Control of Loosely Coupled Joint by Soft Actuators via Deformable Cartilage

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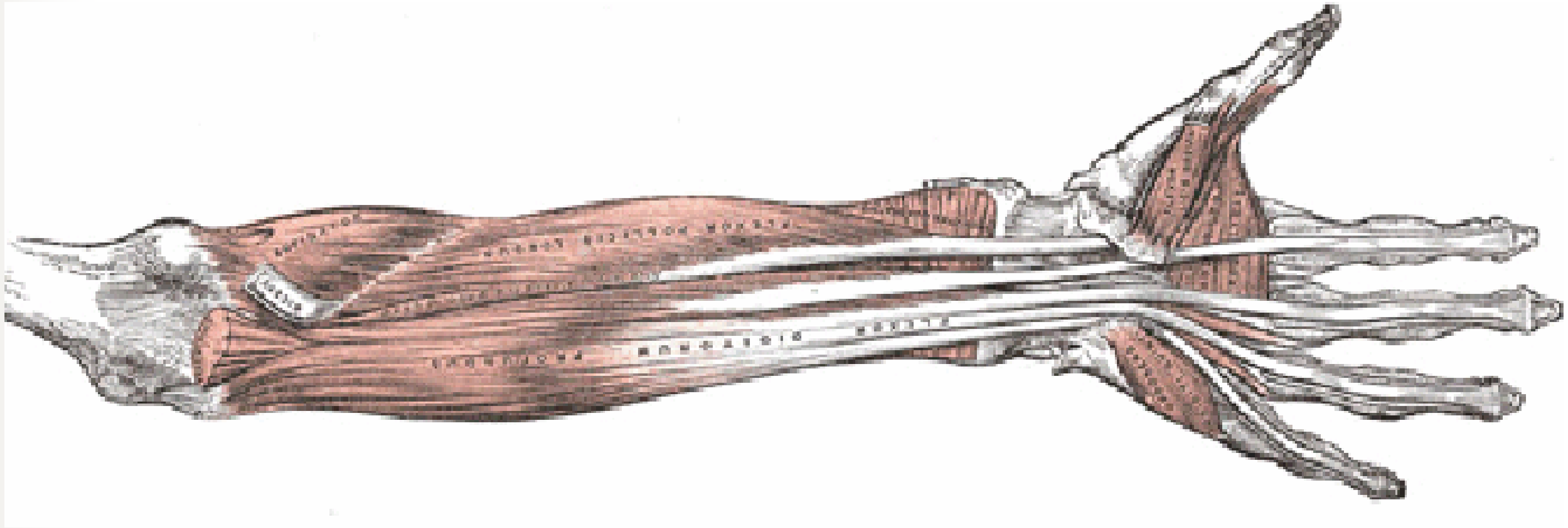
Prototype in 3D space

3D loosely coupled joint

Our goal

** http://www.abdn.ac.uk/diss/historic/museums/anatomy.hti*



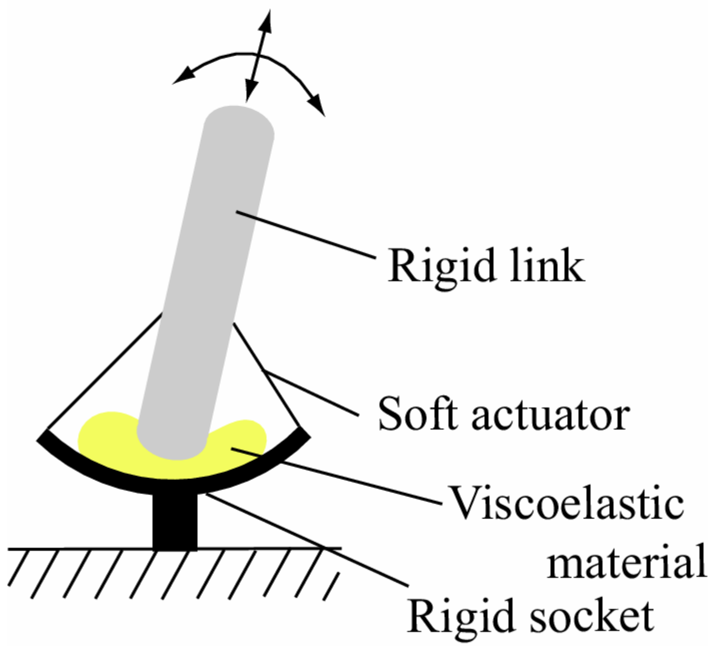
A human arm

Including soft materials driven by soft actuators

Concept of loosely coupled joint

Biomimetic approach

- **soft actuators**
- **soft cartilage**



Concept

Simple mechanism

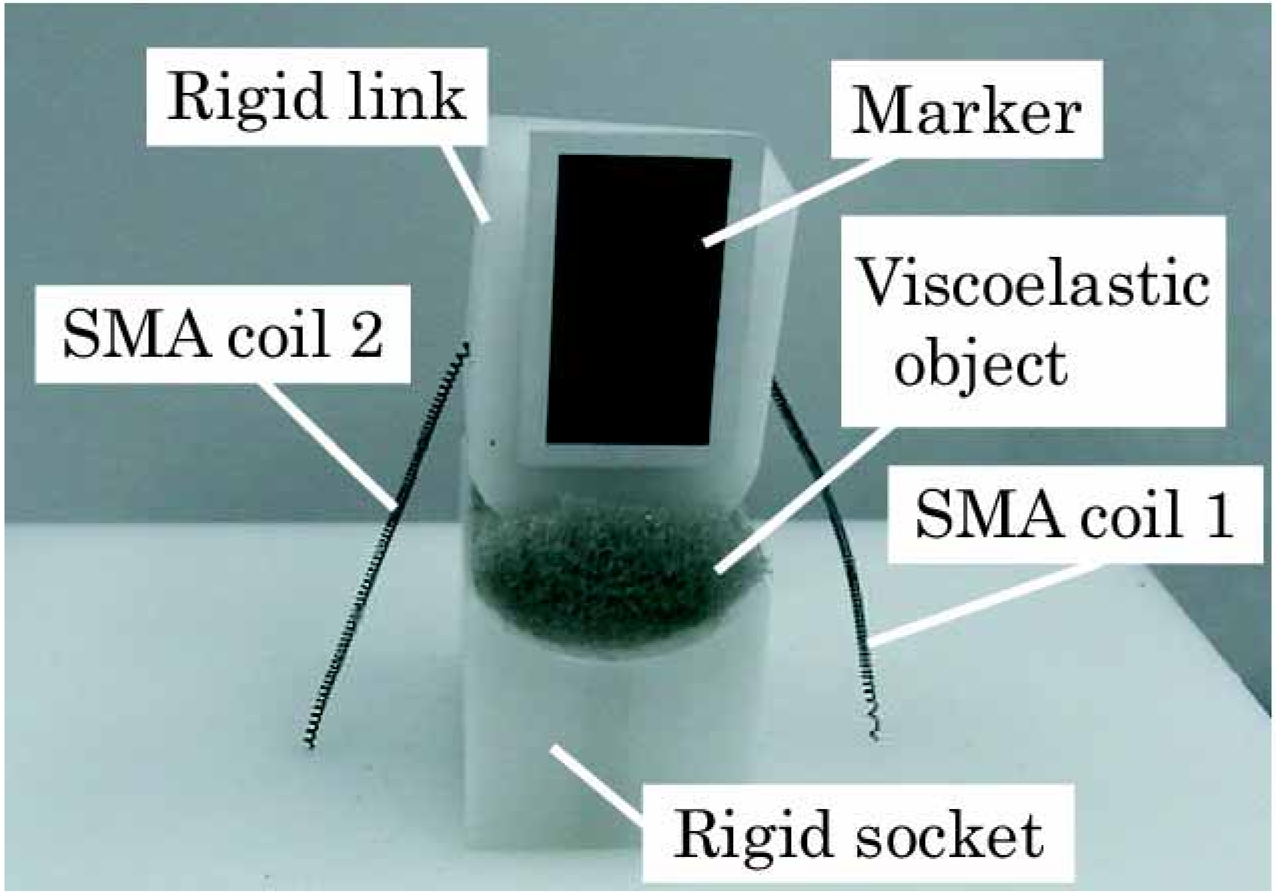
Contributions

- Robotic hand that has high robustness for environmental variation
- Clarification of roles of a human cartilaginous area

