マルチスケールロボティクスの未来

名古屋大学大学院工学研究科
マイクロ・ナノシステム工学専攻
福田敏男

福田敏男 Toshio Fukuda

- President, IEEE Robotics and Automation Society (1998-1999)
- Editor-in-Chief, IEEE/ASME Trans. Mechatronics (2000-2002)
- Director, IEEE Division X, Systems and Control (2001-2002)
- President, Japan Society of Fuzzy Theory and Intelligent Informatics (2003-2005)
- EIC, J. Advanced Computational Intelligence & Intelligent Informatics, J. Micromechatronics, J. Robotics and Mech.
- Founding President, IEEE Nanotechnology Council(2002- 2005)
- Prof. UC Berkeley(2010), Seoul National Univ., CAS IA, BIT, SUT, NCTU, Diakin Univ. , etc.
- Director, IEEE Region 10 (2013-14)

鉄腕アトムのロボット学
福田敏男著
集英社 (2003/4/4)

- PhD: 89, Books>= 20: papers>=2,000

マルチスケール Multi-scale from Macro to Nanometer

DNA

Bacteria

Ants

Buildings

nano-meter ***micro-meter*** ***mili-meter*** ***meter***

10^{-9} m **10^{-6} m** **10^{-3} m** **1 m** **10^{3} m** **10^{6} m** **10^{9} m**

1nm **1μm** **1mm** **1m** **1km**

Atom

Blood Cells

Human

Earth

Multi-scale Robotics

nm μm mm cm m

Nanorobotic Manipulation

Catheter Surgery Simulator

Face Robot

Brachiation Robot

Robotic Manipulation

Laser Micro Manipulation

Multi-mobile Root

Multi-locomotion Robot

サイボーグのためのデバイス　Devices for Cyborg: Cybernetic organism

ロボット
（機械）

融合化

動物
（生物）

マイクロ・ナノ制御工学グループ

Monkey-type Robot

Multi-task Planning for Multi-robot

Object Tracking Based on Cognitive System

Multi-locomotion Robot

Robotics Human Interface
Micro/Nano Robotic System
Mechatronics

Multi-scale Robotics

Intelligent Cane

Nanorobotic System

Robot –Human Co-Assembly

Medical Simulator

Single Cell Manipulation/3D Cell Assembly

社会貢献 Social Activity

NHK (Japan)

NHK (Japan)

BBC “Robo Monkey”（UK）

KBC “Robot Special”（Korea）

NHK (Japan)

News (Japan)

Live News (Japan)

福田研究室の研究の推移 Research Shift of Fukuda Laboratory

福田研究室の主な研究の進展

Nakajima
Kajima
Ikemoto
Ikeda
Ichikawa
Itoigawa
Motoo
Jatomiko
Matsuno
Sakamoto
Abe
Ito
Kobayashi
Yamaji
Higashi
Nakanishi
Wakuda
Chen
Shi
Hoshino
Ushida
Fujisawa
Wada
Ishihara
Guo
Tanimoto
Doi
Yang
Fujiyoshi
Morishima
Shimojima
Hosaka
Shibata
Saito
Uematsu
Yoneda
Maruyama
Takeuchi
Takagawa
Arakawa
Shiotani
Nishihara
Hosokai
Goto
Xue
Tokita
Isogai
Liu
Kojima
Zyada
Kawauchi
Shoji
Hattori
Kaga
Uchida
Ishigami
Ueyama
Arai
Mitsumoto
Satoh
Haitham
Yu
Kwon
Kiguchi
Imamura
Cai
Sekiyama
Kubota
Ooe
Tercero
Kawahashi
Dong
Kozuka
Wada
Mizoguchi
Kurashige
Kawaji
Hasegawa
Kim
Shen
Chen
Lu
Aoyama
Rokunuzzaman
Nogawa
Negishi
Takahashi
Ahmad

