Micro-neurosurgical system in the deep surgical field

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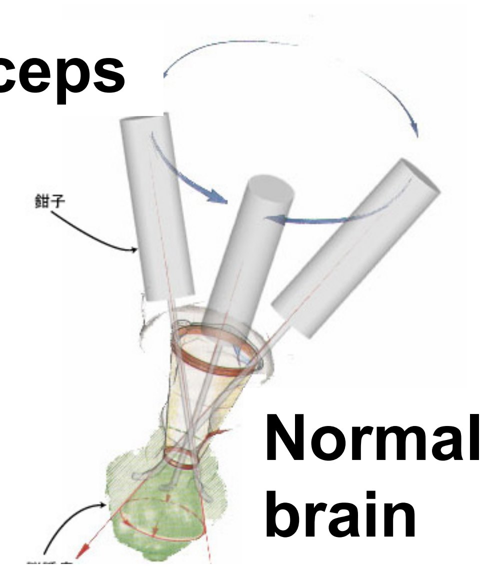
Introduction

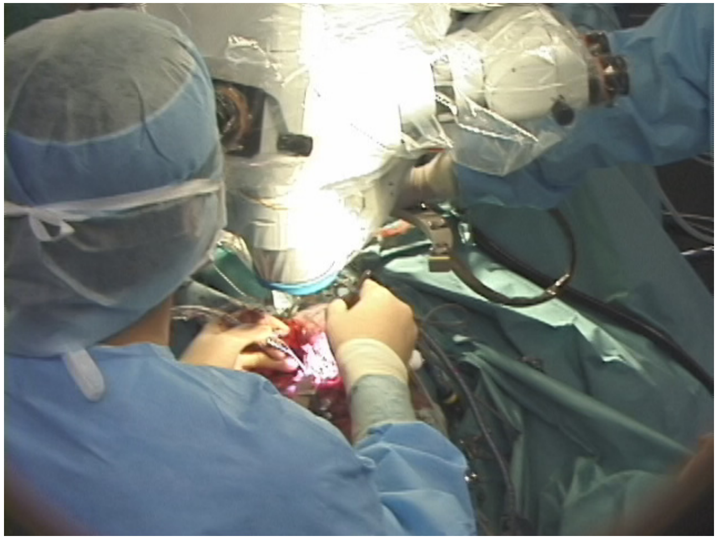
- System should be applicable in routine microsurgery.
- System should be maneuverable in the deep & narrow surgical field.
- Relatively wide range of motion at the depth should be equipped.
- Secure procedure need to be performed.

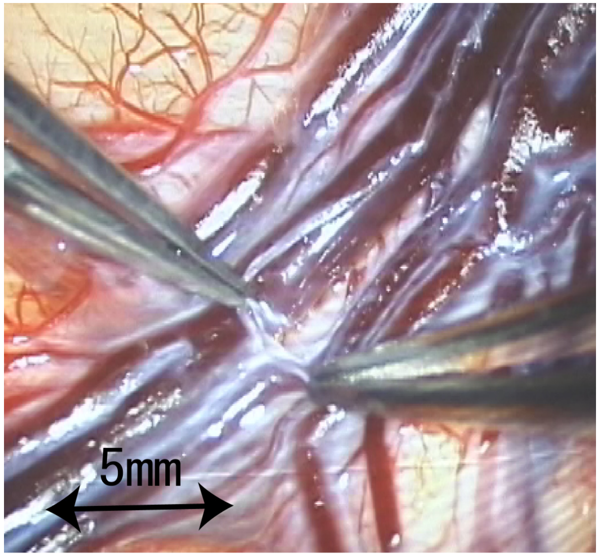


Introduction

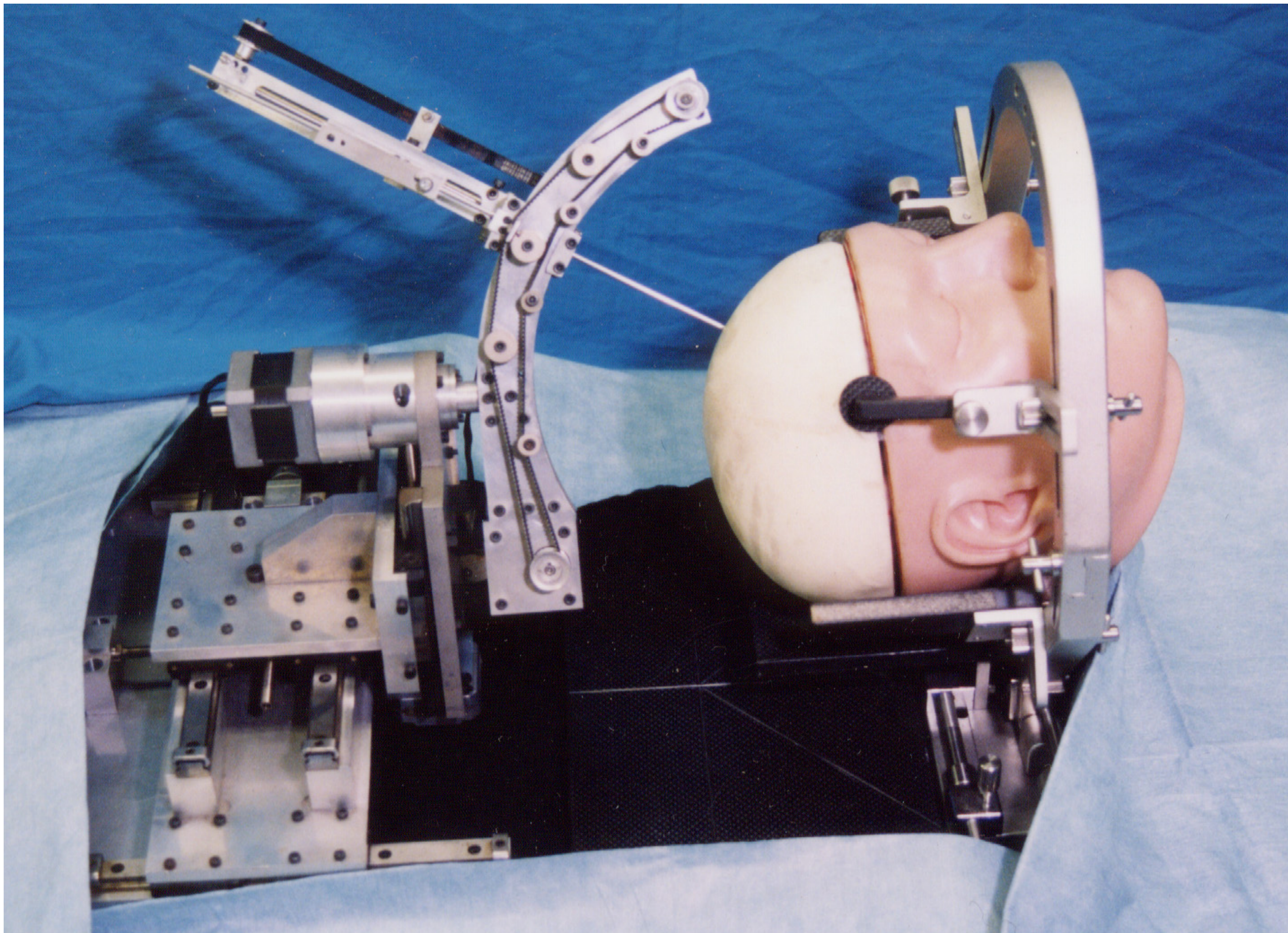
In the neurosurgery,

- **Surgeon has to perform a precise manipulation.**
- **In particular, the surgical operation is difficult in the deep surgical field.**
- **It is still a challenge to reduce the invasiveness.**





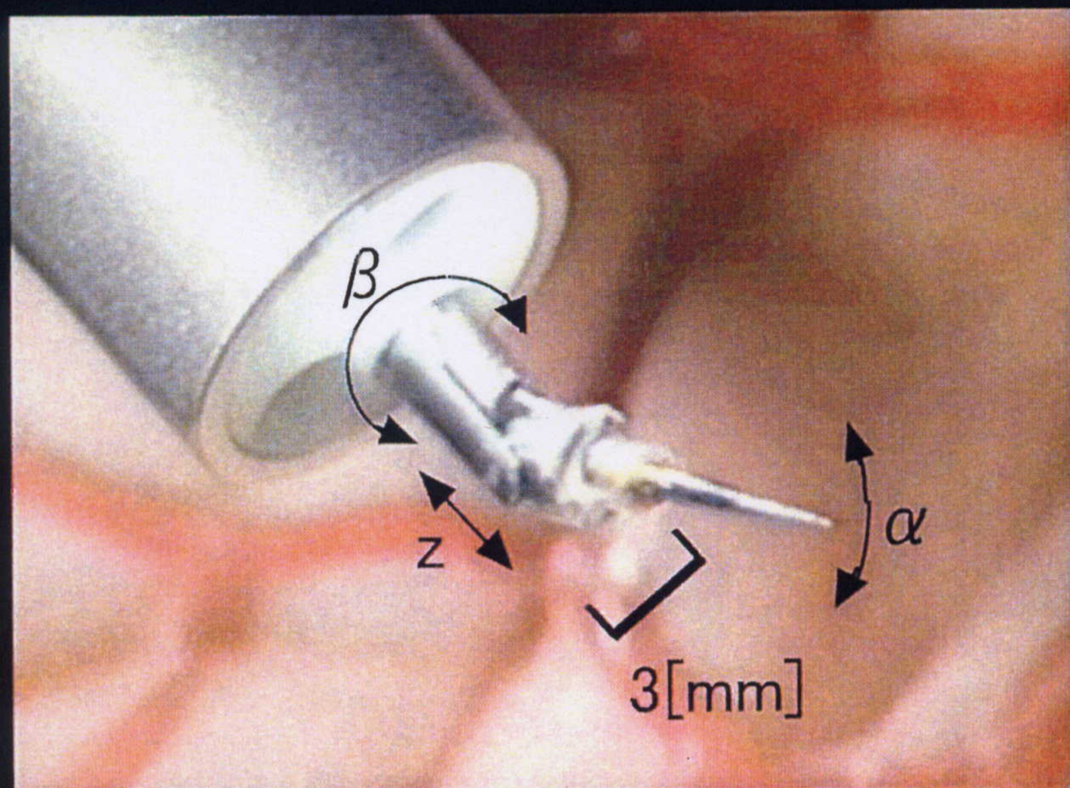
Dohi, Univ. of Tokyo: Needle inserting system for neurosurgery



Neuromate: Integrated Surgical Systems

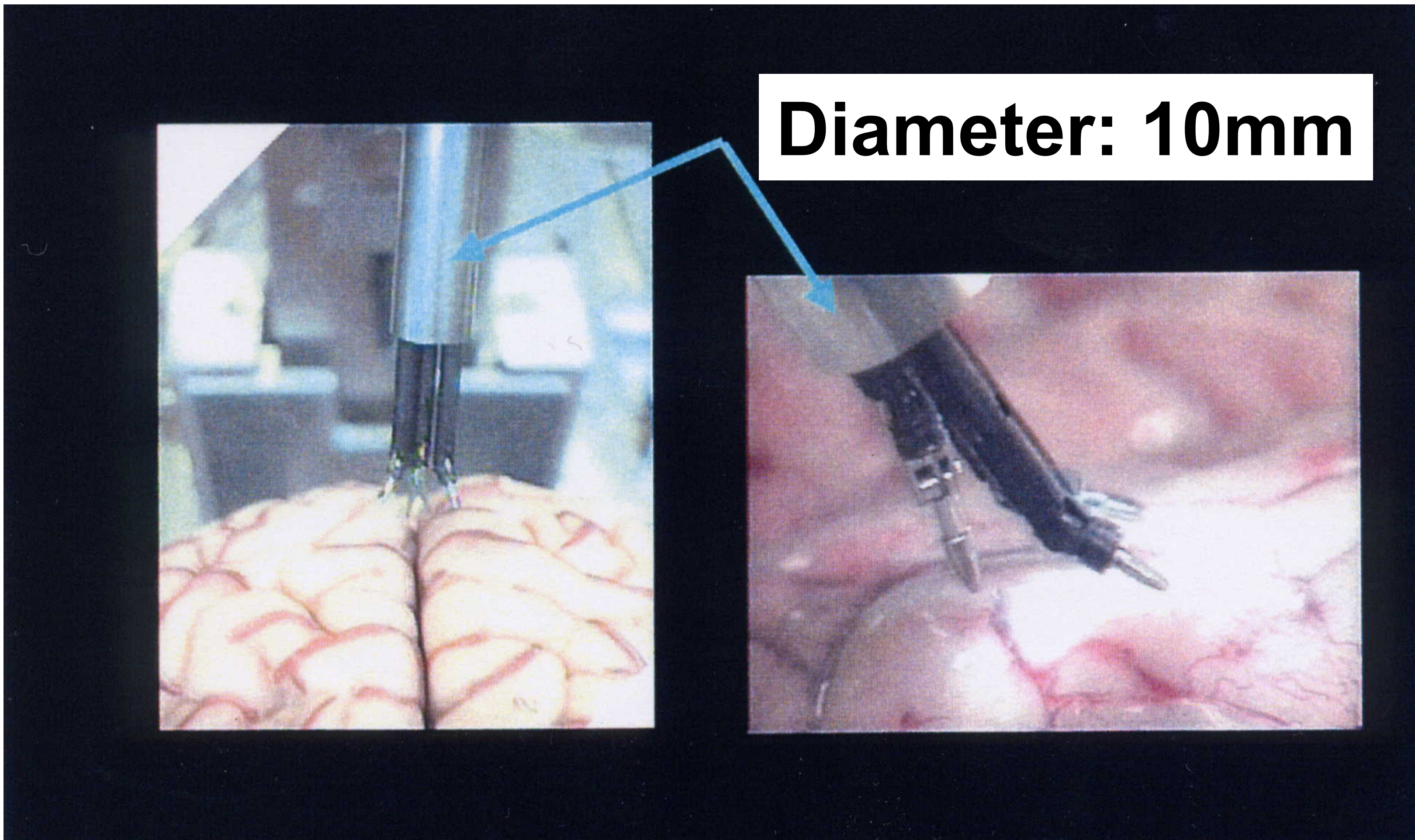
Mechanical safety is not insured.

