# Humanoids with Whole-Body Soft Sensor Flesh for Close Interaction with Humans, Objects, and Environments

Tomoaki Yoshikai
JSK Lab, The University of Tokyo
JAPAN

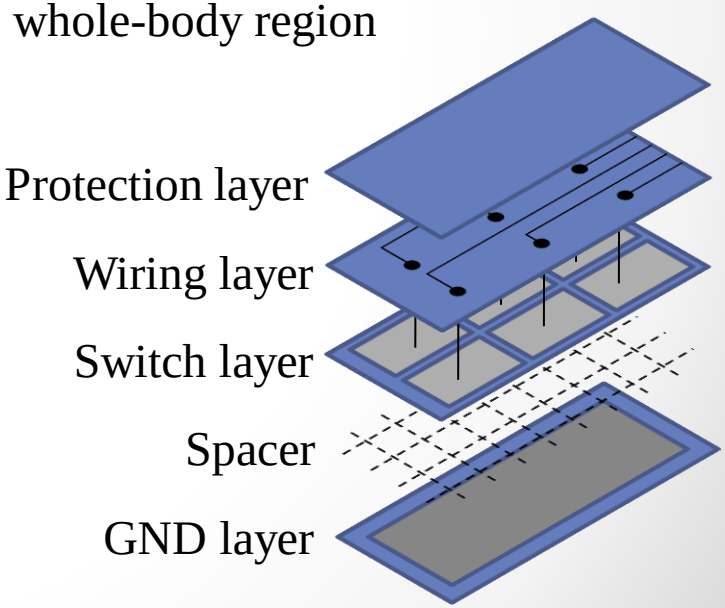
# Our target: soft & close interaction between robots and humans or environments

- Construction of soft sensor exterior for close interaction
- Behavior generation for close interaction
- Sensor information processing for distributed sensor data

# Soft sensor exterior for whole body region of a humanoid robot

- RobovieIIS (Hagita et.al, ATR, 2003)
- R . Daneel (Omura et.al, Tokyo Univ, 2006)
- RI-MAN, RIVA(Mukai et.al, RIKEN, 2006-2009)
- Sensor suit(Hoshino et.al, JSK Lab, 1995)

160 sensing points around whole-body region




- Binary switching structure manufactured with electro conductive cloth and strings.

# Sensor flesh ≠ Robots' skin

- Conventional sensor exterior for robots
  - Tactile sensor skin
  - Tactile sensor suits

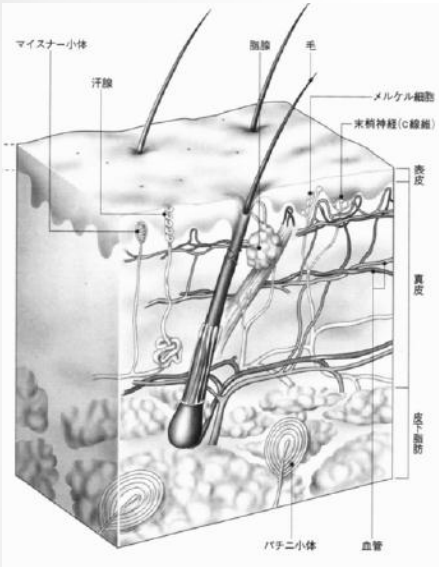
} 'A thin skin with distributed tactile sensors which is mounted on a rigid shell of a robot'

Exterior for humans or animals

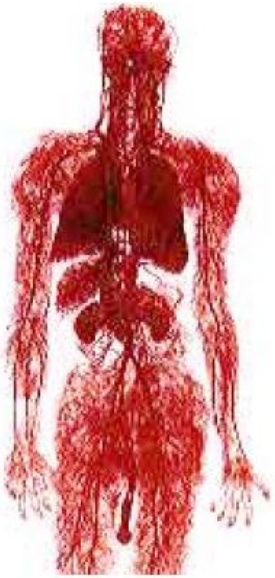
**'A flesh'** which allows soft contacts with others.

Sensor flesh : thick and soft exterior embedded with multi-axis tactile sensors

# ‘Flesh’ for tactile sensors




Various receptors can be contained in a 3D structure of flesh.



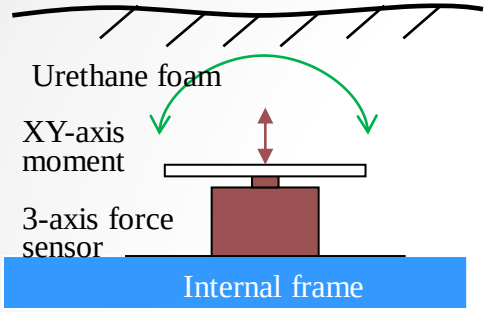
Not only sensors, but also signal wires (nerves) and power cables(blood vessels) can be contained inside a flesh.

‘Flesh’ for tactile sensors

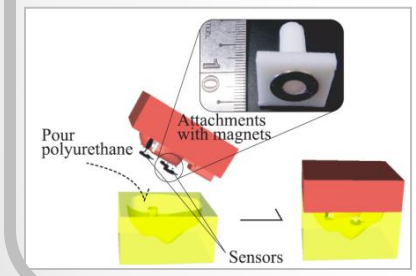
＝ Various sensors, signal and power cables embedded inside 3D structure of soft thick exterior

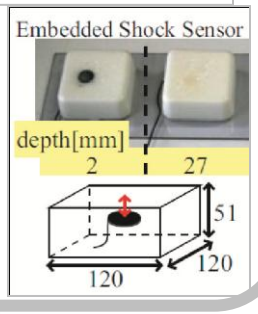
# Research on ‘sensor flesh’ in JSK Lab

**Deeply-placed 3-axis force sensor which is fixed to frame**

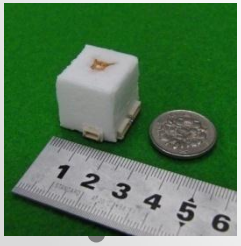


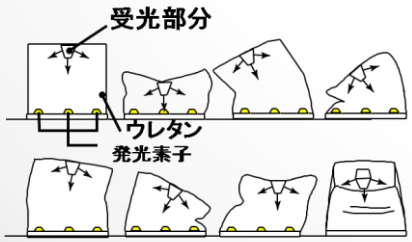

**3D arrangement of sensor elements by monolithic molding**

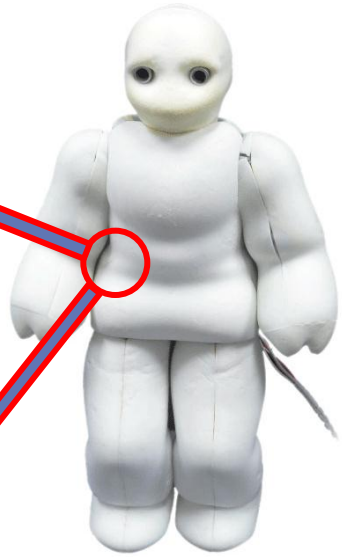


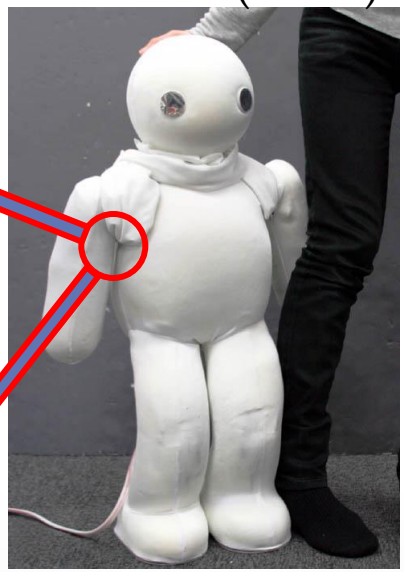

**Soft 3D deformation sensor**



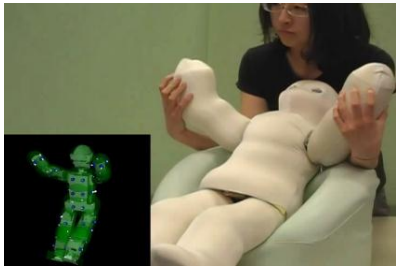


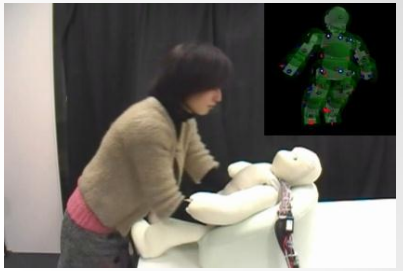
macra(2005-)



macket(2008-)



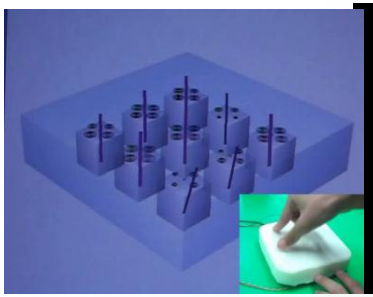
Human robot interaction with self interference



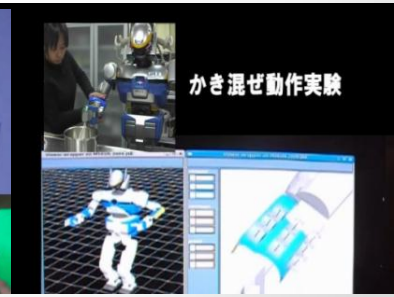
Simultaneous detection of flesh deformation and shock by human patting