World Scientific Series in Robotics and Automated Systems – Vol. 10

CELLULAR ROBOTICS AND MICRO ROBOTIC SYSTEMS

T FUKUDA & T UEYAMA

World Scientific

1994

マン-マシン共生 Human Machine Symbiosis

1. Cell Level

Artificial arm Artificial leg

3. Human and Unit Level

"Multi" robot and "multi" human

5. “Multi" human and Individual Level

Stomach Heart Lung

2. Organic Device Level

one-to-one coordination

4. Human and Individual Level

"Multi" robot and "multi" human through the network

6. Network Level

マルチスケールロボティクス　Multi-scale Robotics

Multi-scale Robotics

セル構造化ロボット　Concept of CEBOT

CEBOT: Cellular robotic system

セル構造化ロボット研究

Research on CEBOT

CEBOT mark I (1985)

CEBOT mark II (1988)

CEBOT mark III (1989)

CEBOT mark IV (1992)

セル構造化ロボット研究

Research on CEBOT

CEBOT mark V (1995)

Computer

- CPU : M68040
- OS : VxWorks (RTOS)
- Bus : VME

Communication

- Wireless LAN

Frequency	2471-2497MHz
Speed	2Mbps
Distance	up to 60m

Sensor

- CCD camera (Robot II)
- Ultra sonic (Robot I)
- Infrared (Robot II, III)

Others

- DC motor x 2
- Battery (12V x 2)

自律分散ロボットシステム
Work on Distributed Autonomous Robotic Systems

- Coupling mechanisms

- Structure reconfiguration methods

- Distributed sensing and cooperative navigation

-Swarm Intelligence

-Micro Autonomous Robotic System (MARS)

CEBOT mark V and Mobile manipulator

Flexible Transfer System(FTS)

21世紀COEプログラム（2003-2008）

Micro-Nano Mechatronics for Information-Based Society

We aim to deepen the understanding of the nano-mechanical science (nano sciences in mechanical engineering) and, by combining micro-nano-mechatronics technologies, we will develop systems technology that will become the next generation infrastructure of an advanced information-based society. We will provide seamless support to further research and education in order to establish novel technologies that will apply nano technology to actual devices and systems, especially using mechanical engineering approaches.

グローバルCOEプログラム　GCOE Program (2008-2013.3)

GCOEの組織　GCOE Organization

Basic research

Nano control engineering

T. Fukuda

G. Obinata

F. Arai

UCLA

C.-M. Ho

Nano measurement engineering

T. Niimi

K. Fukuzawa

Y. Ju

I. Naruse

Nano design and manufacturing

K. Sato

E. Shamoto

N. Umehara

A. Sasoh

Nano materials science

O. Takai

N. Ono

M. Okido

Applied research

Advanced bio/medical technology

M. Ueda

K. Isobe

School of medicine

J. Usukura

研究者の連携　Collaboration network between members

科学研究費補助金「特定領域研究」
平成17年度発足特定領域
（2005-2009）
申請領域名

マルチスケール操作によるシステム細胞工学

申請代表者
名古屋大学大学院工学研究科／高等研究院
教授・福田 敏男

http://www.chem.scphys.kyoto-u.ac.jp/nonnonWWW/bio/index-j.html

本領域のねらい

「システム細胞工学」

工学技術を基盤として細胞機能の統合的理解を目指す新しい学問領域

1. システム細胞工学を創成する.

2. 細胞を構成する要素の素機能および構成要素の統合機能，制御様式を解明する.

3. 細胞機能を模倣したり，機能を制御するための基礎研究を行う.