Fujie, Hitachi: Small manipulator for neurosurgery

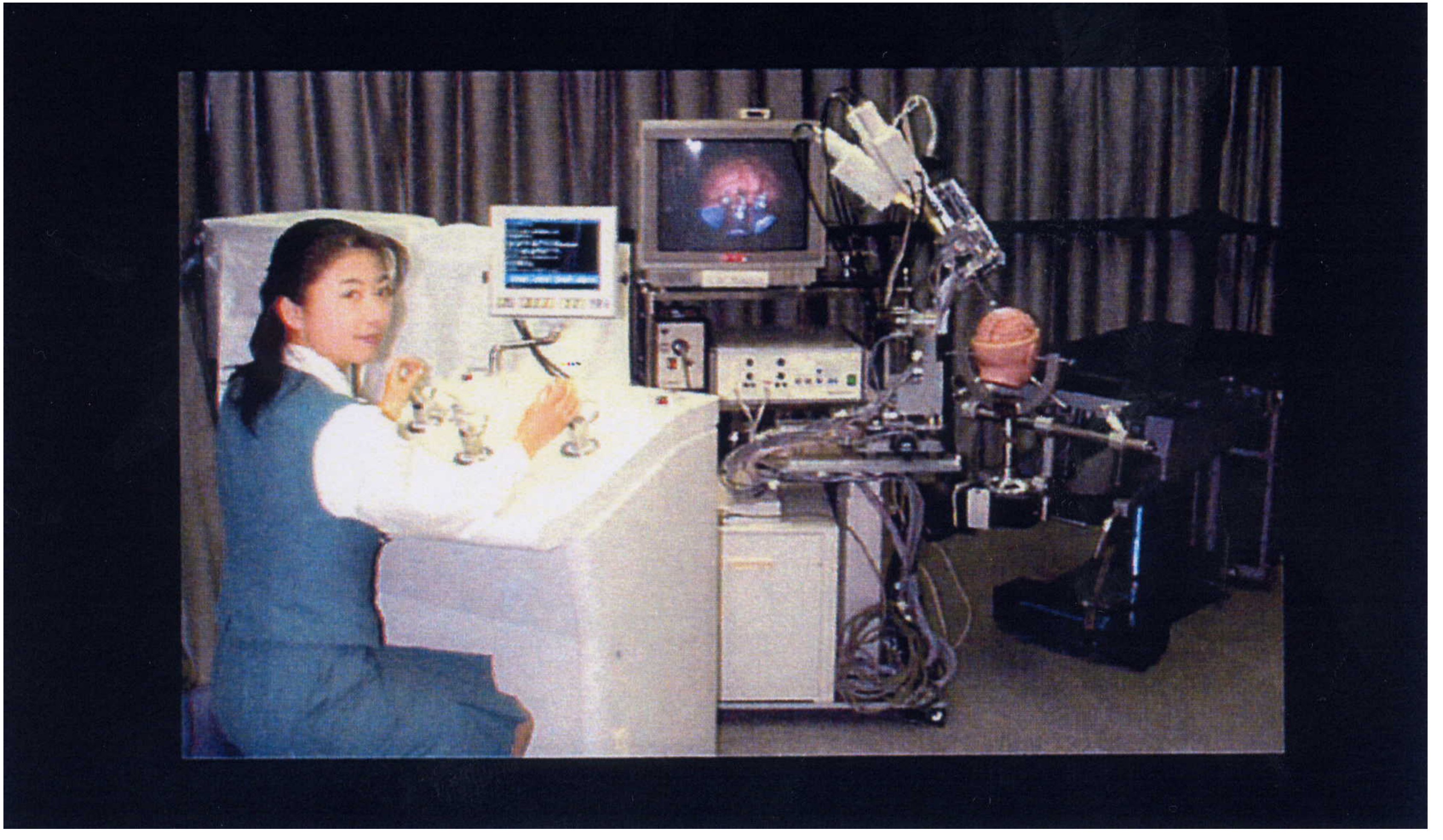


Relative positioning accuracy: 10 micro meter

Inserting point

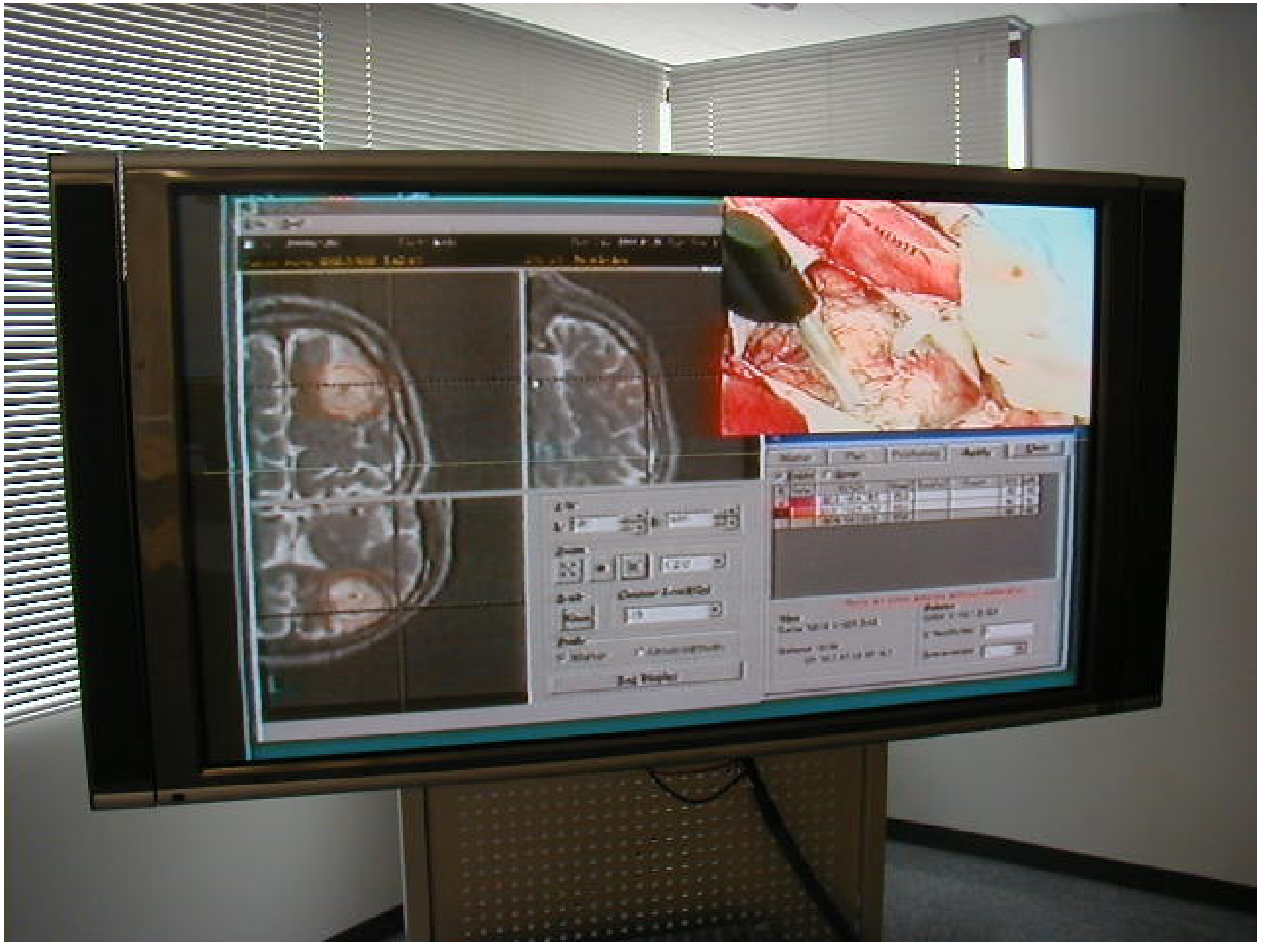


Master and slave system for neurosurgery

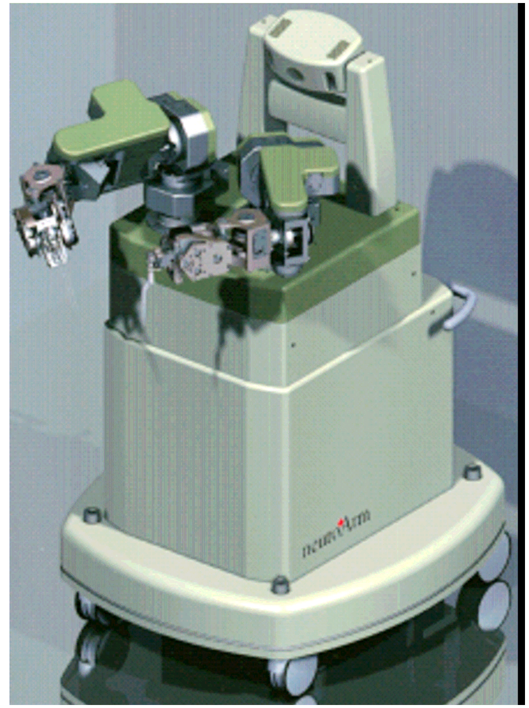


HivisCAS(High definition Visual Computer Aided Surgery)

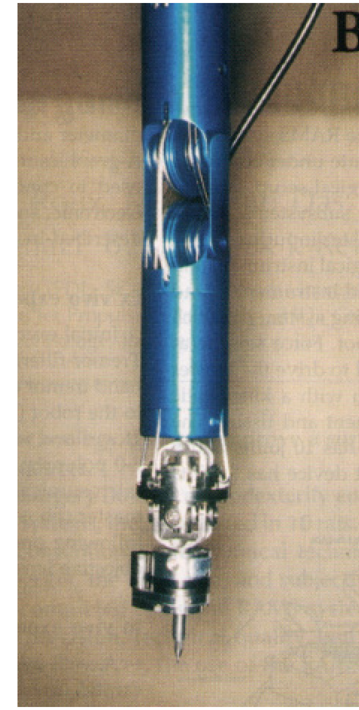
Visual system using high-vision



NeuRobot



NeuroArm

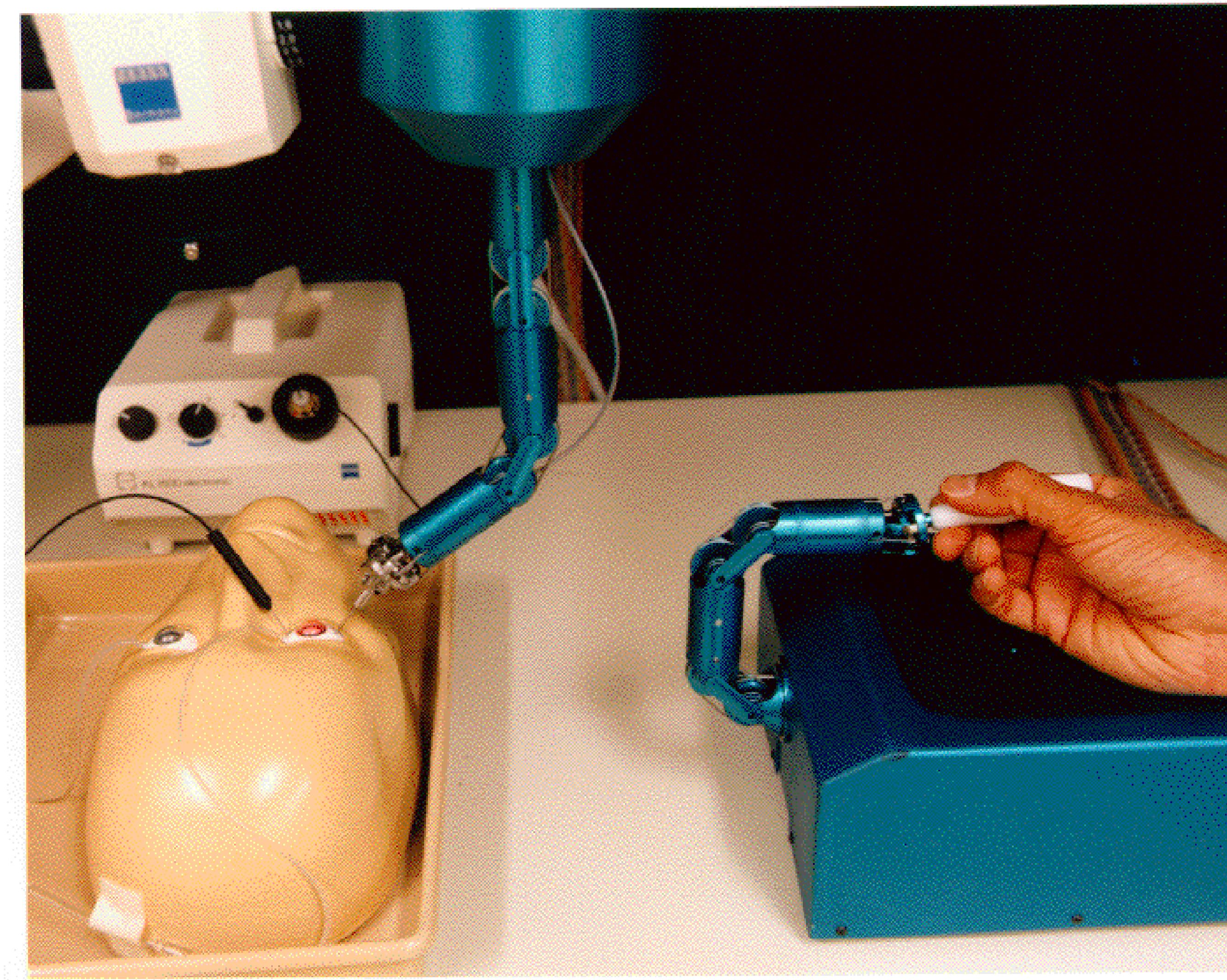


RAMS system

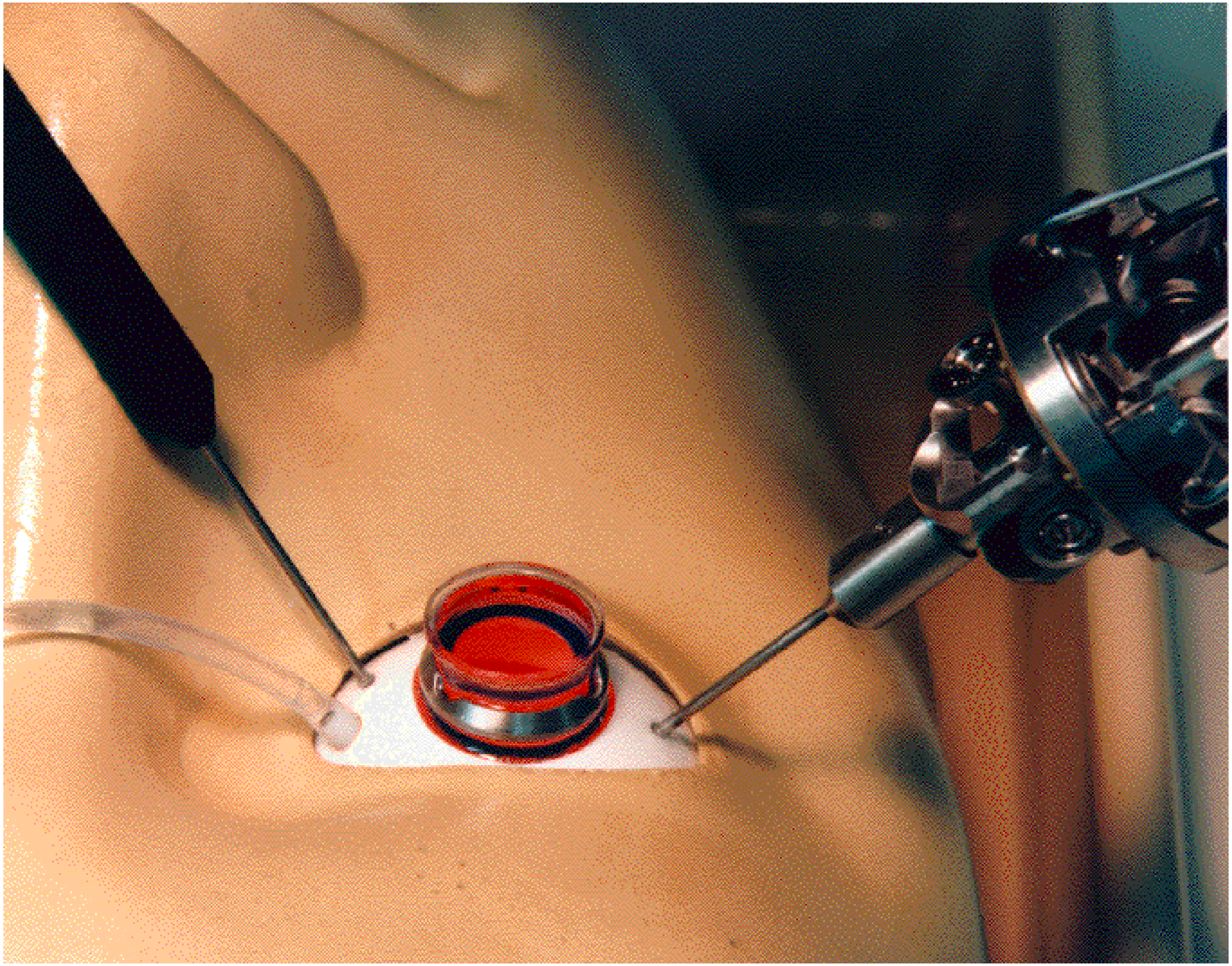
- Fujie and Hitachi: NeuRobot
- D. Louw, et al.: NeuroArm
- P. Le Roux, et al.: RAMS system