Whole-body interaction by deformation sensor

Interaction experiments at an international exhibition



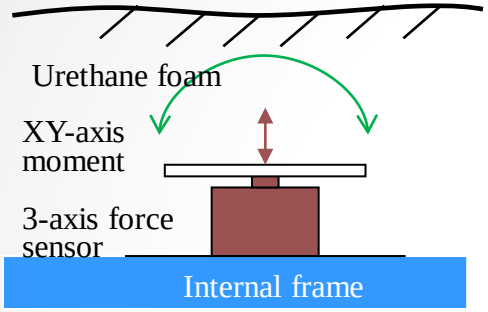
Add-on type 3D deformation sensor



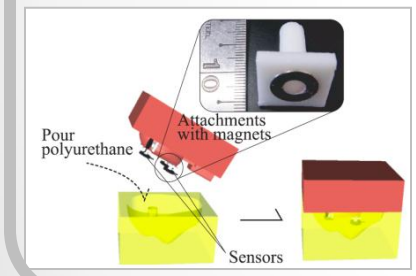

Partial soft flesh for life-size humanoid

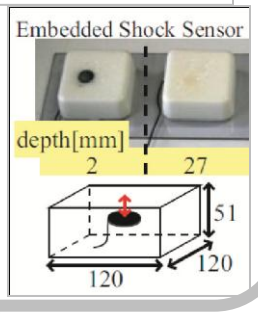
# Research on ‘sensor flesh’ in JSK Lab

**Deeply-placed 3-axis force sensor which is fixed to frame**

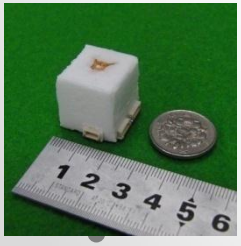


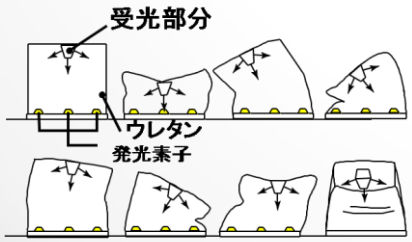

**3D arrangement of sensor elements by monolithic molding**

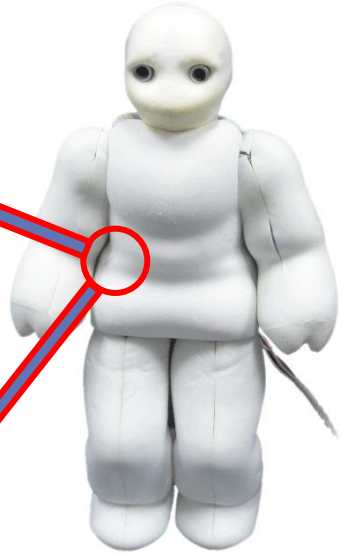


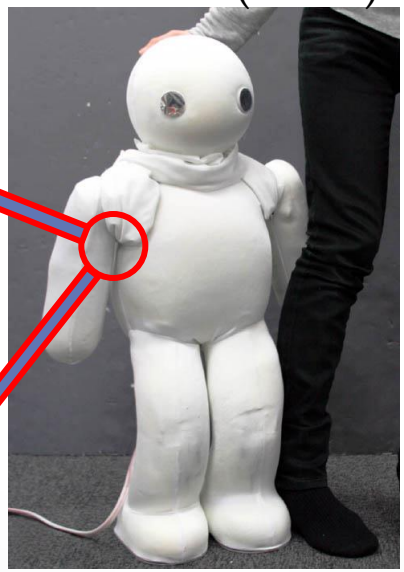

**Soft 3D deformation sensor**



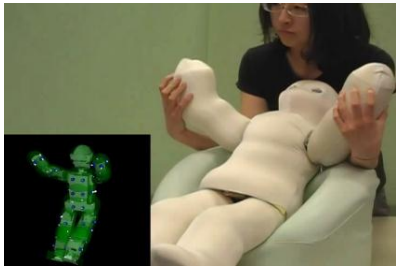


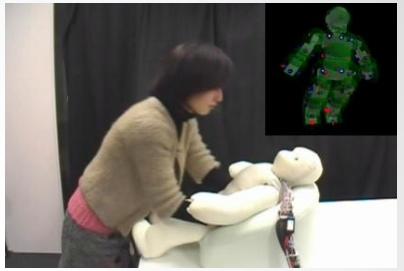
macra(2005-)



macket(2008-)



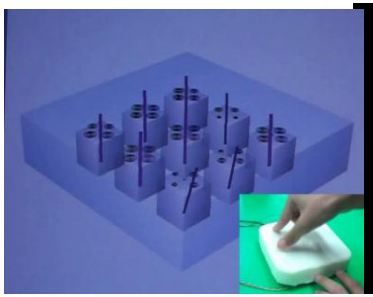
**Human robot interaction with self interference**



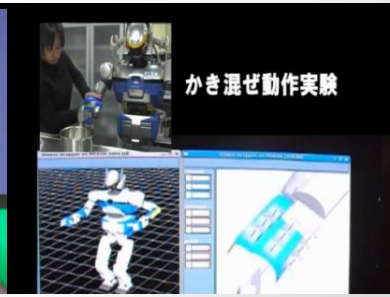
**Simultaneous detection of flesh deformation and shock by human patting**

**Whole-body interaction by deformation sensor**

**Interaction experiments at an international exhibition**



**Add-on type 3D deformation sensor**




**Partial soft flesh for life-size humanoid**

# Material and method for constructing whole-body sensor flesh

Requirements for materials and methods :

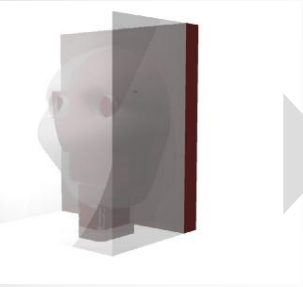
- Possible to make exterior thick enough to place various elements inside exterior
- Light enough even if it is thick
- Repeatability of the shape when constructed
- Repeatability of the shape after constructed

  ⇒ Retention ability to original shape
- Possible to prototype exterior

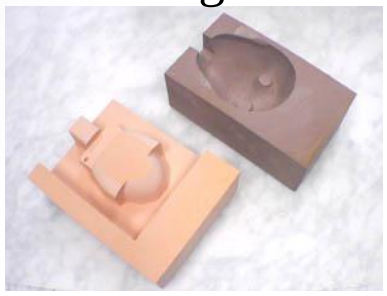
Soft polyurethane foam by molding method

# Molding method

Design of a mold



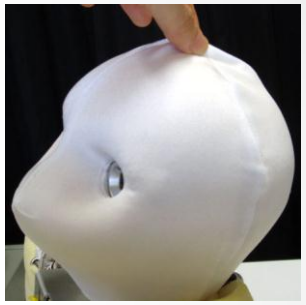
Making a mold by cutting a resin



Molding polyurethane foam

After combining two liquids at room temperature, it becomes hardened in 3 minutes

Finishing surface



- It is hard to get polyurethane foam with appropriate hardness
  → Hardness is adjusted by mixing ratio of two liquids
  - Hardness near human's relaxed thigh（About ASKER CSC2 15）
- Durability of a surface is not good unless it is created by metal mold
  → covering a surface with stretchable cloth

# A humanoid with sensor flesh embedded with deeply-placed 3-axis force sensors

- macra(2005～)

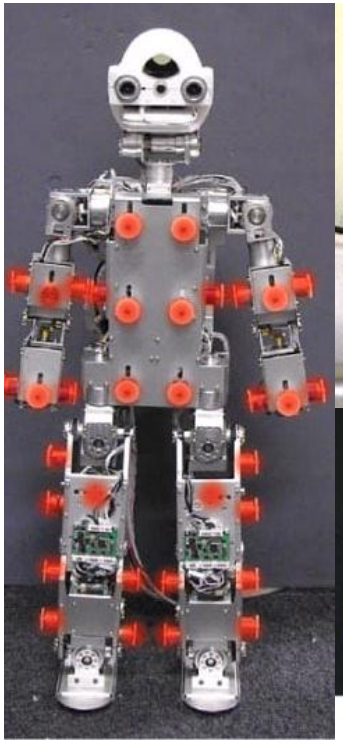
49 3-axis force-torque sensors are embedded on red points

⇒ 147 dimension vector for sensor

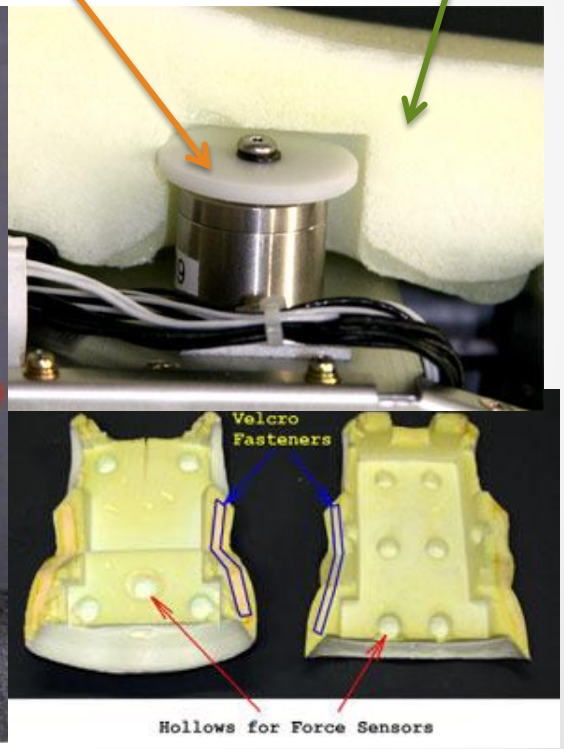
Height : ~700mm

Weight : ~7kg

DOF : 22



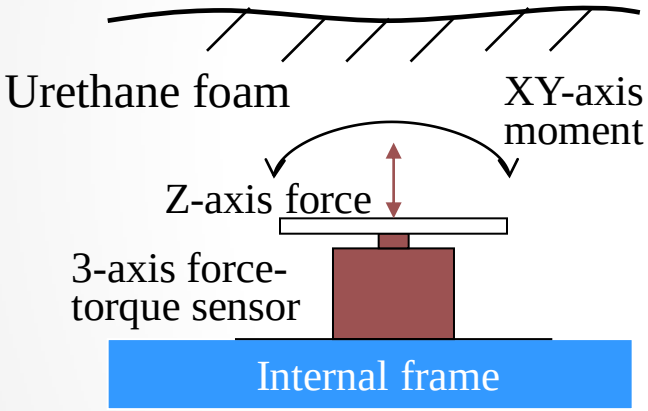
Internal frame




Torso exterior

# Multi-axis tactile sensor deeply-placed in a flesh

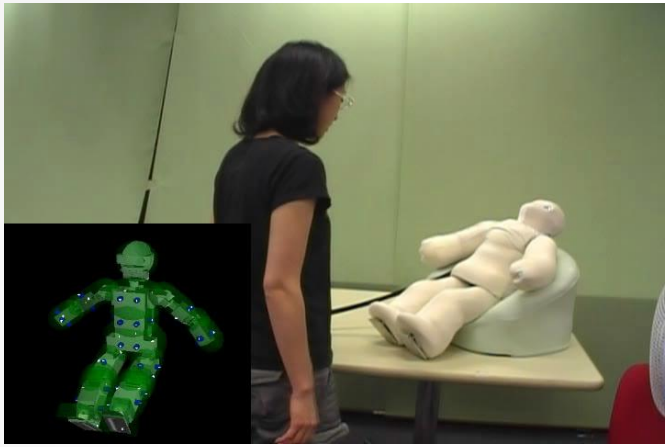
- Embedding Multi-axis force-torque sensor inside thick urethane exterior



