Medical Digitalization (Me-Dig IT) —A Construction Methodology for Medical Support Systems—

MEDICAL & BIO ARE NEW DIGITALS !

Norihiro Koizumi

2018 Overview of Mechanobioengineering

http://www.medigit.mi.uec.ac.jp/ovmbe-p.pdf

100th ANNIVERSARY SINCE 1918

NML Mitsuishi Sugita Lab.

TSBMI Translational Systems Biology and Medicine Initiative

Me-Dig IT

Report (Koizumi)

Due: July 6th, To report box in Mechanical Engineering Office or E-mail: nkoizumi@ieee.org

1. Choose one medical support system.

   Reference:
   http://ieeexplore.ieee.org/search/searchresult.jsp?newsearch=true&queryText=medical+robotics&x=0&y=0&tag=1

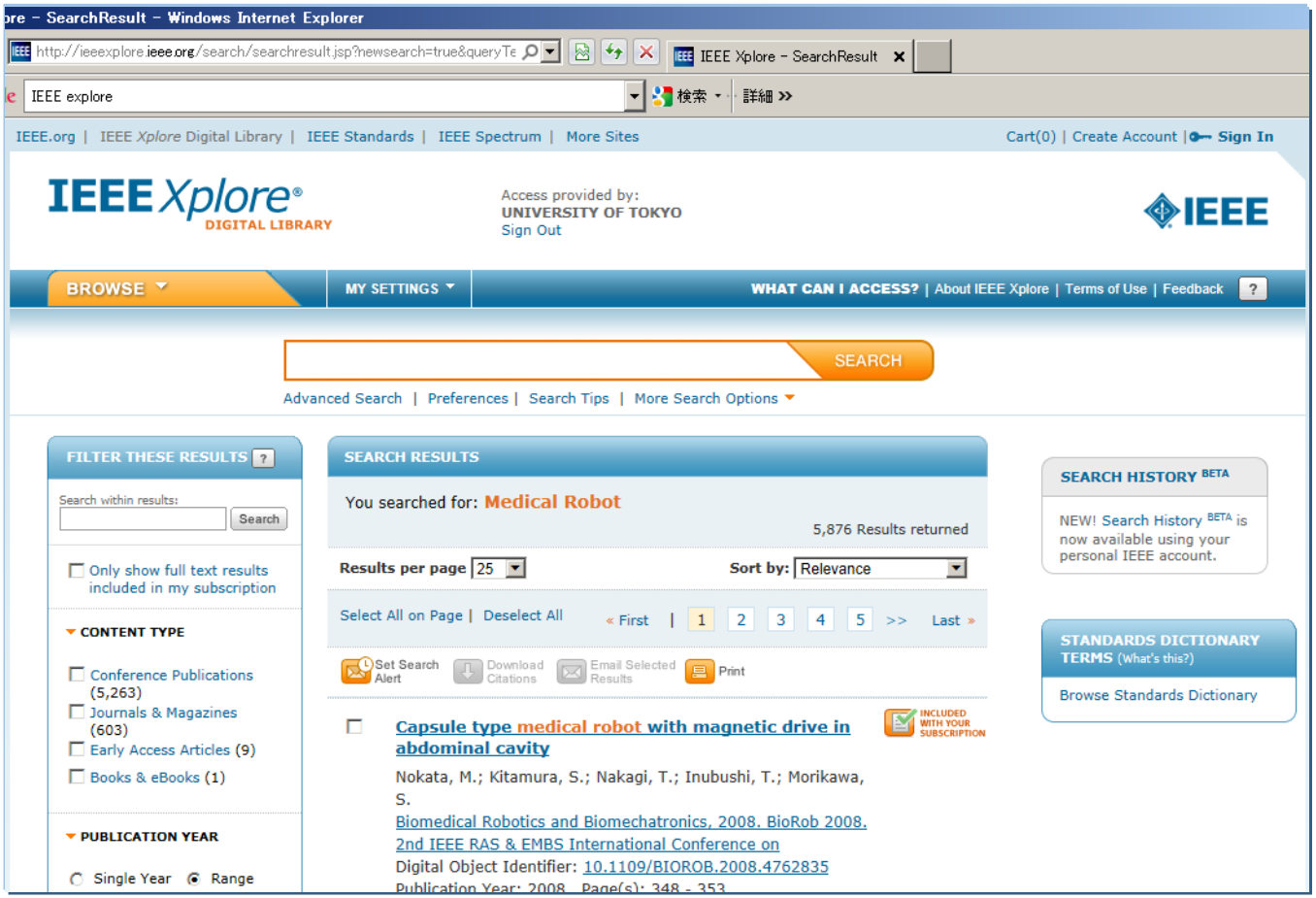
2. Extract functional requirements and structure (decompose and reconstruct) them, considering the implementation of the system.

3. Extract one seed technology for one of the abovementioned functional requirements and discuss how to apply and develop the technology.

   http://www. medigit.mi.uec.ac.jp/jrm2013.pdf

References

http://ieeexplore.ieee.org/Xplore/guesthome.jsp



Search Keywords: Medical Robotics, Rehabilitation Robotics, etc.

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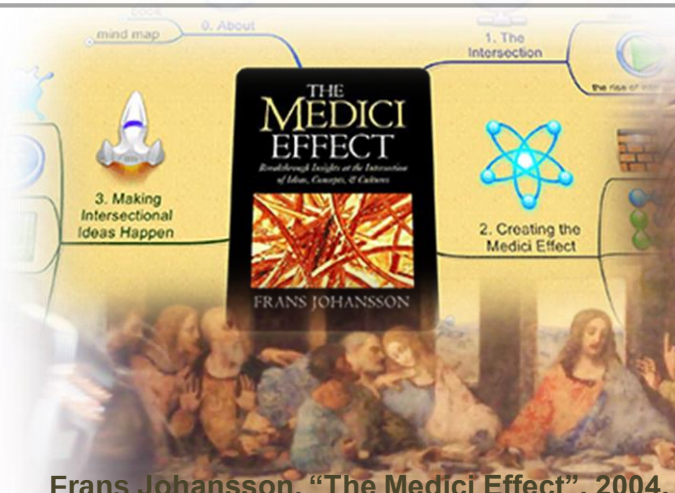
Me-Dig IT Effect

UEC TOKYO



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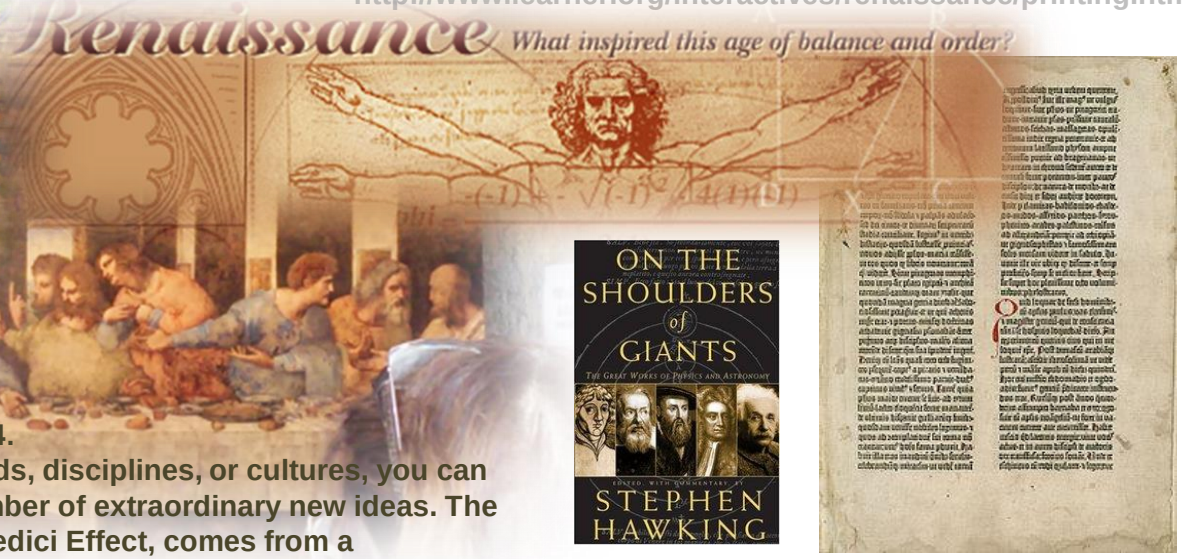


Frans Johansson, "The Medici Effect", 2004.
- When you step into an intersection of fields, disciplines, or cultures, you can combine existing concepts into a large number of extraordinary new ideas. The name I have given this phenomenon, the Medici Effect, comes from a remarkable burst of creativity in fifteenth-century Italy.

Gutenberg's press
Everybody can read bibles

http://www.agtc.com.tr/

MEDICAL & BIO ARE NEW DIGITALS !

Me-Dig IT Effect

Museo Nazionale della Scienza e della Tecnologia "Leonardo da Vinci" in Milano

Everybody can receive high-quality-medicine by IT (Robot) & US technology

Koizumi Lab

Me-Dig ITalization

UEC TOKYO

MEDICAL & BIO ARE NEW DIGITALS !

Me-Dig IT

Therapeutic and diagnostic skills

Reconstruct medical professional skills by utilizing Information and Robot Technology (IRT)

Decomposing and reconstructing functions

- Extract and structure functions
- Parameter analyses of functions
- Make design guidelines for functions
- Implement functions
- Verify systems
- Enhance functions

Implementation of function Embodiment of system

Continuous and high tracking performance motion **controllers**

Safe contact motion **mechanisms**

Robust and precise **image** detection **algorithms** of target

Effect

Goal Establish a method to introduce design guidelines to incorporate medical skills to systems

Reduce the load of medical professionals

Medical professionals

Safety and reliability

Patients

NML
Mitsuishi Sugita Lab.

東京大学
THE UNIVERSITY OF TOKYO

Remote Ultrasound Diagnostic System (RUDS)

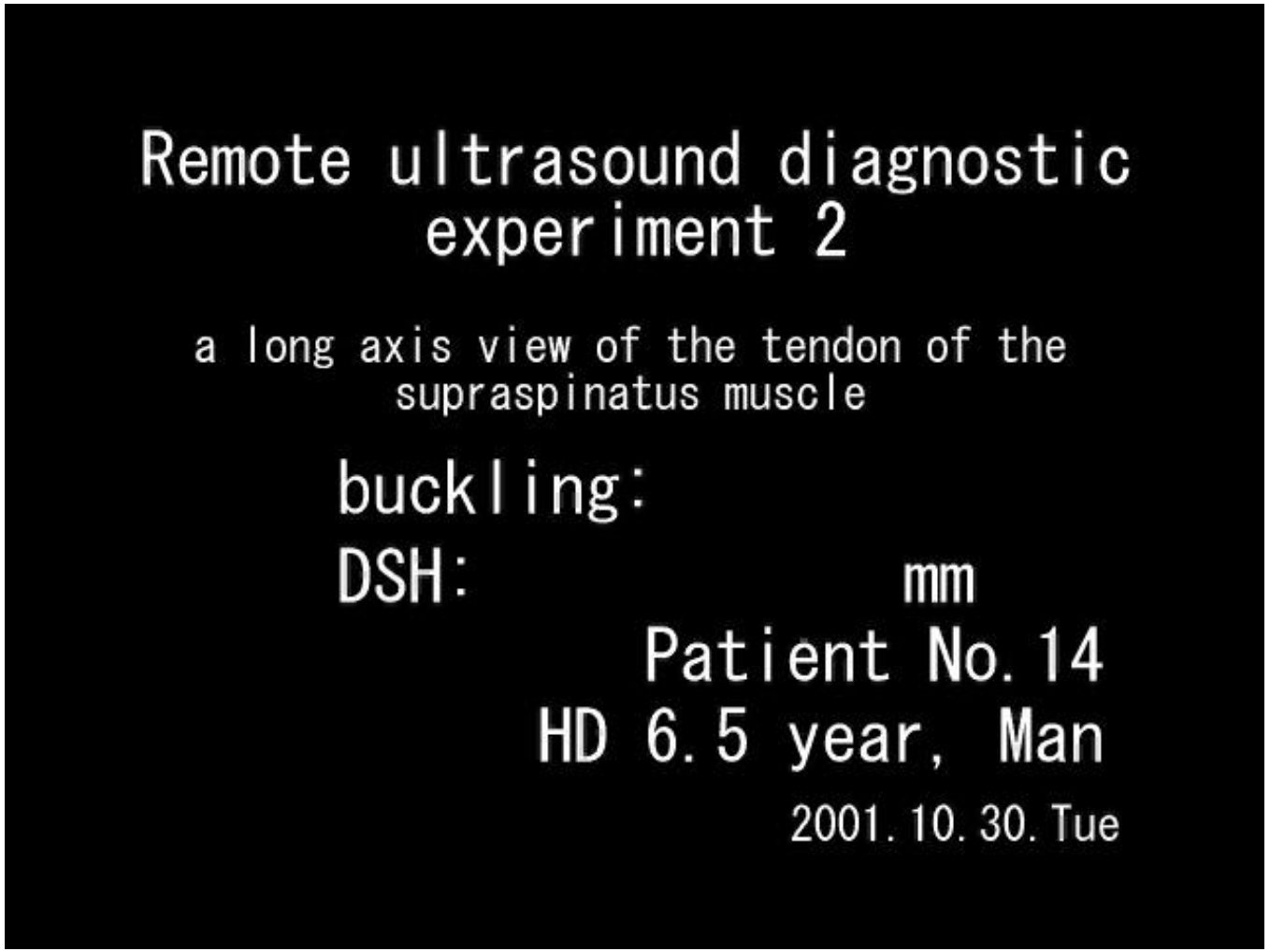
（My Doctoral dissertation）

FEL

GMSI
Global Center of Excellence for Mechanical Systems Innovation

TSBMI
Translational Systems Biology and Medicine Initiative

Diagnostic experiment（clinical use）



Background

Arriving of the aging society

→ Medical support system

→ Remote ultrasound diagnostic system

↓

1. Lessen regional difference in medicine
2. Lessen load of patient and medical doctor
3. Efficient medicine

Purpose

Establishment of construction methodology for the remote ultrasound diagnostic system

Diagnosis

Function analysis & reconstruction

Extract functions

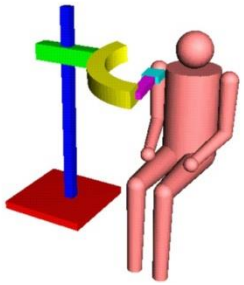
Analyze and reconstruct functions

Make guideline for design

Install functions & implement the system

Safety motion & contact function (Impedance control)

Smooth motion & high traceability (Continuous Path control)



Manipulability enhancement function (Dynamic switching controller)

Construction methodology

Required function

Guideline for design

(i) Realize proper contact force

(ii) Realize proper position

(iii) Realize proper orientation

(iv) Secure safety

(v) Improve manipulability

(vi) Lessen uneasiness

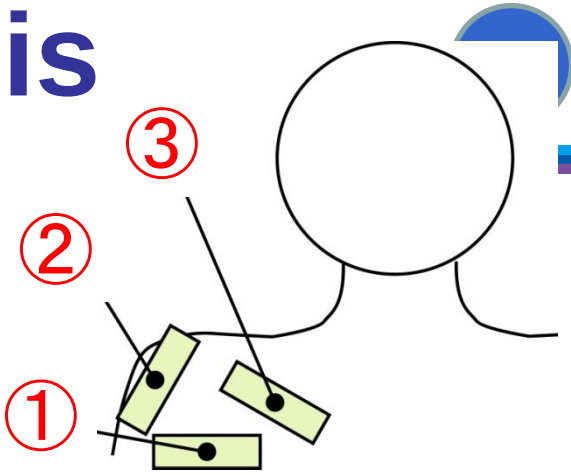
(vii) Maintain stable contact

(viii) Correspond to personal difference

(a) Mechanism to realize proper position and orientation

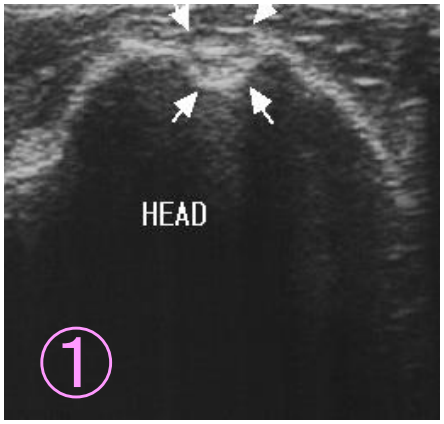
(i) Adjustable controller according to personal difference of medical doctor and patient

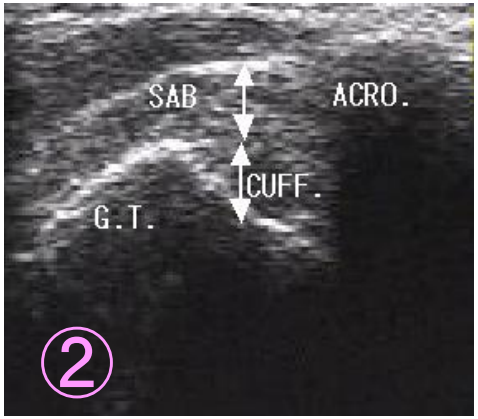
Object of diagnosis

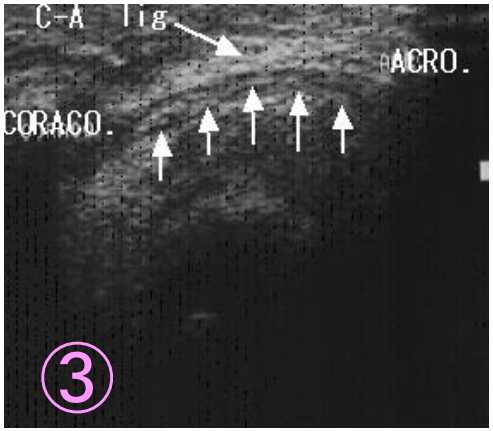


Shoulder pain in hemodialysis patients

Diagnostic image







[Diagnostic image ①]
A tendon of the long head of the biceps brachi

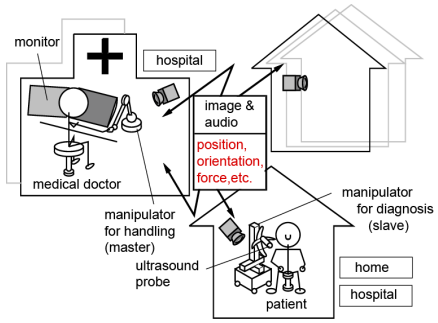
[Diagnostic image ②]
A short axis view of the tendon of the supraspinatus muscle

[Diagnostic image ③]
A long axis view of the tendon of the supraspinatus muscle

Extract functions

Extract and decompose functions

- Remote ultrasound diagnostic system
  - Display information to medical doctor
    - Acquire diagnostic image
      - Approach probe to affected part
      - Push probe on affected part
      - Find affected part
      - Maintain acquired diagnostic image
      - Pull probe apart from affected part
    - Transmit diagnostic image
    - Display diagnostic image
  - Communicate



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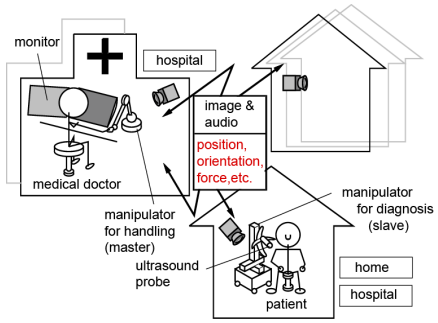

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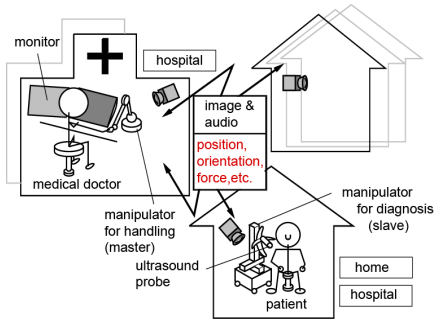

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Extract and decompose functions

Acquire diagnostic image

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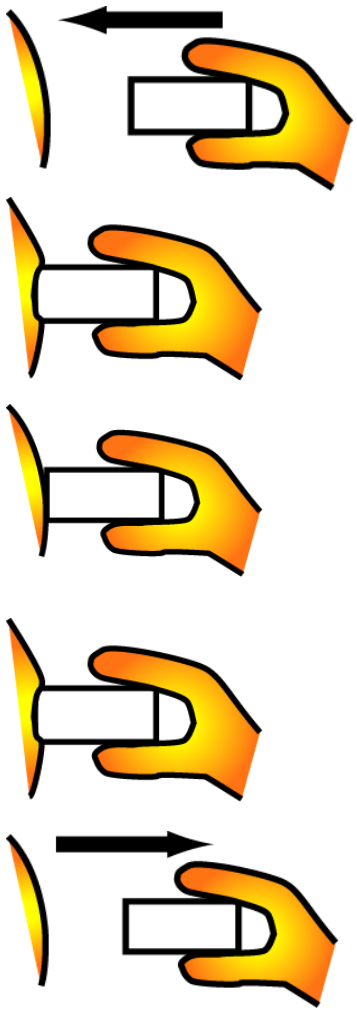