JPL, NASA

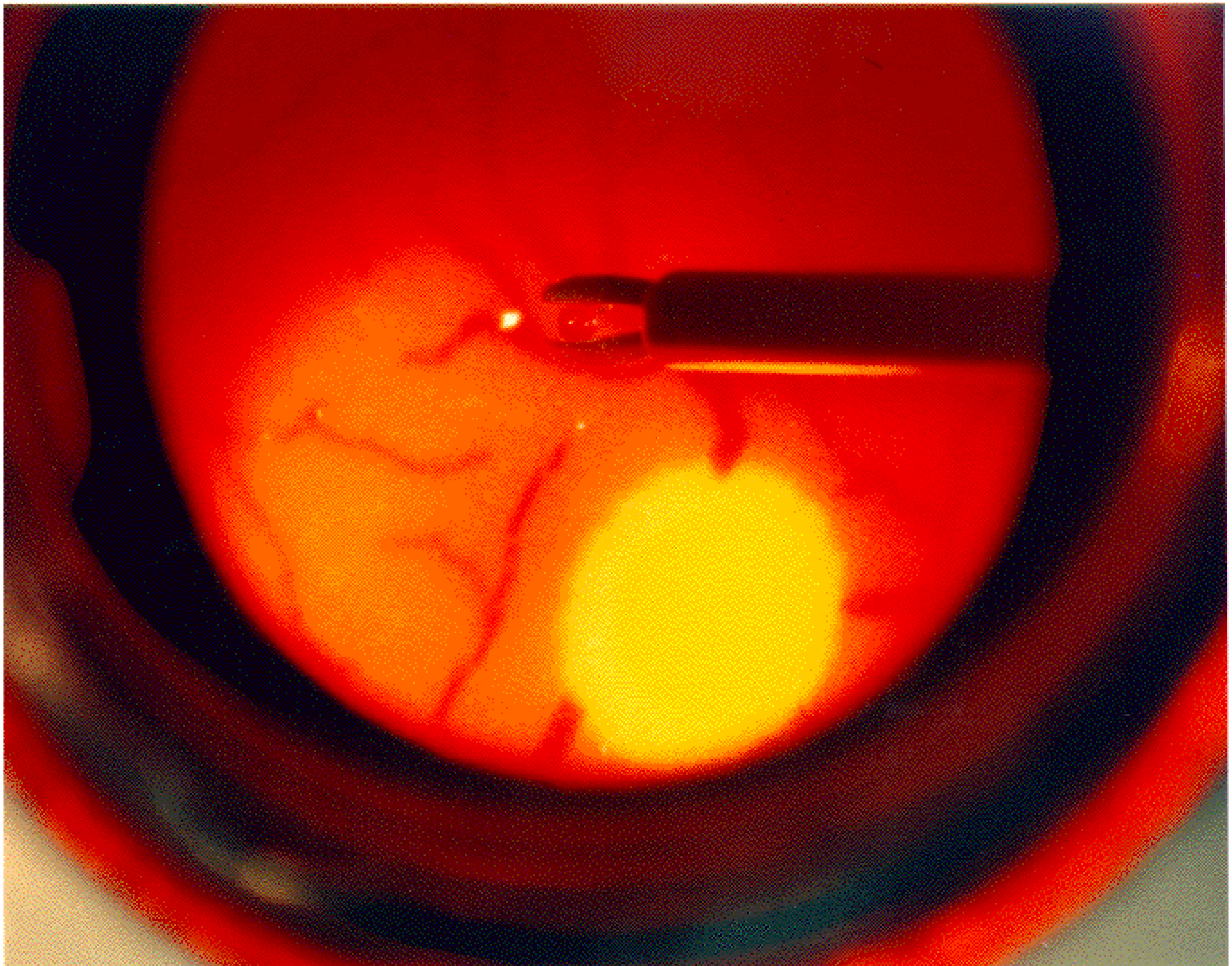
Robot Assisted MicroSurgery



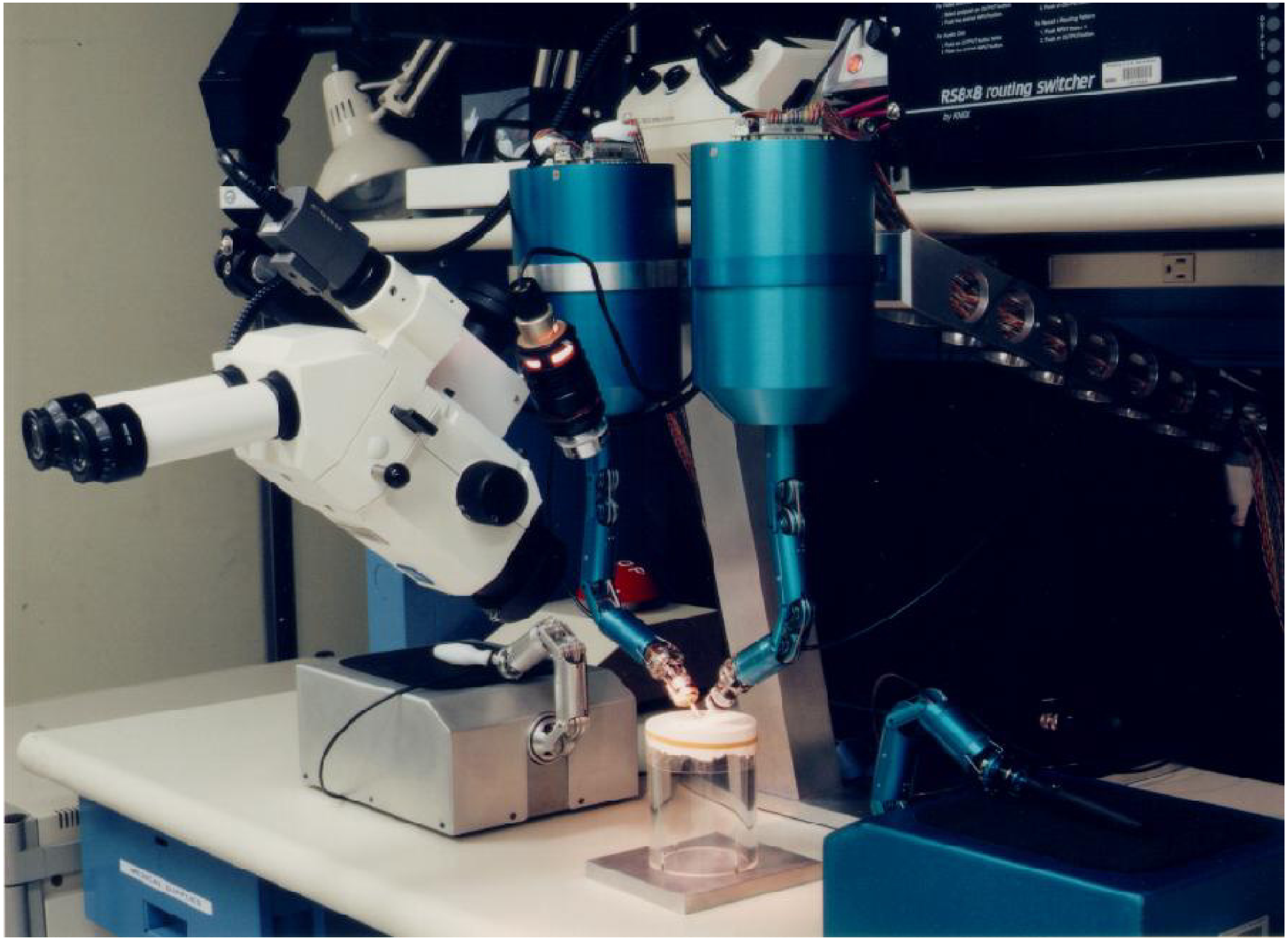
Simulated eye microsurgery



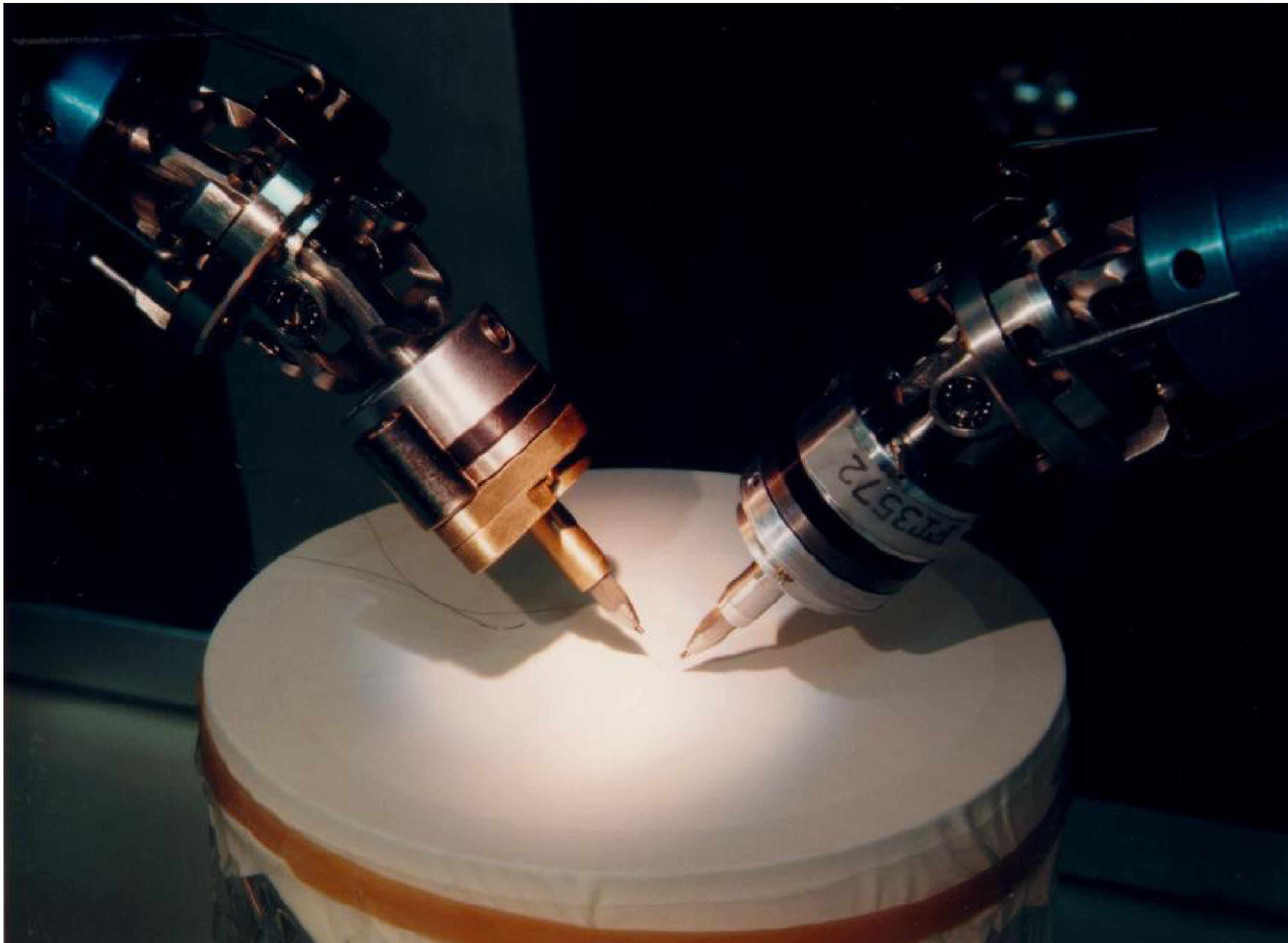
Simulated eye microsurgery



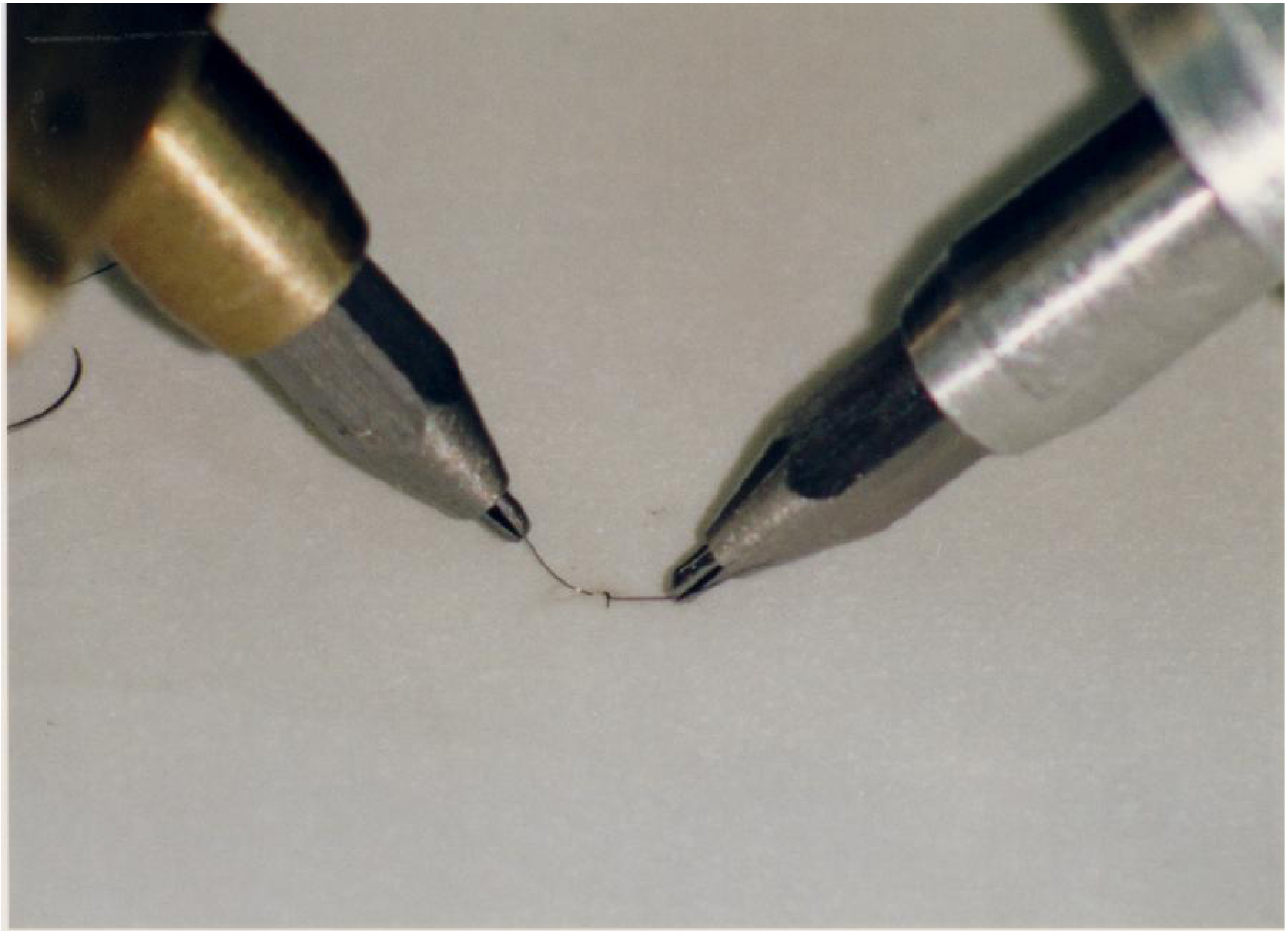
Dual-arm telerobotic microsurgery workstation