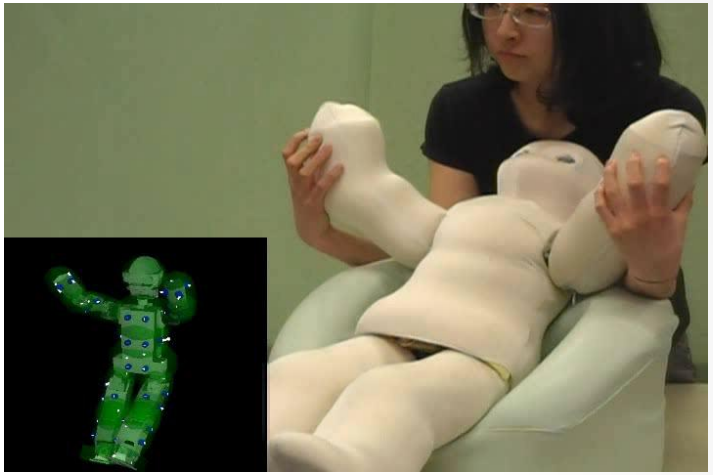

Not only pushing motion, but also holding up motion caused by resultant force of normal and sheer direction can be detected.

# Contact behavior of macra with humans or environments

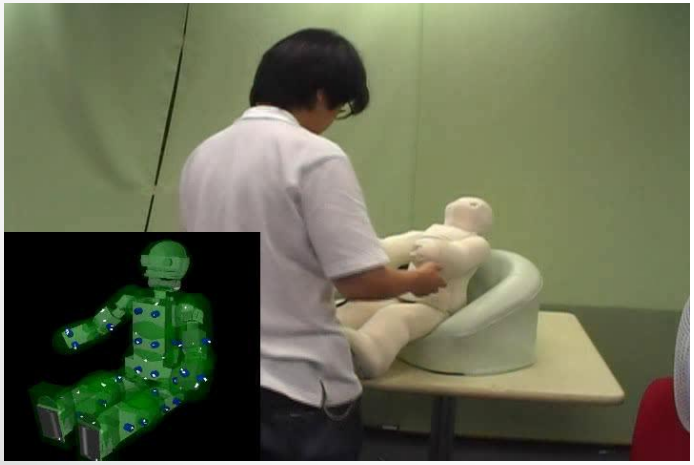
Holding up



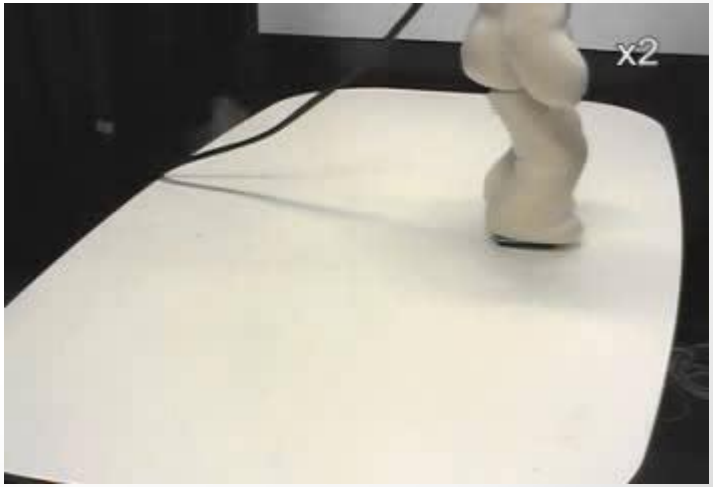
Self interference



Pushing & Pulling

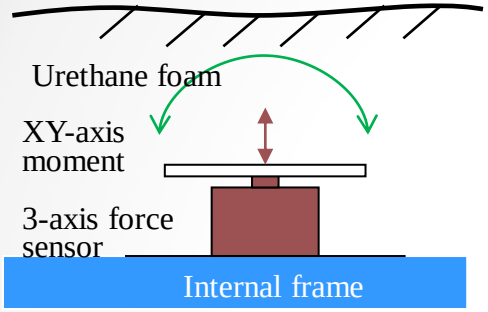


Falling down & rolling over

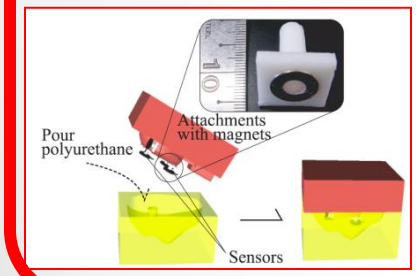


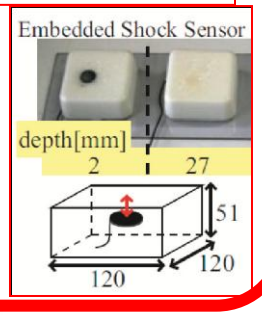
# Research on ‘sensor flesh’ in JSK Lab

**Deeply-placed 3-axis force sensor which is fixed to frame**

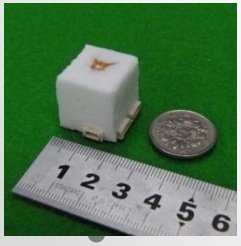


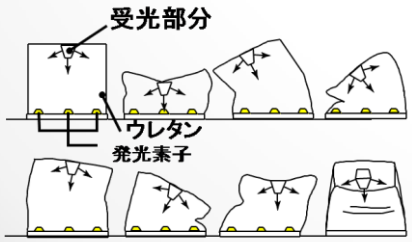

**3D arrangement of sensor elements by monolithic molding**

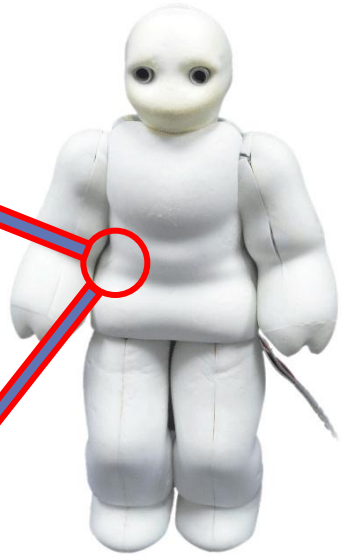


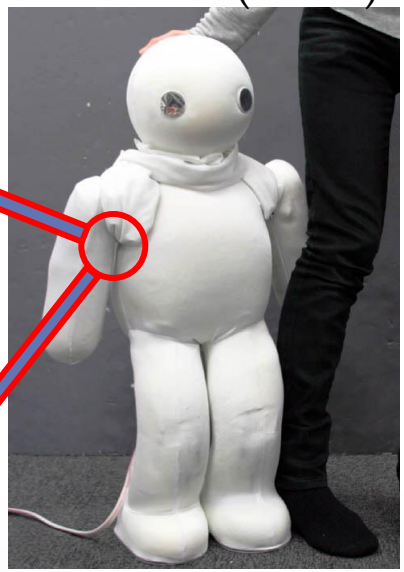

**Soft 3D deformation sensor**



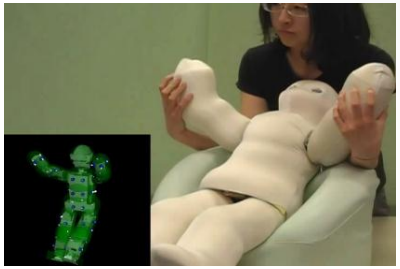


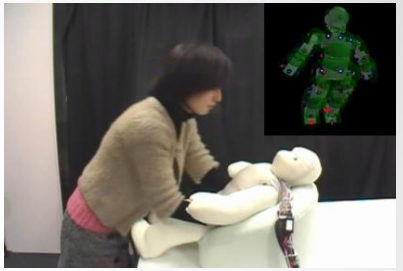
macra(2005-)



macket(2008-)



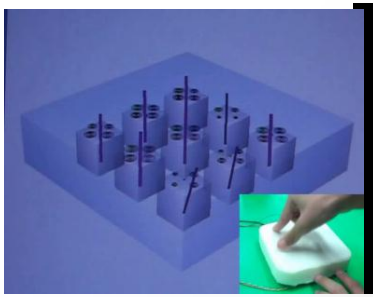
**Human robot interaction with self interference**



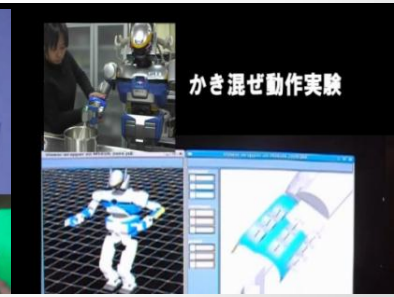
**Simultaneous detection of flesh deformation and shock by human patting**

