Challenge to Design and Control of more Humanlike Tendon-Driven Musculoskeletal Humaonids

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Outline

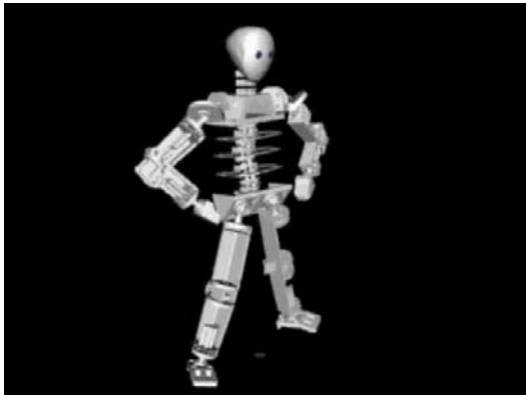
- <u>Our motivation and basic approach</u>
- History of our developed tendon-driven robots
- Summary and Recent works

My research's motivation:
Flexible and powerful motions like humans

- Human body structures :
  - a spine structure, multi-DOFs, driven by redundant muscles

→ They are important in natural fullbody motions in sports.

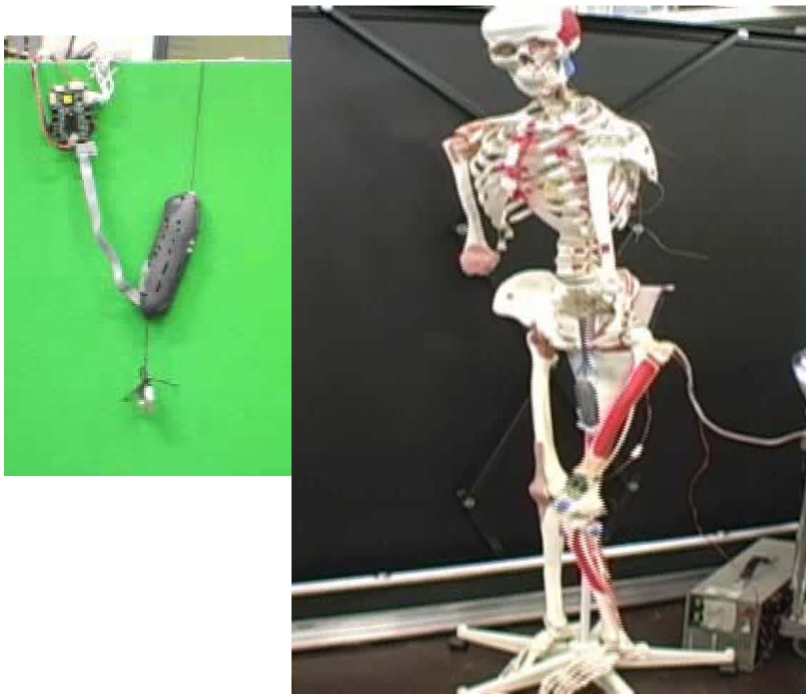
  - For example, pitching motion of a baseball player

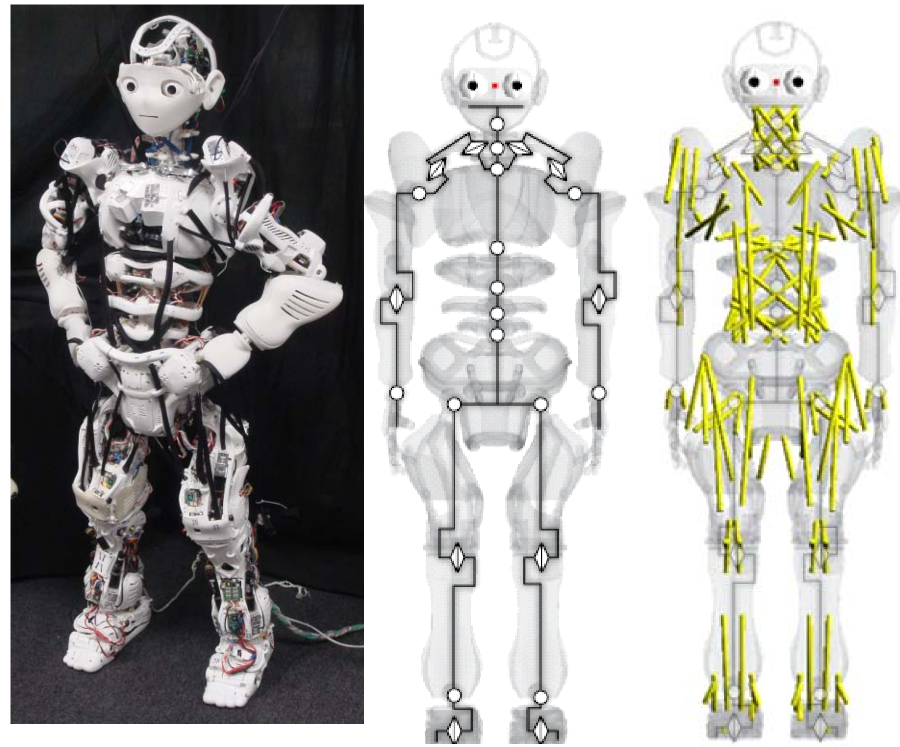


- Our interest:
  - How to develop more humanlike humanoids?
  - How to manage such a complicated body?

Flexible and powerful motion!

Our design approach:
tendon-driven musculoskeletal humanoids





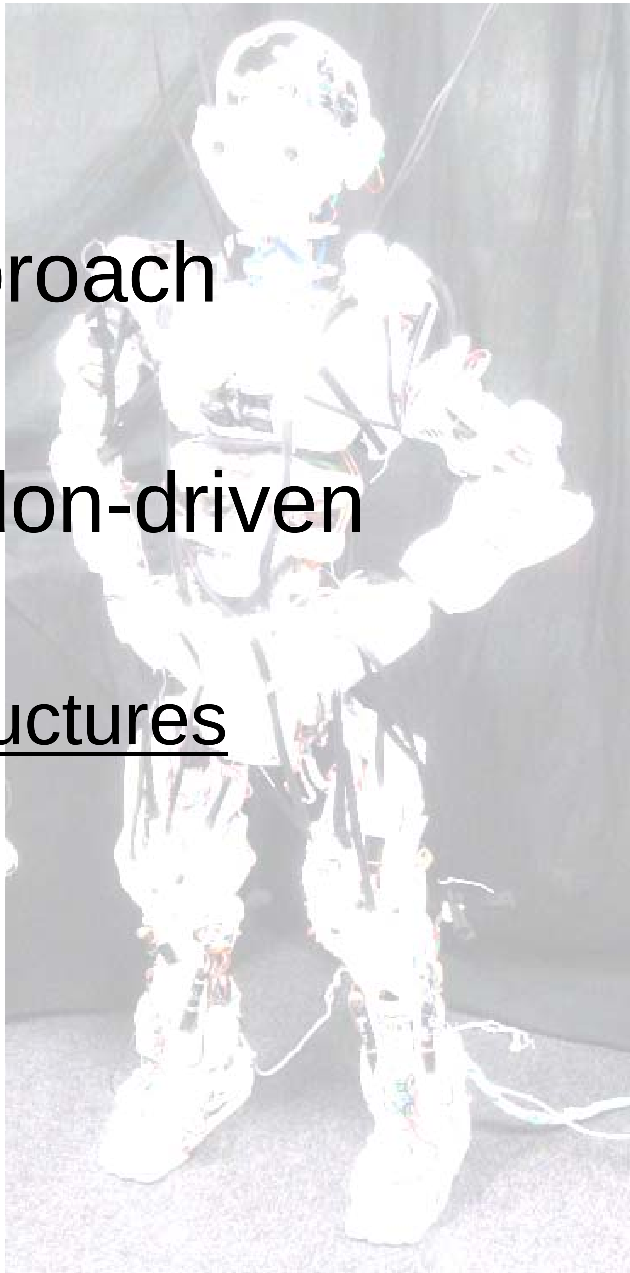
Joint structure can be simplified

-> more joints(DOFs), more sensor, more actuator!

Passive bone structure and tendon modules

Outline

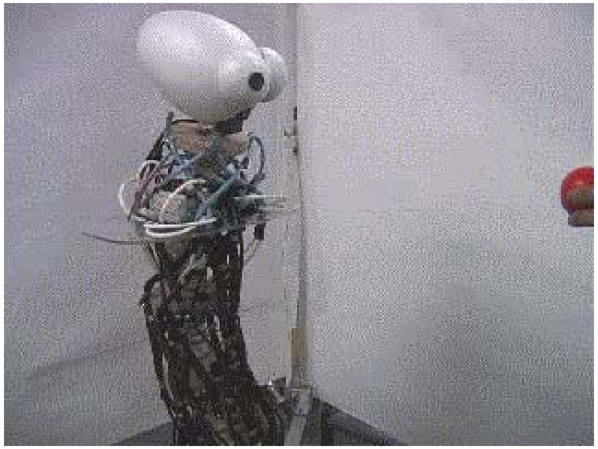
- Our motivation and basic approach
- History of our developed tendon-driven robots
  - Development of robot body structures
  - Control strategy of our robots
- Summary and Recent works



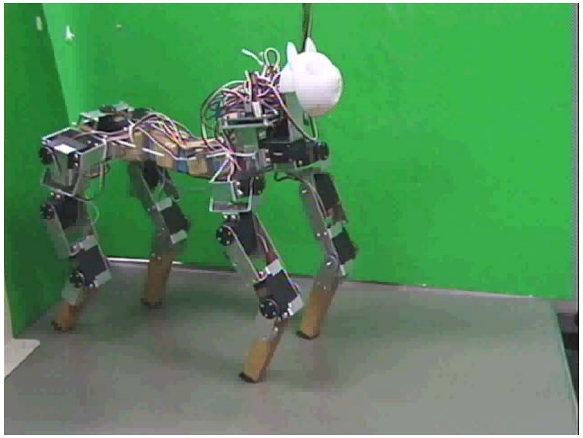
Small robots with spines

(1999、2000, Mizuuchi et.al)

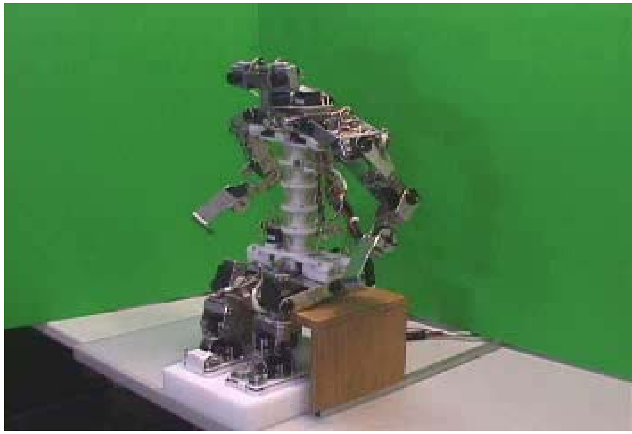
- Prototype spined and tendon-driven robot



Spine robot “Bebe”



Spine 4 legged robot “SQ43”

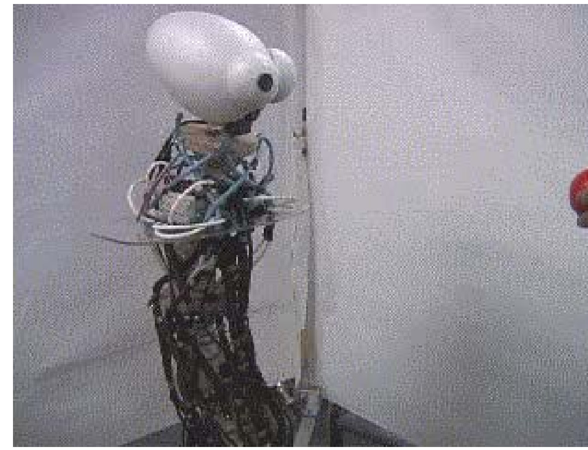


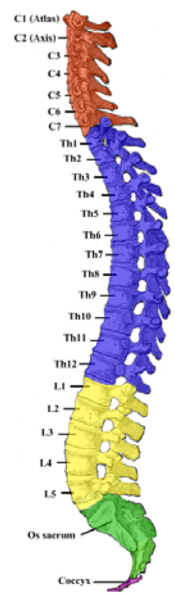
Spine small humanoid “Cla

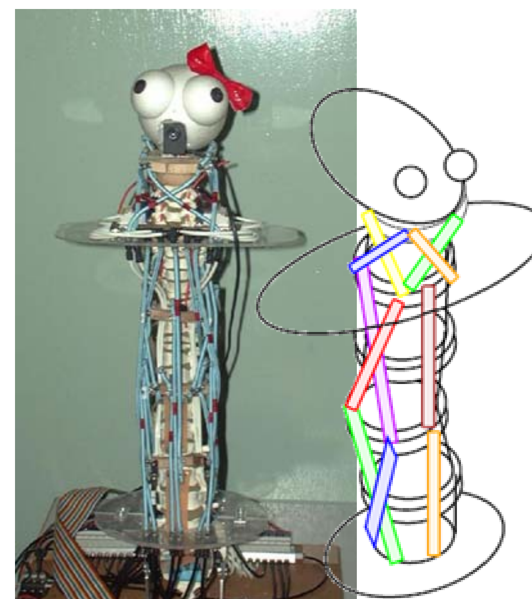
Spine robot BeBe

- <u>Imitation of human detail spine</u>
  - Using medical spine model with 24 vartebrae
  - Using 36 pneumatic actuators
    - Control only valve ON/OFF switching
  - CCD camera on head

- As simple platform for vision based motion learning with redundant DOFs and many actuators



