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## A Soft Robot Arm with Flexible Strain Sensors for Master-Slave Operation

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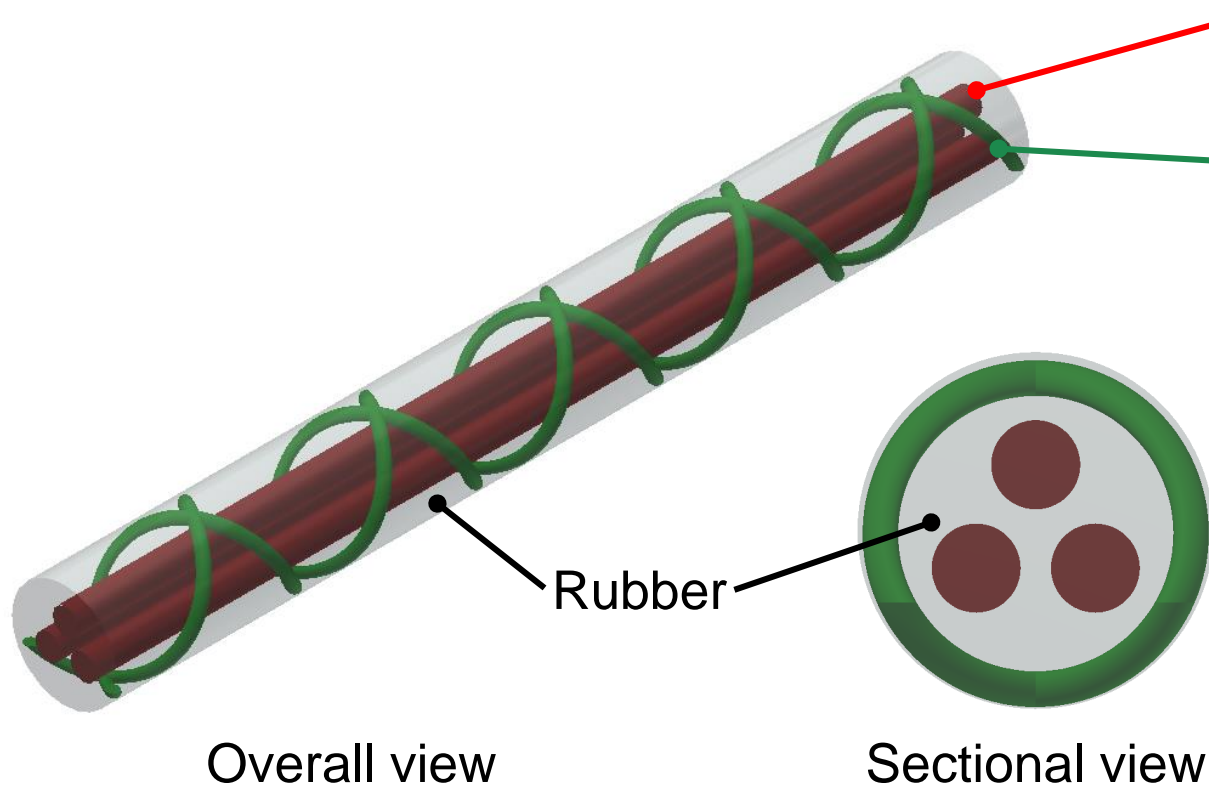
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# Research Background

- Soft Robot Arm : McKibben artificial muscles embedded in rubber structure



- ✓ Three artificial muscles in axial direction  
→ Bending motion
- ✓ Two artificial muscles in oblique direction  
→ Twisting motion