Outline

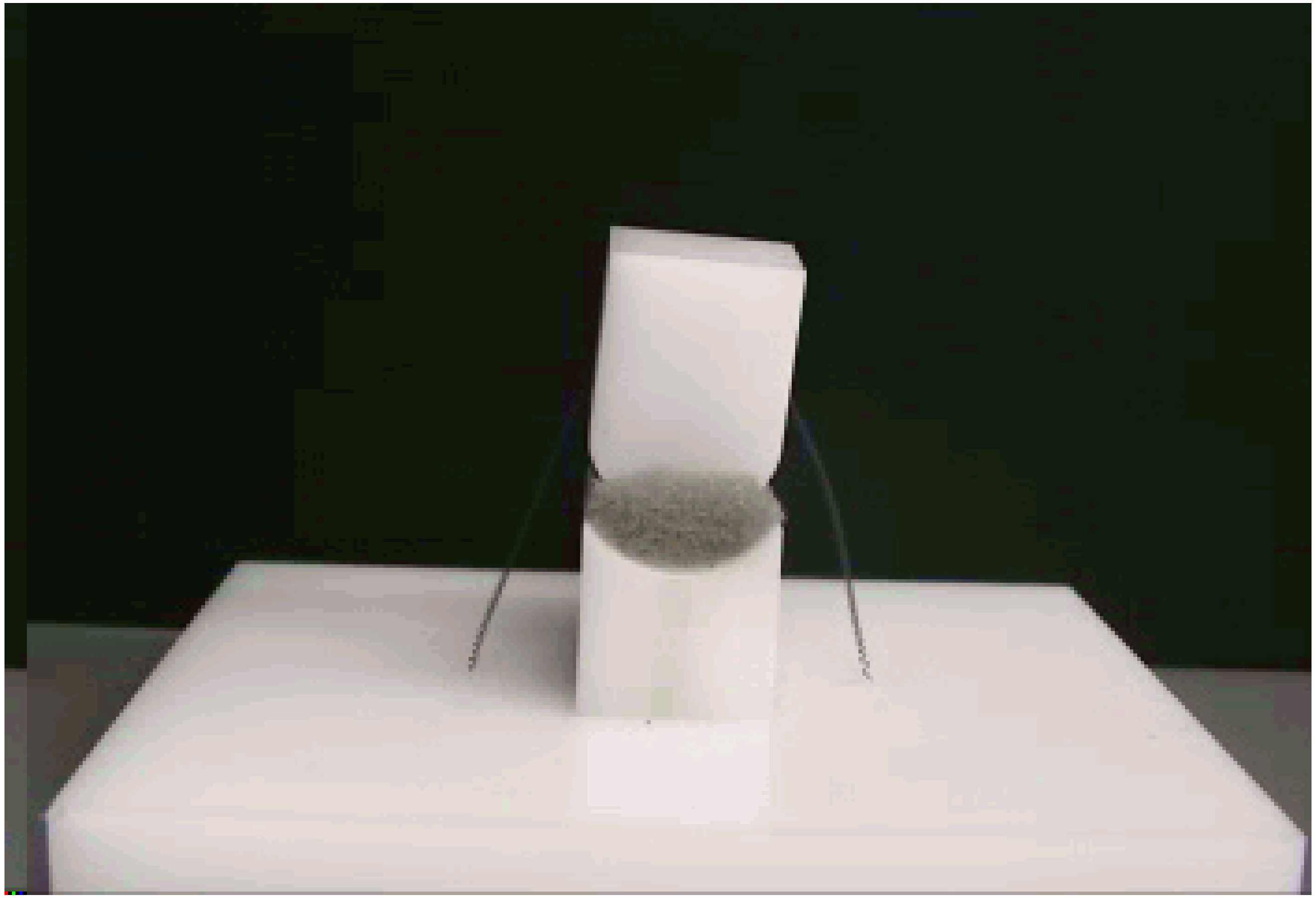
- Introduction
- Basic characteristics of loosely coupled joint
- Angle control using visual feedback
- Angle control using one length sensor
- Angle measurement method to reduce errors
- Conclusion

Prototype of loosely coupled joint



2D loosely coupled joint

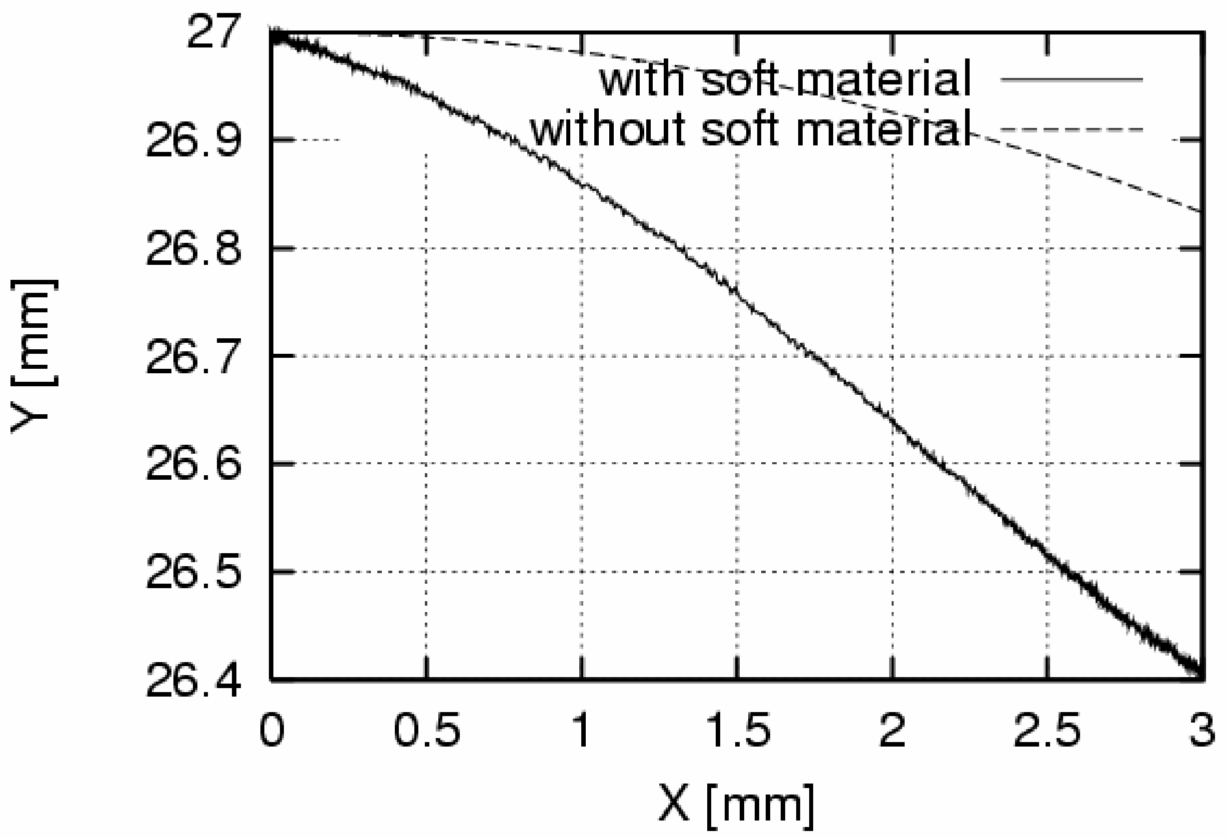
Movie



2D loosely coupled joint (movie)

