新学術領域「ソフトロボット学」
Science of Soft Robot

Soft Robotics : Principles and Perspectives

Koichi Suzumori
Tokyo Institute of Technology

Koichi SUZUMORI

1984-2001： Toshiba R&D Center
  Robots in nuclear plants, Medical robots, MEMS, Soft robots, etc.

1990 PhD from Yokohama National Univ.

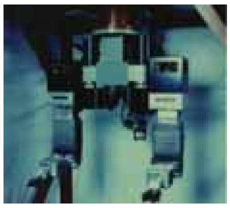
1999-2001： Micro Machine Center

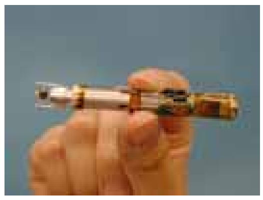
2001-2014： Professor, Okayama Univ.
  New actuators and their applications

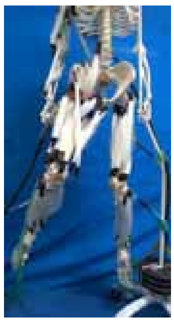
2014-current： Professor, Tokyo Tech.
  New actuators for robots,
  Pneumatic thin muscles, Hydraulic actuators

2016-current: President, s-muscle Co., Ltd.
  Thin soft muscles

2018-2023: Project manager of soft robot project of MEXT





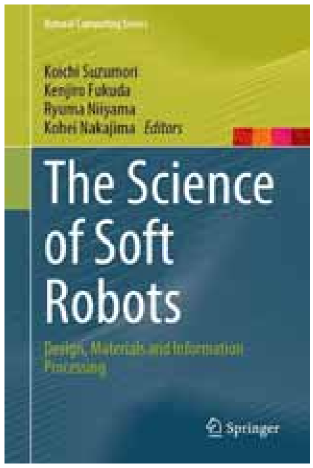


Reference books

Koichi Suzumori,
E-kagen robots,
Kgaku dojin, 2022,
¥1,760

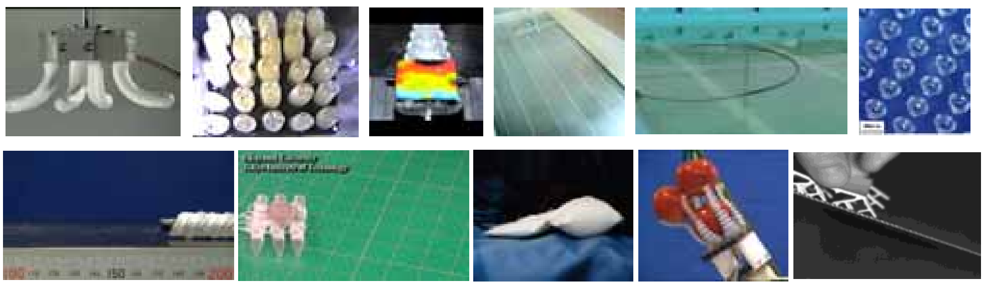
Koichi Suzumori,
Why robots
resemble animals?
Kgaku dojin, 2011,
¥968

Introduction of soft
robotics, 2011,
¥3,960



Springer, 2023,
$99.99

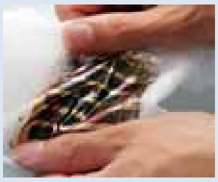
1 What’s Soft Robot?



Background of soft robotics

Researches on softness in Japan

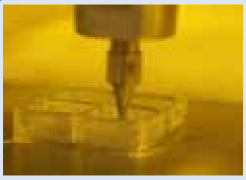
mechatronics



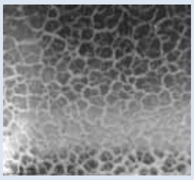
flexible electronics

soft machines

materials



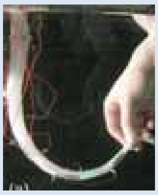
gel 3D printing



biological materials

computer

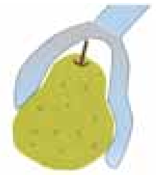
soft computing



bio-computing

Soft Robotics

Values of Biological Systems;
flexibility, adaptability, E-kagen



Conventional Robotics

Values of conventional engineering;
speed, force, accuracy, certainty

Conventional robots and living creatures

Conventional robots

Rigid metal bodies,
precise servo motors &
careful programming

→ **Speed, force, accuracy, & reliability**

International Robot Exhibition 2017

DARPA Robotics Challenge, 2017

Living creatures

Soft body,
flexible motion &
adaptable intelligence

→ **Flexibility, adaptability, & E-kagen**

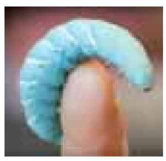
Flexible body shape change

winding

Dynamic motions using flexible body

Shape adaptability
passive force control

adaptability

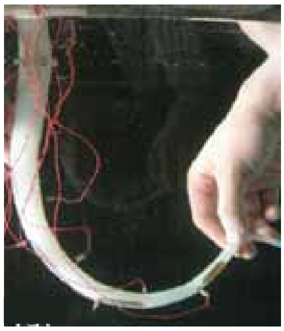


FMA, Shape adaptability
K. Suzumori, Tokyo Tech.

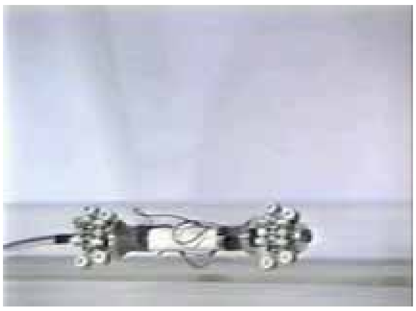
Self path-finding
K. Suzumori, Tokyo Tech.

Elastic energy
R. Niiyama, The Univ. of Tokyo

Motion generation
Umedachi, Shinsyu Univ.



Computing
K. Nakajima, The Univ. of Tokyo



Shape adaptability to the environment

Trans. IMACS/SICE Robotics and Manufacturing System, 1993

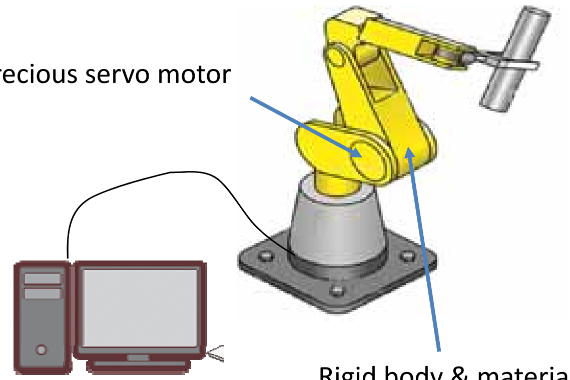
Self motion generation of ray

ICRA, 2007

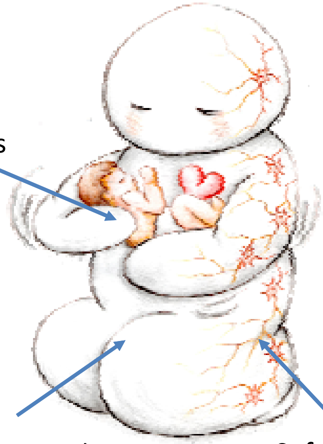
What’s soft robot?

やわらかい身体を持ち，環境や対象物に対して柔軟性と適応性を持って作用するロボット
(ロボット工学ハンドブック第3版　2020年12月刊行予定)
A robot that has a soft body and acts with flexibility and adaptability to its environment and objects. (3rd edition of the robot hand book by the Robotics society of Japan, to be published in Dec. 2020) (Deep L translation)

Soft Robotics is the specific subfield of robotics dealing with constructing robots from highly compliant materials, similar to those found in living organisms. (Wikipedia)



Power, accuracy, and certainty

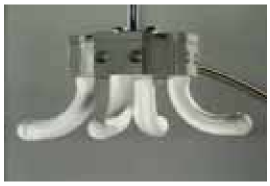


Flexibility, adaptability，E-kagen

Brief history of soft robotics

■ **1980’s～**
Various researches on soft robot in Japan


Film actuator, T. Higuchi


FMA, K. Suzumori

■ **2007～**
Big projects in US & EU
- DARPA Chembots, 2008-2010
- Maximum Mobility and Manipulation, 2011-2012
- NSF Soft Material Robotics PhD Program, 2012-2018
- EU(ICT-FET), OCTOPUS, 2009-2012,
- STIFF-FLOP, 2012-2015
- EU RoboCom++, 2017-2020


Whitesides, PNAS, 2011

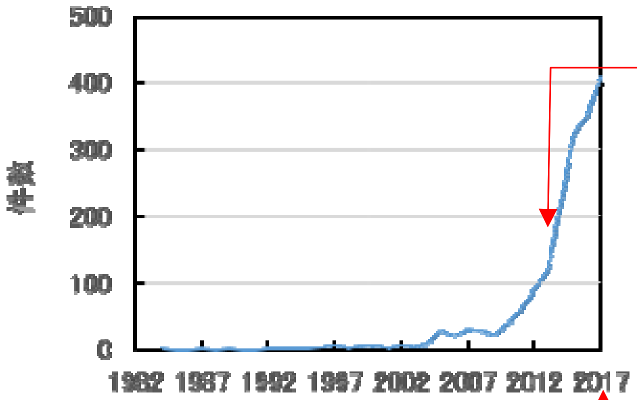

Jamming Gripper

■ **Academic**
2014- : **Soft Robotics Jour**. starts
2018-: IEEE **RoboSoft**

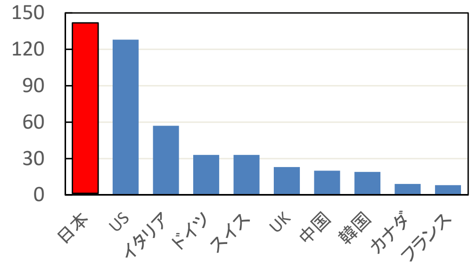

Octopus, EU 2009-2013


Disney, 2014

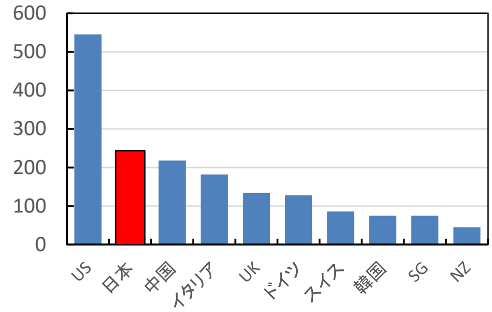
Rapidly rising activities



Number of academic papers on soft robots



Numbers of papers, 2013



Numbers of papers, 2017

検索ワード："soft robot*" OR "soft robotics*" OR "soft actuator*" OR "soft bodied robot*" OR "soft material*" AND "robot" (**論文タイトル、抄録、キーワード**) by Scopus