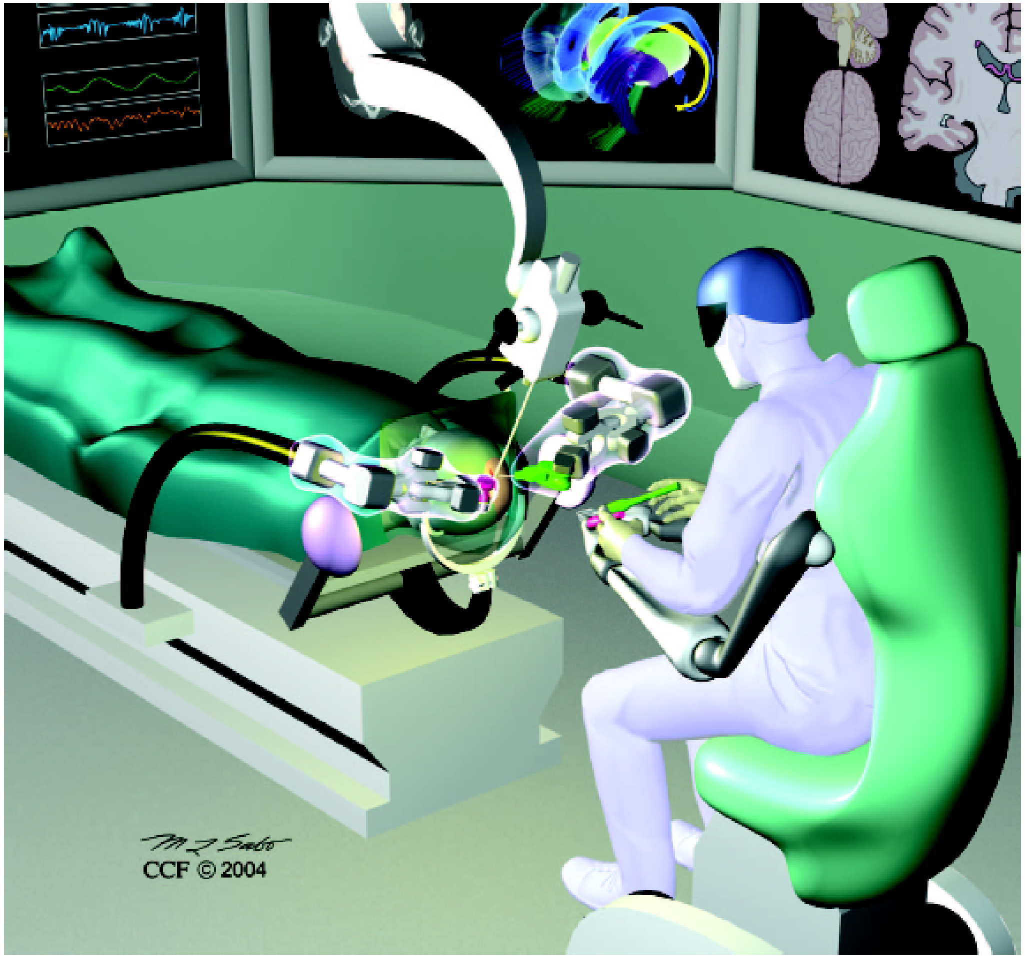
Slave manipulators



Microsurgery suturing



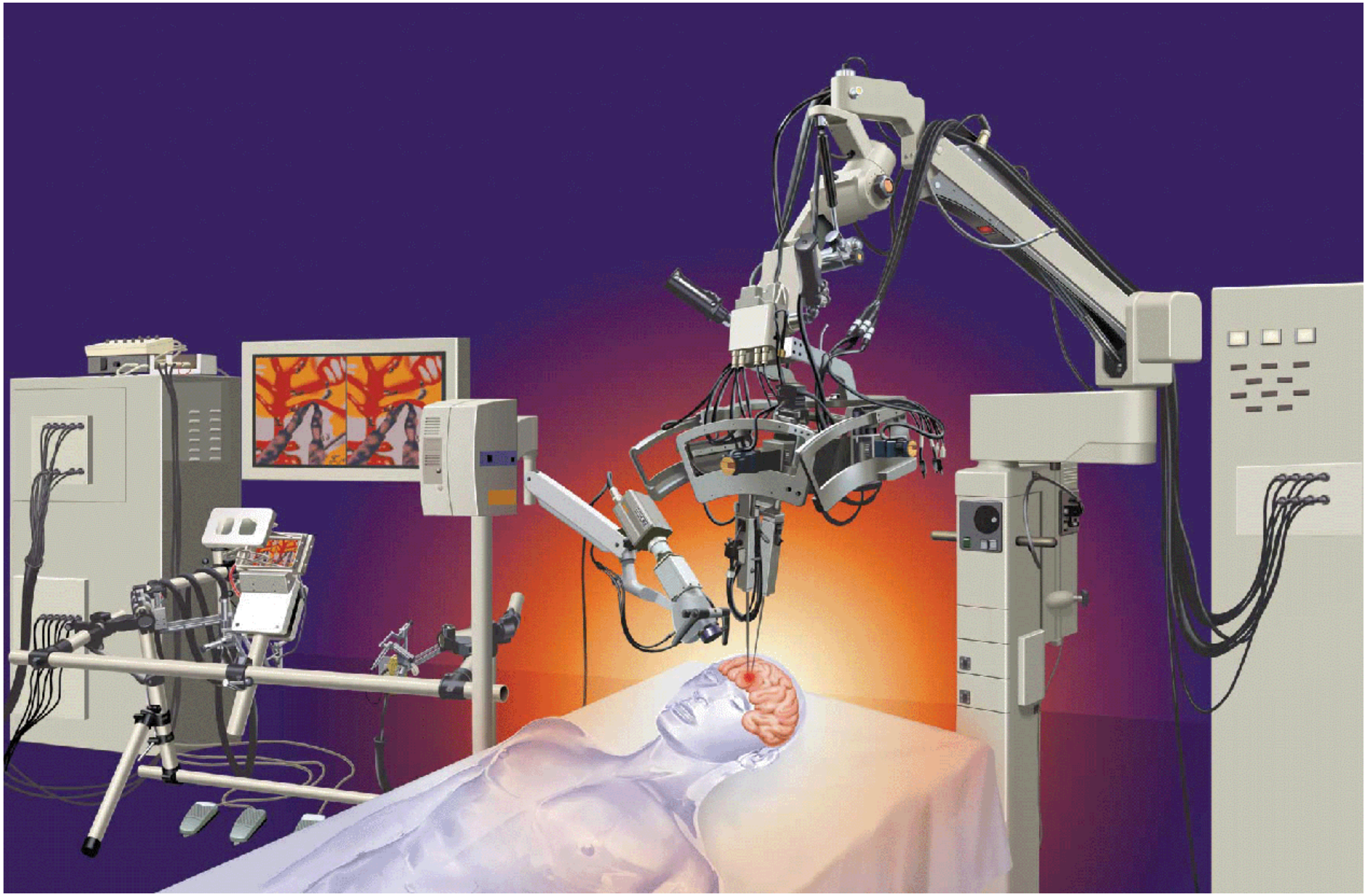
In Touch with Robotics: Neurosurgery for the Future, Neurosurgery, March 2005.
Narandra Nathoo, M.D., Ph D., et al.
Cleveland Clinic Foundation. Ohio, U.S.A.,



Method 1: Hardware

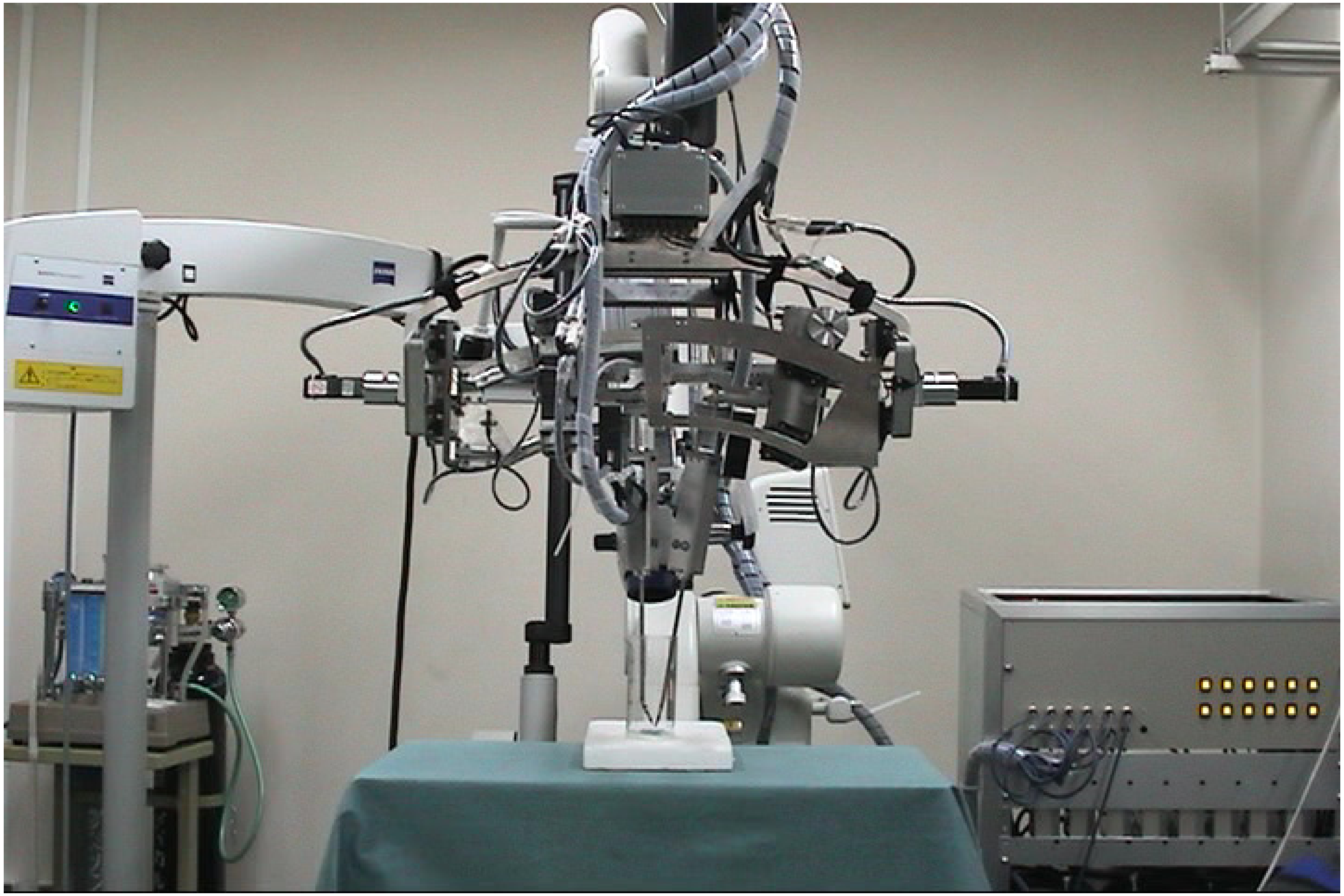
- **Robotic master-slave system**
  - Microsurgery system: Type I was built
  - 2 micro manipulators : 12 motion freedom
  - Motorized bending mechanism of the manipulator tip
  - Hanging base with additional 6 freedoms
- **Visual system**
  - 3D (HD) viewer system(NHK Engineering Services, Inc.)
  - 3D video microscope/endoscope system(Olympus)

Total system design



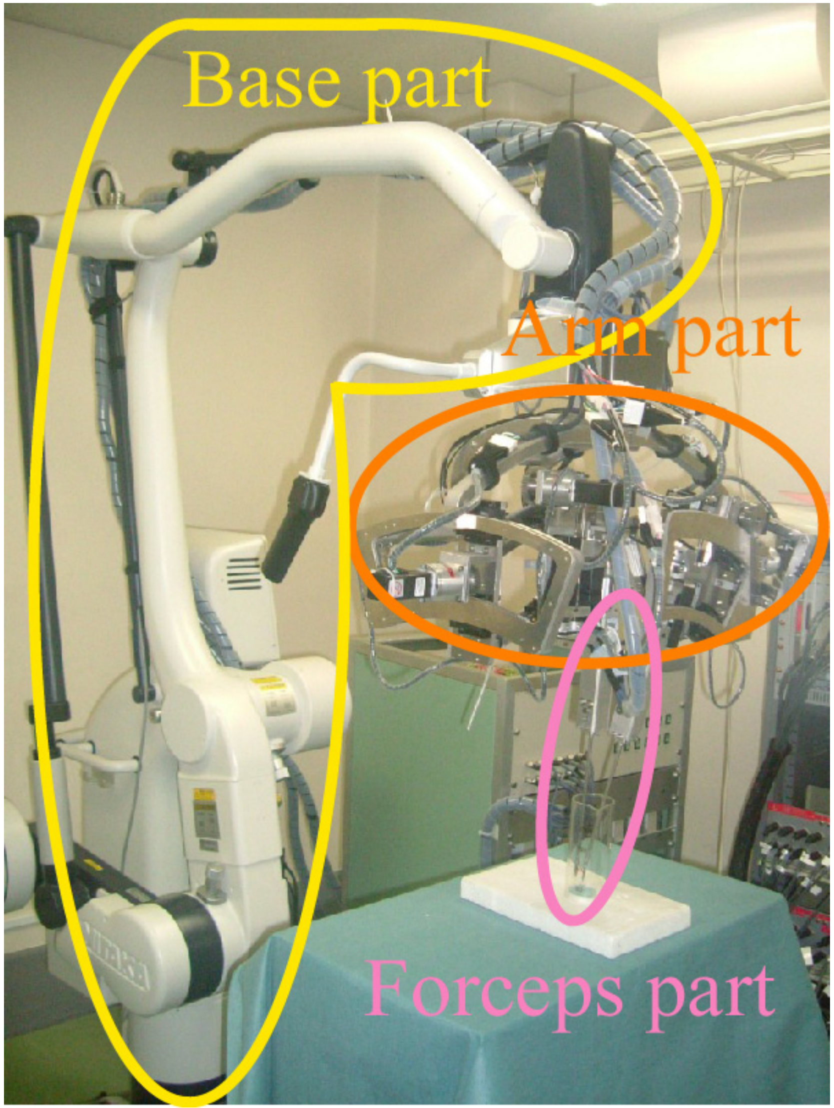
From Newton, Sep. 2004

Slave manipulator (MM-2)



Slave manipulator (MM-2)

- Forceps part
  Motion inside of cranium
- Arm part
  Precise positioning outside of cranium
- Base part
  Pre-operative positioning for arm and forceps parts



Slave manipulator (MM-2): Arm part

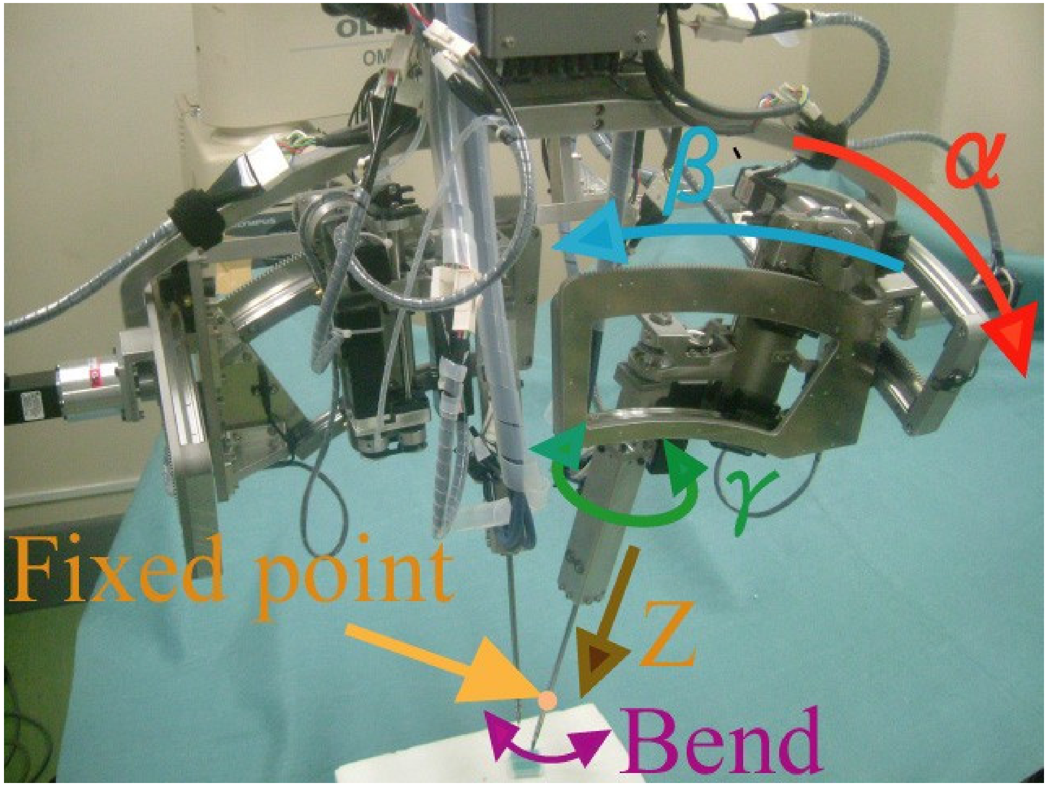
Basic specification

- Left and right arms
- Each arm has

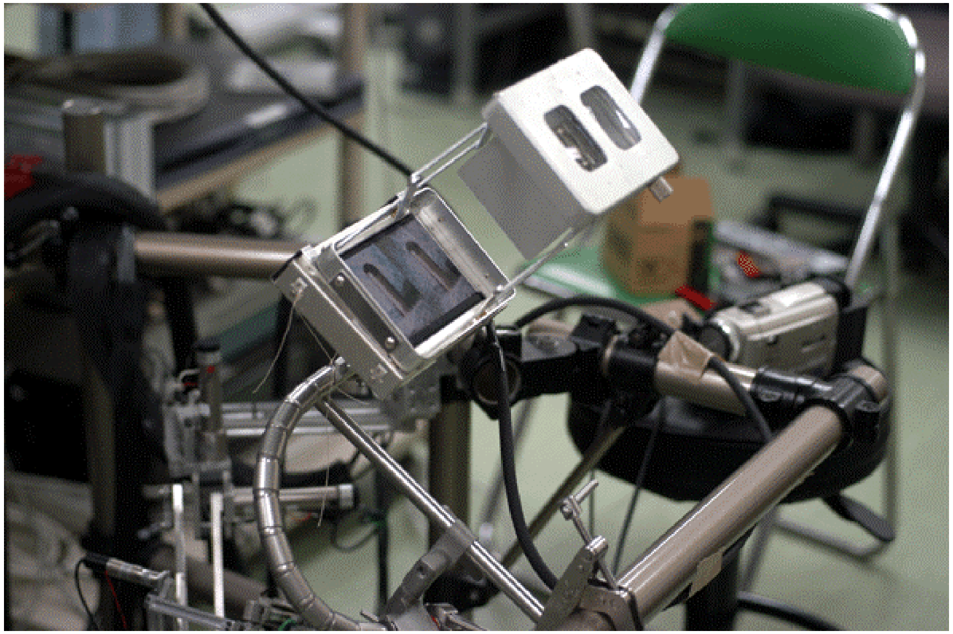
- 3 rotational degrees of freedom (α, β, γ)

- 1 translational degree of freedom (Z)

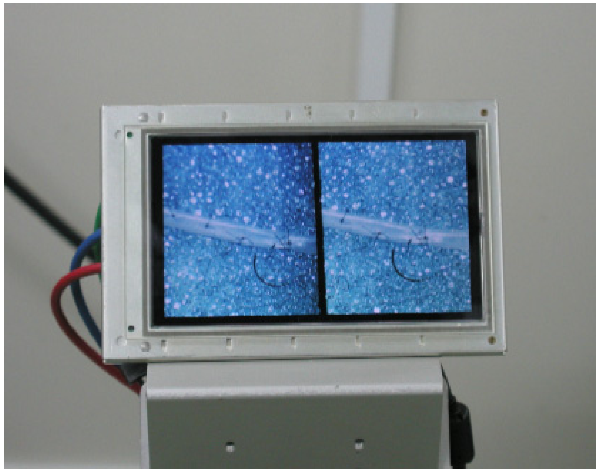
- Fixed point on the axis in the insertion direction



