2013 MICCAI Tutorial
Visual tracking and 3D reconstruction for computer-assisted interventions
State-of-the-art and challenges
Sep. 22 2013

Utility of Multi-view Camera System for Navigation Surgery

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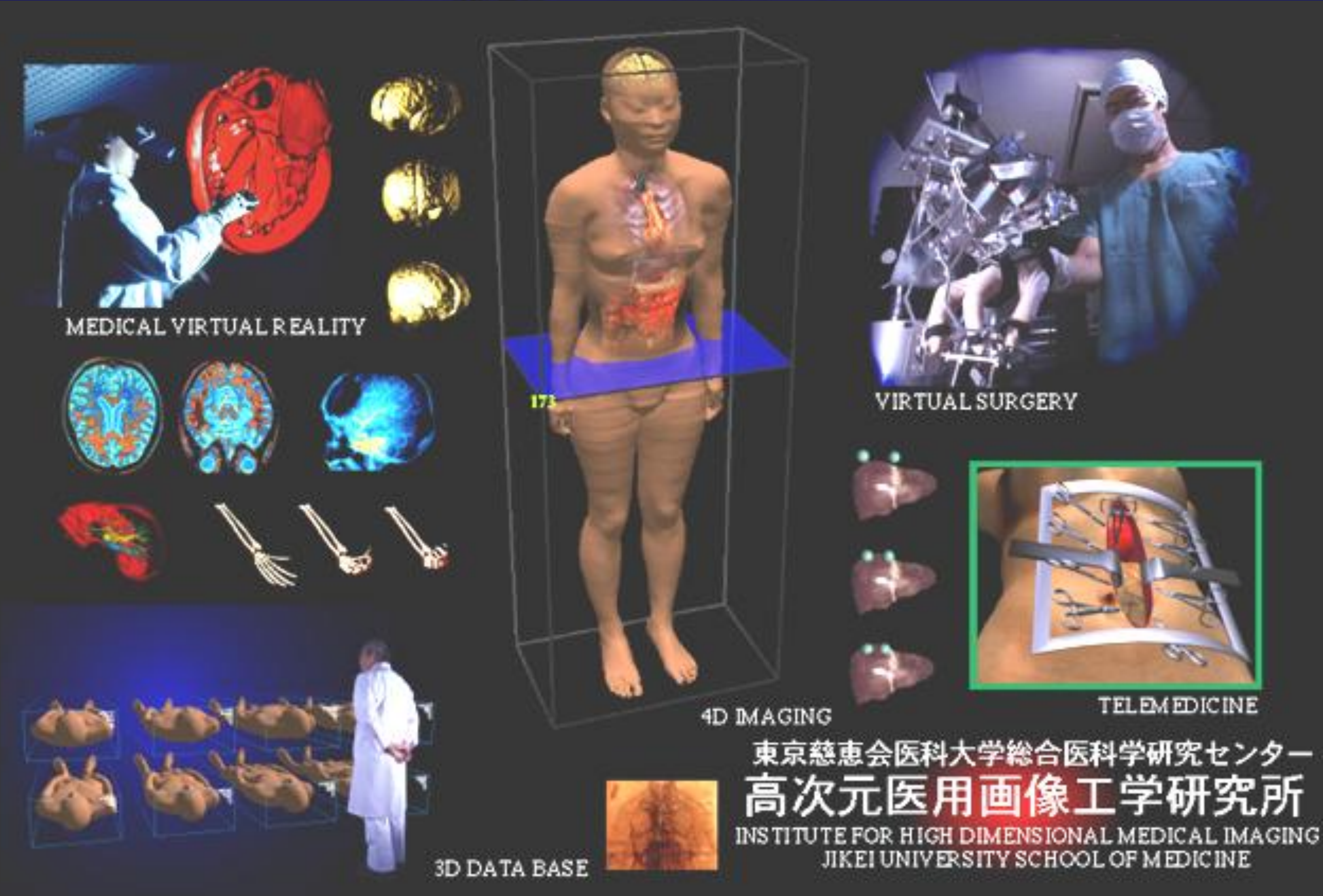
Current laparoscopic and robotic surgeries have difficulty in obtaining visual information in the operating field. Limits to surgeons' views in these operations can lead to accidents. Operational instruments can unnecessarily touch soft tissue, or surgeons may be unaware of bleeding in areas out of their view.

To overcome these problems, we used multi-view camera for laparoscopic surgery to provide greater field of view to surgeons.

We also devised a system to enhance the field of view using AR technology.

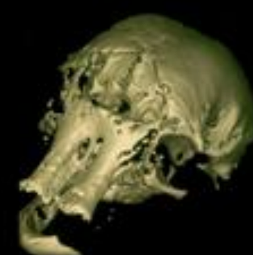

MEDICAL VIRTUAL REALITY
VIRTUAL SURGERY
TELEMEDICINE
4D IMAGING
3D DATA BASE
東京慈恵会医科大学総合医科学研究センター
高次元医用画像工学研究所
INSTITUTE FOR HIGH DIMENSIONAL MEDICAL IMAGING
JIKEI UNIVERSITY SCHOOL OF MEDICINE


Main Control Room


3D CT Laboratory

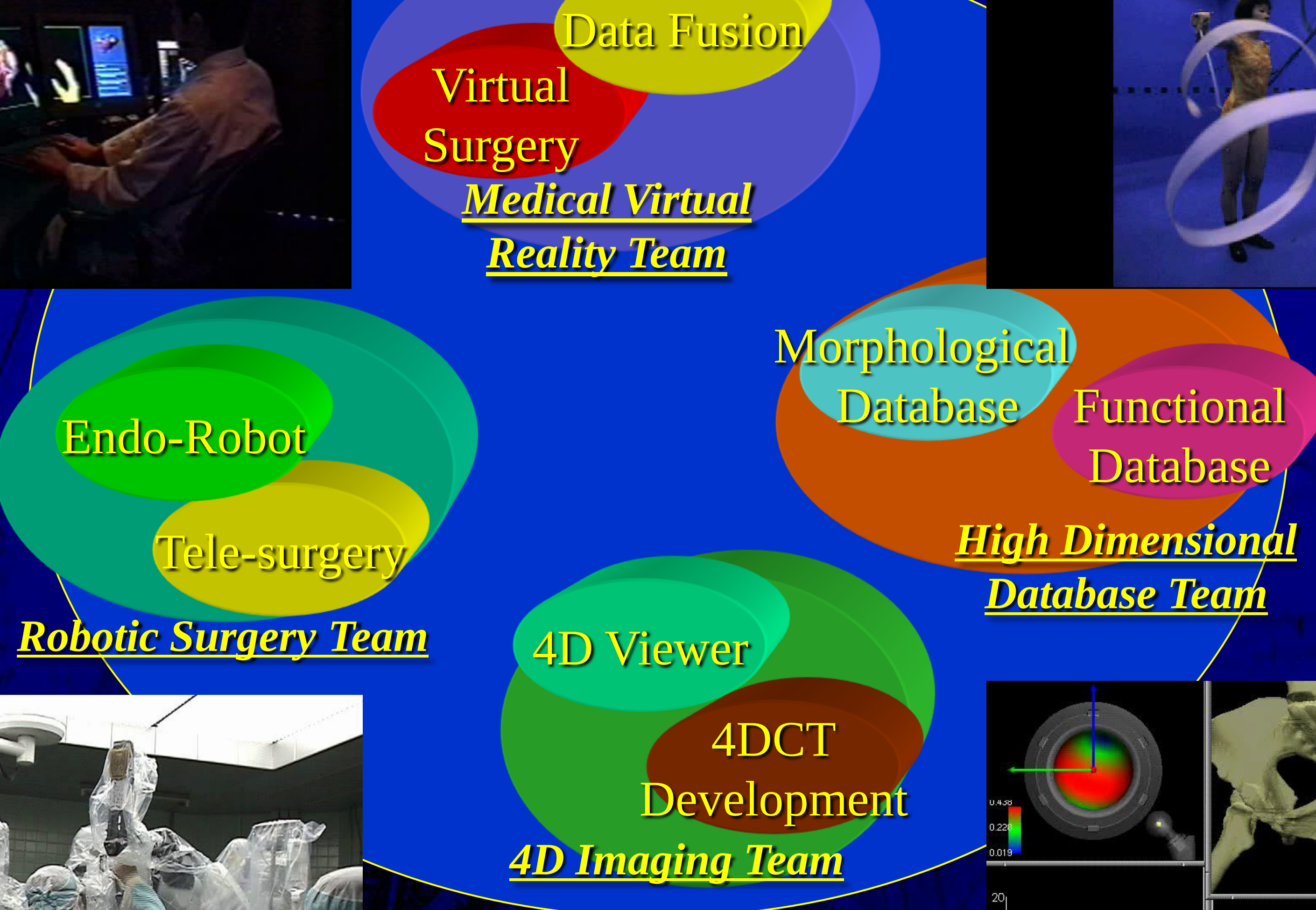

4D Motion Analysis Studio

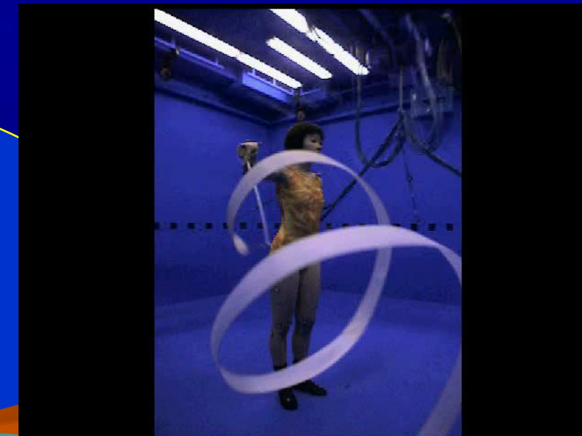

Medical Virtual Reality Laboratory




Hi-tech Navigation Operating Room

Institute for High Dimensional Medical Imaging
The Jikei University School of Medicine, Tokyo Japan



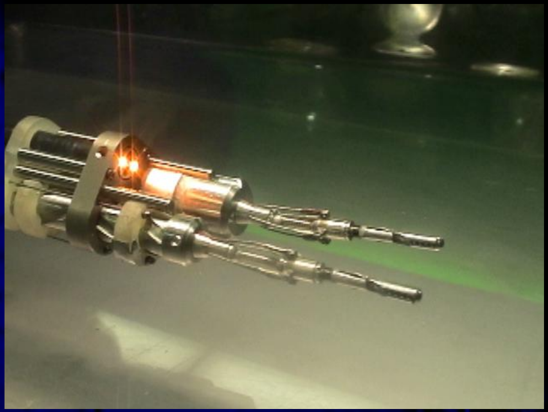


Institute for High Dimensional Medical Imaging

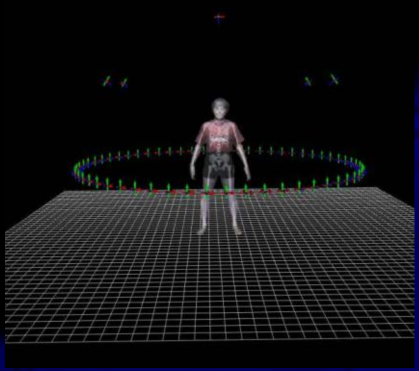
Virtual Surgery

Open surgery simulation with haptic sensation
Laparoscopic surgery simulation
Robotic surgery simulation

Overlay system for navigation surgery
High-tech navigation operating room
Image-guided surgery using AR



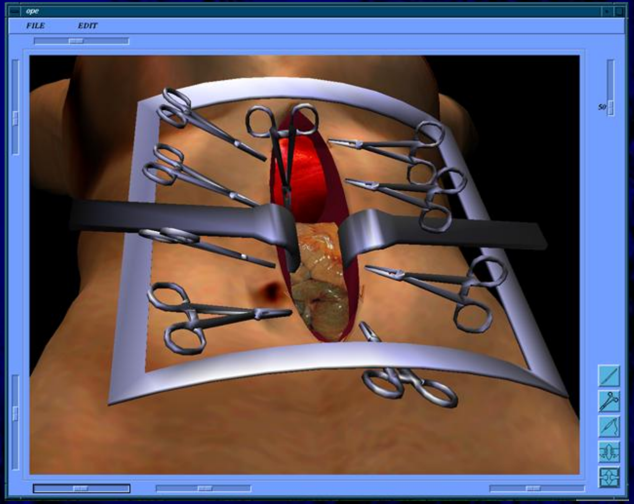
Endoscopic surgical robot
Robot arm with haptic sensation
Surgeon's console enhanced by VR

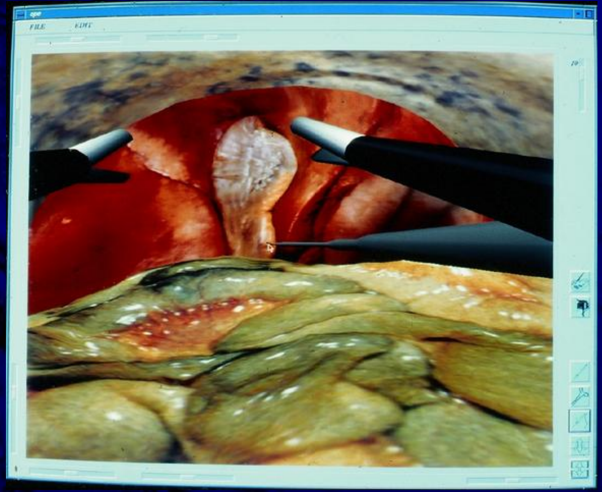


Visualization of whole body skeletal system
Time-spatial observation of human locomotion
Analysis of artificial joints

Characteristics of the virtual surgery system

1) The system should enable the user to design and determine surgical procedures based on 3D model reconstructed from the patient's data.
2) By using force feedback device, the system must transmit authentic tactile sensations to the user during organ manipulations.





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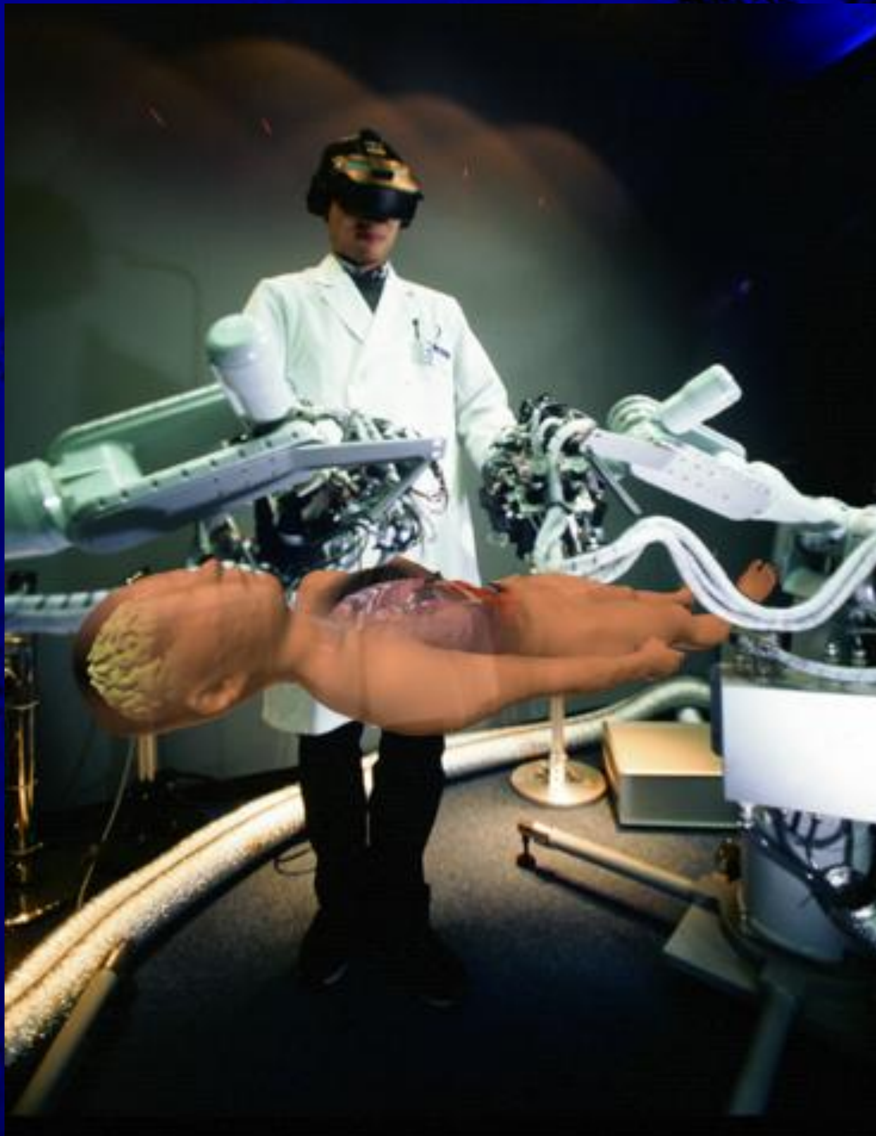