High flexibility  
→ Shape adaptability, Safety

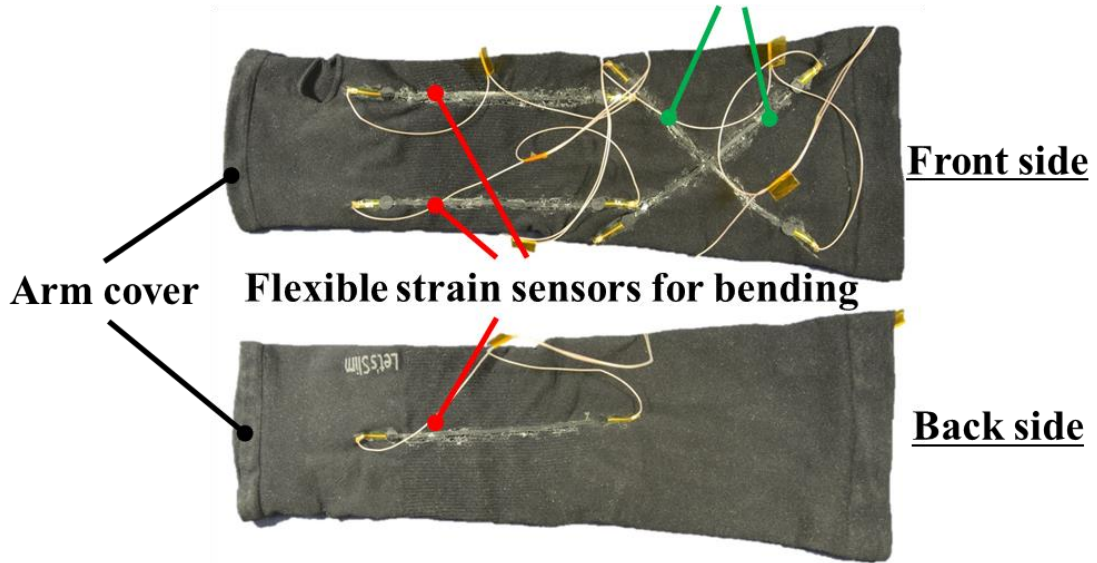


## Potential Application fields

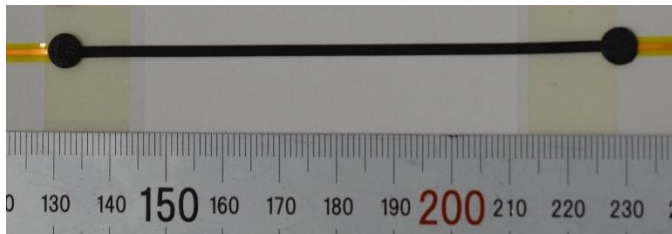
- ✓ Medical and welfare care
- ✓ Agriculture work

# Wearable Interface

Flexible strain sensors for twisting



Wearable Interface [1]



Flexible strain sensor

## ● Wearable Interface [1]

- Five flexible strain sensors on stretchable arm cover
  - ✓ Three at 120[° ] intervals at the wrist joint  
→ **Bending motion**
  - ✓ Two crossed arms at the forearm  
→ **Twisting motion**

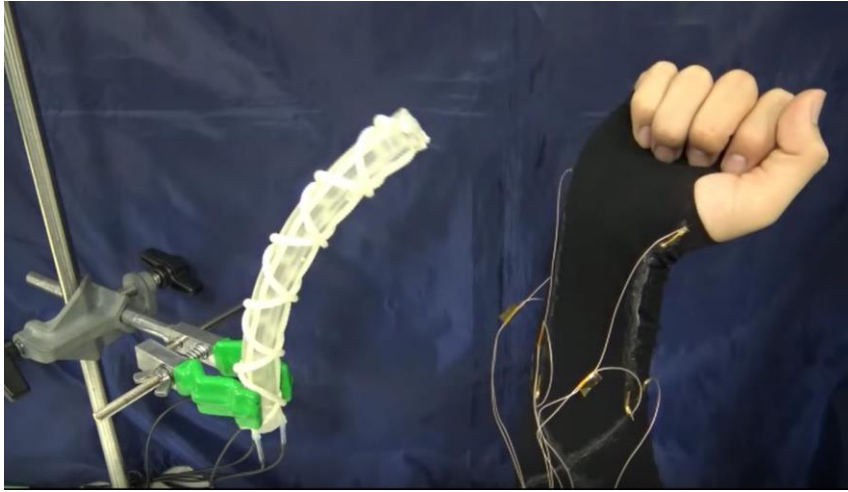
## ● Flexible strain sensor\*

- CNT (Carbon Nano Tube) and polymer layers
- Change of electrical resistance by strain

[1] Hagihara, H.; Wakimoto, S.; Kanda, T.; Furukawa, S. Operation of a pneumatic soft manipulator using a wearable interface with flexible strain sensors. *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems 2019*, pp.4949-4954.

