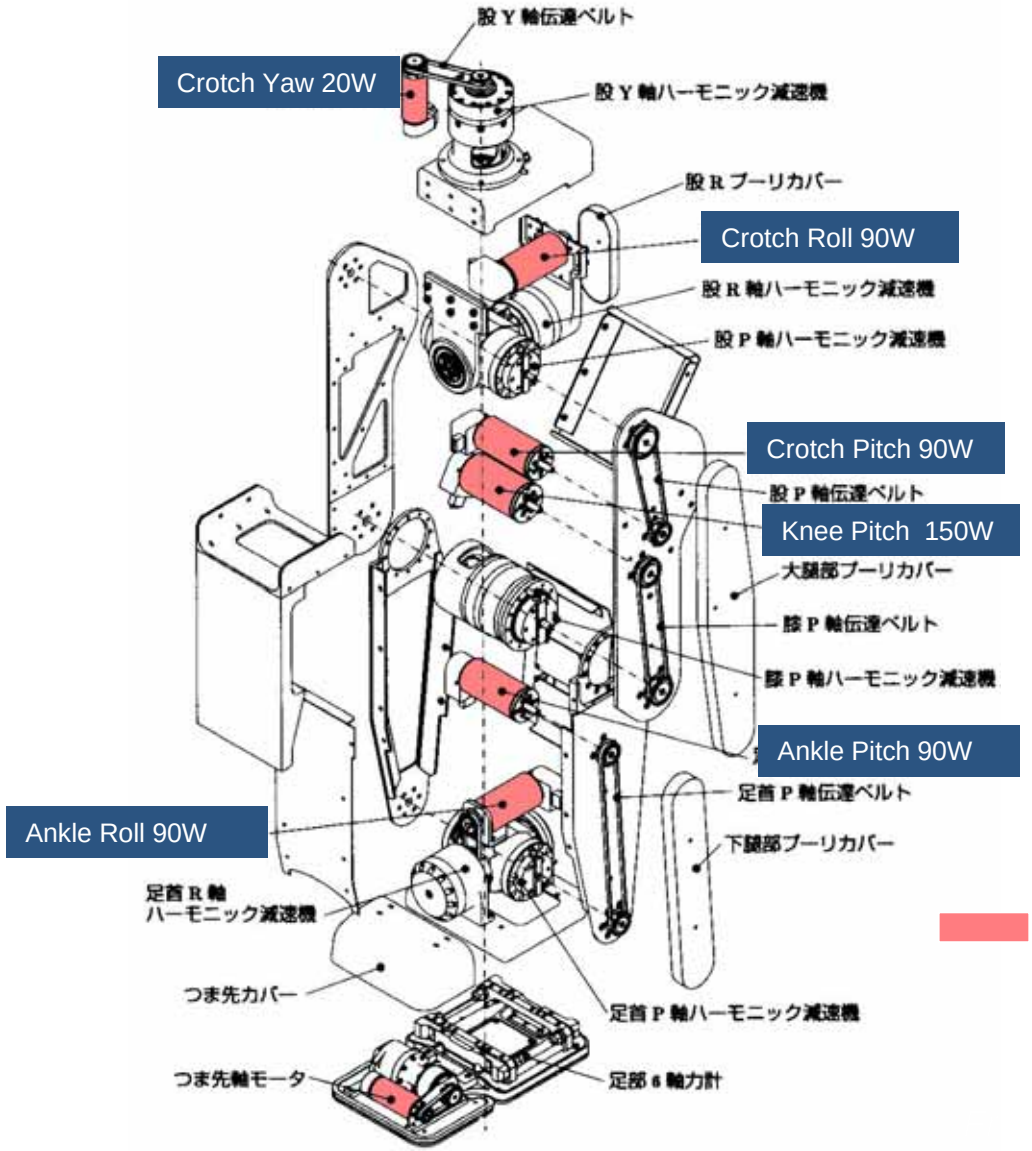
The Anatomy of H7 [U of Tokyo]