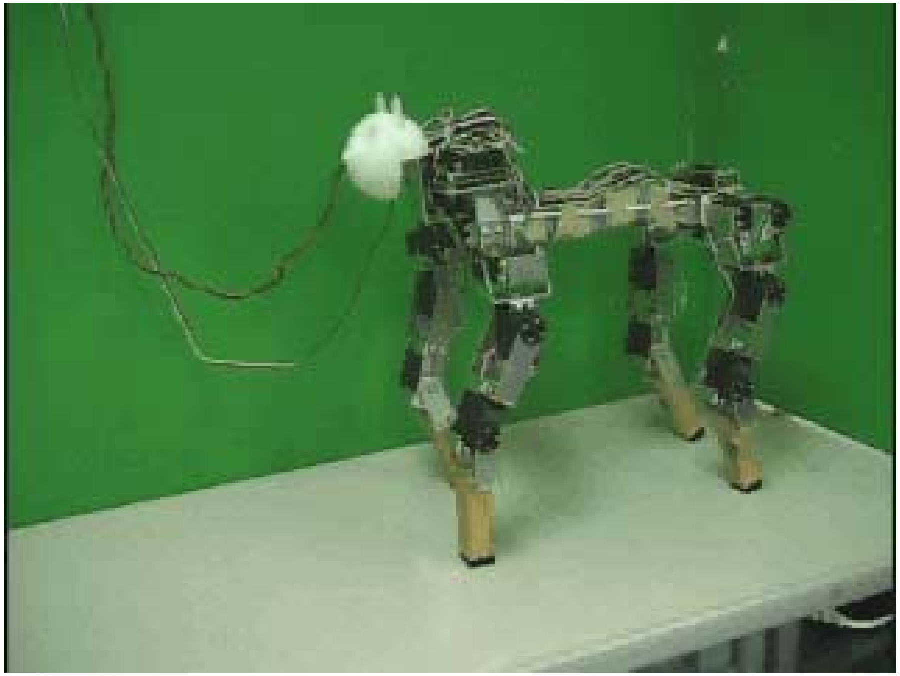


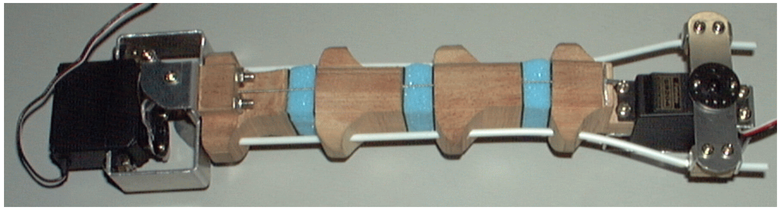


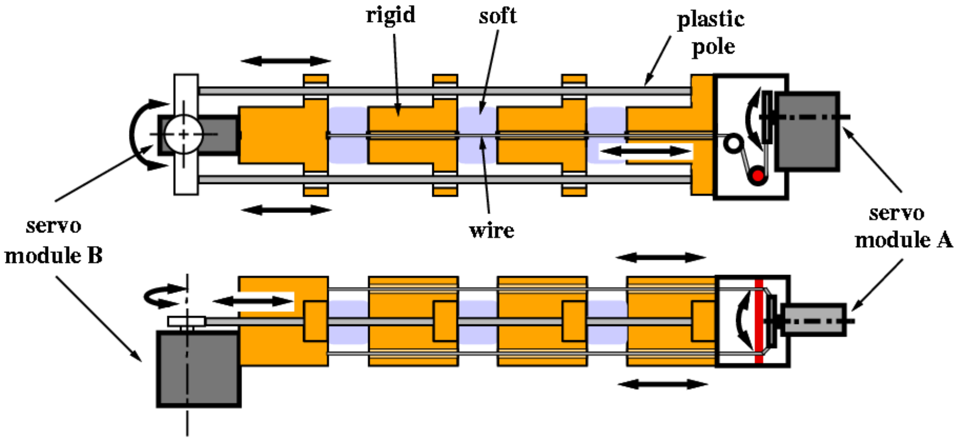
Human spine structure (24 vartebrae)

4 legged robot SQ43 with flexible spine

- <u>Focus on spine's flexibility</u>
  - Evaluation of influence to walking performance
  - 2 actuators for bending spine
  - Passive joint to twist its spine
  - No stiffness adjustment actuator (stiffness is constant)



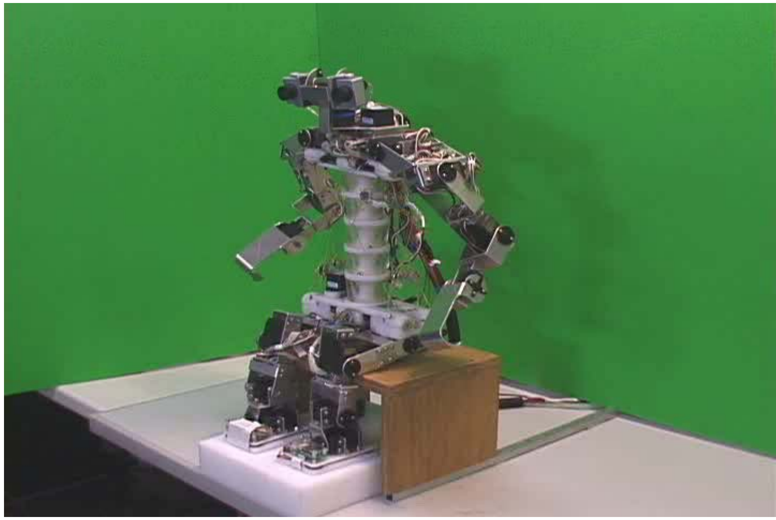


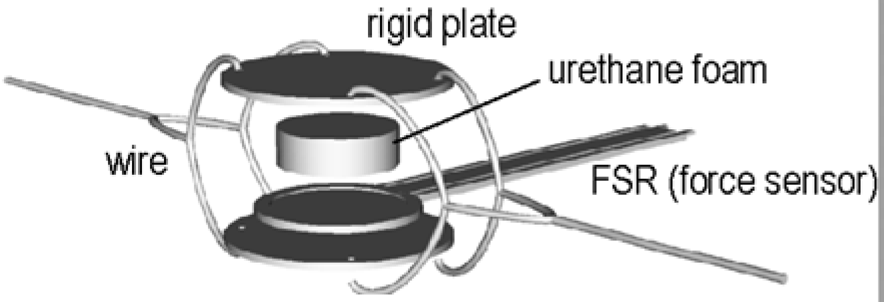


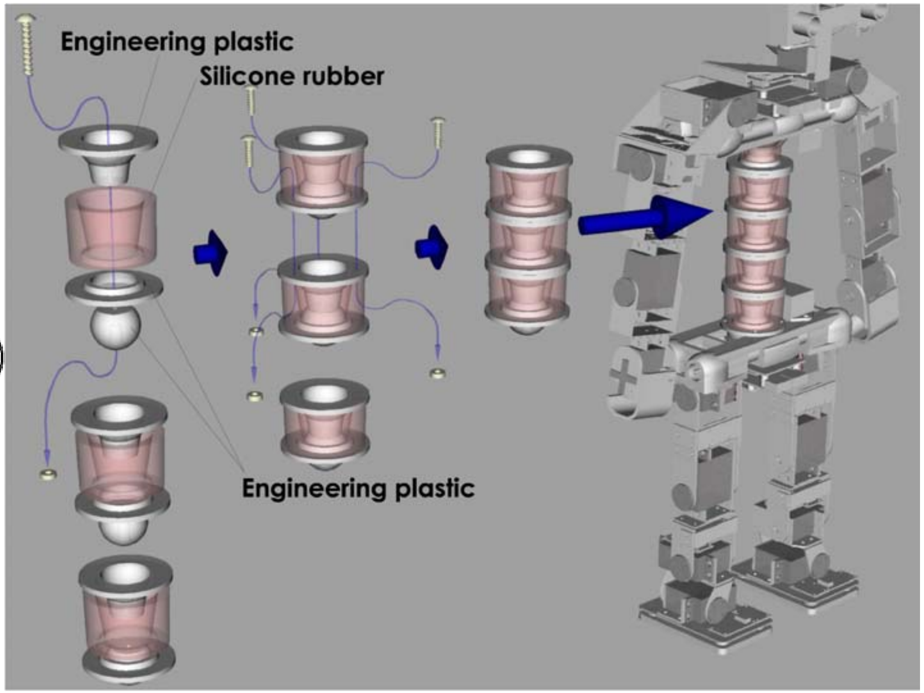
Small spine robot Cla

Cla's spine structure

- 5 spherical joint by 8 tendons
- Each tendon: force control based on sensor
  - spine stiffness control



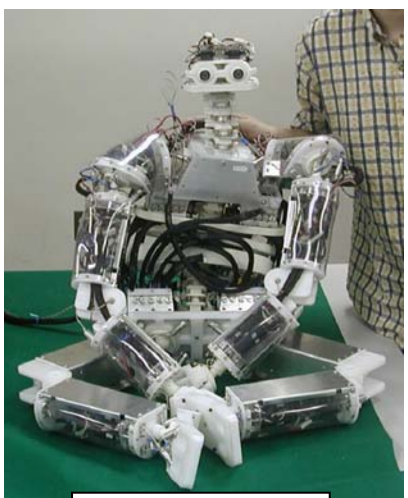




Lifesized tendon-driven humanoid (2001~)

- More complicated, more humanlike body structure
  - how to design humanlike structure
  - how to contain many components in body

Kenta(2001~)

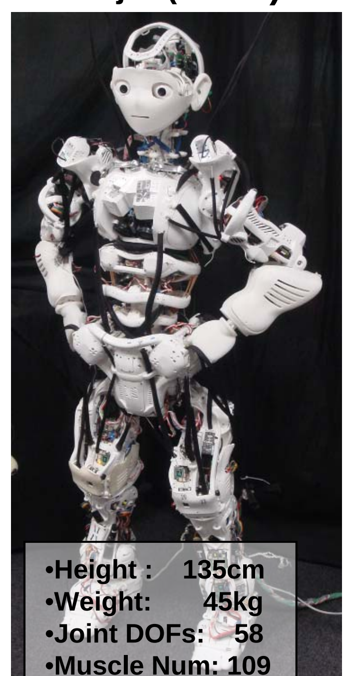


- Height : 123cm
- Weight: 19kg
- Joint DOFs: 73
- Muscle Num:94

Kotaro(2005~)

- Height : 130cm
- Weight: 20kg
- Joint DOFs: 63
- Muscle Num: 108

Kojiro(2008~)



- Height : 135cm
- Weight: 45kg
- Joint DOFs: 58
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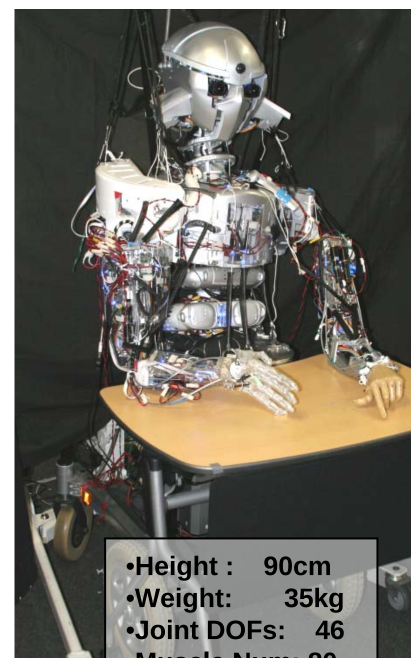
Kenzoh(2011~)

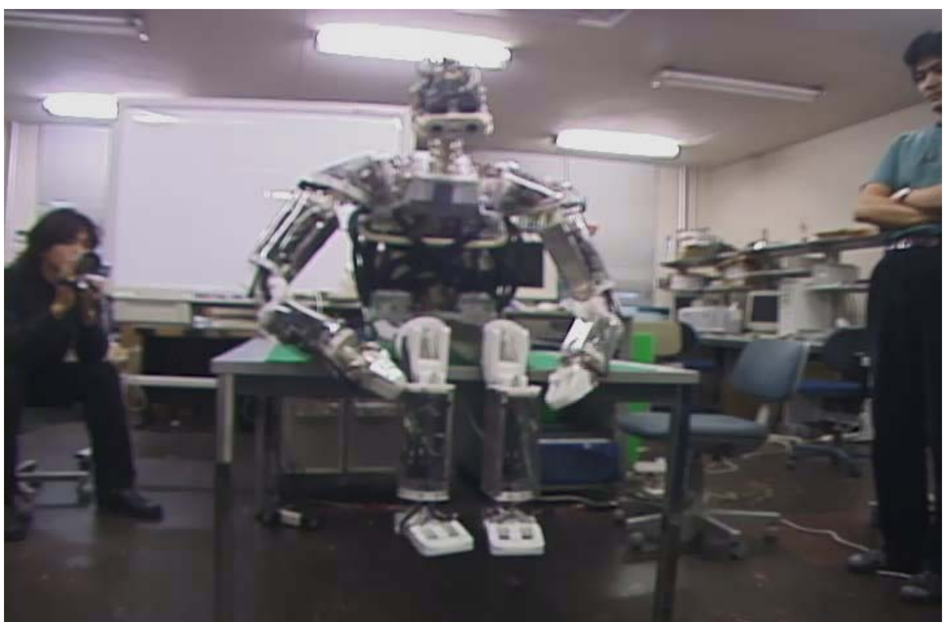


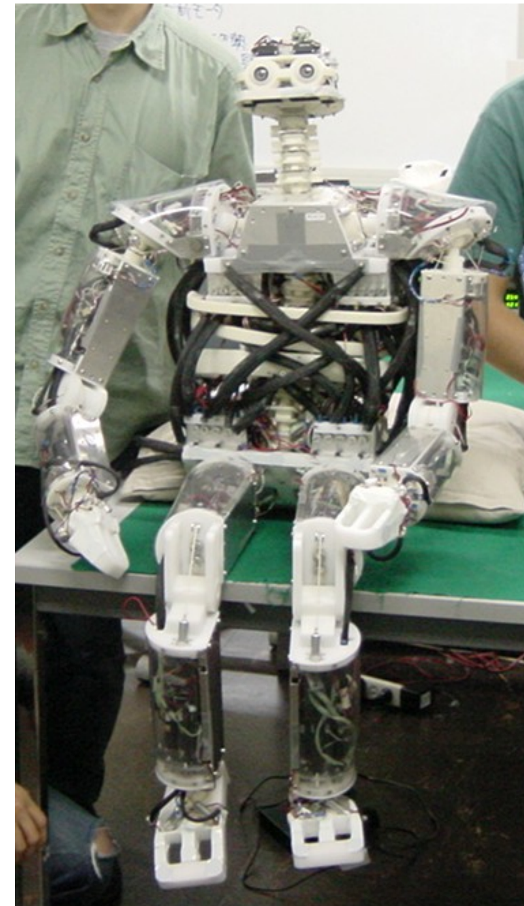
- Height : 90cm
- Weight: 35kg
- Joint DOFs: 46
- Muscle Num: 80