Science of Soft Robots
JSPS KAKENHI Grant-in-Aid for Scientific Research on Innovative Areas (2018-2022)

2 MEXT KAKENHI Project on Soft Robotics in Japan

Outline of project

MEXT KAKENHI
Grant-in-Aid for Scientific Research on Innovative Areas

【Project name】
Science of Soft Robot: Interdisciplinary integration of mechatronics, material science, and bio-computing

【Head Investigator】 Koichi SUZUMORI
【Homepage Address】 http://softrobot.jp

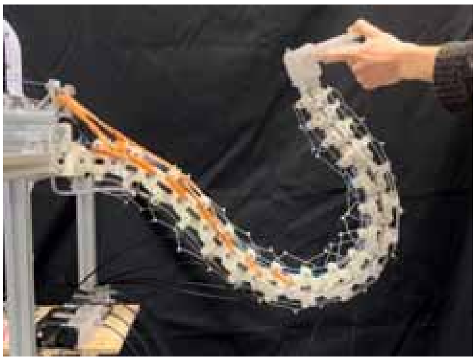
【Project Term】 FY2018-2022
【Budget Allocation】 236,340,000 Yen
【Research Subjects】 9 designated and 16 selected from public applications

MEXT KAKENHI, Science of soft robots

PV Science of Soft Robots

Search “science of soft robot” in YouTube

Flexible Bodies



Ostrich Robot
R. Niiyama, M.Gunji, H.Mochiyama

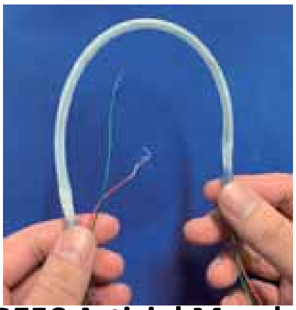
Thin Solar Cell
K.Fukuda

Soft Avatar Growing out
S. Young ah

Flexible Wing H.Tanaka, T.Nakata, T. Yamasaki

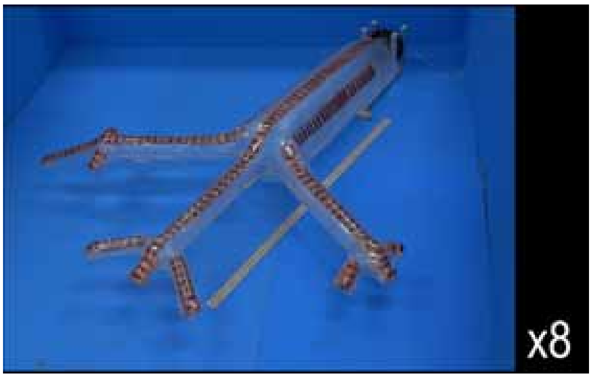
Flexible Shoulder Hammock
A.Fukuhara, M.Gunji, Y. Masuda

Flexible Motion



PEFC Articial Muscle
K. Suzumori, H. Nabae, K. Asaka, T. Horiuchi

IPMC Robot
K. Suzumori, H. Nabae, K. Asaka, T. Horiuchi

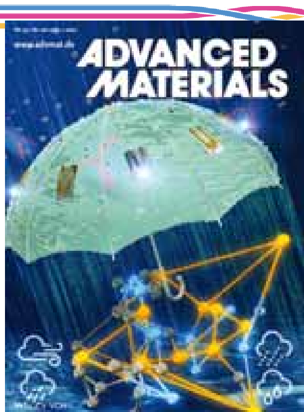


Extending Torus Robot K. Tadakuma

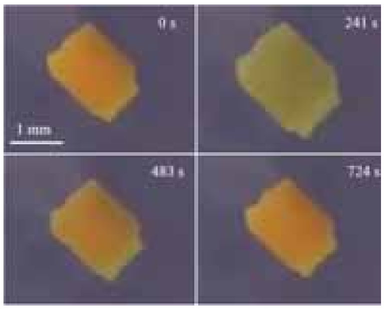
EHD Pump S.Maeda

Flexible Intelligence

Physical Deep Learning with Biologically Inspired Training Method,
K. Nakajima

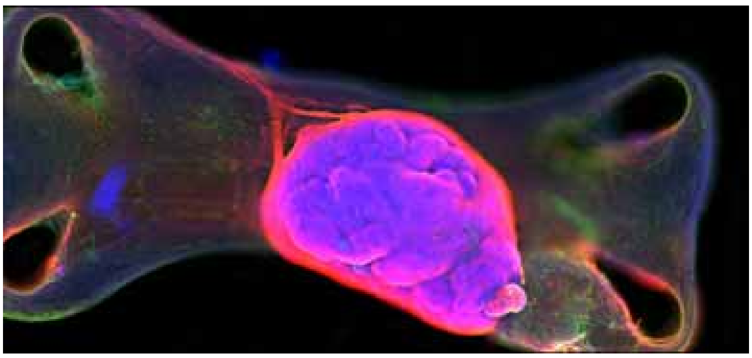


Water Droplet Sensor
K.Takei, K. Nakajima



Biological/Polymer Rhythms
H.Ito, S. Maeda

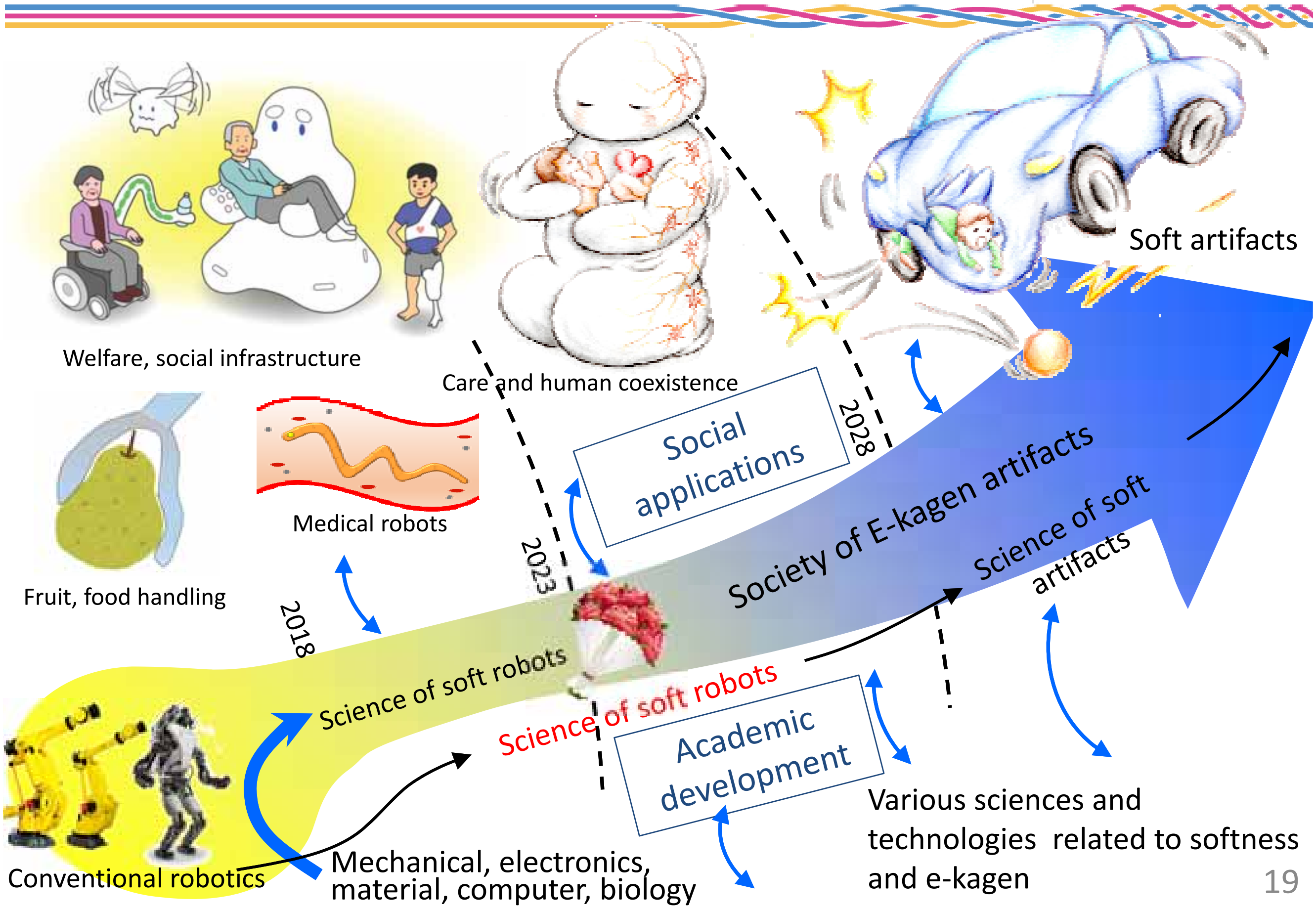
Thin EMG Sensor T. Fujie



Organoid M.Shimizu, K. Furusawa

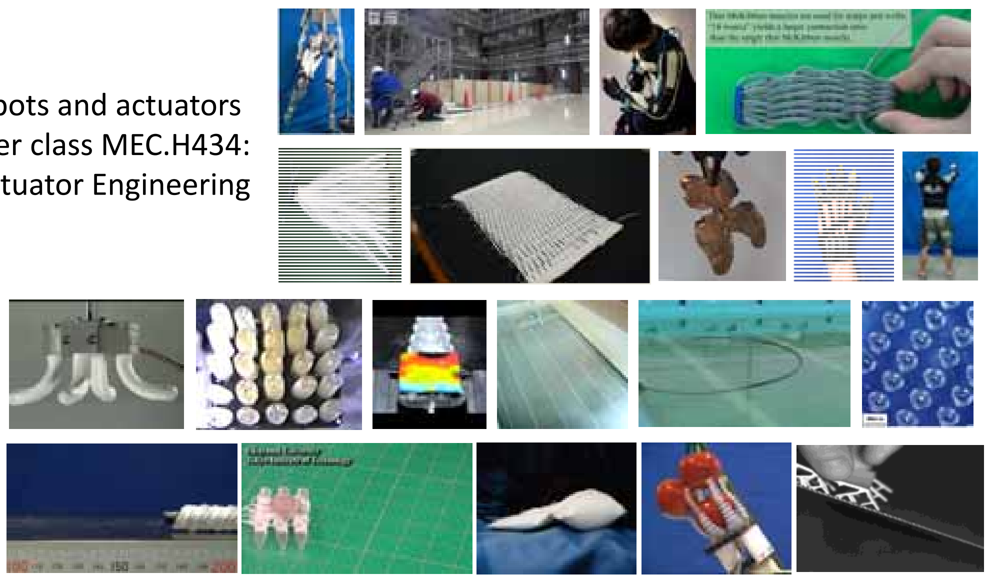
Future vision

Science of Soft Robot

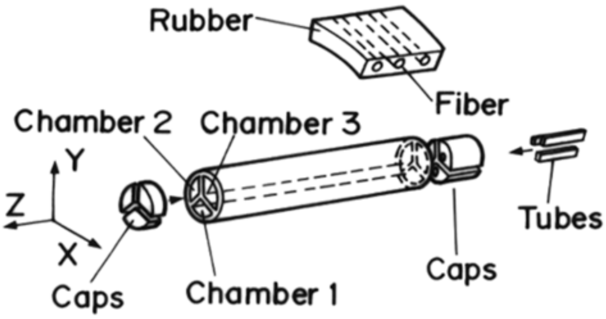


3 Several examples of soft robots

The details of these robots and actuators will be taught in another class MEC.H434: Advanced Course of Actuator Engineering in 3Q semester.