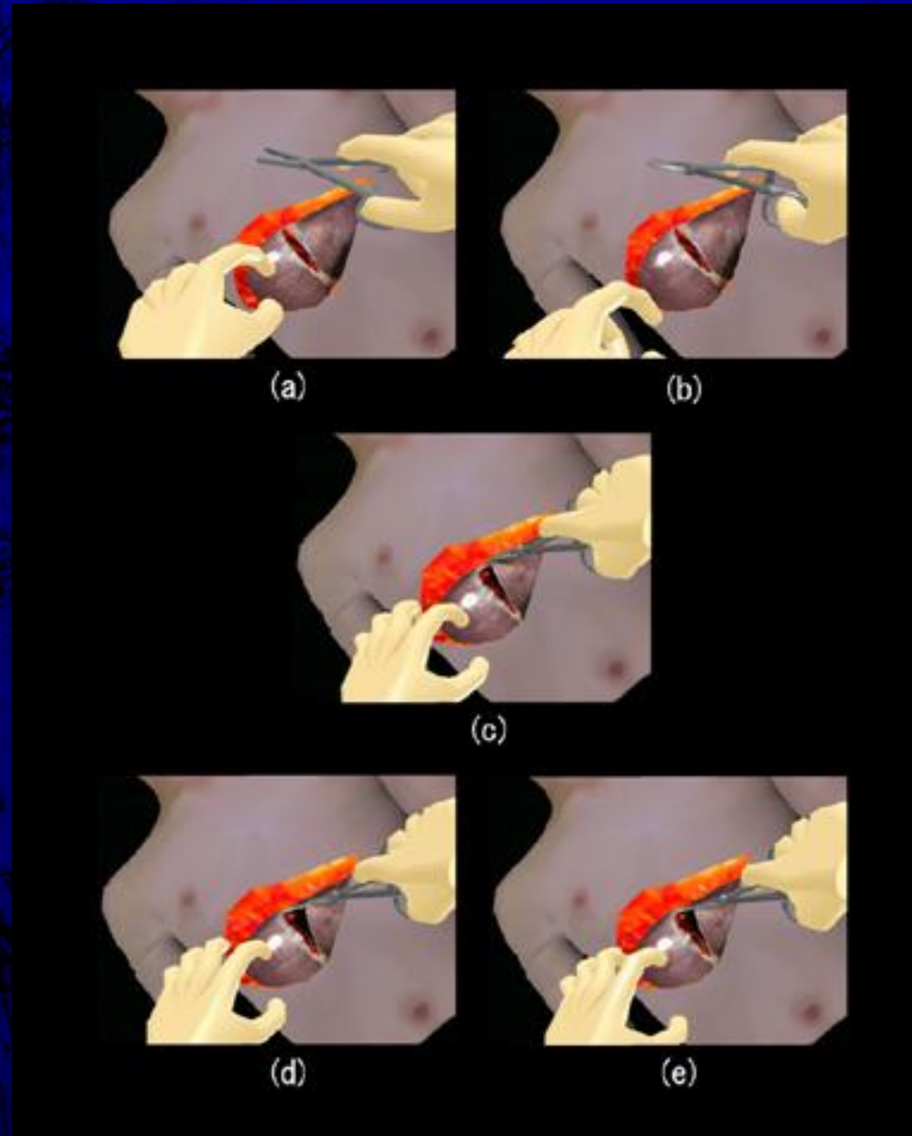

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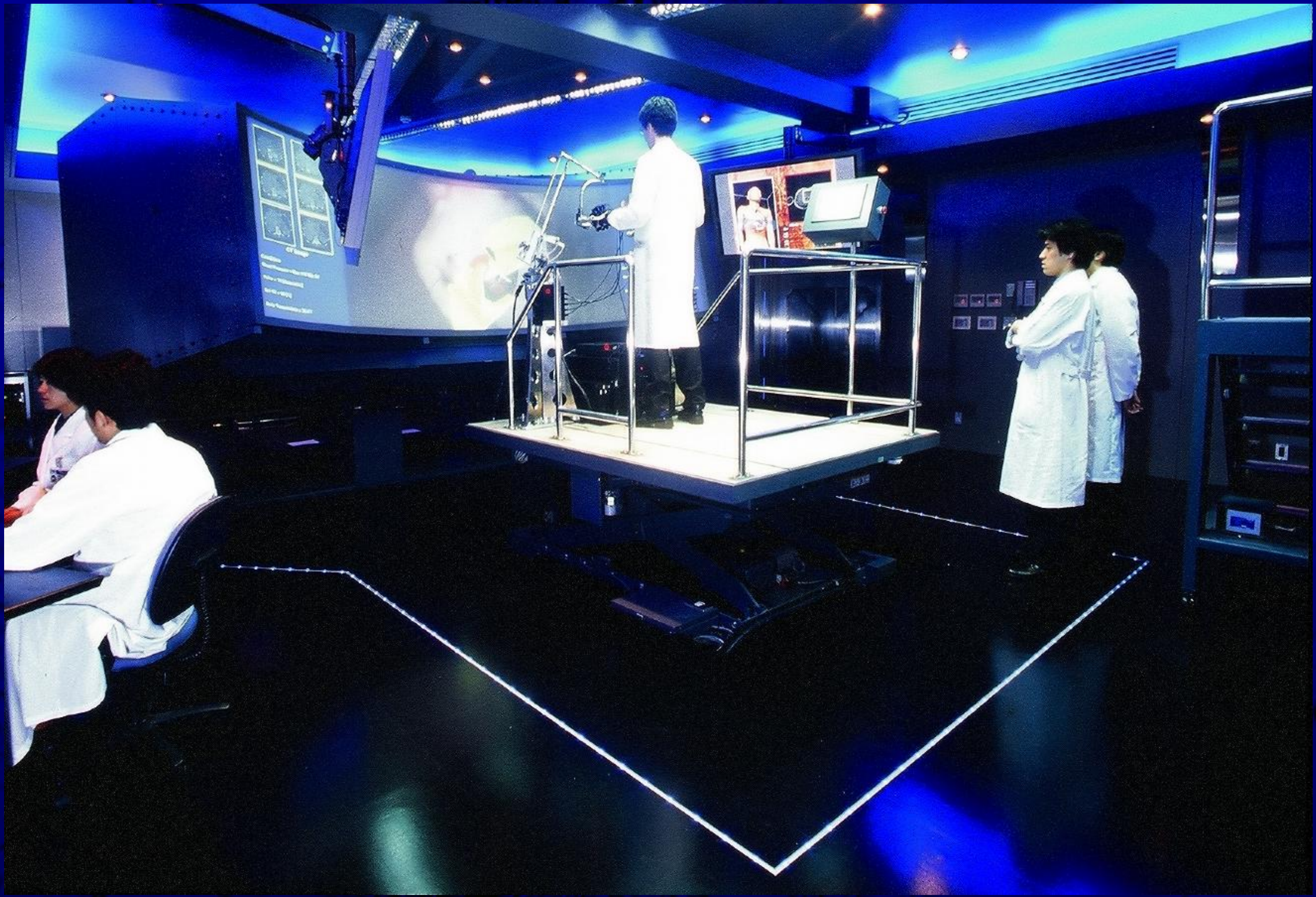
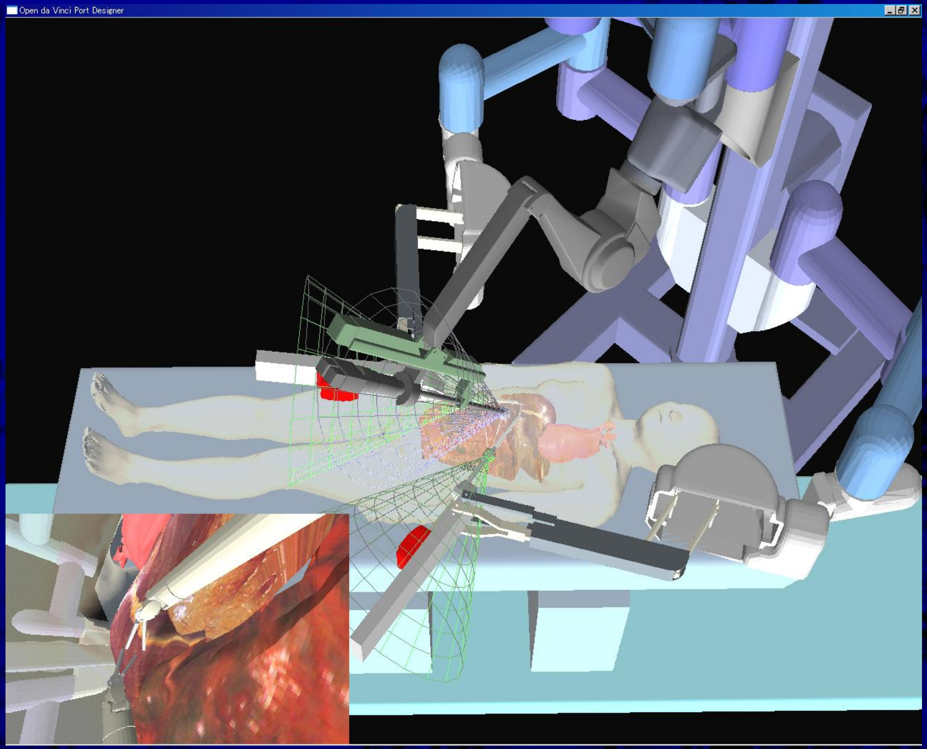
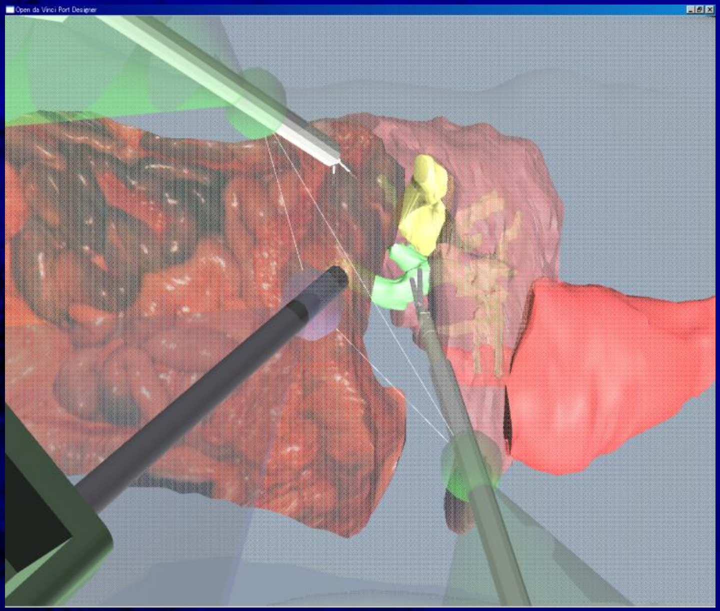


2002

Preoperative setup simulation for laparoscopic cholecystectomy



Surgical robot setup simulation for cholecystectomy

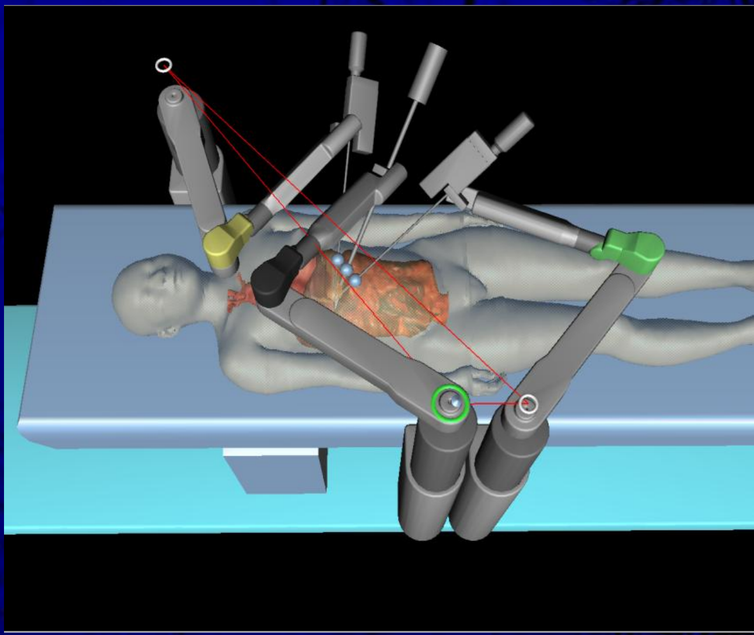


Results of setup simulation using patient data

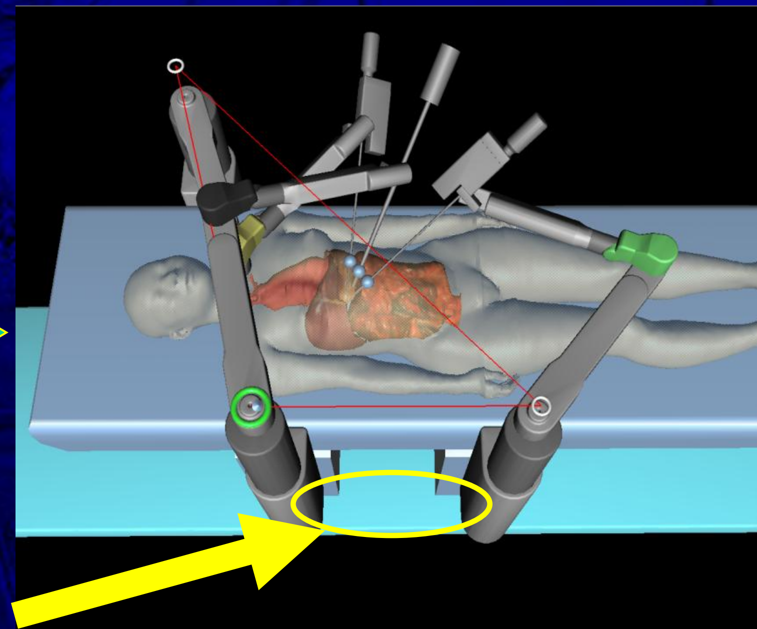
cholecystectomy setup with actual equipment

- Laparoscopic image is depicted in subwindow. Each arm's movable area, which depends on the fixed point, is shown for the operator.
- MRCP images of the patient who was actually operated on by da Vinci were segmented and processed in this system for clinical evaluation.
- Triangle shows the positional relationship of two forceps port and a camera port. We could confirm the feasibility of surgical robot setup simulation with clinical patient data.

Intuitive Interface to edit the robot base position to make space for surgical assistant



Slide base position of centered robot keeping the trocar sites.



Space for surgical assistant

Conclusion

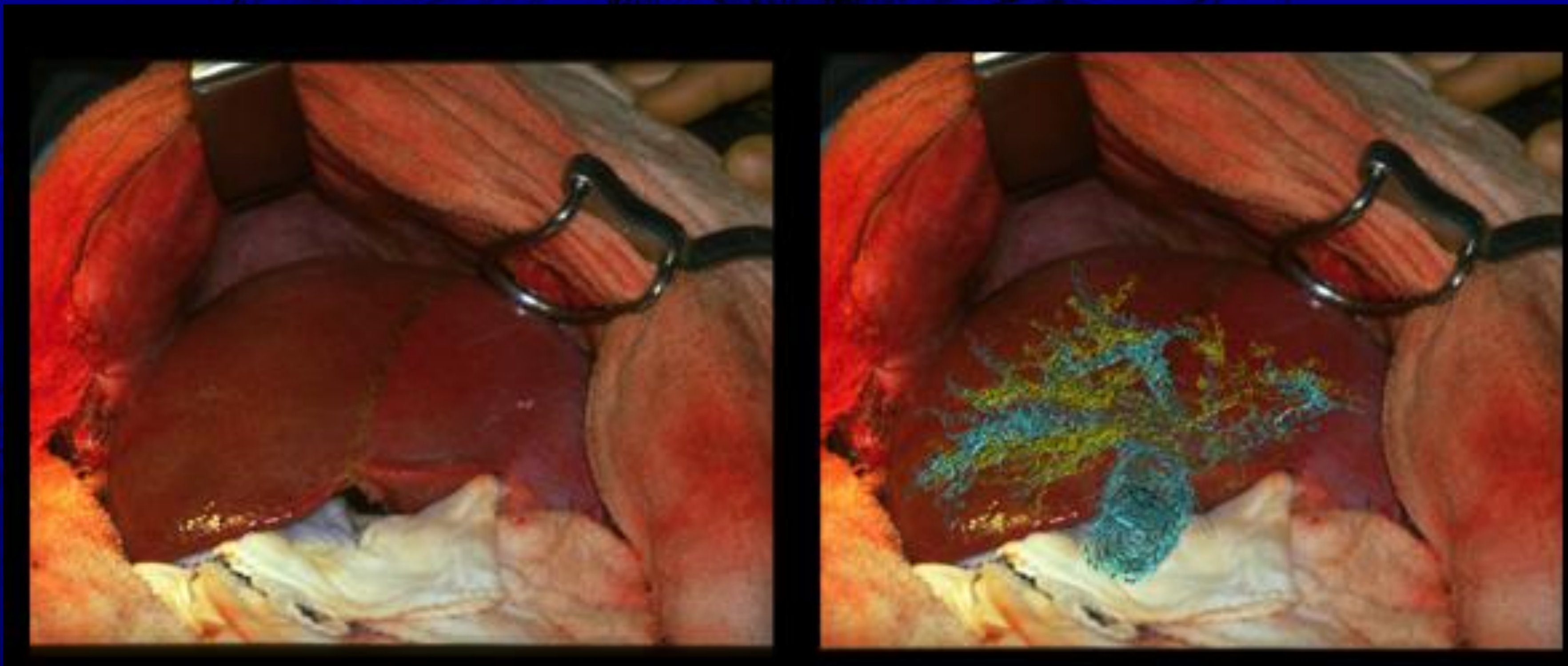
- A surgical robot setup simulation system for abdominal surgery has been developed. The motion of the surgical robot could be simulated and rehearsed preoperatively with the kinematic constraints at the trocar site, and the inverse-kinematics of the surgical robot.

- Being integrated with a haptic interface, surgeons could push and drag the arms of the virtual surgical robot in a manner that has consistent kinematics with the real robot.
- Simulation experiments using clinical patient data verified the functionality and showed the performance.

Basic research of this Project 1

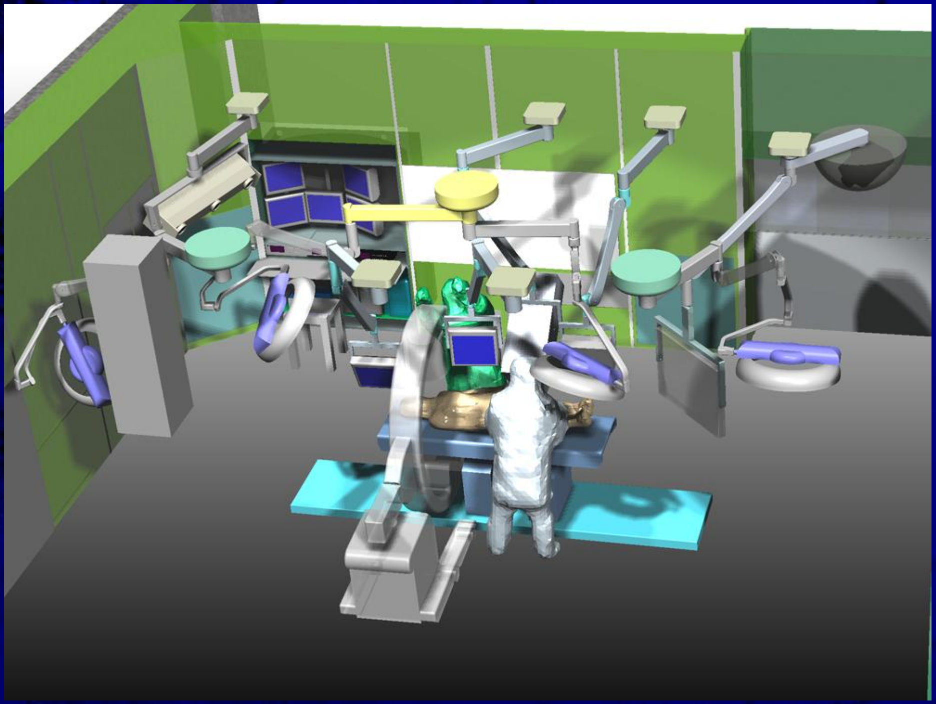
Development of AR Navigation method

Augmented Navigation Surgery



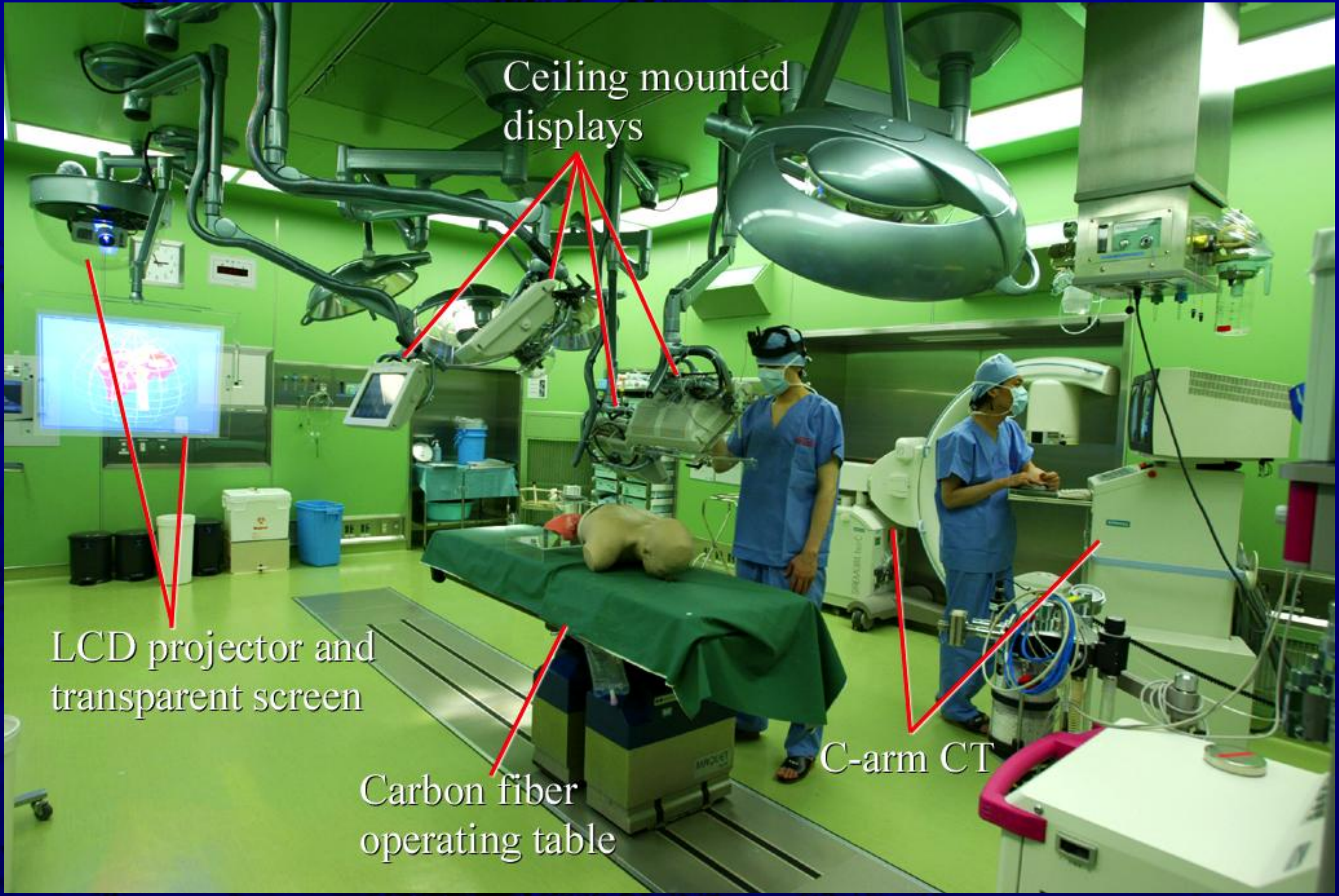
Equipments in the operating room

- C-arm CT
- Operating table made of carbon fiber material
- Ceiling-mounted displays
- Optical 3D location sensor
- Image processing computers
- LCD projector with a transparent screen