http://www.jsk.t.u-tokyo.ac.jp/research/h7/index-j.html

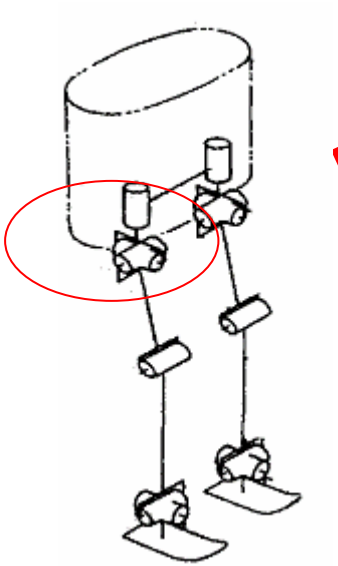


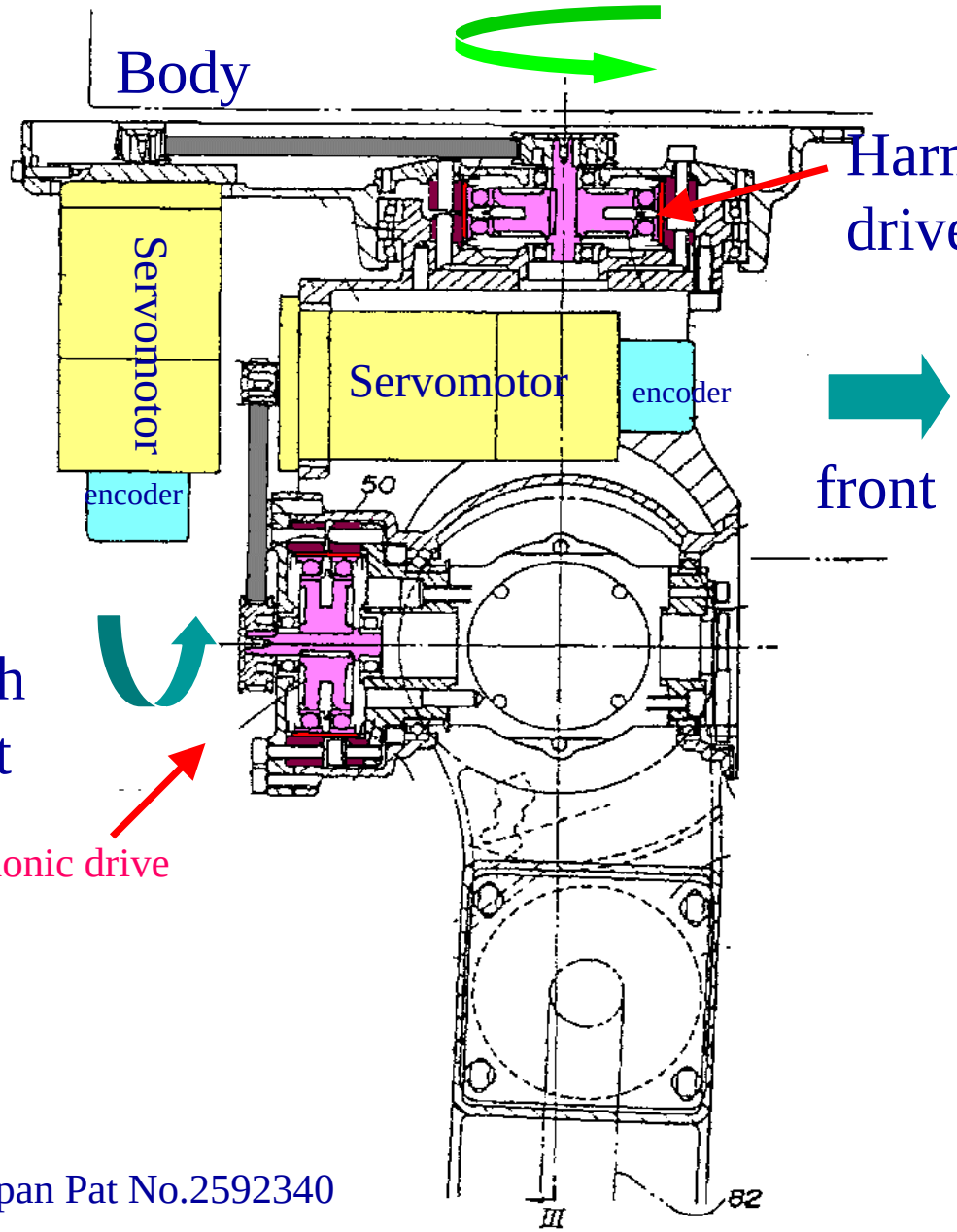
The Anatomy of a Leg of H7





Hip Joint

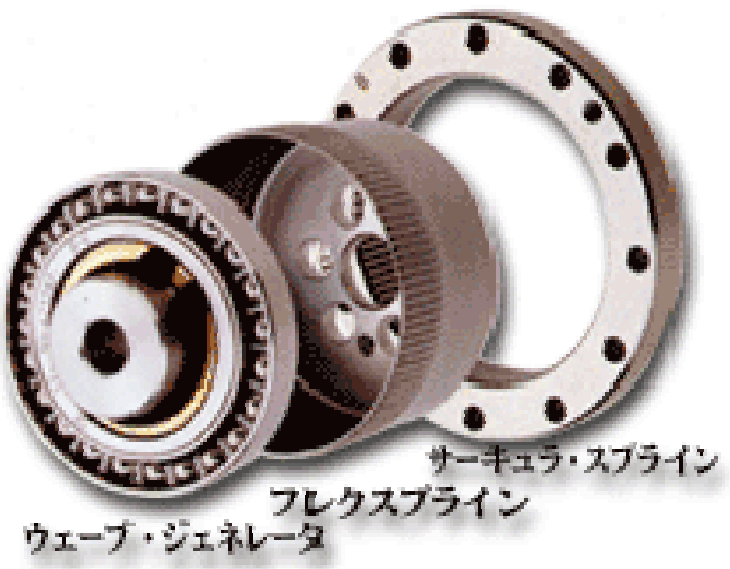


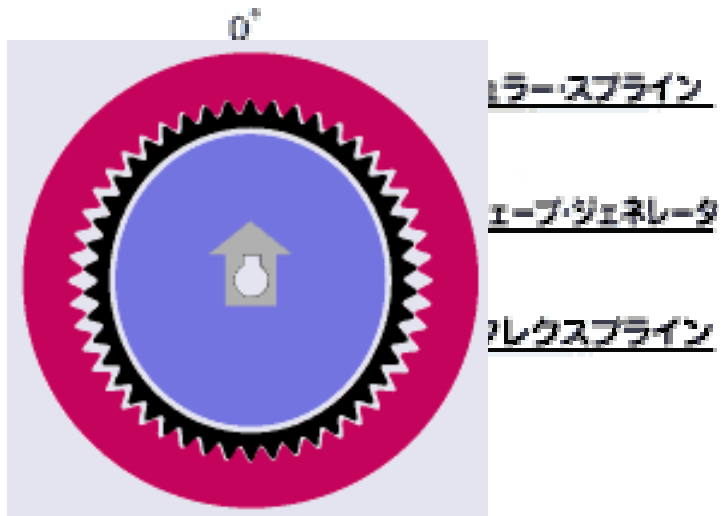


Japan Pat No.2592340

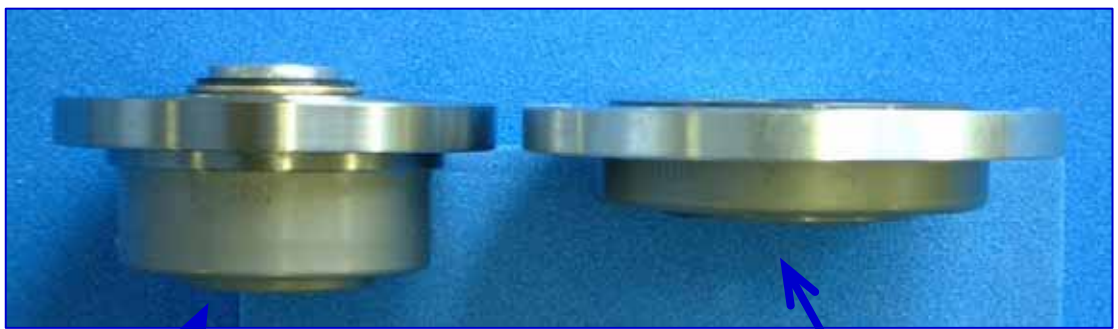
Harmonic Drive

- Reduces 6,000-10,000 rpm of a motor to 20-100 rpm of a joint.
- Usual gears are too heavy and have too much backlash.





Thin and Light Harmonic Drive



Thickness: 50%

Weight: 65% off

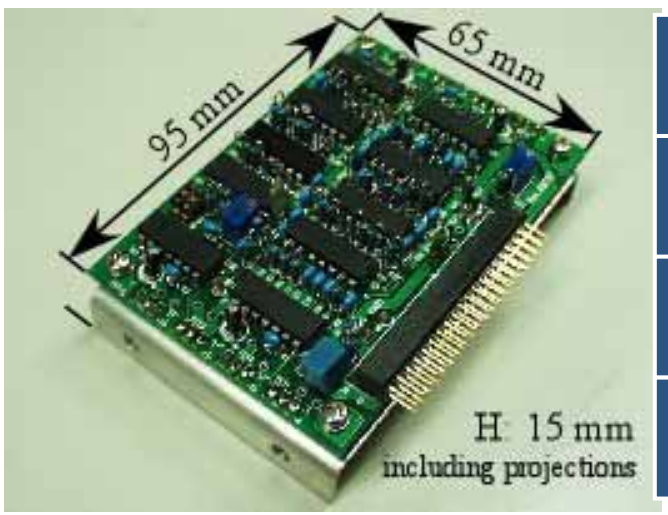
Conventional Harmonic

New Harmonic

Servo Driver Module

Required Specifications for Humanoid Robots

- The size should be compact.
- The maximum current should be very large.

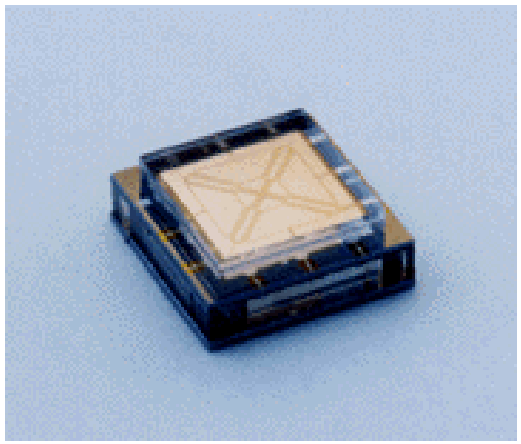


Controllable Axes	2-Axes Independently
Output Current	Max. 20 [A]
Size	Almost 15% of Product
Weight	Almost 33% of Product

How were the motions realized?