My First Soft Robot --- FMA --- in 1986



Flexible Microactuator

Robotics Soc. Jpn, 1986

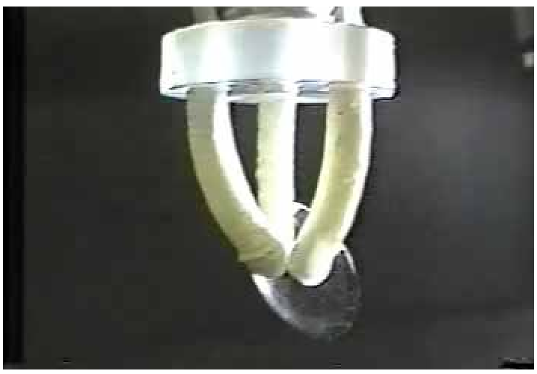
IEEE ICRA, 1991

IEEE MEMS Workshop, 1991

Robot Applications of FMA

IEEE ICRA, 1991

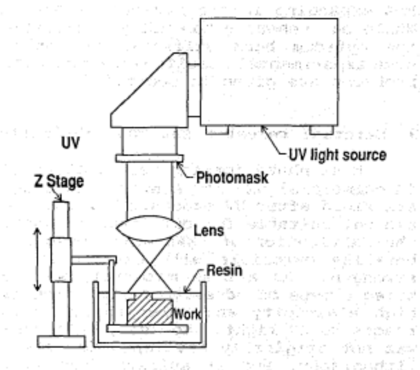
IEEE MHS, 1991

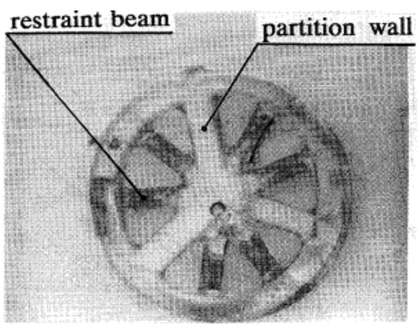


Miniature fingers handling a contact lens

Manta robot, 1994

Integrated FMAs --- Stereo lithography, 3D printing --- 23





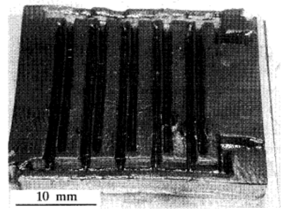
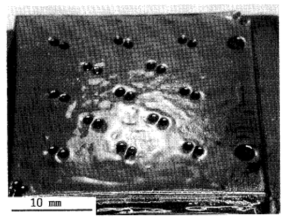
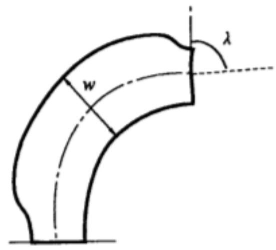


Fig.12 Pneumatic circuits, each line 0.8 mm wide and 2.5 mm high



Integrated miniature FMAs fabricated through stereo lithography, IEEE MEMS Workshop, 1994

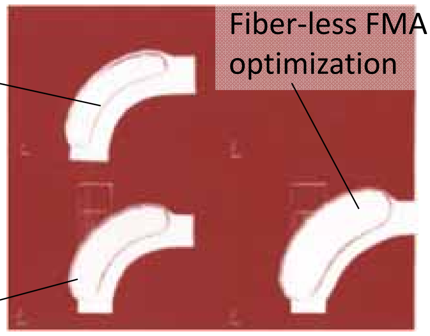
Fiberless FMA with Optimized Design of Cross-section 24