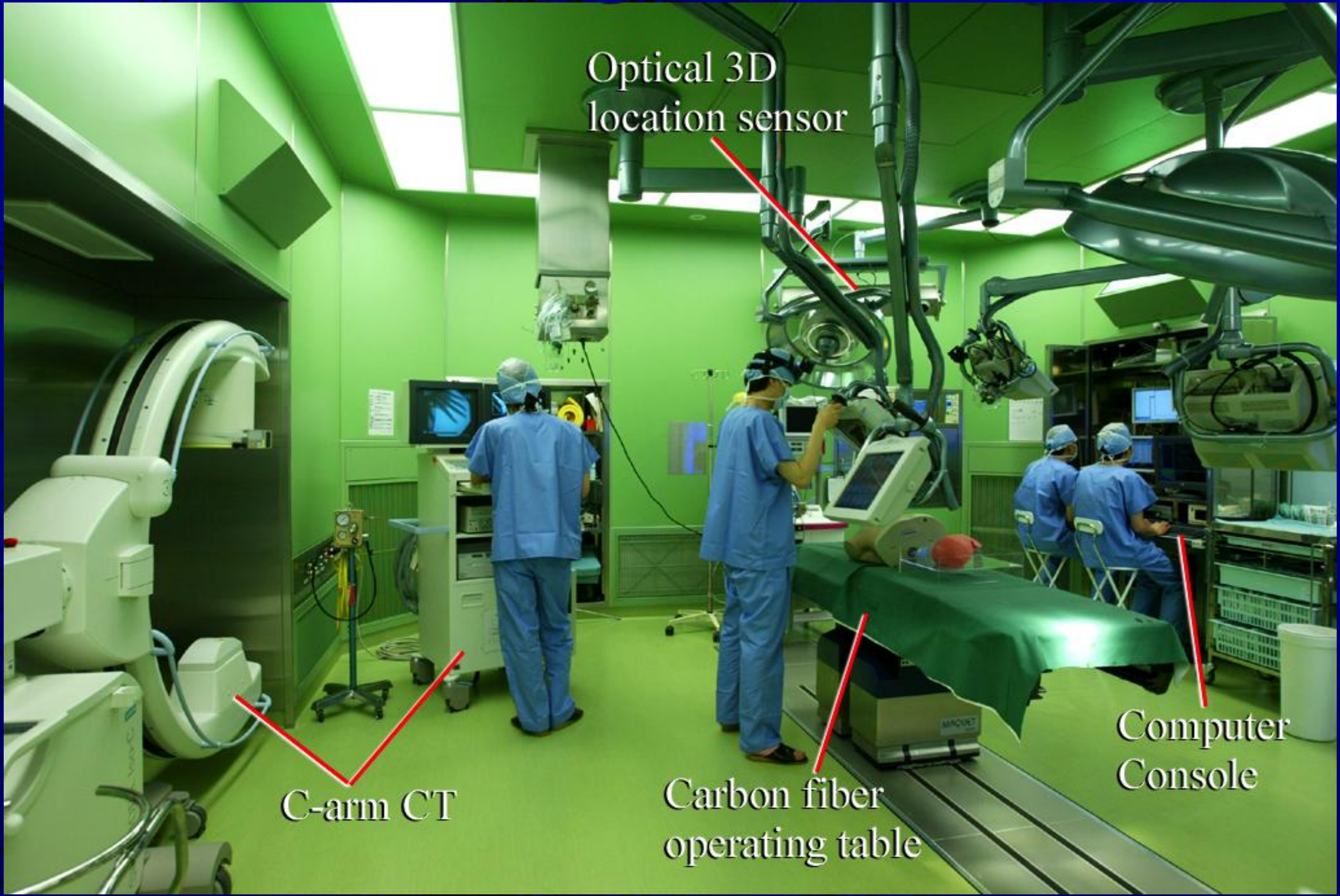


Operating Room No.9

The operating room has been connected to our institute by an optical fiber network to utilize our visual super computer.

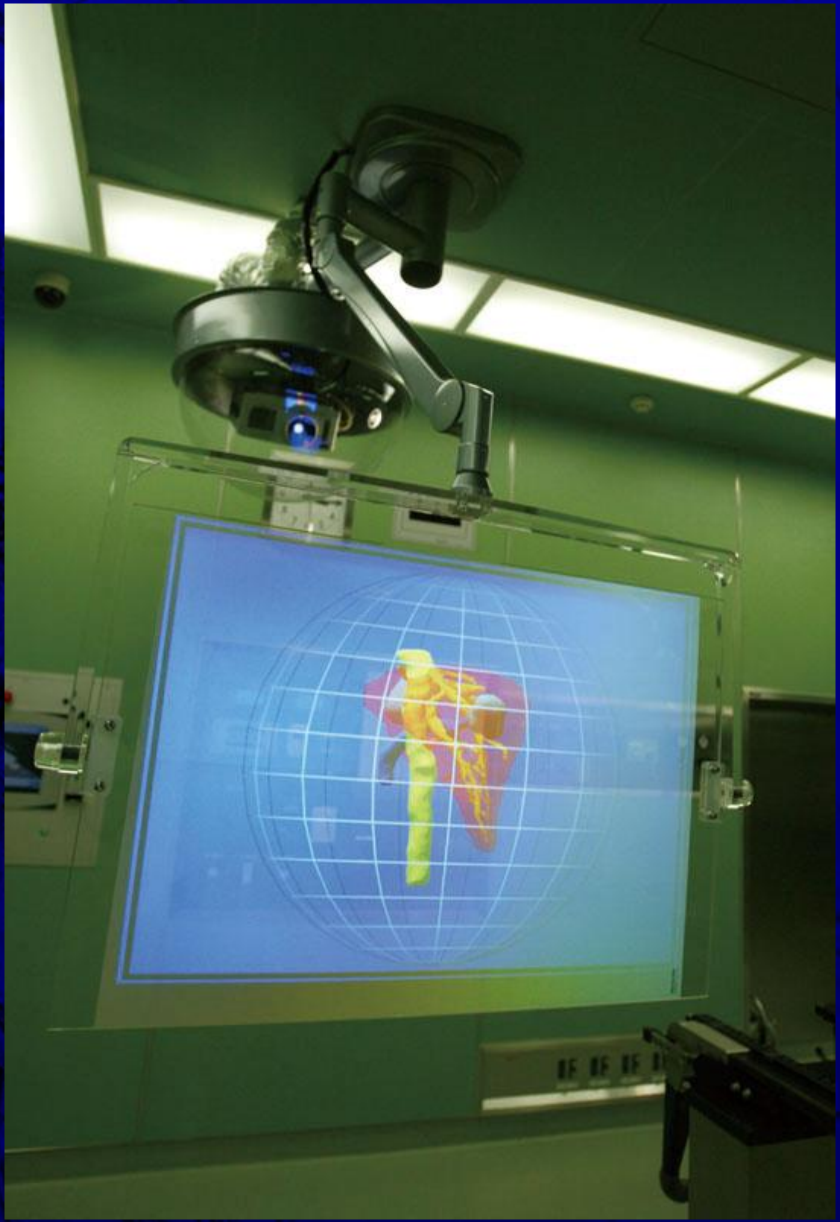


Overview of the high-tech operating room



Overview of the high-tech operating room

Computer Console



The transparent hologram screen and the sealing formula LCD projector

We assumed that surgery, such as an endoscopic surgery, that needs the operator to look at a monitor will increase; so we used diffused green lighting that can have its brightness adjusted, instead of the usual operating room lighting, to aid the operators concentration.

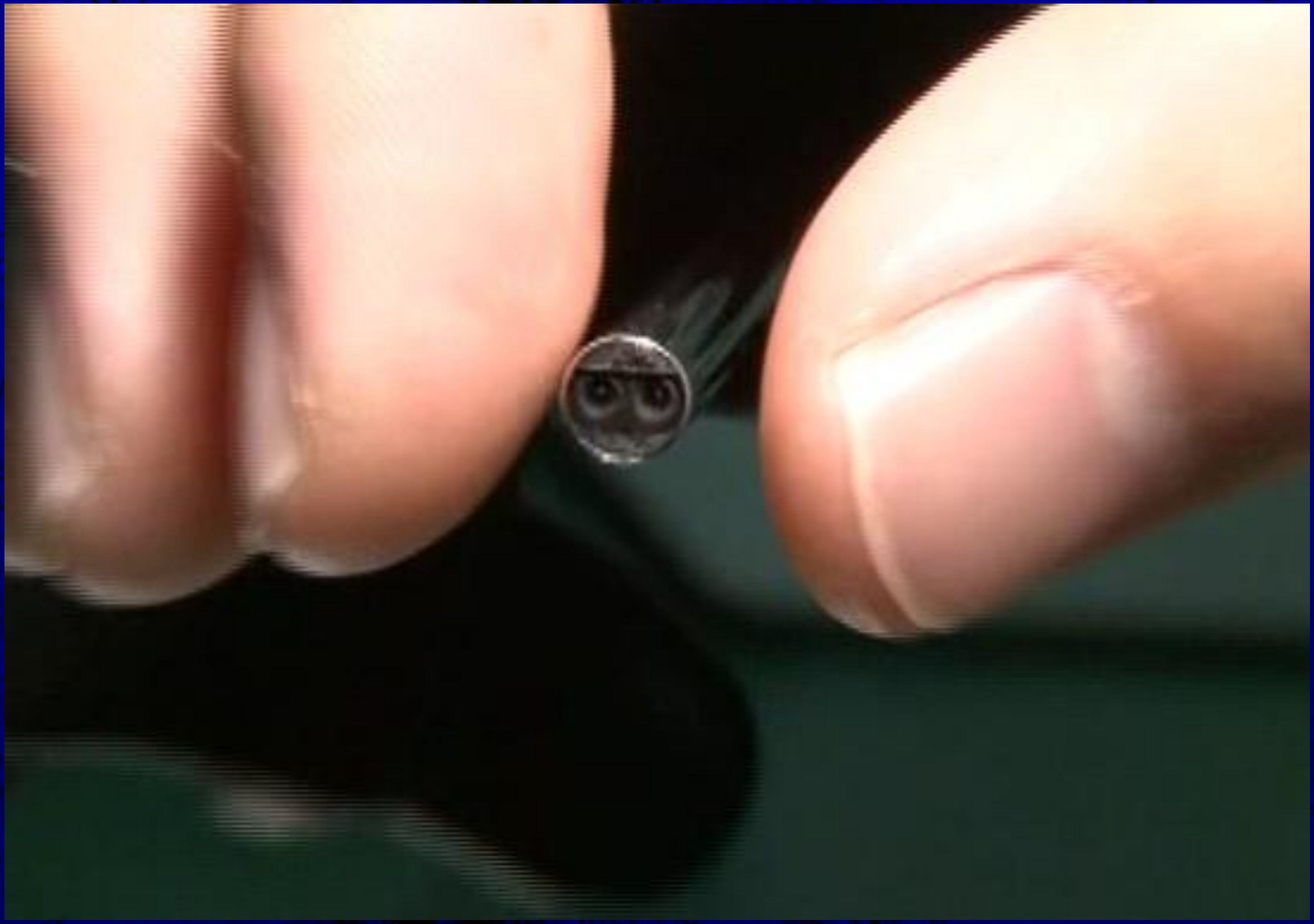
Image Display Systems for Image-guided Surgery

Video see-through type display

Image Display Systems for Image-guided Surgery

Optical see-through type display

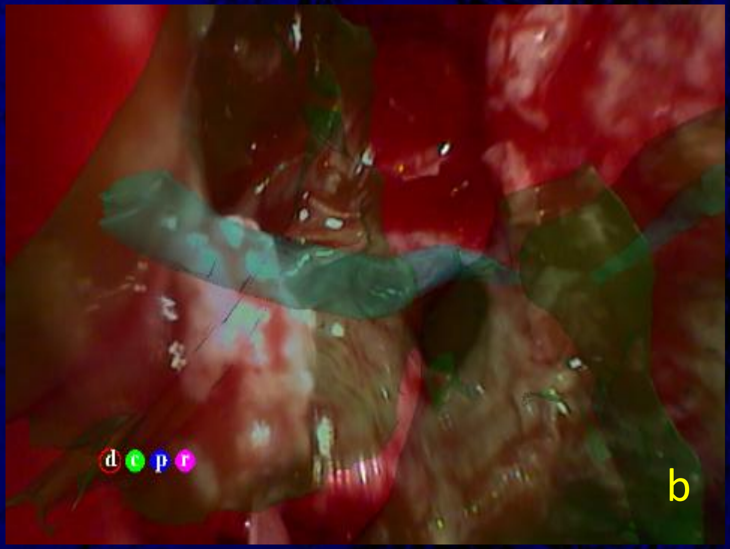
Application for Otorhinolaryngology

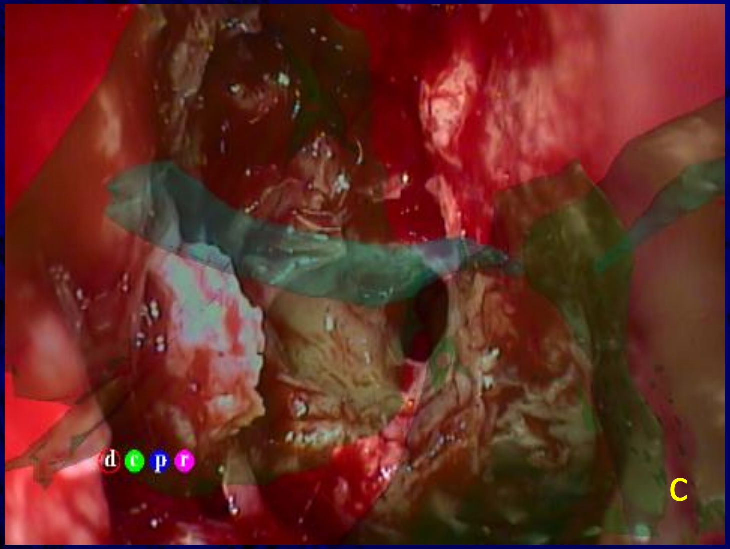


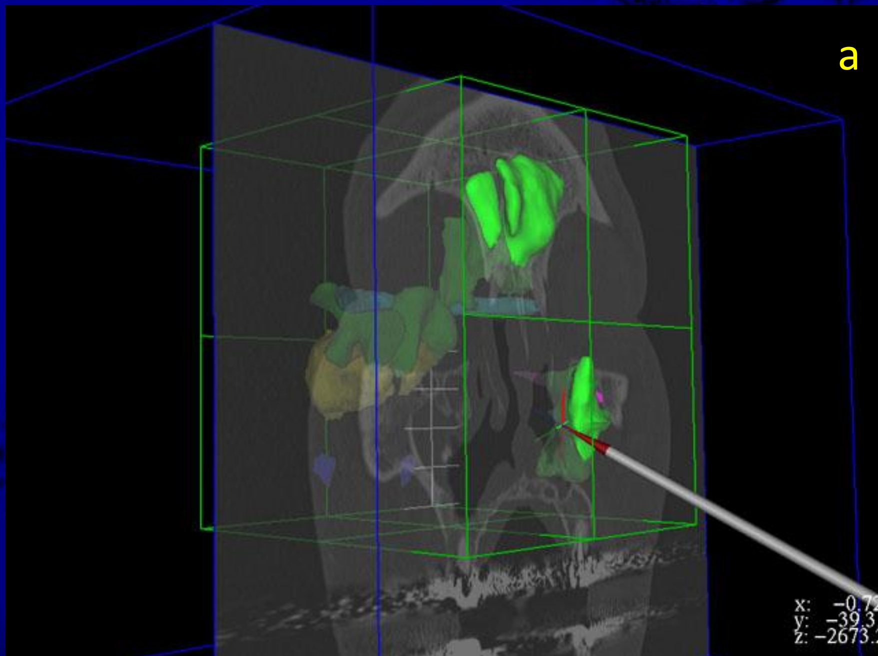
Experiment of Navigation Function for Stereo-Endoscopic Sinus Surgery

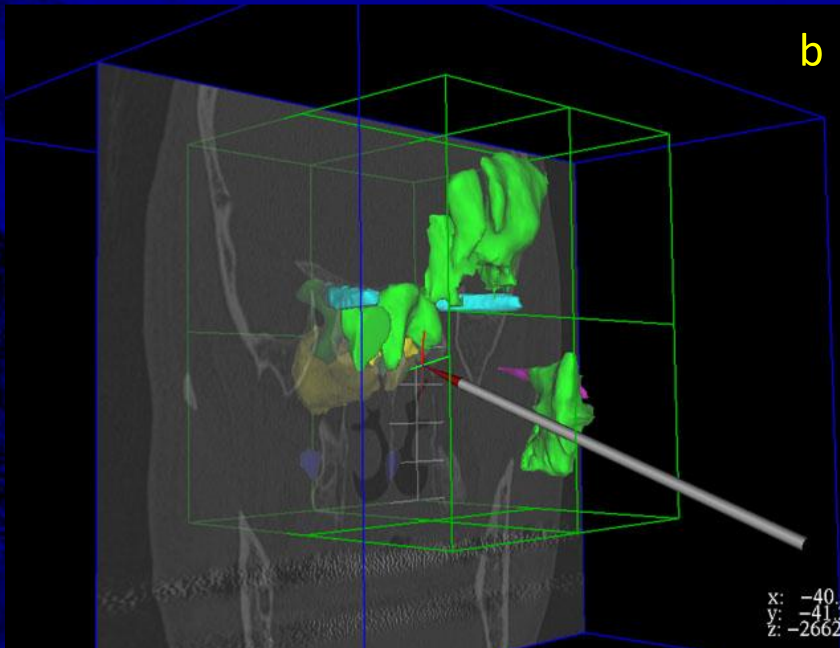
Stereo-endoscope based navigation

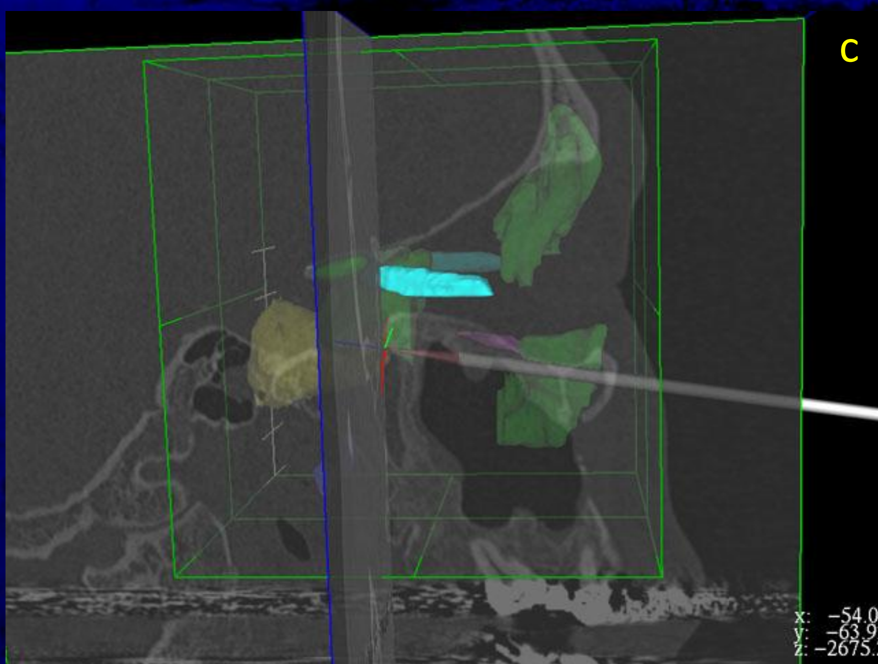
Superimposed images on the GWS display (a); the patient's organ models are superimposed onto the surgical field image; top window: the left eye view, bottom window: the right eye view. Figure b, c show left (b) and right (c) eye navigation images displayed on the stereoscopic monitor.