**Whole-body interaction by deformation sensor**

**Interaction experiments at an international exhibition**

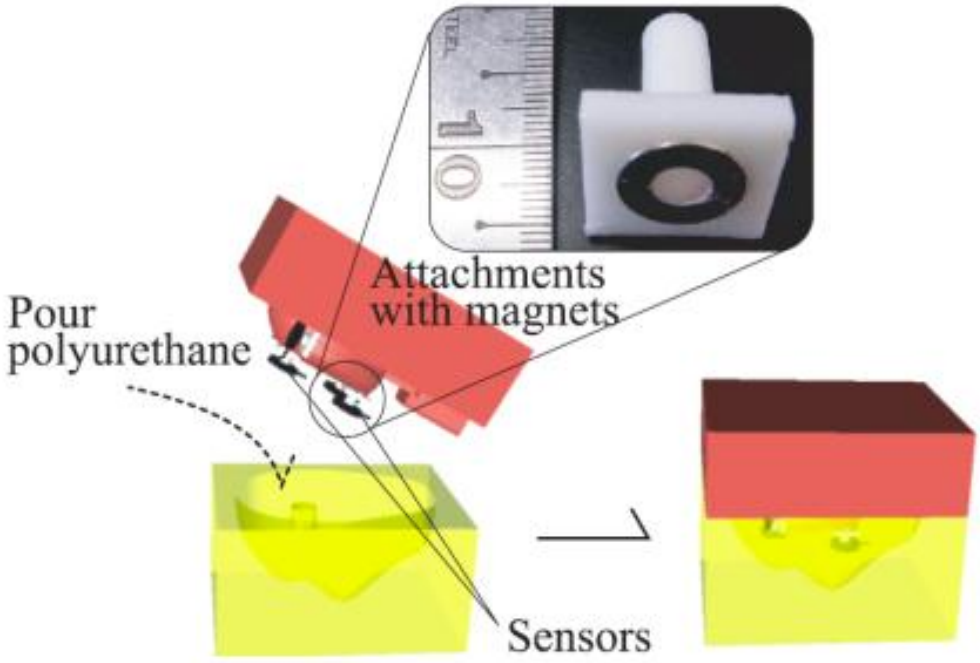


**Add-on type 3D deformation sensor**

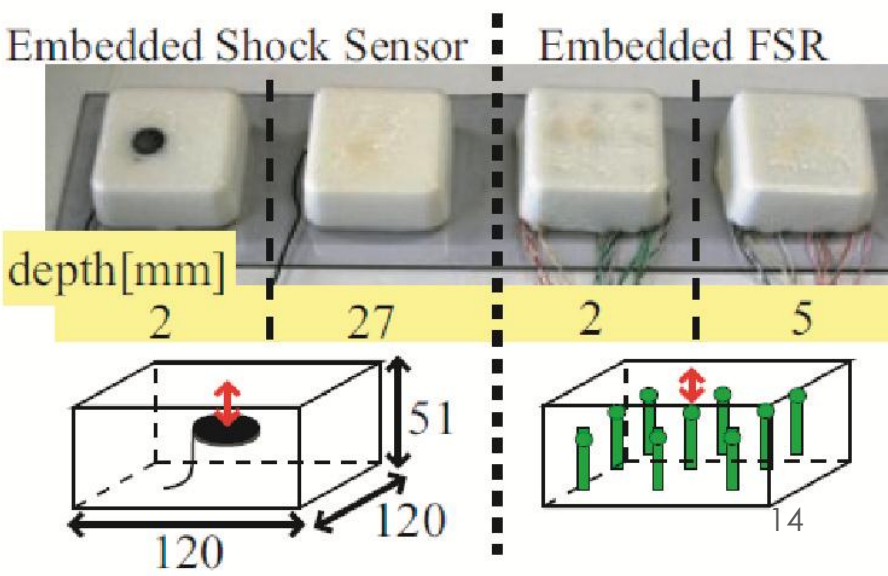



**Partial soft flesh for life-size humanoid**

# 3D arrangement of sensor elements by monolithic molding



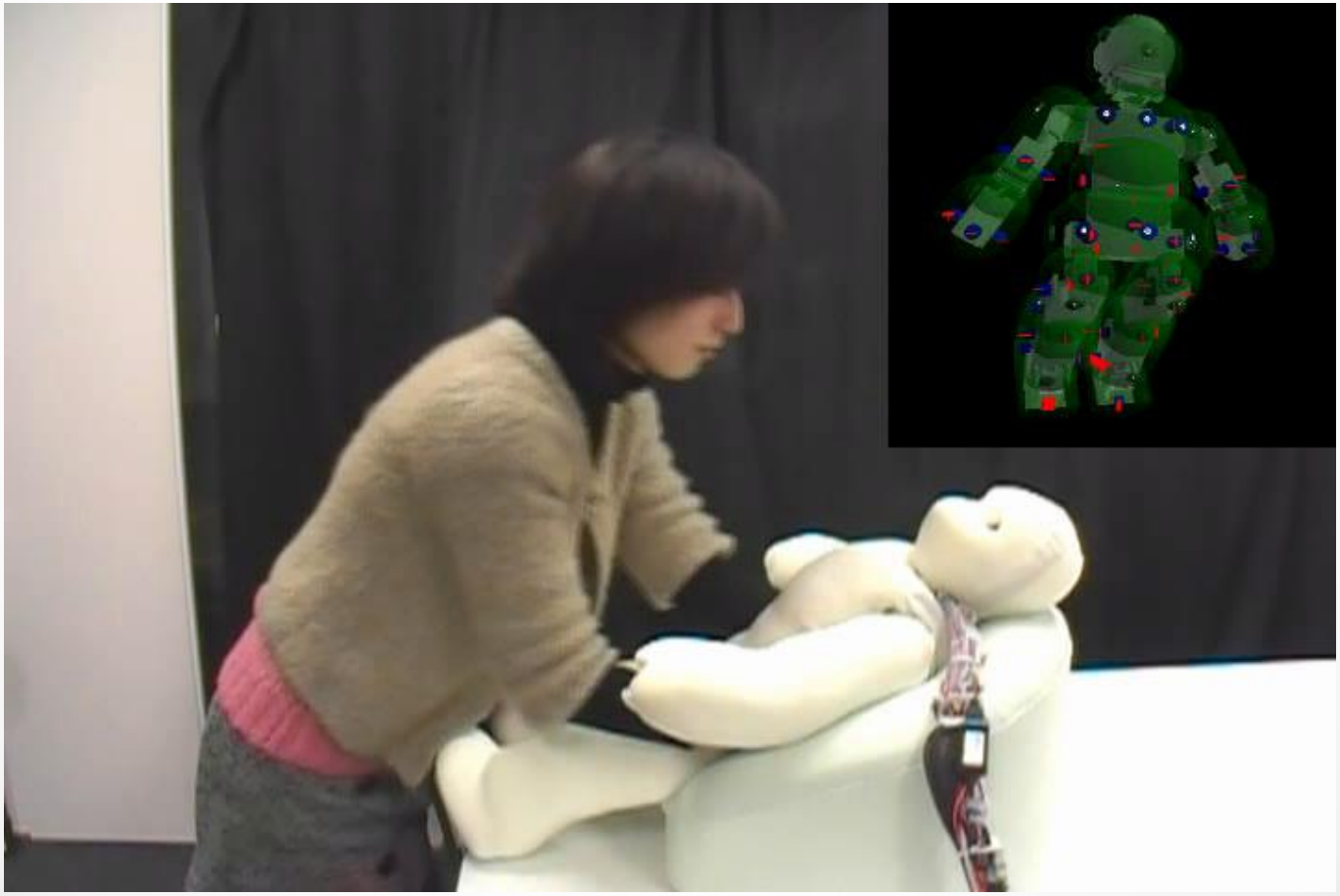

3D arrangement of sensors is possible by a combination of deeply-placed multi-axis sensors and monolithic molded sensors.




By arranging sensor elements with plastic attachments fixed to an inside surface of a mold, they are molded in the flesh.

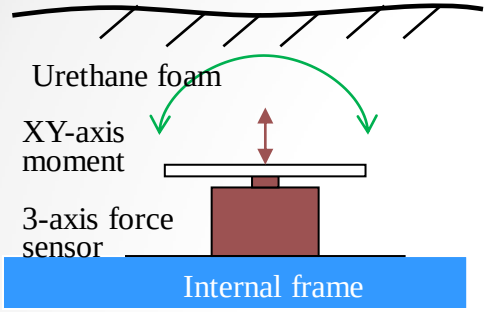
# Simultaneous detection of flesh deformation and shock by human patting