Evaluation function

$$f = C_1\lambda + C_2\varepsilon_d + C_3 T_{max}$$

Normal FMA with fiber

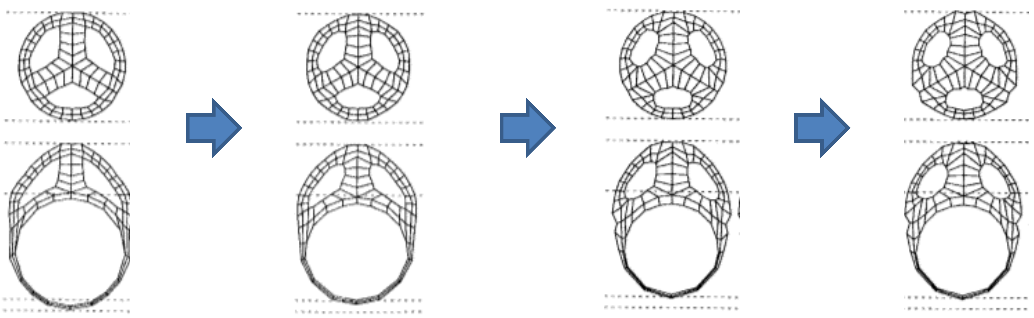


Optimized design of fiber-less FMA

12 16 22 28

Cross-section without pressurized

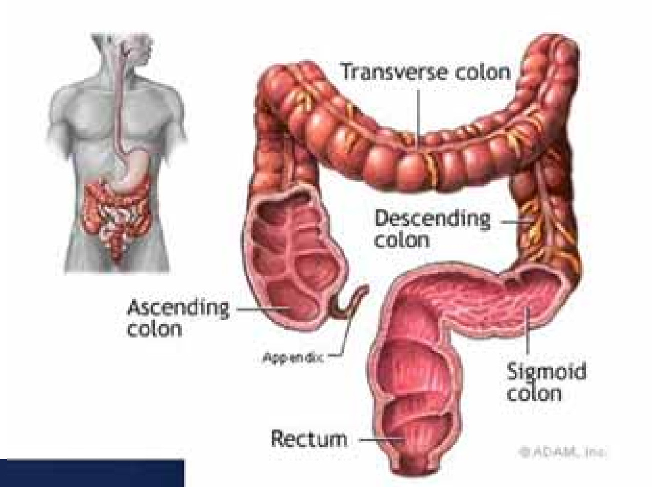
Cross-section when pressurized

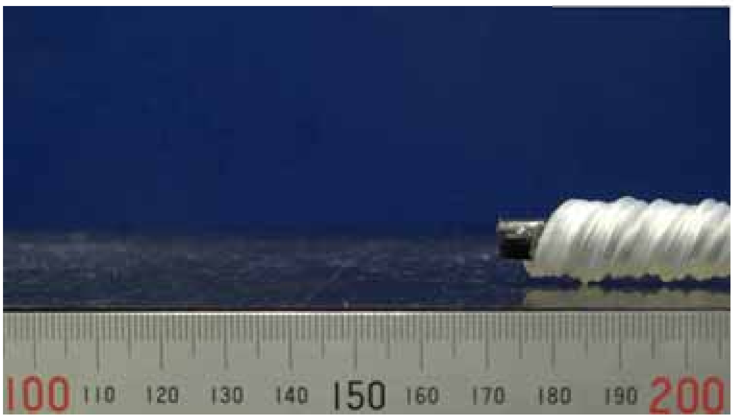


K. Suzumori et.al., IEEE/ASME Trans. Mechatronics, 1997

Medical Applications of Pneumatic Rubber Actuators / Robots

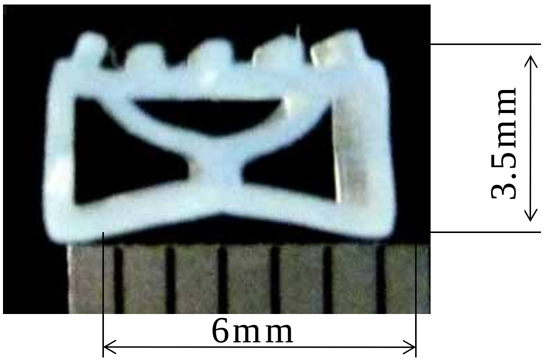
Self-propelling colonoscope

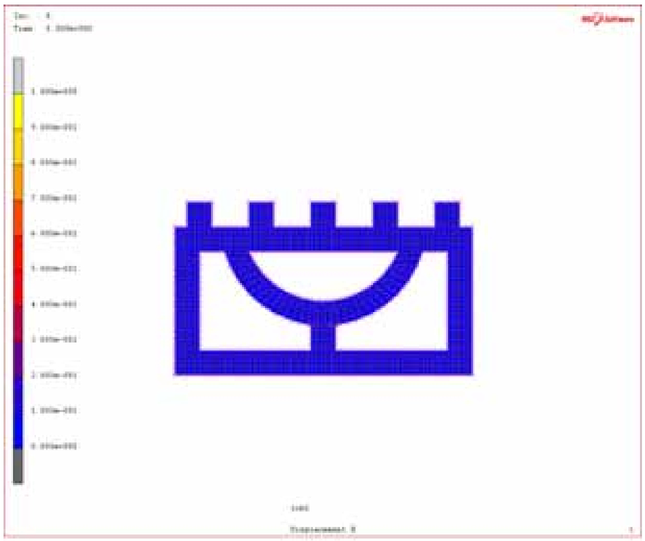


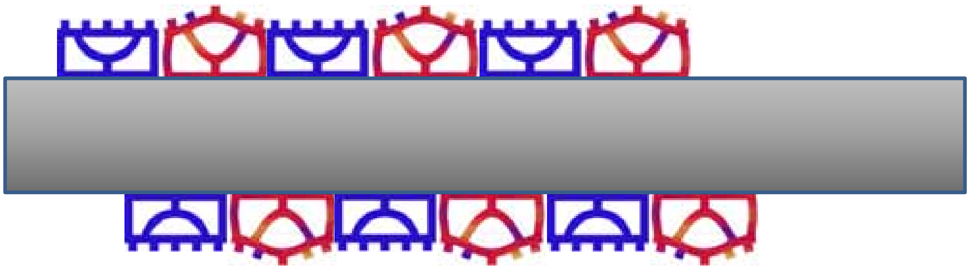


IEEE ICRA, 2006
IEEE ICRA, 2010

Self-propelling colonoscope

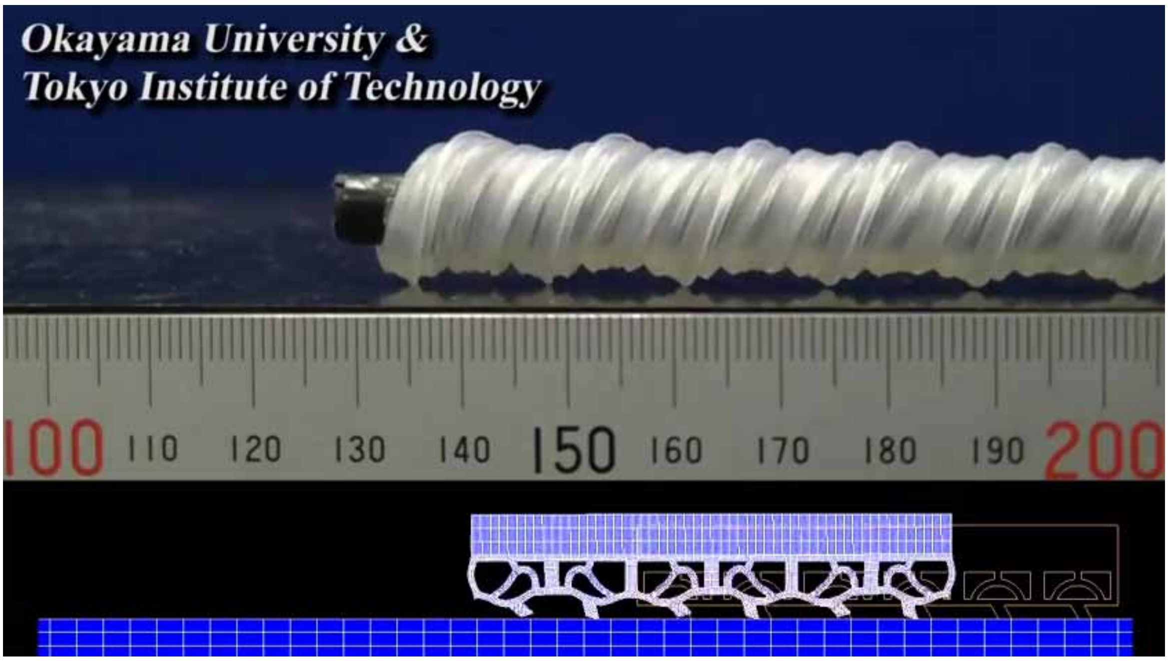






IEEE ICRA, 2006
IEEE ICRA, 2010

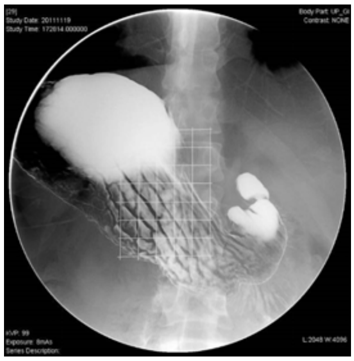
Self-propelling Colonoscope



IEEE ICRA, 2006
IEEE ICRA, 2010

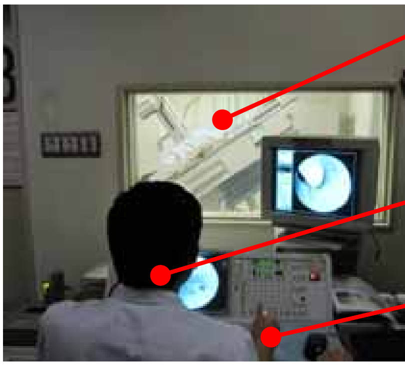
Medical application of soft robot (2) --- X-ray stomach diagnosis --- 29

IEEE ROBIO, 2014



barium contrast x-ray exam for stomach

Soft actuator with 3 DOF pressuring abdomen of subject

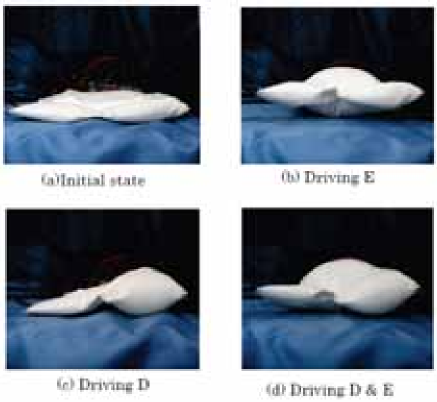


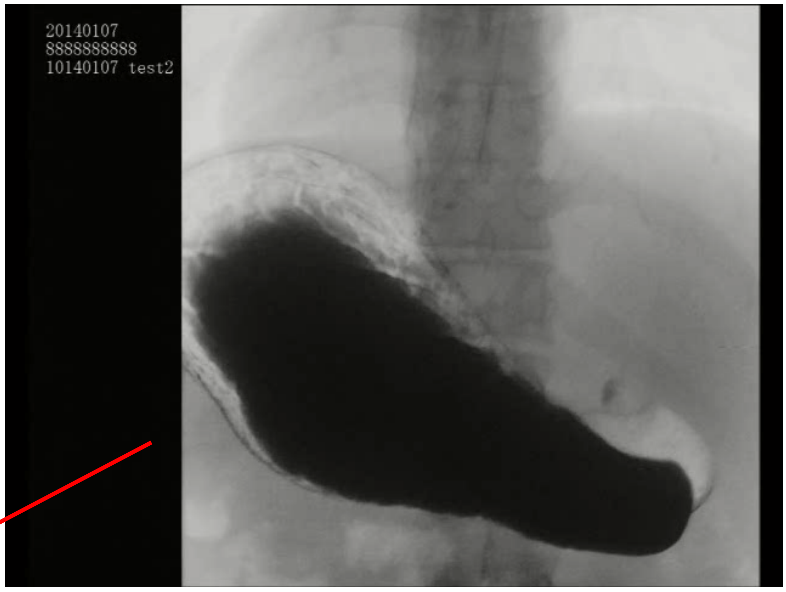
subject

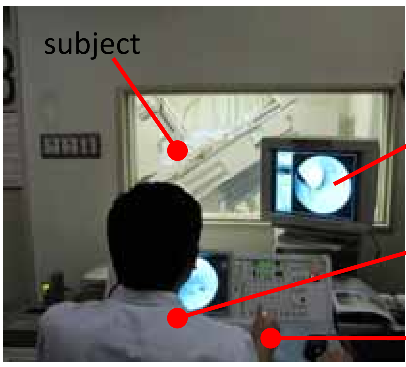
Doctor or radiation technologist

Joystick for actuator control

Medical application of soft robot (2) --- X-ray stomach diagnosis --- 30







subject

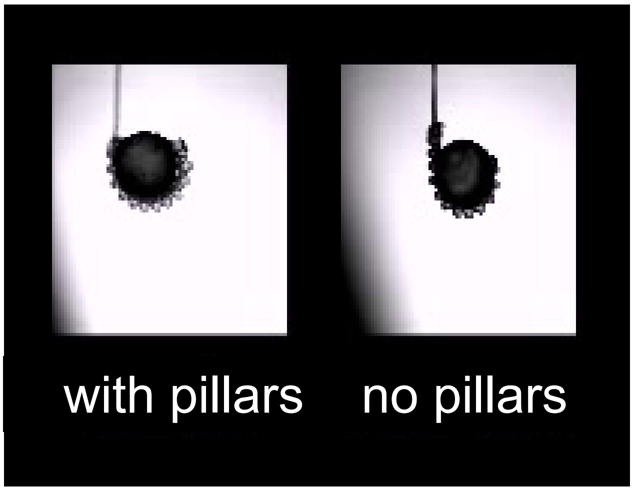
Doctor or radiation technologist

Joystick for actuator control

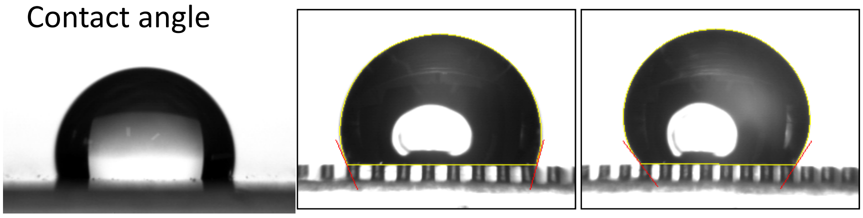
IEEE ROBIO, 2014

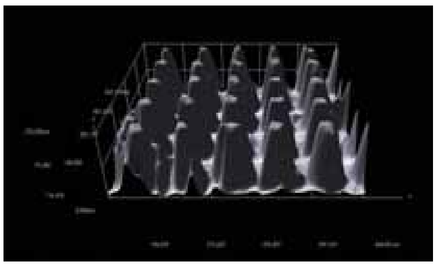
Functional Surfaces of soft Robots
---- Rubber surface Improvement ---