Pointer based navigation

The result of the pointer based navigation function. Figure a,b shows a coronal image at the location of the tip of pointer. According to the pointer's movement, the image is changed in the 3D virtual space. The 3D patient's models are also displayed. Figure c shows a sagittal image after changing view point.

Basic research of this Project 2

Development of acquisition and display of surgery information in robot surgery

Robotic Surgery Needs Augmented Reality

1) The surgeon has to control the surgical robot through a man-machine interface and can not see the operating field directly
2) The surgeon has to operate the surgical robot using this limited view compared with what is obtainable using the naked eye
3) The detailed condition of the operation field and also the accurate direction of view are sometimes lost during this kind of operation

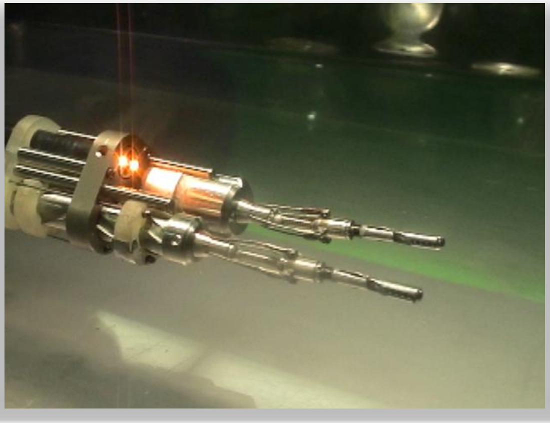
Left View
polaris
camera
target
read matrix ver.2.0 finished
read pers
read matrix
object op.
read object
rendering
matrix
k0
opaq 50%
matrix 1
k1
opaq 50%
matrix 2
ve
opaq 50%
matrix 3
nodisp
ave.
navi.
calib
frame rate = 9
Right View
read pers
calib
Utilities
Digital In 1
Digital Out 1
CCIR-601 525
Internal
Genlock Input
Off
CCIR-601 525
CCIR-601 525
calib matrix
matrix 2
reset
done
Manual Page
Trash
sgi

2003

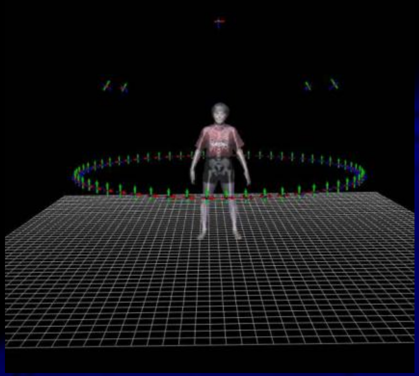
Open surgery simulation with haptic sensation
Laparoscopic surgery simulation
Robotic surgery simulation

Overlay system for navigation surgery
High-tech navigation operating room
Image-guided surgery using AR

Endoscopic Surgical Robot and Tele-surgery

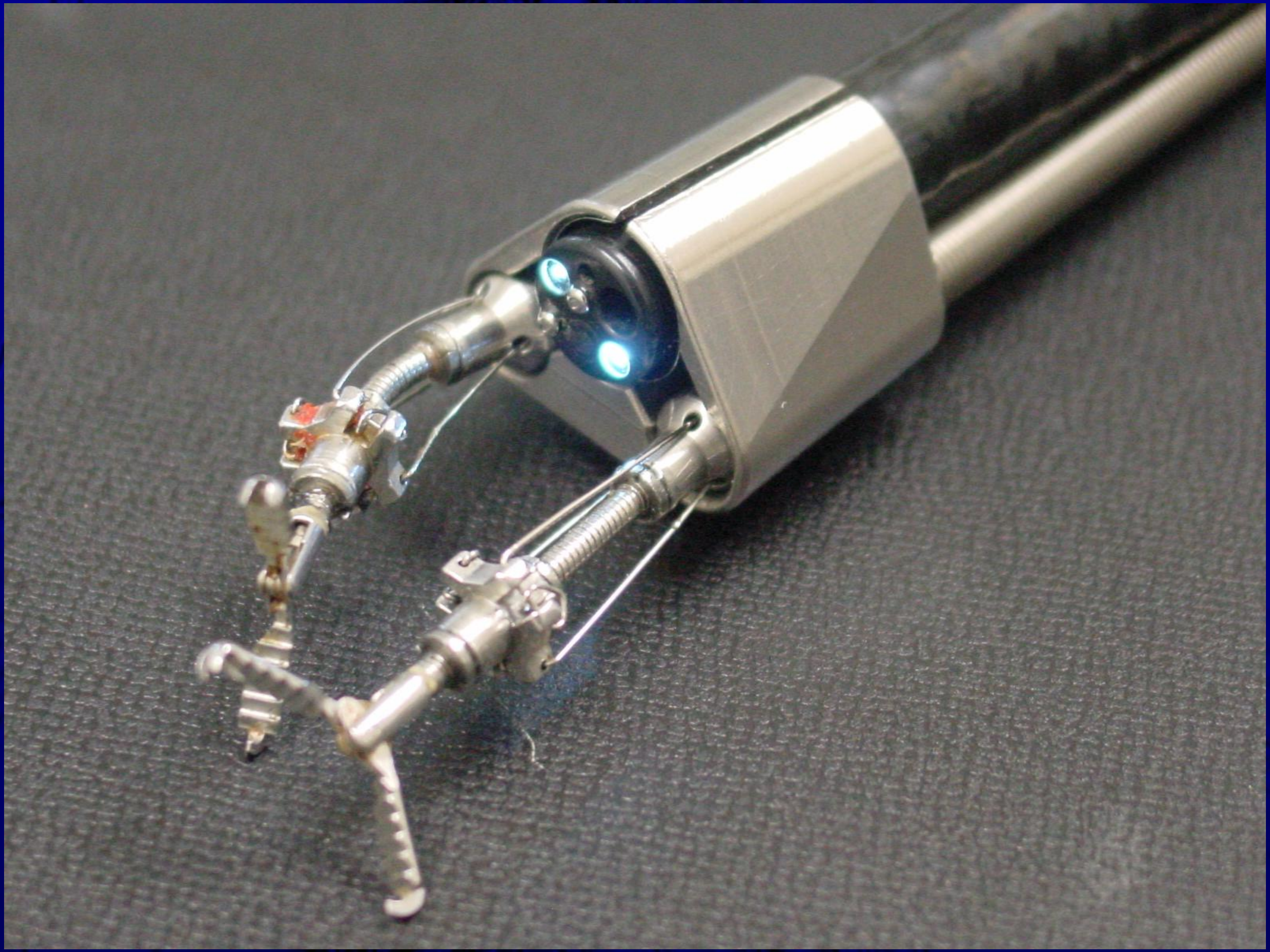


Endoscopic surgical robot
Robot arm with haptic sensation
Surgeon's console enhanced by VR

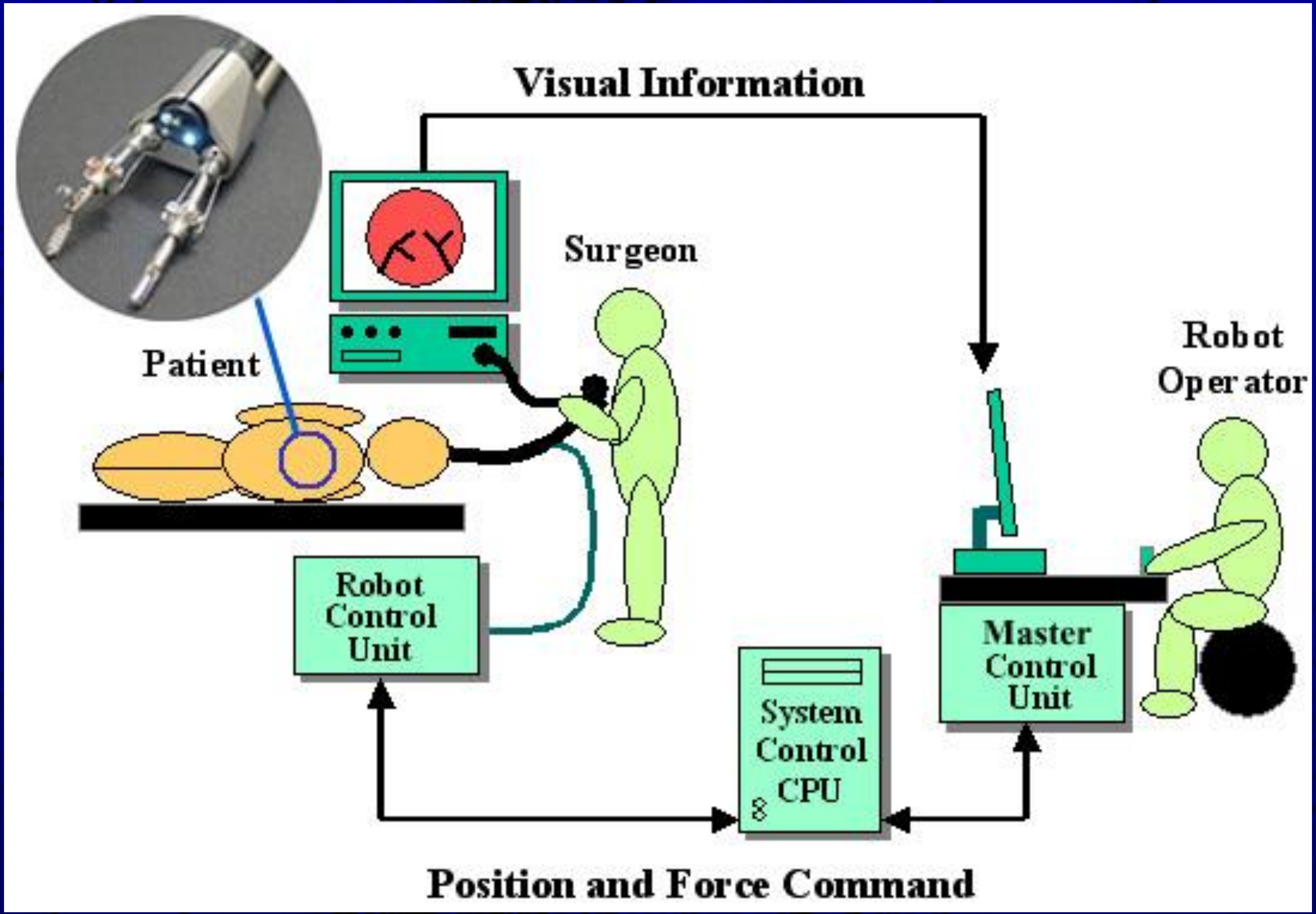


Visualization of whole body skeletal system
Time-spatial observation of human locomotion
Analysis of artificial joints

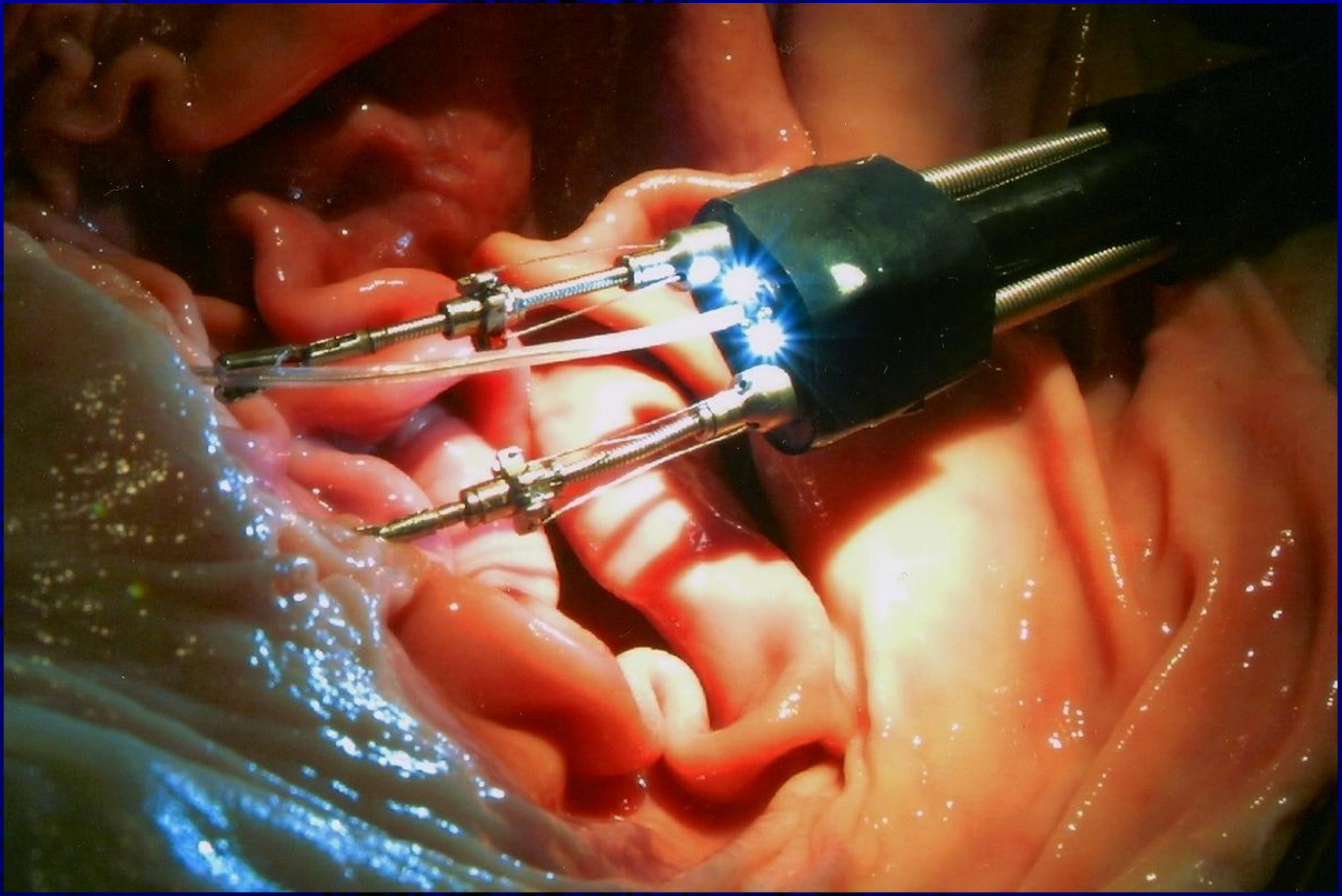
Development of an Endoscopic Robot Surgery System with Navigation Function



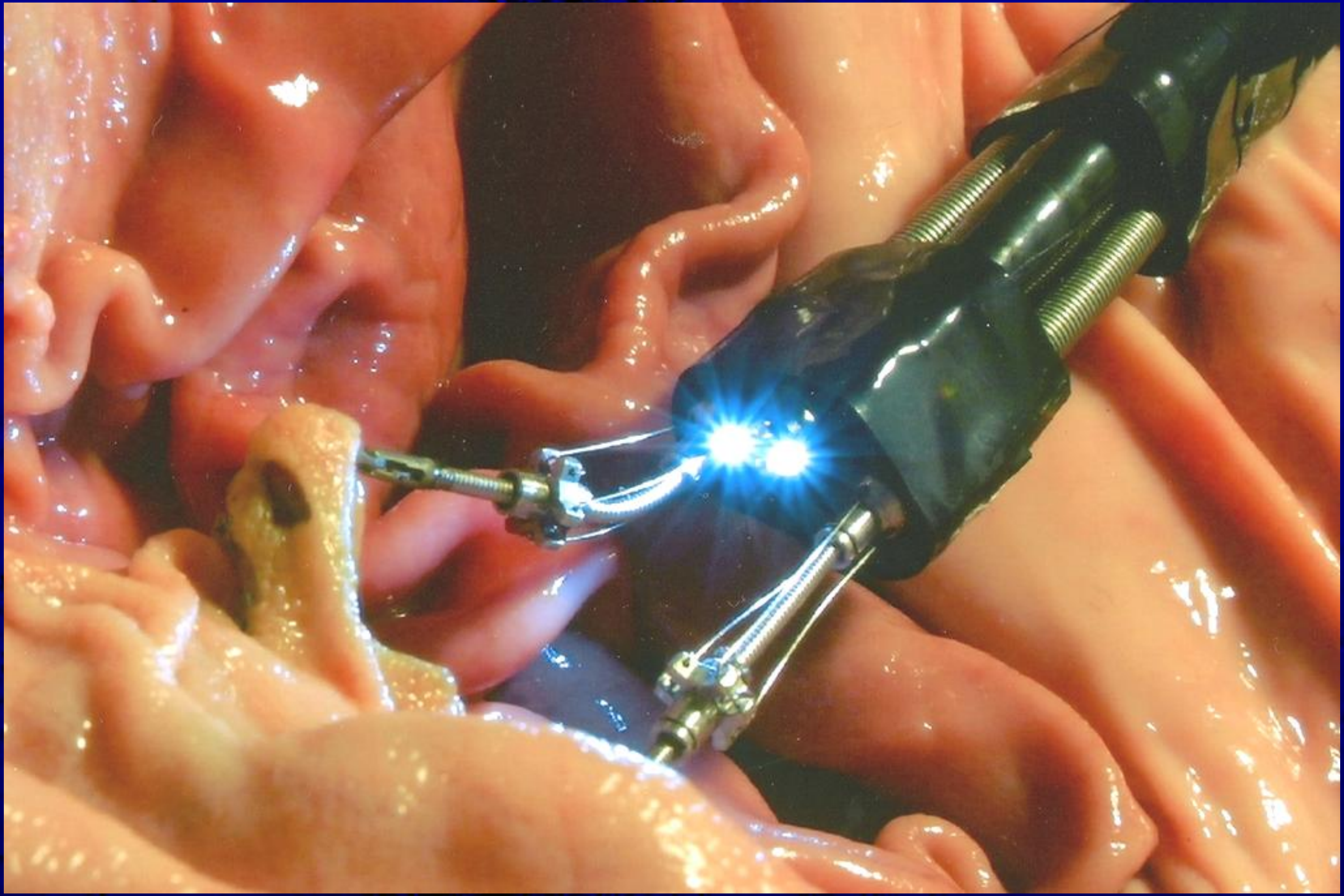
An appearance of the endoscopic robot



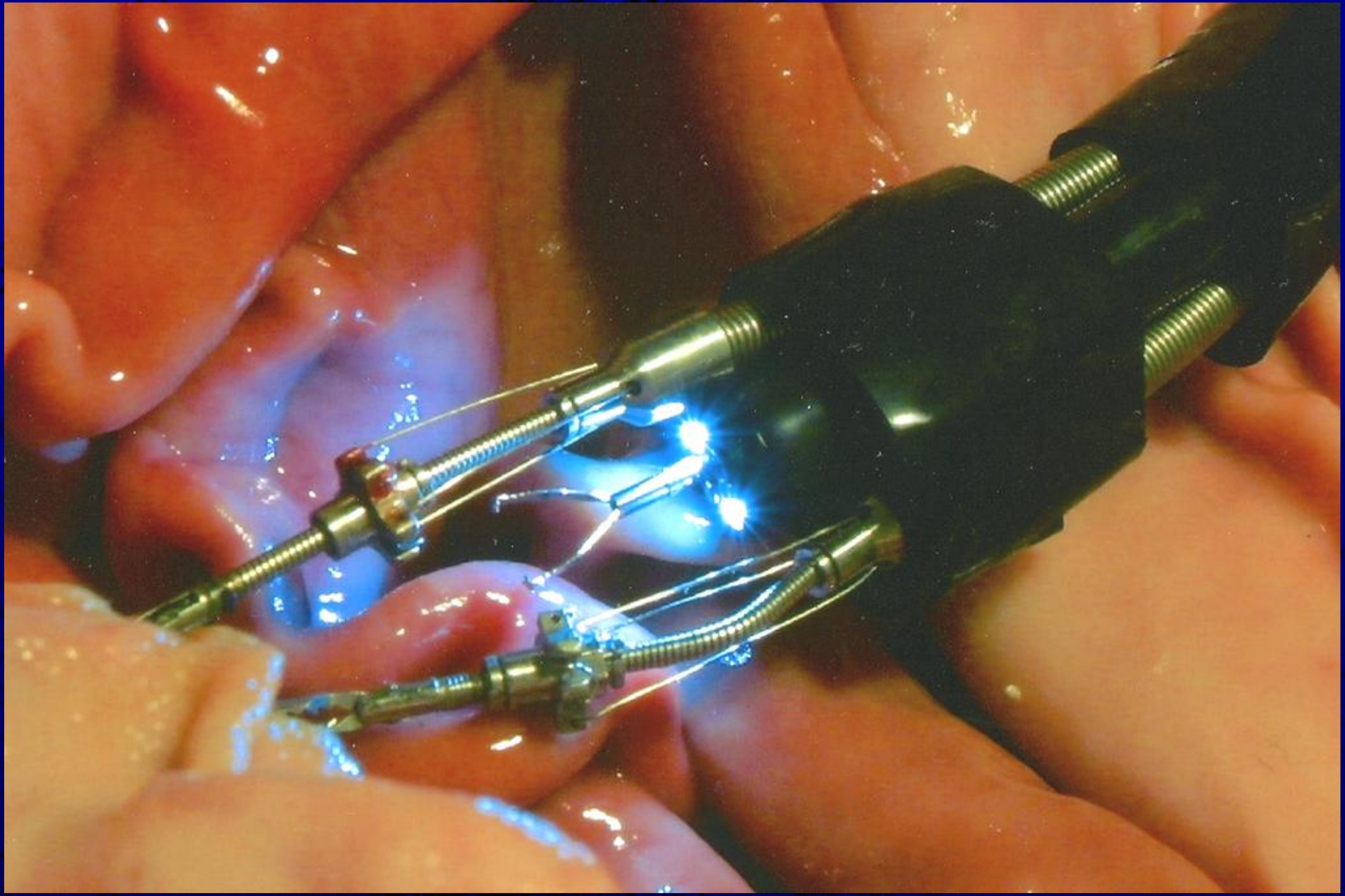
Scheme of the Master-Slave System of Endoscopic Robot