- Shock sensors are embedded inside macra's exterior by monolithic molding

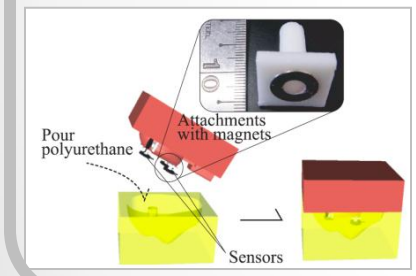


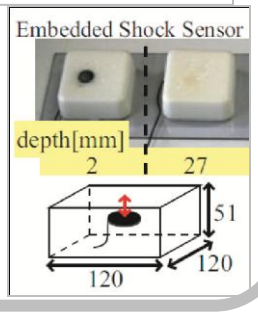
# Research on ‘sensor flesh’ in JSK Lab

**Deeply-placed 3-axis force sensor which is fixed to frame**

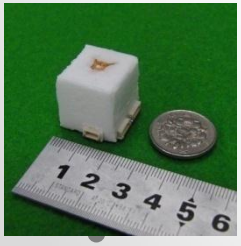


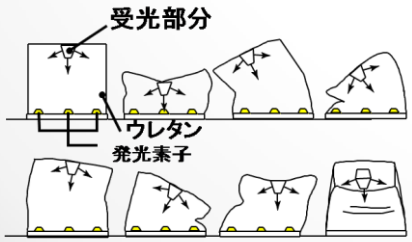

**3D arrangement of sensor elements by monolithic molding**

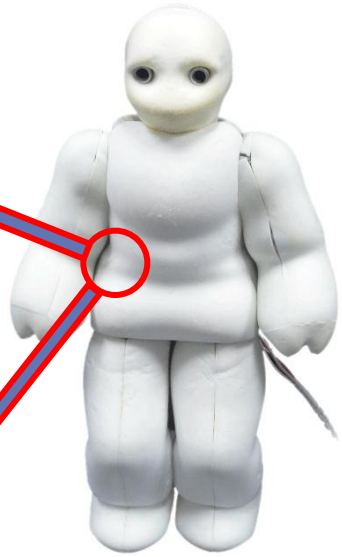


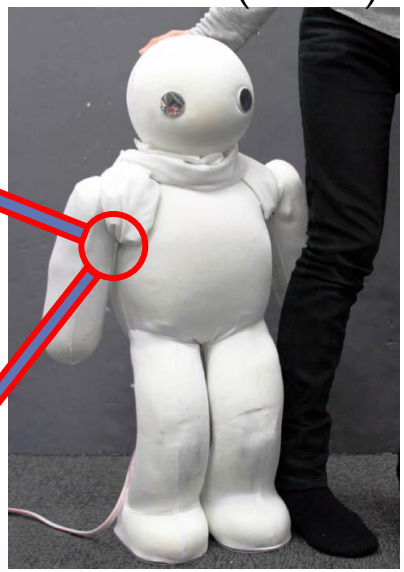

**Soft 3D deformation sensor**



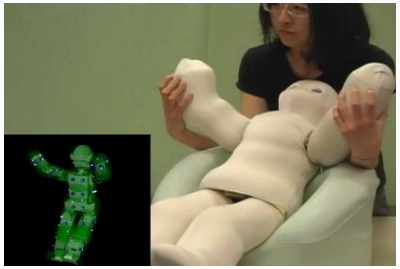


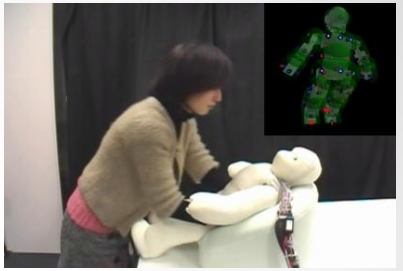
macra(2005-)



macket(2008-)



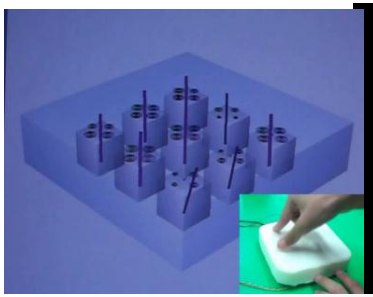
**Human robot interaction with self interference**



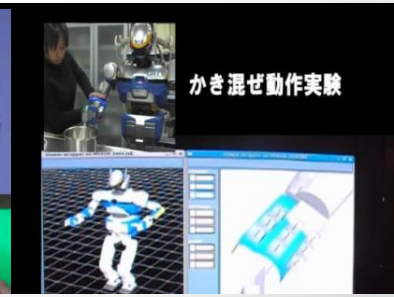
**Simultaneous detection of flesh deformation and shock by human patting**

**Whole-body interaction by deformation sensor**

**Interaction experiments at an international exhibition**

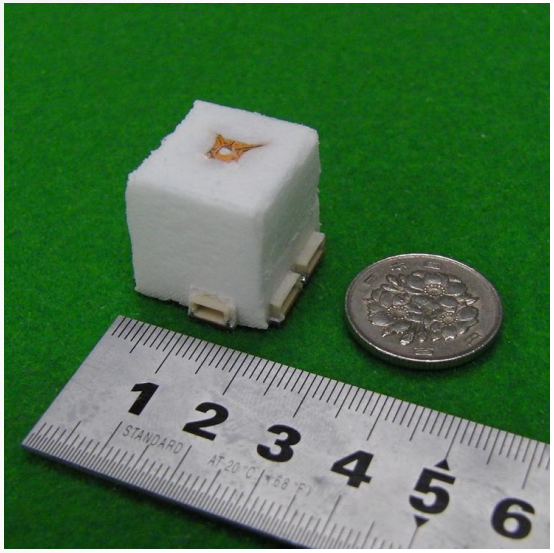


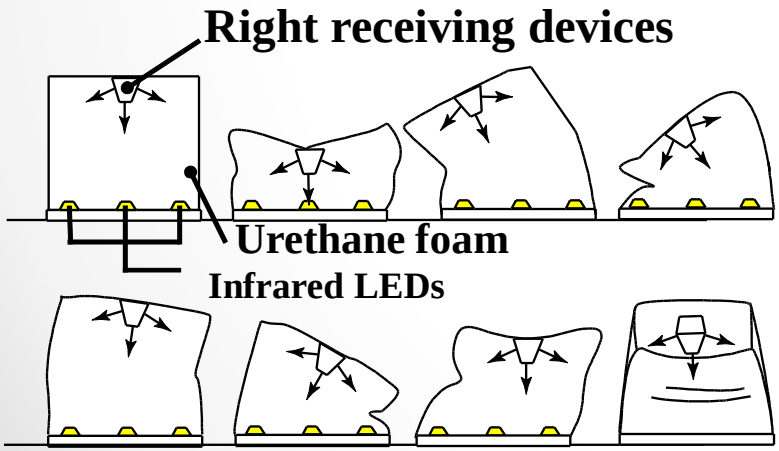
**Add-on type 3D deformation sensor**



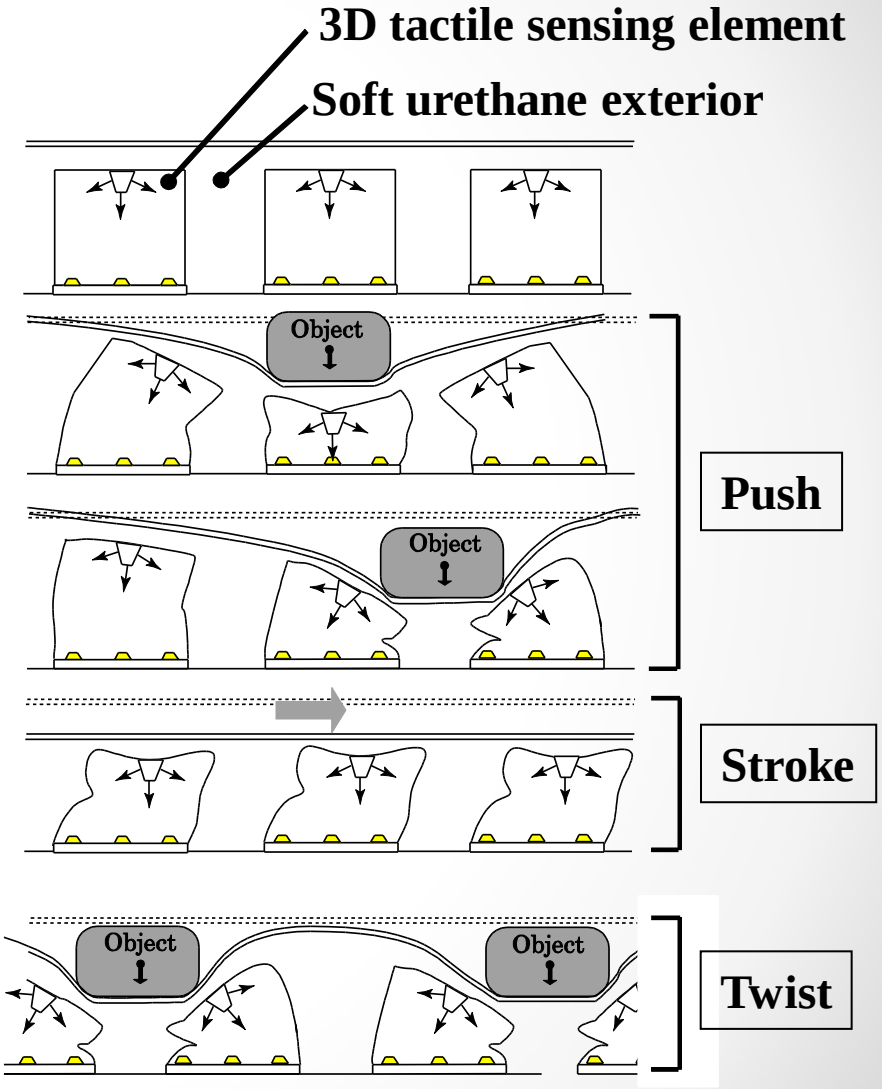

**Partial soft flesh for life-size humanoid**

# Soft 3D deformation sensor



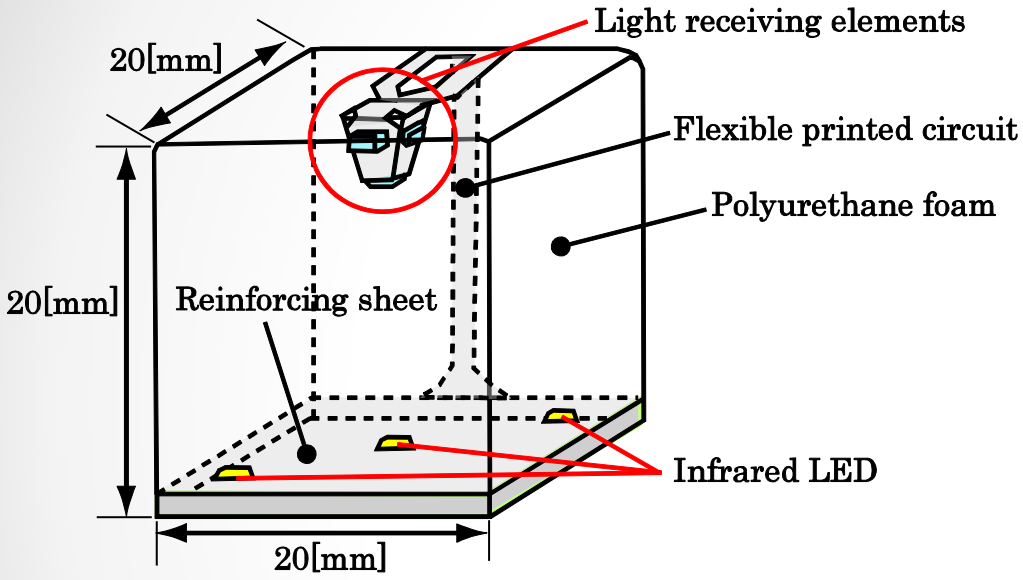



Deformation of sensing element




Deformation of soft sensor exterior

# Features of soft 3D deformation sensor




- Detecting multi-axis deformation
- Soft contacts against environment
- Keeping softness of the exterior embedded with many elements
- Strong against heat accumulation
- Interpolating function when some of them are embedded in the foam