(only upper body)

Kenta：fullbody tendon-driven humanoid with complex spine structure (2001～)

- Complex spine structure
  - <u>10 spherical joints by 40 actuators</u>
    - winding wire by rotating pulley
  - All tendon actuators has tension sensors





- **Height : 123cm**
- **Weight: 19kg**
- **Joint DOFs: 73**
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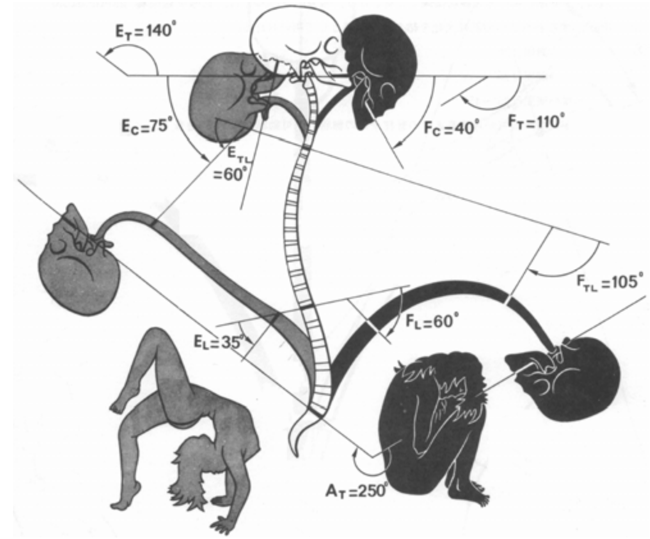
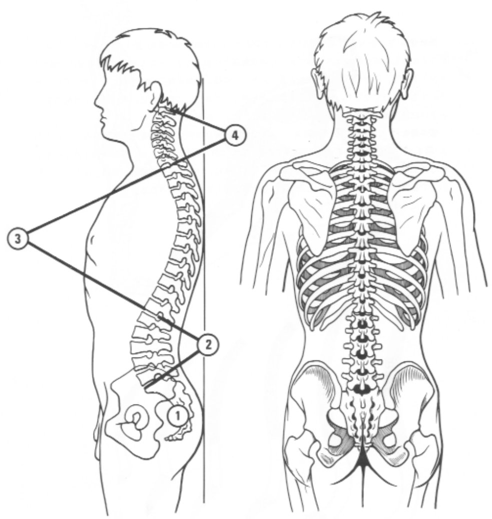
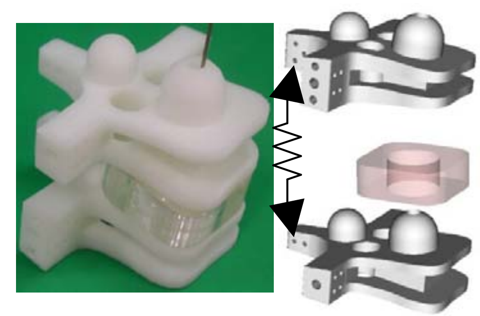
Kenta’s spine structure

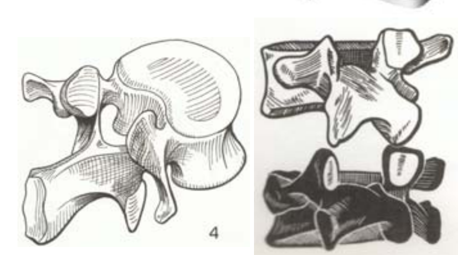
- S curve like human spine
  - Adding flexibility in vertical direction of trunk body
- Costal bones
  - For attachment points for tendons
  - For large moment arm to generate enough torque
- Humanlike shape of vartebra

- Humanlike movable range of spine
  - bending: ±90 degree



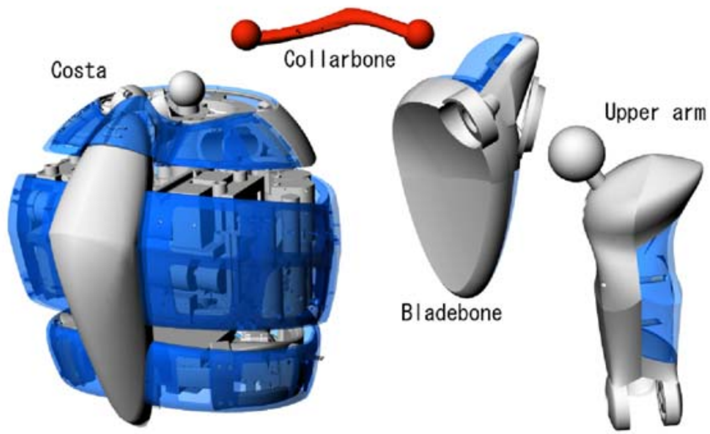


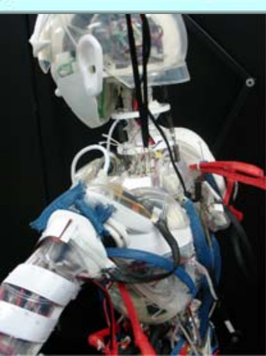


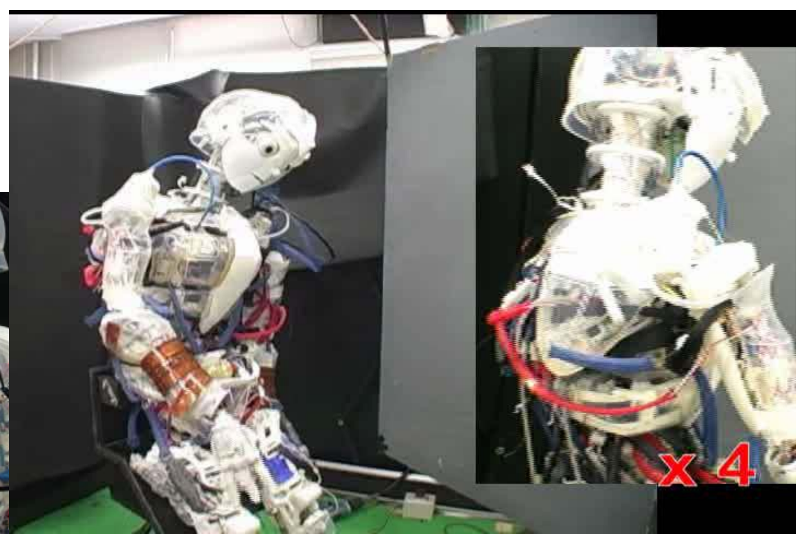


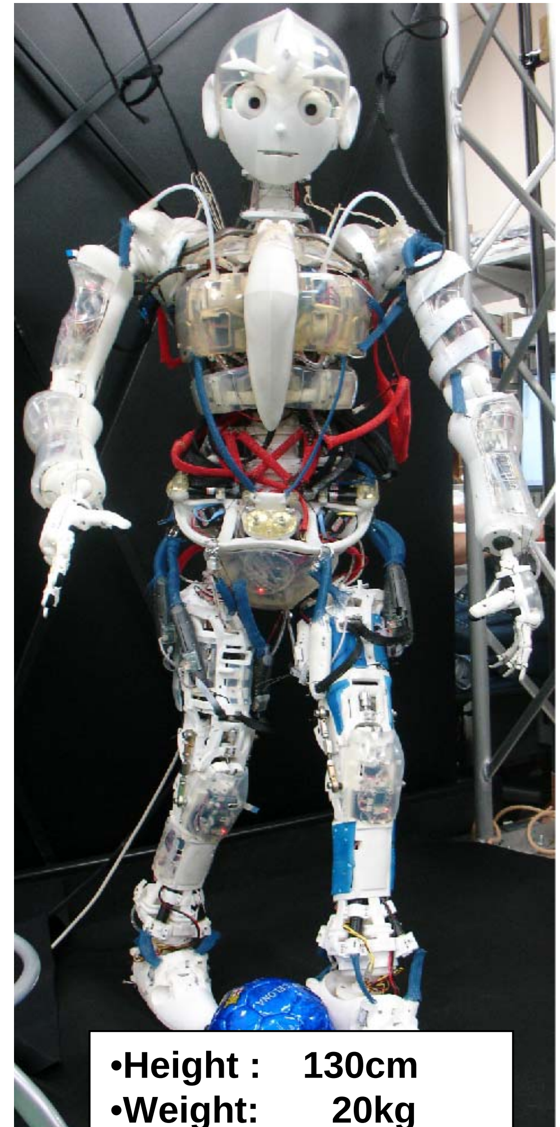
Kotaro: Reinforceable fullbody musculoskeletal humanoids (2005～)

1. <u>Totally more humanlike bone structure</u>
   – spine, <u>collarbone, bladebone</u>, spherical hip joint





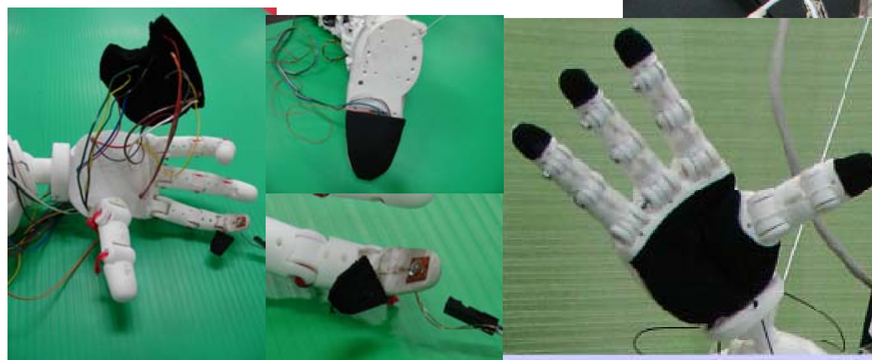




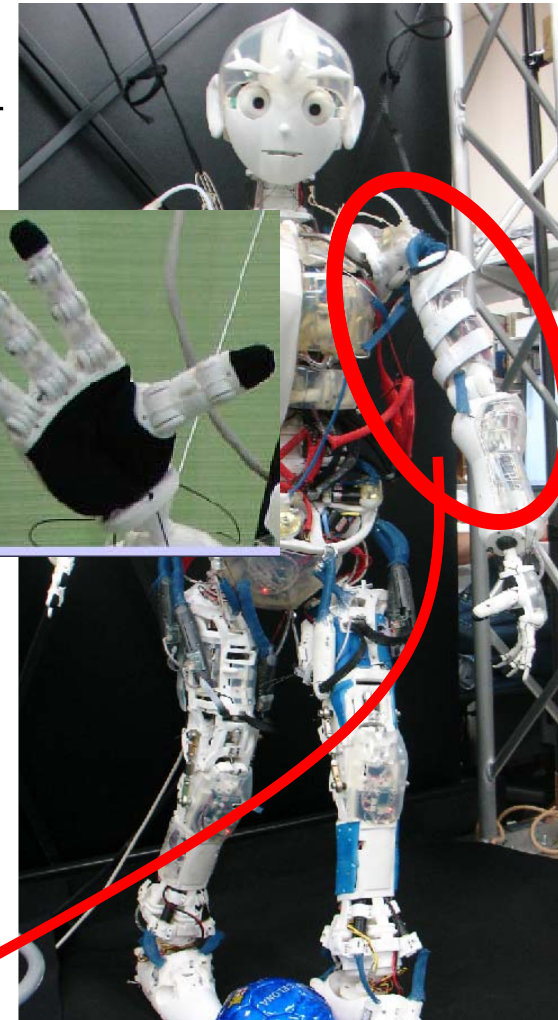
- Height : 130cm
- Weight: 20kg
- Joint DOFs: 63
- Muscle Num: 88-100

Kotaro: Reinforceable fullbody musculoskeletal humanoids (2005～)

1. Totally more humanlike bone structure
2. <u>Adding more sensors</u>
   – Tension sensor, vision sensor + <u>Tactile sensor</u>, IMU sensor



Using conductive foam

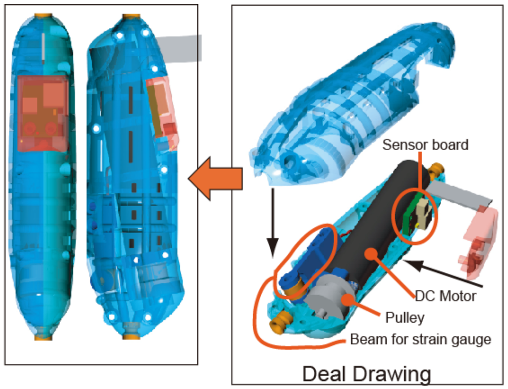


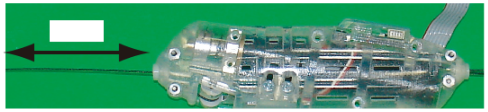
•**Height : 130cm**
•**Weight: 20kg**
•**Joint DOFs: 63**
•**Muscle Num: 88-100**

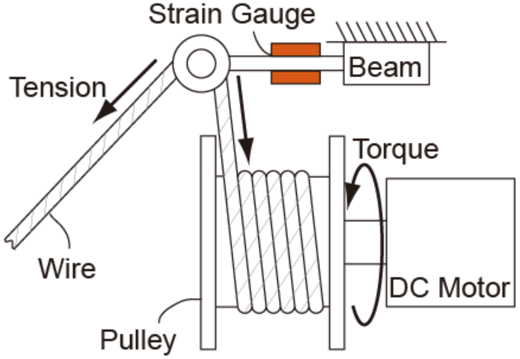
Using conductive rubber

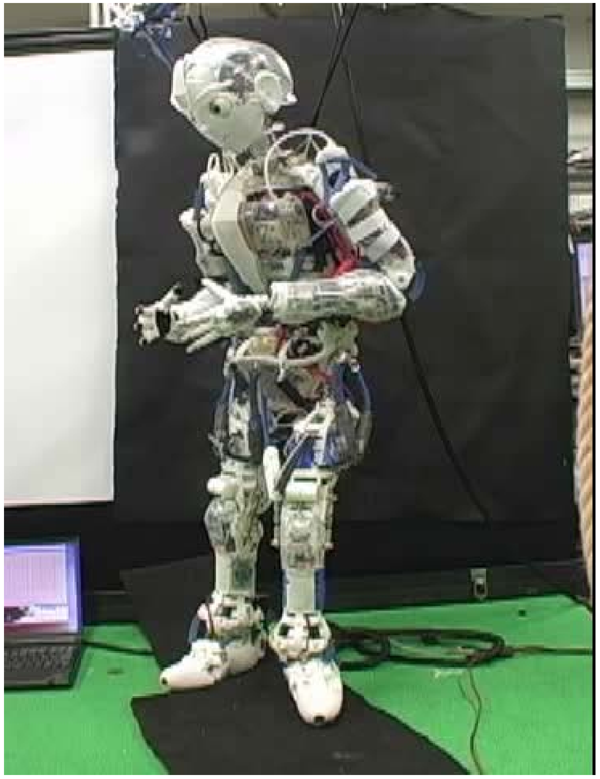
Kotaro: Reinforceable fullbody musculoskeletal humanoids (2005～)