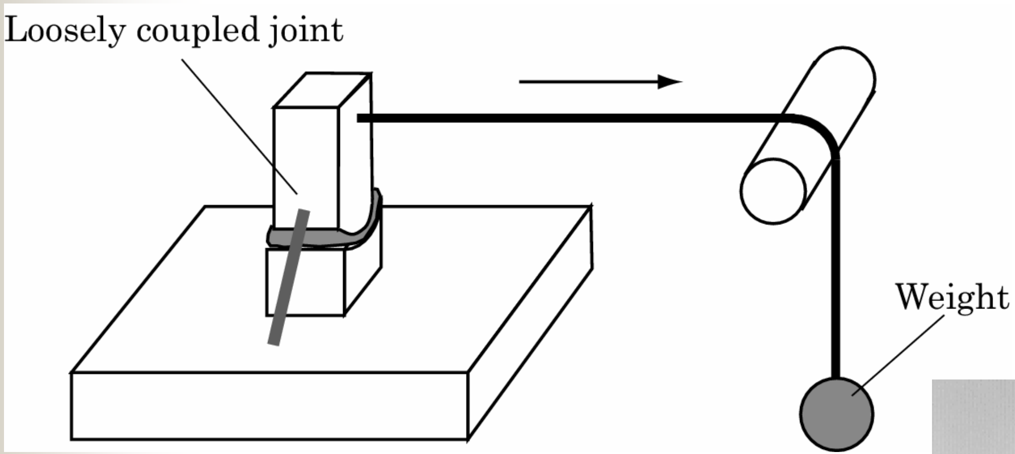
Sift of center of rotation

*** Measured by 1 kHz CMOS camera**



End-point position

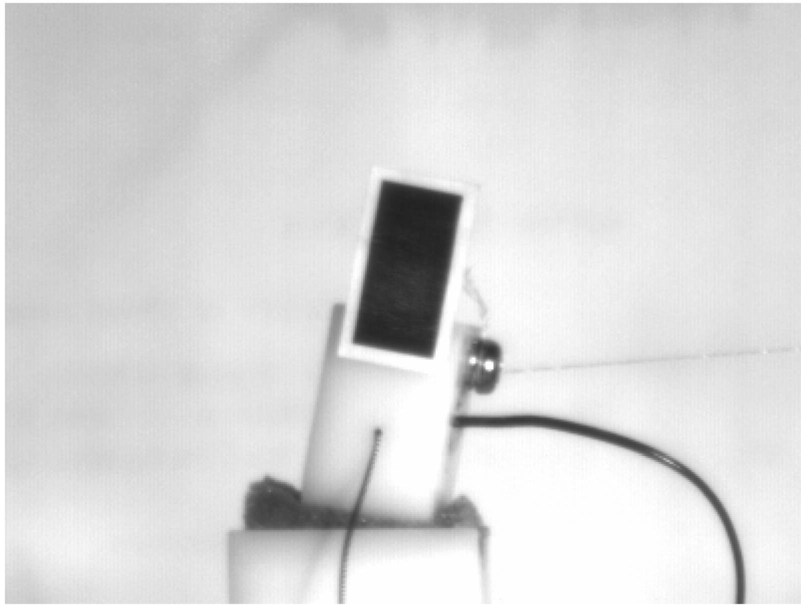
Compliance (1/2)



Experimental setup

Weight : 50 g

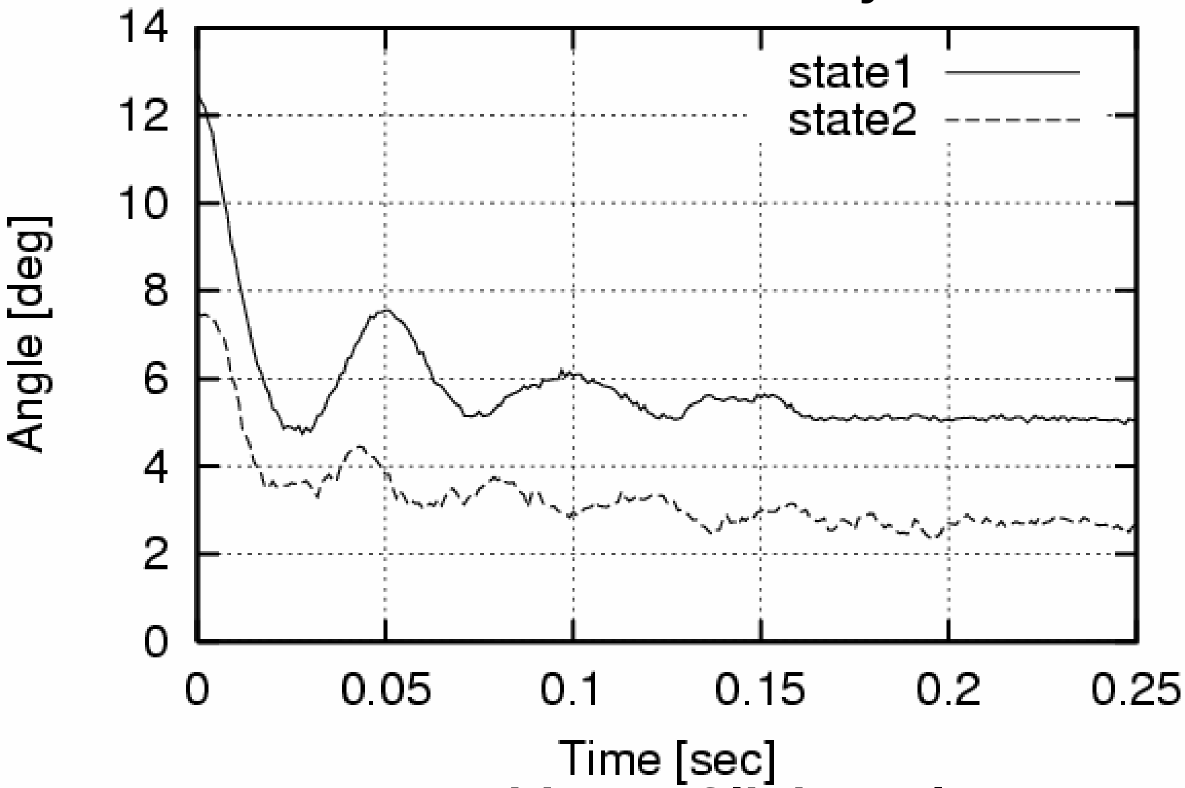
state1 : no-voltage
state2 : v_1=2.0V, v_2=3.0V



movie captured by 1 kHz CMOS camera

Compliance (2/2)

*** Measured by 1 kHz CMOS camera**



Transitions of link angle

state1 : no-voltage
state2 : v_1=2.0V, v_2=3.0V

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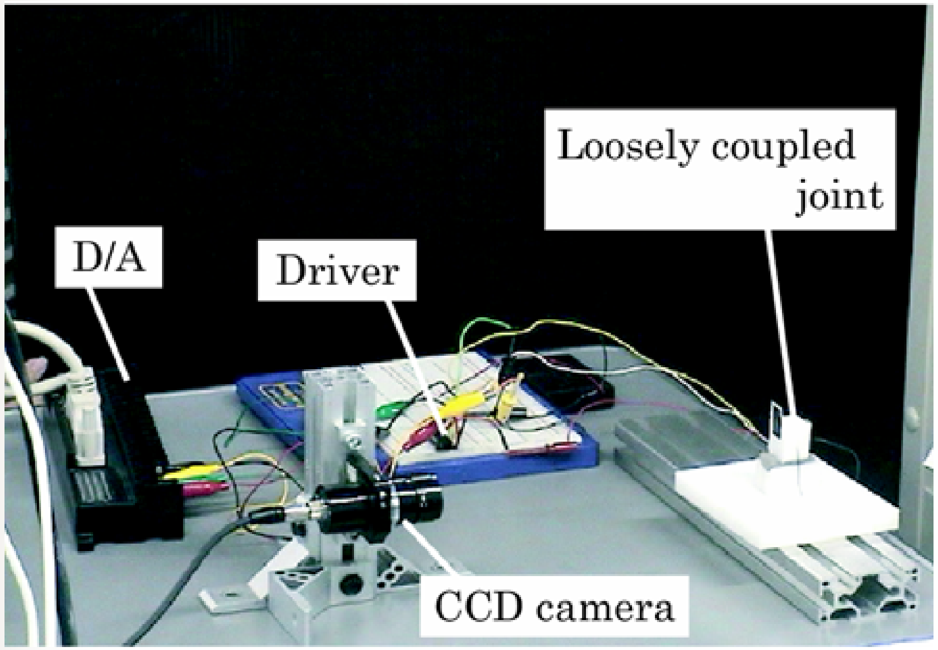
Experimental setup

Control laws (Proportional control for link angle)

$$\begin{cases} v_{inp}^{1} = -K_P(\theta(t) - \theta_d) + v_{offset} \\ v_{inp}^{2} = 0 \end{cases}$$