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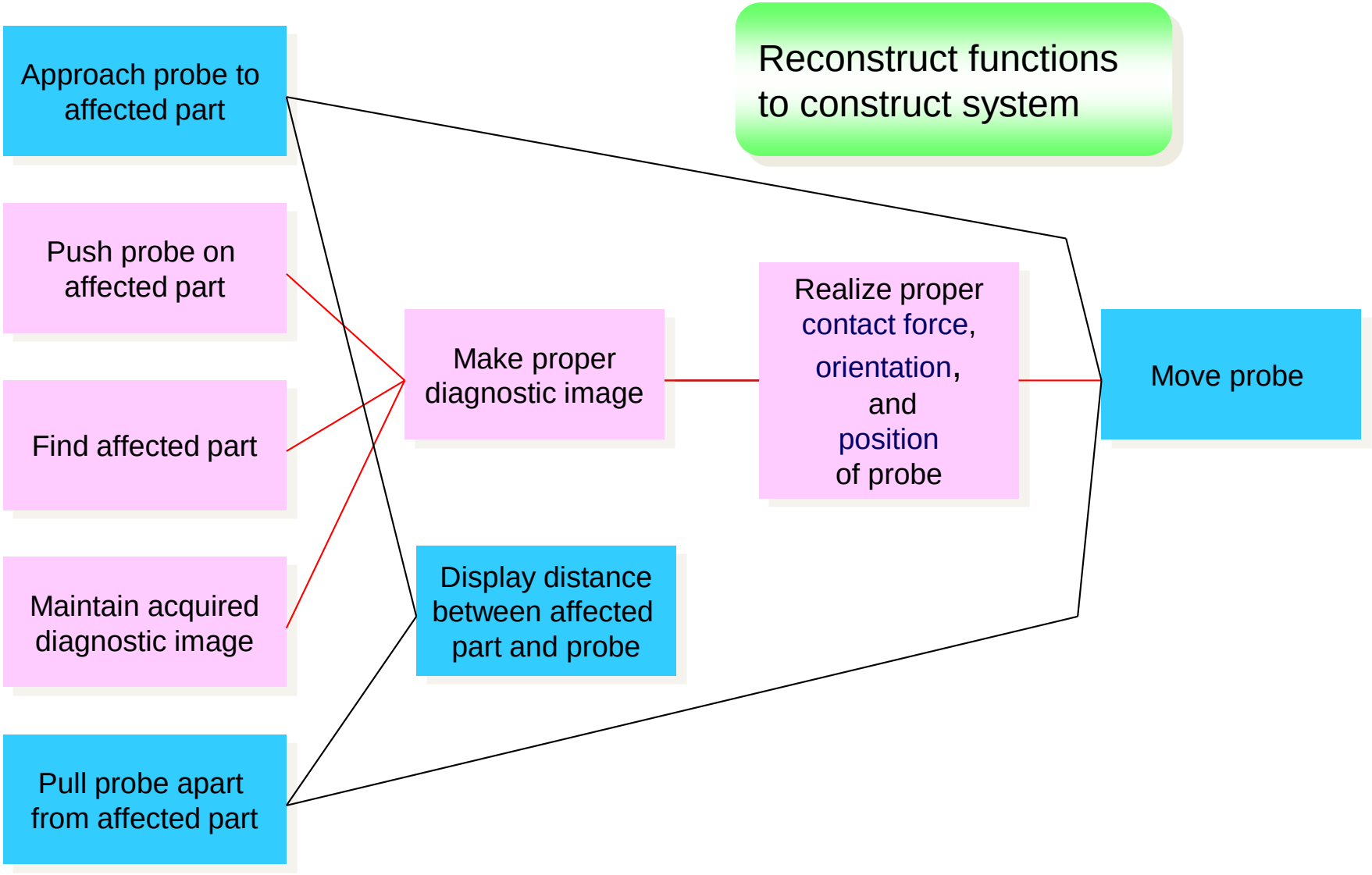


Required contact force

Objective

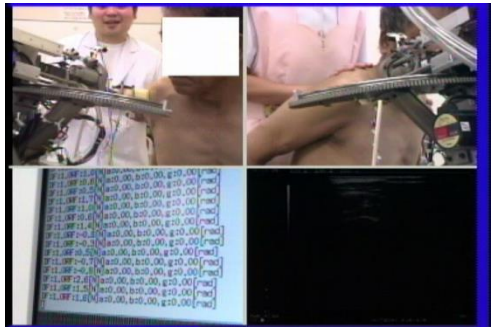
Clarify the required contact force.

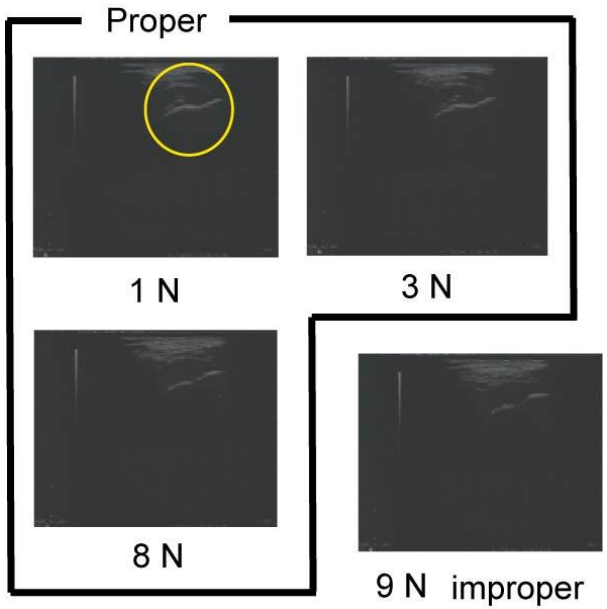
Method

Confirm whether diagnostic image is proper or not by changing the contact force with step of 1 N from proper diagnostic image.

Condition

object : Diagnostic image 1～3
examinee : 3 patients
2 healthy men

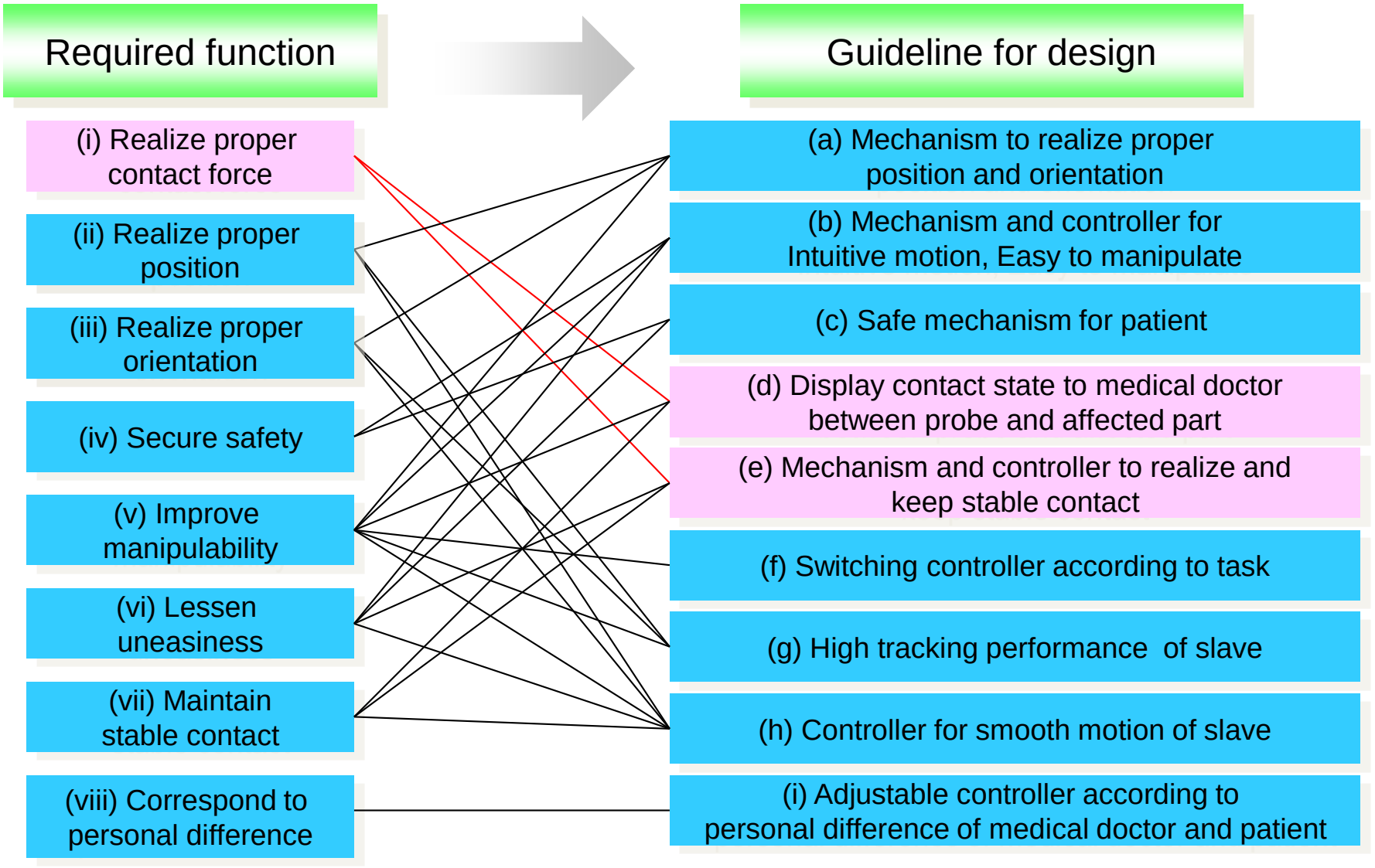




Results

Required contact force
Image 1: 2 N～8 N
Image 2: 1 N～7 N
Image 3: 1 N～10 N
(average of 5 examinee)

Make guideline for design



Required precision for orientation

Objective

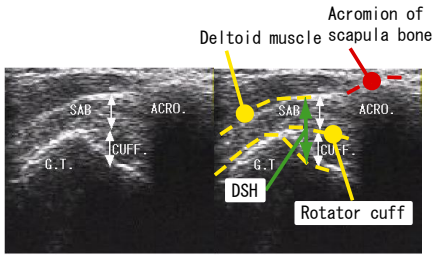
Clarify the required precision for orientation.

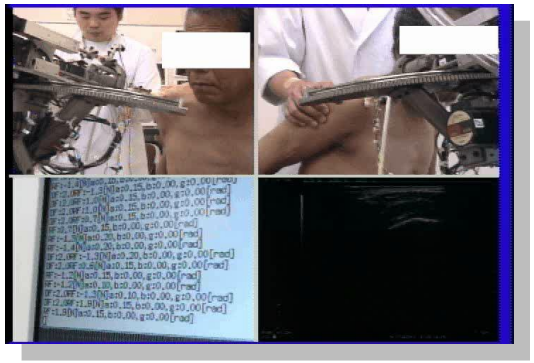
Method

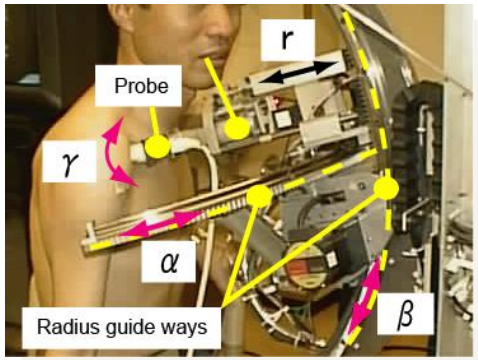
Confirm whether diagnostic image is proper or not by changing the orientation with step of 0.05 rad from proper diagnostic image.

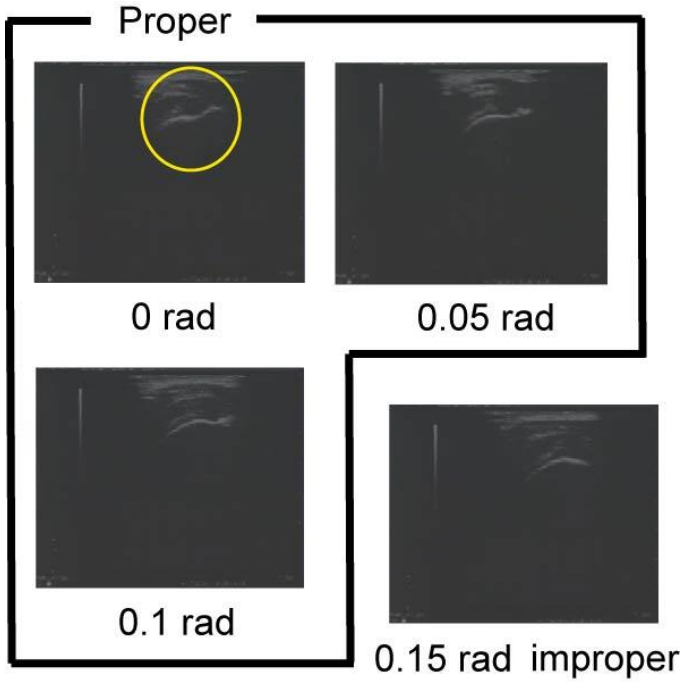
Condition

object： Diagnostic image 2
examinee：3 patients
2 healthy men





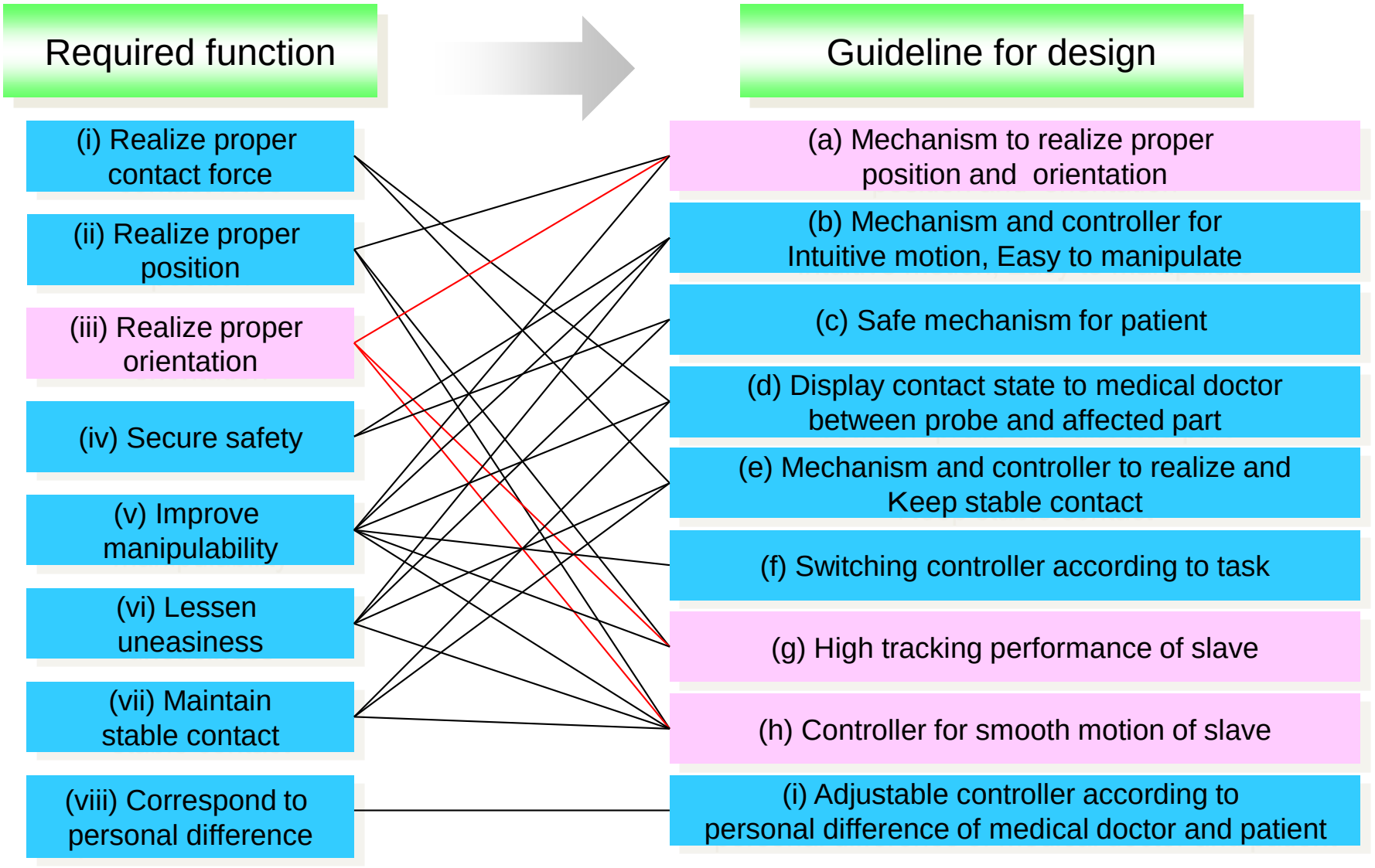




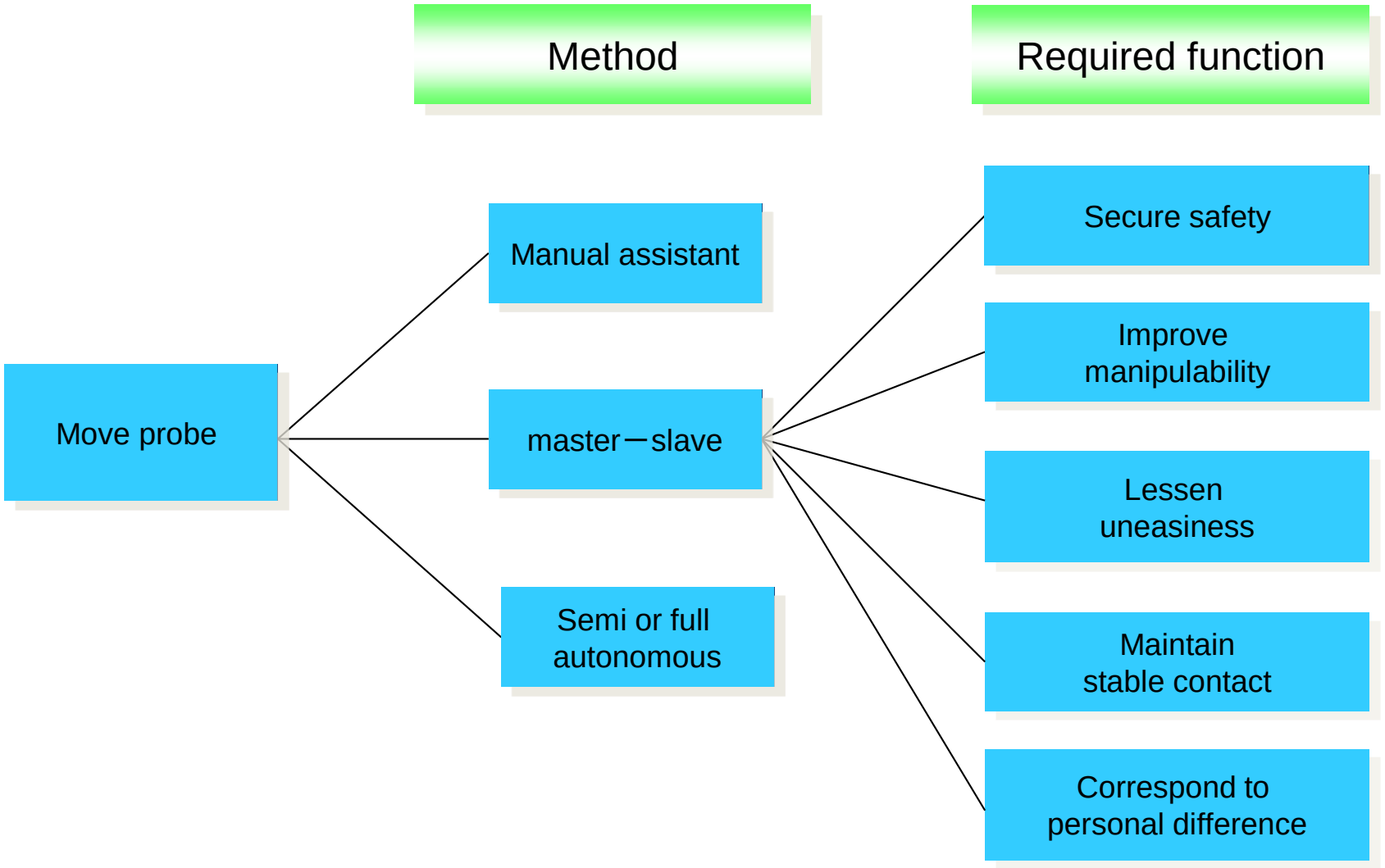
Results

Required precision for orientation
αaxis:0.1rad
βaxis:0.2rad
γaxis:0.3rad
(average of 5 examinee)