- Mechanism
- Sensing
- Design

Attitude Sensors



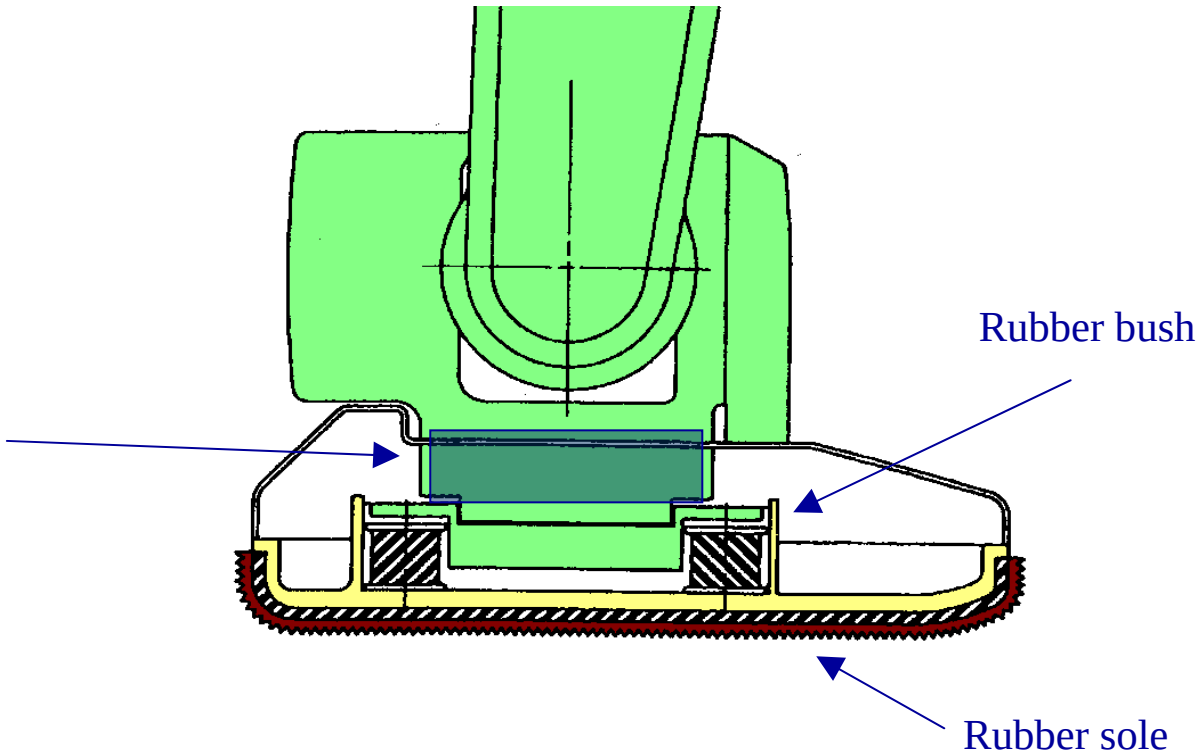
Accelerometer
- Linear acceleration
- Temperature drift

Gyroscope
- Angular velocity
- Drift

Both sensors are used to find the angular velocity of the body

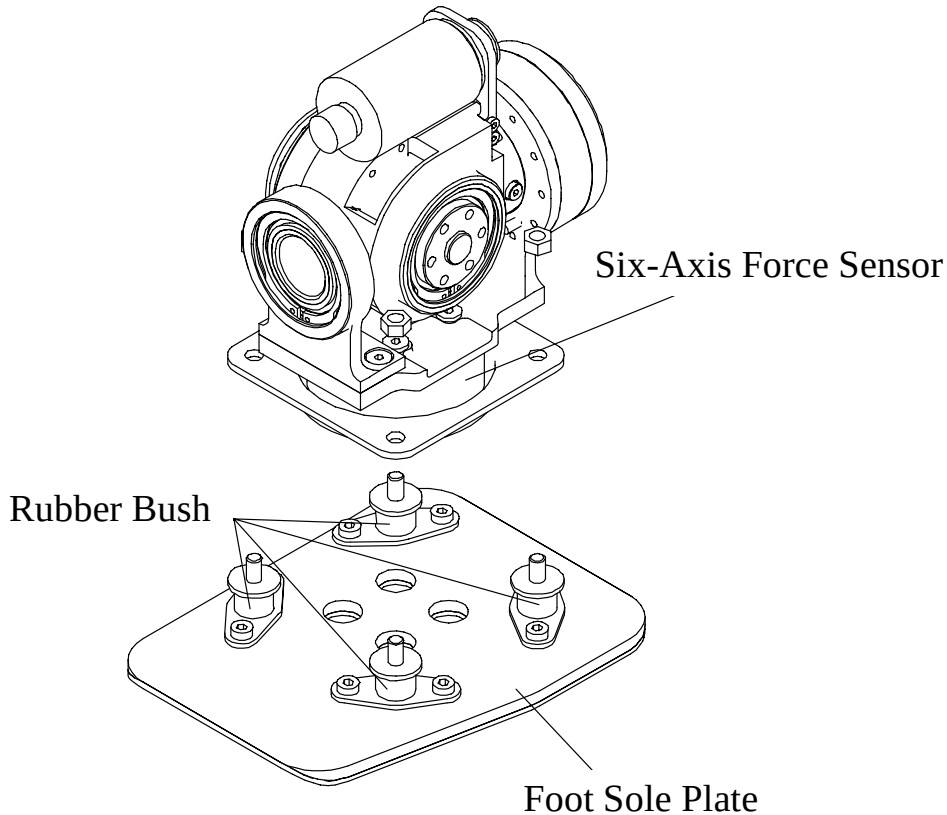
Force Sensor at a Foot

6-axis force sensor



The rubber bush protects force sensor from impact at touchdown.
It is also important to make the force control stable.

Mechanism of the Foot



Stereo Cameras

[HRP-2 Prototype, 2002]

Microphone Array

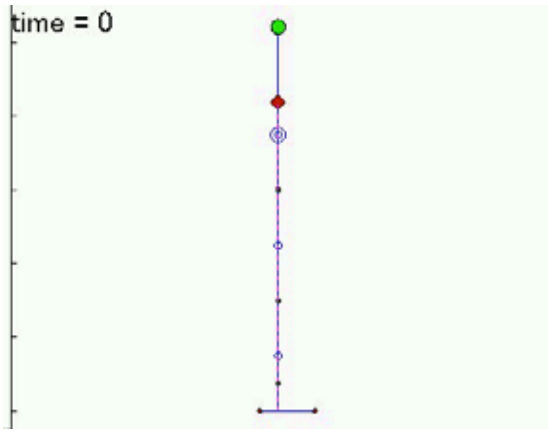
Eight pieces of Microphone for a Cellar Phone
With Noise Reduction Processor

How were the motions realized?