特定領域研究　マルチスケール操作によるシステム細胞工学　成果報告書
http://www.mext.go.jp/a_menu/shinkou/hojyo/chukan-jigohyouka/1301312.htm

本領域の特色：研究体制

工　学（制御班）

ナノデバイス

バイオチップ

ナノ・マイクロマニピュレータ

バイオ（再構成班）

リポソーム

蛋白質合成

メディカル（組織班）

角膜再生

テーラード血管モデル

工学を中心とした横断的研究

基盤技術の分担と融合

特定領域研究　マルチスケール操作によるシステム細胞工学　成果報告書
http://www.mext.go.jp/a_menu/shinkou/hojyo/chukan-jigohyouka/1301312.htm

工学に基づく基盤技術

nm　μm　cm

細胞内

高効率遺伝子発現

細胞群

大腸菌の固定　遺伝子発現計測

組織内

分化の促進

無細胞発現系の構築
1. 発現制御

遺伝子の発現計測と制御
2. 局所制御

細胞形態・分化誘導
3. 機能制御

特定領域研究　マルチスケール操作によるシステム細胞工学　成果報告書
http://www.mext.go.jp/a_menu/shinkou/hojyo/chukan-jigohyouka/1301312.htm

Future Goal/Direction (Example)

In vitro simulator of In vivo environment

Super-simulator

http://www.micro-nano.jp/en/project.html

福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m

cm

mm

μm

nm

- Multi-locomotion Robots
- Multi-mobile-robot Corporation
- Interface Robotics
- Grasping, Tactile Sensing
- Medical Robotics -Vascular Model and Scaffold-
- Bio-micro Manipulation for Single Cell Manipulation
- Nanodevice/Nanomanipulation

ブラキエーションロボット　Brachiator I~III

What is brachiation?

:A interesting form of long-armed apes' locomotion

- **Dynamics of the pendulum**
- **Under-actuated mechanical system**
- **Variable constraint system**

Brachiation

Brachiator
Fukuda et al. (1986)

Brachiator II
Saito et al. (1993)

Brachiator III
Saito et al. (1996)

マルチロコモーションロボット
Multi-Locomotion Types

■**In many cases, one creature has multiple types of locomotion in order to improve its mobility.**

■**The motivation of our study is to develop a robot mechanism and a control architecture which can achieve multiple locomotion.**

Concept of Multi-Locomotion Robot(MLR)

マルチロコモーションロボットの推移
Prototype of the Multi-locomotion Robot

Gorilla Robot I
(2000)

Gorilla Robot II
(2001)

Gorilla Robot III
(2002)

マルチロコモーションロボット
Realization of Multi-locomotion

- **In many cases, one creature has multiple types of locomotion in order to improve its mobility.**
- **The motivation of our study is to develop a robot mechanism and a control architecture which can achieve multiple locomotion.**

Yoneda et al.(IROS2008)

Kajima et al.(IROS2003)

Doi et al.(ICRA2004)

Aoyama et al.(IROS2008)

Lu et al.(IROS2010)

Multi-locomotion Robotics Systems; Fukuda *et al.*; ISBN:978-3642301346

Experimental Video

-from Ladder Climbing to Brachiation

Z. Lu et al., Proc. in Int. Conf. Int. Robots and Systems 2010 (IROS 2010)

Multi-Locomotion Robotic Systems

New Concepts of Bio-inspired Robotics

Toshio Fukuda, Yasuhisa Hasegawa, Kosuke Sekiyama, Tadayoshi Aoyama

Springer

ISBN 978-3-642-30134-6, May 2012

福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m

cm

mm

μm

nm

- Multi-locomotion Robots
- Multi-mobile-robot Corporation
- Interface Robotics
- Grasping, Tactile Sensing
- Medical Robotics -Vascular Model and Scaffold-
- Bio-micro Manipulation for Single Cell Manipulation
- Nanodevice/Nanomanipulation

ケインロボット Cane Robot

- Assistant Functions and Objects
  - Help the elders walking in daily life
  - Assist the patients for recovering the motion function
  - To guide the user for walking and avoiding the obstacles