Make guideline for design



Functional requirements by adopting master－slave method



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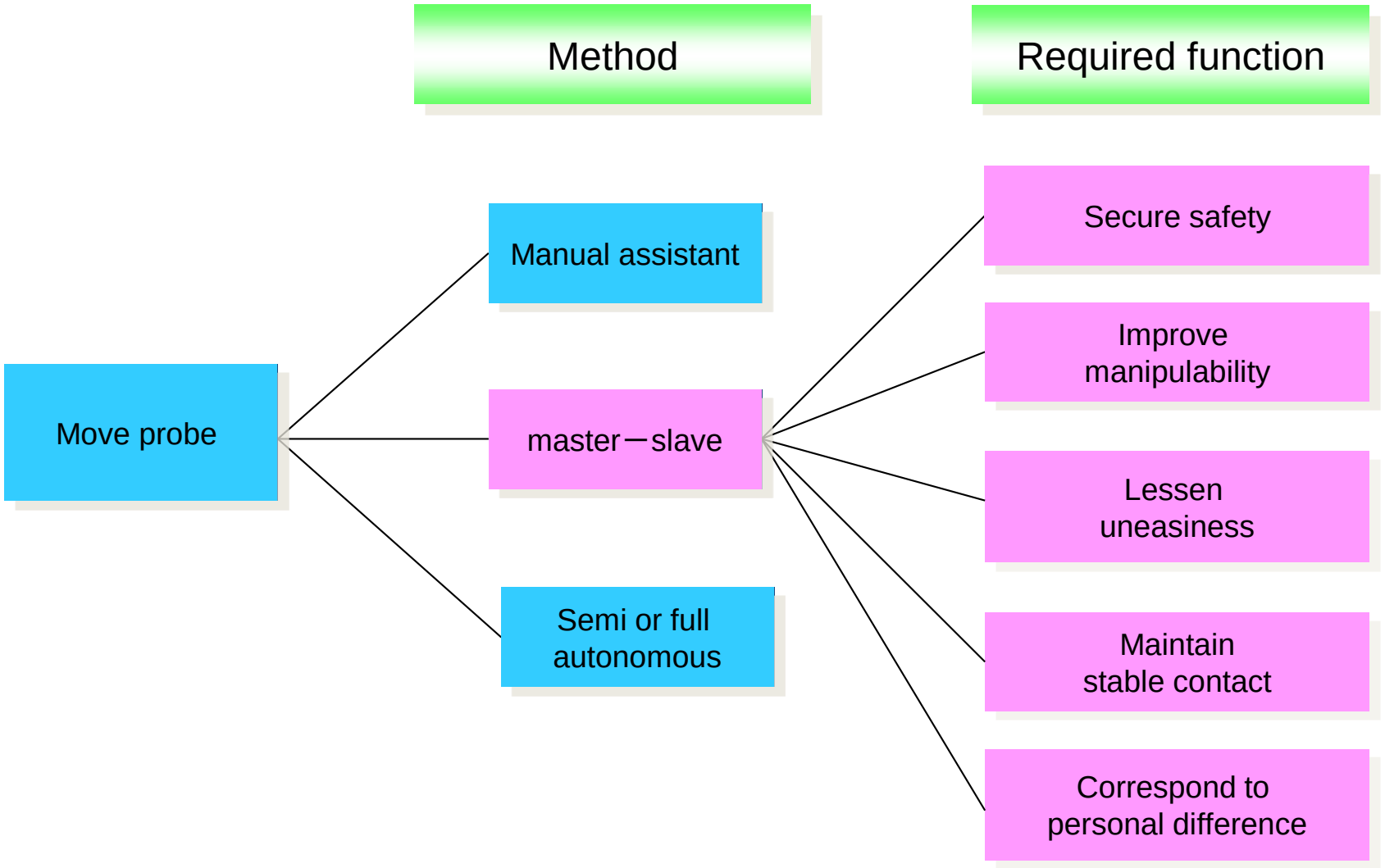

Make guideline for design

Required function	Guideline for design
(i) Realize proper contact force	(a) Mechanism to realize proper position and orientation
(ii) Realize proper position	(b) Mechanism and controller for Intuitive motion, Easy to manipulate
(iii) Realize proper orientation	(c) Safe mechanism for patient
(iv) Secure safety	(d) Display contact state to medical doctor between probe and affected part
(v) Improve manipulability	(e) Mechanism and controller to realize and Keep stable contact
(vi) Lessen uneasiness	(f) Switching controller according to task
(vii) Maintain stable contact	(g) High tracking performance of slave
(viii) Correspond to personal difference	(h) Controller for smooth motion of slave
	(i) Adjustable controller according to personal difference of medical doctor and patient

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Install functions & implement the system

Install functions & implement the system

Diagnosis

Function analysis & reconstruction

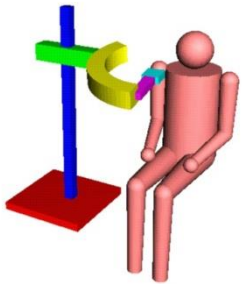
Extract functions

Analyze and reconstruct functions

Make guideline for design

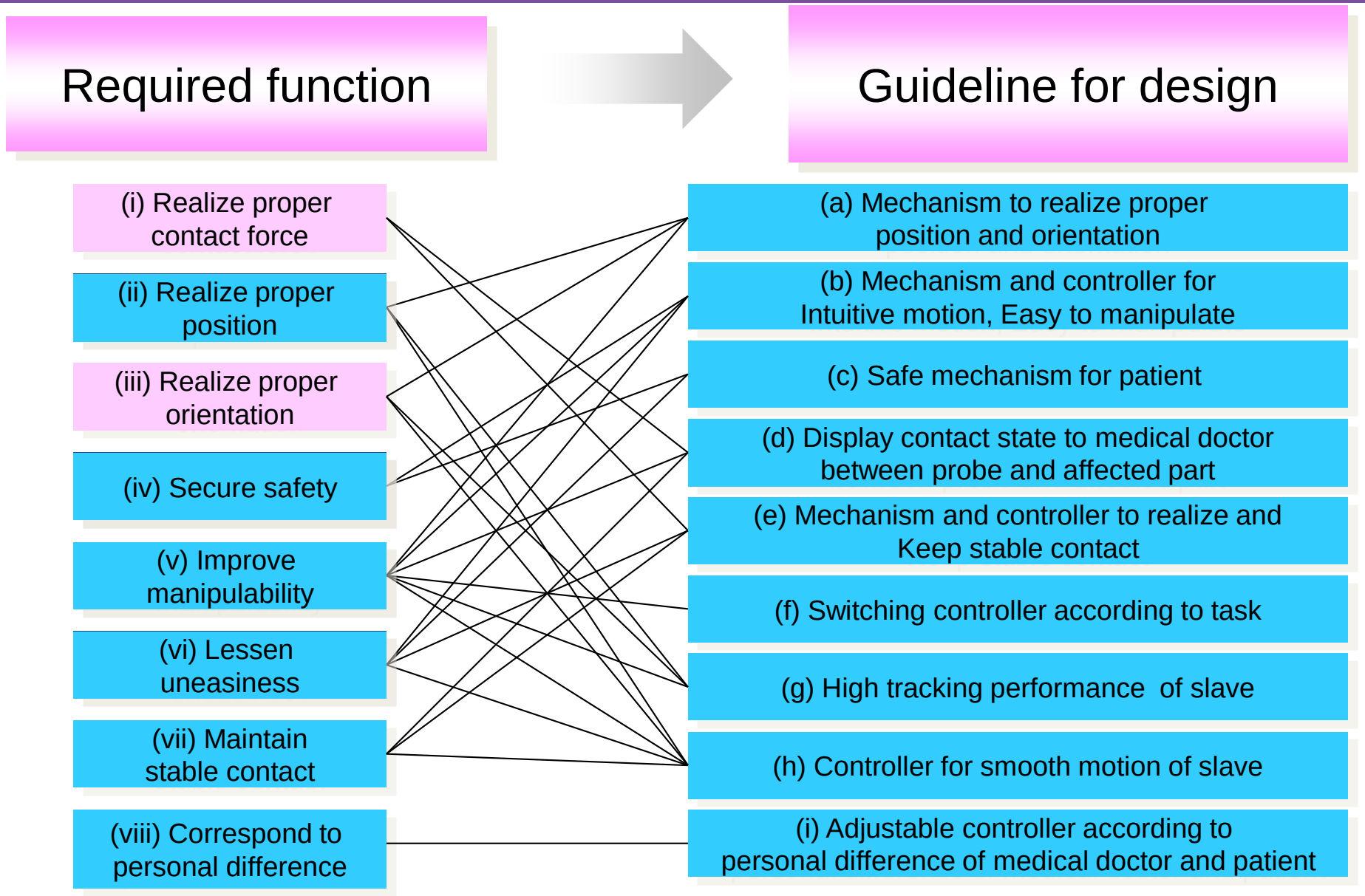
Safety motion & contact function (Impedance control)

Smooth motion & high traceability (Continuous Path control)



Manipulability enhancement function (Dynamic switching controller)

Make guideline for design



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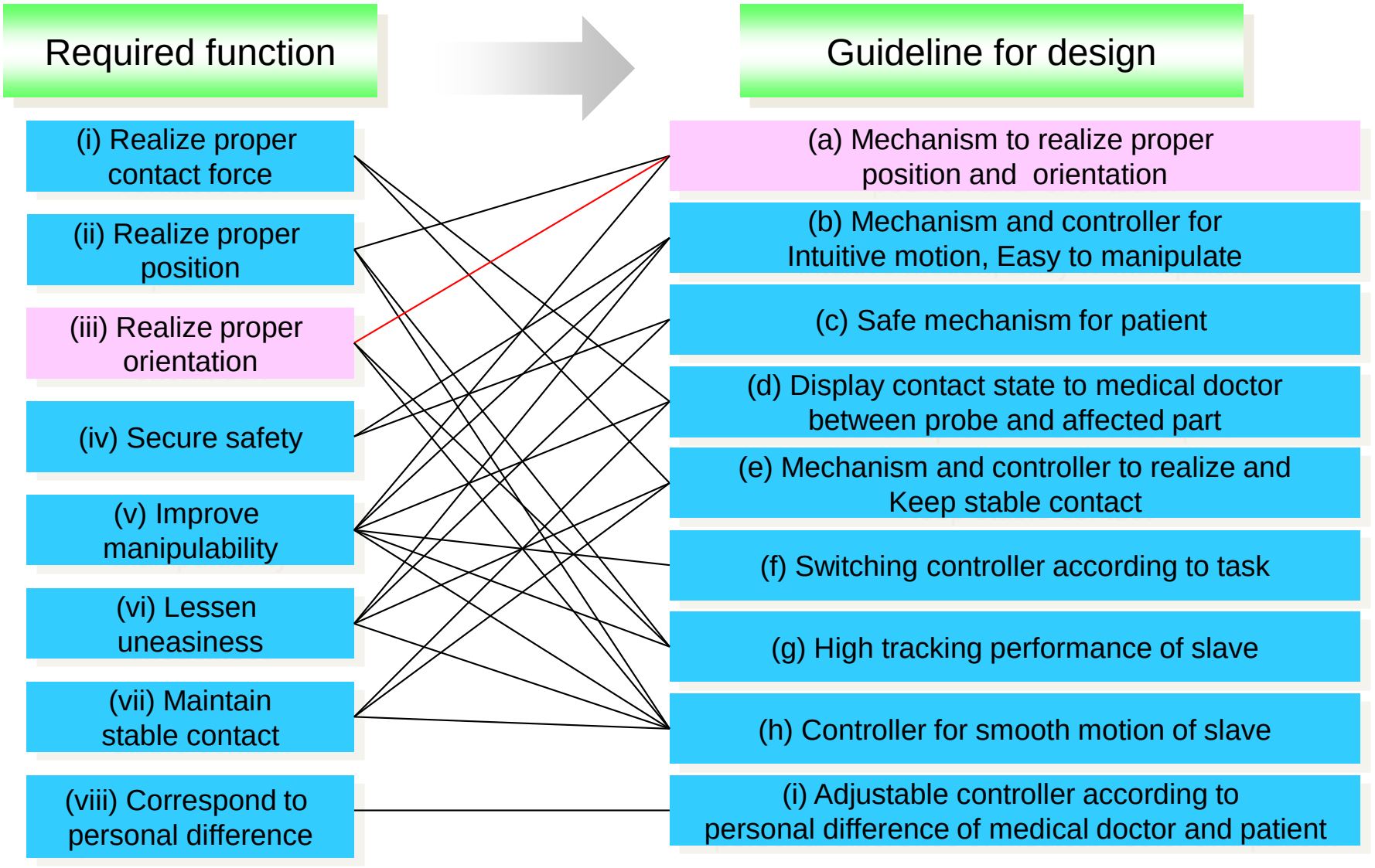
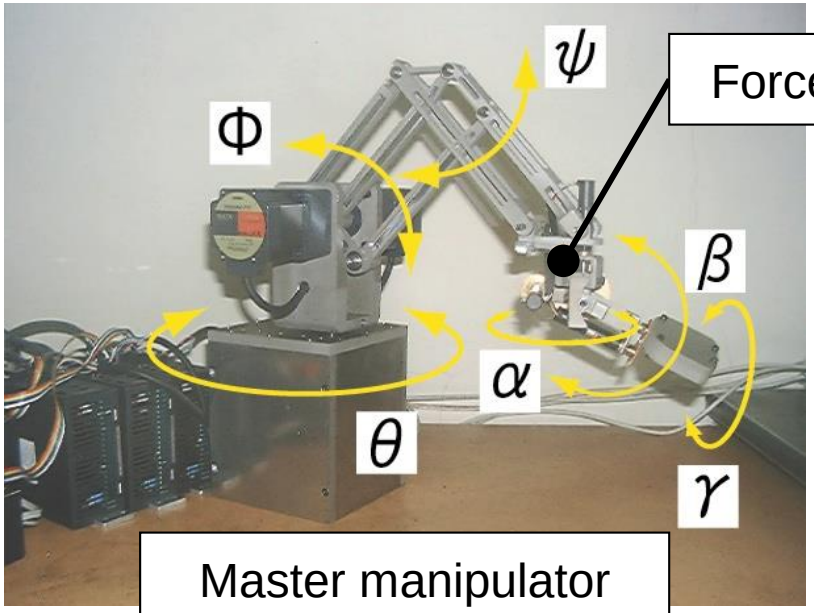


Mechanical configuration

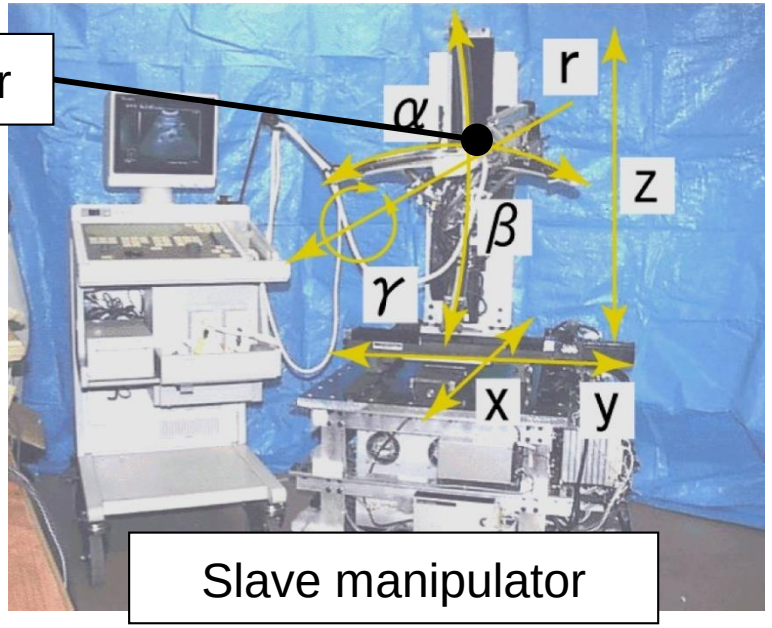
(a) Mechanism to realize proper position and orientation

① Change only orientation while adjusting position
② Highly rigid mechanism



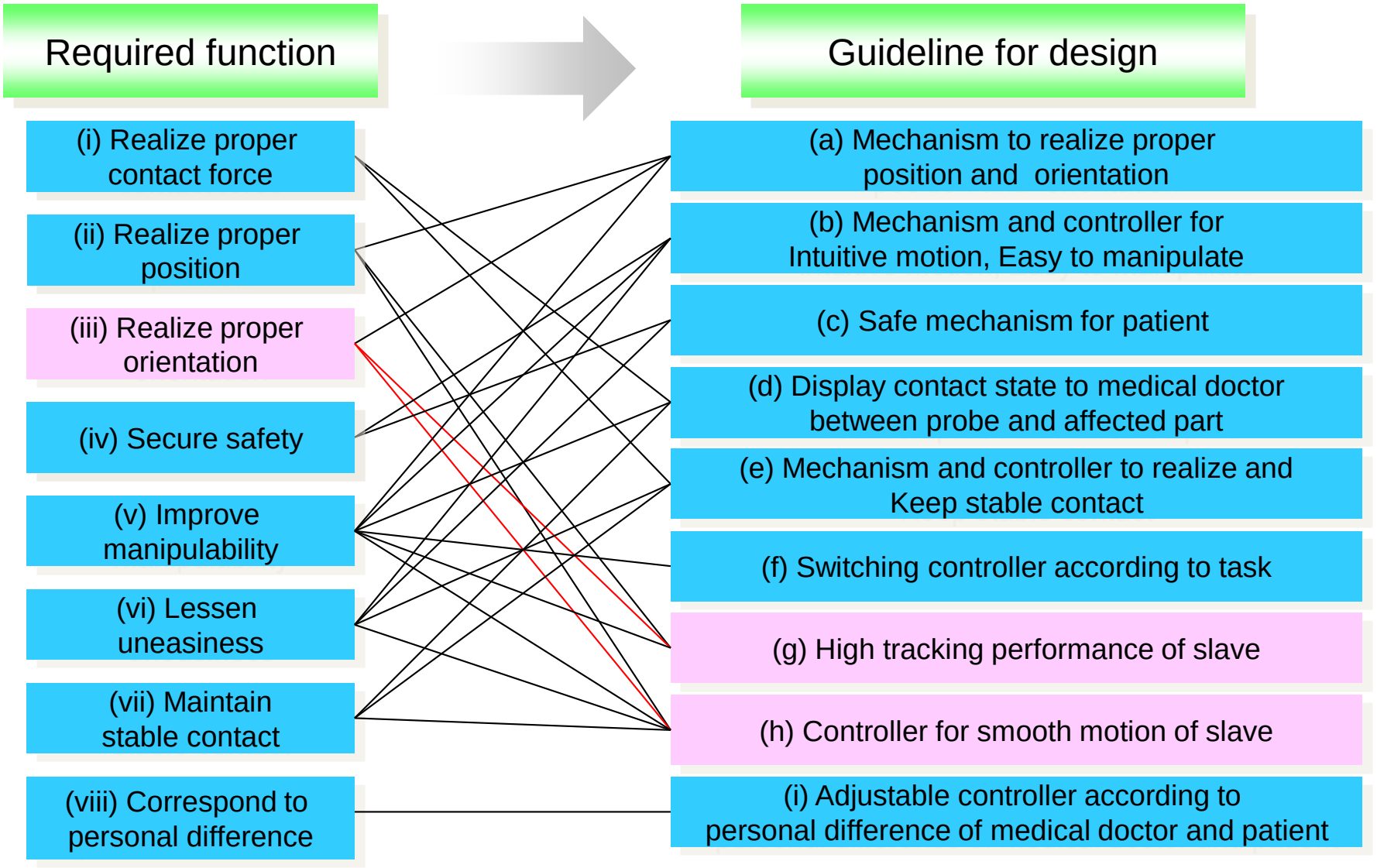
Force sensor

Master manipulator



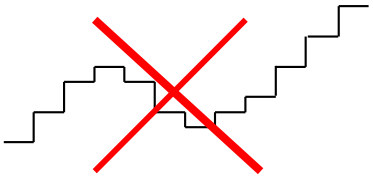
Slave manipulator

Make guideline for design



Continuous Path control

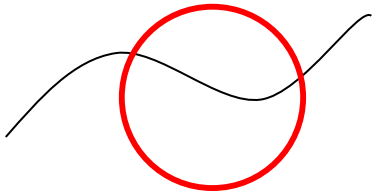
Problem



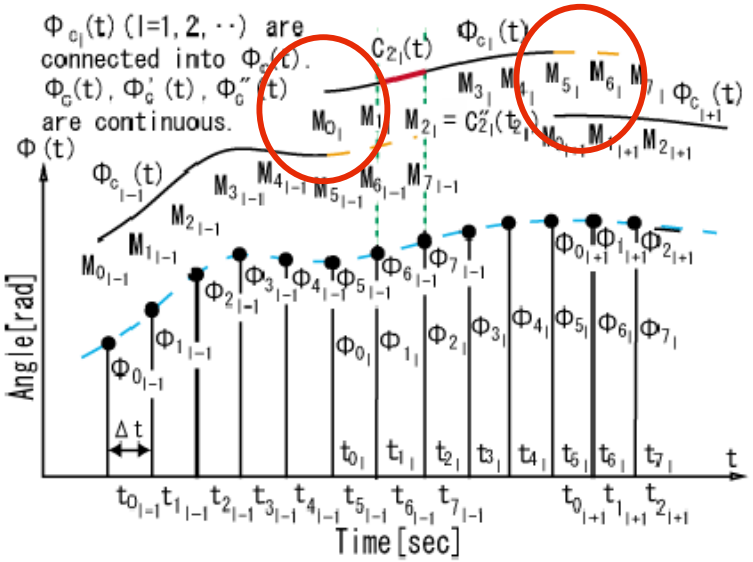
Transmitted data is not smooth !