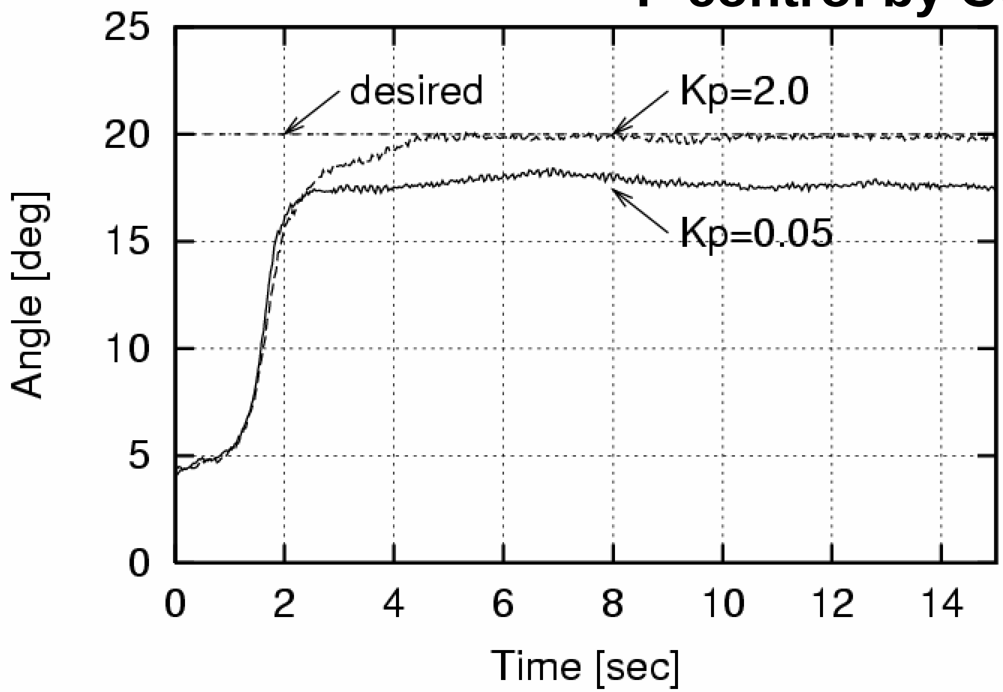


System

Vinp : Input voltage
Voffset : Offset voltage (= 1.7 V)
Kp : Proportional gain
θ (t) : Current angle
θ *d* : Desired angle

Experimental result

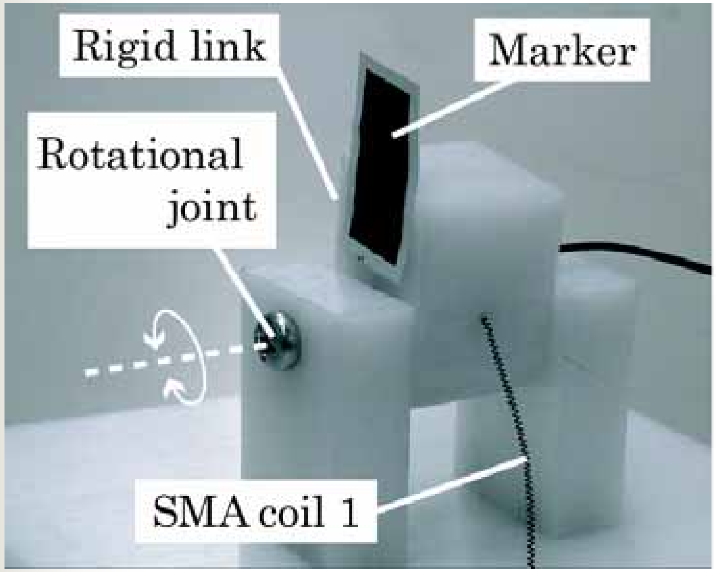
* P control by CCD image



Transitions of link angle

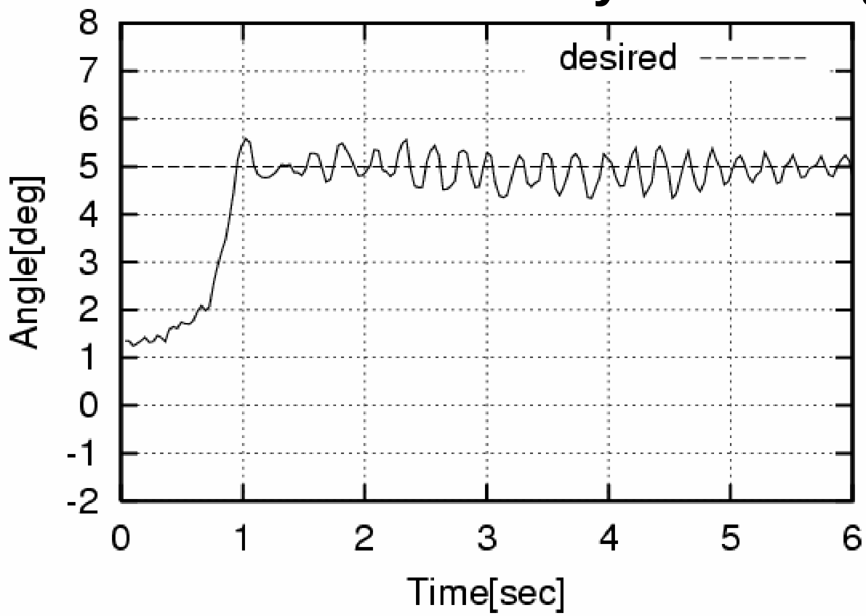
The link converges to the desired angles stably using simple P control only.

Comparative experiments



(a) Photograph

*** P control by CCD image**

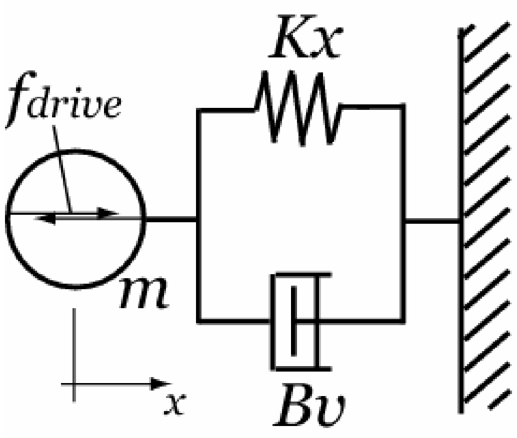


(b) Link angle

Pin joint

→ **Viscoelastic object of cartilaginous area contributes the system stability.**

Viscosity of the cartilaginous area



Pushing a viscoelastic object on a wall

The system converges due to the viscosity of the soft material.

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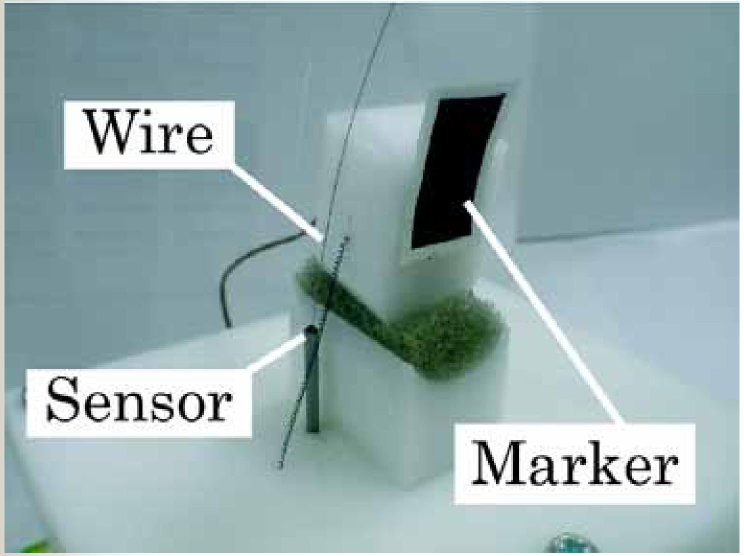
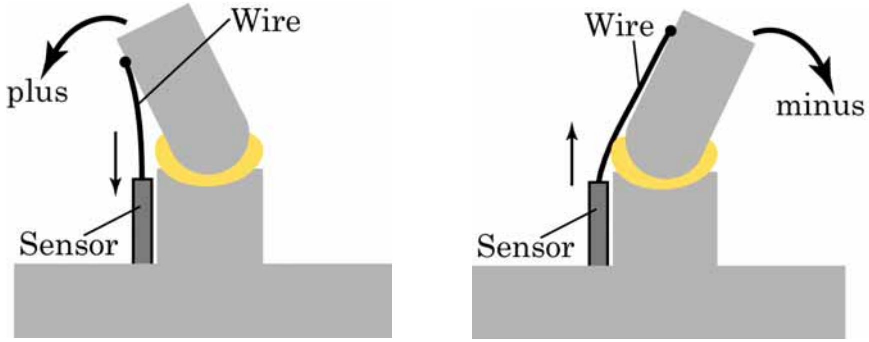
With length sensor (1/4)