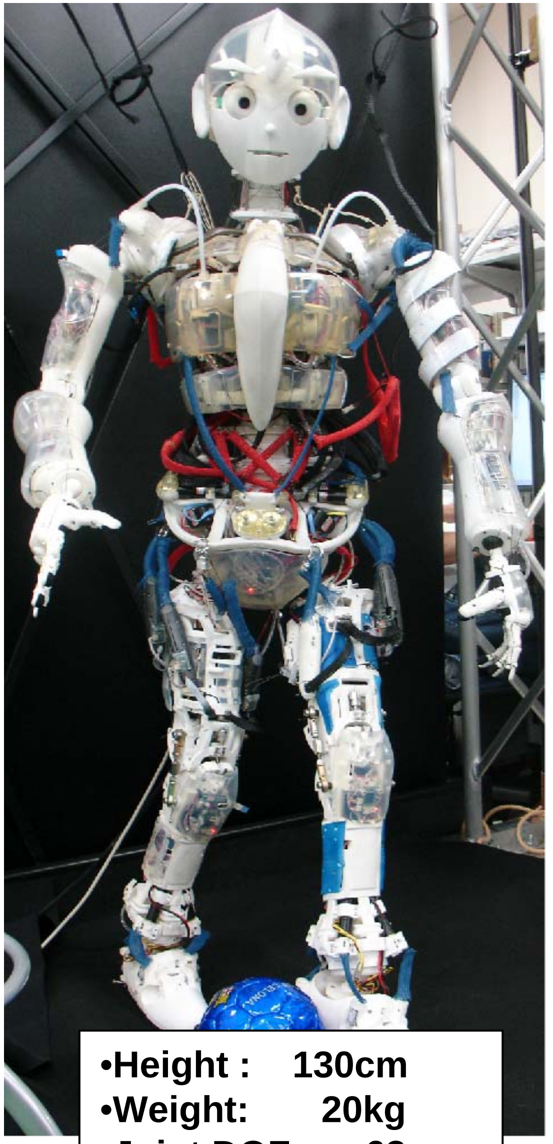
1. Totally more humanlike bone structure
2. Adding more sensors
3. <u>Improvement of maintenance</u>
   – Individually remove/add actuator unit
   -> Reinforceable tendons according to task







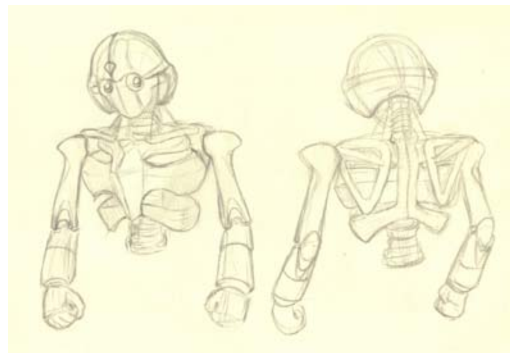


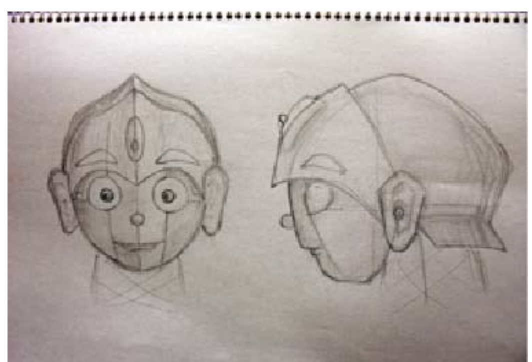


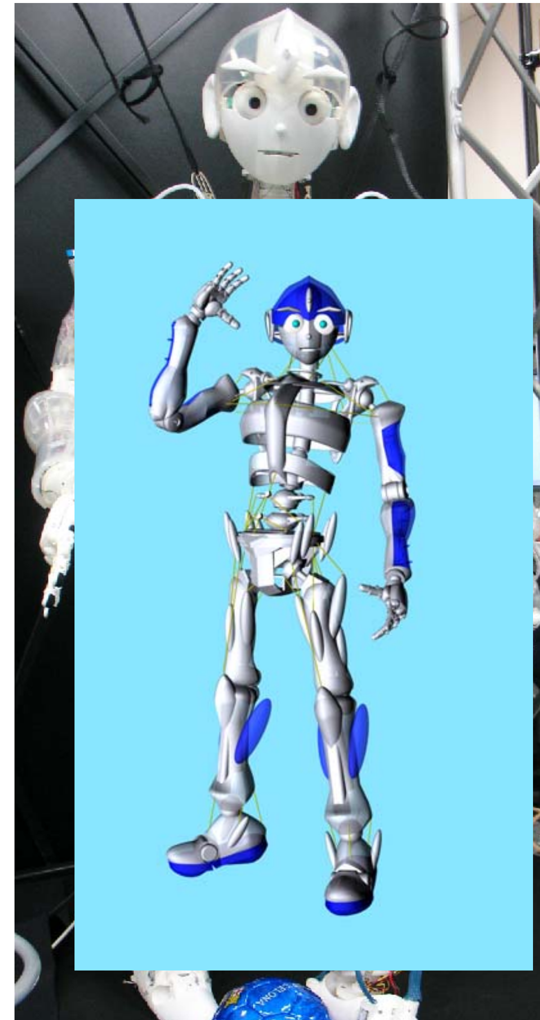
- •Height : 130cm
- •Weight: 20kg
- •Joint DOFs: 63
- •Muscle Num: 88-100

Kotaro: Reinforceable fullbody musculoskeletal humanoids (2005～)

1. Totally more humanlike bone structure
2. Adding more sensors
3. Improvement of maintenance
4. <u>More familiar total design</u>
   - for exhibition in Aichi Expo 2005







- **Height : 130cm**
- **Weight: 20kg**
- **Joint DOFs: 63**
- **Muscle Num: 88-100**

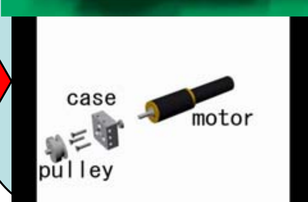
Kojiro: Powerful musculoskeletal humanoid 2008～

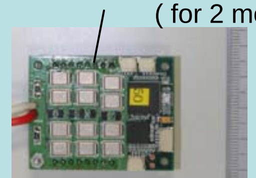
- Kenta, Kotaro: Too weak and fragile to do fullbody motion
  - we always have to repair robots before experiments
- Characteristics
  1. Same size and more powerful
     - Improvement of actuator system (4.5WDC motor⇒40WBrushless motor)
     - Increase of number of muscles (32muscles -> 44 muscles in lowerbody)

- **Height : 135cm**
- **Weight: 45kg**
- **Joint DOFs: 58**
- **Muscle Num: 109**

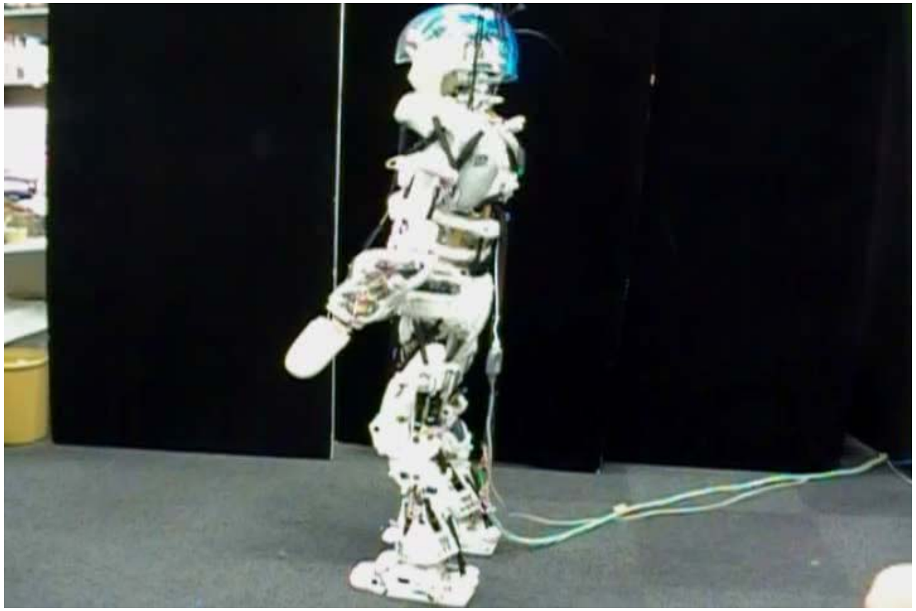
- In the old humanoid (Kotaro)
  - 4.5W DC motor
  - Cont. max tension 5 [kgf]

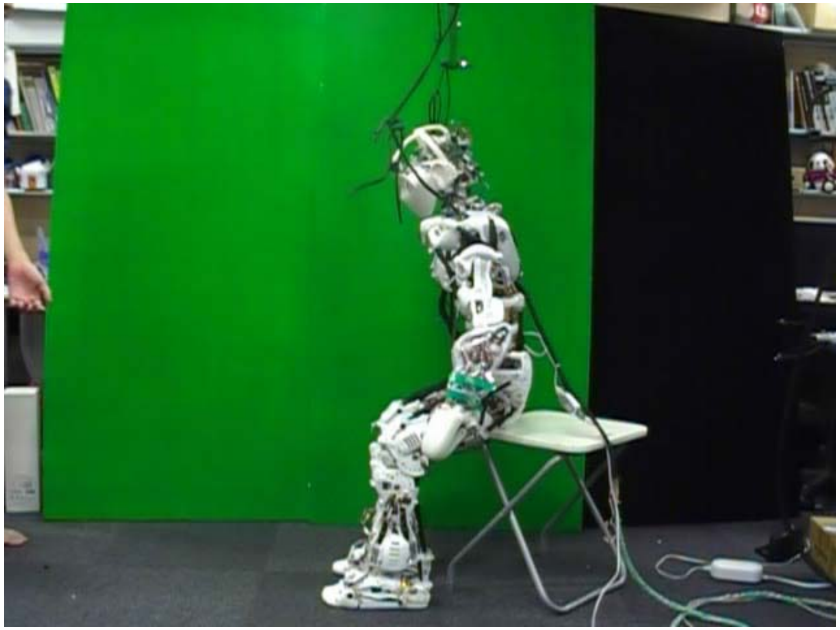
- In the new humanoid
  - 40W AC motor
  - Cont. max tension 28[kgf]
  - Cont. max velocity 95[mm/s]