\*Stretchable dynamic strain sensor, Yamaha Corporation

# Purpose



Bending and twisting motion



Application example with robot hand

Master-slave operation by feedforward control [1]

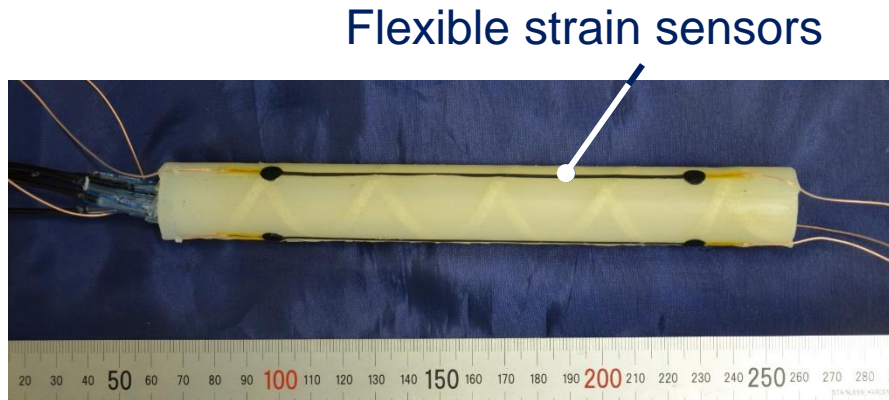


**Purpose : Feedback control by installing sensors on the soft robot**

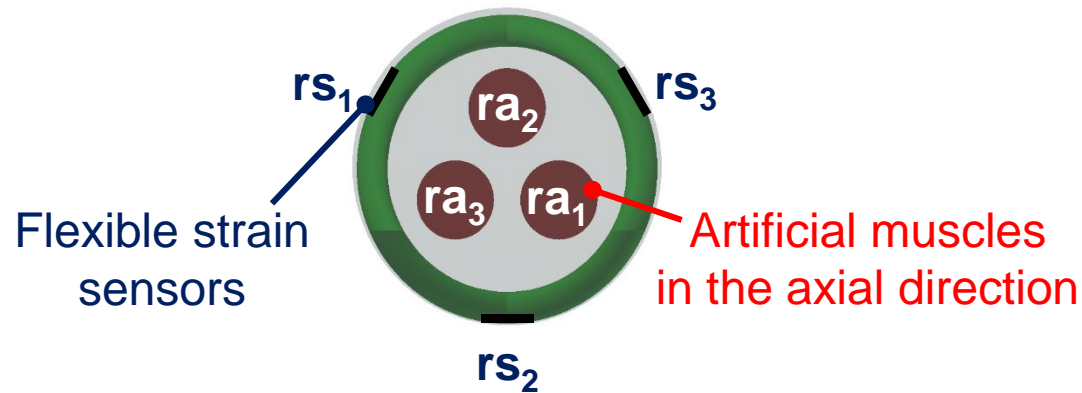
In this report, we focus on the bending motion as a basic research.

[1] Hagihara, H.; Wakimoto, S.; Kanda, T.; Furukawa, S. Operation of a pneumatic soft manipulator using a wearable interface with flexible strain sensors. *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2019*, pp.4949-4954.