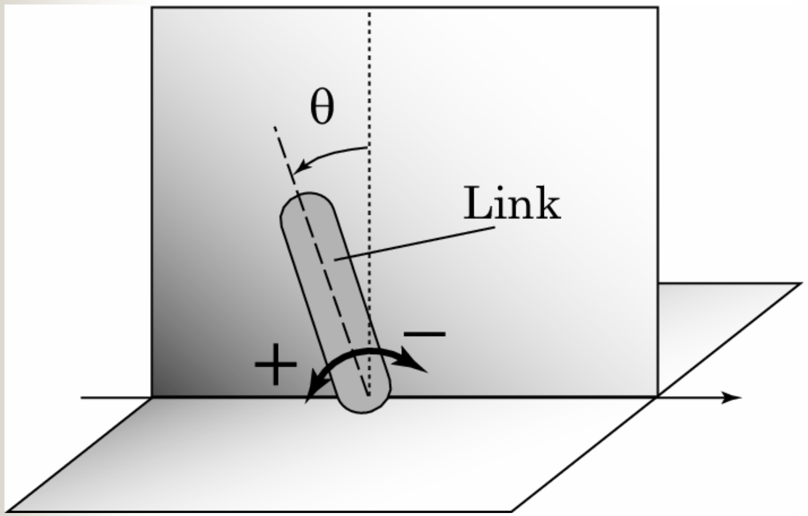
(a) Photograph



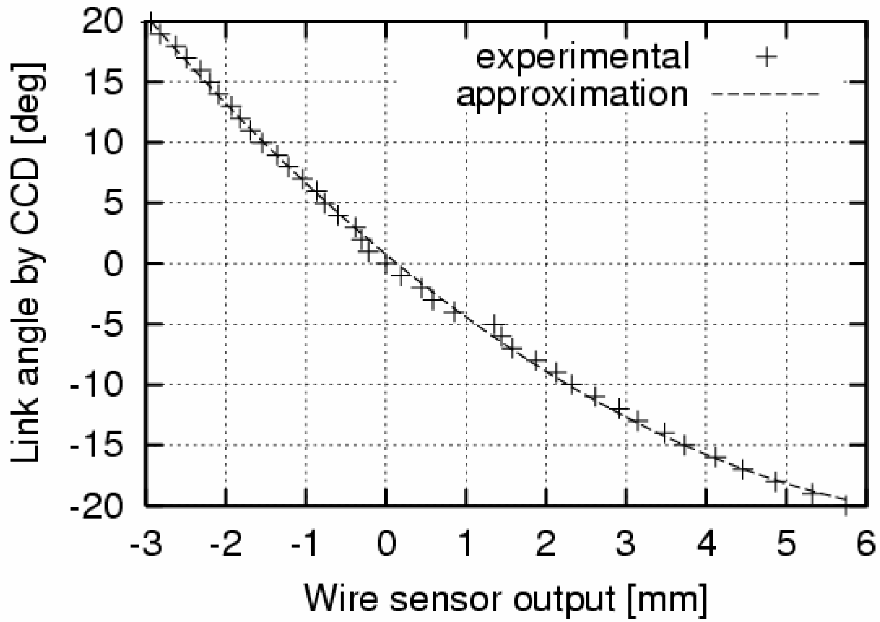
(b) Configuration

Loosely coupled joint with length sensor

With length sensor (2/4)



Coordinate system for 2D



Angle identification for the length sensor (2D)

$$\boxed{\theta = Ad^2 + Bd + C}$$

With length sensor (3/4)

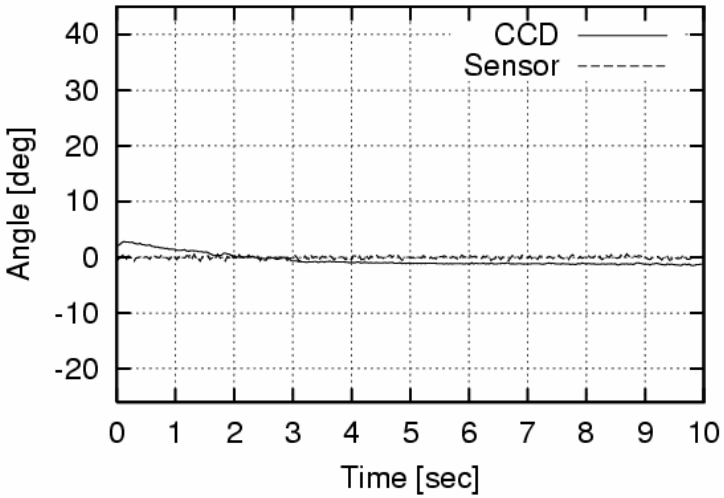
Control laws (Proportional control for link angle)

$$v_{\text{inp}}^1 = \begin{cases} -K_P(\theta(t) - \theta_d) + v_{\text{offset}} : & \text{when } \theta(t) < \theta_d \\ 0 : & \text{when } \theta(t) \geq \theta_d \end{cases},$$

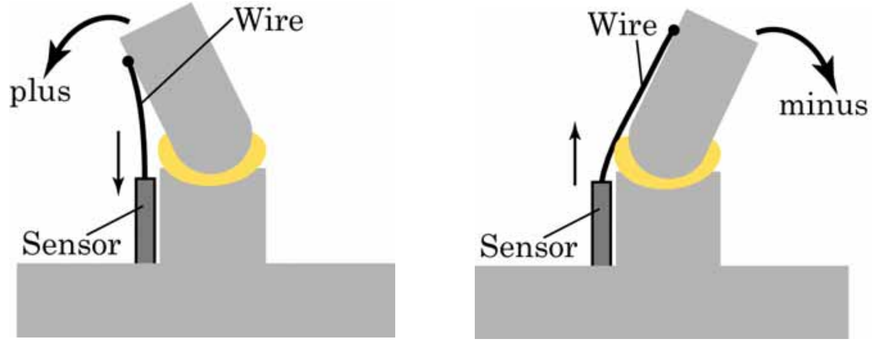
$$v_{\text{inp}}^2 = \begin{cases} 0 : & \text{when } \theta(t) < \theta_d \\ -K_P(\theta(t) - \theta_d) + v_{\text{offset}} : & \text{when } \theta(t) \geq \theta_d \end{cases}.$$

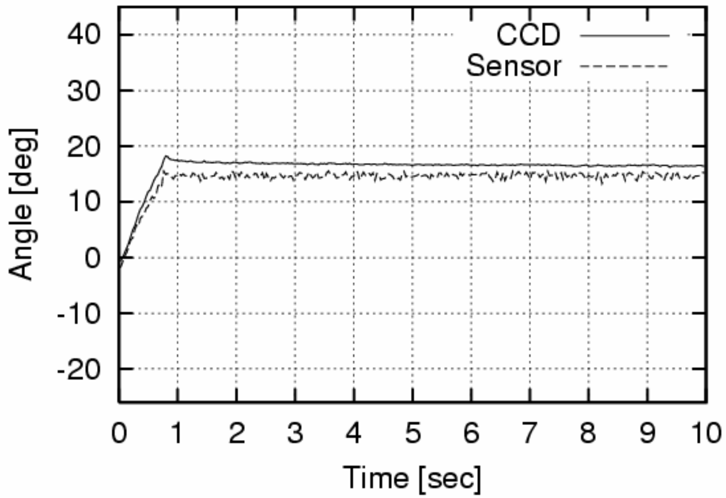
V_{inp} : Input voltage
V_{offset} : Offset voltage (= 1.7 V)
Kp : Proportional gain
$\theta(t)$: Current angle
θ_d : Desired angle

With length sensor (4/4)