The right side manipulator hold the diathemic needle knife which takes out from the instrument channel to incise the mucosal layer



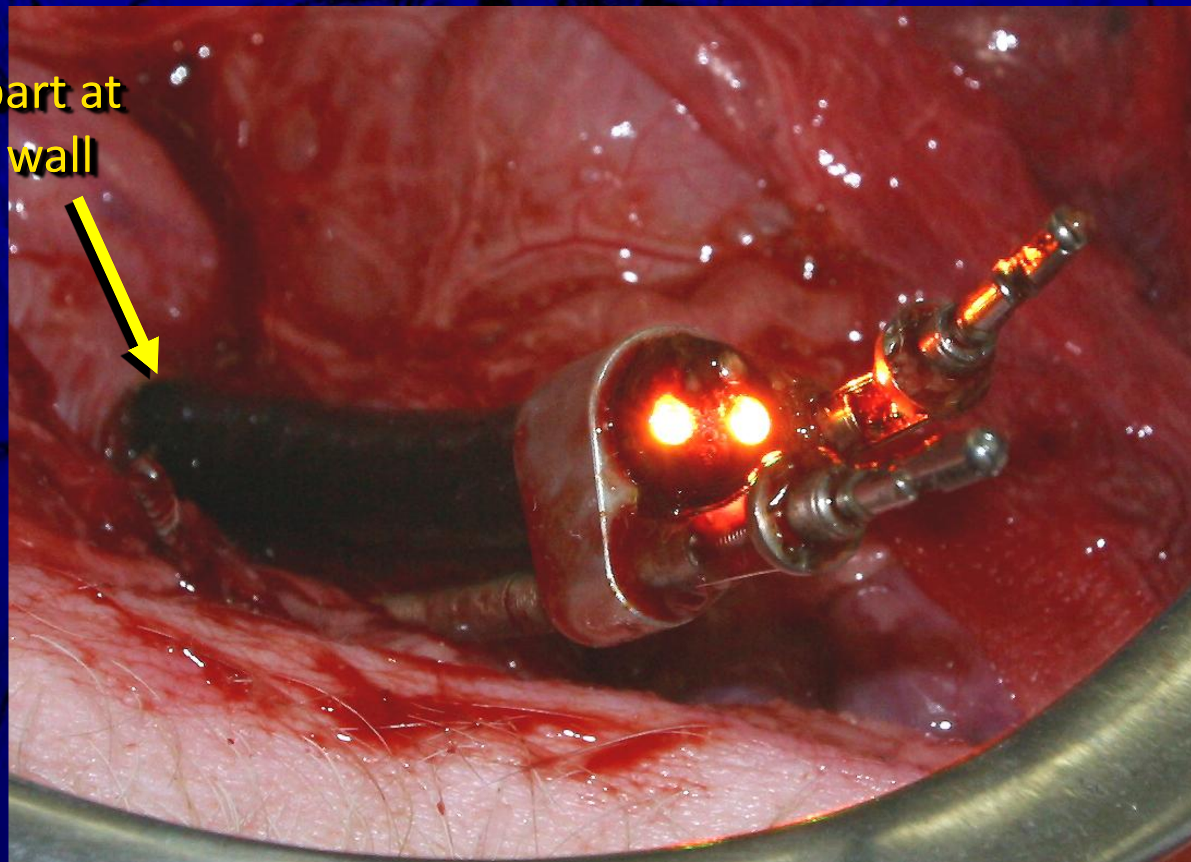
The manipulator has enough power to lift the incised wall tissue



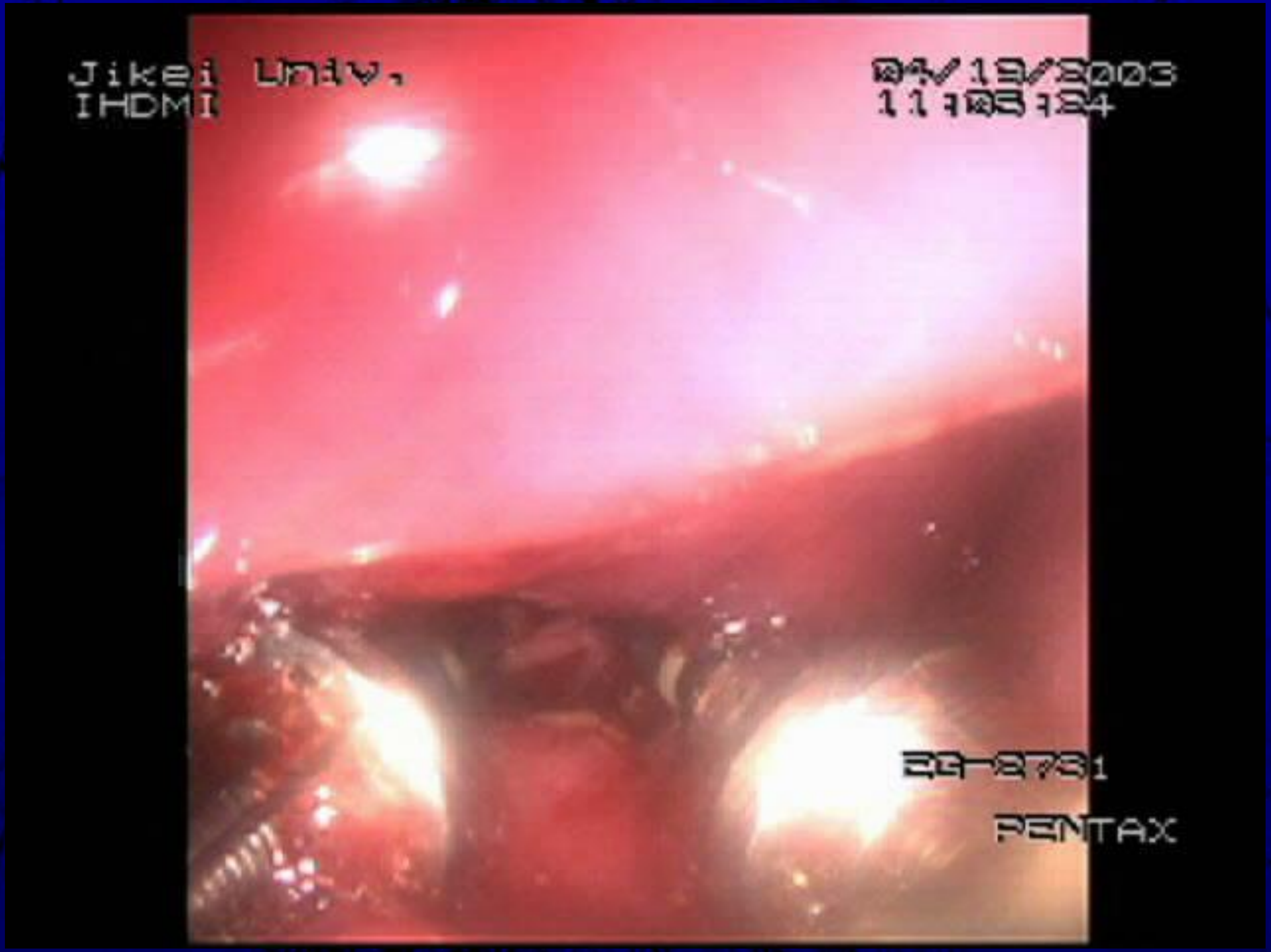
The scene the surgeon try to close the incised part using clips


09/14/2002
11:48:02
IHDMI
Jikei Univ
Comment
[004]
PENTAX

Surgical protocols for organs in the abdominal cavity by penetrating stomach wall



Scene of the endoscopic robot penetrating the stomach wall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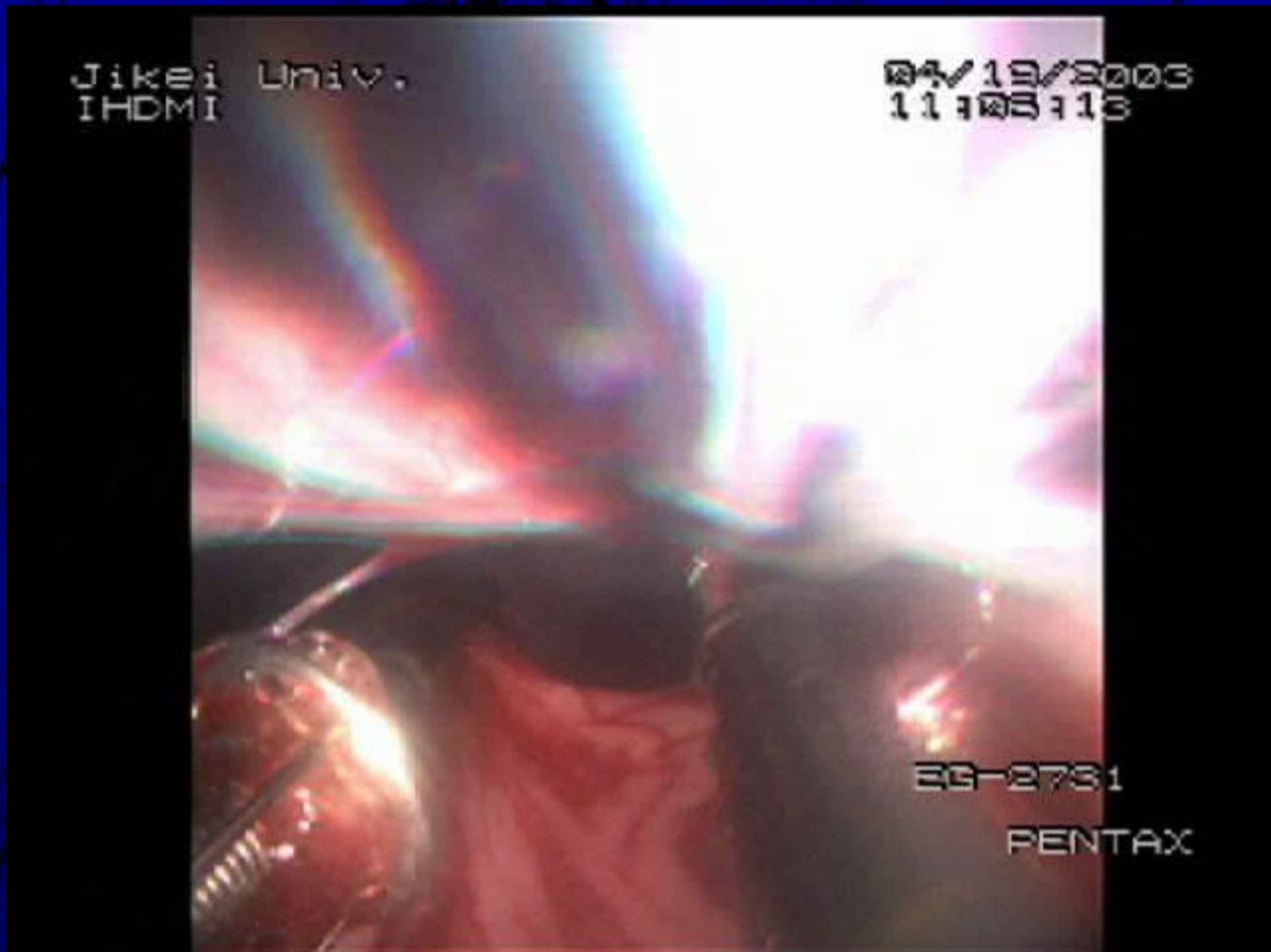

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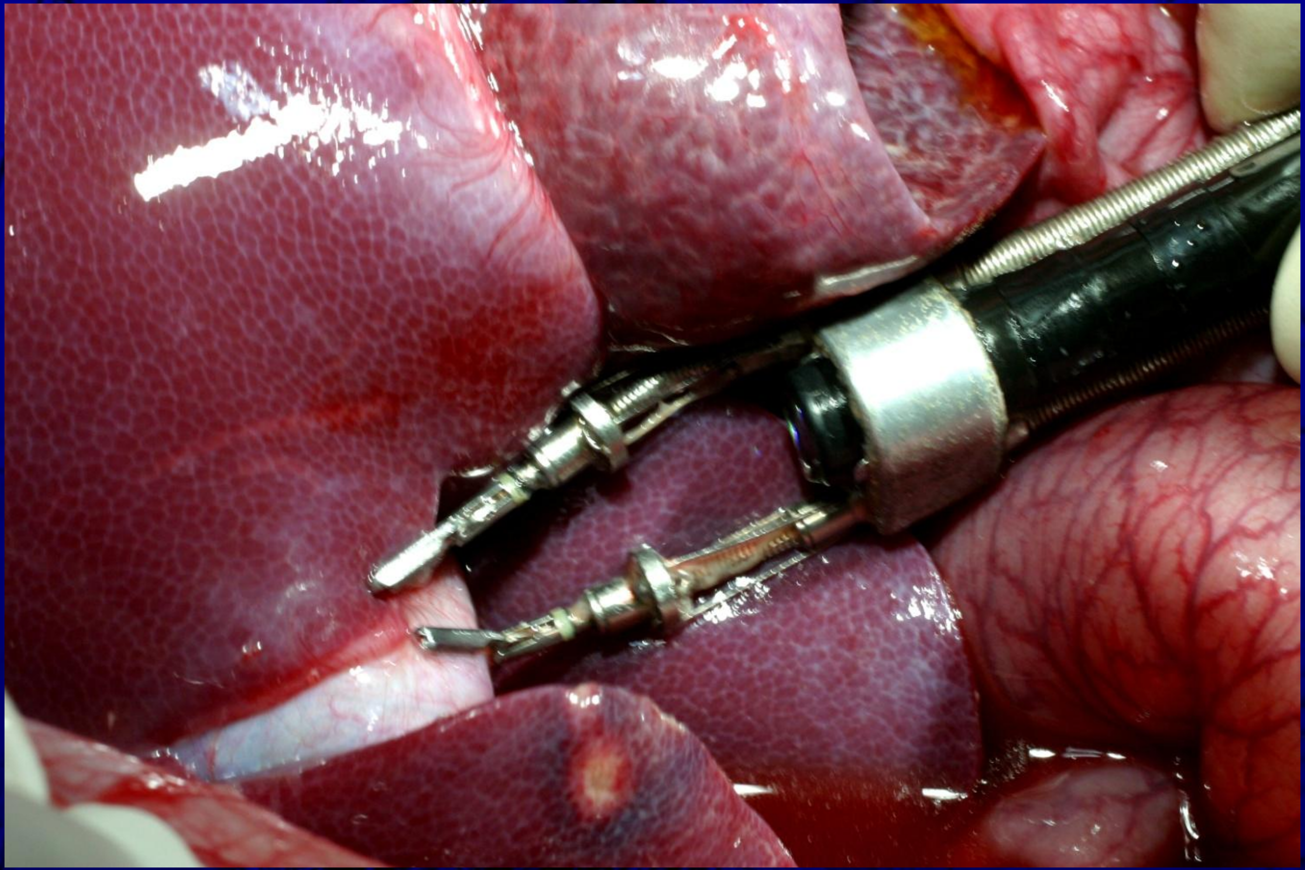