Conventional control
difficult to realize smooth
motion not losing tracking performance

Technique: Continuous Path control



Smooth motion
and
high tracking
performance

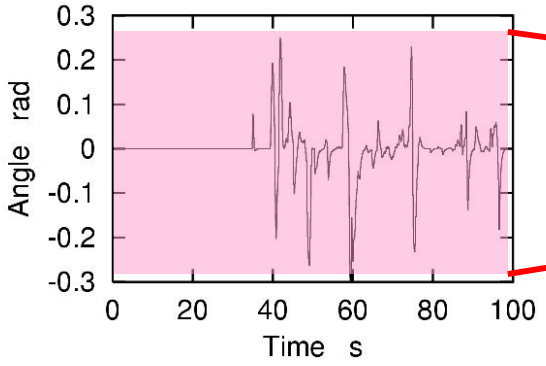


① Continuous paths are generated by using spline function
② Generated paths are connected to the previous paths continuously
③ Smooth motion can be realized not losing tracking performance

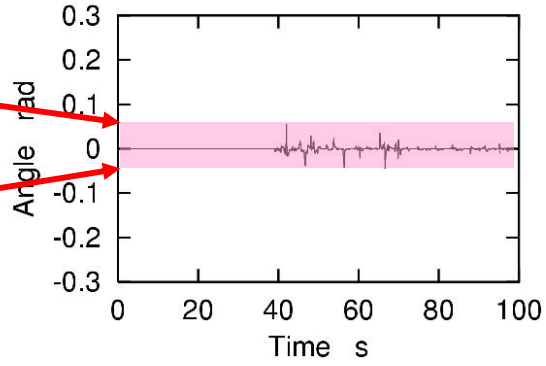
High tracking performance by adopting CP control

Orientation error
between master and slave

Conventional control

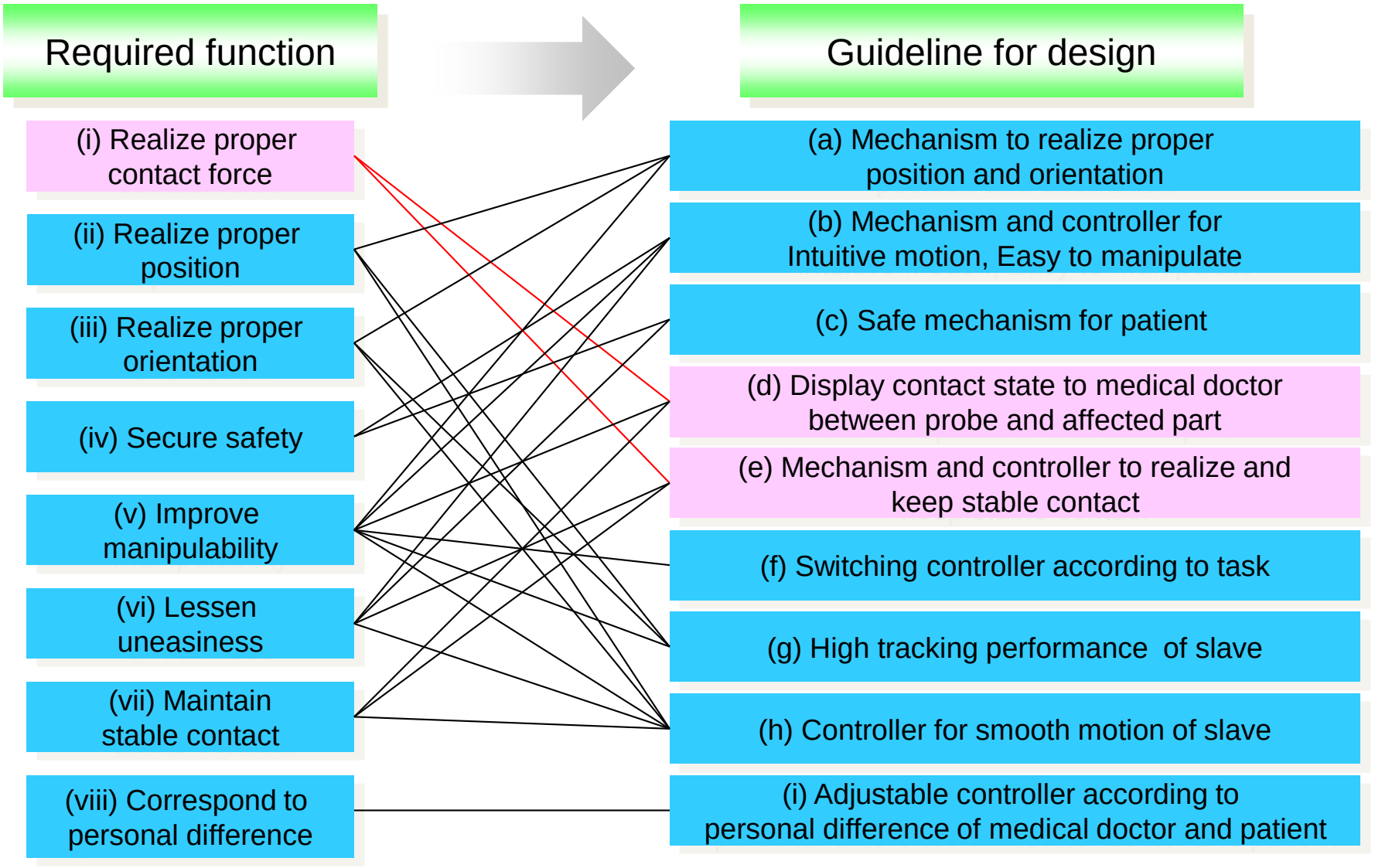


Proposed CP control



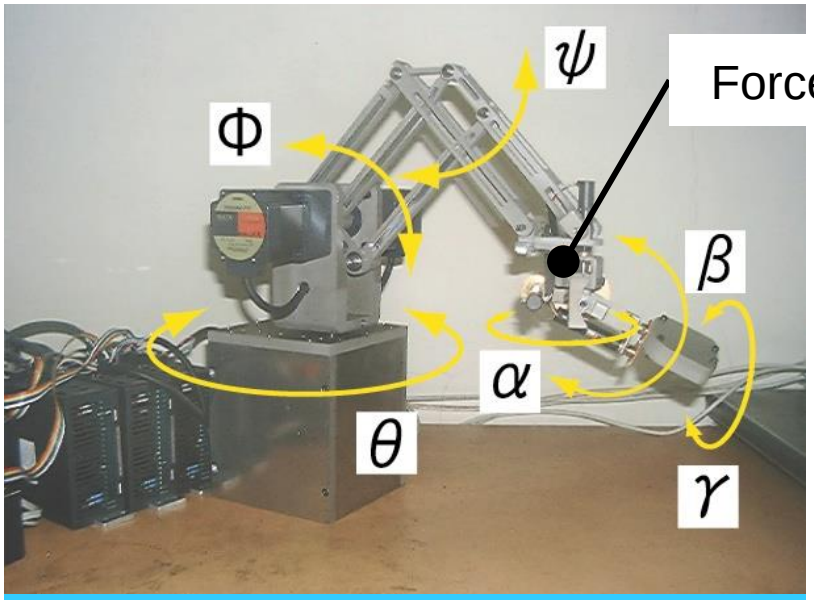
Tracking performance improved !

Make guideline for design

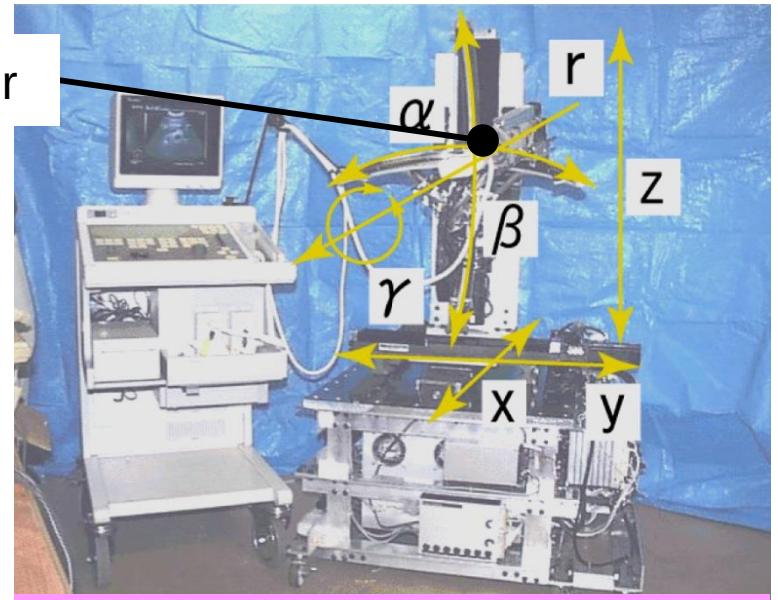


Mechanical configuration

① Highly rigid mechanism
② Force sensors are installed to display contact states and keep stable contact



Master manipulator



Slave manipulator

Impedance control

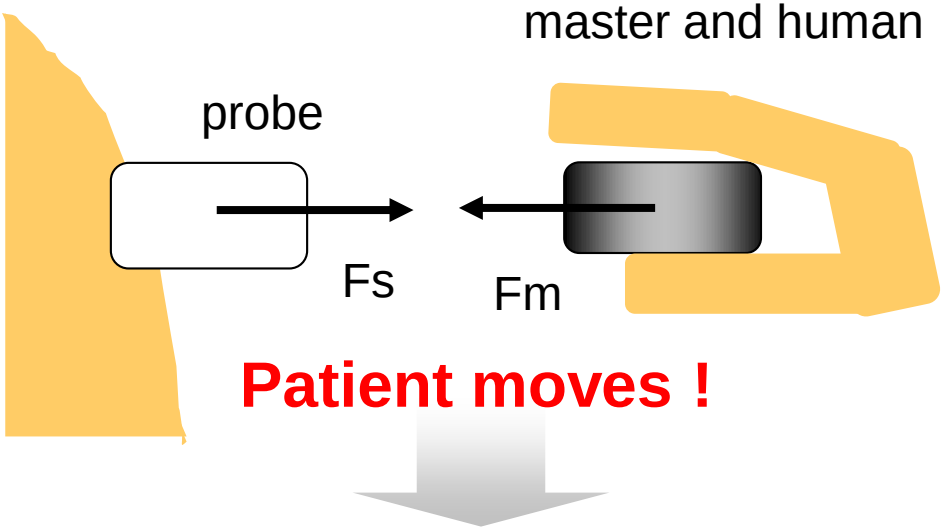
Problem

In conventional master-slave manipulation system,
the object is static and
the main purpose is to realize the same
slave motion as master motion

Patient moves during diagnosis & difficult to keep stable contact

Safety motion and
Stable contact

master and human

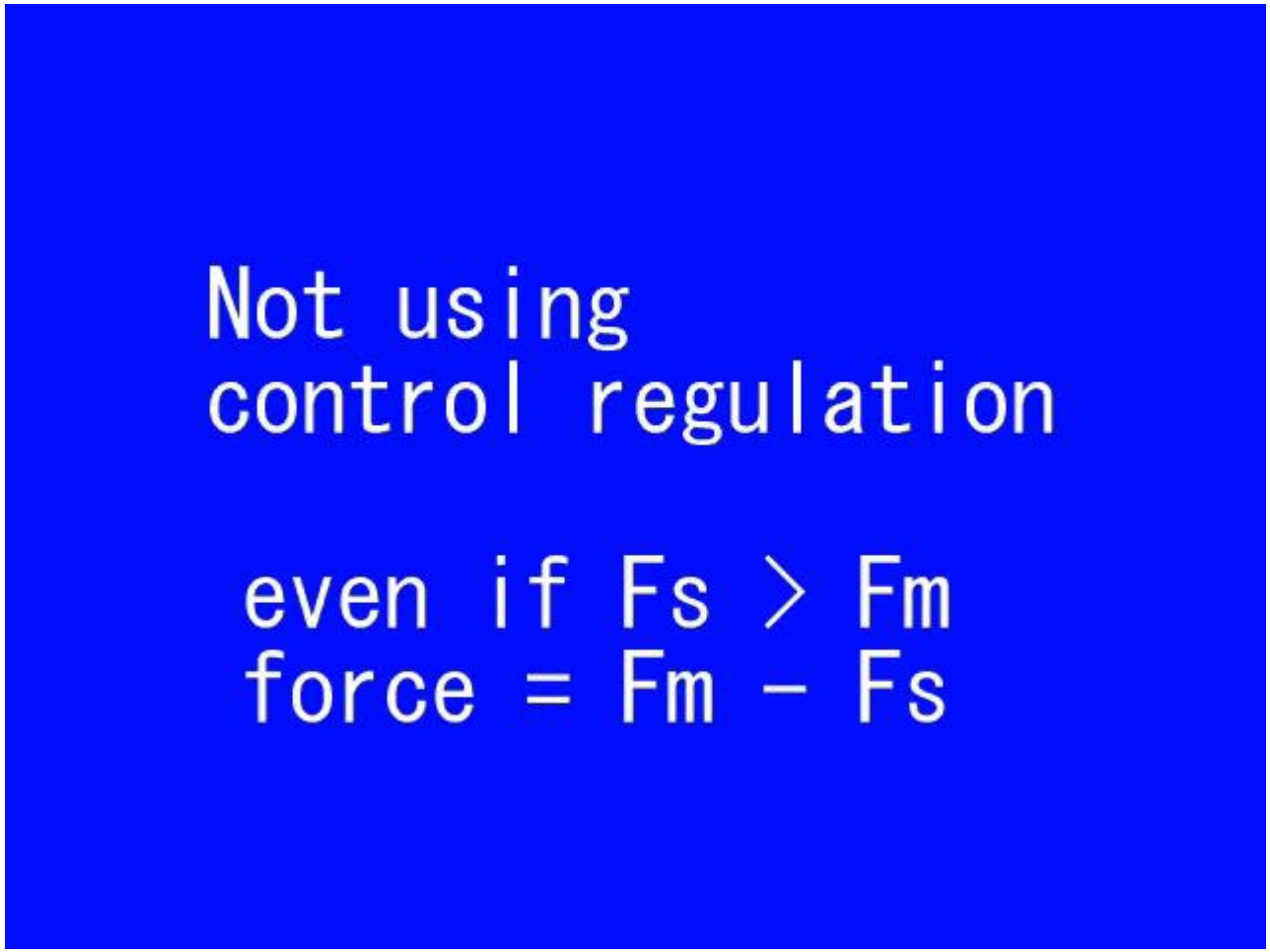


Patient moves !

① Probe moves according to motion control law to display contact states
② Motion control regulation could be customized to keep stable contact

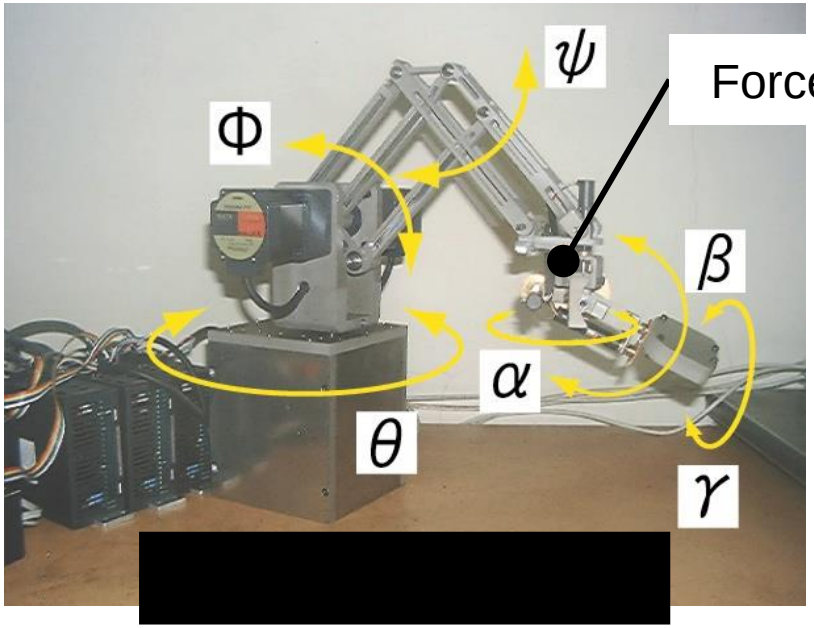
Technique: Impedance control

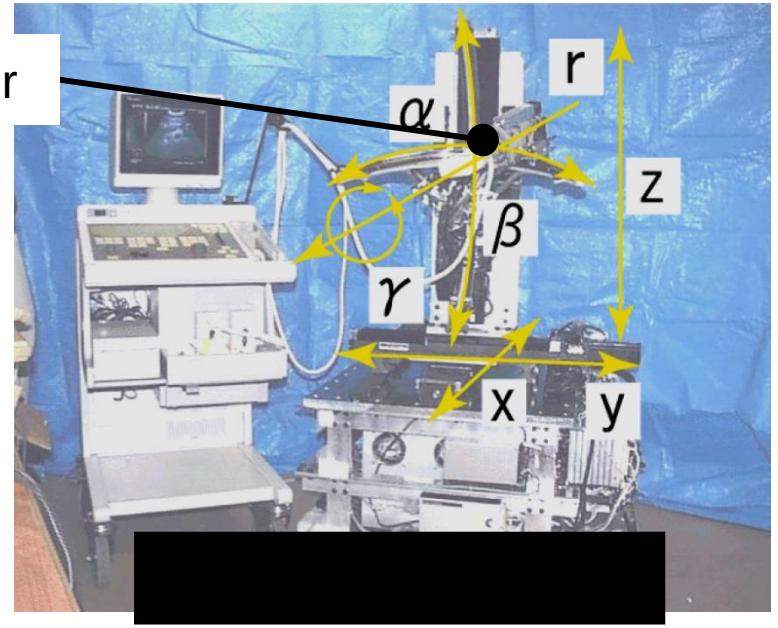
Control regulation in impedance control



Mechanical configuration

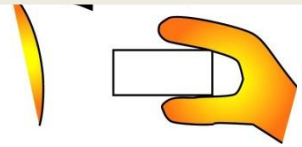
① Change only orientation while adjusting position
② Highly rigid mechanism
③ Force sensors are installed to display contact states and keep stable contact



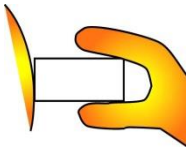


Dynamic control switching

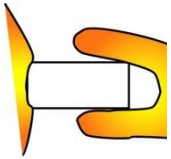
Problem



Task 1) Move probe far from affected part



Task 2) Precise motion around affected part including soft contact



Task 3) Precise motion around affected part including hard contact

Favorable control changes !