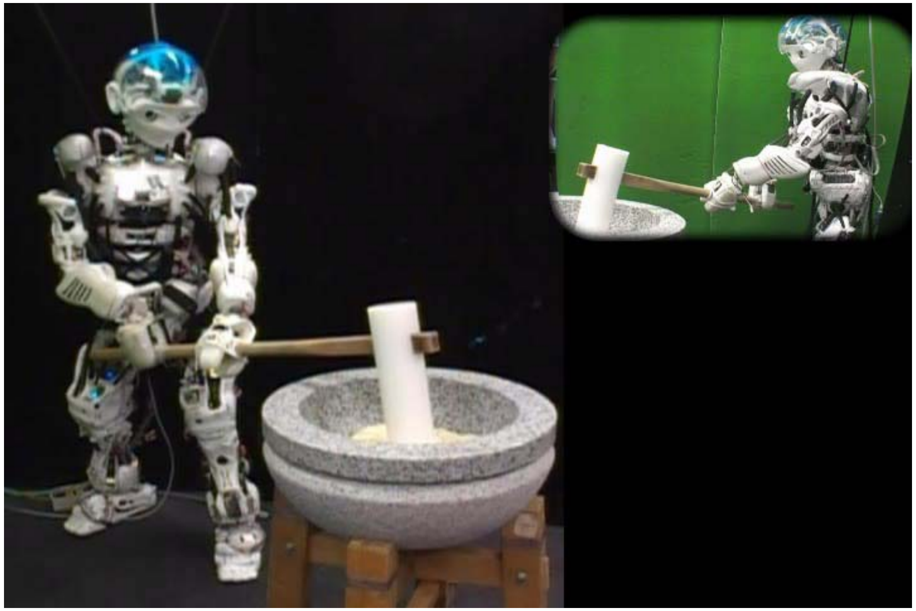




Demonstrations of fullbody motion



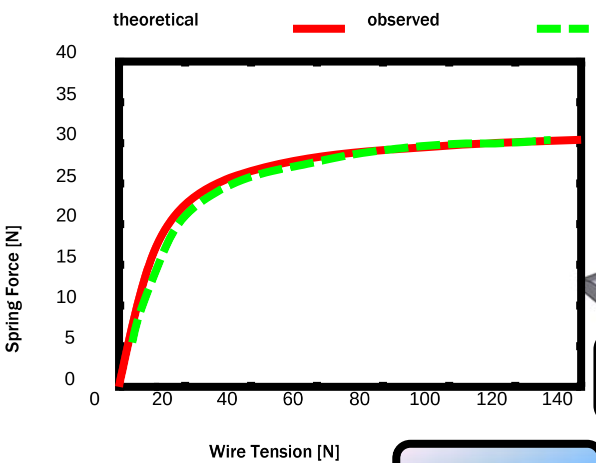


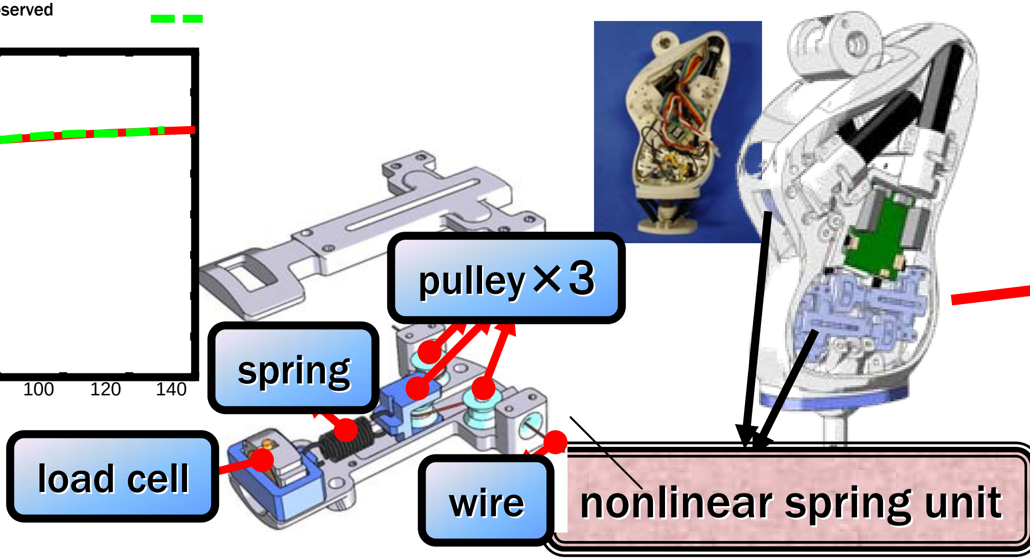


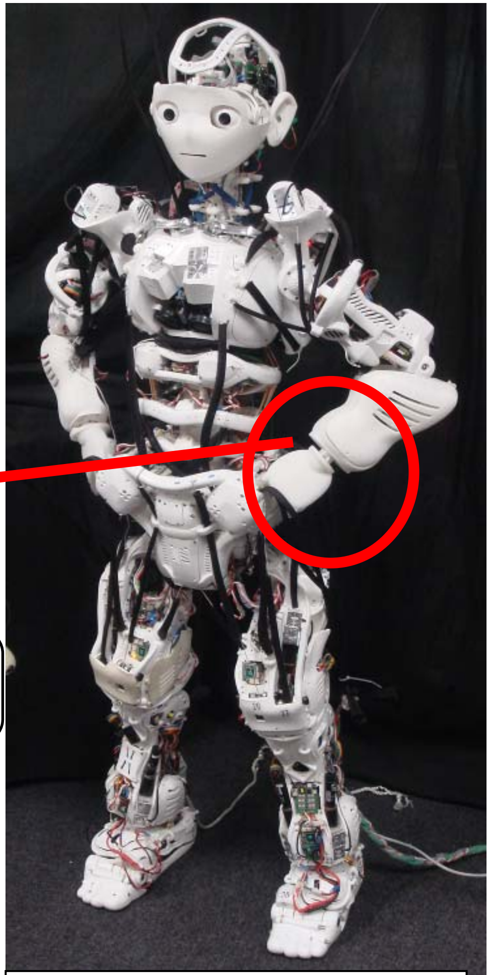
Kojiro: Powerful musculoskeletal humanoid 2008～

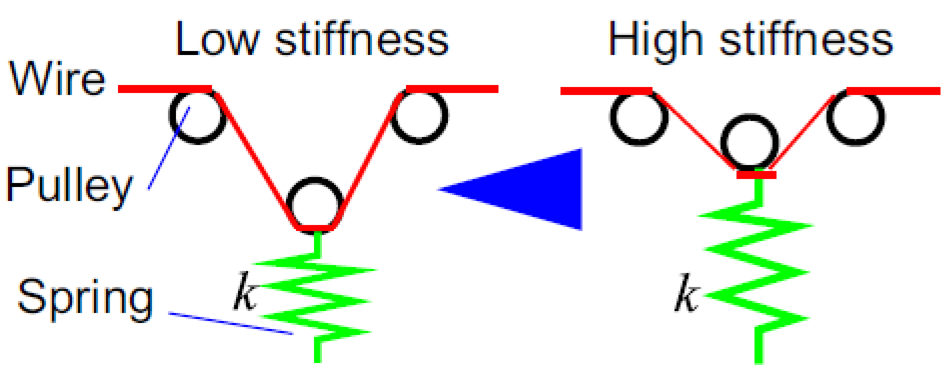
Characteristics

1. Same size and more powerful
2. <u>Adding mechanical stiffness adjustable tendon units to wrist</u>
   - Reduction of impact shock peak









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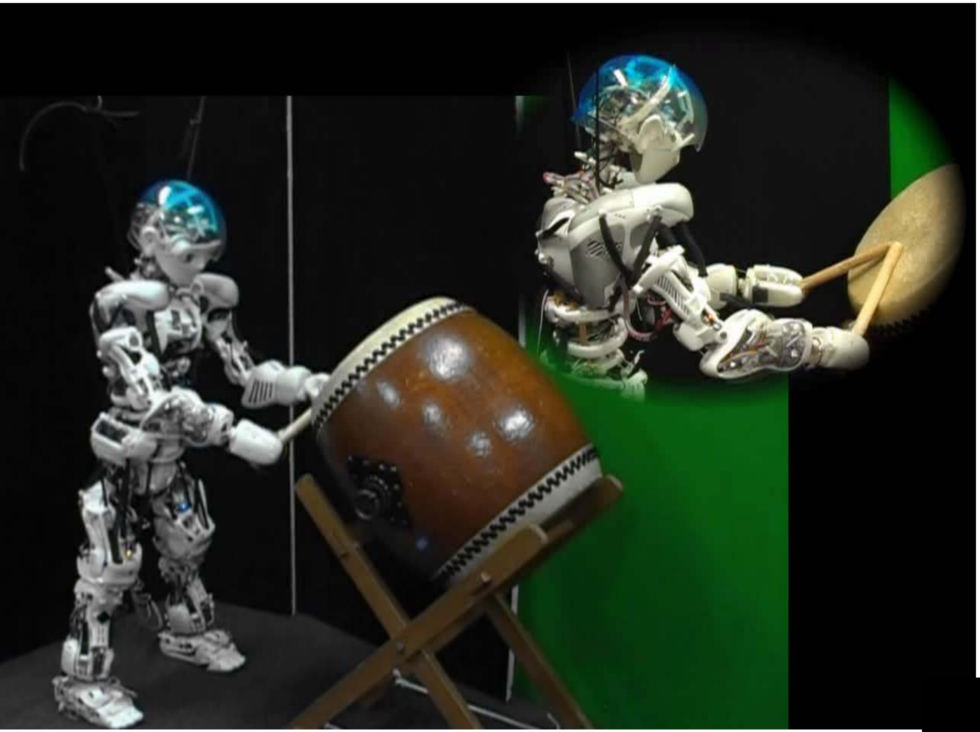
Demonstrations of using wrist joint flexibility



Drumming motion

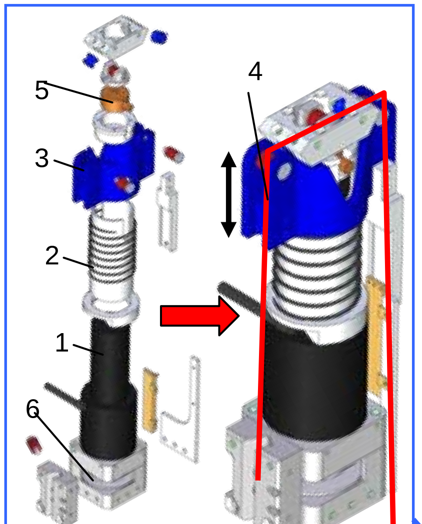
Nailing motion

Thanks to nonlinear spring mechanism

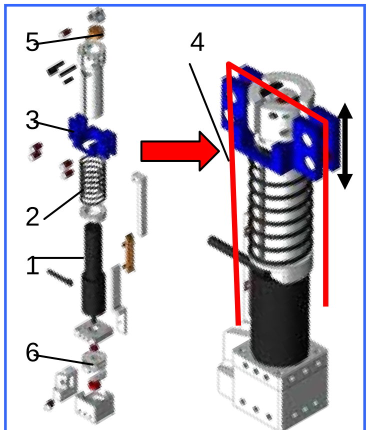
- Absorption of impact force
- High speed motion using spring extension

Kenzoh: powerful and adaptive musculoskeletal humanoid 2011~

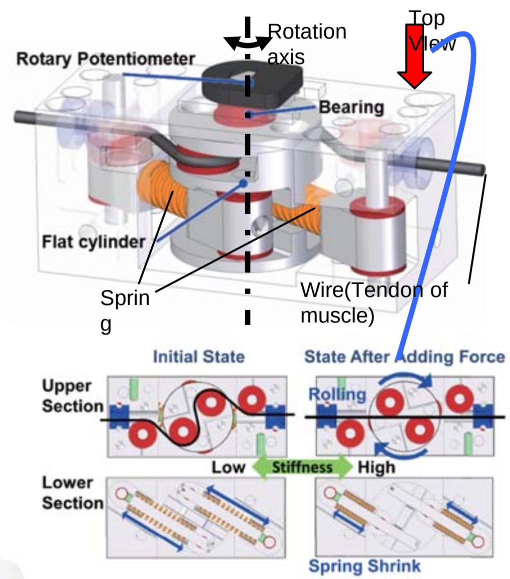
1. More powerful
   - Kojiro: 40W motor -> Kenzoh: 90W motor
   - Kojiro: 65 motors(upper body) -> Kenzoh: 80 motors
2. Mechanical nonlinear spring units are embedded in all muscles
   - Kojiro: only wrist part