# Mounting Flexible Strain Sensors on a Soft Robot Arm



General view



Sectional view

- ✓ Three sensors in the axial direction  
→ Bending motion

- ✓ Correspondence of artificial muscles and sensors

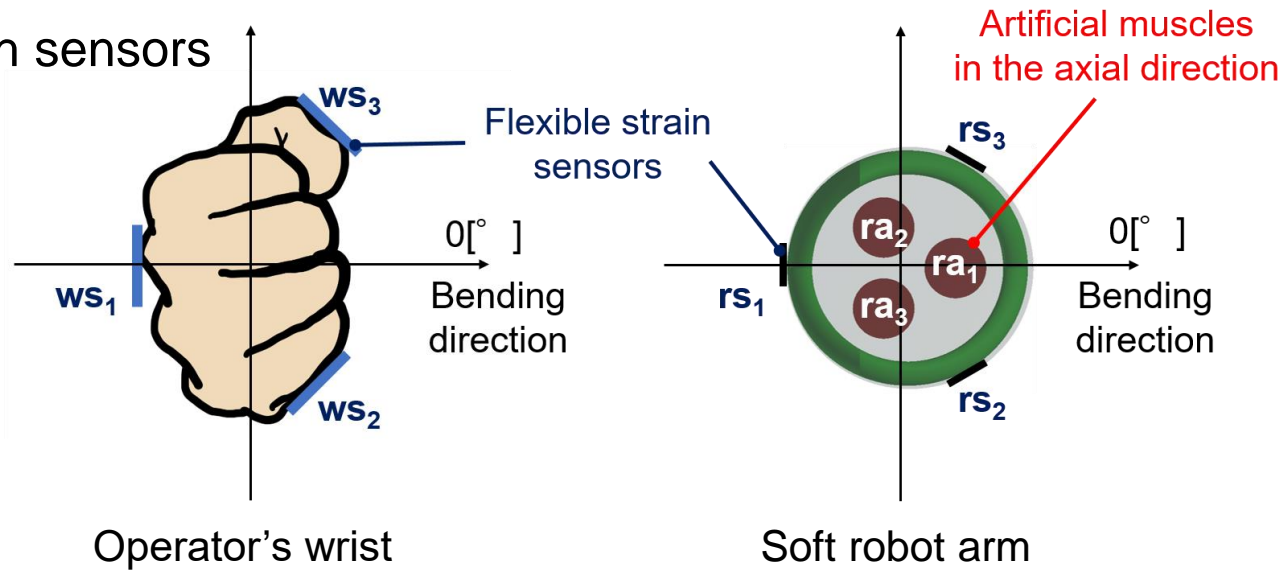
$$rs_i \Leftrightarrow ra_i \quad (i=1,2,3)$$