In conventional system,
There is only one control through the work

Technique: Dynamic control switching

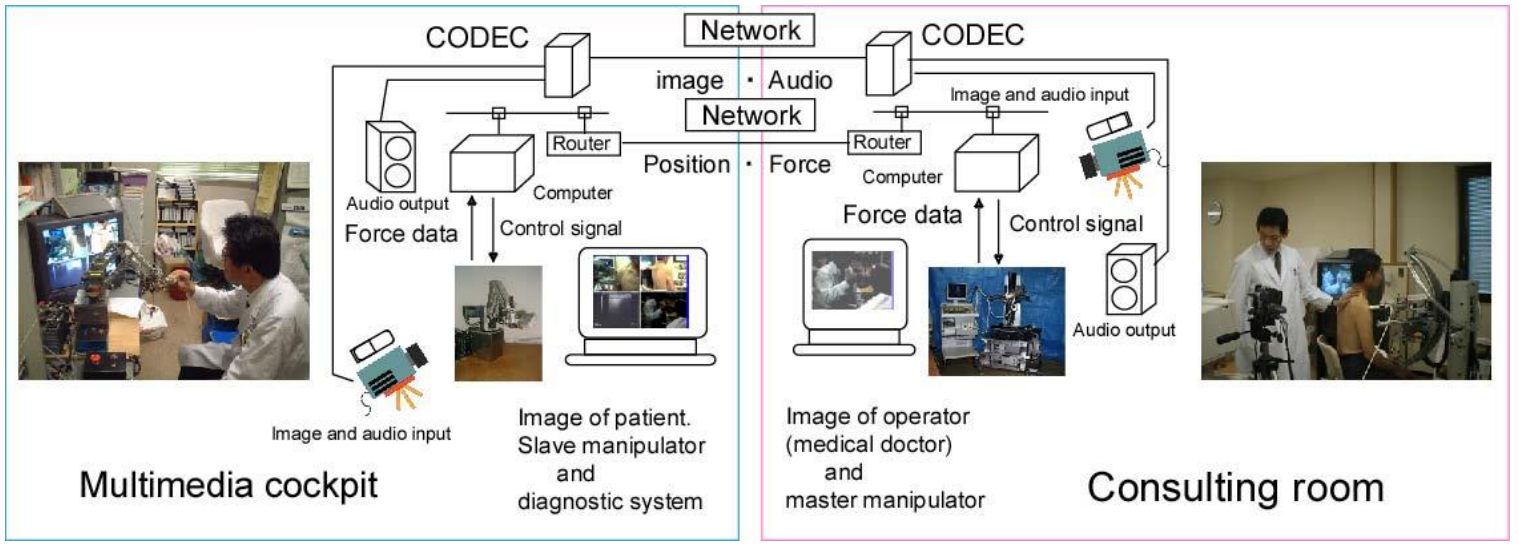
Manipulability enhancement
by switching controller
in accordance with probe task

① Probe manipulating tasks are recognized according to contact force, handling force, and distance information
② Impedance parameters should be switched by presumed tasks to enhance manipulability

Dynamic control switching

Manipulability enhanced through diagnosis!

Realized system configuration

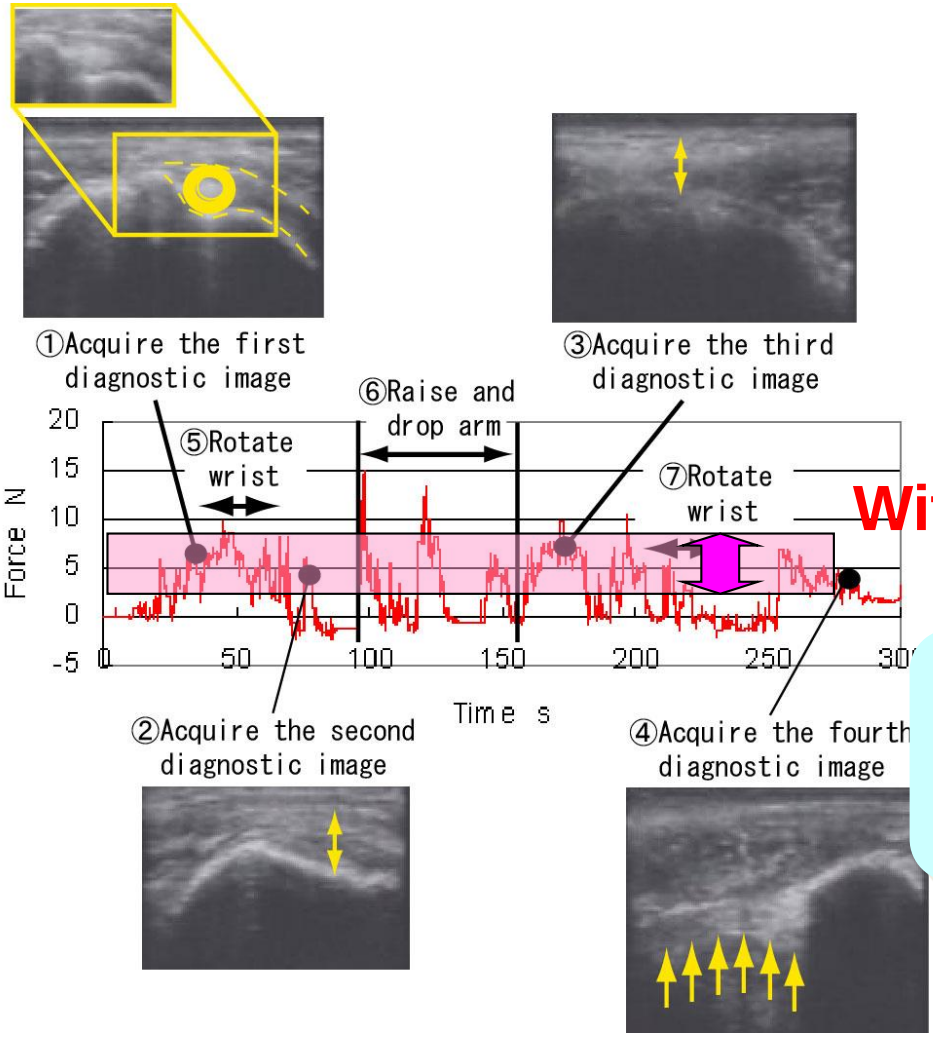


Master site

Slave site

① 10 km between master and slave site
② [master site] medical doctor and master in multimedia cockpit
③ [slave site] patient, helper and slave in consulting room
④384 kbps for image & audio
⑤128 kbps for control

Contact Force in Remote Diagnosis



Within the scope!

Required Contact Force

Diag. Image 1：2 N～8 N

Diagnostic Image 2：1 N～7 N

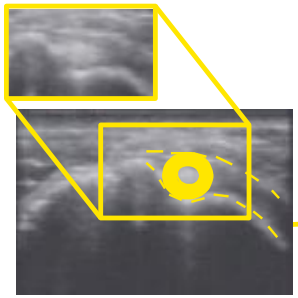
Diagnostic Image 3：1 N～10 N

(Avg. of 5 people)

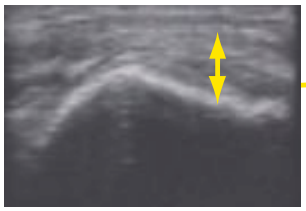
Orientation Precision in Remote Diagnosis

Required orientation precision

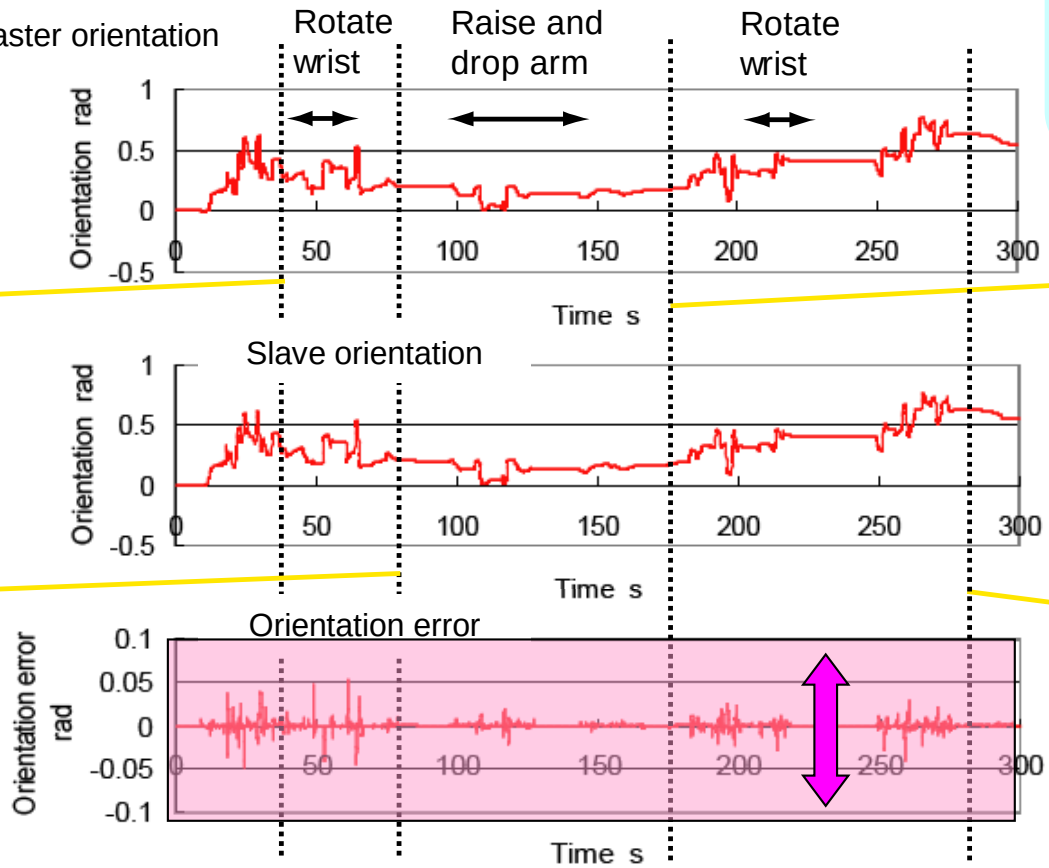
αaxis:0.1rad
βaxis:0.2rad
γaxis:0.3rad
(Avg. of 5 people)

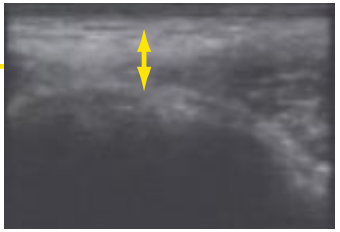


(1) Acquire the first diagnostic image

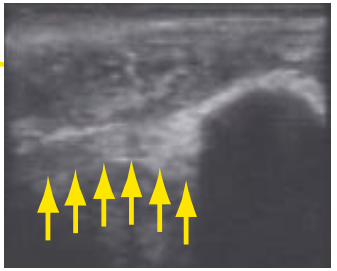


(2) Acquire the second diagnostic image





(3) Acquire the third diagnostic image



(4) Acquire the fourth diagnostic image

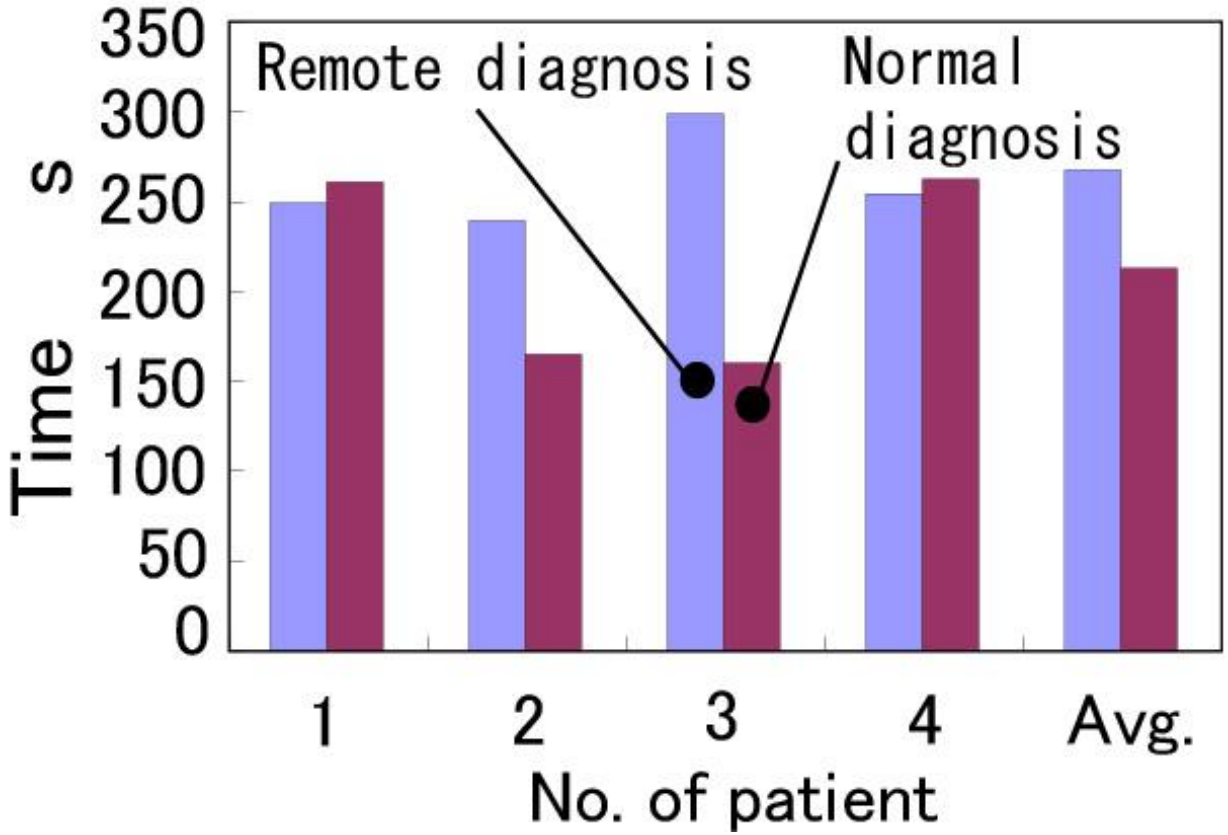
Within the tolerance!

Characteristic Value

	Remote	Normal
Effusion	No	No
Buckling	Yes	Yes
DSH	5.3mm	5.5mm
Balloon sign	Yes	Yes

Same characteristic values acquired!

Diagnostic Time



Same level of diagnostic time!

Non-Invasive Ultrasound Theranostic System (NIUTS)

Koizumi Lab

Me-Dig ITalization

UEC TOKYO

MEDICAL & BIO ARE NEW DIGITALS !

Me-Dig IT

Therapeutic and diagnostic skills

Reconstruct medical professional skills by utilizing Information and Robot Technology (IRT)

Decomposing and reconstructing functions

- Extract and structure functions
- Parameter analyses of functions
- Make design guidelines for functions
- Implement functions
- Verify systems
- Enhance functions

Implementation of function Embodiment of system

Continuous and high tracking performance motion **controllers**

Safe contact motion **mechanisms**

Robust and precise **image** detection **algorithms** of target

Effect

Goal Establish a method to introduce design guidelines to incorporate medical skills to systems

Reduce the load of medical professionals

Medical professionals

Safety and reliability

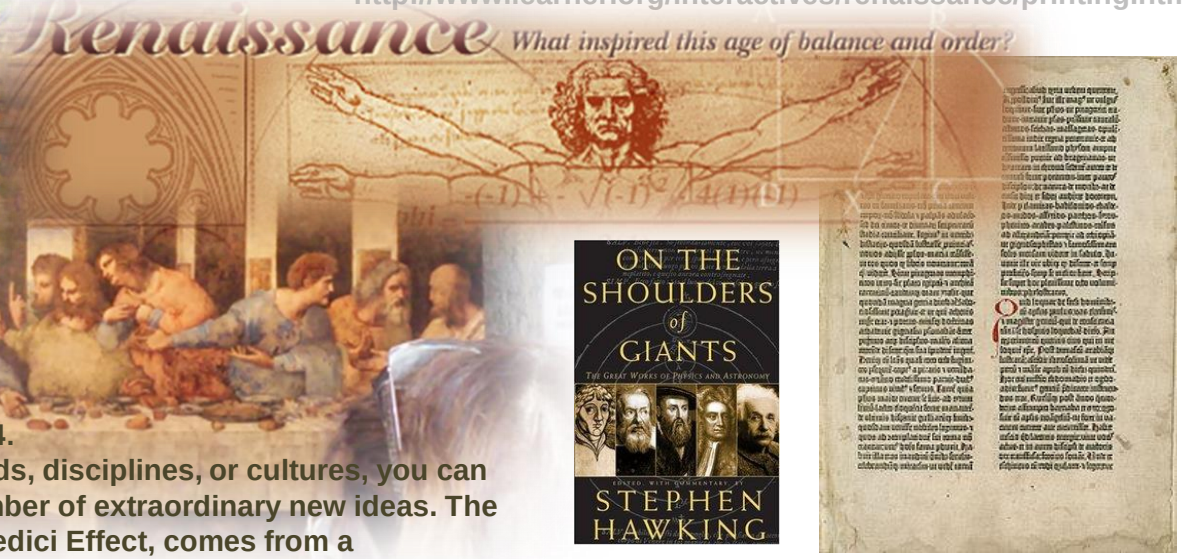
Patients

Koizumi Lab

Me-Dig IT Effect

UEC TOKYO

http://www.learner.org/interactives/renaissance/printing.html



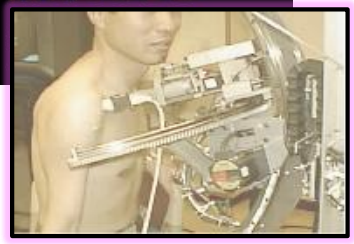
Frans Johansson, "The Medici Effect", 2004.
- When you step into an intersection of fields, disciplines, or cultures, you can combine existing concepts into a large number of extraordinary new ideas. The name I have given this phenomenon, the Medici Effect, comes from a remarkable burst of creativity in fifteenth-century Italy.

Gutenberg's press
Everybody can read bibles

http://www.agtc.com.tr/

MEDICAL & BIO ARE NEW DIGITALS !

Me-Dig IT Effect



Museo Nazionale della Scienza e della Tecnologia "Leonardo da Vinci" in Milano

Everybody can receive high-quality-medicine by IT (Robot) & US technology

Related works

Robotics

[1] T.Yoshikawa, et. al, "Toward Observation of Human Assembly Skill Using Virtual Task Space," Experimental Robotics VIII, 2003.

[2]M.Kaneko, et,al, "Hyper Human Vision / Manipulation," http://www.robotics.hiroshima-u.ac.jp/hyper_human_manipulation/index-e.html.

[3] M. Mochimaru, et. al, "Digital Human Research Center," http://www.dh.aist.go.jp/en/

Medical and welfare robotics

[4] A. Knoll, et al., "Human-Machine Skill Transfer Extended by a Scaffolding Framework," IEEE International Conference on Robotics and Automation (ICRA), 2008.

[5] Y. Yamauchi, et al., "Surgical Skill Evaluation by Force Data for Endoscopic Sinus Surgery Training System," Medical Image Computing and Computer-Assisted Intervention (MICCAI'02), 2002.

[6] G. Zong, et al., "Visually Servoed Suturing for Robotic Micro Surgical Keratoplasty," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2006.

[7] O. Fukuda, T. Tsuji, M. Kaneko, A. Otsuka, "A Human-Assisting Manipulator Teleoperated by EMG Signals and Arm Motions", IEEE Trans on Robot. and Automat., Vol.19, No.2, 2003.

Our group

Technologizing and digitalizing tech.

[8] N.Koizumi, M.Mitsuishi, et.al., "Construction methodology for a remote ultrasound diagnostic system," IEEE Trans. on Robotics, Vol.25, No.3, 2009.

Non-invasive US therapeutic tech.

[9] J.Seo, N.Koizumi, M.Mitsuishi, et.al., "Three-dimensional computer controlled acoustic pressure scanning and quantification of focused ultrasound,," IEEE Trans. on Ultrasonics, Ferroelectrics, and Frequency Control, Vol.57, No.4, 2010.