Surface force Control of soft robot



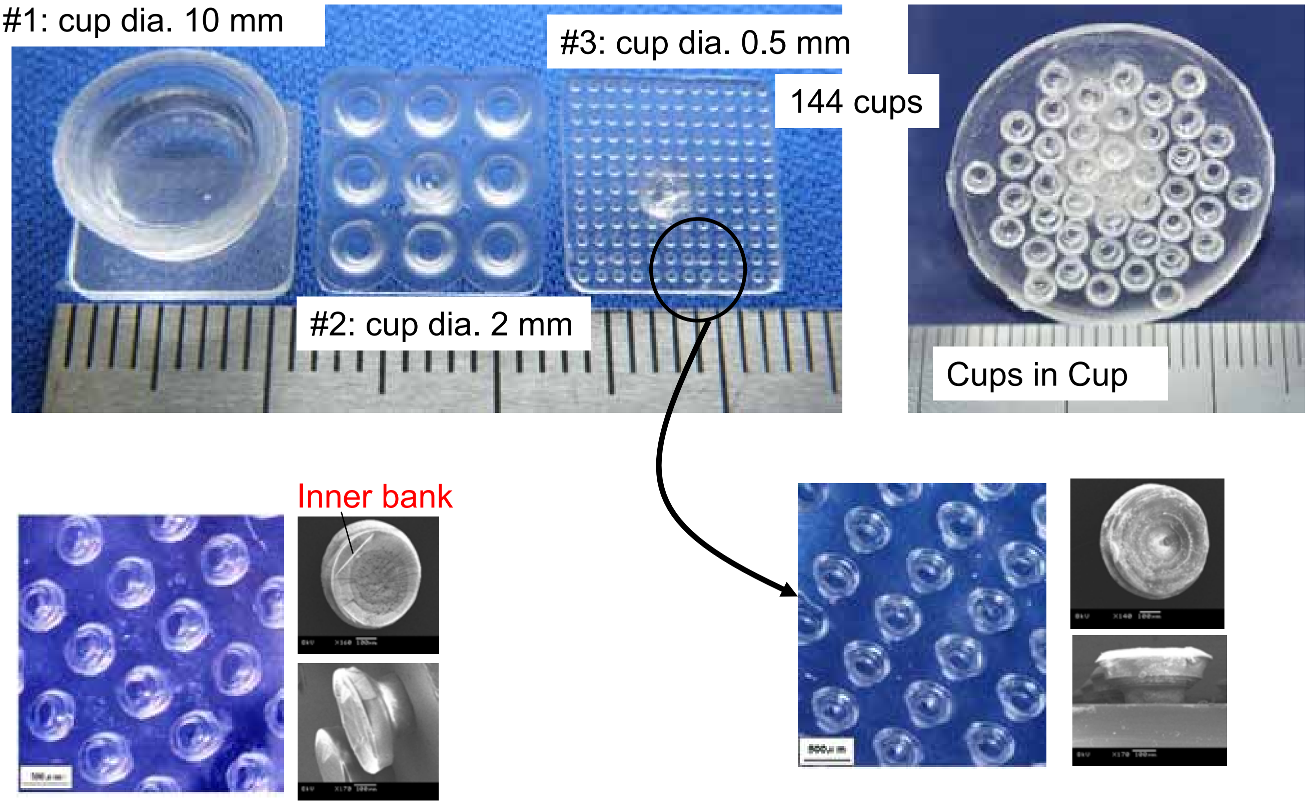
Contact angle





IEEE/SICE SII, 2015

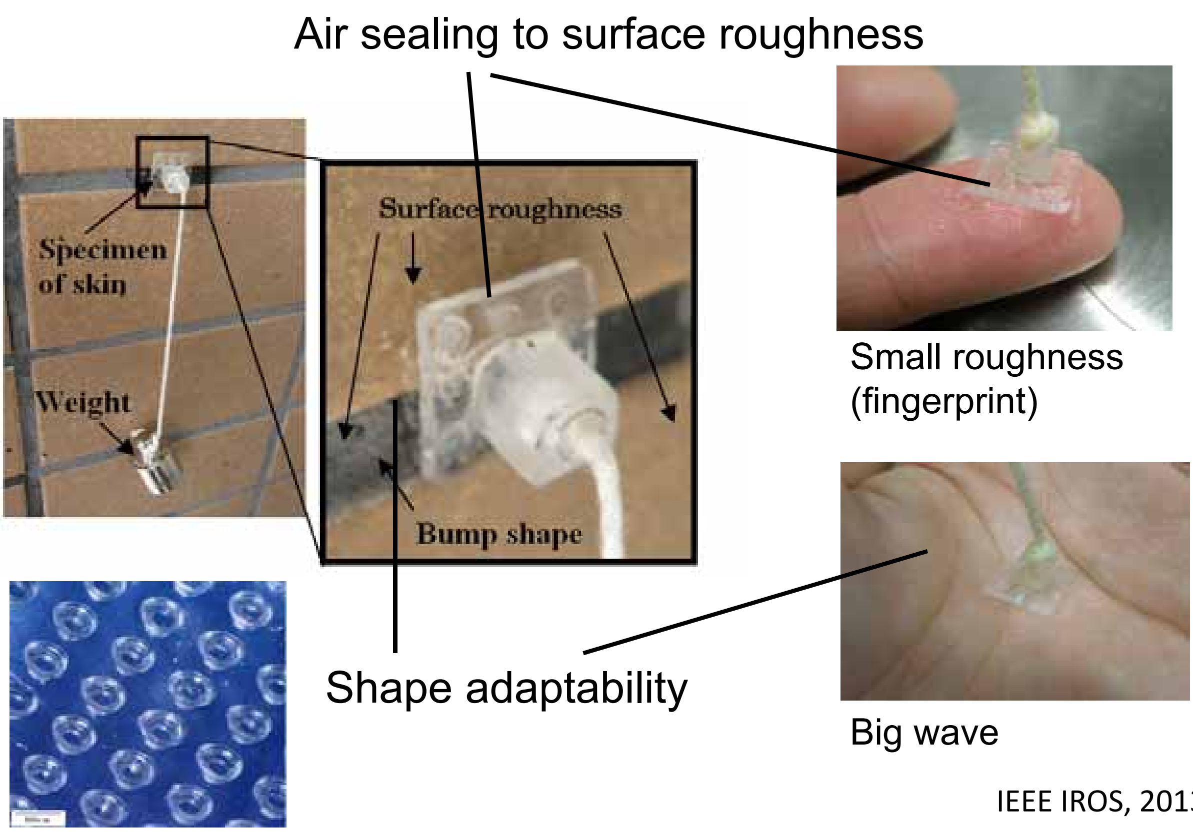
Integrated Micro Suction Cups



Anisotropic Suction Cups

IEEE IROS, 2013

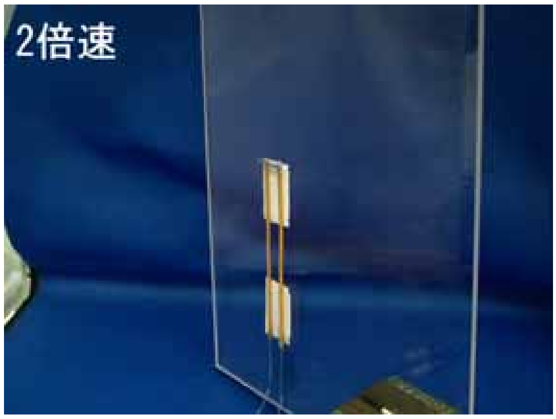
Integrated Micro Suction Cups



IEEE IROS, 2013

Integrated Micro Suction Cups

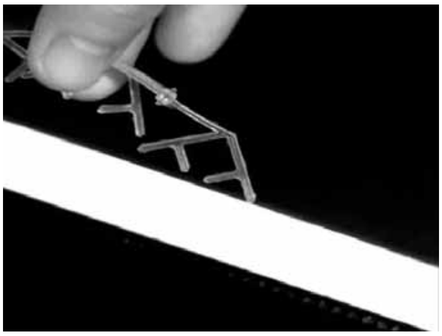
Crawler with Micro Suction Cups

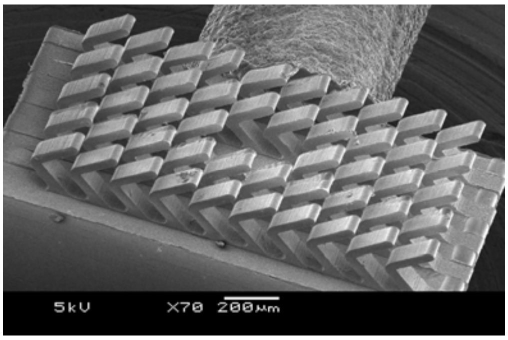


Rubber soles with Anisotropic Friction

IEEE IROS, 2013

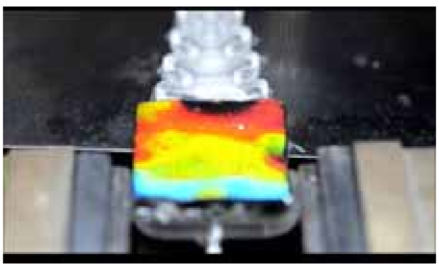
Other Functional Rubber Surfaces

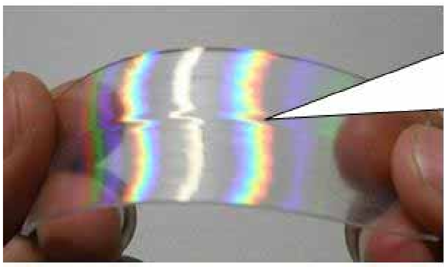


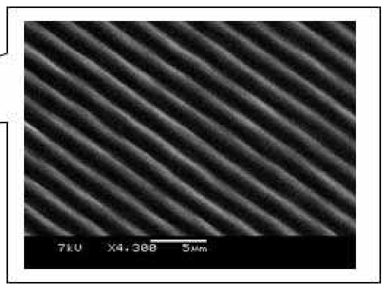


Multi-legged Passive Walking

IEEE IROS, 2008
IEEE IROS, 2009





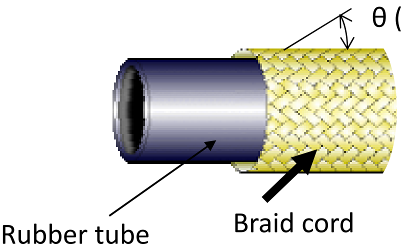


Rubber Surface showing Structural Color

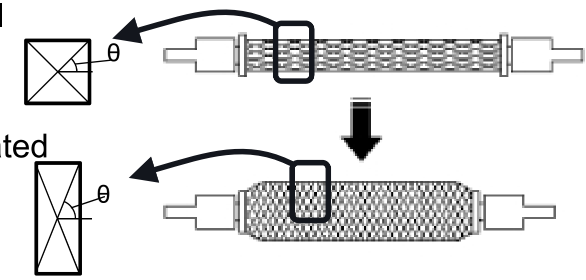
IEEE ICRA 2011

Thin McKibben Muscle

McKibben Muscle



Working principle originally invented in Germany in 1948.