# Feedback Control in Bending Motion

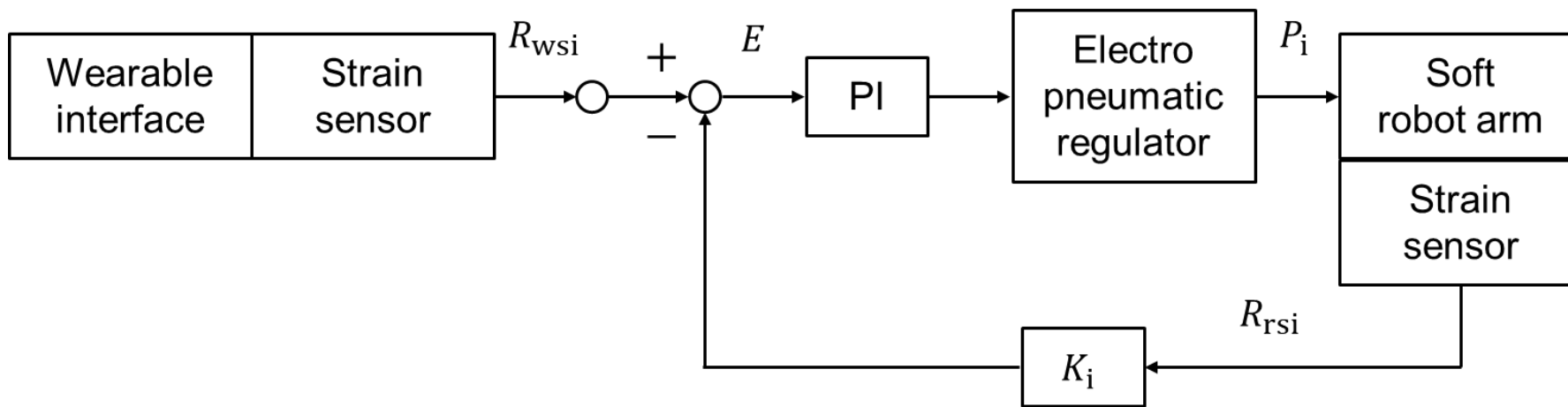
- Correspondence of each sensors

Wrist  $\Leftrightarrow$  Soft robot

$WS_i \Leftrightarrow rs_i$  ( $i=1,2,3$ )



- Block diagram of the system

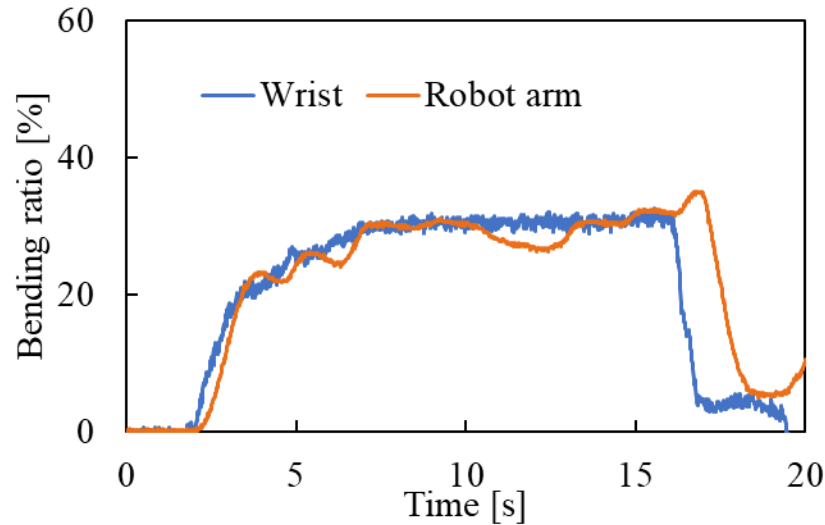
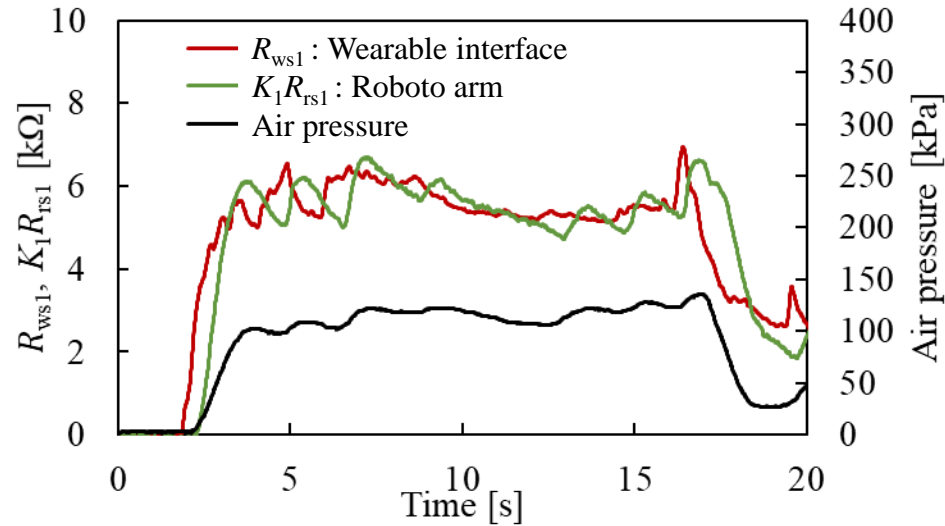