Lower-extremity
Muscle Weakness

Lower-extremity
Rehabilitation

Guide and
Avoid Obstacle

インテリジェントケインノコンセプト
Concept of Intelligent Cane Robot

Guidance and obstacle avoidance

Emergency aid

Rehabilitation and evaluation

Assist for sitting and standing up

Can be used in various environments

Fall detection and prevention

Easy operation

技術課題 Technical Issues

Safety

- Hazard Detection
  - Fall Detection 2009
  - Obstacles Detection
- Hazard Avoidance
  - Fall Prevention 2010
  - Obstacles Avoidance 2012
- Hazard Reporting
  - Alarm or Vibration
  - Call for Help by Phone

Fall Detection and Prevention

Call for Help by Phone

Assistance

- Walking Assistance
  - Using Comfortable
  - Reduction of Fatigue
- Navigation
  - Intelligent Guidance
  - Voice and Visualization Guidance
- Sit/Stand Assistance
  - Assist User to Sit Down
  - Assist User to Stand Up

Navigation

Assist for sitting and standing up

Usability

- Human Intention Estimation
  - Intended Direction of Walking 2008
  - Human Behavior Estimation
- Interface Design
  - Friendly Interface Design 2012
  - Self-Adapted Interface
- Walking Behavior Learning
  - Human Walking Dynamic Model
  - Disability Level Identification

Easy operation

Rehabilitation and Evaluation

現在までの研究活動 Previous research

1. Human Walking Intention Estimation (2008)[1]

1. Jian Huang, Pei Di, Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on

2. Fall Detection (2009)[2]

Gait Phase Diagram

2. Pei DI, Jian Huang, Micro-Nano Mechatronics and Human Science, 2008. MHS 2008. International Symposium on

3. Fall Prevention Strategy (2010)[3]

3. Kohei Wakita, Jian Huang, International Conference on Advanced Mechatronics 2010

4. Pei DI, Jian Huang, International Symposium on Robot and Human Interactive Communication 2012

4. Optimal Posture Control (2011)[4]

福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m

cm

mm

μm

nm

- Multi-locomotion Robots
- Multi-mobile-robot Corporation
- Interface Robotics
- Grasping, Tactile Sensing
- Medical Robotics -Vascular Model and Scaffold-
- Bio-micro Manipulation for Single Cell Manipulation
- Nanodevice/Nanomanipulation

Nagoya University
Micro-Nano Systems Department
Fukuda Laboratory

The EVE project

Challenging the Frontier of the Surgical Simulation since 1989

脳動脈瘤治療 Treatment of aneurysms

Aneurysms

- **Problems**
  - Late identification due to few obvious symptoms
  - Various morphology due to complex forming reasons
  - Massive internal hemorrhage; Permanent damage to organs
  - High death rate after rupture of aneurysms

- **Open surgical therapy**
  - Invasive open surgery
  - Intraoperative and postoperative pain and much bleeding, cause large damages to organs, long postoperative stay in hospital, high mortality
  - High risk for complications
- **Intravascular surgery**
  - Minimal invasion; less bleeding; short operative and recovery time
  - Treatments for various aneurysms with complex morphology
  - Required for high technique for operation

能動カテーテル Active Catheters (1989-1994)

Intravascular Devices

- **Adds maneuverability to the catheter**
- **Endovascular techniques are new in minimally invasive surgery**

- **Need to be compatible wit Xrays**
- **Requires micro systems as catheters has about 1 mm of lumen**

[S.Guo, J. of Robotics Soc. of Japan. 1996]

カテーテル先端への力センサの組込み Force Sensor on catheter tip (1996)

- **Prevents the damage of vessel wall**
- **A pressure sensor detects the force applied to the catheter tip**

In-Vivo Experiment

- **Pressure done by the catheter to an aneurism of canine was measured**
- **Blood pressure fluctuation was measured**

[M. Tanimoto, Trans. of the JSME 1997]

Force Sensor In Vivo Experiment Results

テレサージェリ Telesurgery (1996)

- **First catheter manipulation mechanism using gum rollers**
- **Master device as human interface for catheter manipulation**