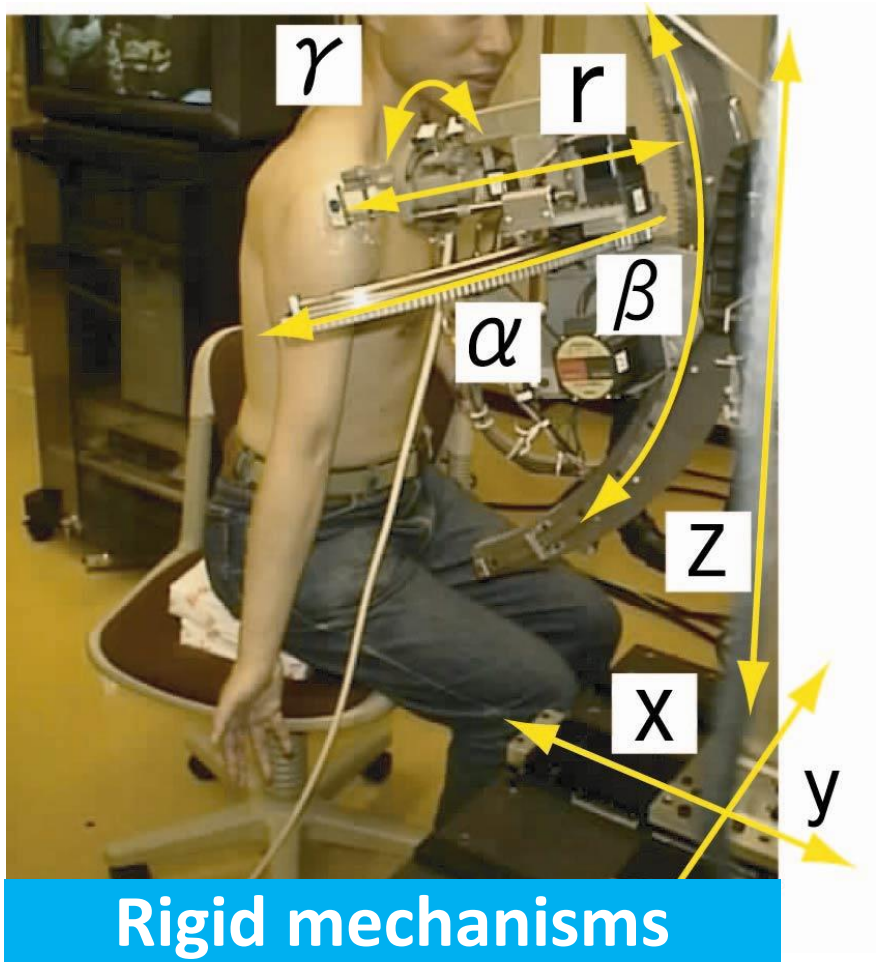
Medical theragnostic skills

[10] A.Ishikawa, et.al.. Renal preservation effect of ubiquinol, the reduced form of coenzyme Q10. Clin Exp Nephrol 2010; Sep 28.

[11] H.Tsukihara, et.al., "Prevention of Postoperative Pericardial Adhesions With a Novel Regenerative Collagen Sheet", Ann Thorac Surg, Vol.81, pp.650 –657, 2006.

[12] M.Kawasaki, et.al., "Effect of local injection of 10% lidocaine hydrochloride on painful osteoarthritis of the knee joint,," PAIN RESEARCH, Vol.14, 2003.

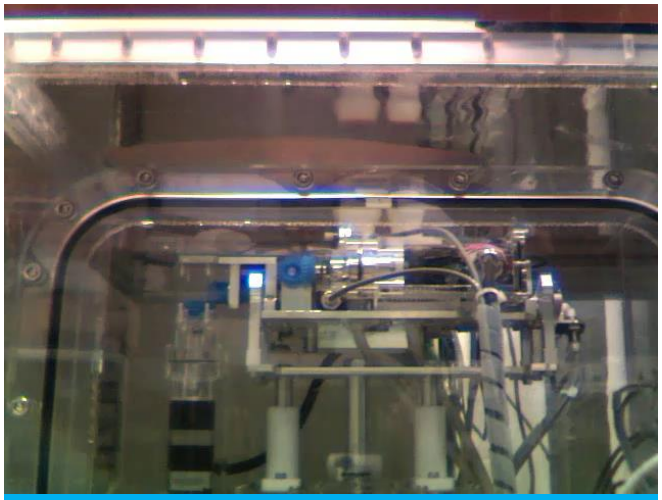
Robot mechanisms



Rigid mechanisms

TRO 2009

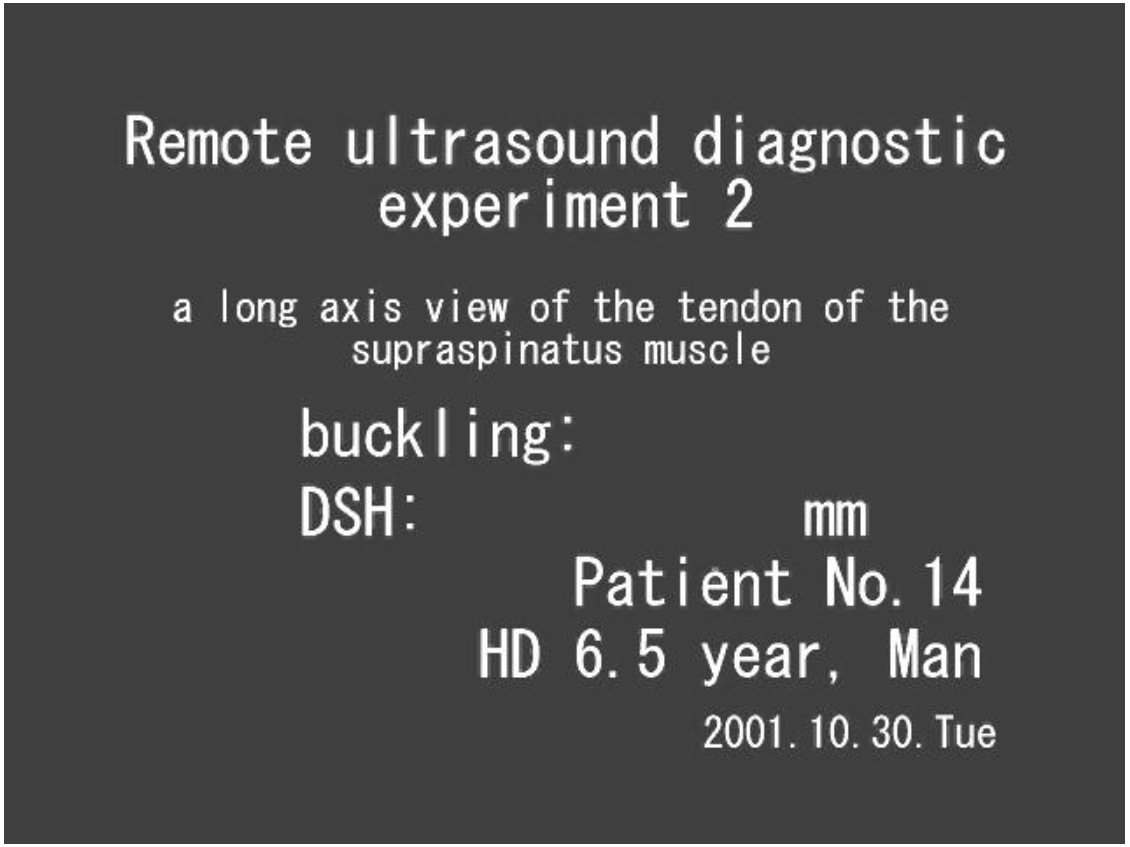
Affordance



Rigid mechanisms

Highly rigid mechanisms realize precise motions / servo controls.

Remote Ultrasound Diagnostic System (RUDS)

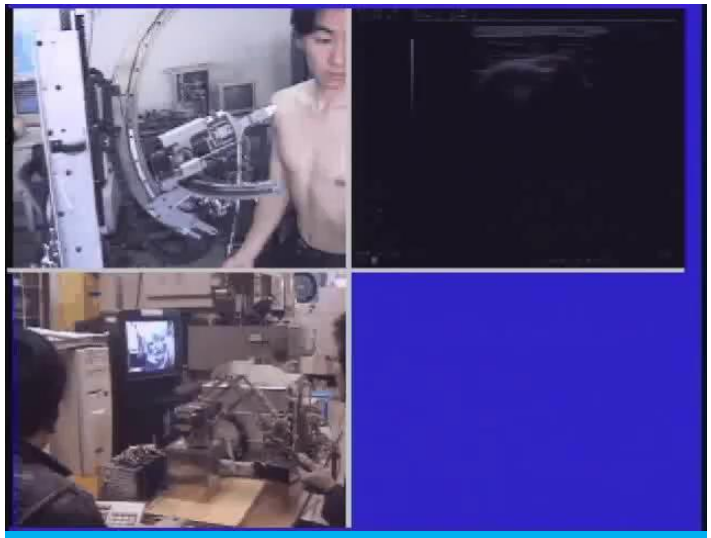


IEEE TRANSACTIONS ON ROBOTICS

TROBOT2009,
ICRA 2003

Remote diagnosis achieved,
First clinical use in the world (2001)

Robot motion cont.

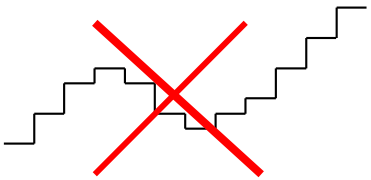


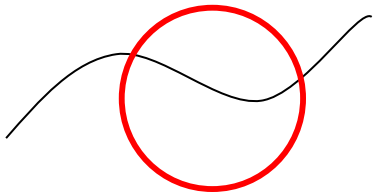
Remote motion control

TMECH 2008

Servo motion control

ICRA 2014



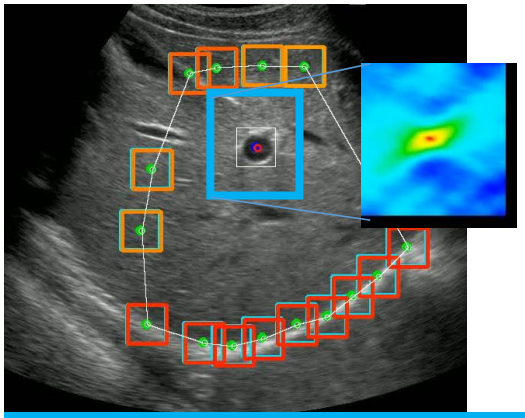


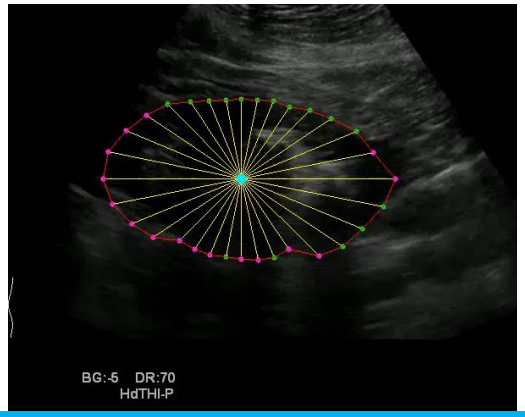
Smooth and accurate robot motion control.

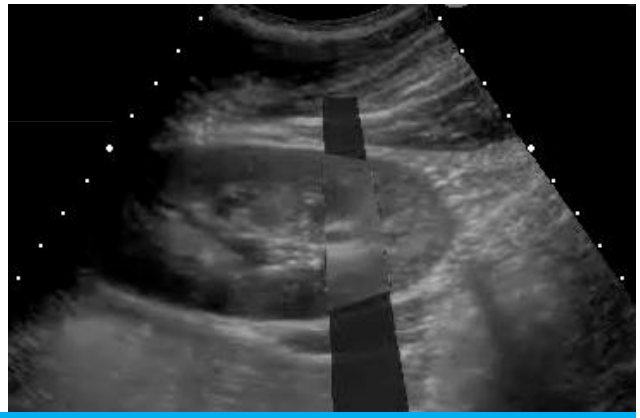
Koizumi Lab

Robot vision

UEC TOKYO







ロボットビジョン技術

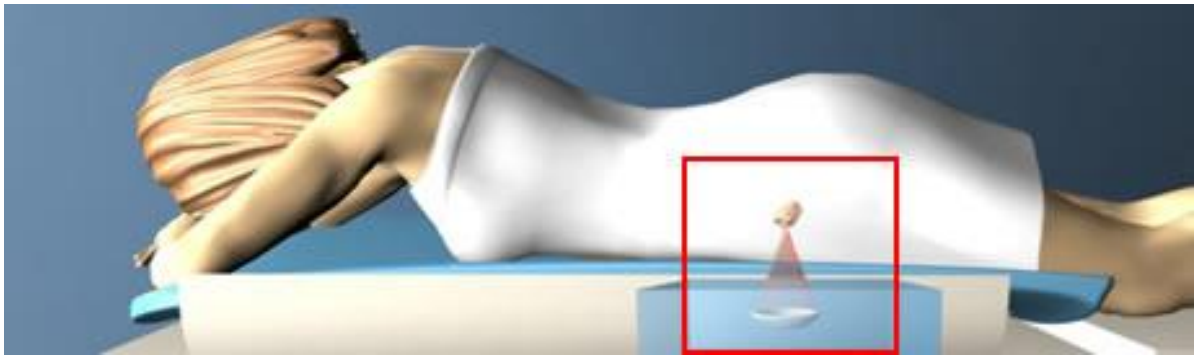
ASA-ASJ 2016

Sharing the worldview of medical professionals

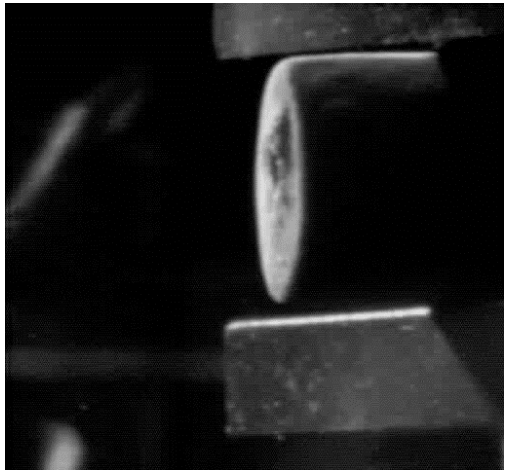
Me-Dig IT

HIFU therapy

HIFU (High Intensity Focused Ultrasound)

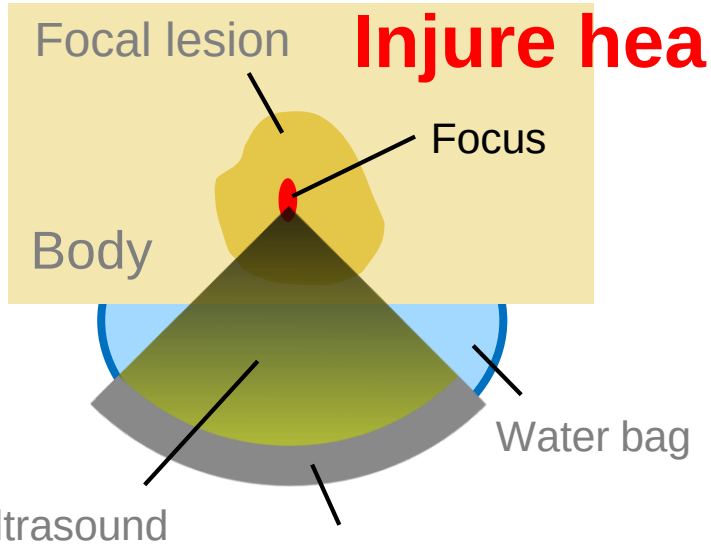


http://japan.gehealthcare.com/cwcjapan/static/rad/mri/MRgFUS_ExAblate2000



Y. Matsumoto, et. al.

Destruction of stone

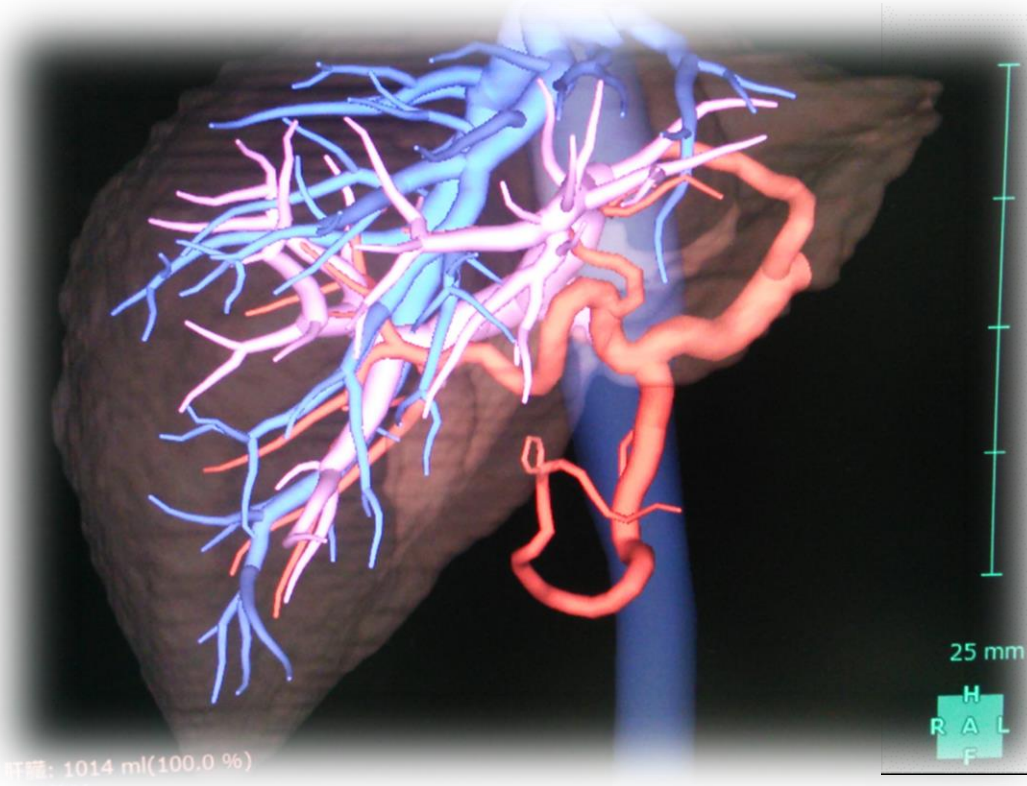


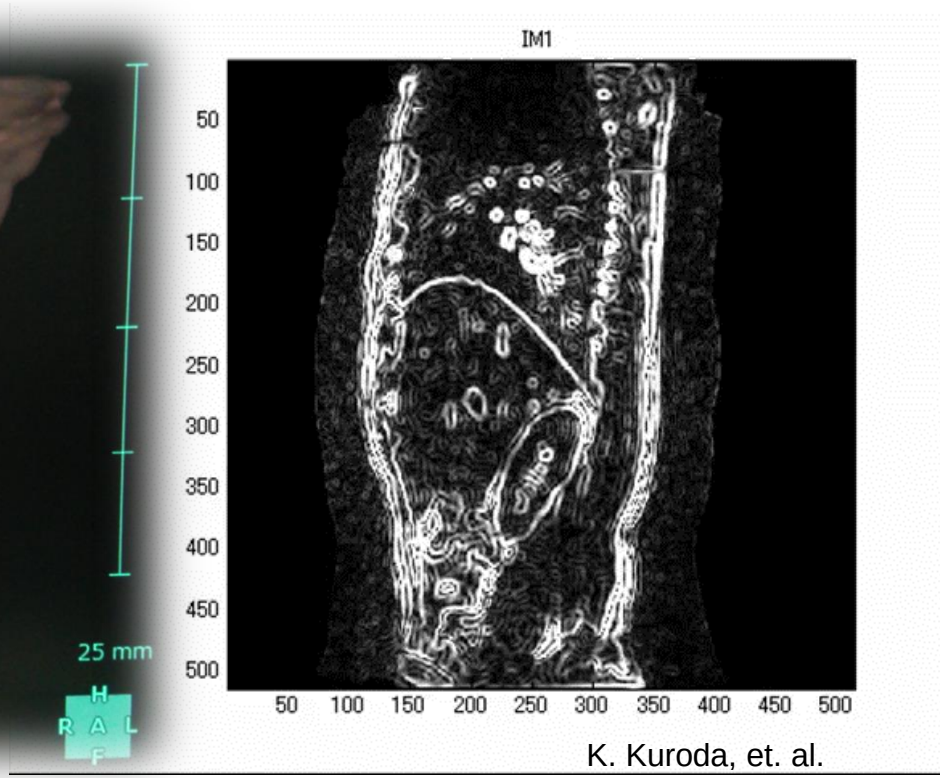
ExAblate 2000 (GE Healthcare)

JC Haifu System (Chongqing Haifu Medical Technology Co. Ltd.)