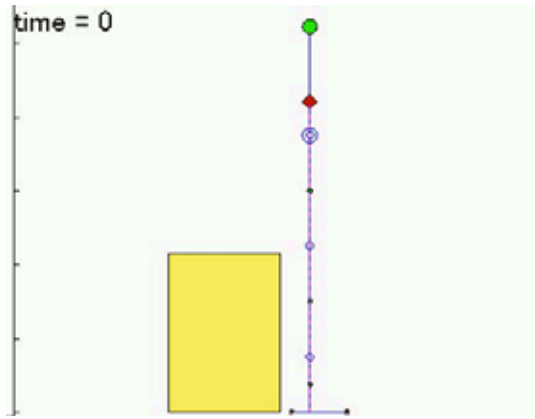
- Mechanism
- Sensing
- Design

Design of Movable Range of Joints

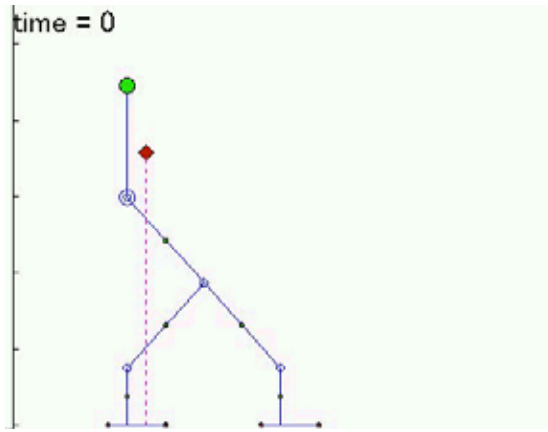
Sitting onto the floor



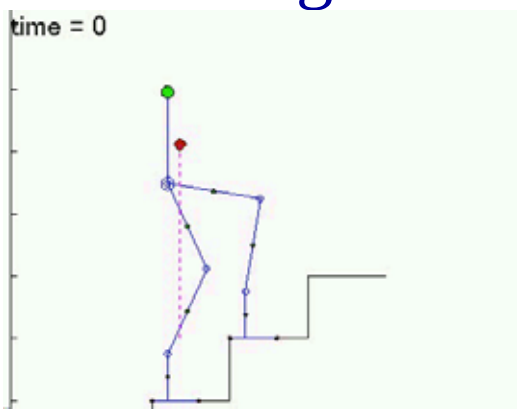
Sitting to a chair



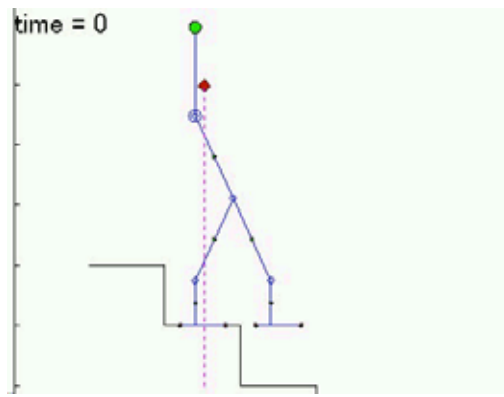
Static walk



Climbing stairs

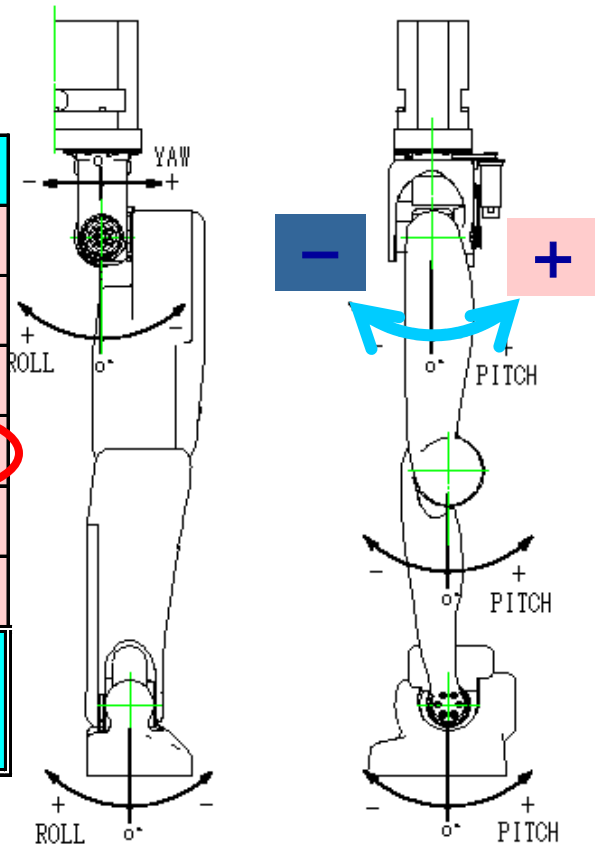


Descending stairs



Hip Pitch Joint

Motions	Hip Pitch Joint		
(0) Standard Human	-125 deg.	to	+15 deg.
(a) Sitting on the Floor	-89 deg.	to	0 deg.
(b) Taking a sheet	-135 deg.	to	0 deg.
(c) Walking Straight	-67 deg.	to	+42 deg.
(d) Going up Stairs	-81 deg.	to	+25 deg.
(e) Going down Stairs	-60 deg.	to	-9 deg.
Requested Movable Range	**-135 deg. to +42 deg.**		