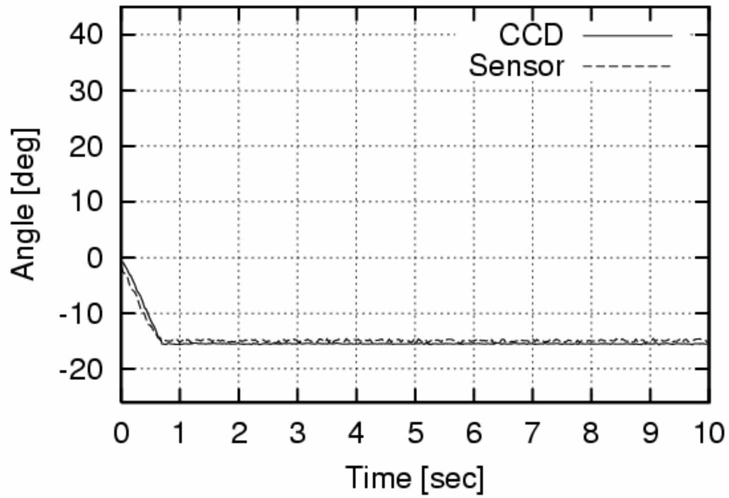


θ_d = 0 deg





θ_d = 15 deg



θ_d = -15 deg

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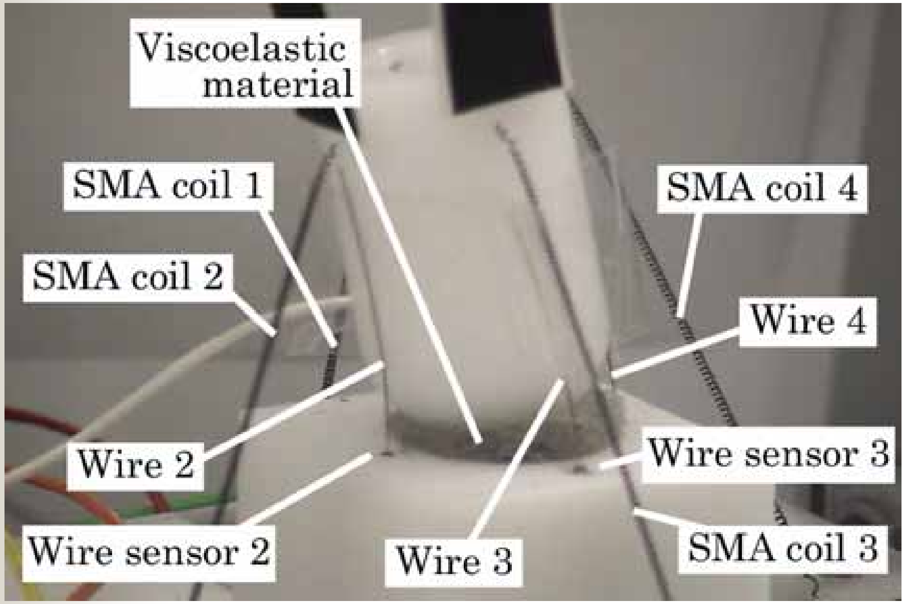
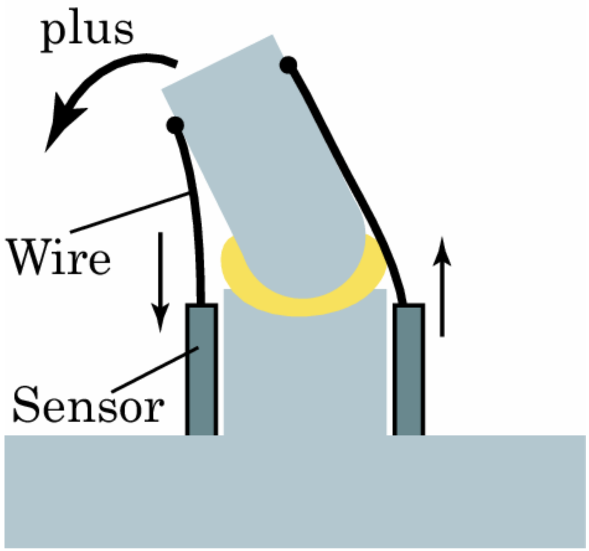
3D type loosely coupled joint (1/4)

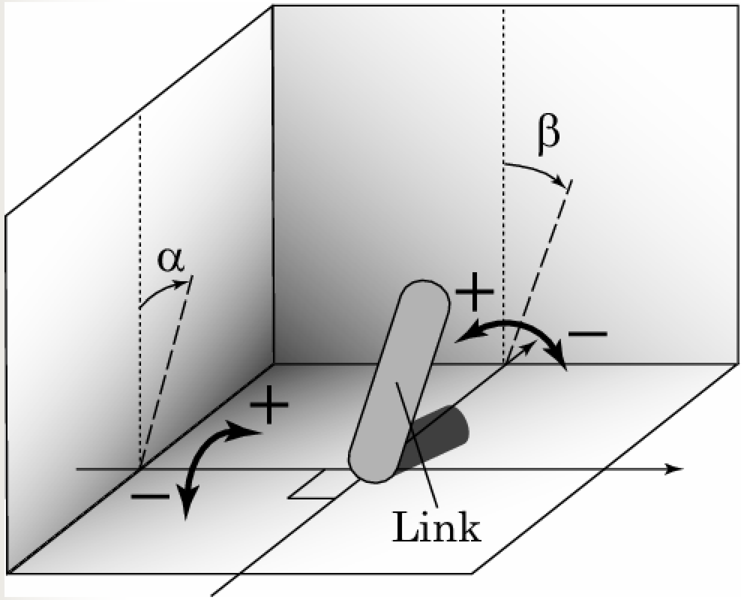




3D loosely coupled joint

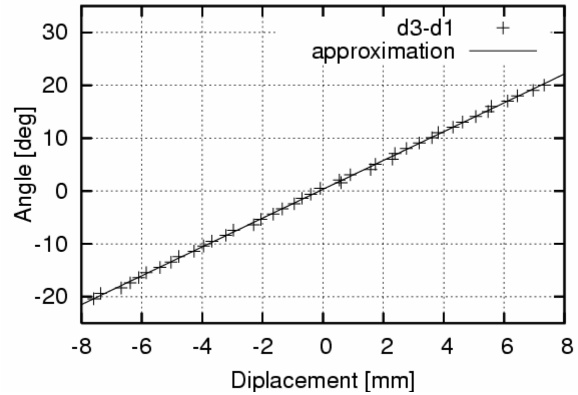
Control of two projecting angles

3D type loosely coupled joint (2/4)

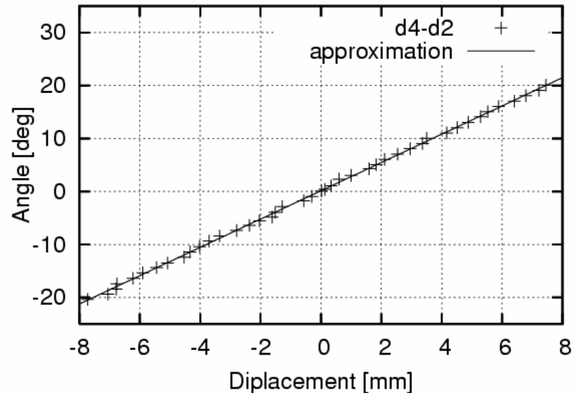


Coordinate system for 3D

$$\alpha = A(d_3 - d_1) + B,$$
$$\beta = C(d_4 - d_2) + D,$$



(a) **α side**



(b) **β side**

Angle identification for the length sensors (3D)

3D type loosely coupled joint (3/4)

Control laws (Proportional control for link angle)

α side

$$v_{\text{inp}}^{1} = \begin{cases} -K_{P1}(\alpha(t) - \alpha_d) + v_{\text{offset}} : & \text{when } \alpha(t) < \alpha_d \\ 0 : & \text{when } \alpha(t) \geq \alpha_d \end{cases},$$

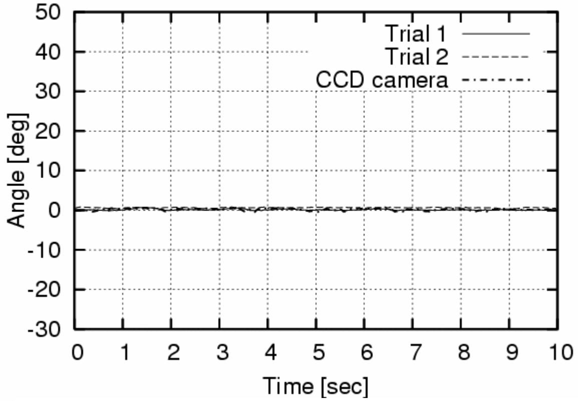
$$v_{\text{inp}}^{3} = \begin{cases} 0 : & \text{when } \alpha(t) < \alpha_d \\ -K_{P3}(\alpha(t) - \alpha_d) + v_{\text{offset}} : & \text{when } \alpha(t) \geq \alpha_d \end{cases}.$$

β side

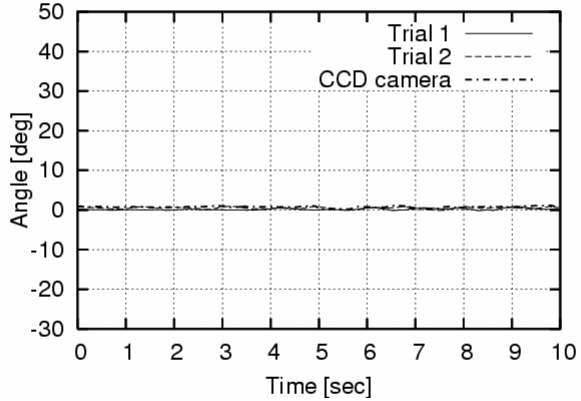
$$v_{\text{inp}}^{2} = \begin{cases} -K_{P2}(\beta(t) - \beta_d) + v_{\text{offset}} : & \text{when } \beta(t) < \beta_d \\ 0 : & \text{when } \beta(t) \geq \beta_d \end{cases},$$

$$v_{\text{inp}}^{4} = \begin{cases} 0 : & \text{when } \beta(t) < \beta_d \\ -K_{P4}(\beta(t) - \beta_d) + v_{\text{offset}} : & \text{when } \beta(t) \geq \beta_d \end{cases},$$