Telesurgery System

- **Reduces the X-rays irradiation to physicians**
- **Manipulated from outside of the surgical room**

[F. Arai, IEEJ Trans. on Elec. 1997]

Experimentation inside surgical room

シミュレーション・ベイスド・メディスン

Simulation Based Medicine

Patient Specific Vascular Modeling

Specification:

- **Information: CT or MRI.**
- **Modeling Resolution: 13 mm**
- **Fabrication Time: < 24 hours**

３次元プリンティング技術による人工血管モデルの構築

Vasculature Model Types by 3D printing technology

Dissection Model

RP Model

Incompetent
As a Simulator

1st Stage Solid Model	2nd Stage Membranous Model	3rd Stage Composite Model	4th Stage Whole Body Model
2002	2003	2004	2005
Fukuda Lab. Set to the Work in 2001	2003 Pulsation Reproduction	2004 Stress Visualization	2004～ Comprehensive Simulator (EVE)

ファインバイオメディカル株式会社

FAIN-Biomedical,Inc.

New Release

■ 超精密血管内手術シミュレータＥＶＥ
（動脈タイプ）

■ 上肢・下肢モジュール

■ 静脈タイプ

■ 脳モデル

ＥＶＥの主要な特徴：
1．ＣＴから血管を精密に再現　－　現実に即した、幅広い疾患のシミュレーションが可能
2．血管組織の物理特性を再現　－　リアルなカテーテル操作感を実現
3．人体の血液循環（血圧、血流量、温度）を再現　－　血流の影響など詳細な評価が可能
4．Ｘ線透視撮影に適合　－　透視撮影下で迫真のシミュレーションが可能
5．幅広い目的で使用可能
6．軽量構造で持ち運び可能

http://www.fain-biomedical.com/

既製品

オプション・オーダーメイド

Master Device for Tele-Surgery (1995)

Catheter Insertion Mechanism (2002)

Linear Stepping Mechanism (2003)

Autonomous Catheter Insertion System (2006)

Human Blood Pressure Simulation (2008)

Micro-Nano Sensors

Slave Device for Telesurgery (1996)

Patient Specific Arterial Models (2004)

PLCL Scaffold (2006)

Patient Specific Scaffold (2007)

Cell Culture in Scaffold (2009)

Artery/Organ Regeneration

Micro Force Sensor (1997)

Endovascular Evaluator and Photoelastic Effect of Arterial Models (2005)

Catheter Performance Analysis (2007)

Stress Analysis in Bleb (2011)

3D Stress Analysis

Whole Vessel Reproduction

Active Catheters (1989-1994)

Robotic Camera IVR Simulation (2006)

IVR Simulation (2008)

Surgical, pathological, immune system simulator

1989 2000 2005 2008 2030

リニアステッピングメカニズム　Linear Stepping Mechanism　(2003)

Rotation

- Variable speed of insertion and extraction of catheter (Feeding force 2N)
- Variable rotation speed
- High resolution of discrete linear motion of catheter (up to 0.1 mm/cicle)
- Easy to clean

Forward

at Variable Speed

Forward feeding characteristics on several reciprocating distance of grasping unit

F. Arai et al., ICRA 2002

患者個人に応じた人工血管モデルによるシミュレーション
Simulation using Patient-Specific Vasculature Models

Whole Body Tomogram

Vasculature Morphology Extraction

Endovascular Evaluator

[Ikeda, JRM 2005]

Treatment Simulation

T. Fukuda, C. Tercero, Microsurgery, Pan Stanford Pub.

光弾性効果によるカテーテル操作評価 Photo-elastic Evaluation by Artificial Model

Experimental Result

Hardware Setup

Observed Image

(a) Analyzed Magnitude

(b) Analyzed Direction

[S. Ikeda, in Proc. of MICCAI 2005]

人工血管シミュレータによる手術シミュレータ Blood Vessel Simulator and Surgical Operation System

Linear Stepping Mechanism (LSM) for catheter control (2003)