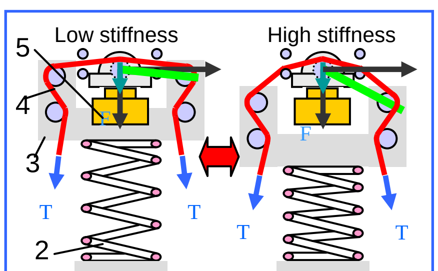


90W Actuator Unit with NST

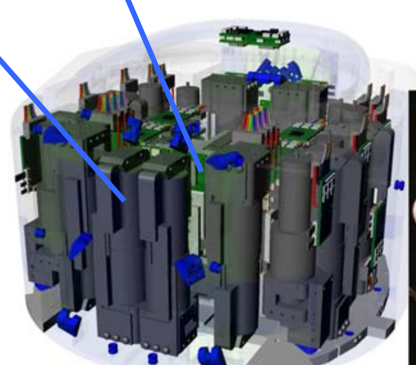


40W Actuator Unit with NST

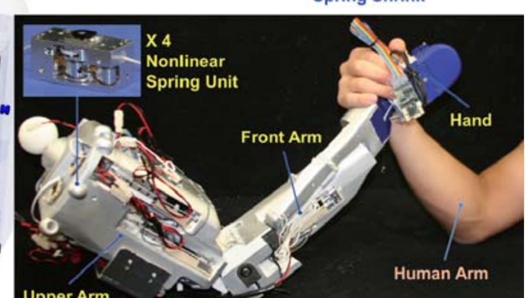


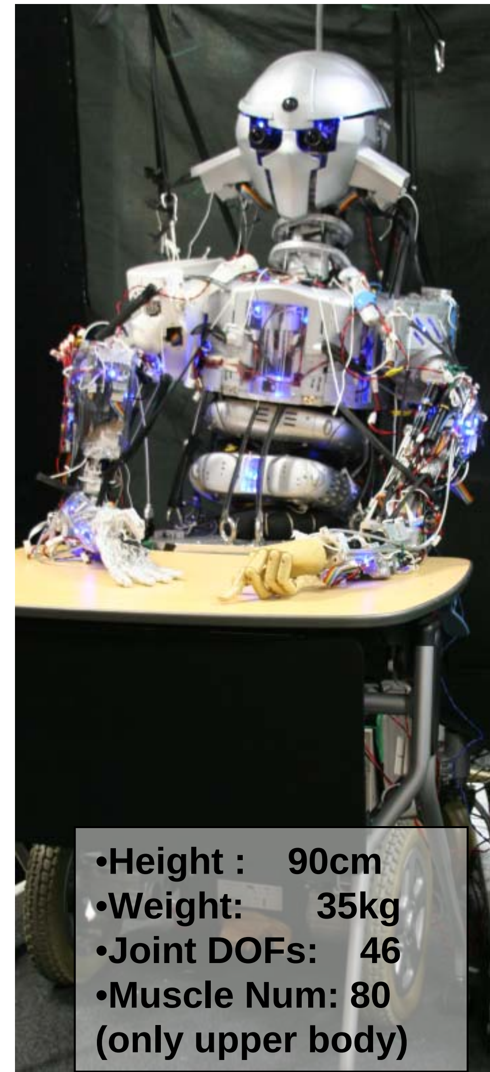


Mechanism of Actuator Unit with NST

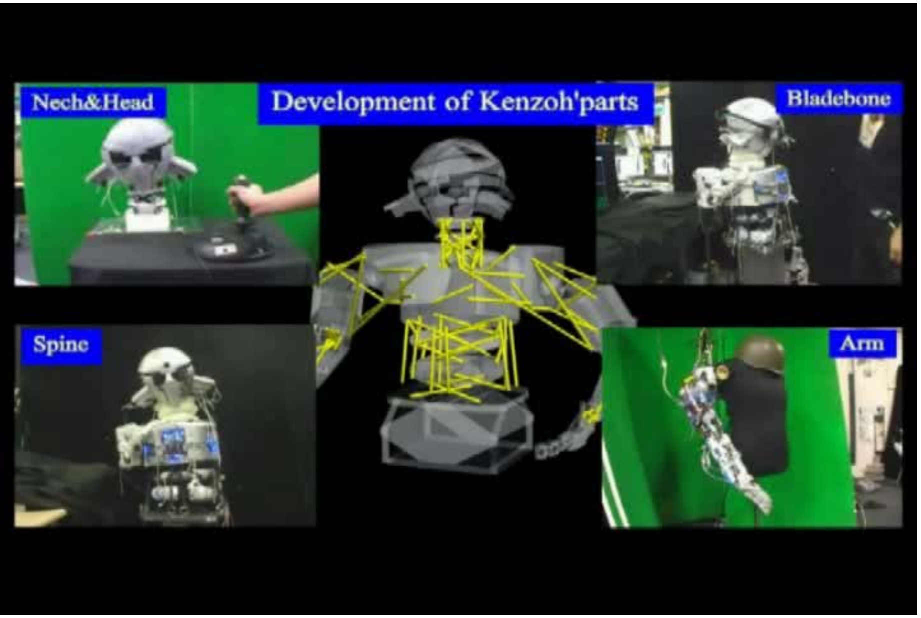


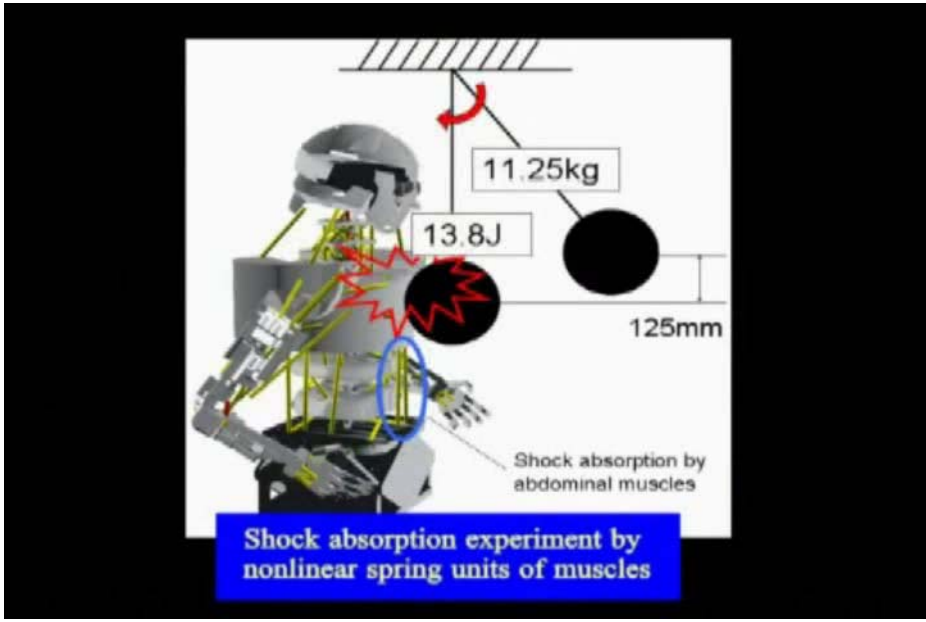
Actuator Elements of Chest bone

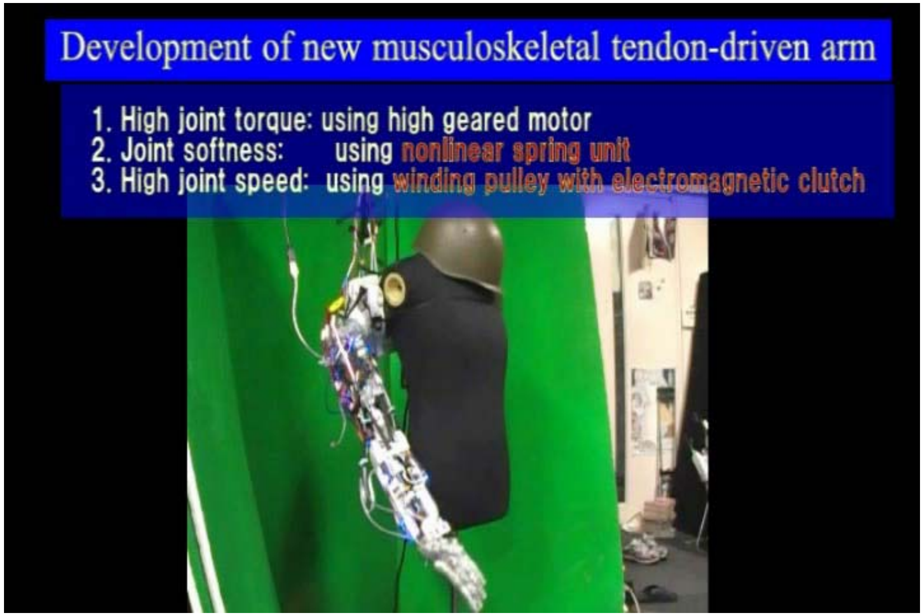




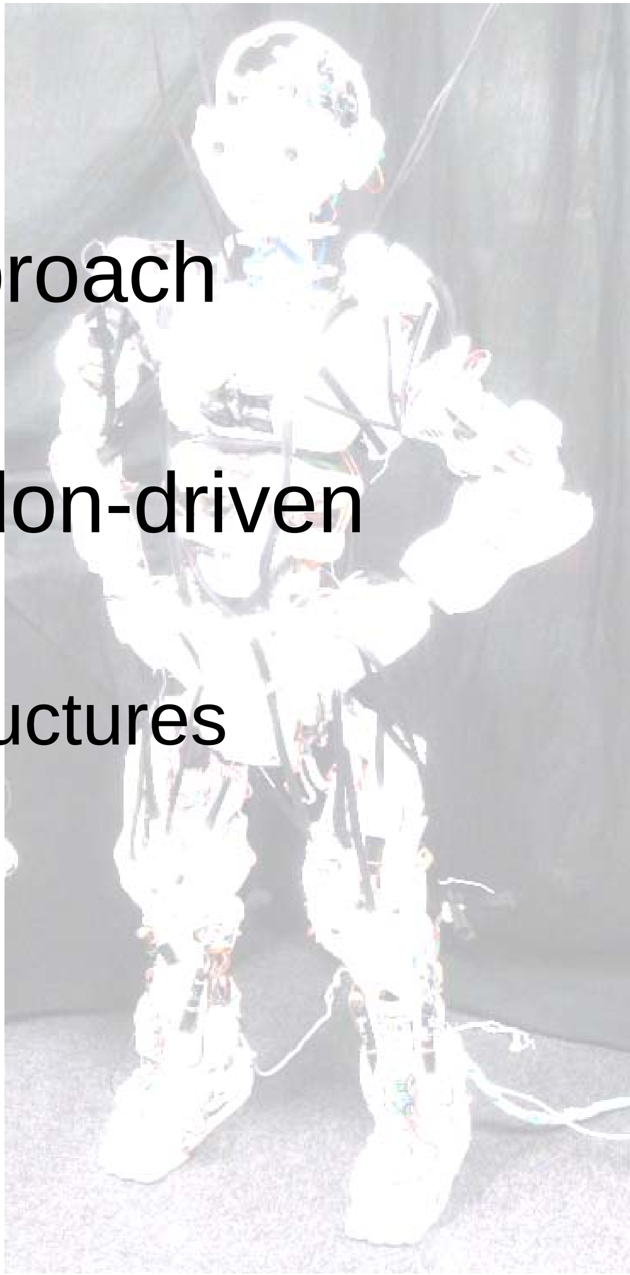
Kenzoh’s demonstrations







Outline



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  - Development of robot body structures
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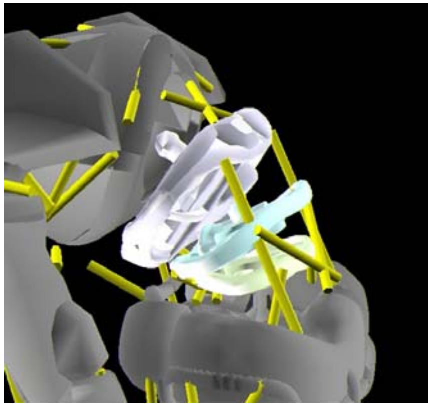
What is difficult to control our robots?

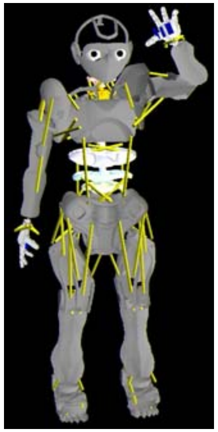
1. Control space is too large
   - Joint DOFs over 60, Actuator over 100, Sensor over 120
2. Difficulty to build precise computational robot model for control
   - Interference between tendons and bones
   - Collision, friction of tendon
3. Uncertainty of robot body
   - Elongation of tendons
   - Drift of sensors day by day(hour by hour)
   - Effect of friction of tendons, spherical joints



Interference with tendon and bones

Our approach

- Motion control based on simple sensor feedback like reflex without detail robot model
- Acquirement of body model for control by learning process in the real world and real robot



Geometric model

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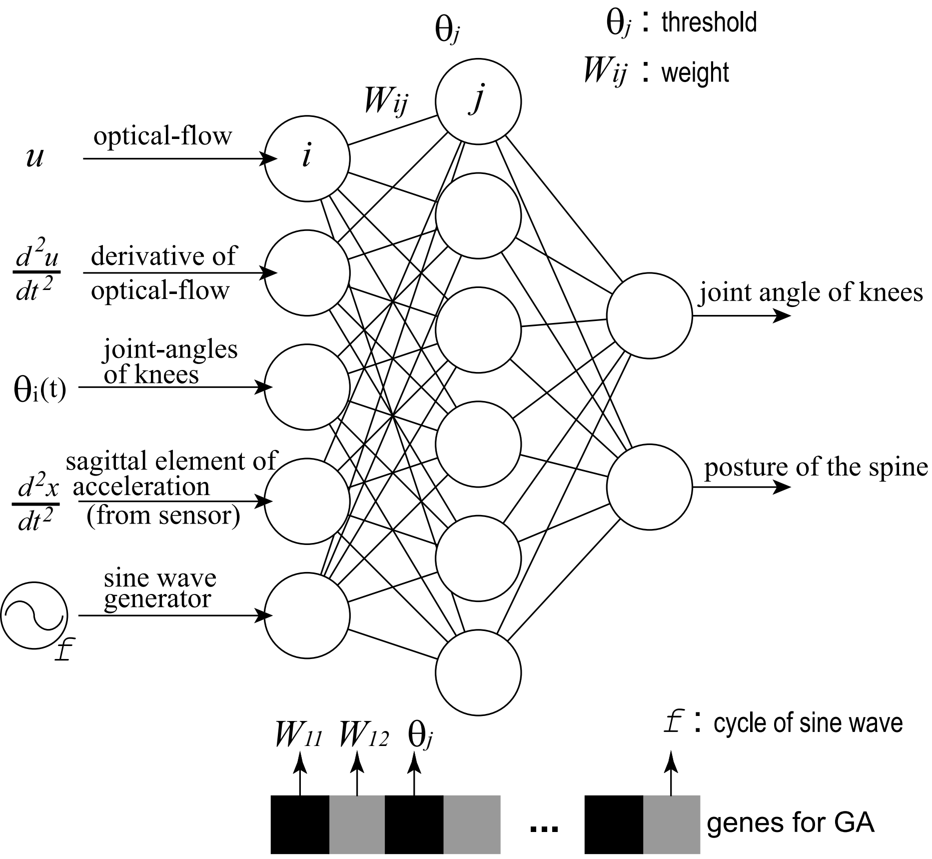
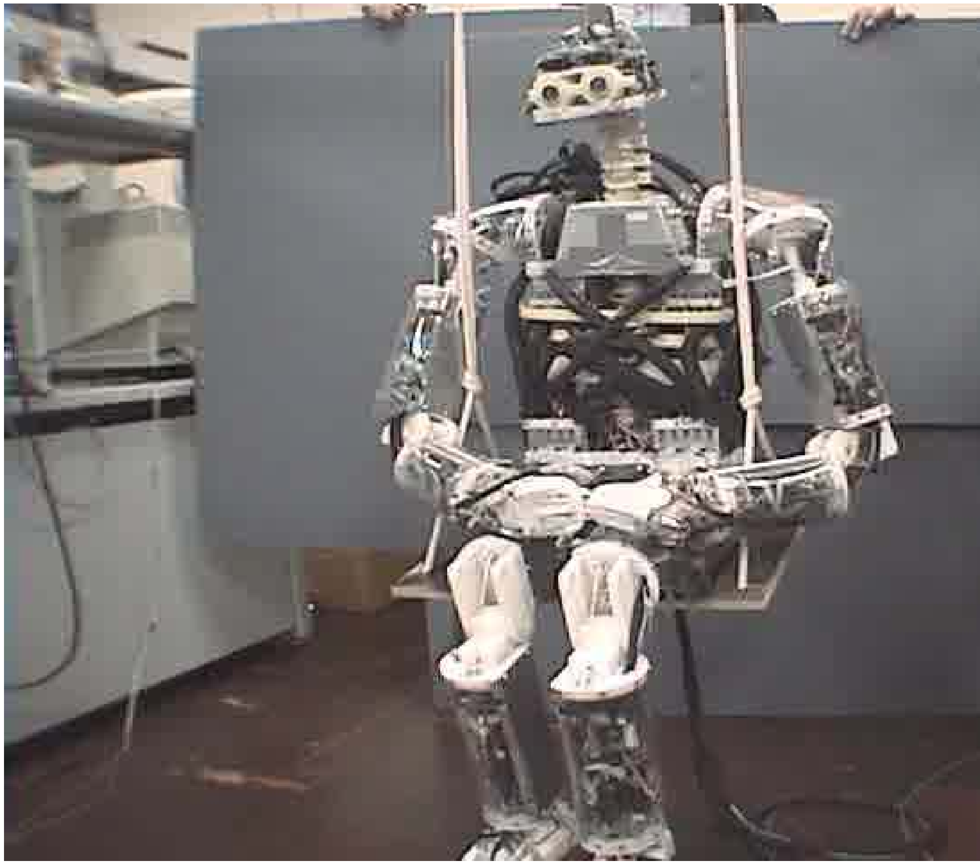
Real body

Swing motion demonstration

- Example of motion control based on simple sensor feedback
  - Acquiring spine reflex movement parameters based on visual motion information