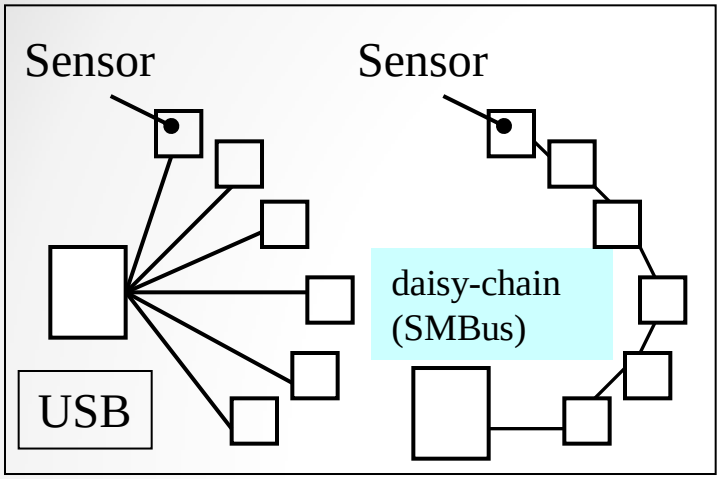
It should be soft enough
to detect 3D deformation

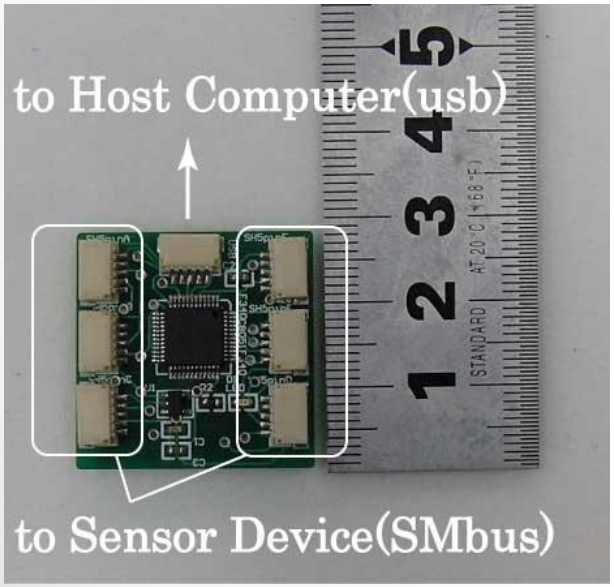
Flexible printed circuit is embedded inside of the urethane foam

Now it is commercially available from Touchence Inc.

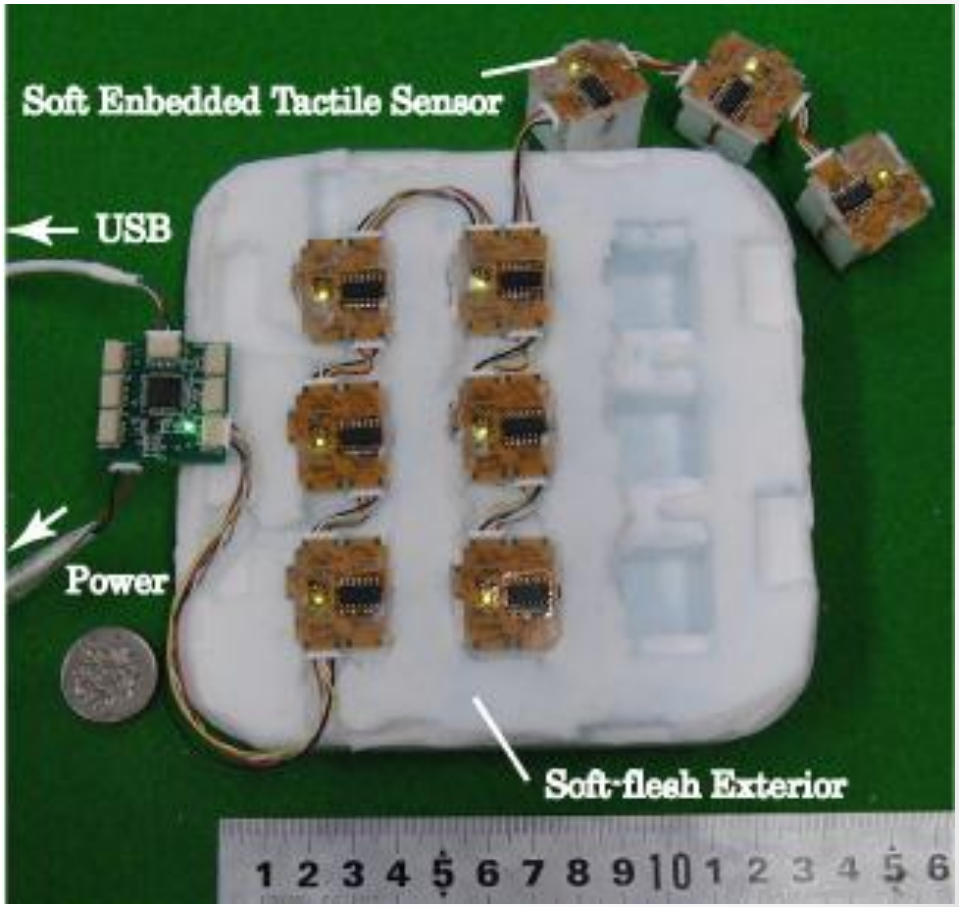
- http://touchence.jp/en/cube/index.html

# Development of sensor exterior prototype



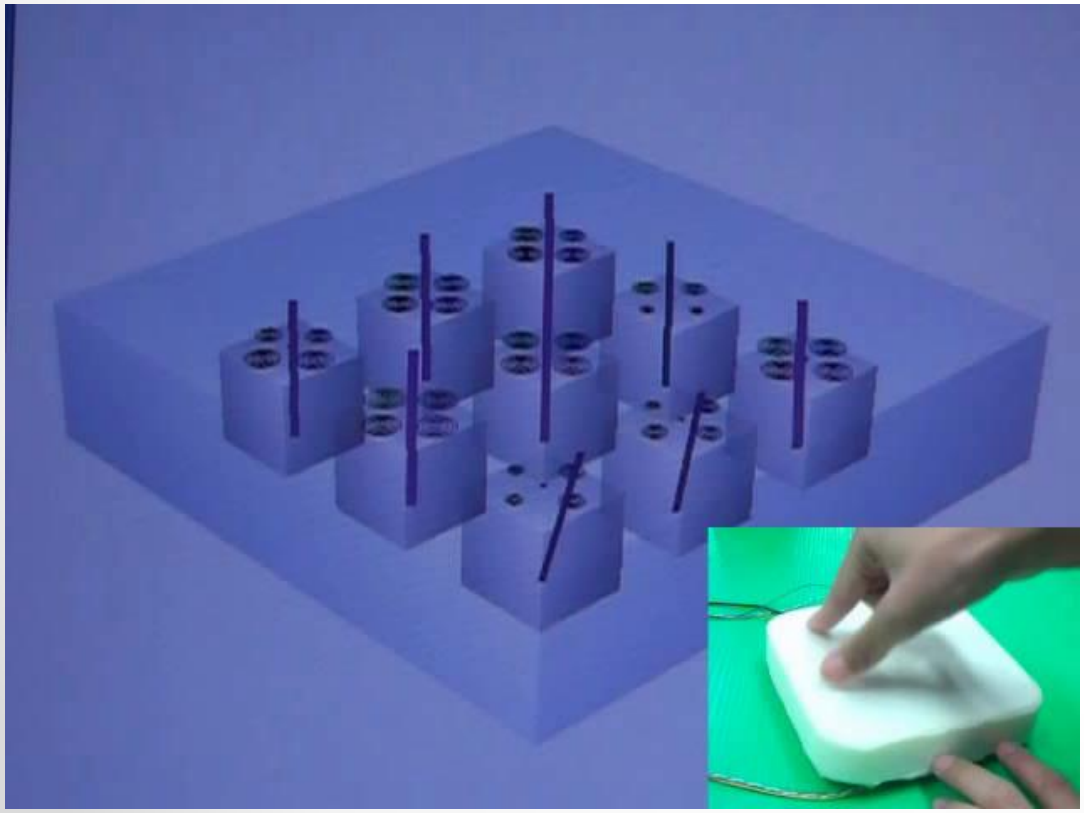

Reducing wires by adopting SMBus protocol

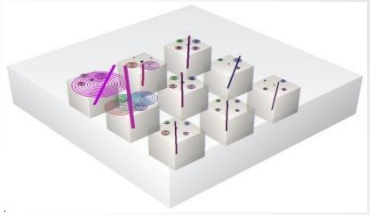



Prototype of soft sensor exterior

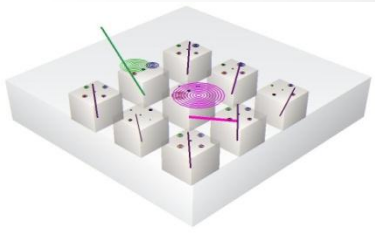
# 3D deformation of the sensor exterior prototype

- Bar is inclined to the deformed direction
- Radius of circles are changed according to the strength of the received light