Handling of gallbladder by the endoscopic robot


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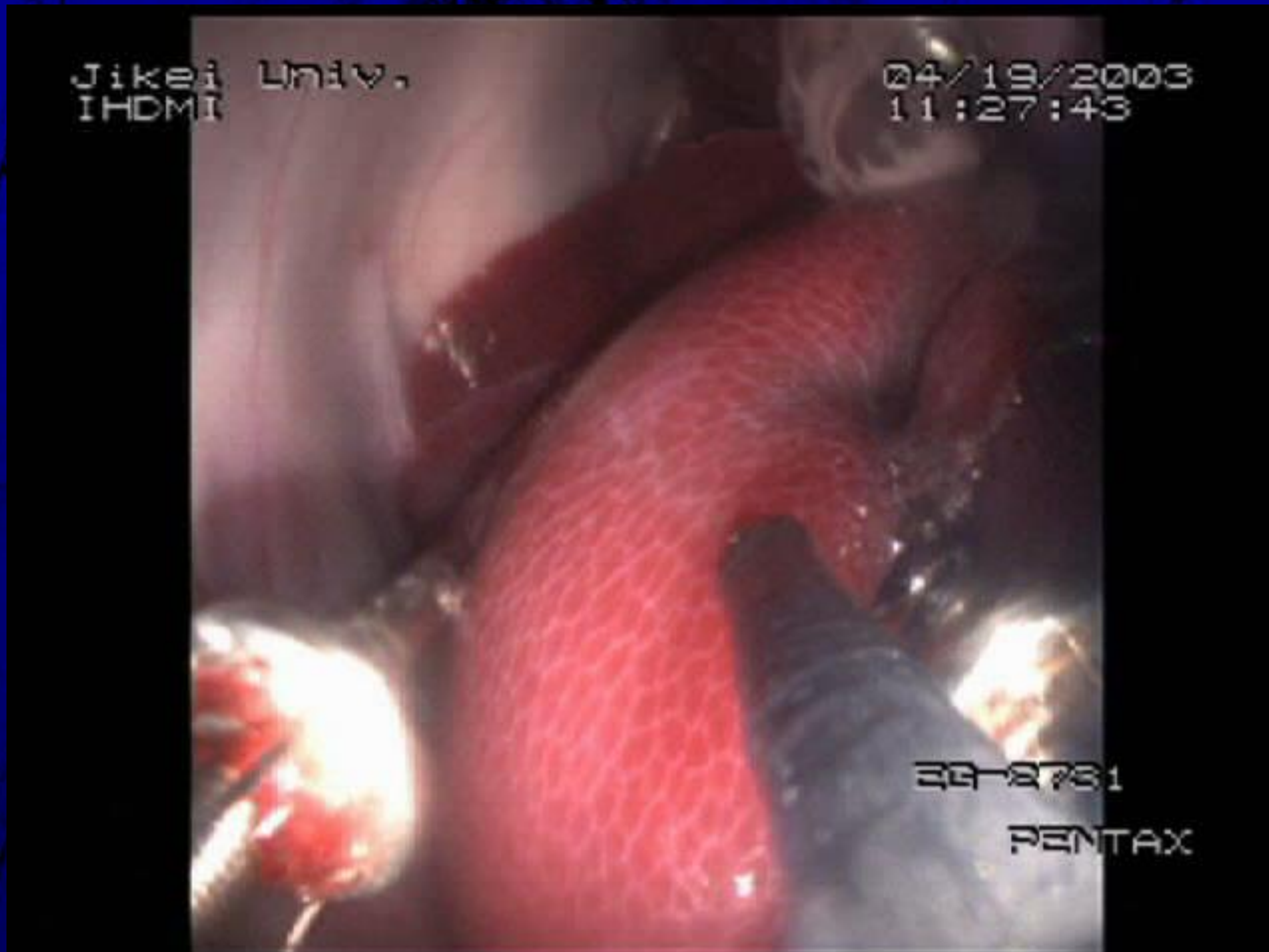
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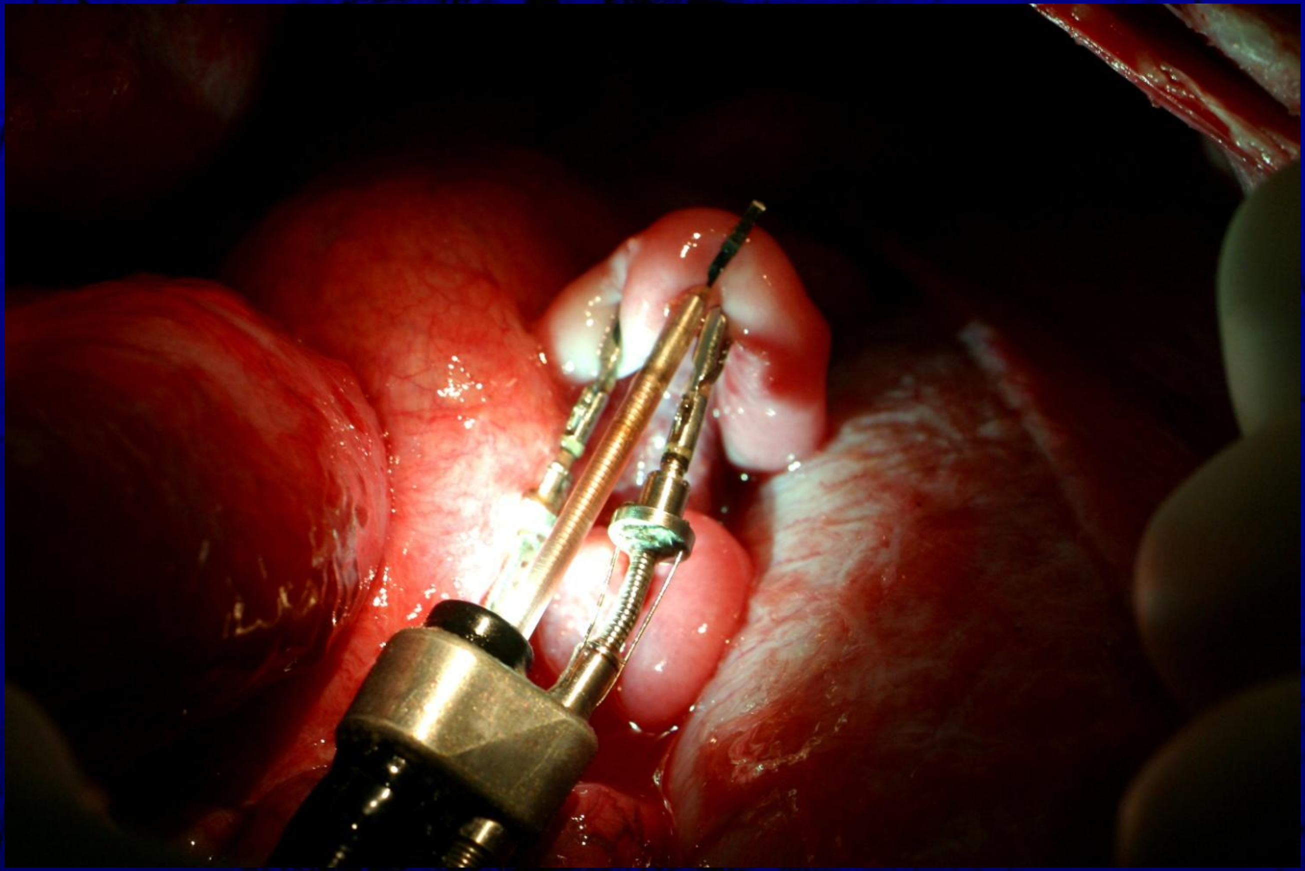

Scene when the endoscopic robot is clipping the oviduct


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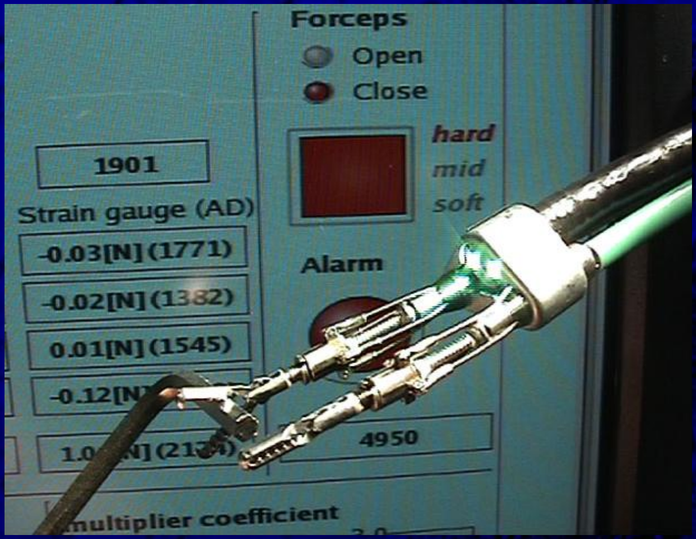
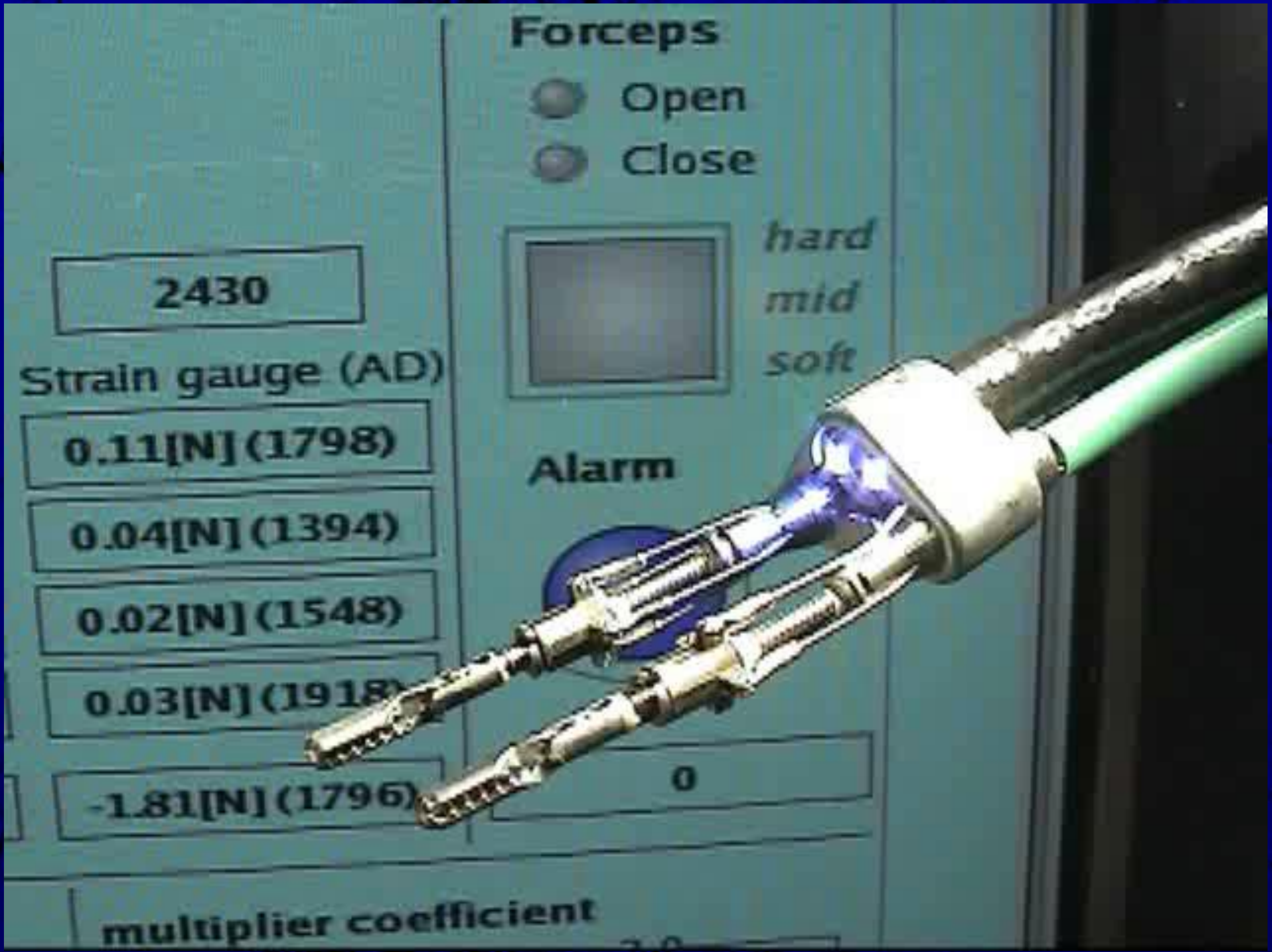
Development of Haptic Sensation for Robot Arm in Small Scale

The tip of the endoscopic robot (two arm type)



Result of haptics monitor function (left: grasping metal, right: grasping sponge)


Forceps
Open
Close
hard
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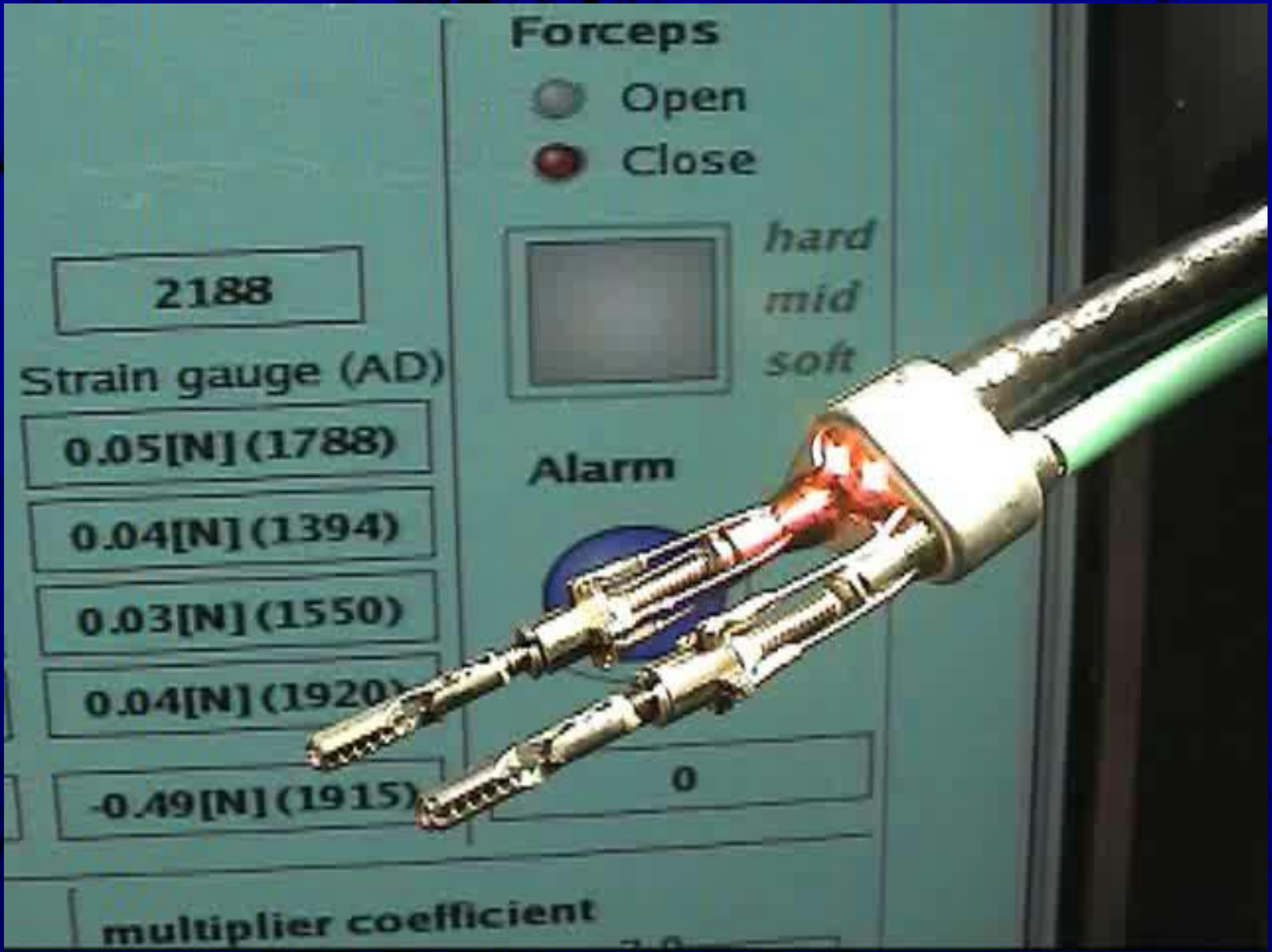
2430
Strain gauge (AD)
0.11[N] (1798)
0.04[N] (1394)
0.02[N] (1548)
Alarm
0
multiplier coefficient



Forceps
Open
Close
hard
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0.04[N](1394)
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Alarm
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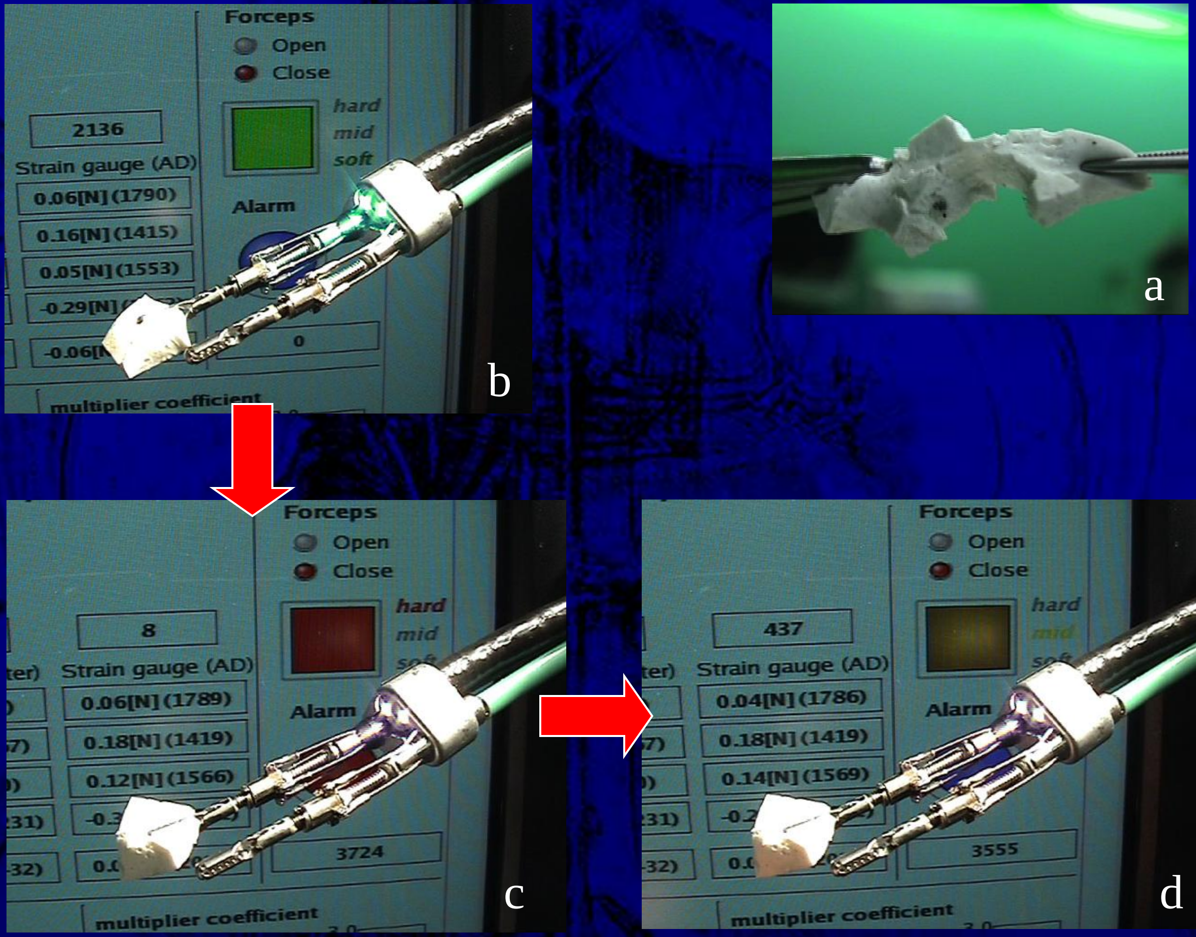
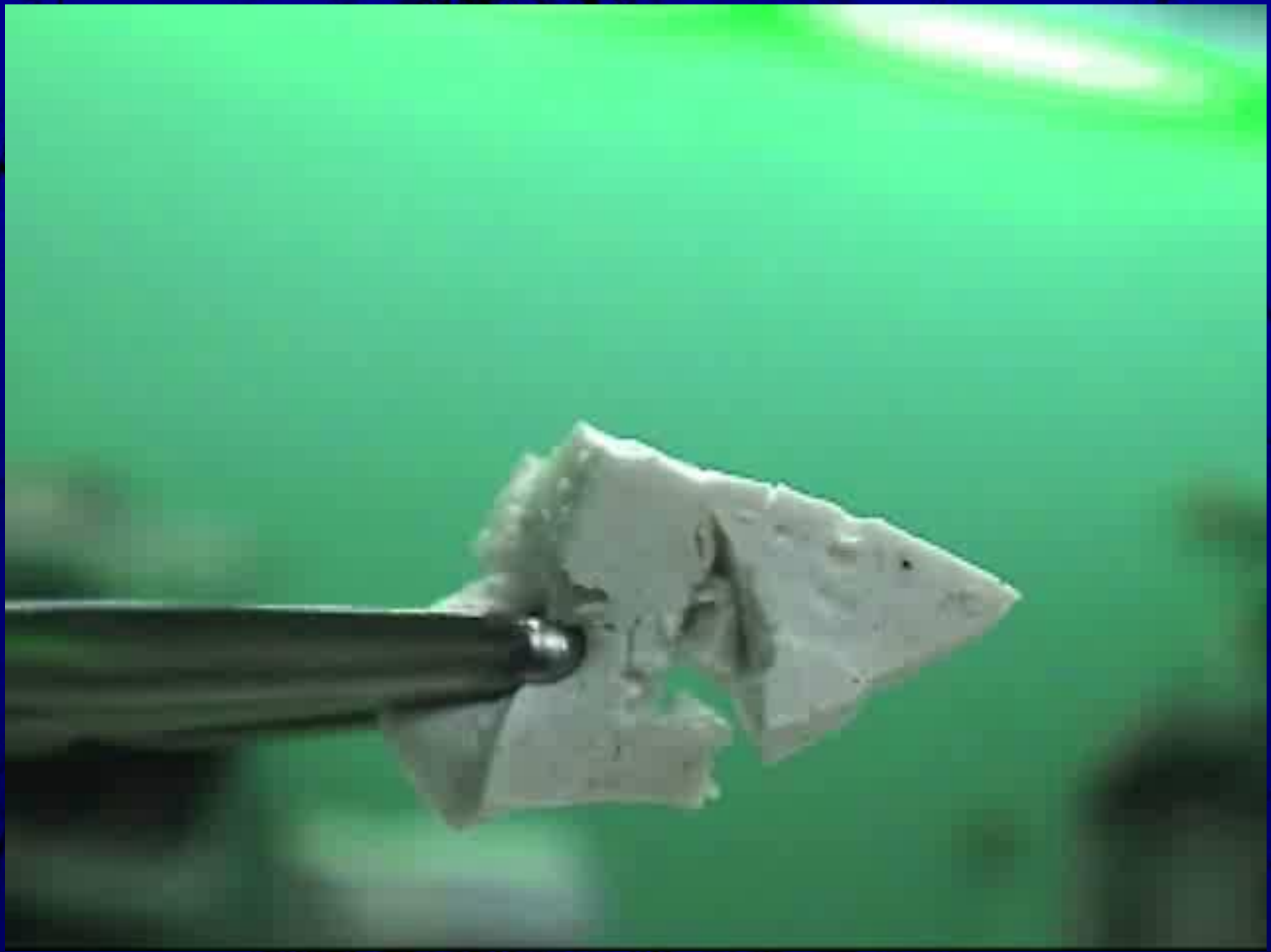


As a result of experiment of grabbing silicon rubber (a) with a robot arm to avoid damaging breakable silicon rubber like gastrointestinal soft tissue, (b) - (d) shows how it is adjusting the power on the operator to grab the object looking at the haptic indicators.