## Parameters

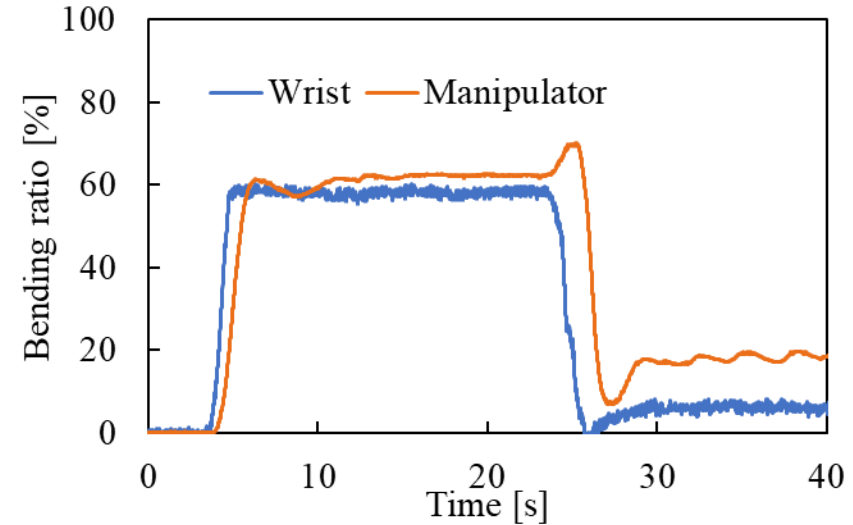
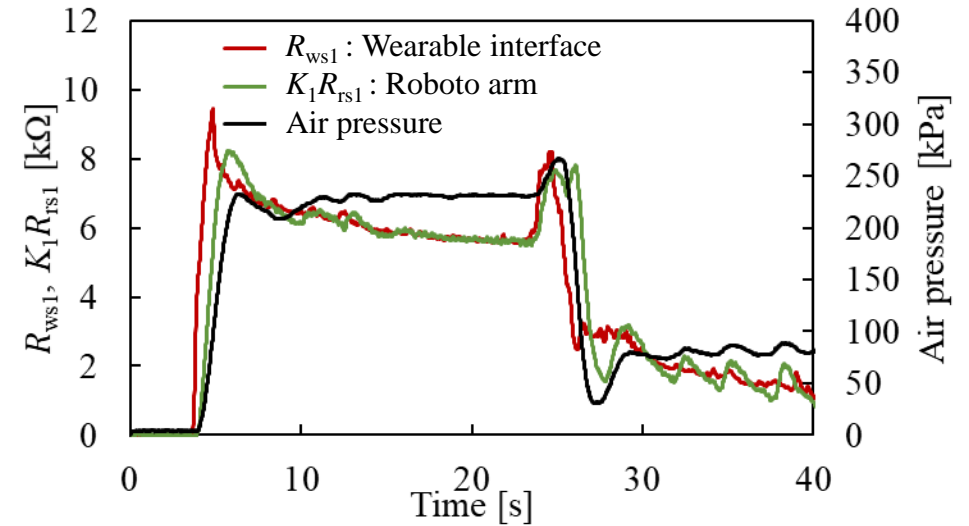
$E$	Deviation
$K_i$ ( $i=1,2,3$ )	Feedback gain
$R_{wsi}, R_{rsi}$ ( $i=1,2,3$ )	Electrical resistance change of sensor [[k $\Omega$ ]]
$P_i$ ( $i=1,2,3$ )	Pneumatic pressure [kPa]

# Result

## Without load



## With load



$$\text{Bending ratio}[\%] = (\text{Bending angle} / \text{Maximum bending angle}) \times 100$$



# Conclusion

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- ✓ We attached three flexible strain sensors on the soft robot for feedback control.
- ✓ By comparing the values of sensors, the wearable interface and the soft robot arm, we realized the feedback control in the bending motion.

## **Current work**

We are establishing the feedback control system for the twisting motion, then we will develop it into complex multiple DOF motions.