Visual System

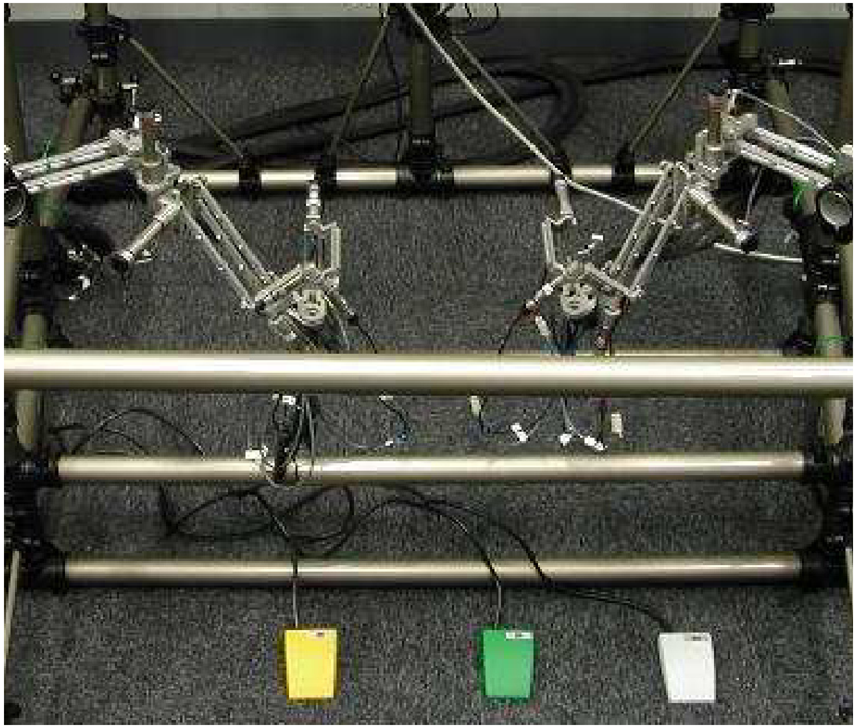


HD 3D video microscope



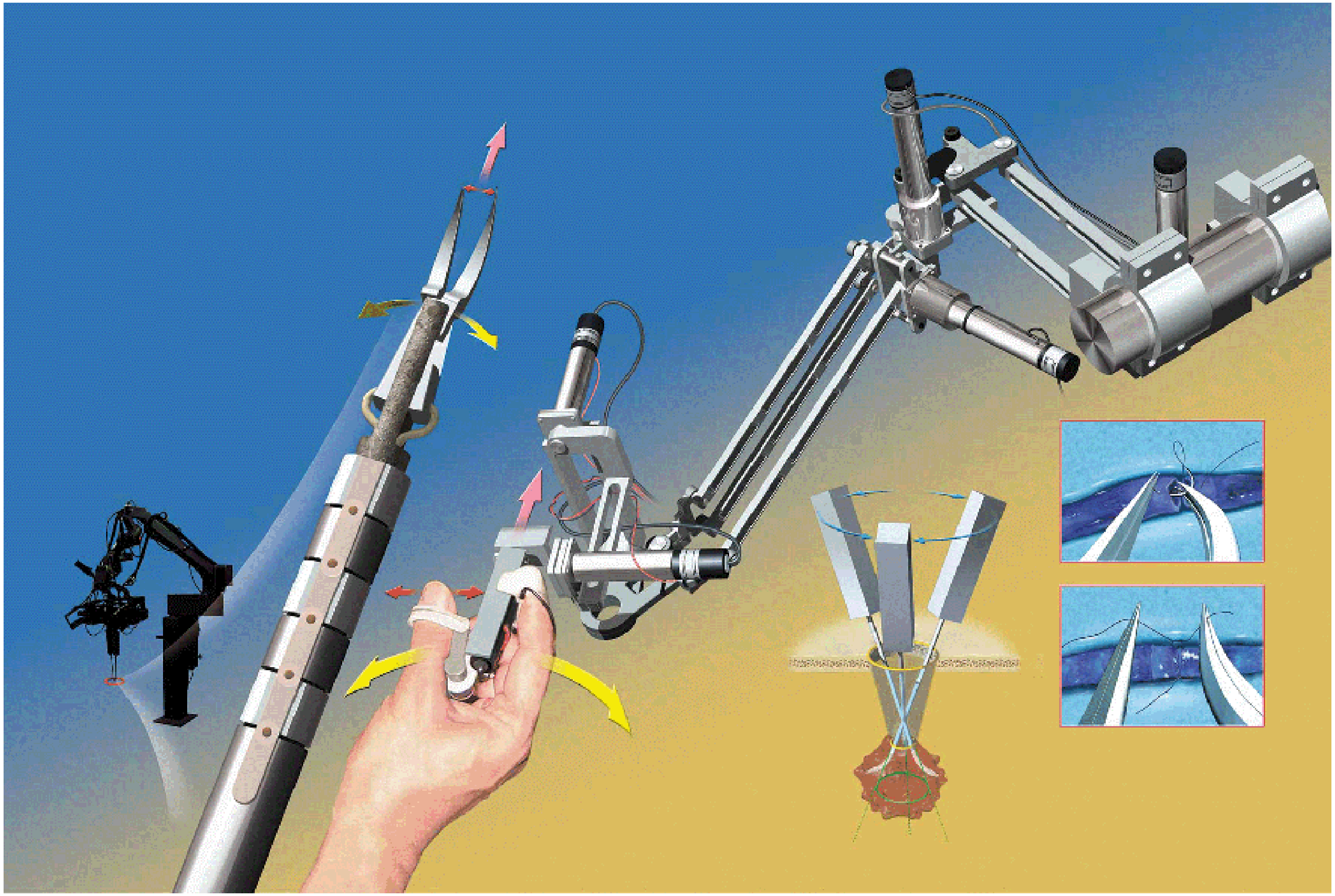
3D viewer
(NHK engineering)

Master manipulator



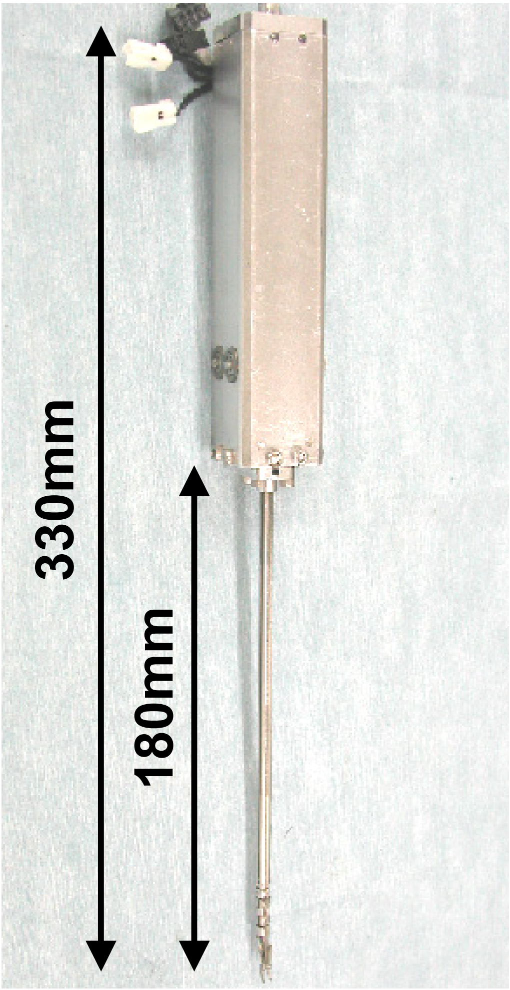
- 7 d.o.f. for each hand: 3 translational d.o.f., 3 rotational d.o.f. and 1 open/close d.o.f.
- Left foot pedal is used as a clutch to control the information flow from the master manipulator to the slave manipulator.
- Right foot pedal is used to modify the motion magnification ratio between the master and the slave manipulators.

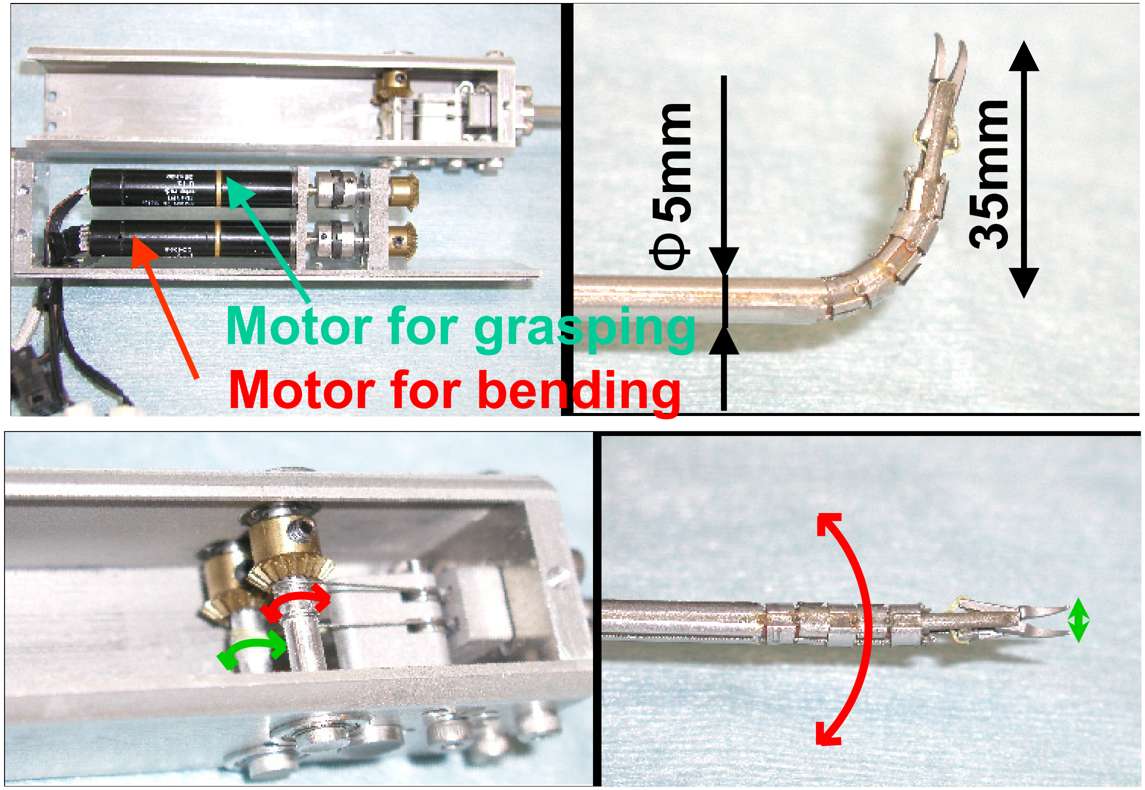
Master manipulator and the forceps



From Newton, Sep. 2004

Slave manipulator (MM-1): forceps part

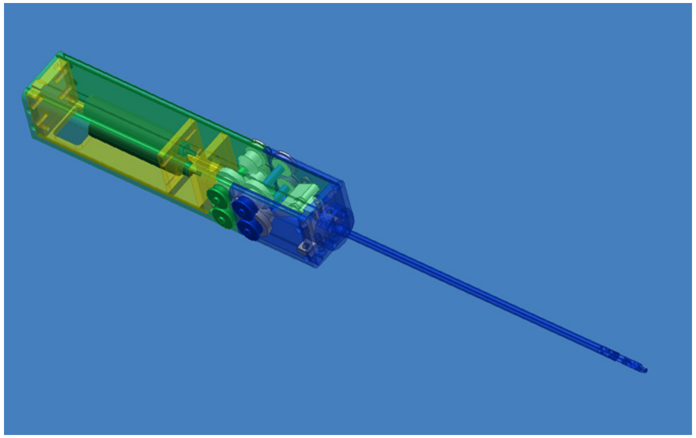


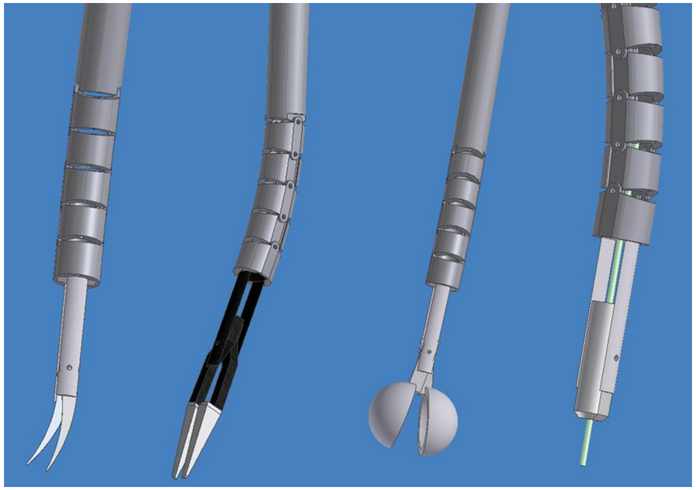


An easily detachable mechanism between the insertion part and the motor of the forceps enables sterilization and irrigation of the insertion part.

Slave manipulator (MM-2): forceps part

- Sterility
- Various equipments
- Miniaturization
- Safety
- Force feedback
- Virtual simulation
- Automation



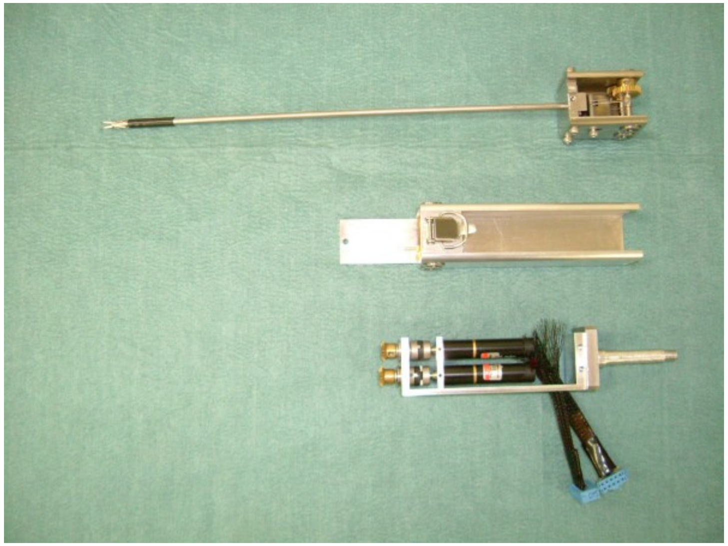


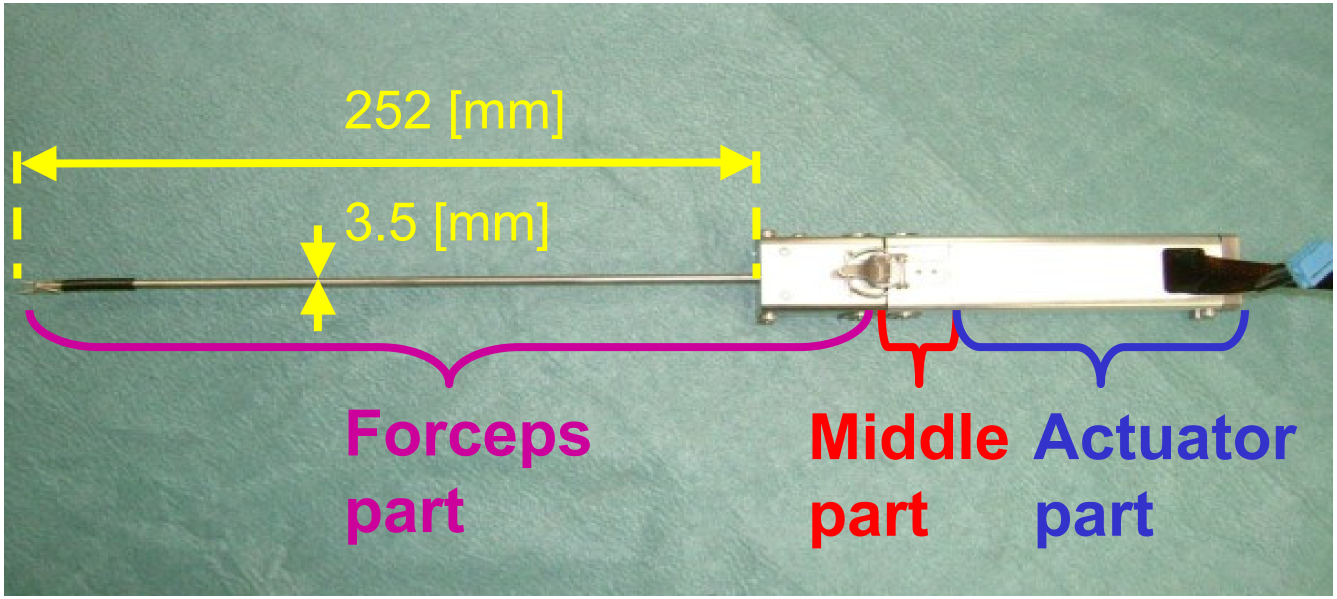
Slave manipulator (MM-2): forceps part

- The forceps consists of forceps part, middle part and actuator part.
- One bending d.o.f.
- One grasping d.o.f.