Commercial systems

Required precision





K. Kuroda, et. al.

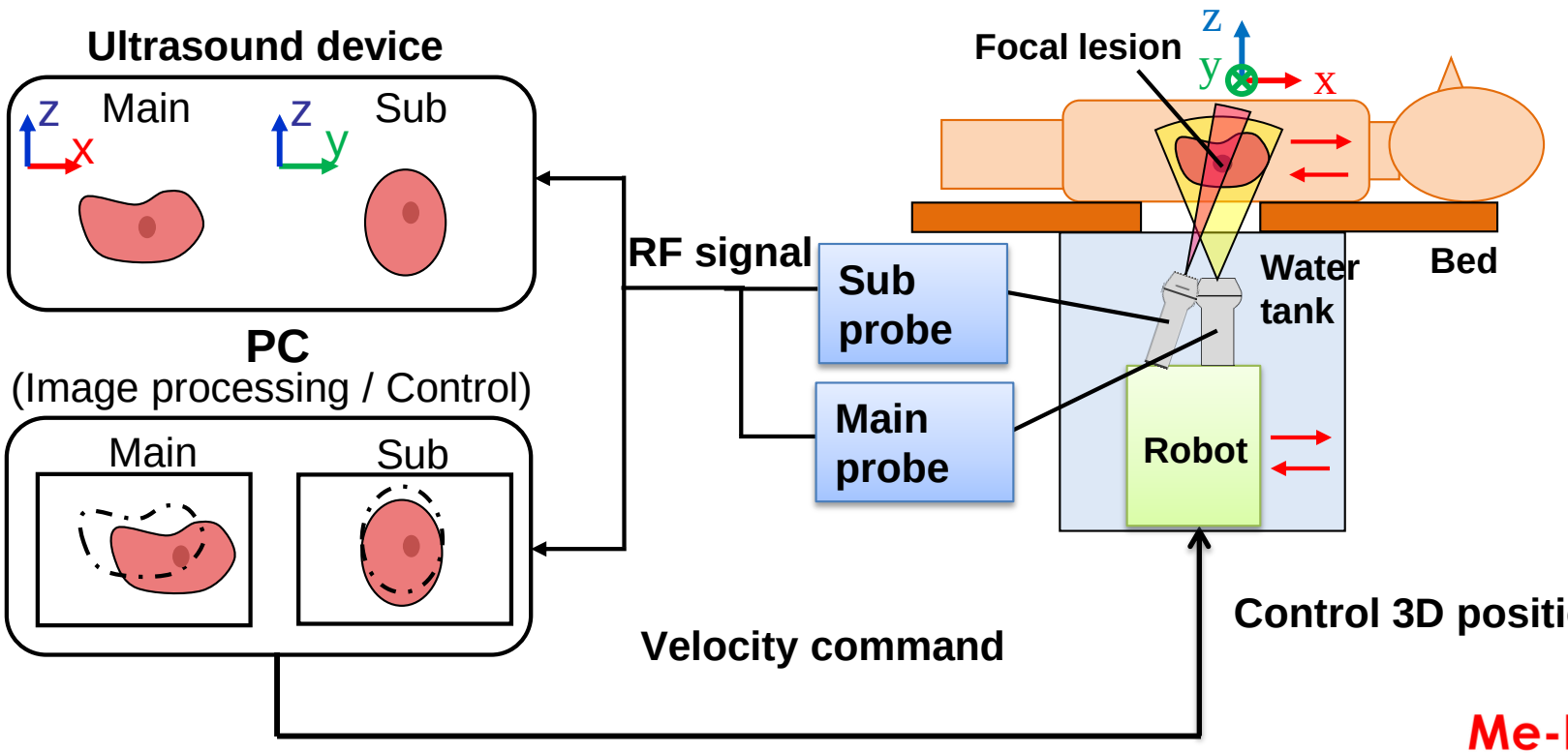
Liver vessels（CT）

Moving organs（MR）

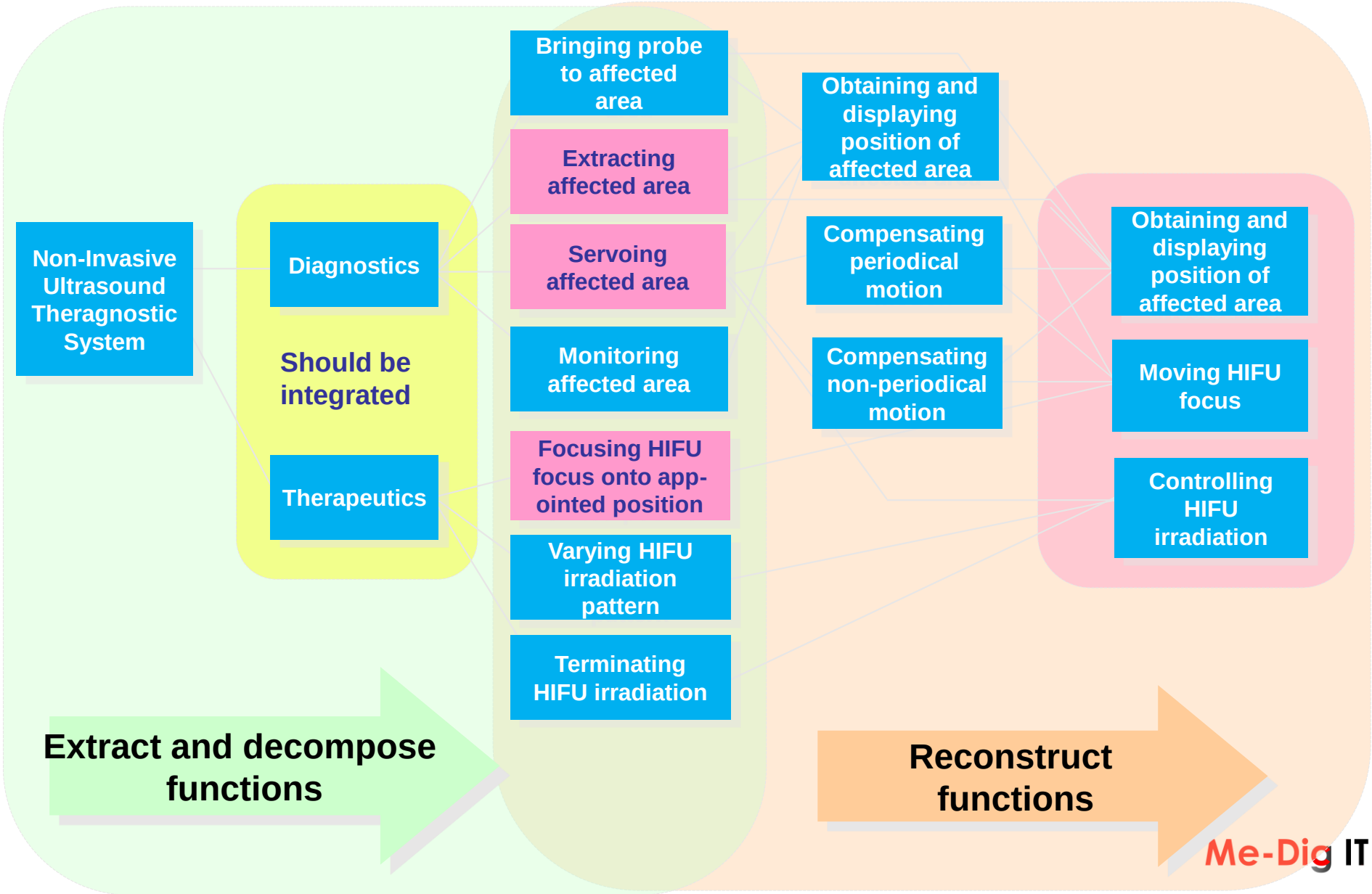
1mm precision required

Concept

Destroy stones / ablate tumours (focal lesions) by utilizing pinpoint focused ultrasound not injuring surrounding healthy tissues (skin, muscles, etc.) of patient by tracking, following, and monitoring focal lesion by US images which moves by respiration, heartbeat, etc.

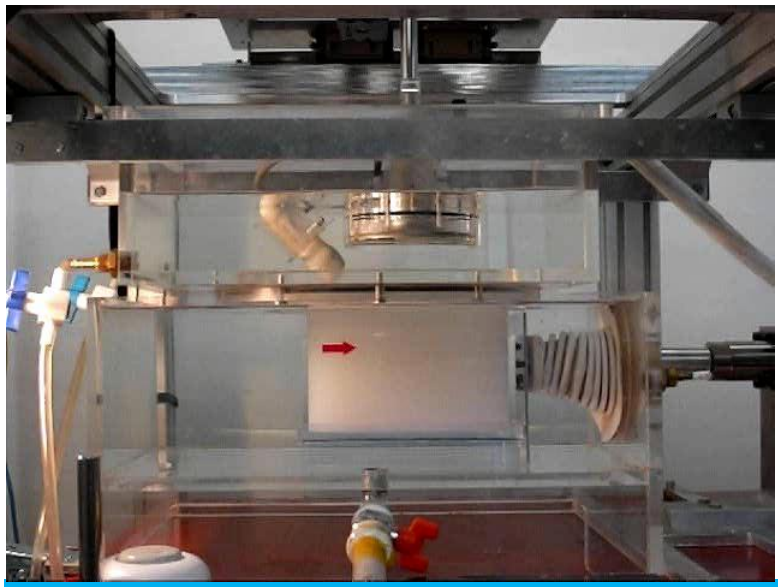


Structured functional requirements

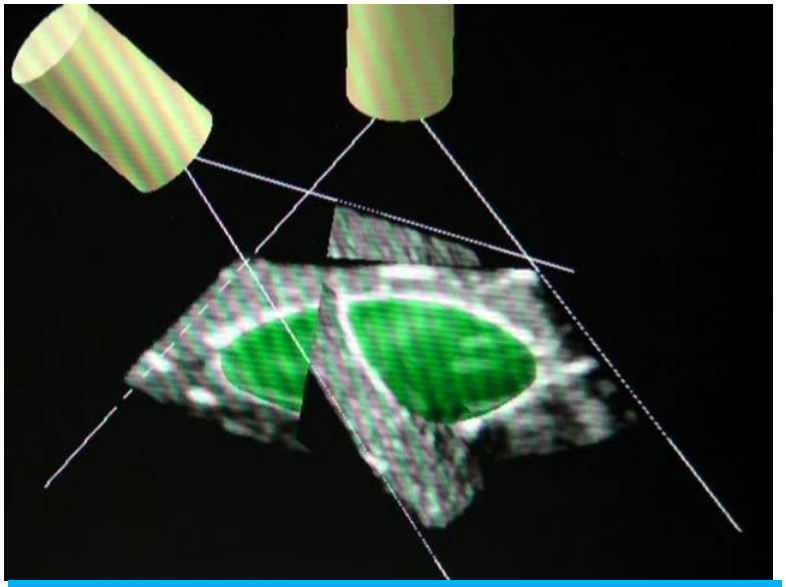


Motion tracking for kidney tumours

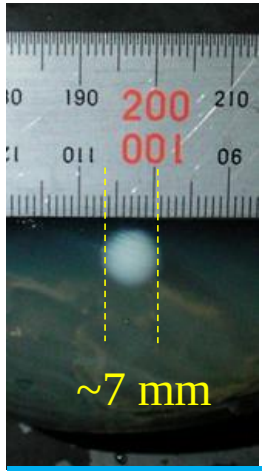
Phantom experiments（kidney tumour）



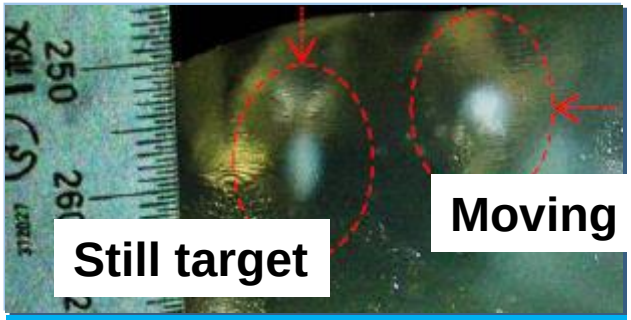
Organ tracking



US image



HIFU irradiation

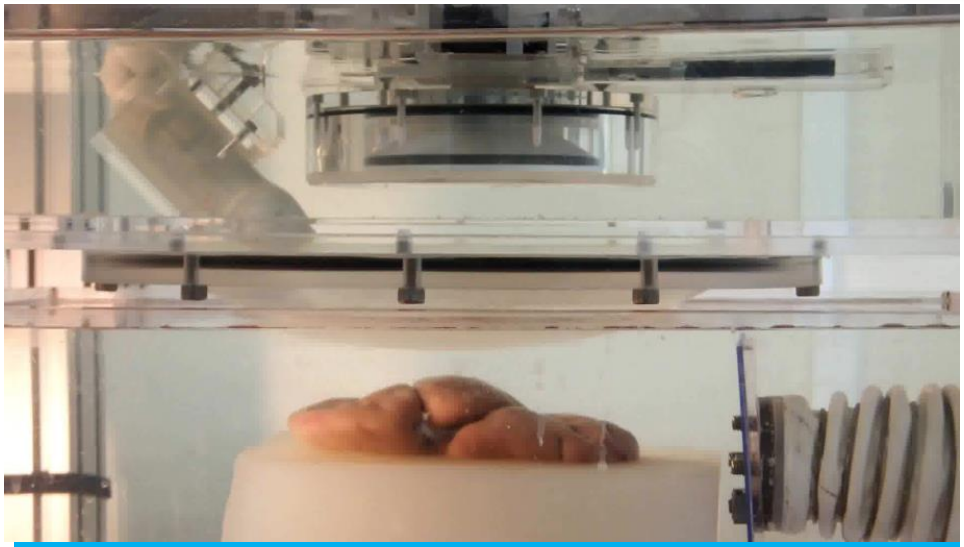


Still and moving targets

Precision：2.5mm achieved ！

Motion tracking for kidney stones

Ex-Vivo experiments（swine, model kidney stone）

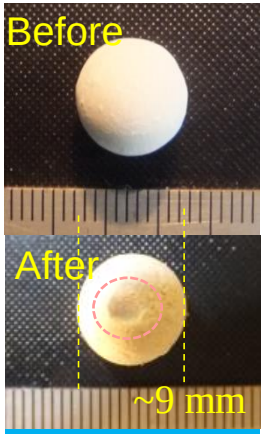


Stone tracking

US images

Binary US images

US image

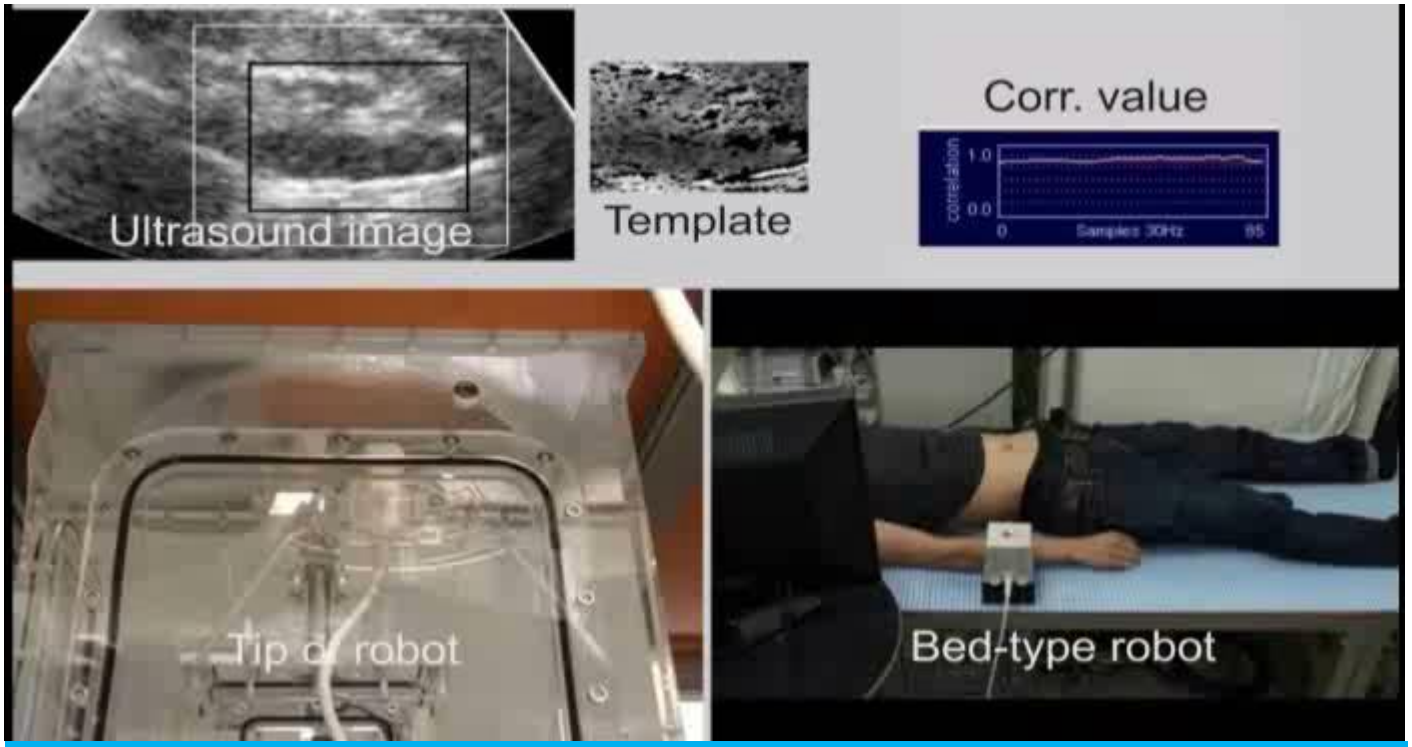


Destruction res.