3D type loosely coupled joint (4/4)

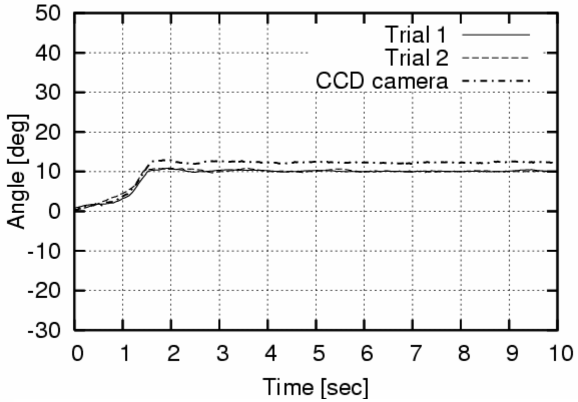


(a) α side

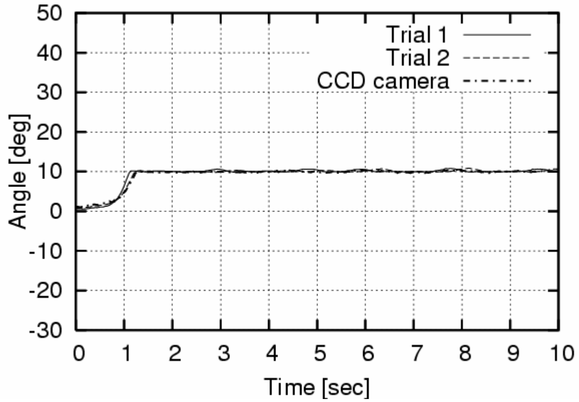


(b) β side

α_d = 0 deg, β_d = 0 deg



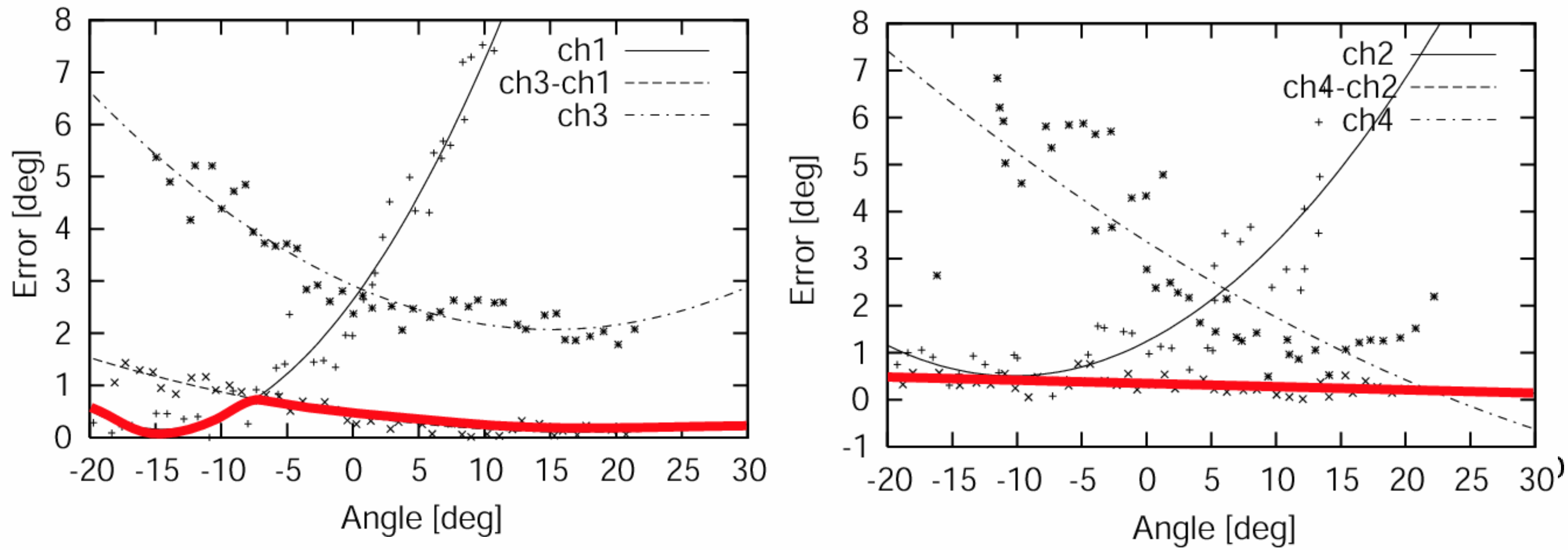
(a) α side



(b) β side

α_d = 10 deg, β_d = 10 deg

Angle measurement method



(a) **α side** (b) **β side**

Relationship between measurement error and method

$$\begin{cases} \alpha(t) = A_0(d_3 - d_1) + B_0 : & \text{when } \alpha(t) \geq \alpha_{th} \\ \alpha(t) = A_1 d_3^2 + B_1 d_3 + C_1 : & \text{when } \alpha(t) < \alpha_{th} \end{cases},$$

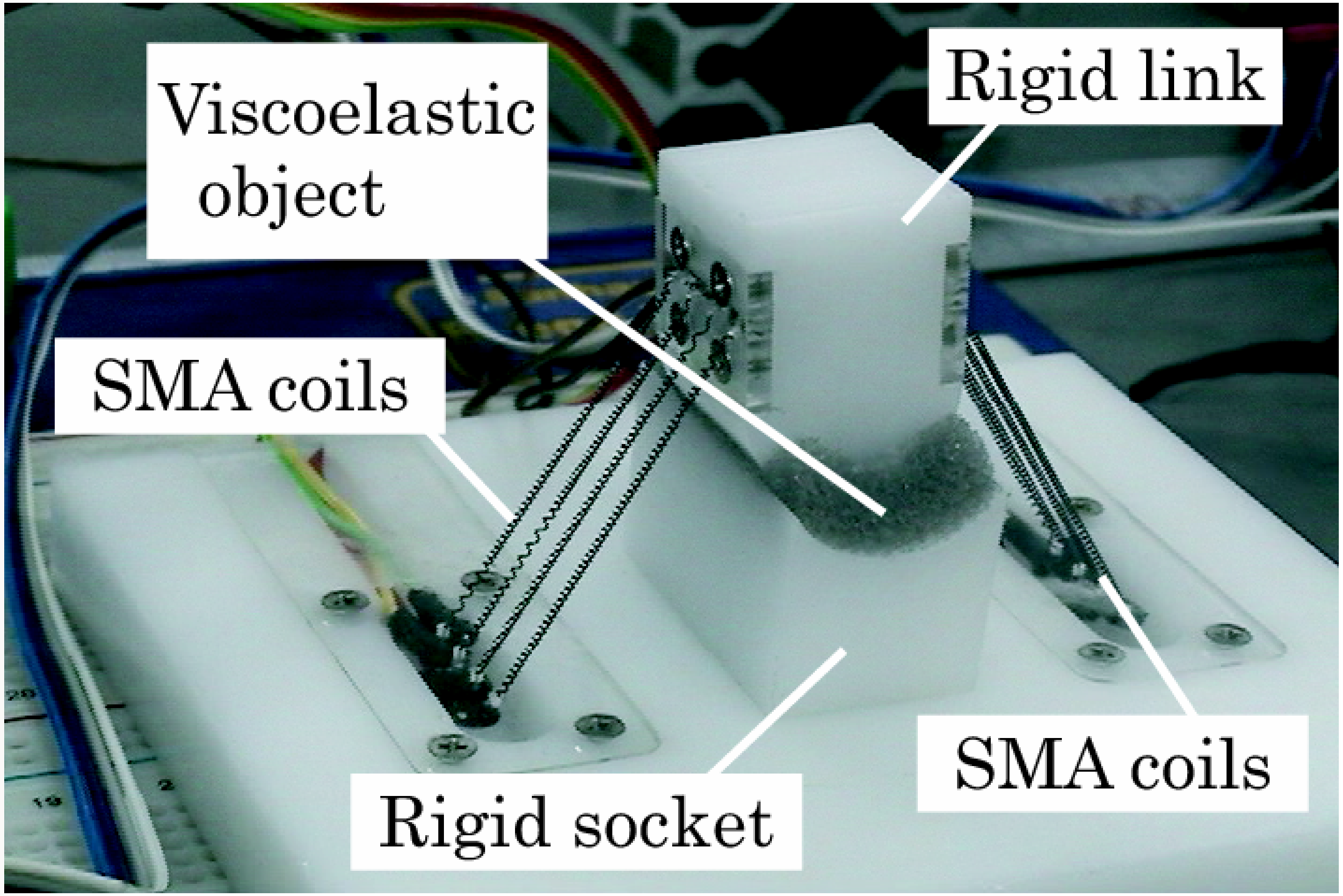
$$\beta(t) = A_2(d_3 - d_1) + B_2$$

Conclusion

- We constructed a robotic joint, dubbed a ***loosely coupled joint***, which has a viscoelastic object and soft actuators that function as the **cartilage** and **muscles** in human joints.
- The link angles converge to the desired angles stably using **simple P control** due to **viscosity of cartilaginous area**.
- Using the 3D prototype with length sensors, we have controlled **two projecting angles**.
- For each projecting plane, the errors were **less than 1.0 deg in our 3D prototype**.