Needed Augmented Reality Function for Endoscopic Surgery Robot

1. Overlay Functions for Robot Eyes
2. Location Map on 3D image
3. Location Map on Serial CT image
4. Haptic Information of Robot Arms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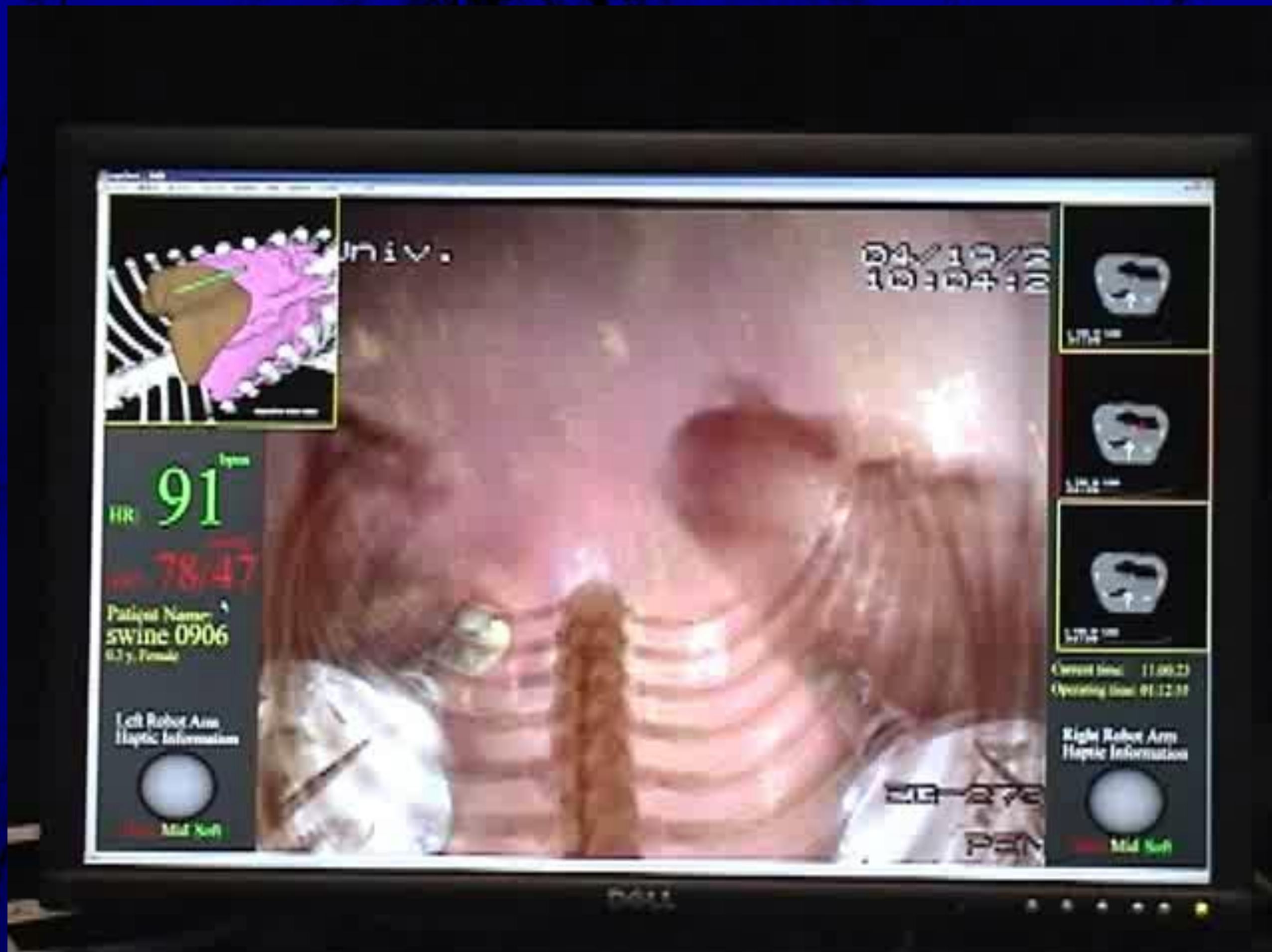
1. Overlay Functions for Robot Eyes

2. Location Map on 3D image



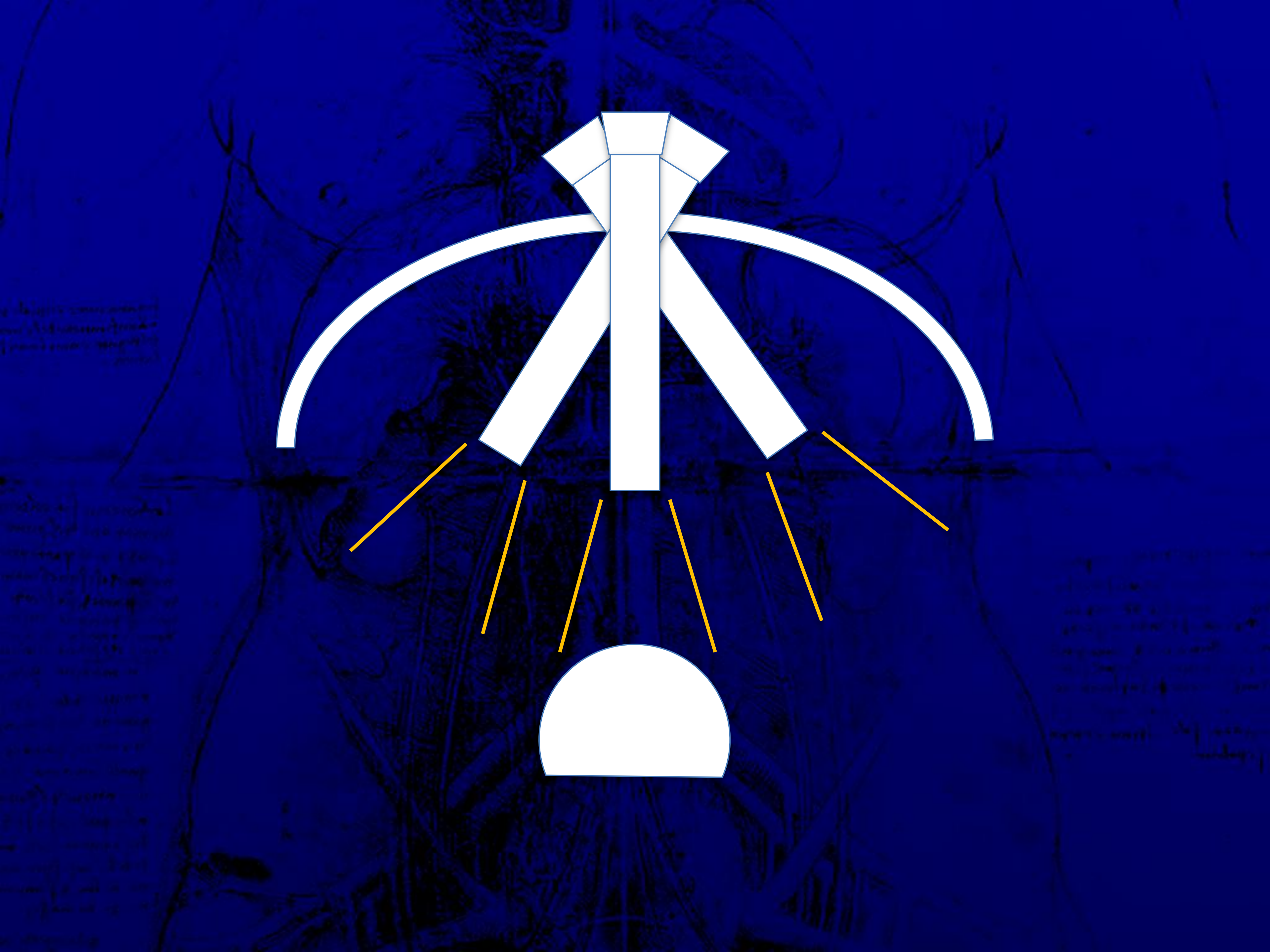
3. Location Map on Serial CT image

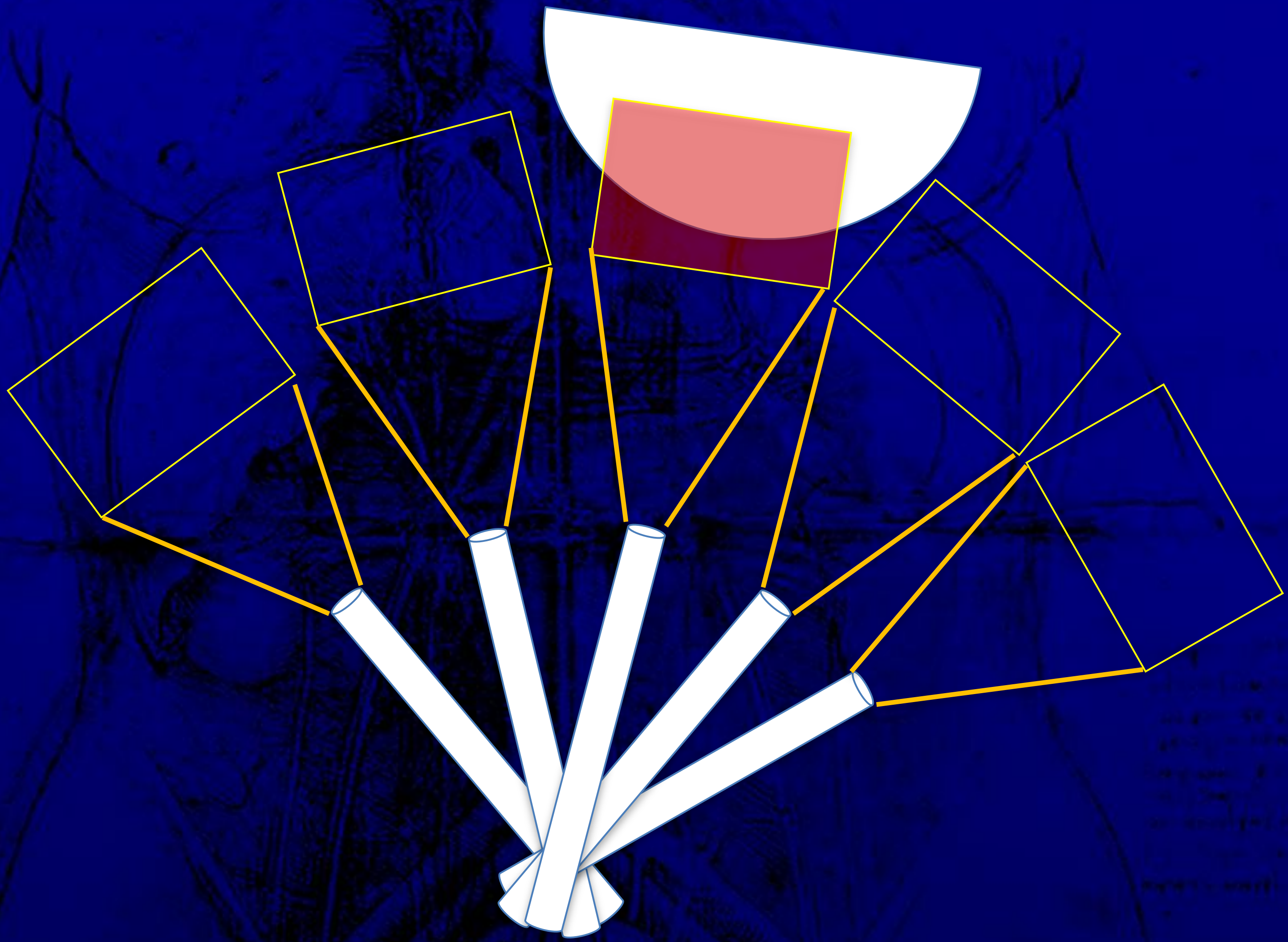
4. Haptic Information of Robot Arms

Development of navigation function for intraperitoneal surgery using multi-view camera structure

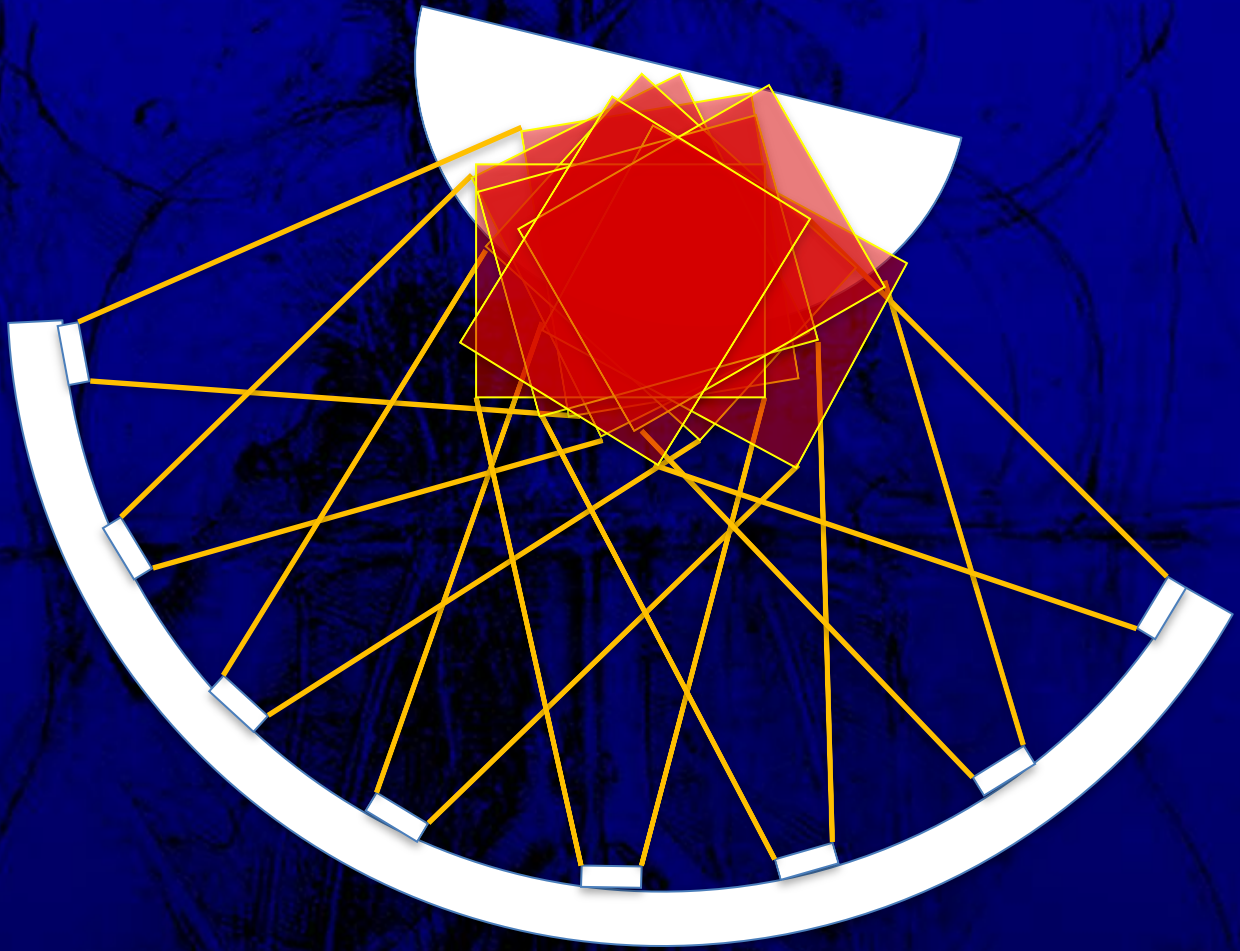
Our aim is to develop a new video camera system that acquires multiple viewpoints in the abdominal cavity. We designed a camera array that consisted of eight small camera modules. Surgeon can change the viewpoint by switching camera output without physically moving the camera.

The main cause of the restriction in view of the laparoscope is in the laparoscopic operation itself. The view of the laparoscope is limited to a fan-like view with the trocar as center.

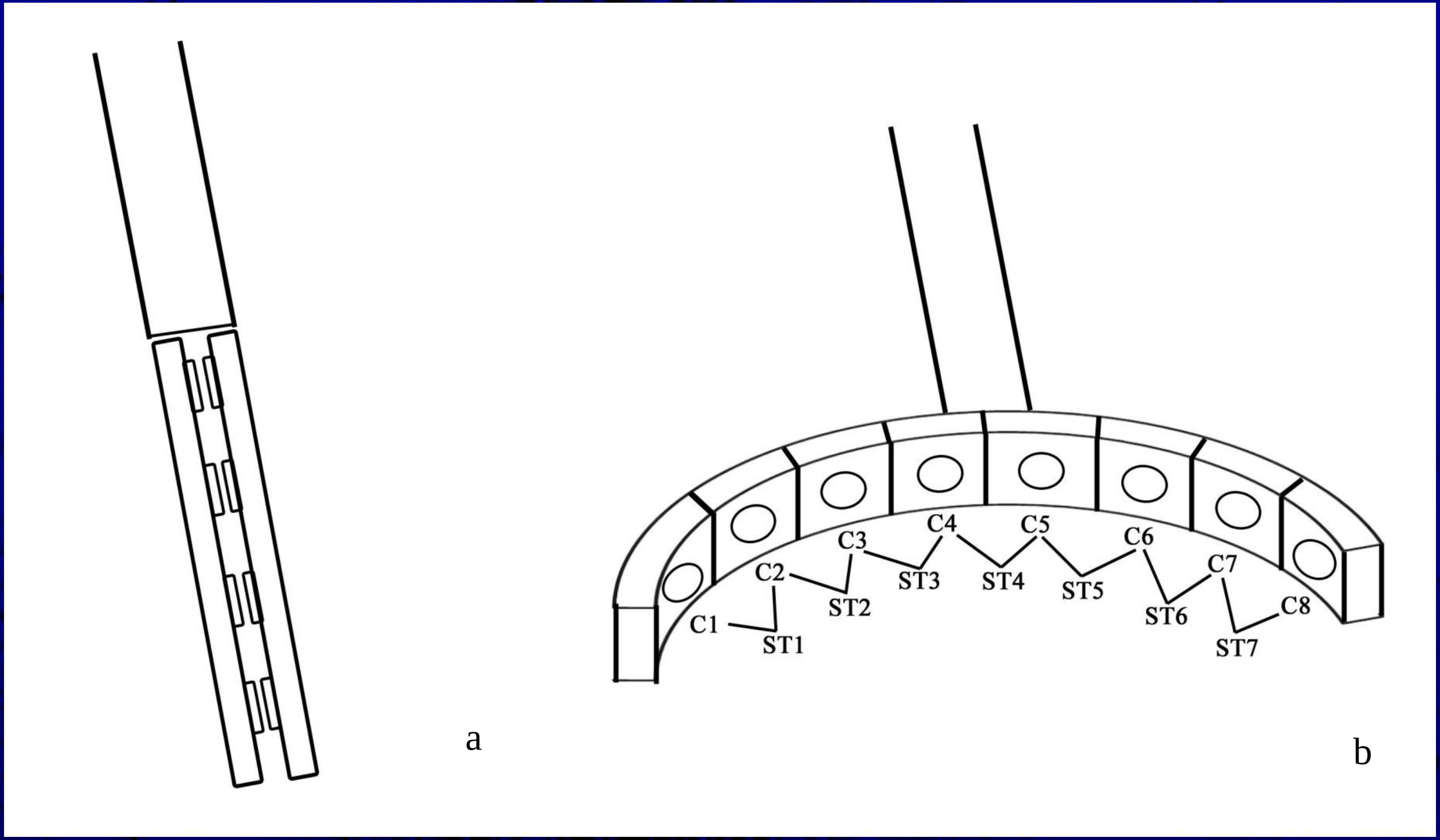




Conventional laparoscopes images are limited to pan the camera and hard to get the optimum viewpoint.