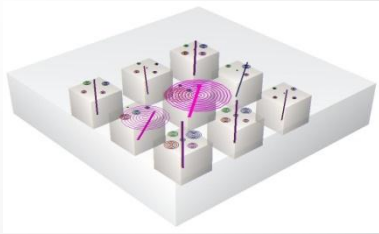




**Push**



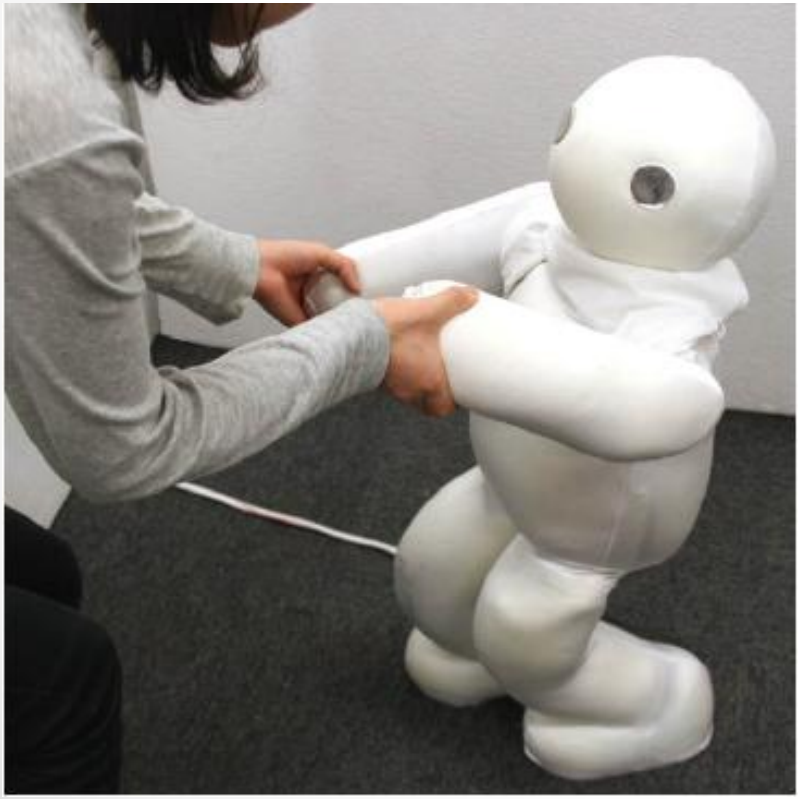
**Twist**

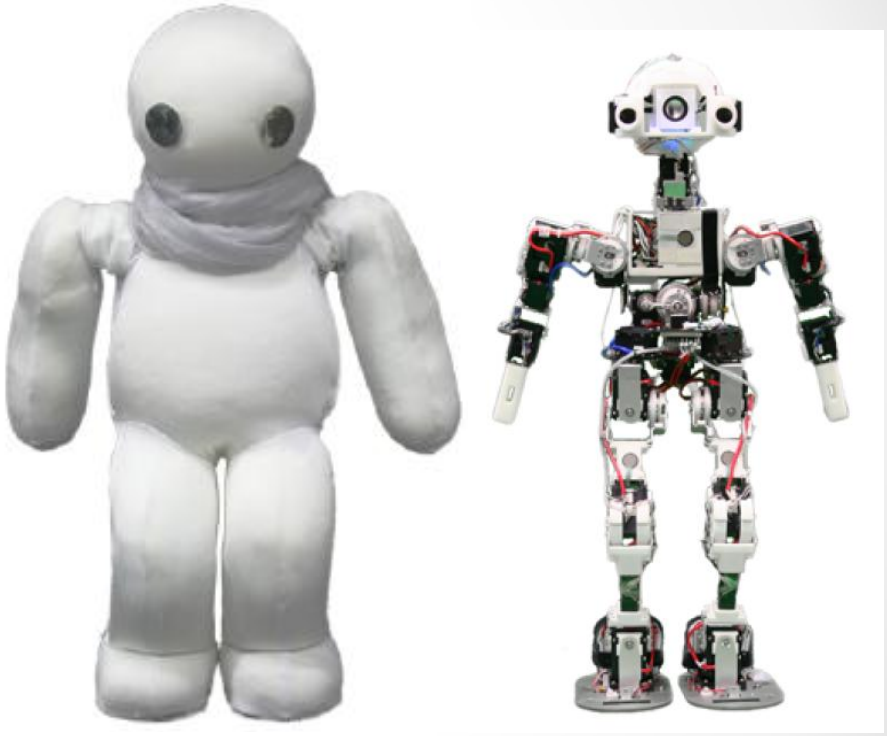


**Stroke**

# A humanoid with distributed soft 3D deformation sensors

- macket(2008～)





Height : ~800mm

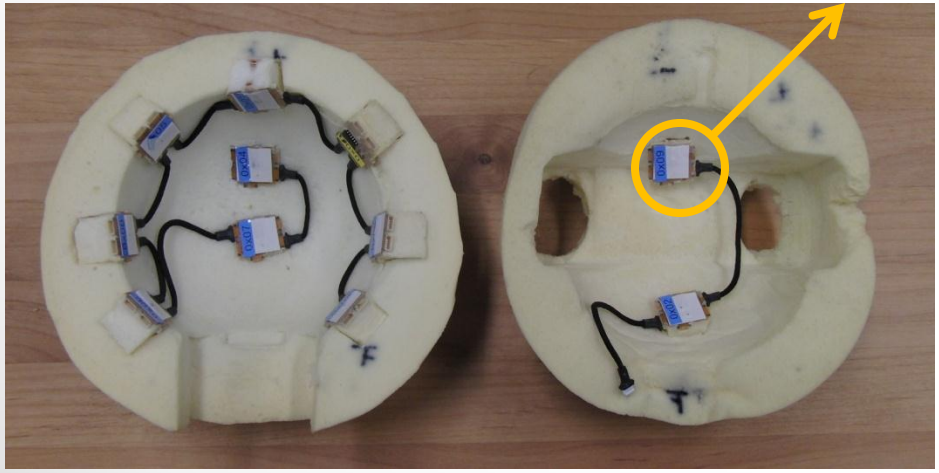
Weight : ~7kg

DOF : 26

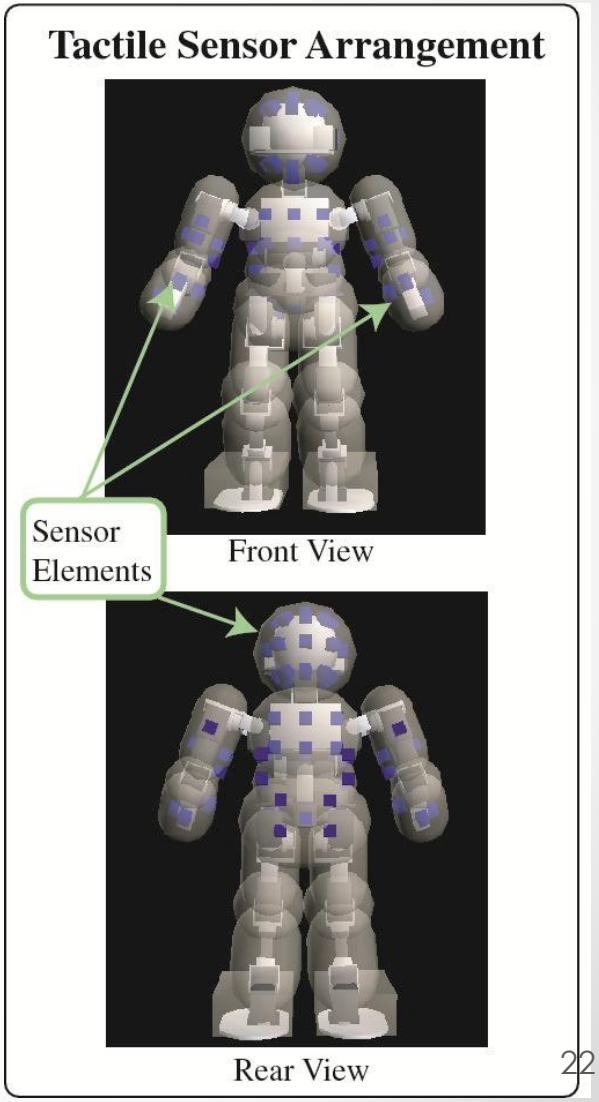
# Arrangement of soft 3D deformation sensor in macket

- 48 sensors for upper body
  - 11 (Head)
  - 10 (Chest・Stomach)
  - 7 (Back)
  - 10 (Each arm)