} 2 d.o.f.

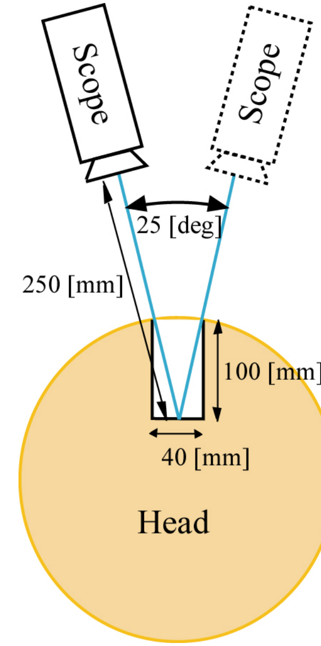
- Stainless wire driven





Slave manipulator (MM-2): arm part

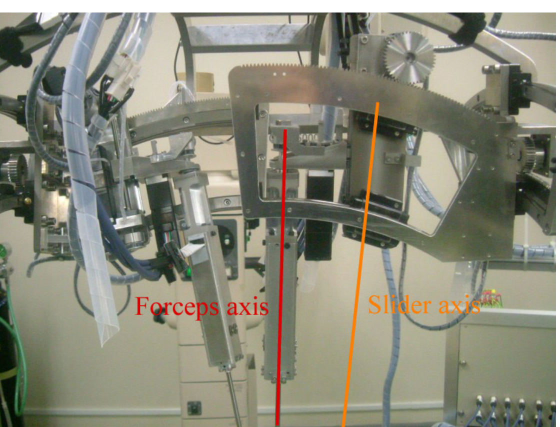
Space configuration with a microscope

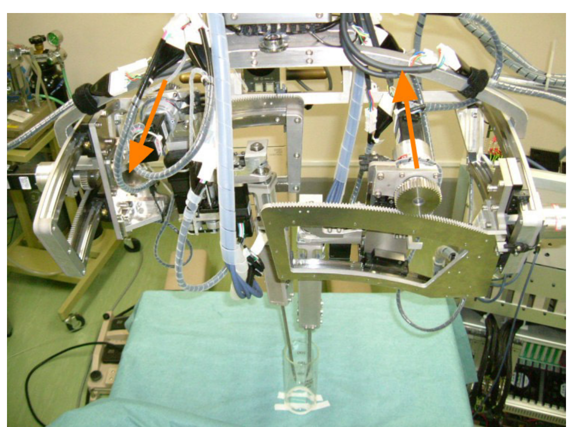


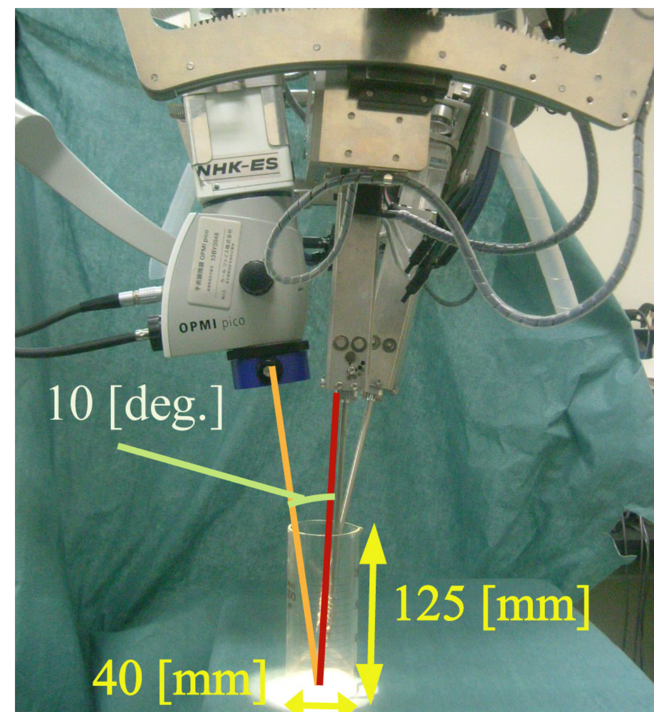
The allowed angle for the microscope is ±12.5 [deg.] to obtain the visual information from the area with diameter 40 [mm] at the depth 100 [mm].

- Offset mechanism was adopted between the slider and the forceps axis
- Actuators were located inner side of the mechanism.

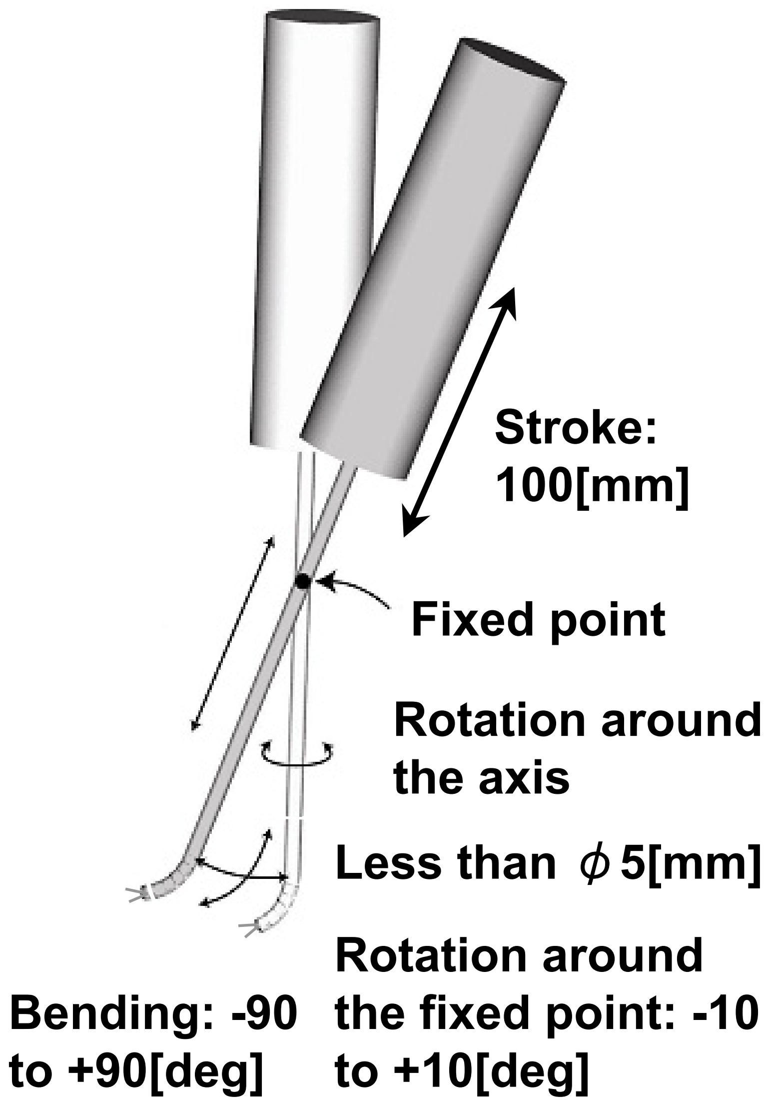
Operation is possible at the depth 125 [mm].





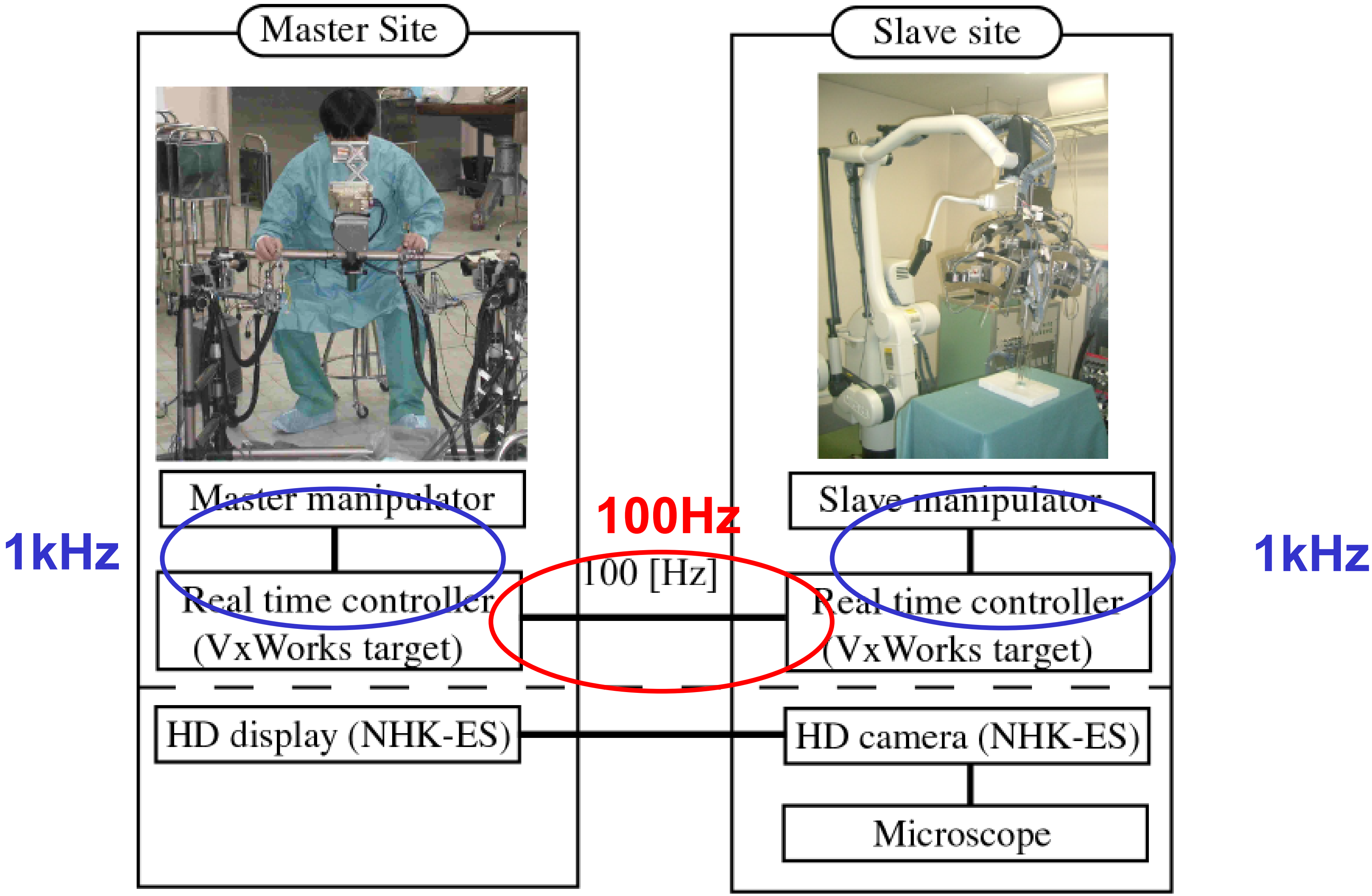


Required specification

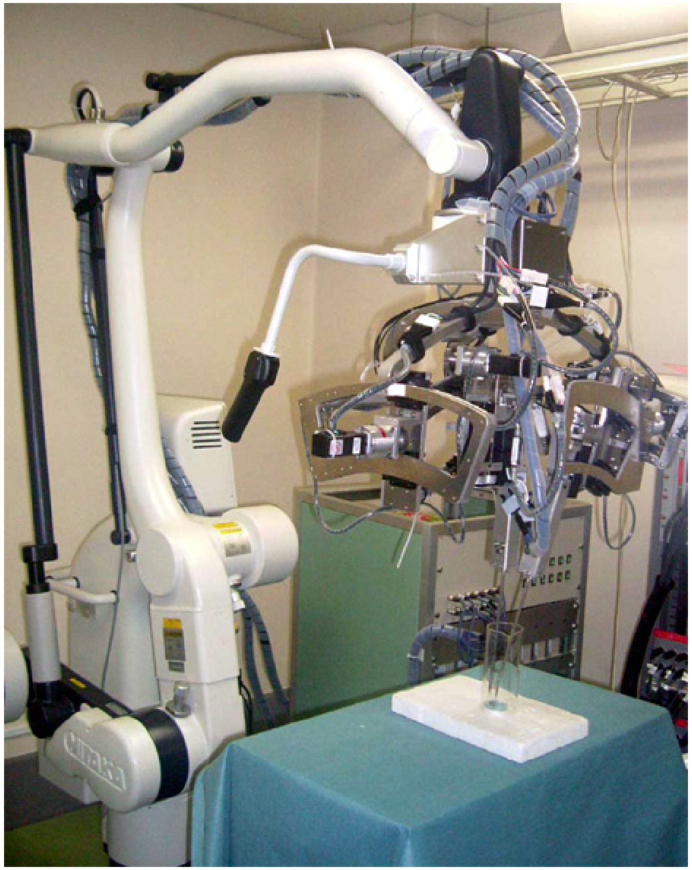


- For the deep surgical field:
  - diameter of the forceps: less than 3.5[mm].
  - motion range: (20[mm])^3
  - mechanical fixed point, rotational motion range around the fixed position: -10 to +10[deg]
  - stroke: 100[mm]
- The bending angle of the forceps: -90 to +90[deg]
- Position accuracy: more than 0.05[mm] to suture a micro blood vessel with diameter 1[mm].
- The forceps can be changed easily.
- Sterilized and irrigated easily.

System implementation (MM-2)



Experimental setting (MM-2)

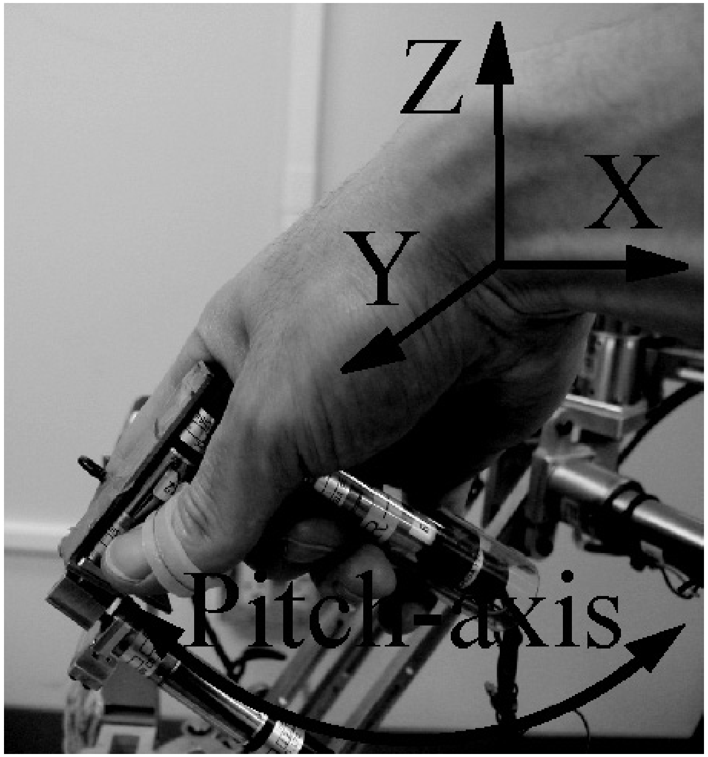


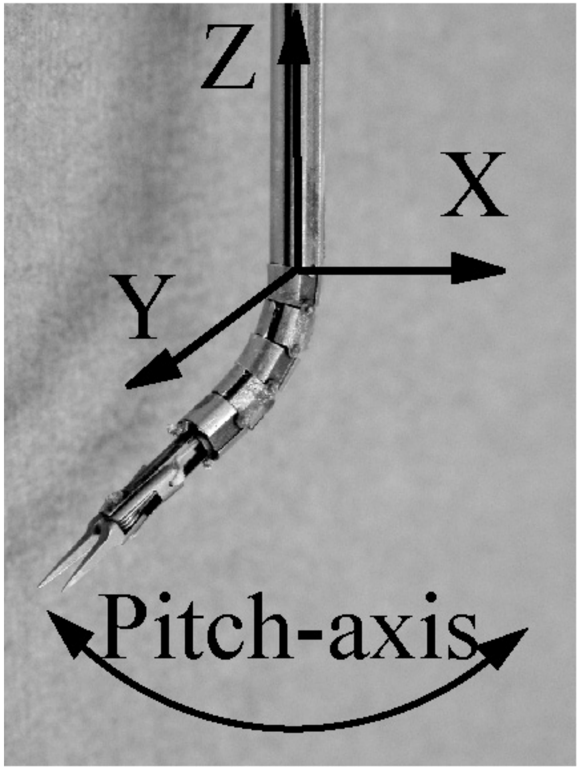
Master manipulator
VxWorks (1kHz)