Left Leg

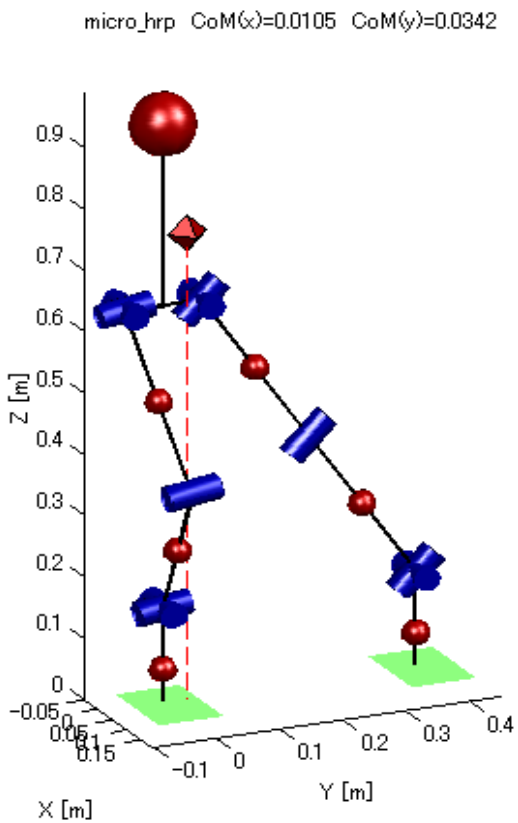
Roll Axes and Yaw Axis

✧ Roll Axes

Side Step Motions

- 40 [cm] Step, Flat Floor
- 30 [cm] Step, Rough Terrain

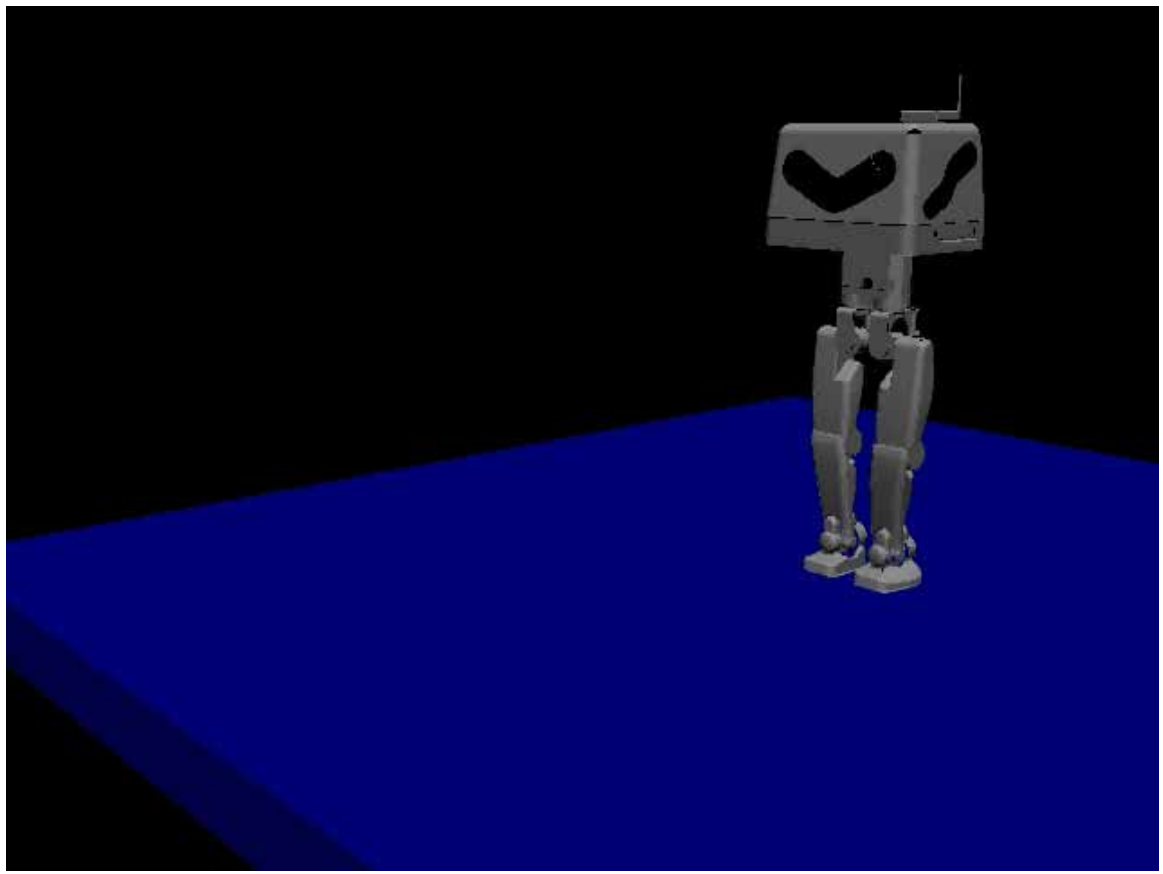
Hip	Roll	-45 to +25 [deg.]
Ankle	Roll	-20 to +35 [deg.]



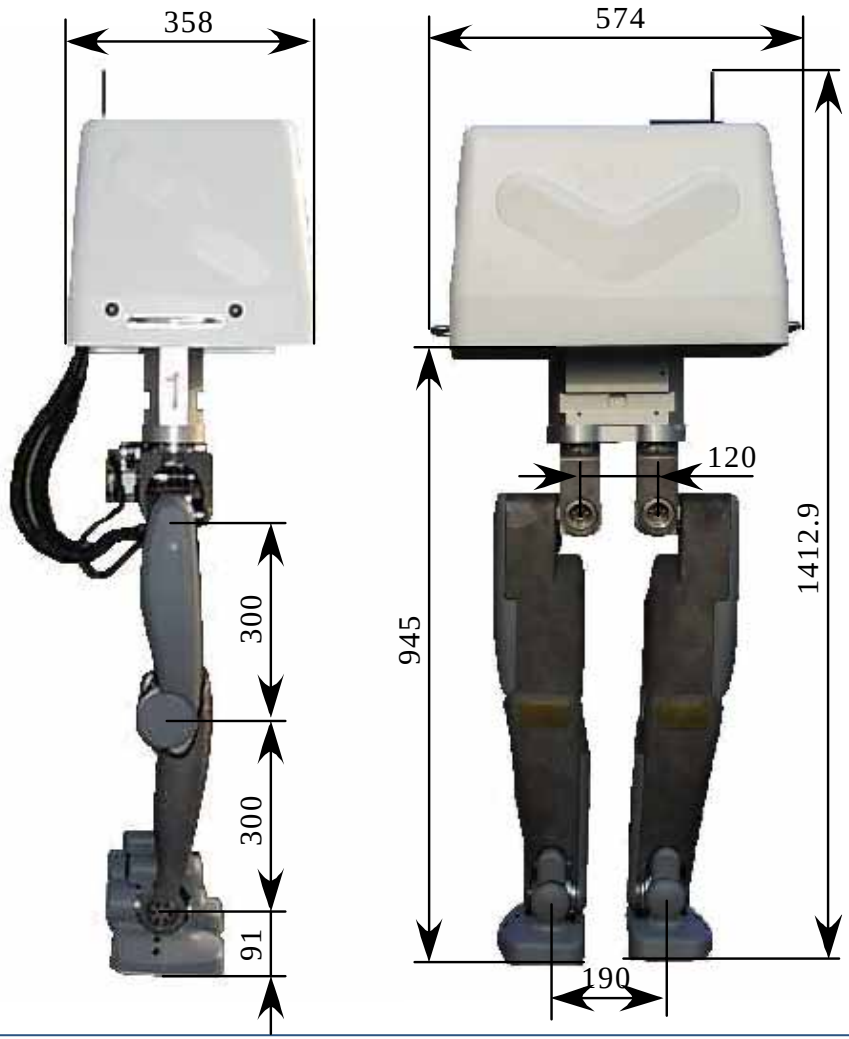
✧ Yaw Axis

Hip	Yaw	-45 to +45 [deg.]

Dynamic Simulation of Walking



HRP-2L



HRP-2L

Upper Leg Length: 300 [mm]

Lower Leg Length: 300 [mm]

Ankle Length: 91 [mm]

Weight of Each Leg: 8.6 [kg/Leg]

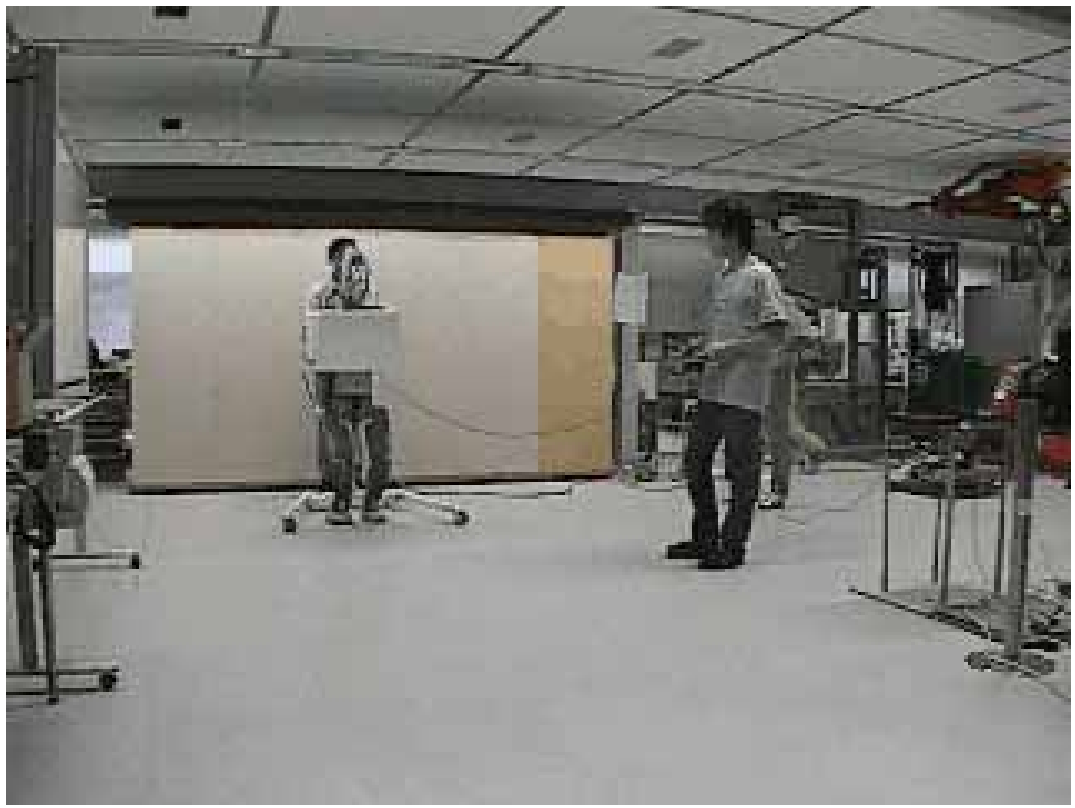
D.O.F.: 12 D.O.F.