Human Blood Pressure Simulation (2008)

Blood vessel simulator and surgical operation system

Catheter with Micro Force Sensor (1997)

Endovascular Evaluator and Photoelastic Effect of Arterial Models (2005-)

T. Fukuda et al., IEEE Industrial Electronics Magazine, Vol. 4,pp. 13-22, 2010.

Pan Stanford Pub, edited by Toshio FUKUDA and Carlos Tercelo,
ISBN 978-981-4364-69-0 (Hard cover)
ISBN 978-981-4364-70-6 (eBook)

福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m

cm

mm

μm

nm

- Multi-locomotion Robots
- Multi-mobile-robot Corporation
- Interface Robotics
- Grasping, Tactile Sensing
- Medical Robotics -Vascular Model and Scaffold-
- Bio-micro Manipulation for Single Cell Manipulation
- Nanodevice/Nanomanipulation

3次元細胞構築コンセプト 3D Cell Assembly

バイオ･シンセシスのためのアプローチ Approach for Biosynthesis

Bio-synthesis in 3D Space
for

- Bionic-simulator
- Regeneration engineering
- Investigation of biological System …

Platelet Production

Paltelet Production from Megakaryocyte

1D Assembly

Assembly by Electro-deposition

Assembly by Thermal-gel probe

2D Structure

Rolling up Hydro-gel fibers on scaffold

Direct assembly of magnetic hydro-gel fibers

3D Structure

Assembly of Micro-structures encapsulated cells

Assembly of Cells sheets in 3D space

Biodegradable Scaffold

Micro-Nano Fabrication/Measurement/Assembly/Tools…

マイクロナノマニピュレーションによるバイオアセンブリ　Bio-Assembly by Micro-Nano Manipulation

Single Cell Manipulation/ Analysis by Nanotools

Platelets Production from Megakaryocytes

Assembly by thermal gel probe

Wrapping by Cell Sheets

Robotics control for realization of In vivo system in In vitro environment

Cell-assembly by Electro Deposition

3D Scaffold for Blood Vessel Structure

Micro-Assembly of Hydro-gel Fibers

Assembly by Magnetic Hydro-gel Fibers

2D/3D Cell Assembly with Photo-linkable Resin

Research objective

Trans. JSME, 2009 Applied Physics Letters, 2013 J. Micro-Bio Robotics, 2013

Fabrication

Fabrication results of microheater

After pulling glass tubes

After gold sputtering

M. Takeuchi, Journal of Micro-Bio Robotics, 2013, DOI:10.1007/s12213-013-0060-x

Fixation force measurement - evaluation -

Fixation force was measured by changing the size of handled micronbead.

- **Microbead size: 20 μm and 50 μm**
- **The embedded surface area of the microbead: 25 % to 35 %**

Surface area of 20 μm microbead

6.3 times

Surface area of 50 μm microbead

Experimental results of fixation force measurement

Handling objects	Fixation force [μN]
50 μm microbead	12.5±3.7
20 μm microbead	2.0±0.8

6.3 times

Fixation force is proportional to the embedded surface area to the gel.

M. Takeuchi, Journal of Micro-Bio Robotics, 2013, DOI:10.1007/s12213-013-0060-x

3D assembly of microbeads

3D microstructure was assembled made of ϕ50 μm microbeads.

(replay speed: 10 times faster)

Assembly of 3 dimensional structure was achieved.