Position information
100Hz

Slave manipulator
VxWorks (1kHz)

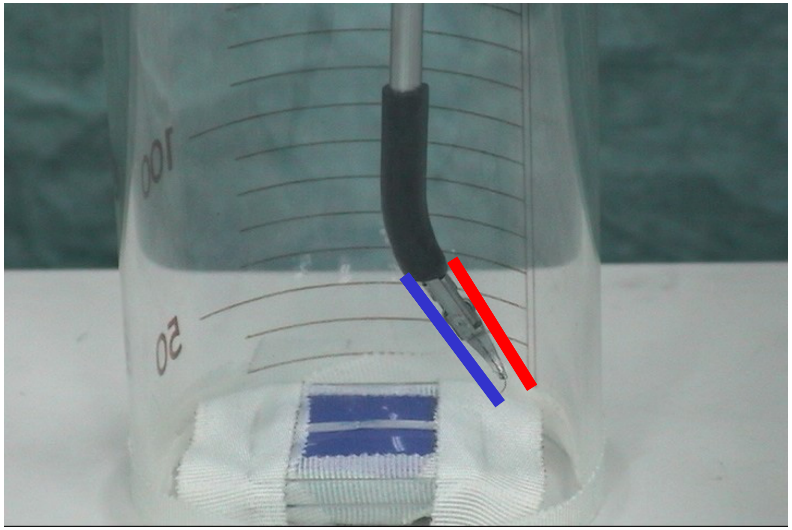
Correspondence of d.o.f. between the master and the slave manipulator

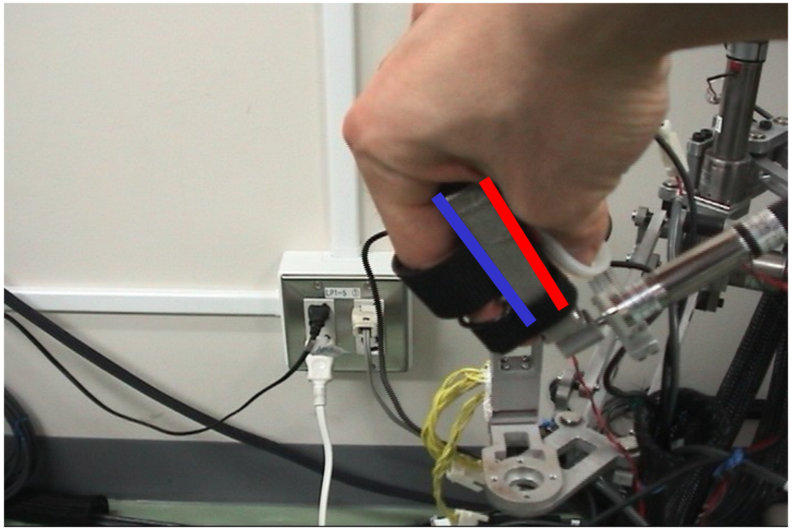




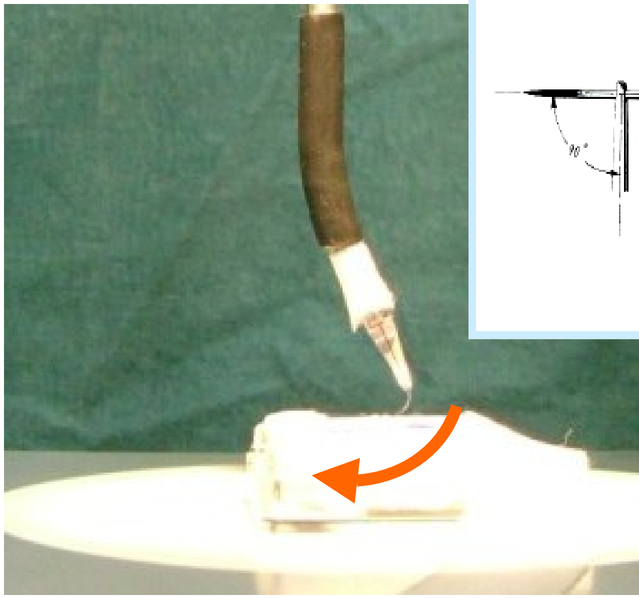
- **The bending motion at the head of the slave manipulator corresponds to a rotation around the surgeon's wrist.**
- **It enables the surgeon to operate the forceps as if he/she held its tip directly.**

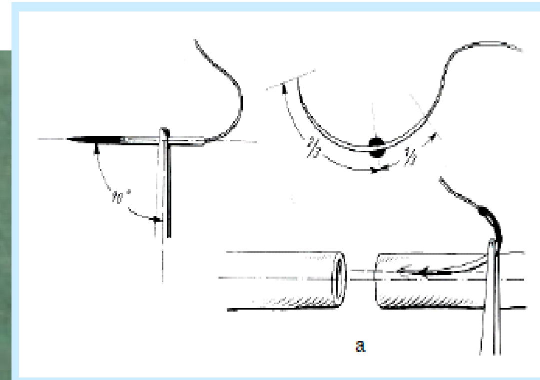
Coordinate system transformation between the master and the slave manipulator (MM-1)

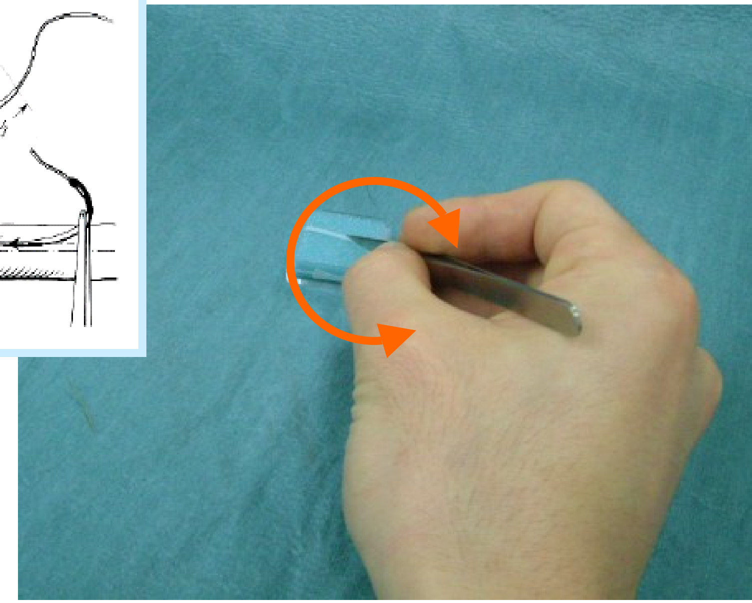


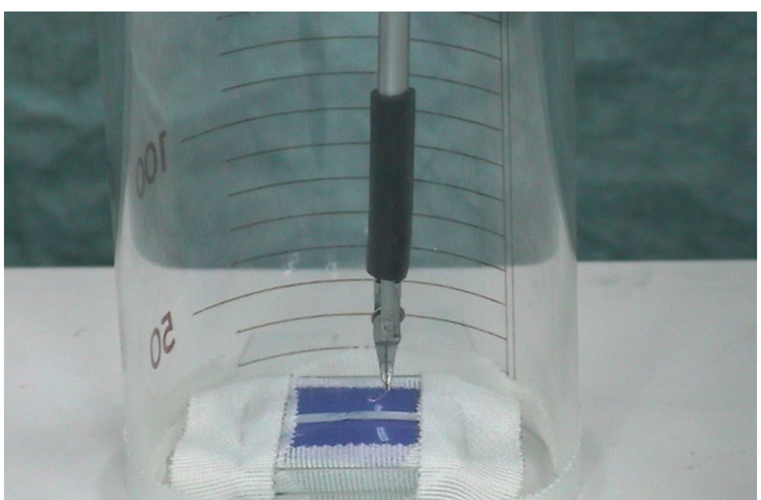


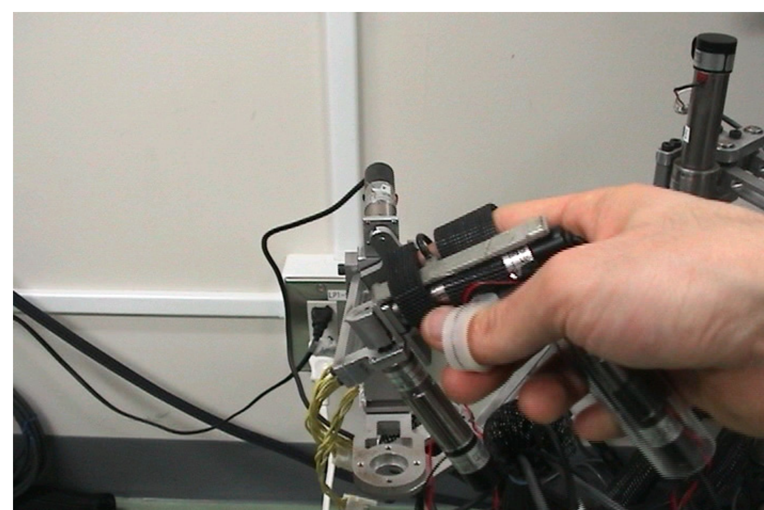
Coordinate system transformation between the master and the slave manipulator (MM-2)



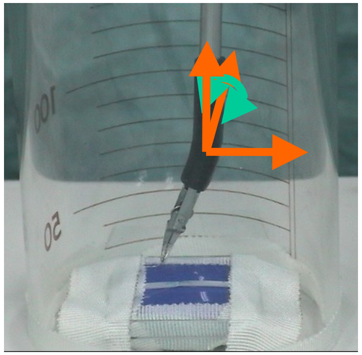


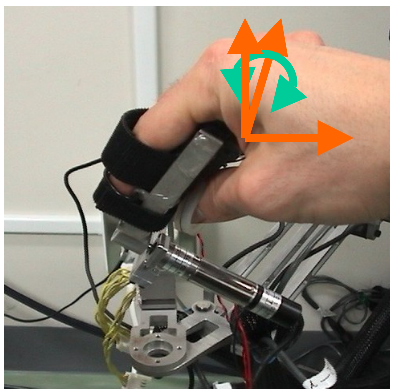




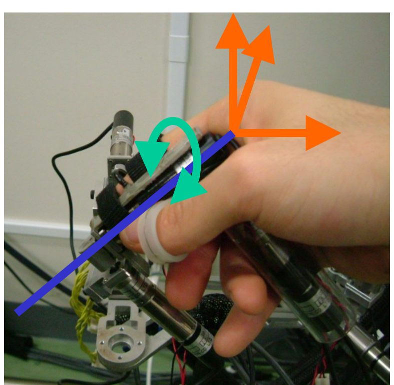


Evaluation of the coordinate system transformation

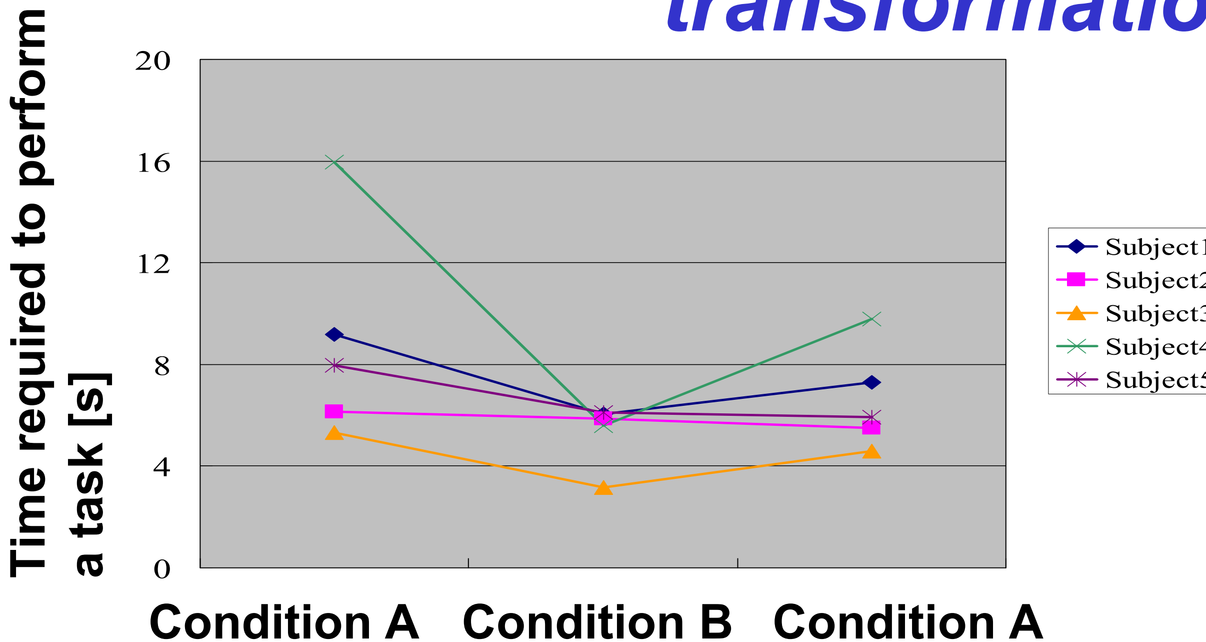


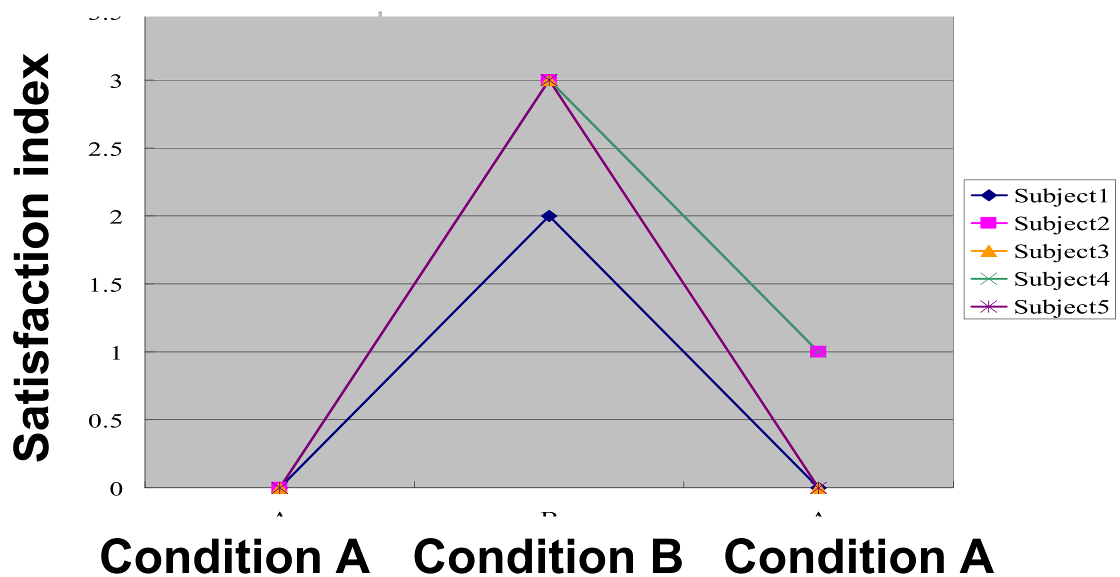


Condition A

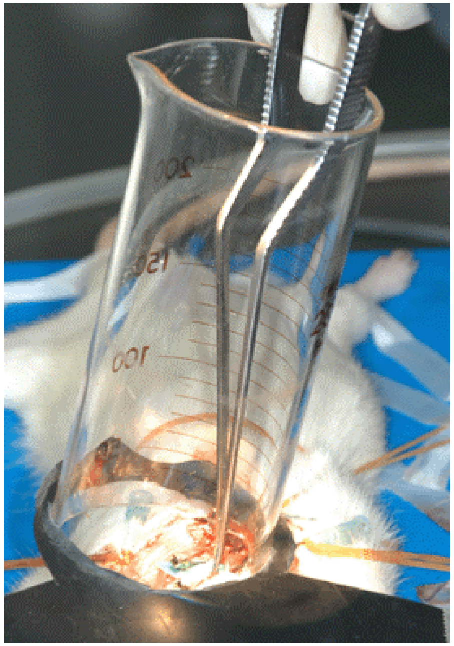


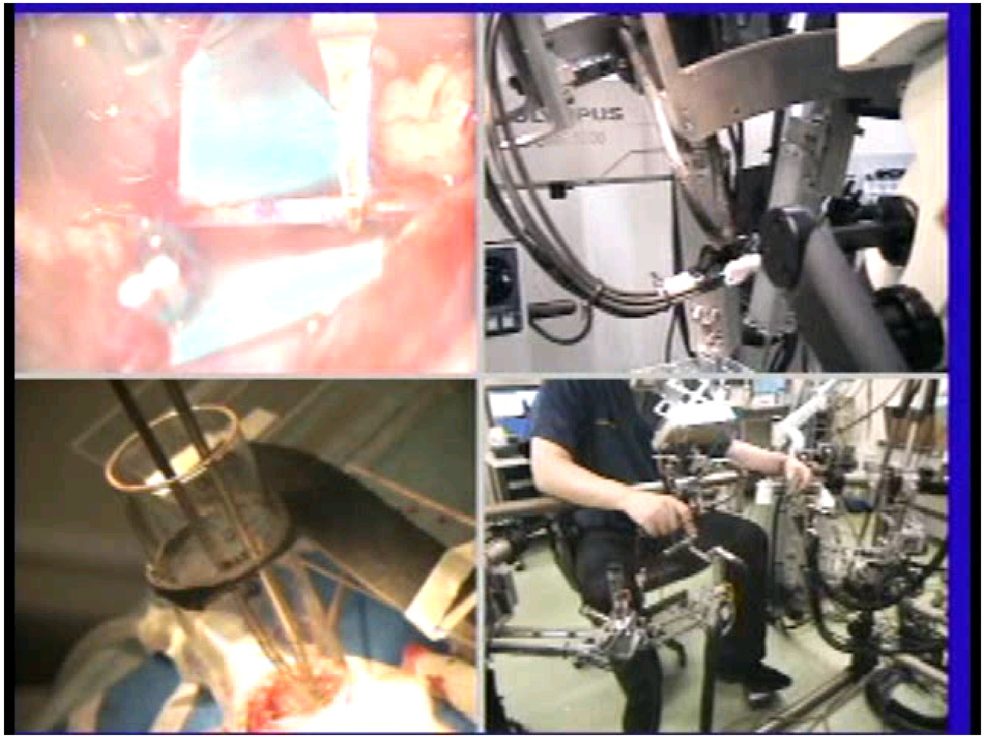
Condition B





Anastomosis of rat common carotid artery (MM-1)