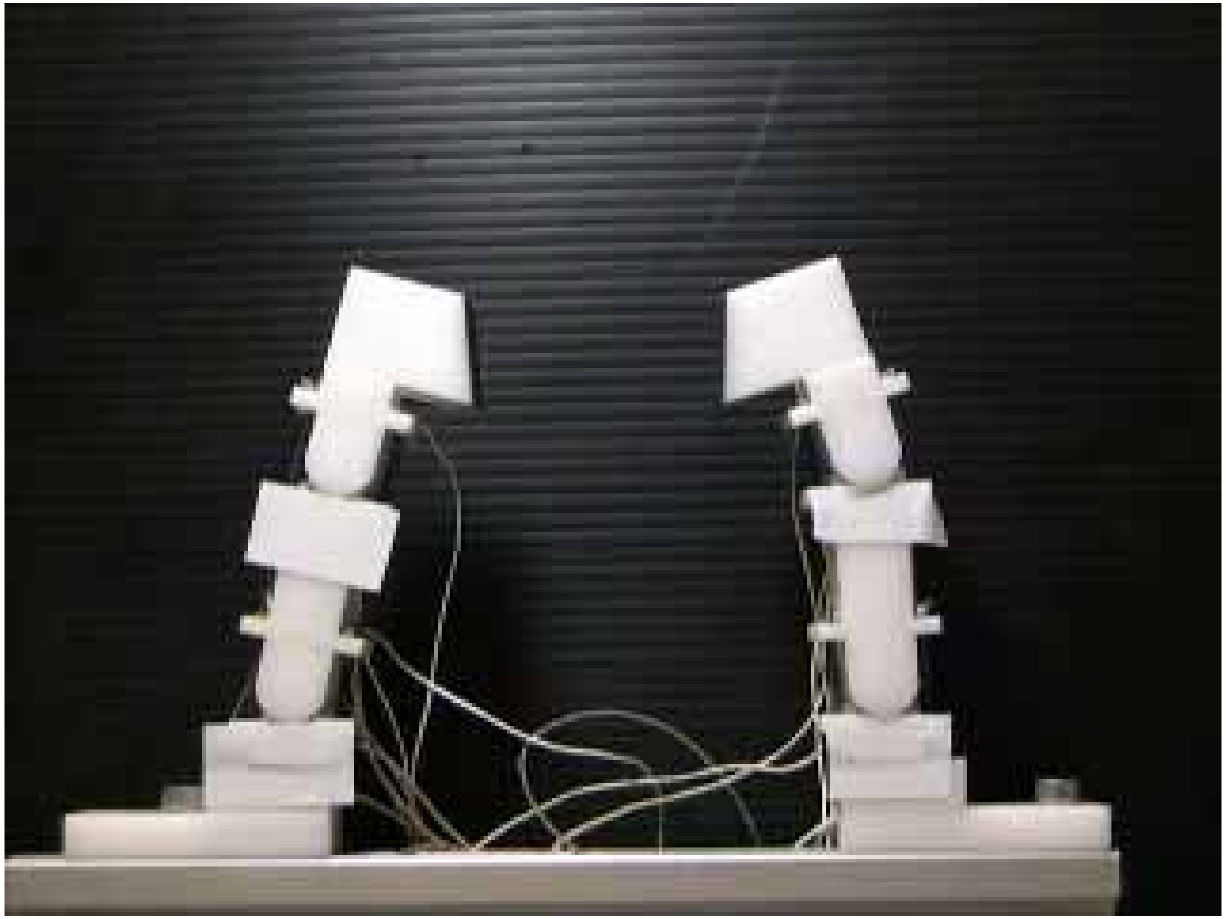
Thank you for your attention.

Ongoing issues



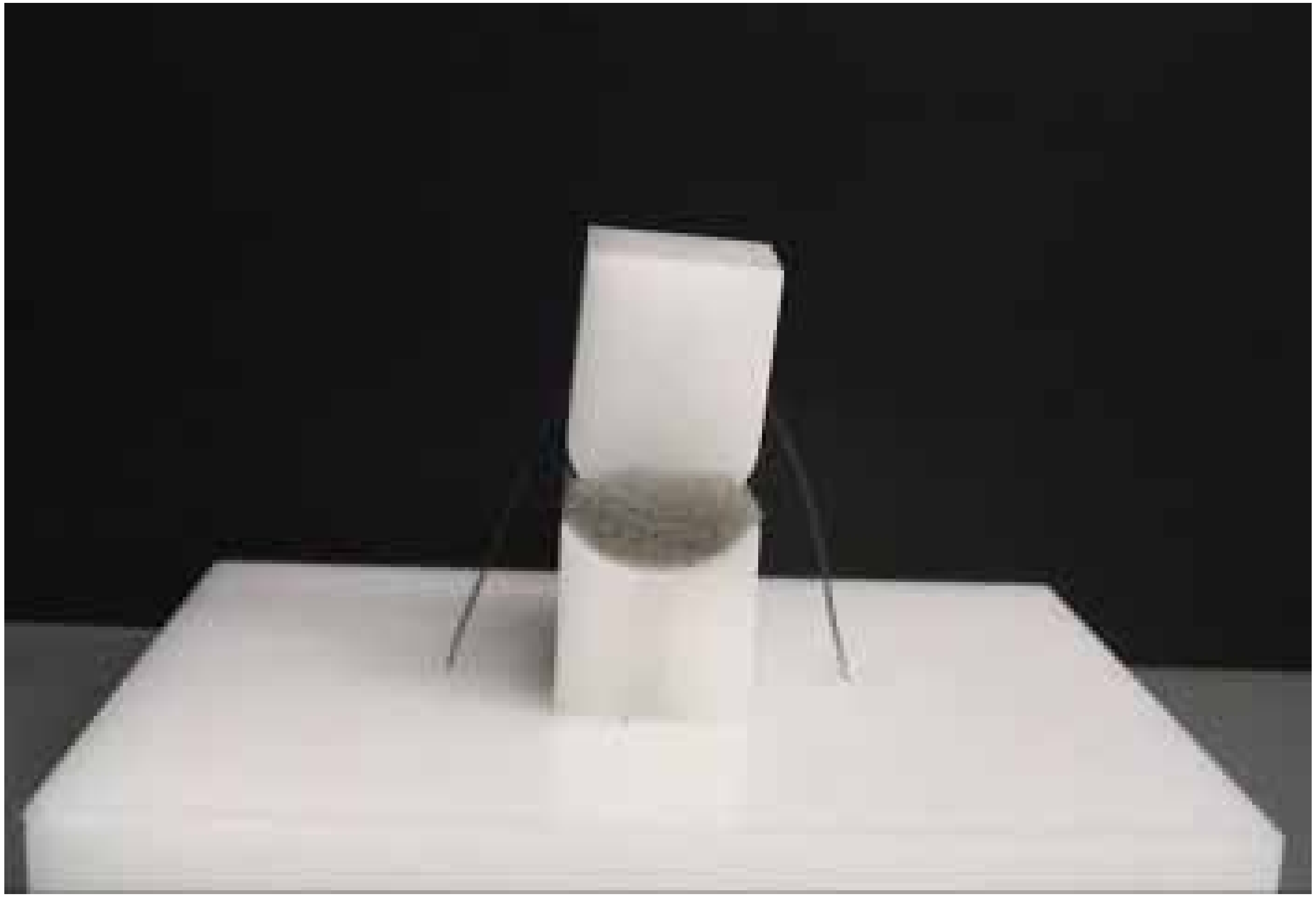
Loosely coupled mechanism with actuator bundles

Ongoing issues



Robotic hand with actuator bundles

Prototype in 2D space



2D loosely coupled joint