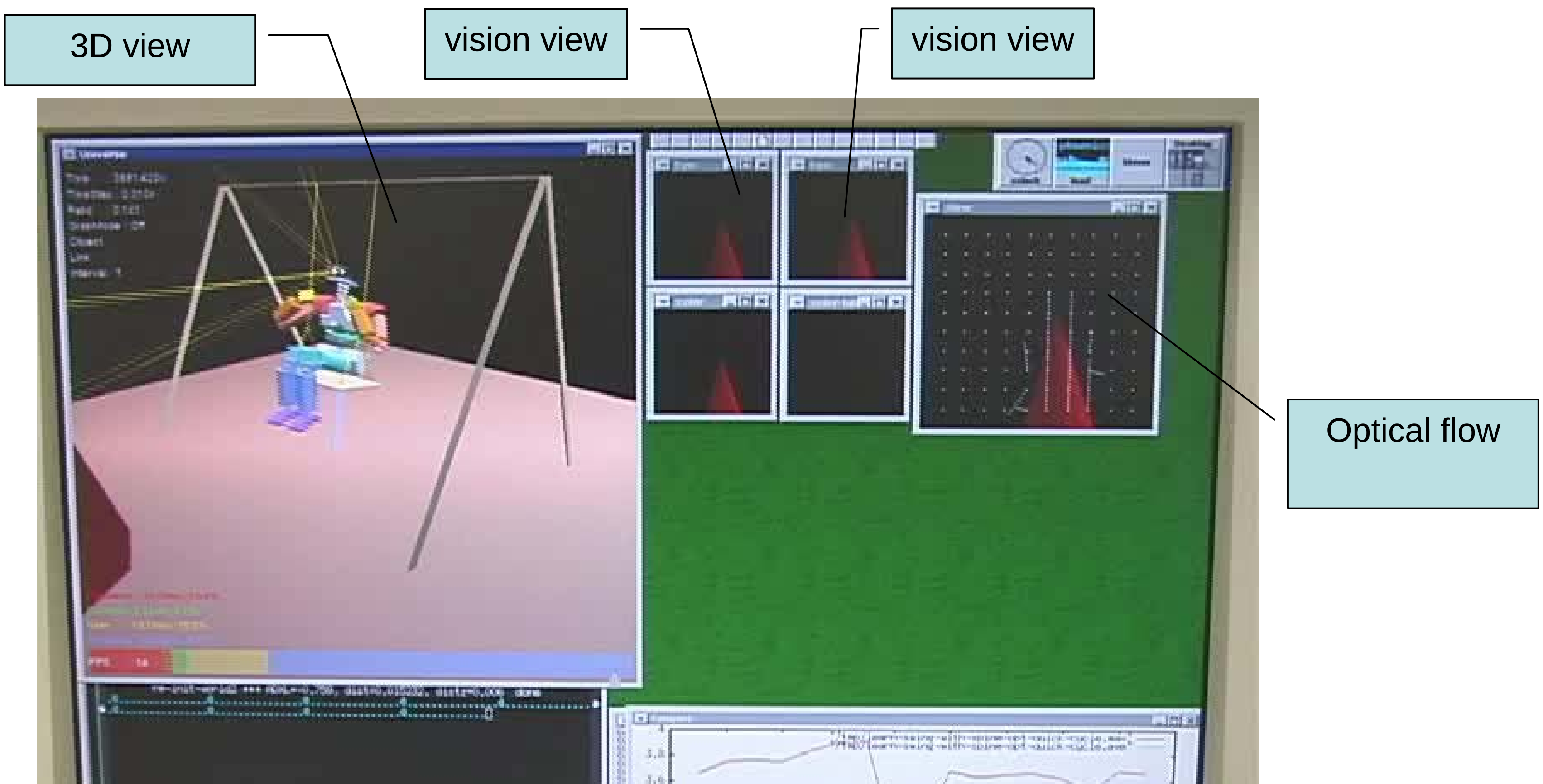




Searching parameters by trial and error

- In this case
  - Using simulation environment because Kenta is too fragile!
    - Only joint space simulation, not tendon space simulation
- Actually,
  - In the real world, the parameter from simulation does not work

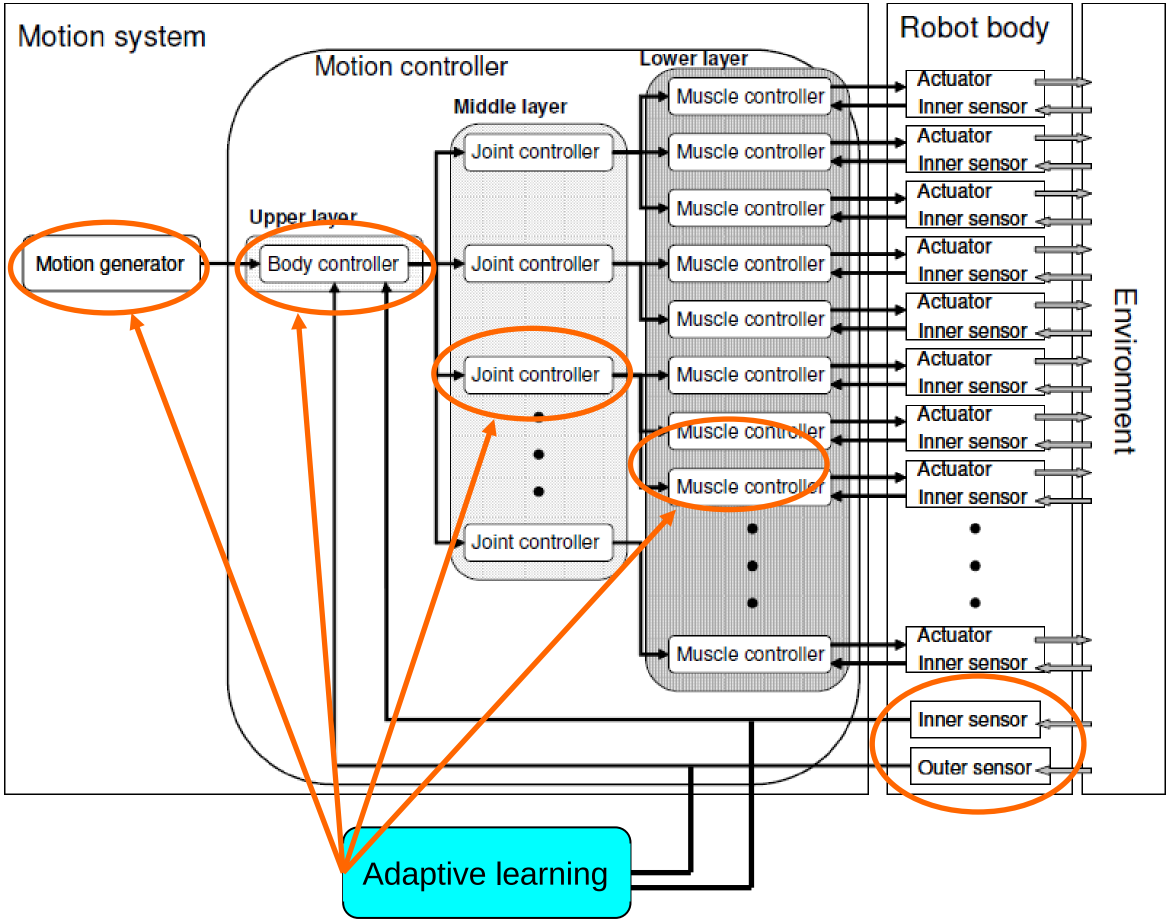
  → Experimenter must modify the parameter for real robot



Learning parameters by trial and error in the real world

1. Trial in the real world
2. Evaluation of robot motion from sensor value
3. Modify motion parameters

- Selecting parameters is important for convergence in the real world



Pedaling learning in the real world

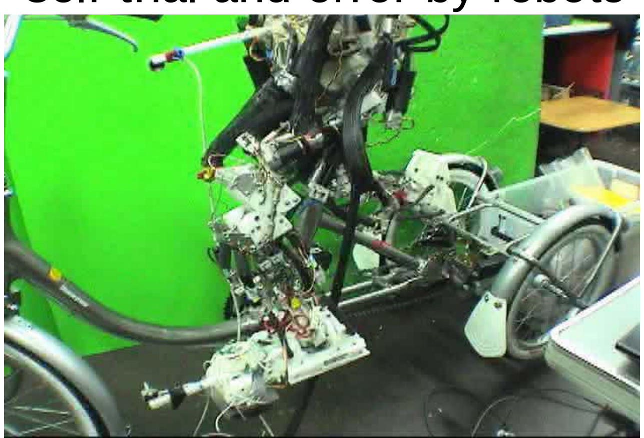
Acquiring tension pattern of legs 16 muscles in pedaling

based on pedaling pressure value

Pedaling on ground

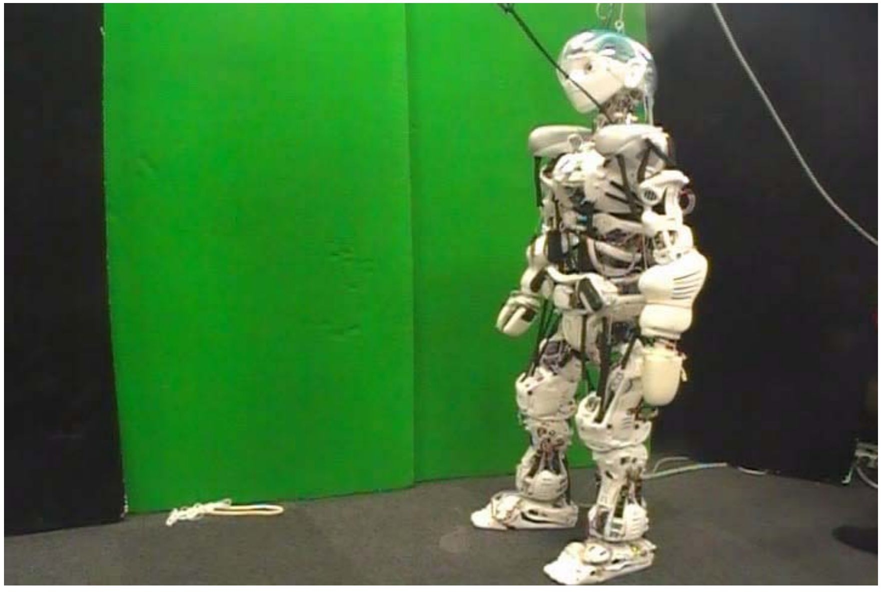
Initial motion trajectory is given

Self trial and error by robots



Other demonstration by learning parameters in real world

- One step using spine motion
  - Parameters: spine goal angle and time step
  - Evaluation: swing of ZMP, gyro
- Rotation of crank
  - Parameters: muscle length reference of the arm during one cycle
  - Evaluation: Internal force measured by muscle tensions value



Outline

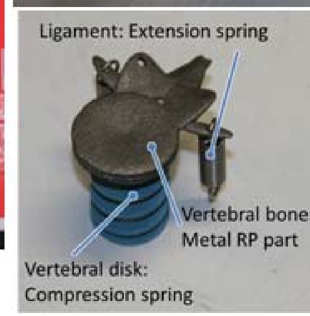
- Our motivation and basic approach
- History of our developed tendon-driven robots
- Summary and Recent works

Summary

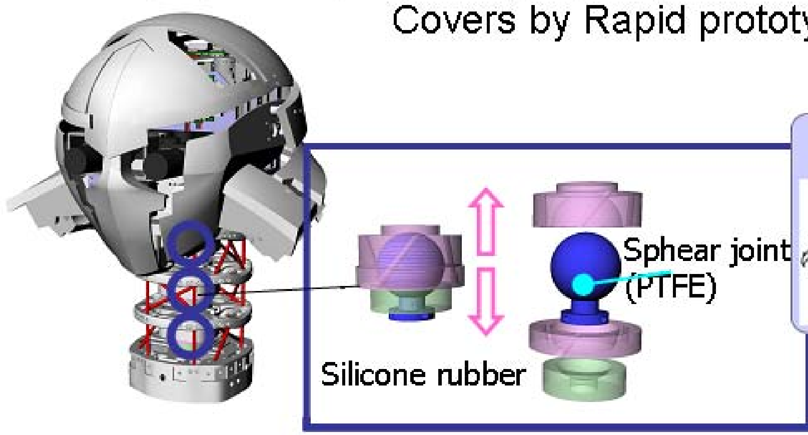
- Development of musculoskeletal humanoids <u>step by step</u>
  - Redesign of bone/joint structures, materials

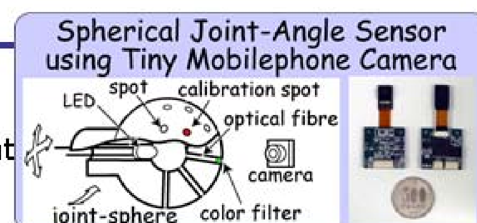
Bone by nylon Rapid prototype(SLS)

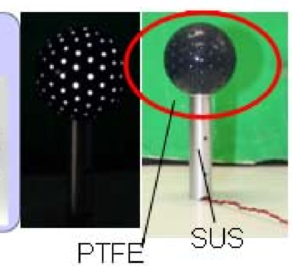
Covers by Rapid prototype(SLA)



Bone by metal Rapid prototype(SLS)