[Hip: 3 D.O.F., Knee: 1 D.O.F., Ankle: 2 D.O.F.]

Actuators and Gears for HRP-2L

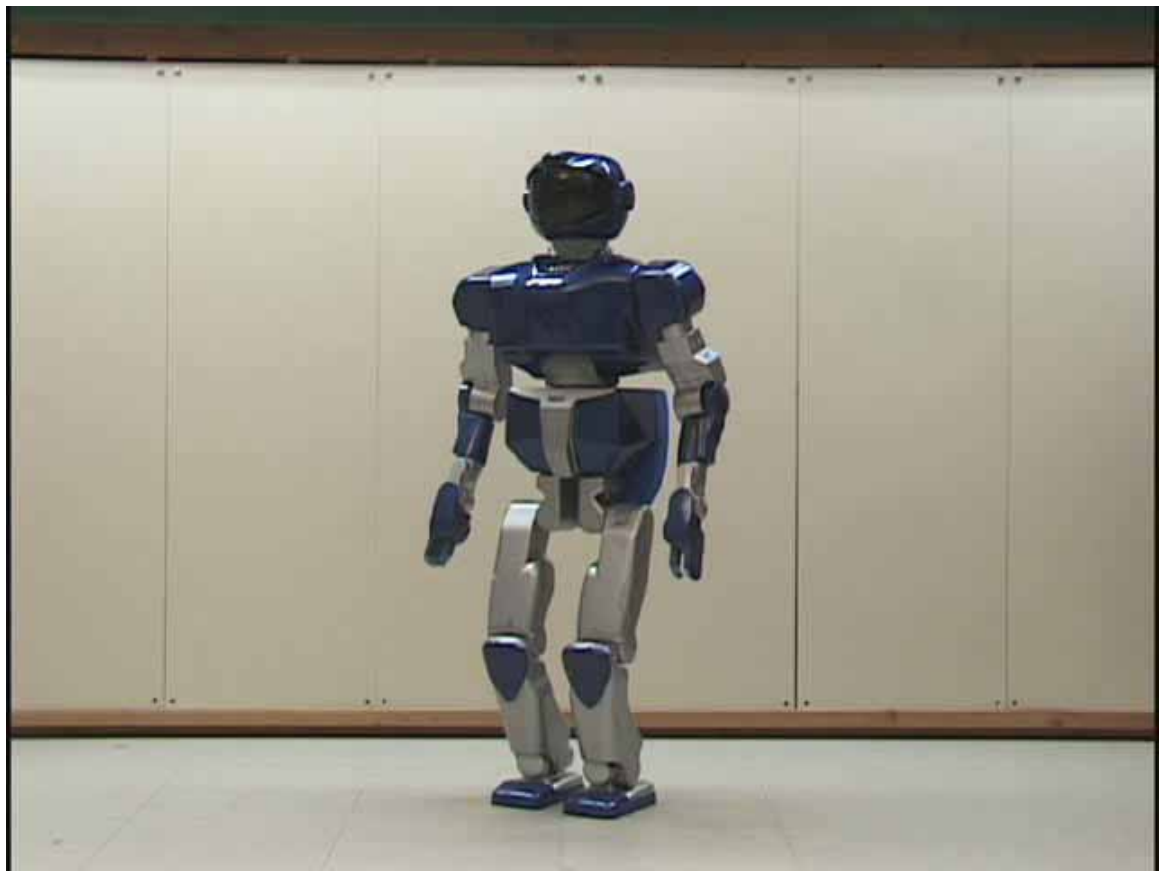
Joint		Actuator	Ratio of Harmonic
Hip	Roll	DC 90 [W]	1:160
	Pitch	DC 90 [W]	1:120
	Yaw	DC 20 [W]	1:160
Knee	Pitch	DC 150 [W]	1:160
Ankle	Roll	DC 70 [W]	1:160
	Pitch	DC 90 [W]	1:160