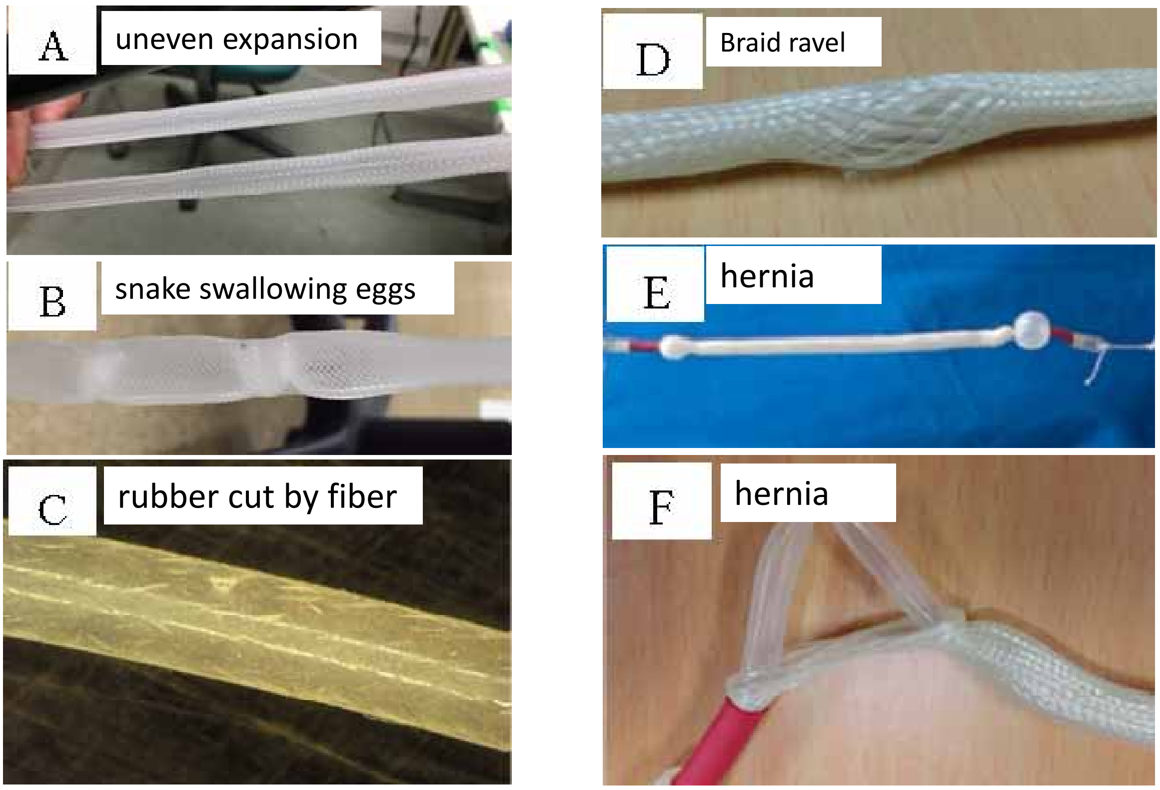


s-muscle Co. Ltd., A university-born venture of Tokyo Tech and Okayama Univ.

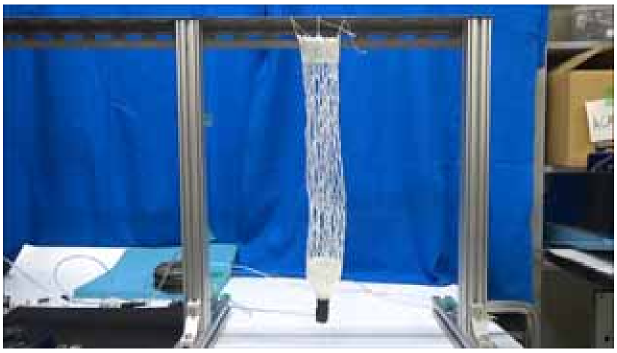
Manufacturing process of Thin McKibben Muscles

S-muscle

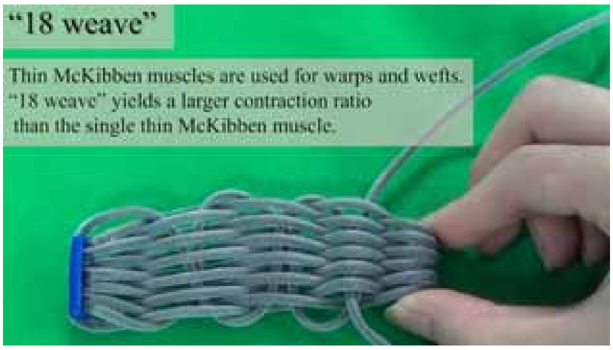
Typical Problems in McKibben muscles with miniaturization



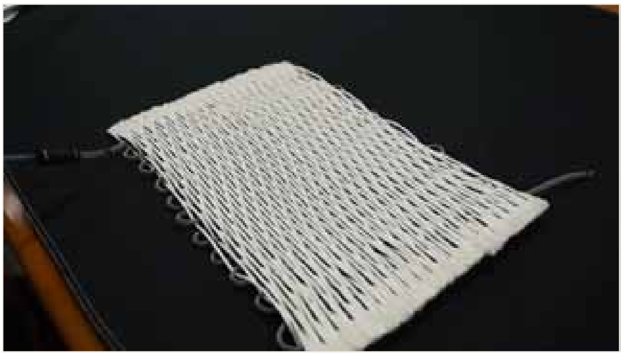
Several types of active fabrics

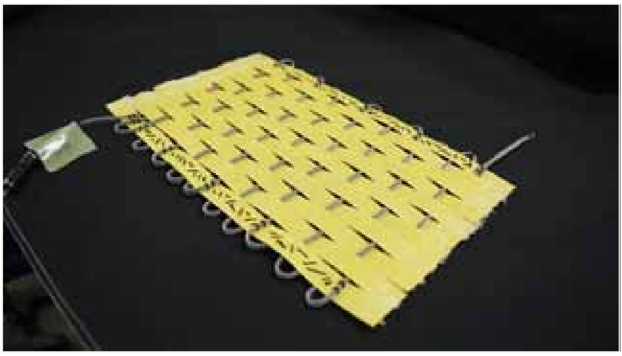


Sensors & actuators A,2017



IEEE RA-L, 2019

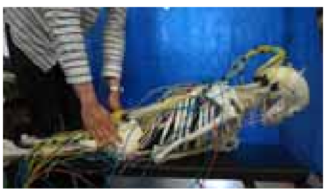




IEEE RoboSoft, 2019

Thin Muscle Applications

Power assist suits

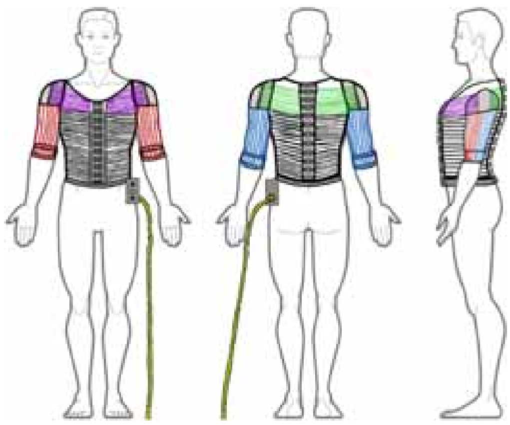


Musculo-skeletal robot

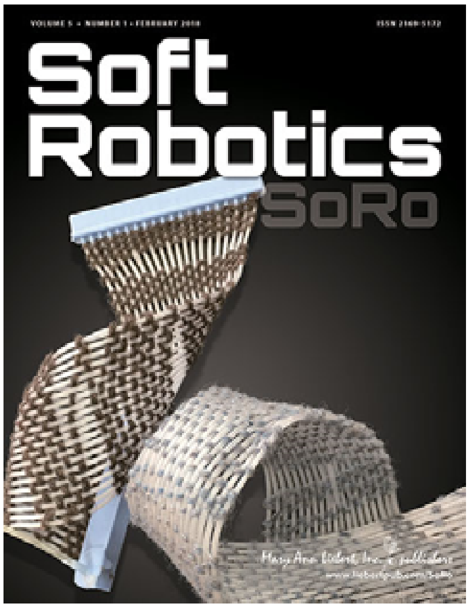
Giacometti robots

Tough robots

Application of thin muscle ① --- Power assist wear ---



Sensors and Actuators A, 2017



Soft Robotics 2018 Cover Art

Application of thin muscle ① : Power assist wear

Application of thin muscle ① --- Power assist wear ---

It's amazingly easy to stand up.

I feel like someone is lifting my buttocks.

Such a softness can not be realized with a thick artificial muscle or a motor.

It is easy to keep this position.

This may be very good for farmer working in middle posture for a long time.

I feel the weight.
But this is supporting my waist and legs when I'm lifting.

IEEE/SICE SII, 2015
RoboSoft, 2018

Application of thin muscle ① : Barrier Free Collection

Barrierfree Variety Show

Eテレ 日曜 夜7:00

再放送 金曜 0:00（木曜深夜）

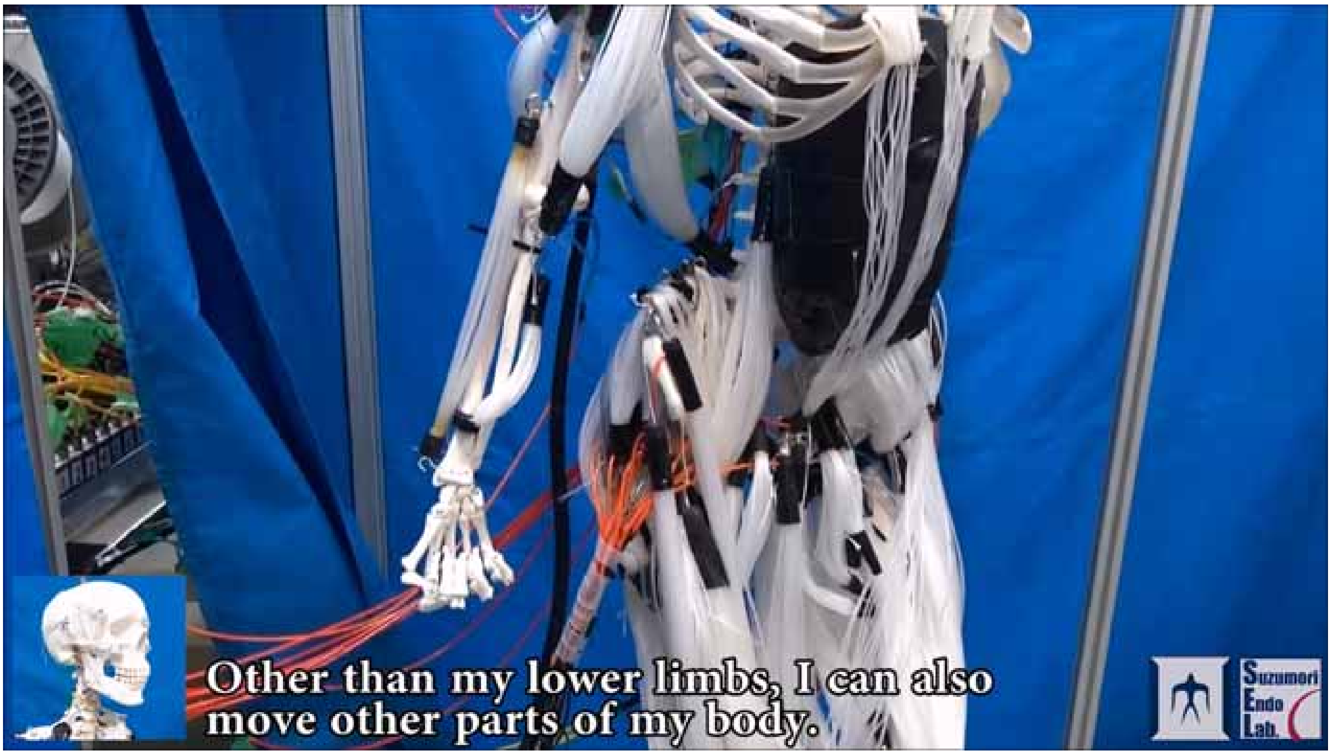
最先端技術でコミュニケーション　～文化服装学院×東京工業大学　～

Motion Assist

Anyone can be a great pianist.