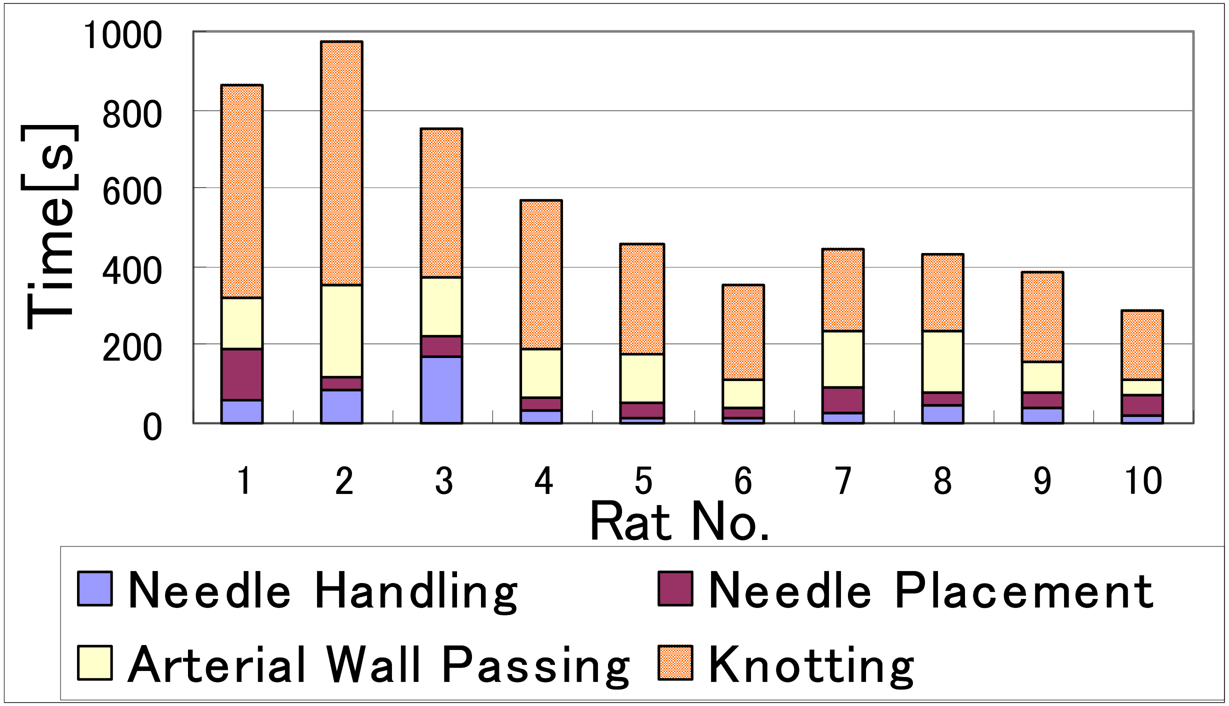
To verify deep surgical field maneuverability

- **Rat carotid artery(ϕ1mm) harf-arteriotomy suturing**
- **Under a glass tube 120[mm] in depth and 50[mm] in diameter**
- **10 week old male Wister rat (220g~440g) * 10**

Results Experiment 1:

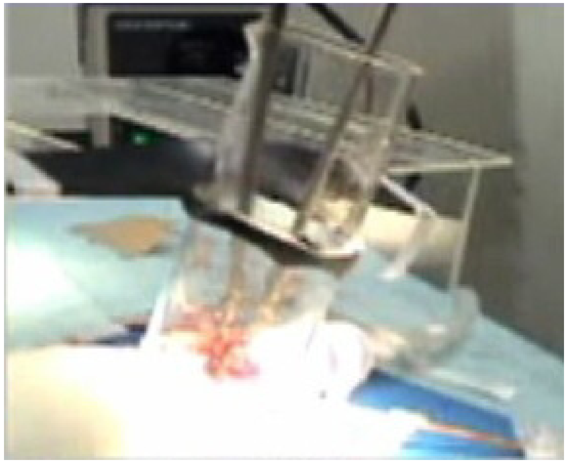
- **8/10 successful suturing with patency**
- **The average required time for one stitch suturing was 9 min.**
- **Time required for initial three experiments were significantly longer than that of the last three experiments.**
- **Knotting required the longest and the most varied time.**

Required time to suture one position



- **Learning effect of operation: knotting, Goal: 1 min.**
- **Time required for initial three experiments were significantly longer than that of the last three experiments.**
- **Knotting required the longest and the most varied time.**

Anastomosis of rat common carotid artery (MM-1)



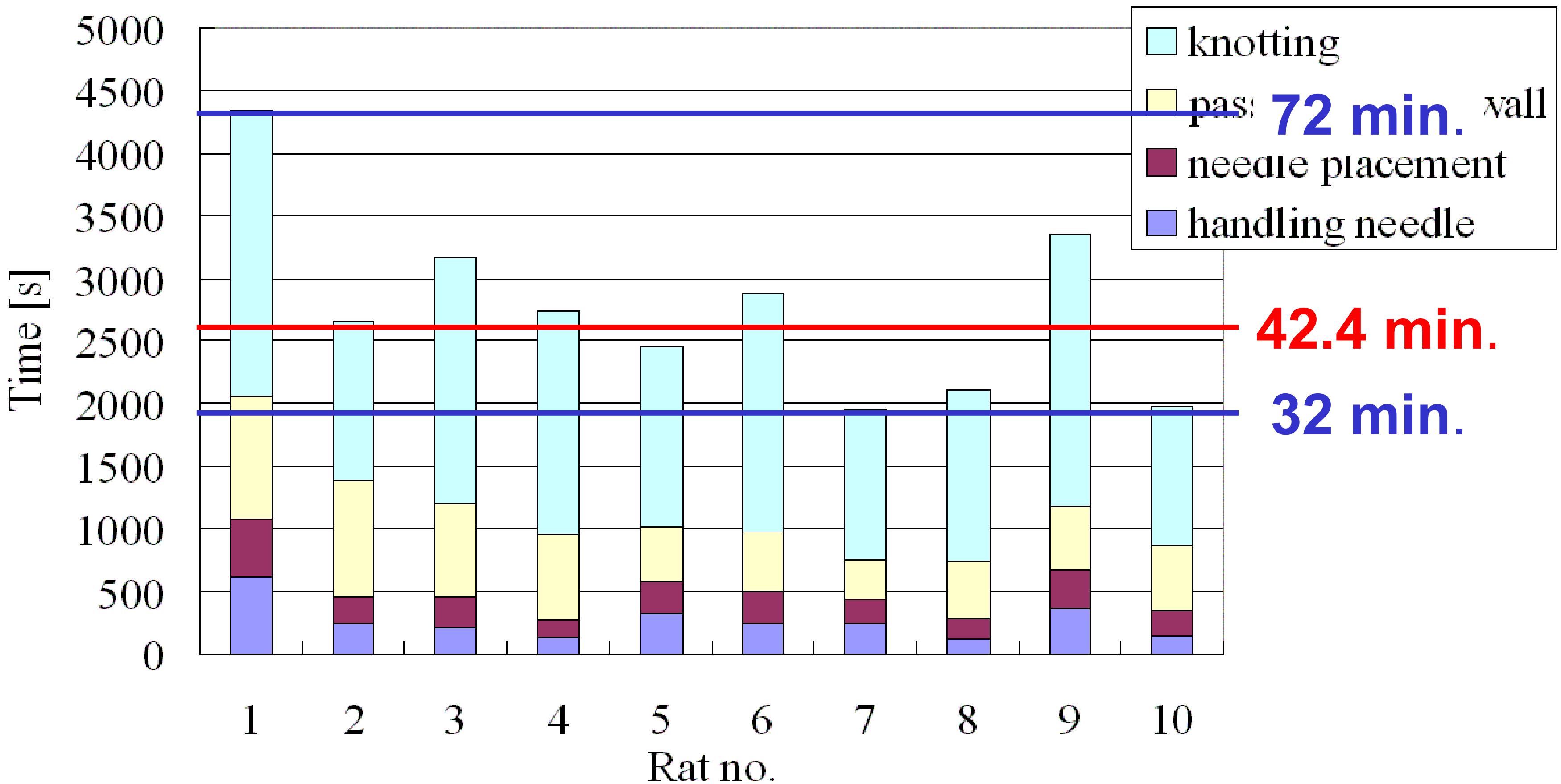
To verify deep surgical field maneuverability

- **Rat carotid artery(ϕ1mm) complete arteriotomy suturing**
- **Under a glass tube 90[mm] in depth and 40[mm] in diameter**
- **10 week old male Wister rat (270g~420g) * 10**

Results Experiment 2:

- **A carotid artery was sutured 10 to 13 times using a 10-0 needle and suture.**
- **All anastomoses were successfully executed with patency**
- **The average time to complete anastomosis was 42.4 min.(Min.: 32 min., Max.: 65 min.)**
- **The target time is 20 min.**

The sum of the every operation time

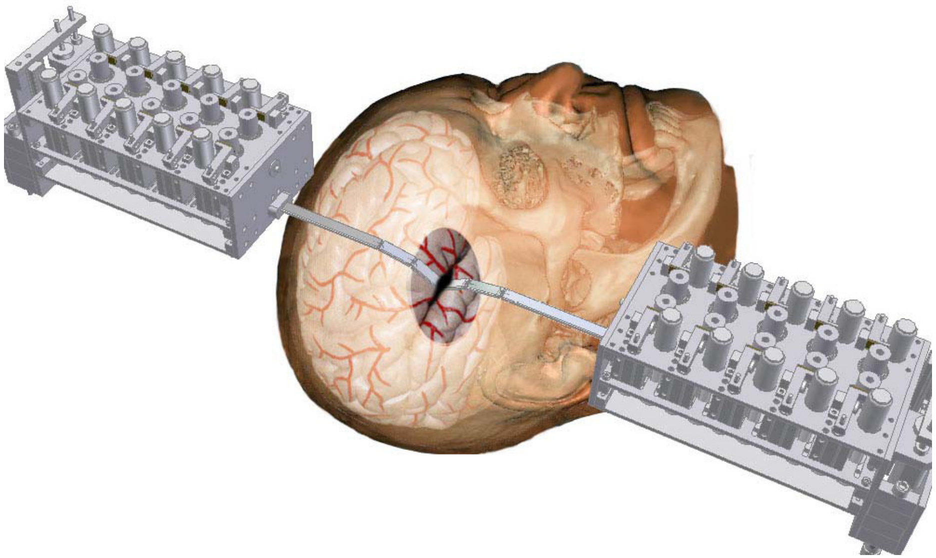


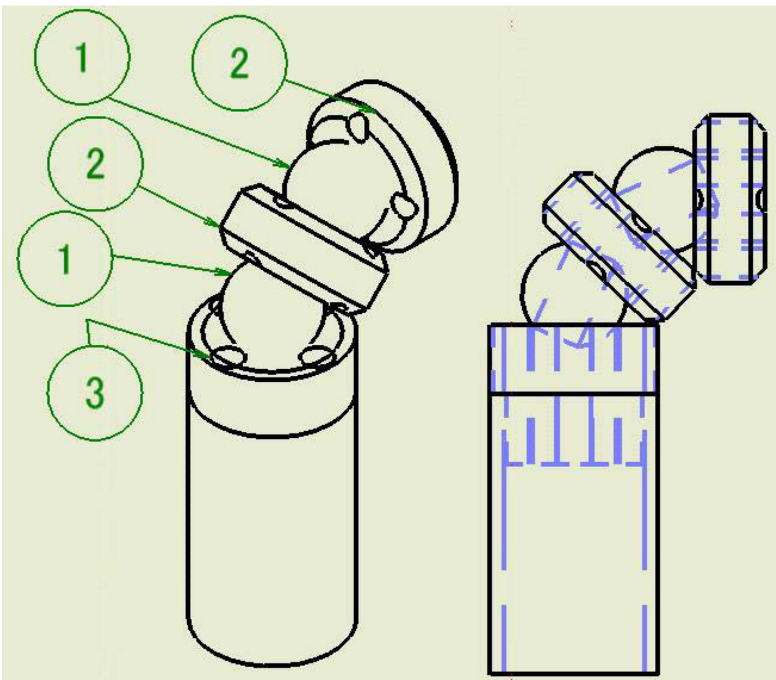
- **The average time to complete anastomosis was 42.4 min. (Min.: 32 min., Max.: 72 min.)**
- **The target time is 20 min.**

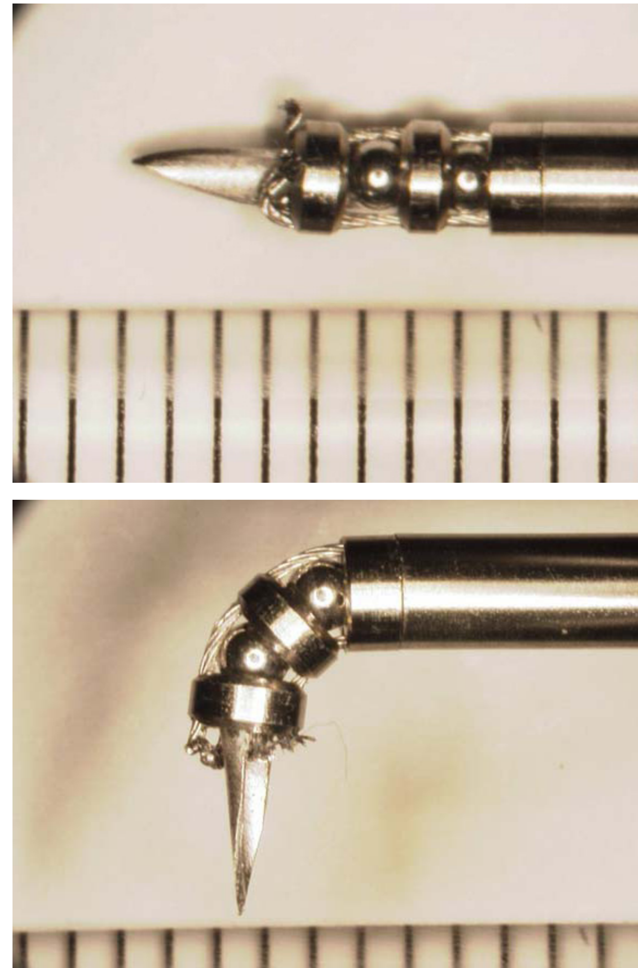
Summary

- The authors have developed a microsurgical system for neurosurgery in the deep surgical field.
  - The diameter of the forceps is 3.5 [mm].
  - The surgical operation is feasible at the depth 125 [mm] at the area with diameter 40 [mm].
  - Coordinate system transformation between the master and the slave manipulator was executed considering the actual suturing motion.
- Cadaveric experiments were successfully executed using the developed system.

Brain Spatula Type Robot
M.Fujie, Waseda Univ., Jpn







Φ2.4