Walking Experiment of HRP-2L



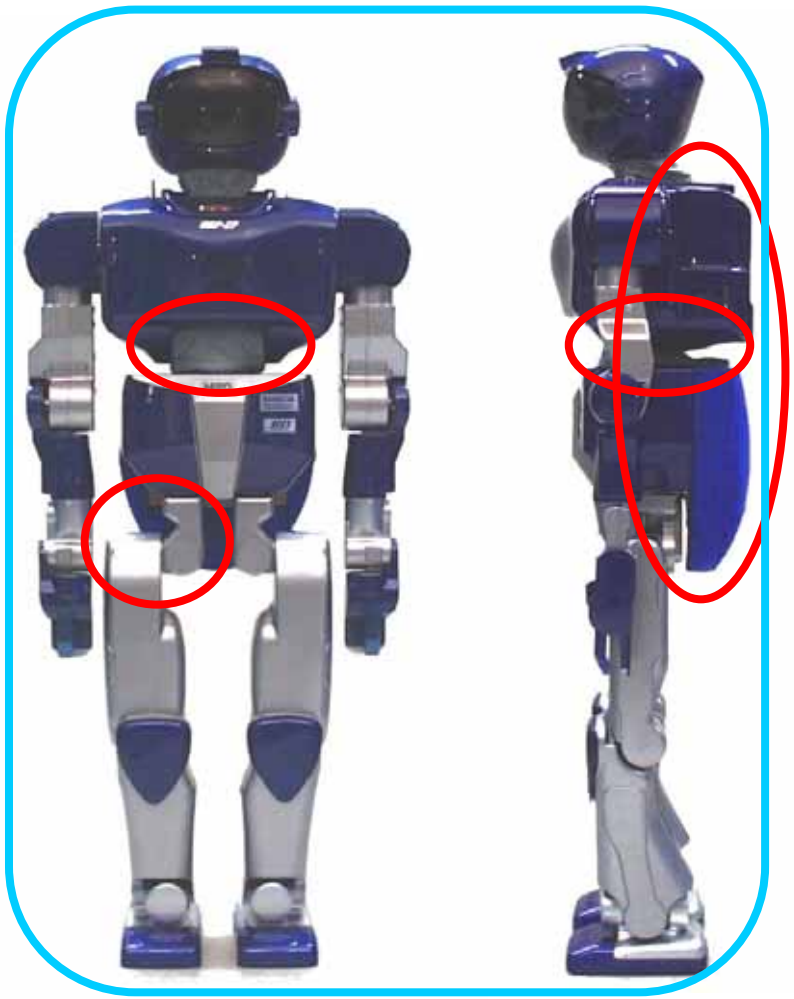
HRP-2A
- Design of the Upper Body

Humanoid Robot HRP-2P



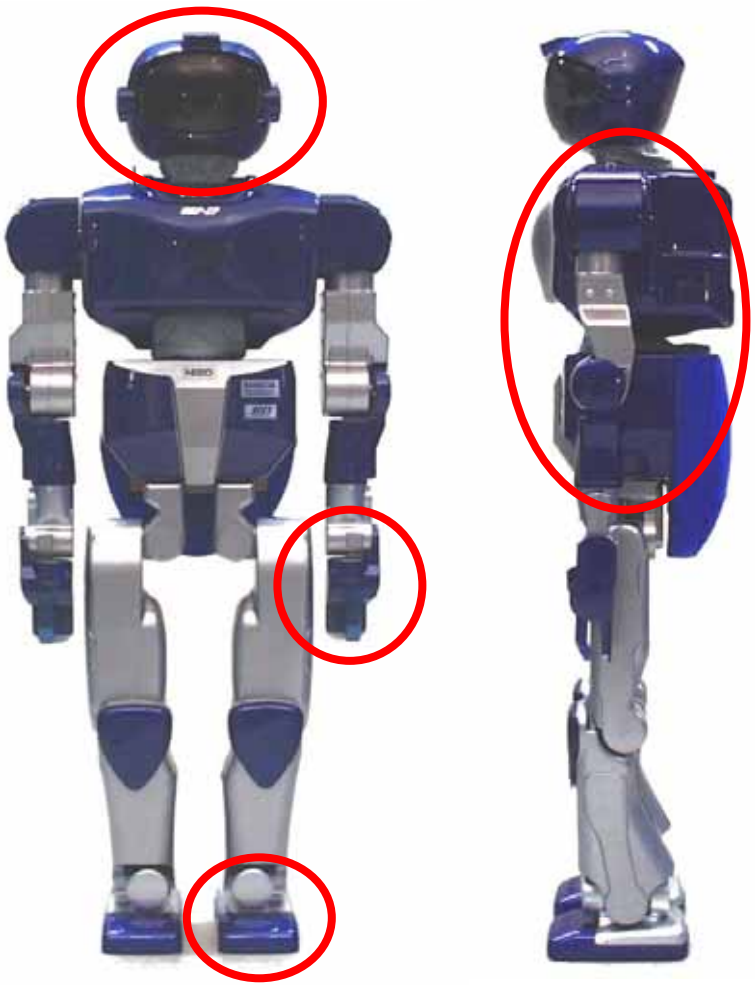
[Kawada Industrties & AIST 2002]

Mechanical Features



- Compact & Light Weight with 30 D.O.F.
- No Backpack
- Waist Joint
- Cantilever Crotch Joint

Sensors and Batteries

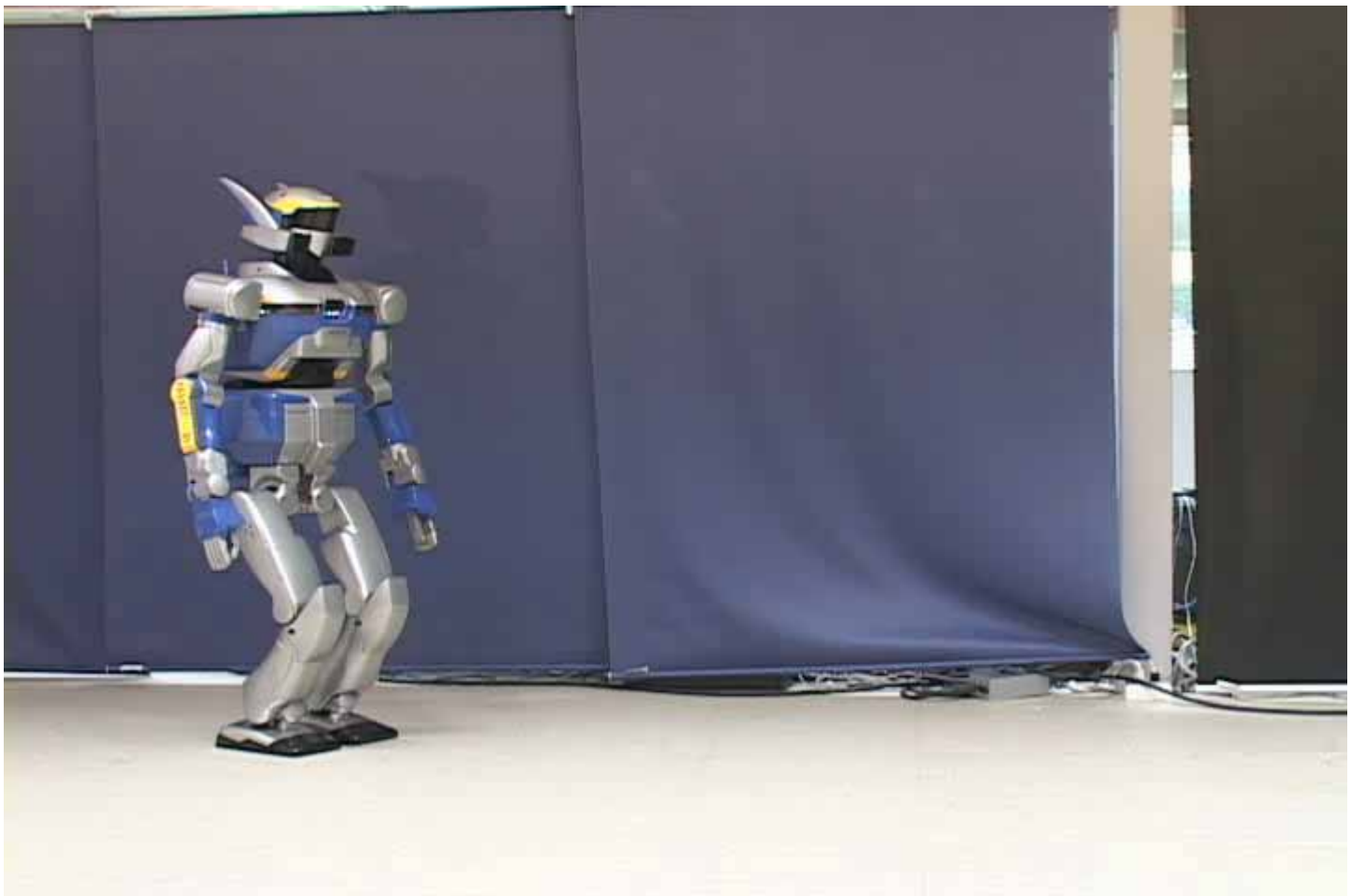


- 3D Stereo Camera
- 3-Axes Accelerometer
- 3-Axes Gyro
- Batteries
- Wrist 6-Axes Force Sensor
- Foot 6-Axes Force Sensor

Specifications of HRP-2

Dimensions	Height	1,540 [mm]
	Width	600 [mm]
	Depth	340 [mm]
Weight **inc. batteries**		58 [kg]
D.O.F.		Total 30 D.O.F.
	Head	2 D.O.F.
	Arm	2 Arms × 6 D.O.F.
	Hand	2 Hands × 1 D.O.F.
	Waist	**2 D.O.F.**
	Leg	2 Legs × 6 D.O.F.
Walking Speed		up to 2.0 [km/h]

Biped Walking on a Flat Floor



[HRP-2, AIST 2003]

HRP-2 works with a human

[AIST, Shimiz, Yaskawa 2003]

Roadmap of Humanoid Robotics

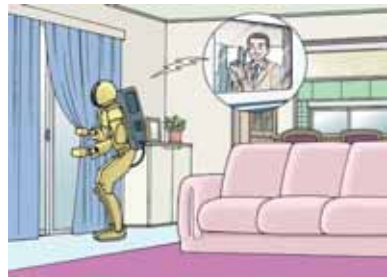
- It will take many years before millions of humanoid robots appears in the society.
- The roadmap of humanoid robotics is very important to make the development of the technologies sustainable.