Precision：2.5mm achieved！

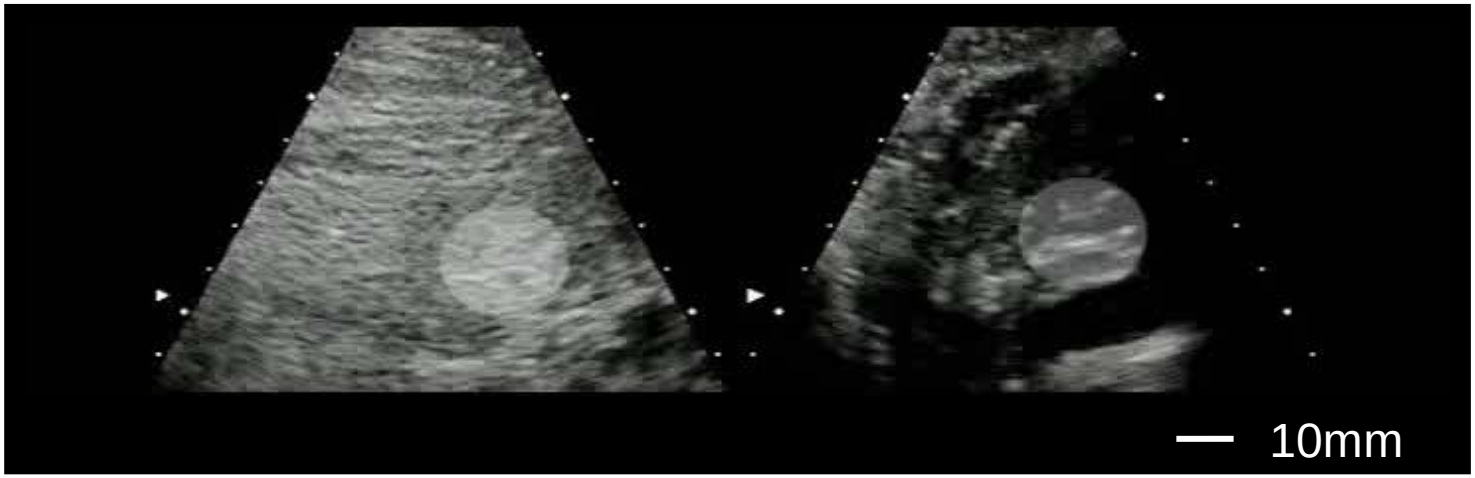
Human body motion tracking

Human body target (kidney stones / tumours) motion tracking for non-invasive ultrasound theragnostics



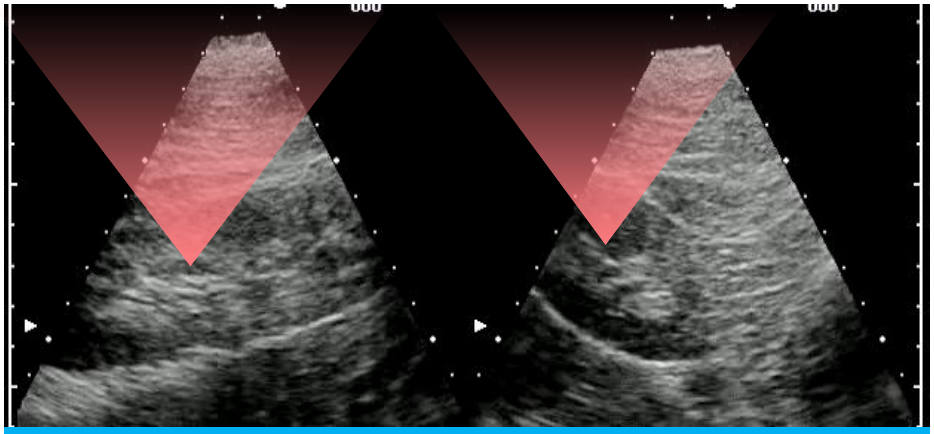
Motion tracking for human kidney

Human body motion tracking

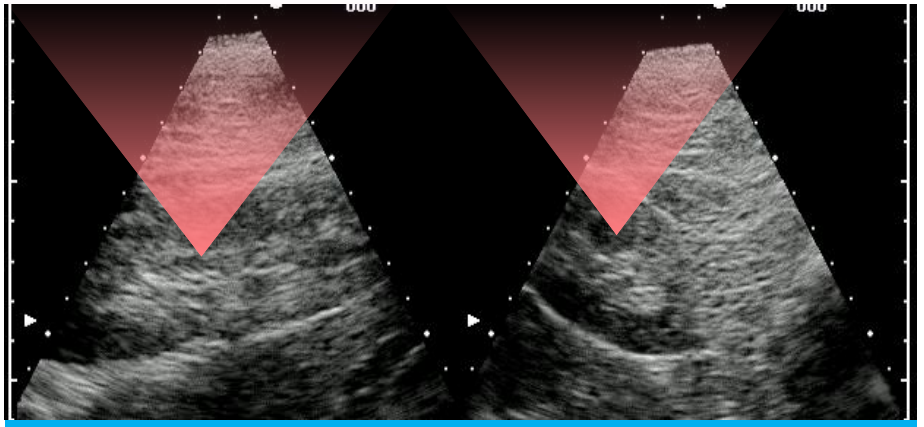


Motion tracking for human kidney

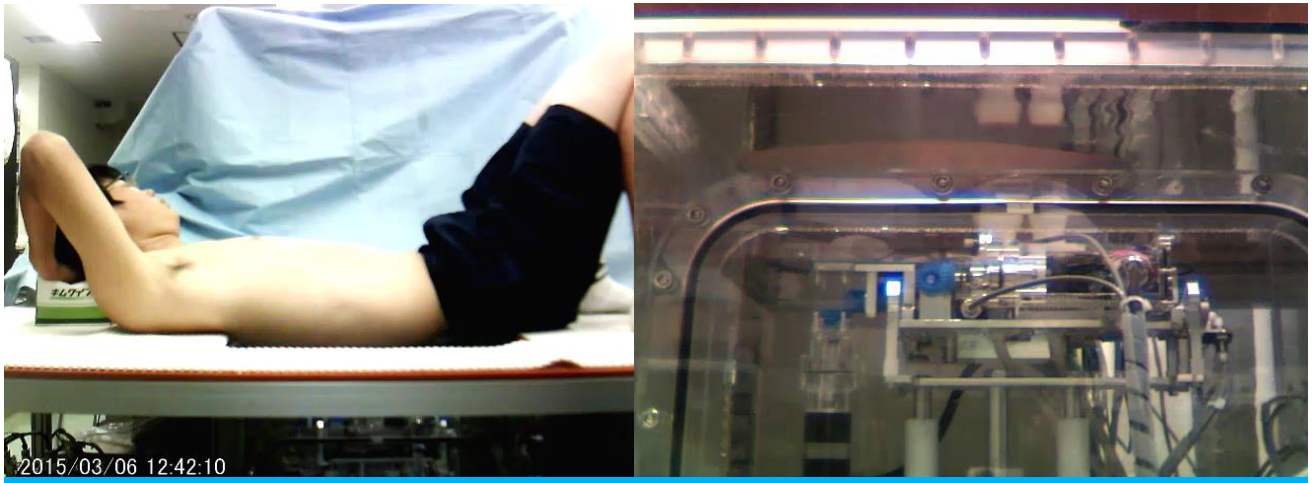
Kidney motion compensation



Without servoing



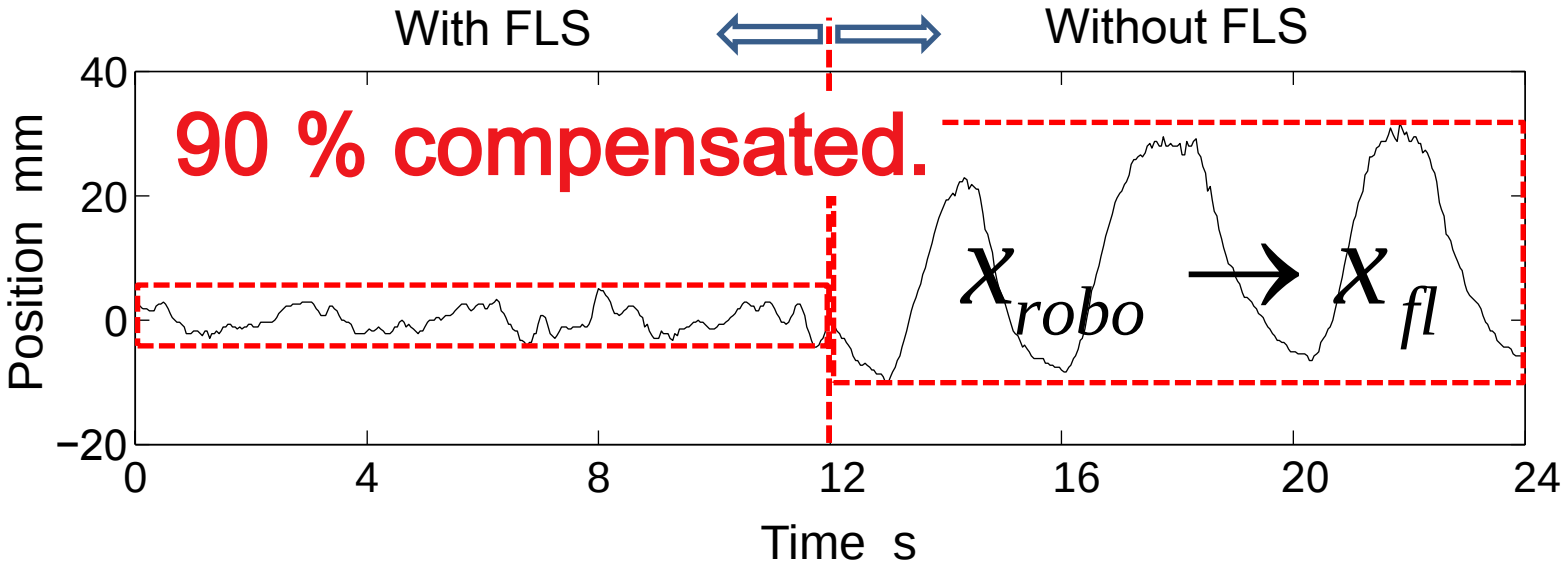
With servoing

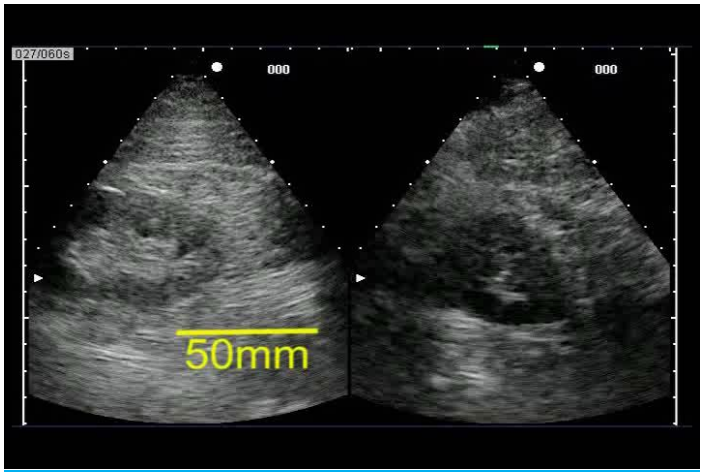


Kidney motion compensation

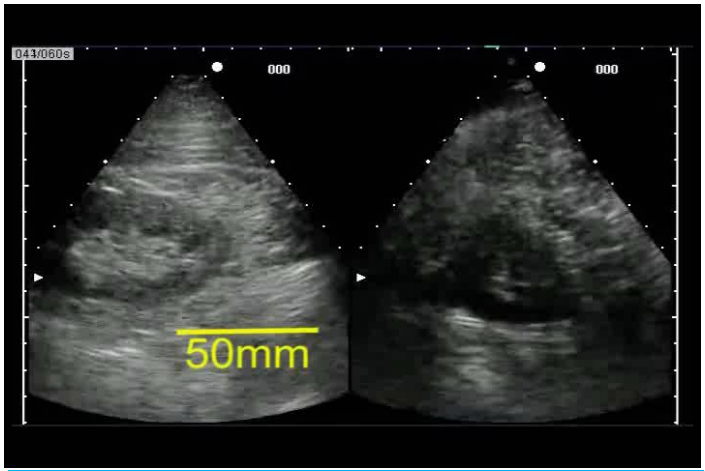
1mm precision achieved

Kidney motion compensation



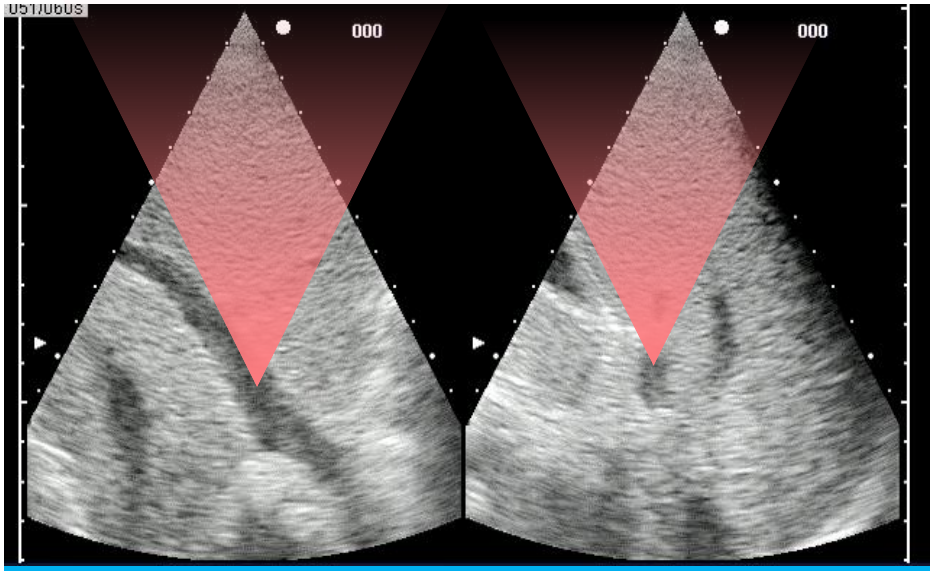


With servoing

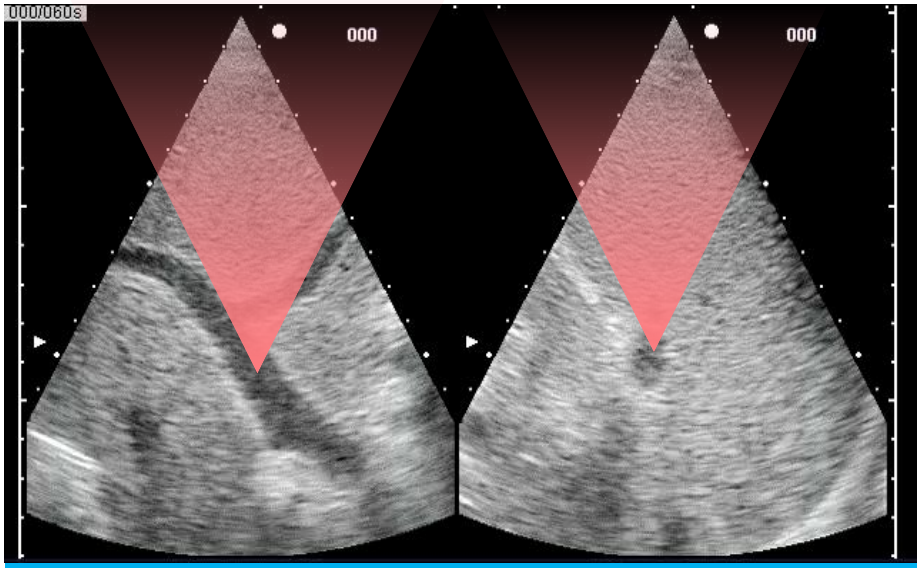


Without servoing

Liver motion compensation



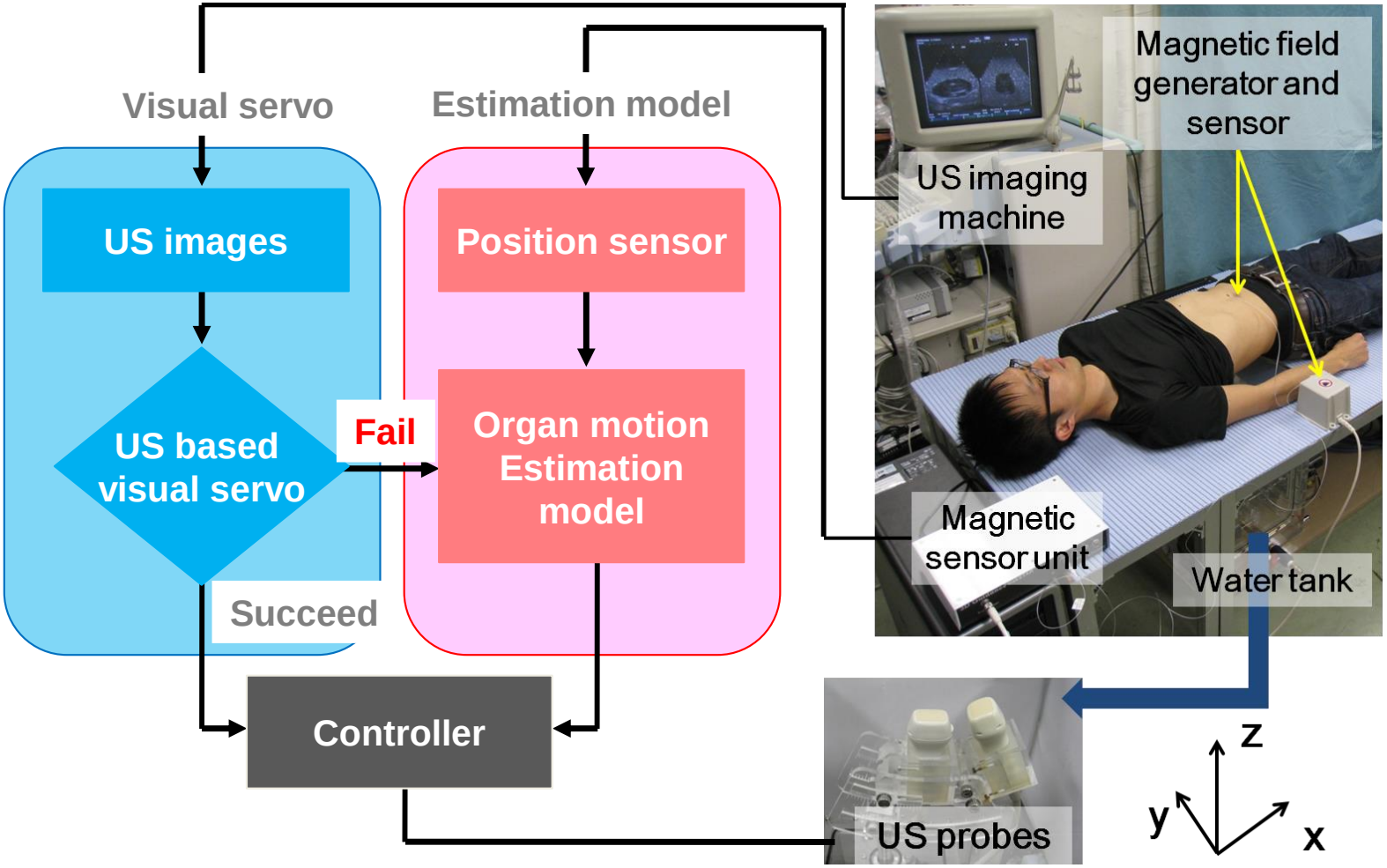
Without servoing



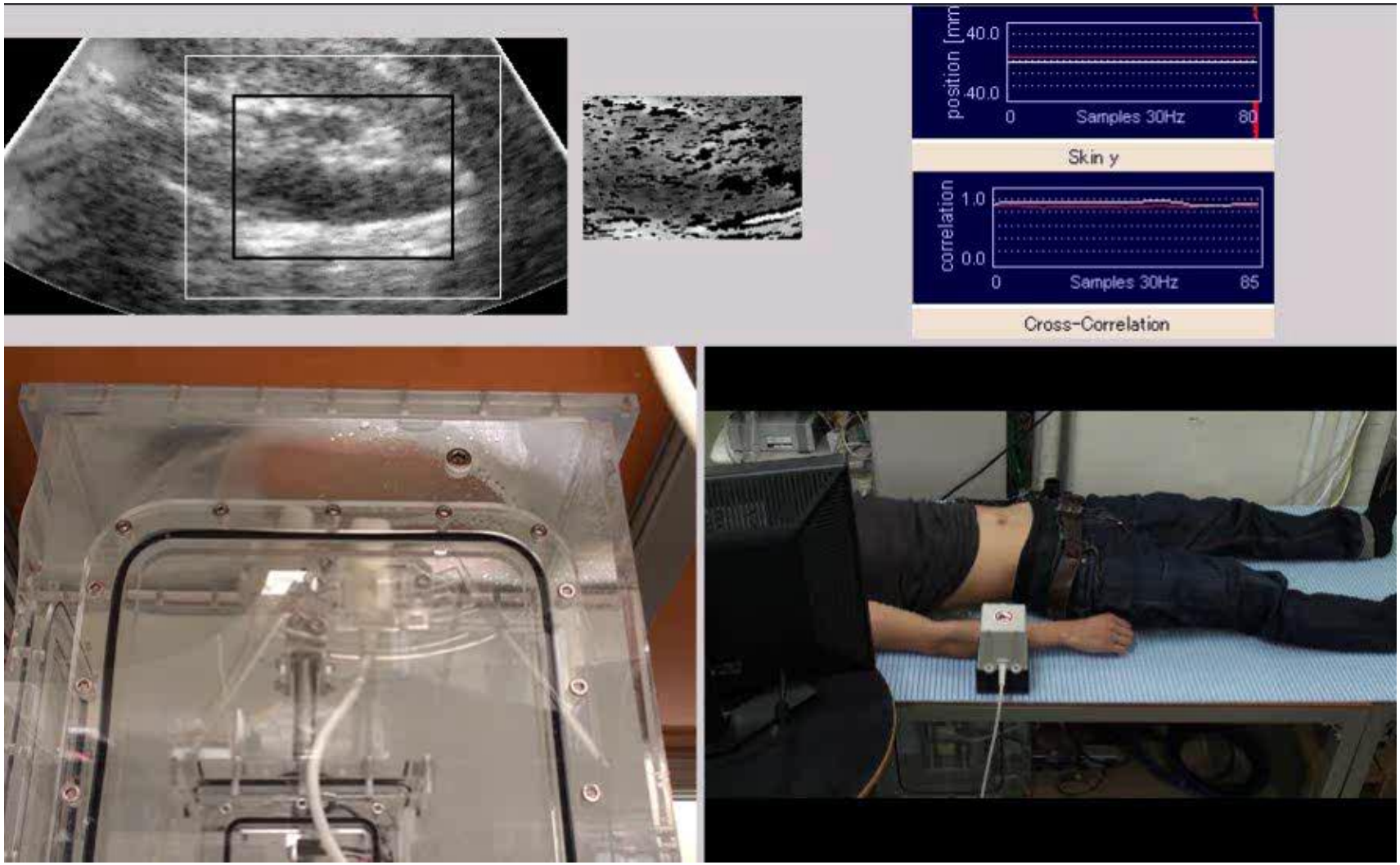
With servoing

1.3 mm precision achieved

Robust servoing



Robust servoing



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