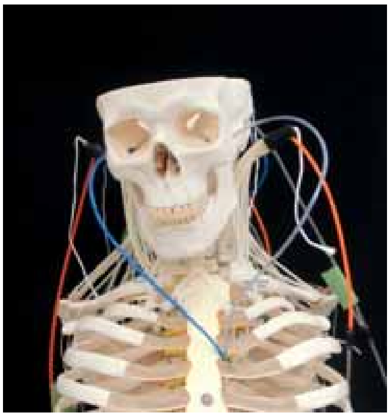
Joint work with Prof Koike Lab , Tokyo Tech

Application of thin muscle ② --- Musculo-skeletal robots ---

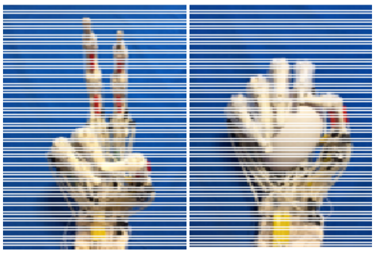


Robomech Jour., 2016

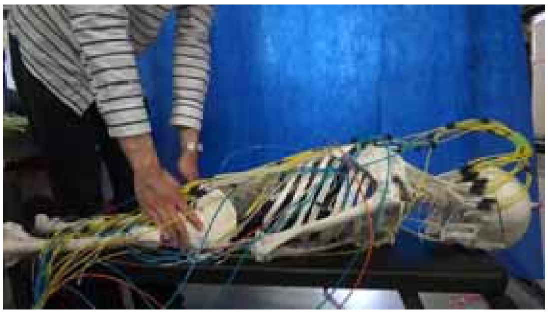
Application of thin muscle ② --- Musculo-skeletal robots ---



IEEE ROBIO 2017

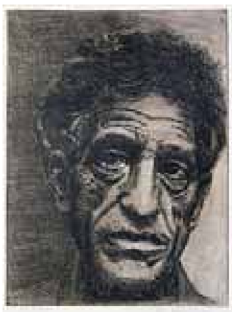


IEEE RA-letter, 2018
IEEE IROS, 2017



Application of thin muscle ③ ---Giacometti Robotics ---

Very light, very long, and very simple robot.
Realizing essential functions by removing excess fat.



Alberto Giacometti, 1901-1966

Application of thin muscle ③ ---Giacometti Robotics --- 51

IEEE RA-letter, 2018
IEEE IROS, 2017

Application of thin muscle ③ ---Giacometti Robotics --- 52

20m robot arm

IEEE RA-Letter, 2017
IEEE IROS, 2017

Application of thin muscle ③ ---Giacometti Robotics ---

Negotiating to the roof window to approach the pipe

The arm can contact the construction with no damage. Essentially safe!

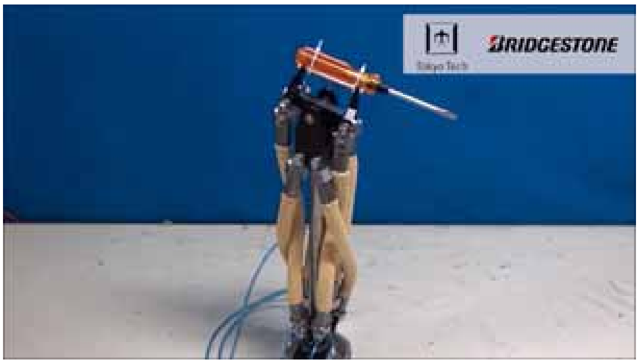
Getting the image of the pipe.

Power soft robotics

my current big interests

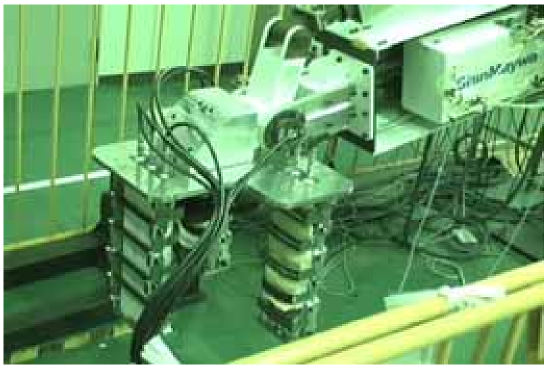
Hydraulic artificial muscle

(joint work with Bridgestone)



Suzumori lab., Advanced Robotics, 2018

(joint work with Bridgestone)



Suzumori lab., ICRA2010

(joint work with ShinMaywa)

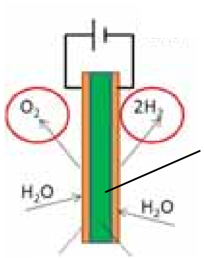
Elephant trunk mimetics

Suzumori lab.,
2023 JSME Robomech

Air-Hose-free pneumatic actuator

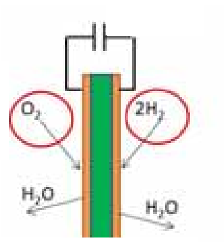
Reversible Gas/liquid Phase Change Chemical Reaction

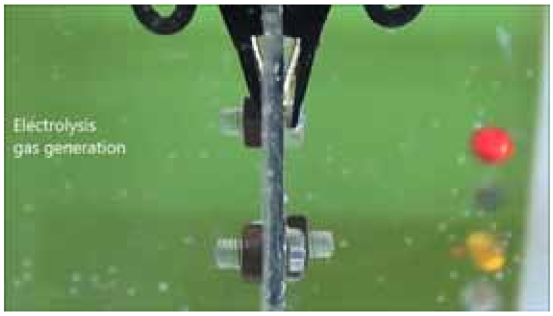
Power supply
electrolysis of water



proton exchange membrane (PEM)