Smooth spherical joint by PTFE

Summary

- Development of musculoskeletal humanoids step by step
  - Redesign of bone/joint structures, materials
  - Developing new sensors, powerful/small actuators, boards
  - ⇒ As frontier of developing new technology
    - More humanlike: more compact, lighter, stronger, more efficient, …
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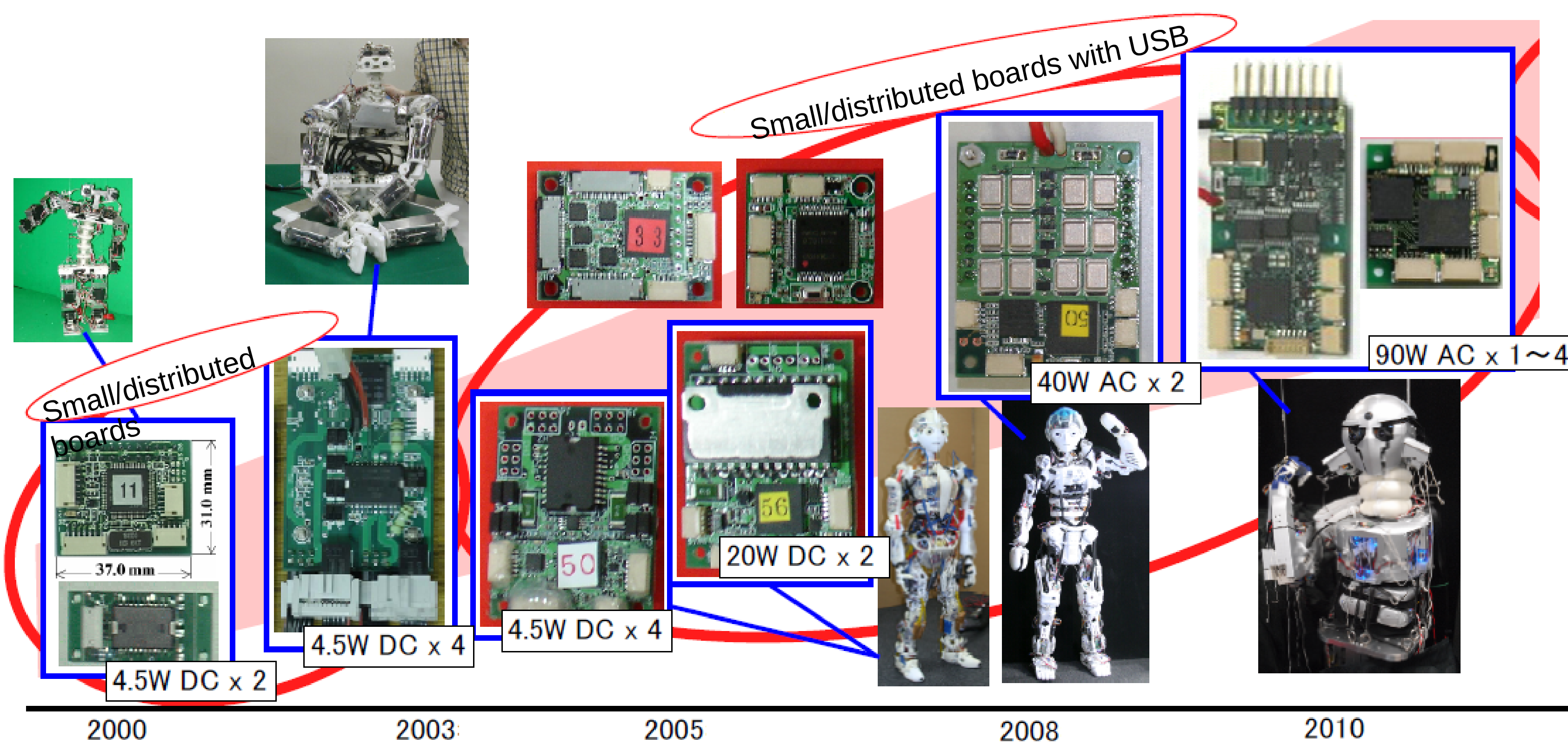

Summary

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    - More humanlike: more compact, lighter, stronger, more efficient, …

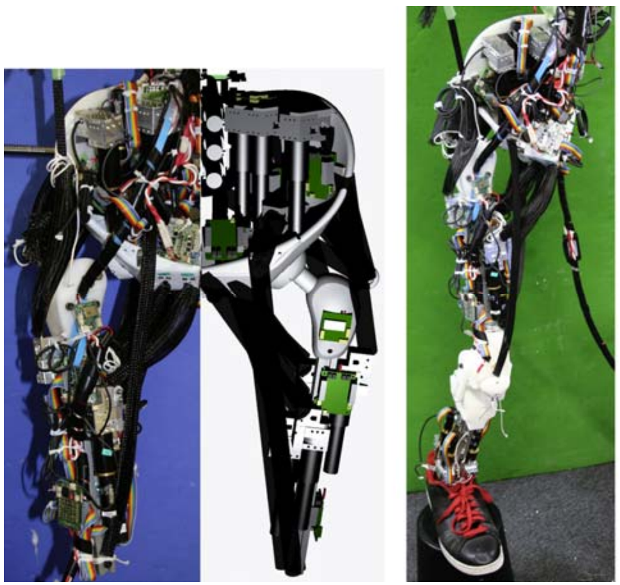
- Control of musculoskeletal humanoids by trial and error <u>in the real world</u>
  - Acquired motion is not optimized, however, <u>it works recently</u>.
    - Thanks to improvement of musculoskeletal humanoid body.
  - Problems
    - Every time, parameter re-learning is needed
      - How to re-use any learned information?
        - » Probabilistic information
        - » Based on relative information not absolute one
    - At each task, the parameters are selected by experimenter
      - How to generalize learning process?
        - » Automatically robot must understand
        - » What information or control parameter is important?

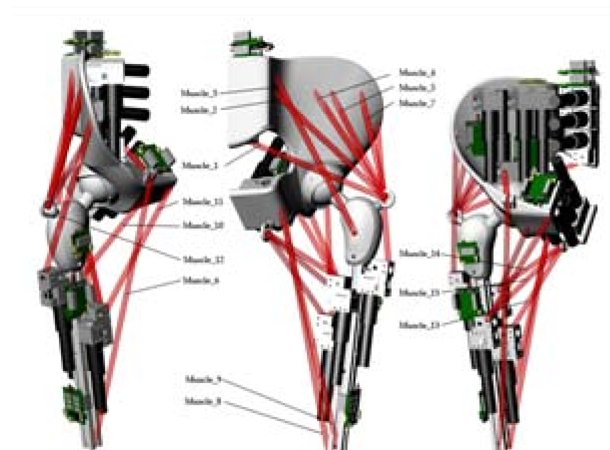
Recent works

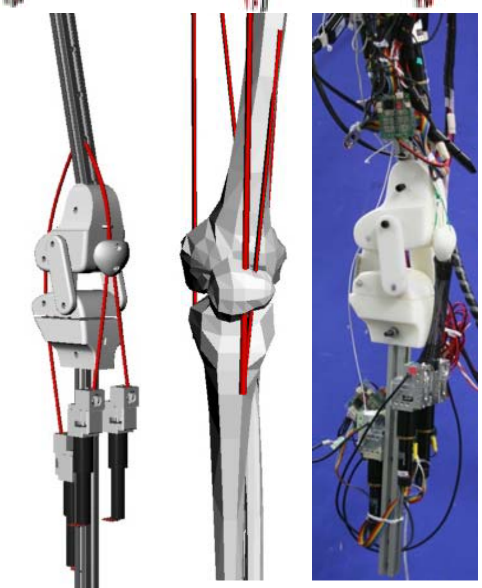
New musculoskeletal humanoid “Kenshiroh”

More similar to human musculoskeletal structure

- Arrangement of muscles, tendon paths
  - 15 muscles around hip joint
- Shape of bone structure
  - Pelvis, Spines, Knee joint







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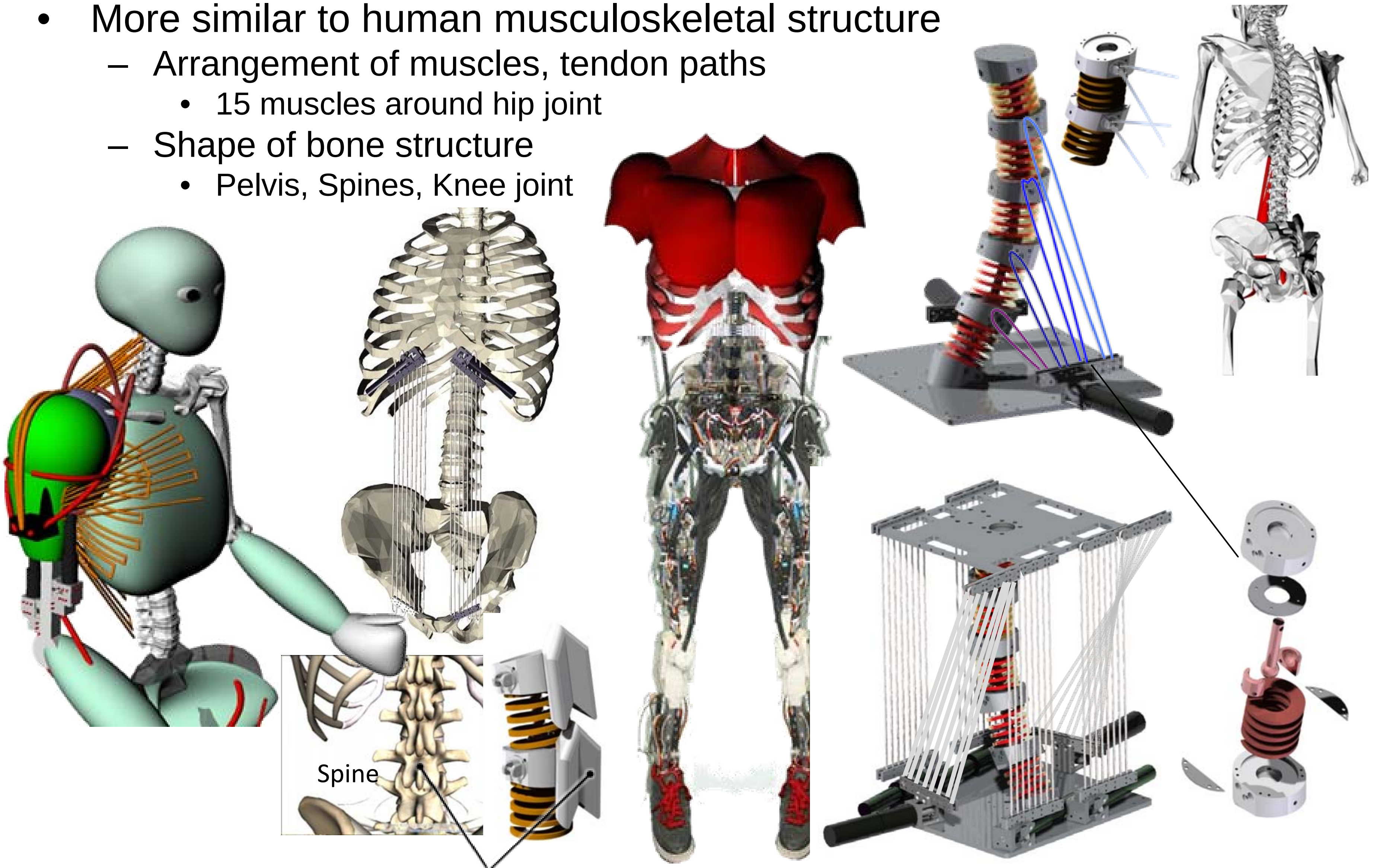
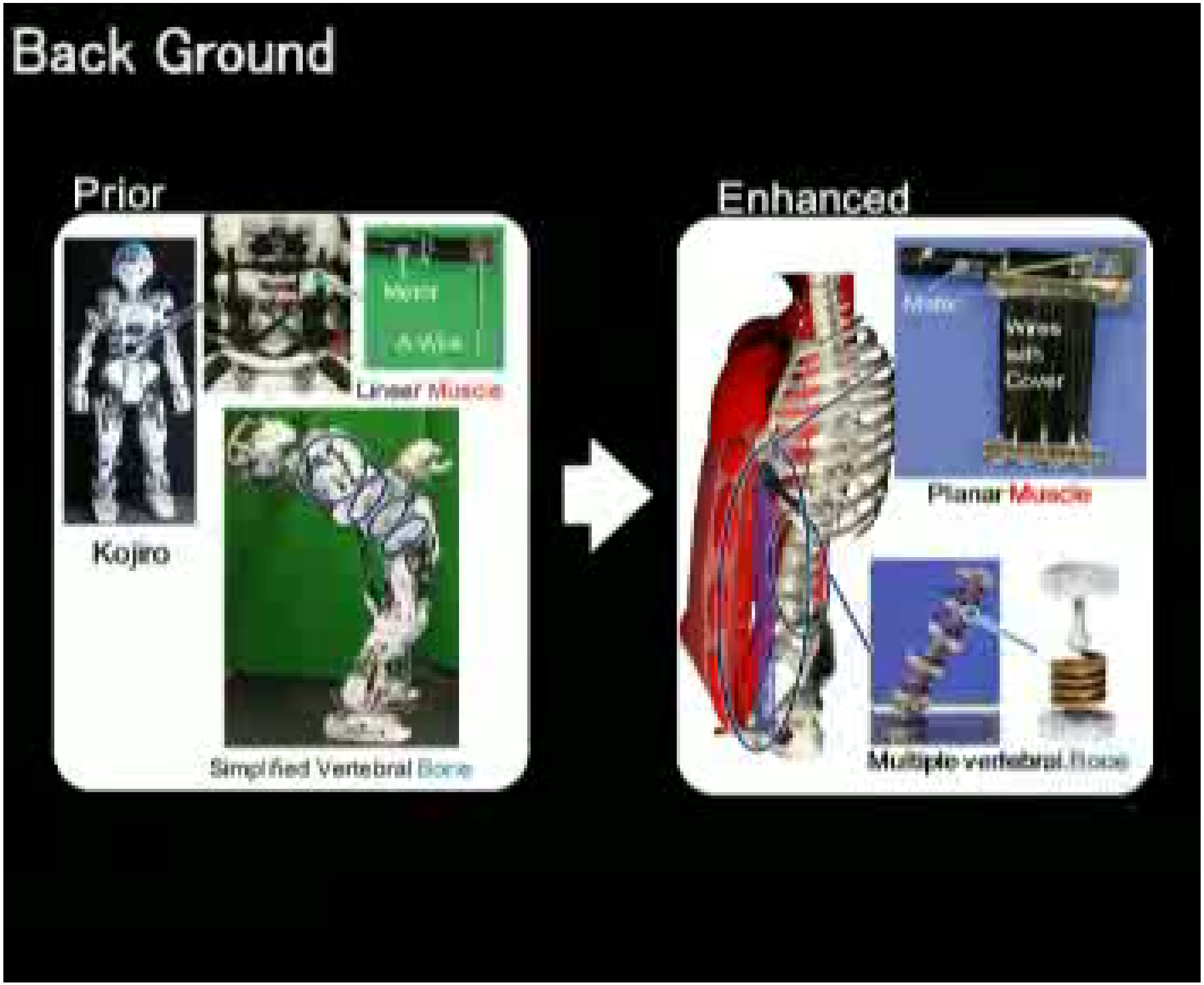


Kenshiro's new actuator idea: planer muscle Osada, et.al. Humanoids2011



Thank you!