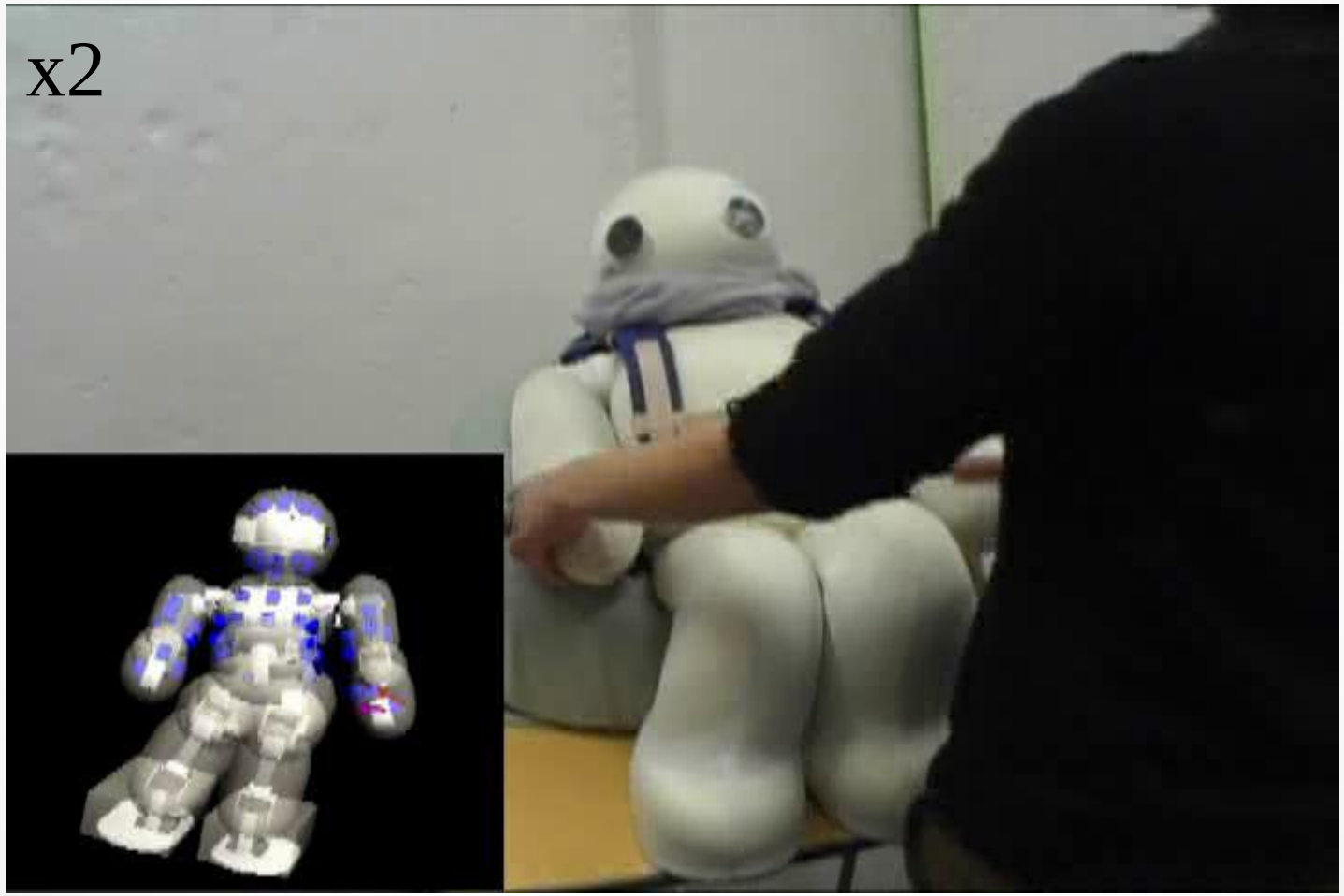
Soft 3D deformation sensor



- Arrangement of the sensors in head exterior

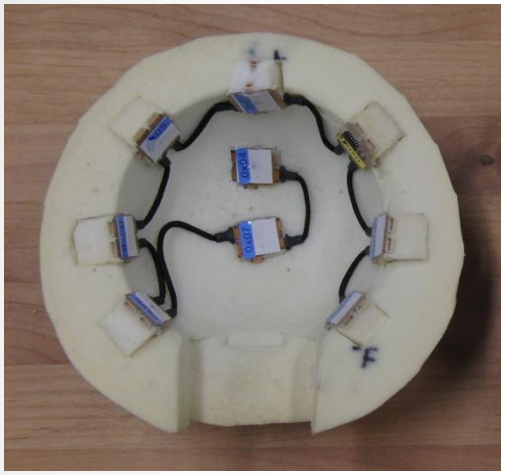


# Online sensor view for macket during close interaction

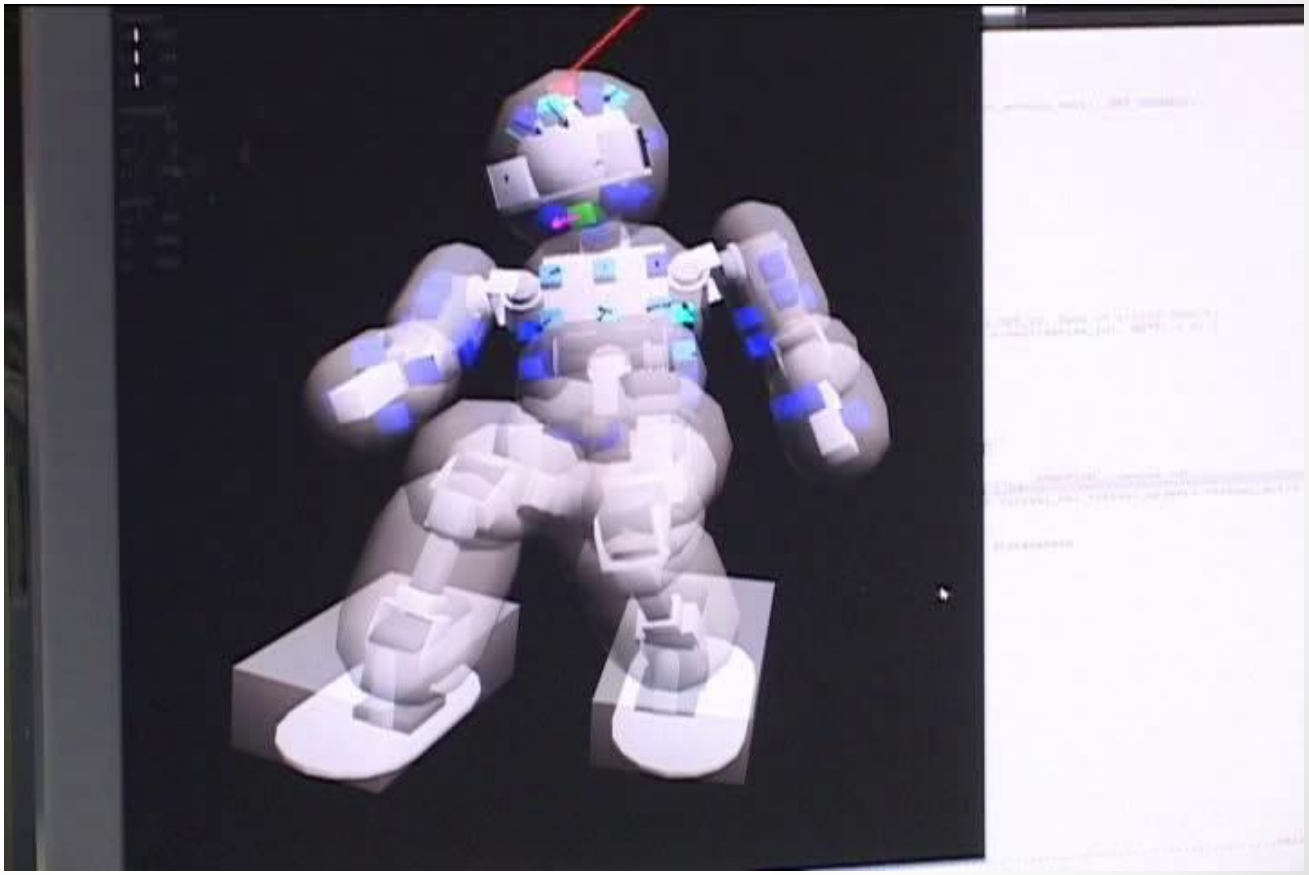



Replayed by X2 speed, Sensor sampling speed is 25[Hz]

# Signal wires are also embedded inside flesh



Signal wires should deform to some extent when urethane exterior is deformed.

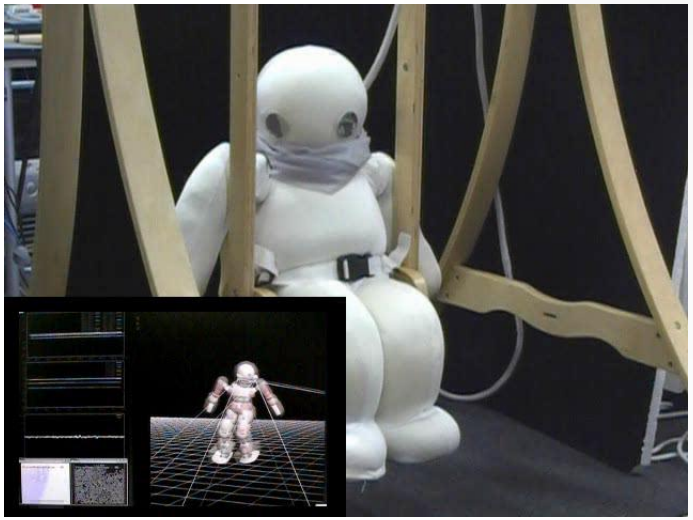


Stretchable signal wires are used inside flesh (ROBODEN, Asahi Kasei Fibers corporation)

# Various contact behavior with environments

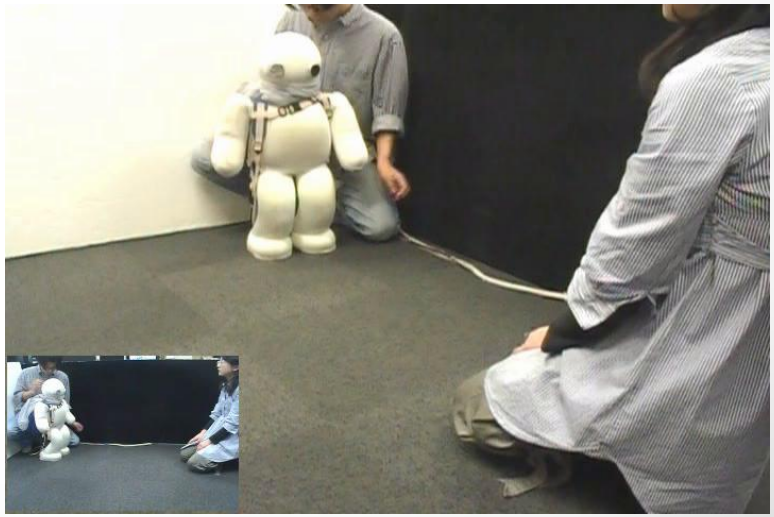
Acquired rolling over motion by GA x3

Swinging motion using accelerometer x3



Dynamic walk

Tactile sensor triggered scenario based behavior



# Close interaction with humans using macket

Tactile sensor triggered hug motoin with a child

Open experiment at International exhibition (ARS Electronica 2008), many visitors tries to hug a robot.

# Summary

- Soft sensor flesh, not sensor skin
  - Combination of thick urethane exterior and embedded multi-axis tactile sensors
  - Exterior with enough thickness to contain various devices inside it
  - Sensors and cables themselves should be soft
- Various contact behavior by humanoid robots with sensor flesh
  - Using macra and macket, feasibility is confirmed.
- Next Step for a sensor flesh
  - Distributed hardness of a flesh(ROBIO2011)
  - Developing soft and small multi-axis deformation sensor with twisting sensation(Humanoids2011)
  - Online tactile sensor information summarizing(ROBIO2011)
  - Applying whole-body sensor flesh to Life-size Humanoid
  - Active shape deformation of a flesh