Roadmap of Humanoid Robotics

Intelligence

Vision
Speech Recognition
Autonomous Manipulation
Safety Intelligence

Domestic Applications
Human Care
Security



Mobility

Tough body
Falling motion

Stairs / Ladder
Rough terrain
Path planning
Narrow space
Open/Close doors

Environment can be used as it is
Nuclear Plants
Hazardous Environment

NEDO's Project

Walk on slippy plane
Arm/Leg Coodination

Water proof
Long time operation
Teleoperation

Tools for humans can be used as it is.
Evaluation of Machines for Humans

METI'S HRP

Applications
HRP-2/OpenHRP

Sony SDR

Honda P2

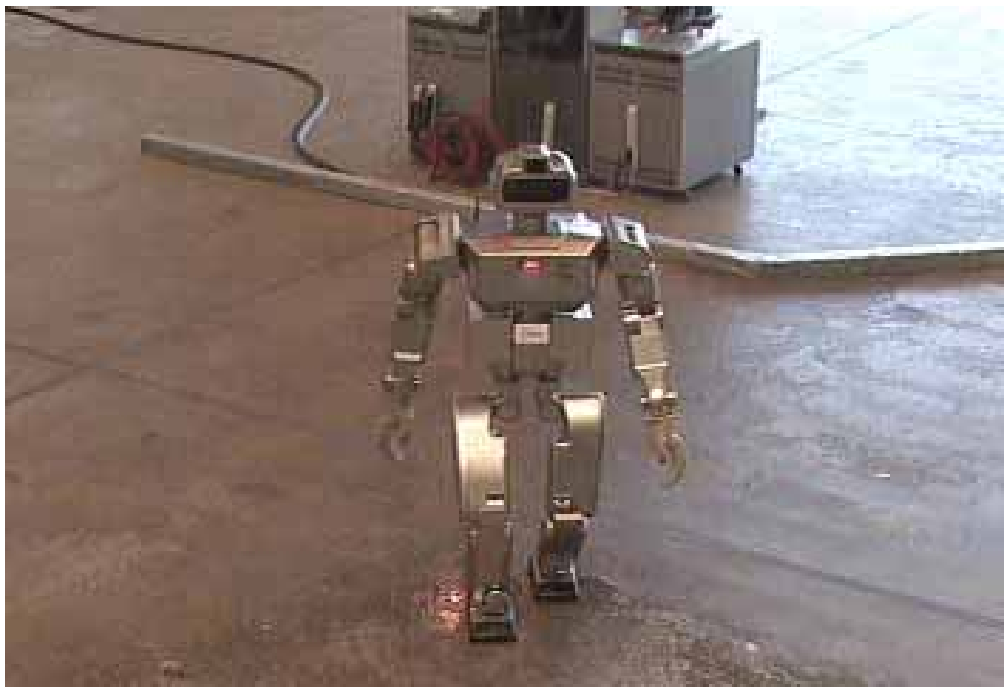
ASIMO

Human shape is important
Digital Archives of Dance Culture
Entertainment

Basic Research at Universities

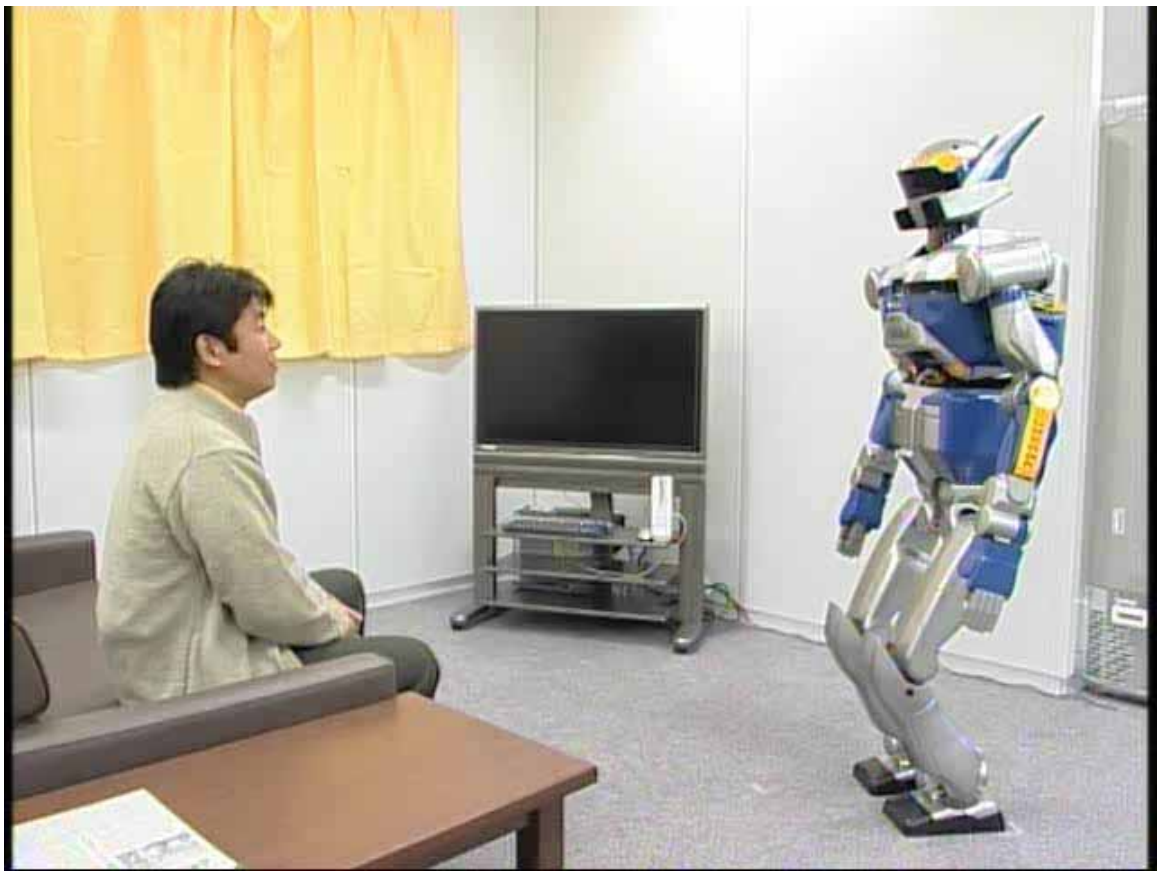
1995 2000 2005 2010 2015 2020 2025

HRP-3P in a shower



[Kawada Industries Inc. 2005]

HRP-2 works at home



[Hara et al. 2006]

Summary

- A humanoid robot is another creature that has one voice, but two, three or four feet.
- The robot looks like a human, moves like a human and uses tools like a human.