M. Takeuchi, Journal of Micro-Bio Robotics, 2013, DOI:10.1007/s12213-013-0060-x

福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m

cm

mm

μm

nm

- Multi-locomotion Robots
- Multi-mobile-robot Corporation
- Interface Robotics
- Grasping, Tactile Sensing
- Medical Robotics -Vascular Model and Scaffold-
- Bio-micro Manipulation for Single Cell Manipulation
- Nanodevice/Nanomanipulation

ナノマニピュレーションによる単一細胞ナノサージェリシステム
Single Cell Nano－surgery System

Single Cell Electrical Measurement

Single Cell Stiffness Measurement

- Nano-probe
- Dual-Nano-probe
- Nano-fork
- Nano-putter

Diagnosis

Cell-Cell Adhesion Force Measurement

Cell-Cell Adhesion Force Measurement

Extraction

Cutting

Single Cell Measurement

Single Cell Nano-surgery System

- Nano-knife

Single Cell Cutting

Injection

Embedded

- Nano-injector

E-SEM Manipulator

Semi-wet Environment

IEEE Transactions on Nanotechnology, Vol. 7 Issue 5, pp. 607-616, 2008
IEEE Transactions on Nanobioscience, Vol. 7 Issue 3, pp. 185-193, 2008
IEEE Transactions on Nanobioscience, Vol. 9, No. 1, pp. 12-23, 2010
Nanotechnology, Vol. 24, Number 14, 145703, 2013
Nanotechnology, vol. 22, No. 30, p. 305701, 2011.
Ultramicroscopy, 111, 8, 1176-1183, 2011
IEEE Transactions on Nanotechnology, Vol. 10 Issue 2, pp. 226-236, 2011
IEEE Transactions on Nanobioscience, Vol. 11 No. 1, pp. 70-78, 2012
IEEE Transactions on Nanotechnology, Vol. 11, No. 2, pp. 298-306, 2012

ナノフォークによる単一細胞の付着力計測
Adhesion Force Measurement of Single Cell by Nanofork

Dynamic Sticking Forces Measurement

Nano-fork fabricated by FIB

Line-patterned substrate fabricated by Nano-imprinting

Measuring the sticking forces by the deflection of each cantilevers

M. A. Ridzuan et al., Proc. of IEEE Conf. on Nanotechnology 2010 (IEEE-Nano 2010).

ナノフォークによる単一細胞の付着力計測結果
Results of Single Cell Adhesion Force Measurement by Nanofork

Force Analysis in Single Cell Adhesion Measurement

$$\textbf{Adhesion force} = k * \delta = k\left[\varphi \frac{2}{3} L\right]$$

k = Spring constant of the cantilever
L = Length of the cantilever
δ = Deflection length
φ = Deflection angle

	Parameters for Nanofork		Release Force (nN)
	Spring constant (N/m)	Length (μm)	
Nanofork for 1 μm gap	2.47	192.30	707 ± 106 (n = 2)
Nanofork for 2 μm gap	2.57	191.90	475 ± 87 (n = 4)

M. A. Ridzuan et al., Proc. of IEEE Conf. on Nanotechnology 2010 (IEEE-Nano 2010).

ナノピッカーの作製

Nano picker fabrication using the cantilever with a spring constant 0.02 N/m

Y. Shen et. Al, Biochemical and Biophysical Research Communication, vol. 409, no. 2, pp. 160-165, 2011.

ナノピッカーによる単一細胞の細胞間付着力計測結果

Y. Shen et. Al, Biochemical and Biophysical Research Communication, vol. 409, no. 2, pp. 160-165, 2011.

Micro-Nanorobotic Manipulation Systems and Their Applications

Toshio Fukuda, Fumihito Arai, Masahiro Nakajima, Springer (to be published)

Micro-Nano Mechatronics

- New Trends in Material, Measurement, Control, Manufacturing and Their Applications in Biomedical Engineering-

Edited by Toshio Fukuda, Tomohide Niimi and Goro Obinata, ISBN 978-953-51-1104-7, 364 pages, Publisher: InTech, Chapters published June 05, 2013

Q & A

Acknowledgments

This work was partially supported by MEXT KAKENHIand Japan Science and Technology Agency, Global-COE program in Nagoya University (COE for Education and Research of Micro-Nano Mechatronics).

μ-Mech GEAR
GLOBAL COE PROGRAM

BIO Assembler

Thank you for your attention