Power recovering
synthesis of water

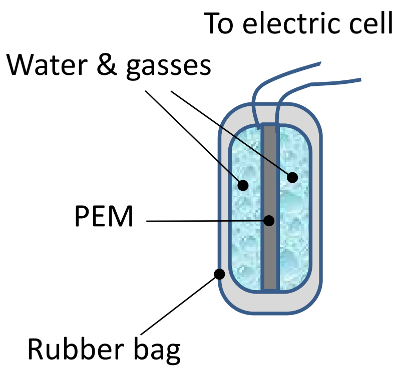




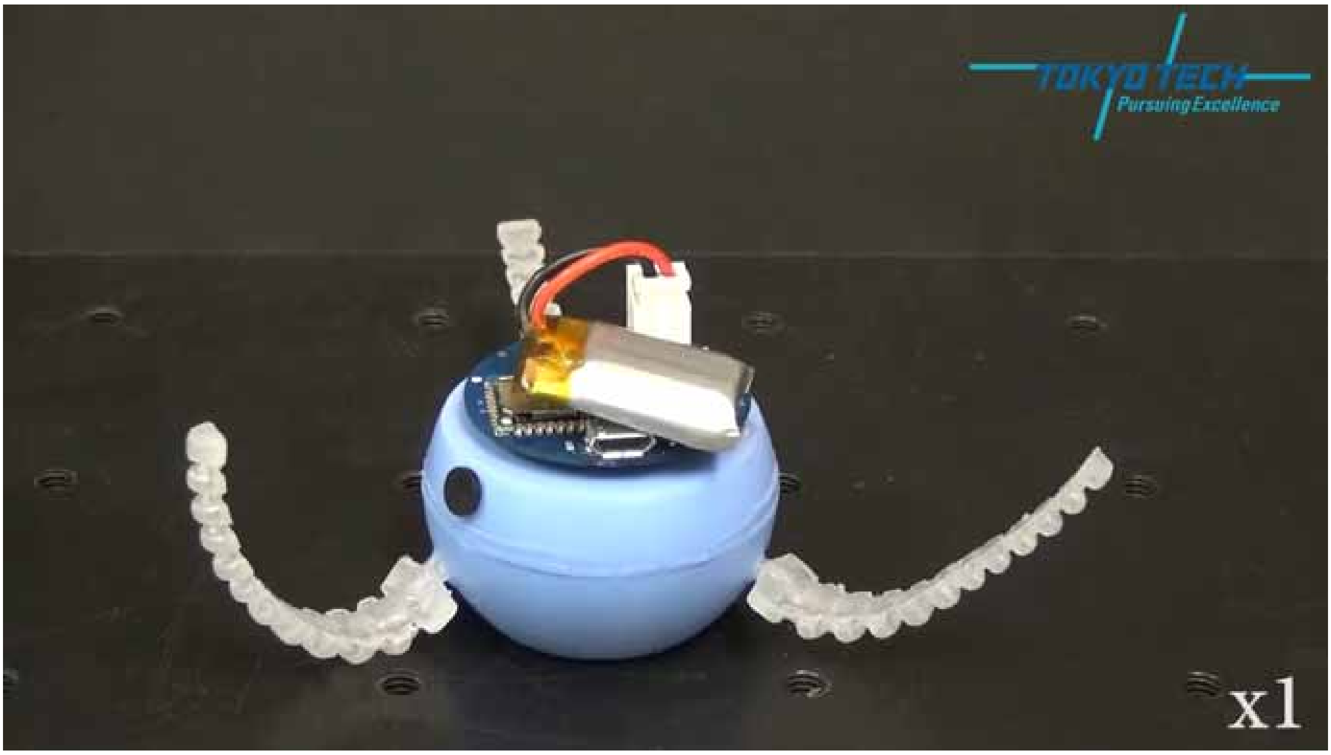
Gas generation ↔

Gas absorption ↔

Sensors and Actuators A, 2013



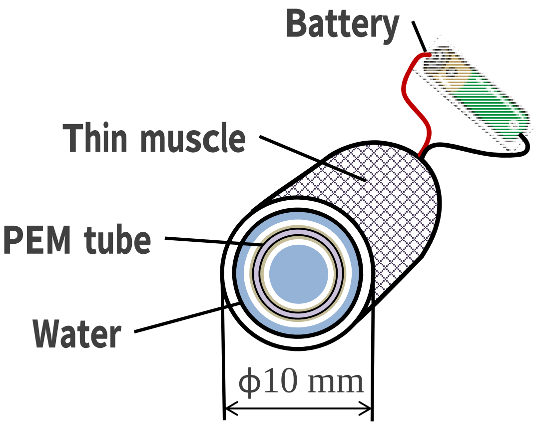
Air horse free Pneumatic Robot

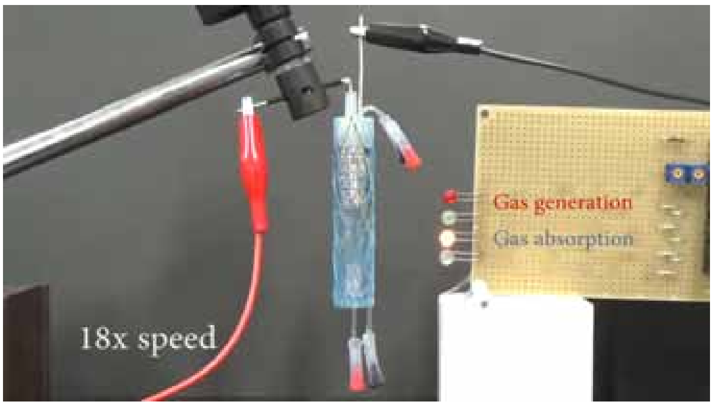


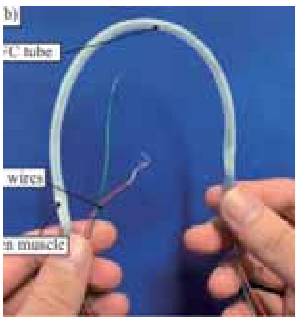
Sensors and Actuators A, 2016

Air horse free Pneumatic Robot

Thin McKibben muscle driven with electric cell





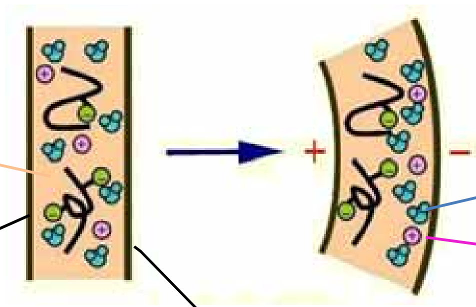


To be presented in IROS2019

IPMC; ionic polymer-metal composites actuator

Thin film robots driven by IPMC

PEM
Proton exchange membrane



Water molecules
Cations
electrodes

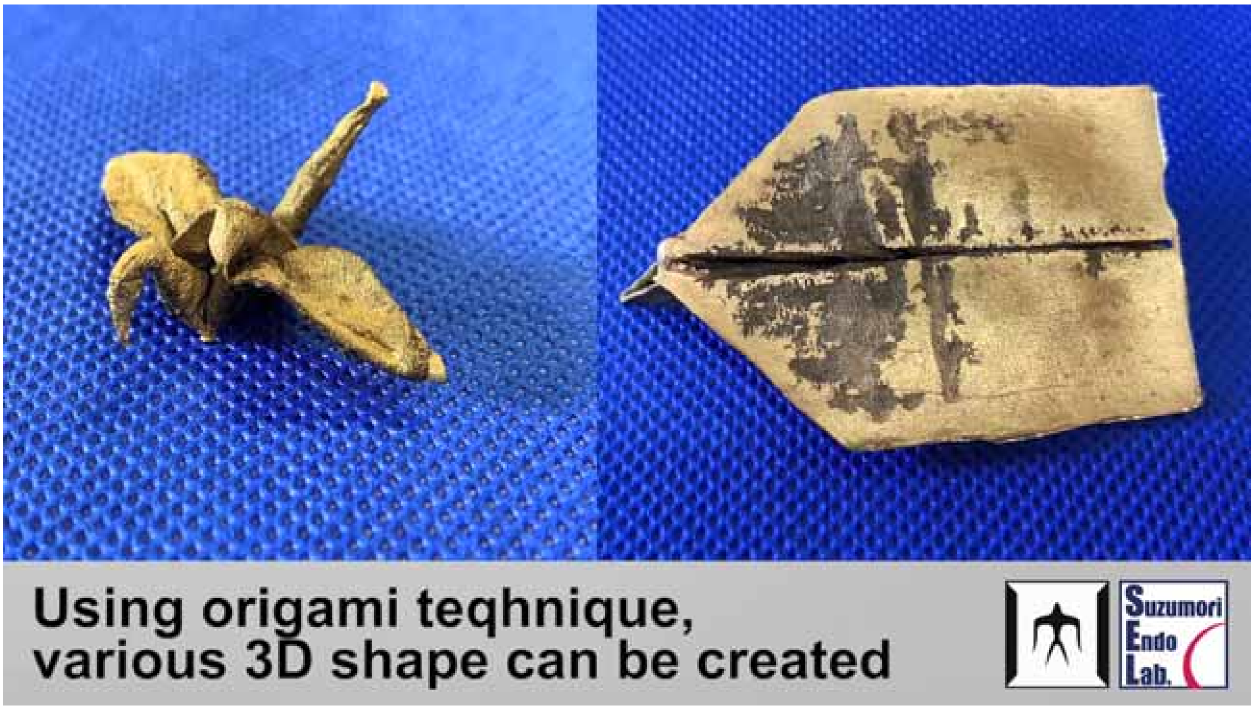
Oguro, et al., 1991

Anomalocaris robot

Butter fly robot

IEEE RA-L, 2019

Paper/fabric assisted IPMC

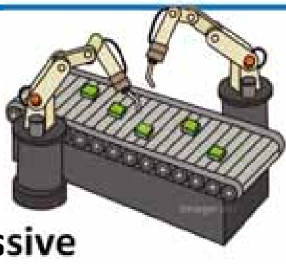


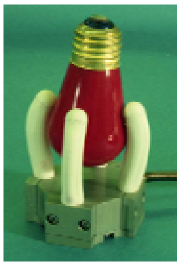
Suzumori Lab., IEEE RA-L, 2020

4

Soft Robotics changing the values as E-kagen Science

Soft Robotics: Value Changer in Robotics





Values of Conventional Robotics:
force, speed and accuracy

New Values of Soft Robotics:
shape-adaptability, back-drivability, passive force control, stress dispersion, gentle touch, essential safety, etc.

Accepting ambiguity and uncertainty and using them to make robots work in an appropriate manner

いいかげん(E-kagen)

Negative meanings:
ambiguous, irresponsible, sloppy, unreliable…
Positive meanings:
moderate, adaptable, appropriate, suitable…

Examples of E-kagen in Nature and Industry

新学術領域 ソフトロボット学

Accepting ambiguity and uncertainty and using them to do in an appropriate manner

Weeping willow
Dependent lifestyle is tough

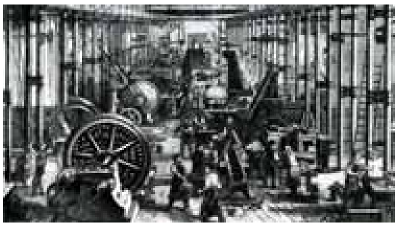
Mutation and evolution
DNA copy error makes evolution.

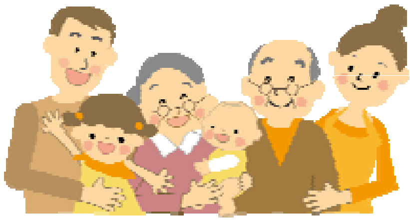
Compliance control
Poor positioning accuracy results in smooth assembling.

Teddy Bear
Poor quality control results in unique bear.

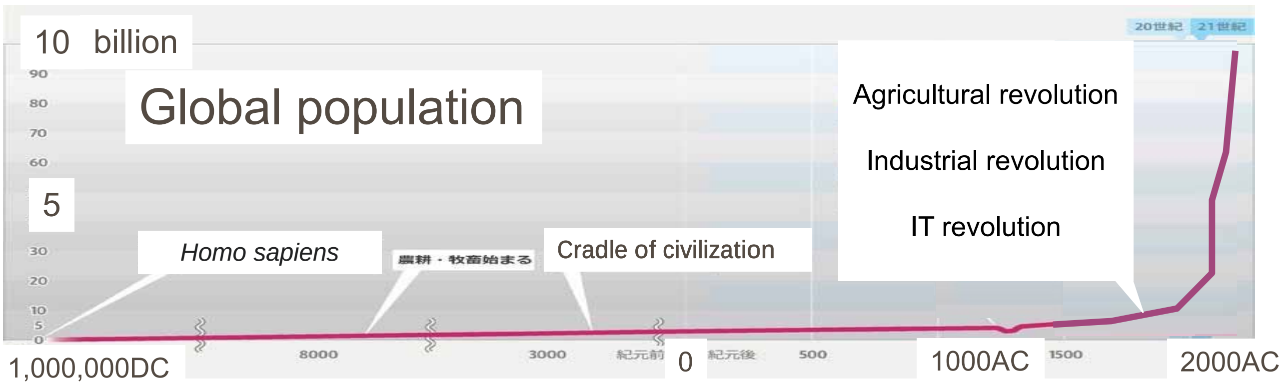
Growing society:
Power and accuracy

Sustainable society:
Gentleness and flexibility

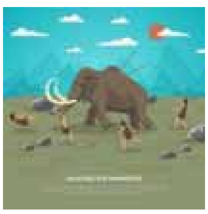



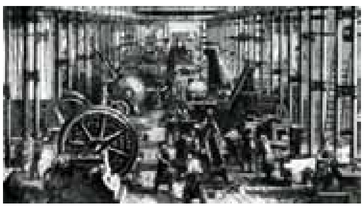

Turning point of Science & Technology



Technology for Power, Speed, and Accuracy

E-kagen ?






Thank you for your attention.
Wishing great success of new robotics!

Homework Assignment

You can find many movies of soft robots on the web. Choose one movie that interests you the most, and summarize its working principle, advantage, novelty, and what interests you.

1. specify the name and URL of the research institute which developed the robots,
2. summarize your work in English or in Japanese, including figure(s), on one page in pdf file.