This system can get various sweet spots of the targeted part.



The camera array is split into two rows of right and left. When the camera array is inserted, a wire can be pulled from outside the body and the cameras reposition themselves in an arc in the abdominal cavity.

Group of cameras lined in a fixed rule exerts certain effectiveness.

Randomly lined group of cameras can also construct 3D image environment.

But images of aligned camera groups

1) can acquire visuals putting surgeon's experience into use
2) can acquire field of view optimizing camera's resolution

Structure we adopted:

Structure to create field of view groups by aligning camera groups in an arc with overlapping views of neighboring camera

Aligned camera groups :

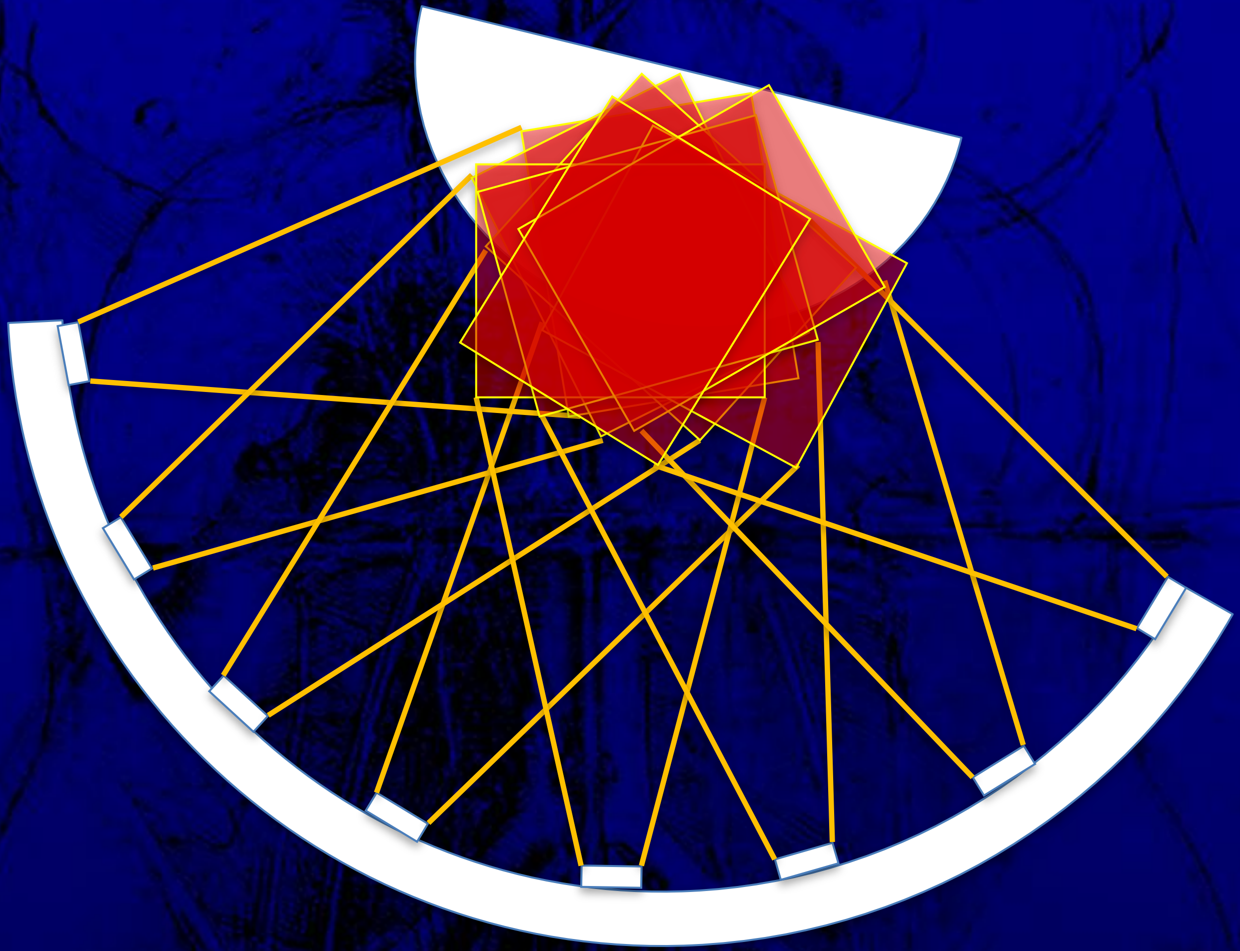
1) can acquire multiple views simultaneously

2) can acquire change of viewpoint without physical movement

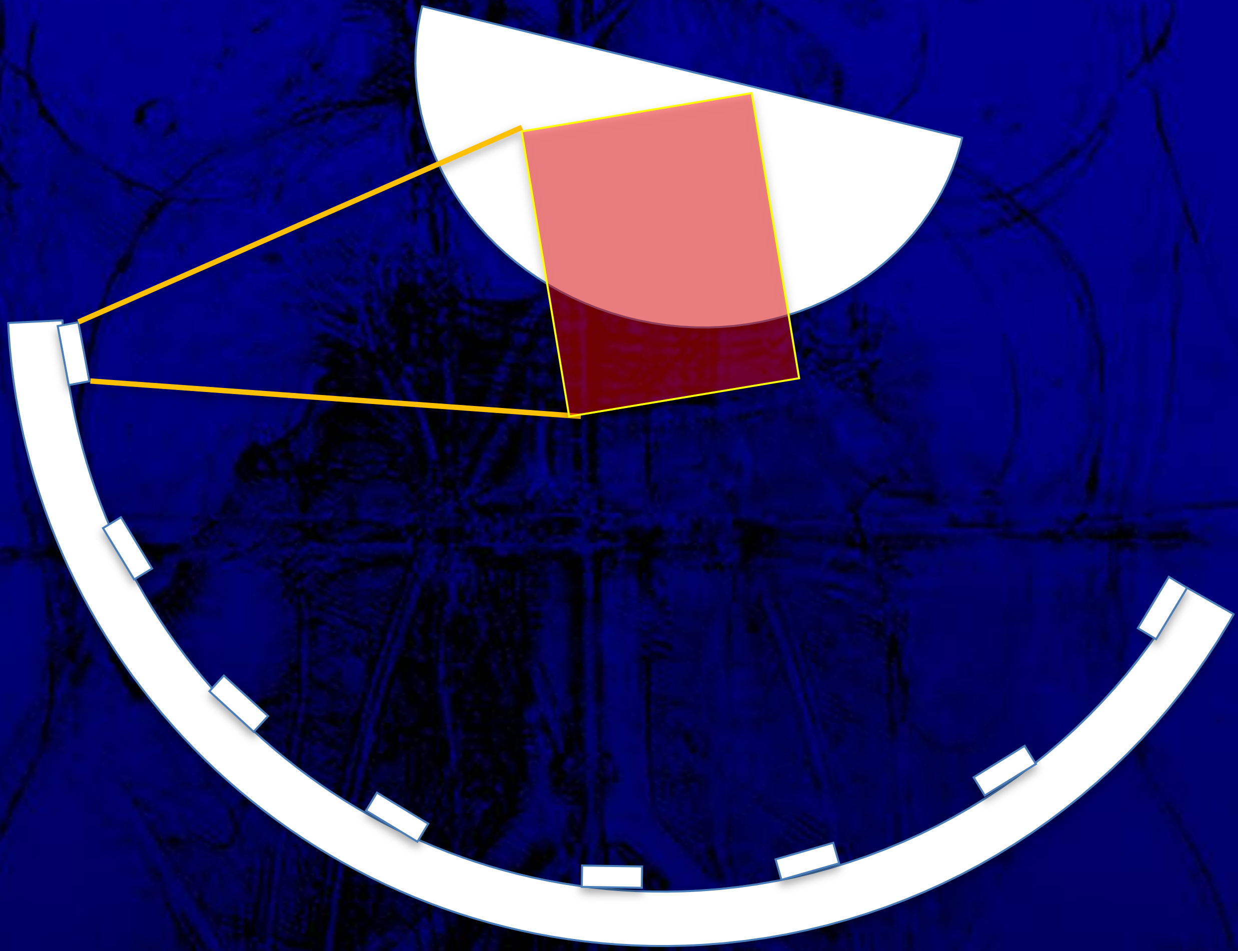
(changes viewpoint by changing array direction)

3) can acquire stereo view from any direction

4) can enhance viewpoint in stereo view

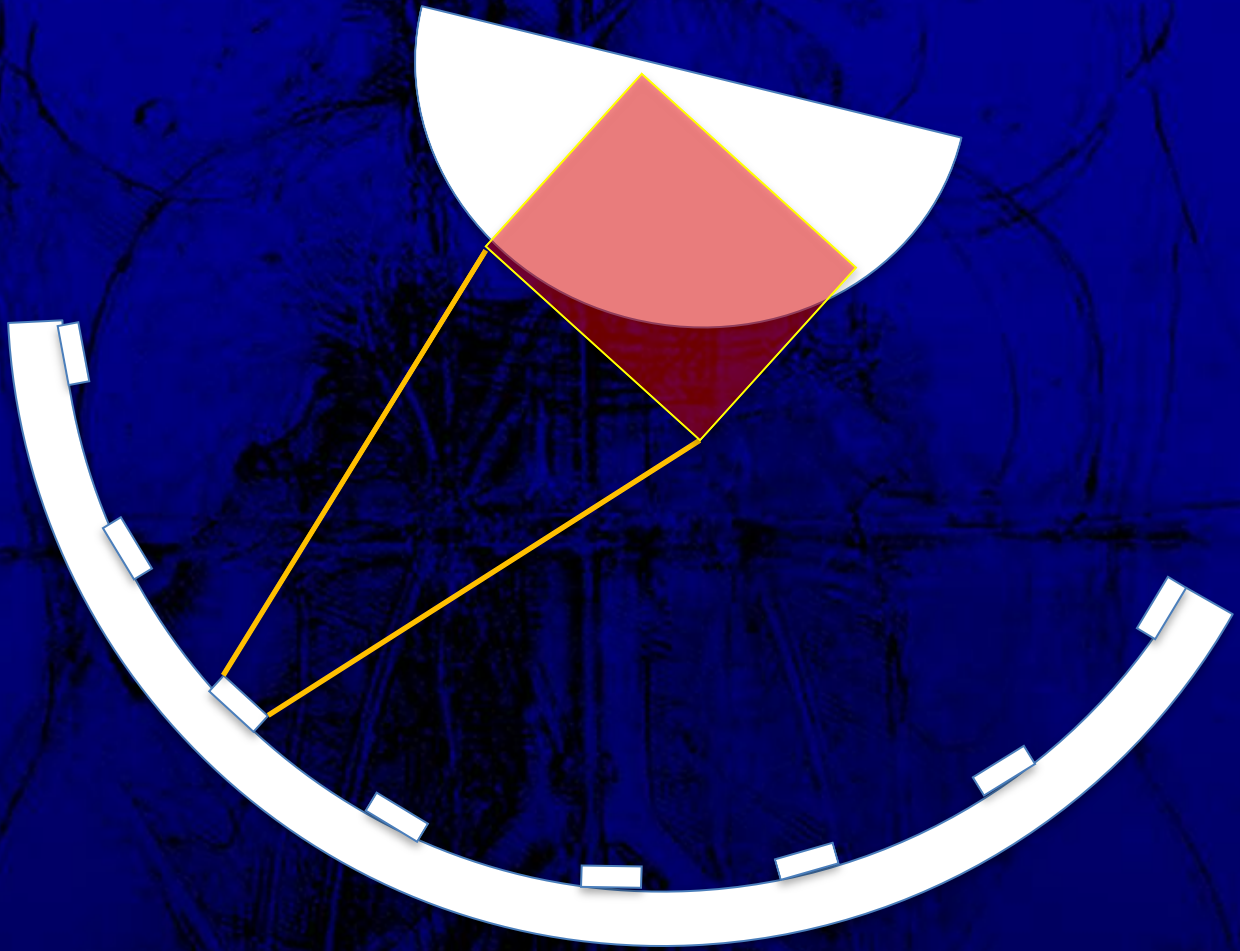


1) can acquire multiple views simultaneously

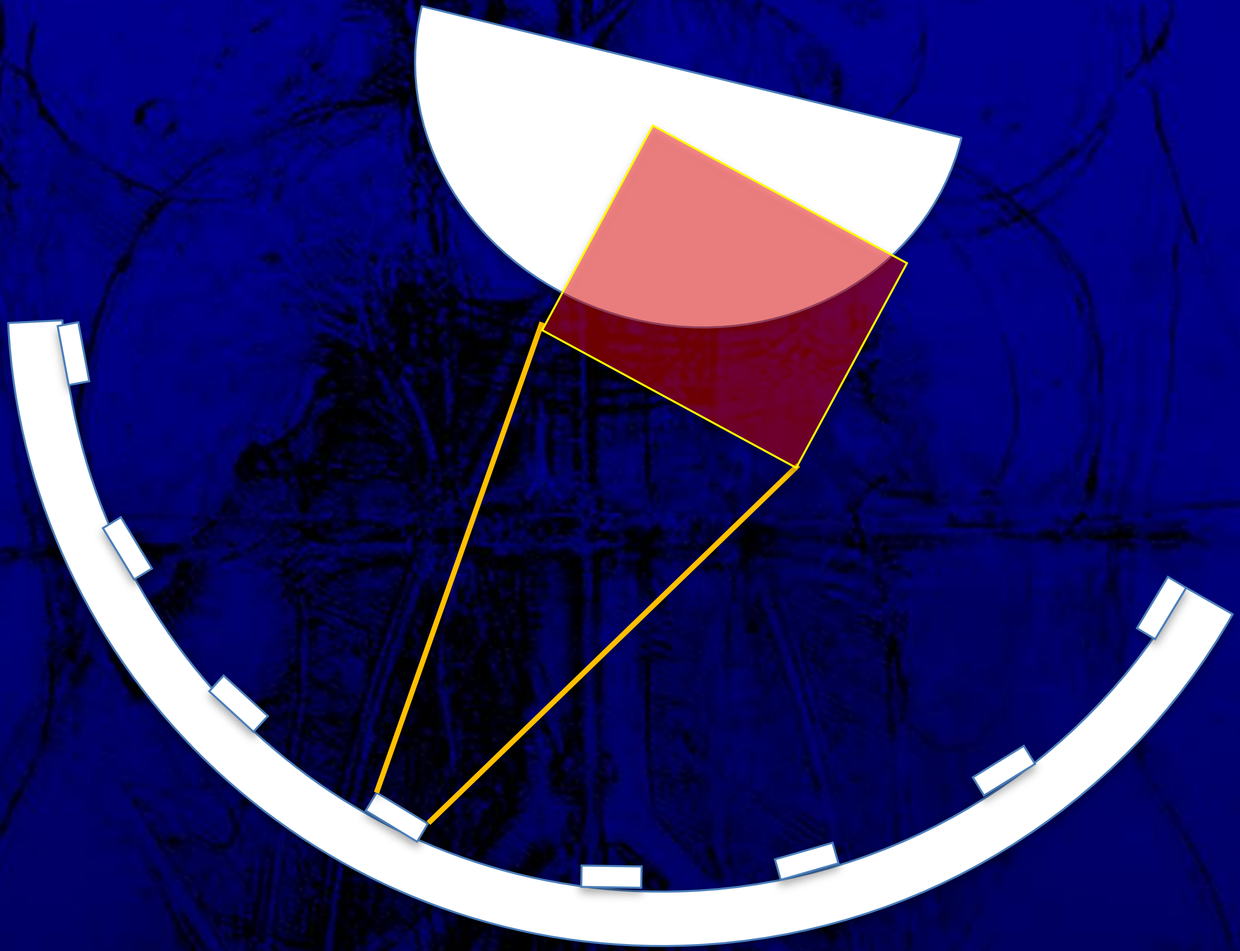


2) can acquire change of viewpoint without physical movementy

2) can acquire change of viewpoint without physical movementy



2) can acquire change of viewpoint without physical movement



2) can acquire change of viewpoint without physical movement

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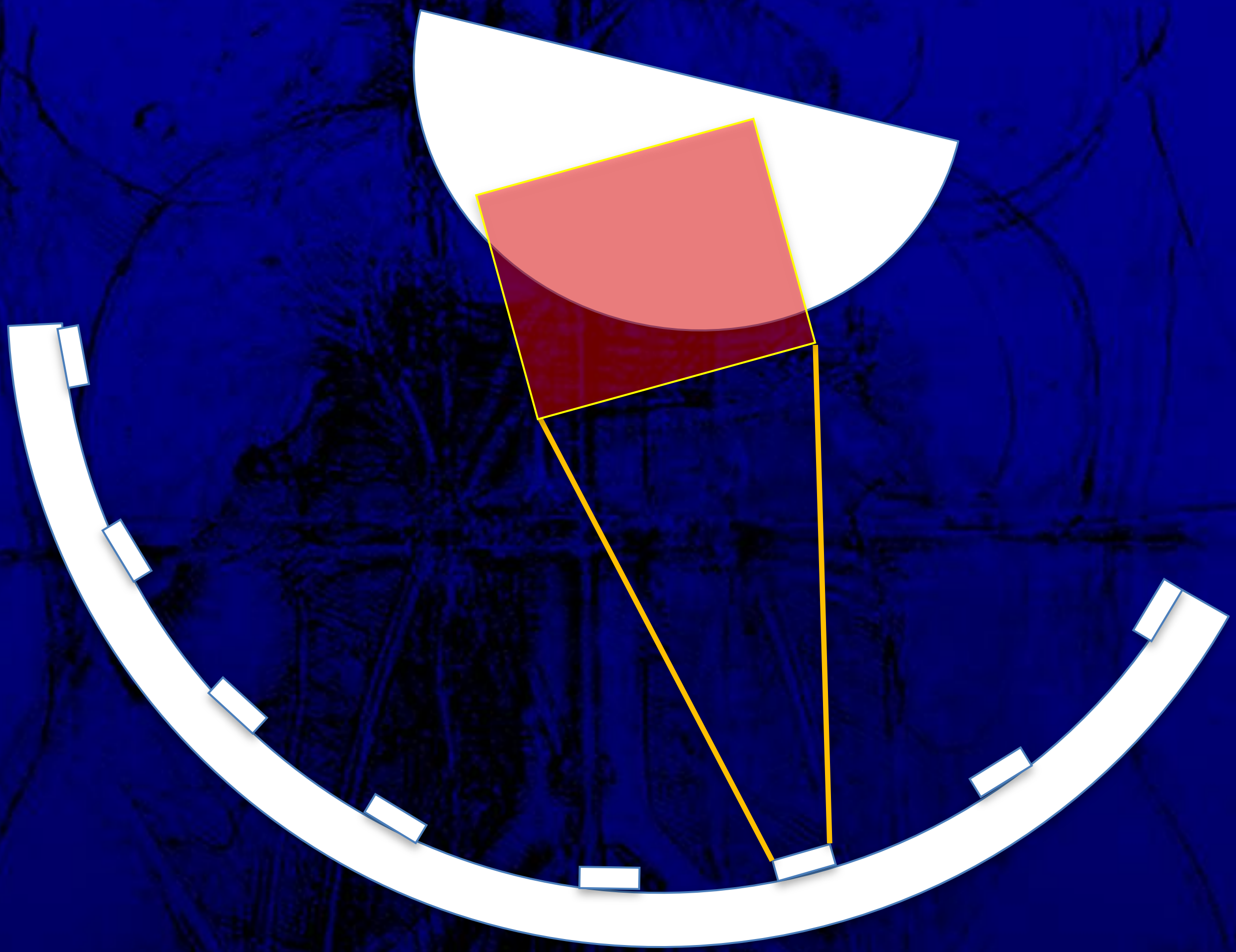
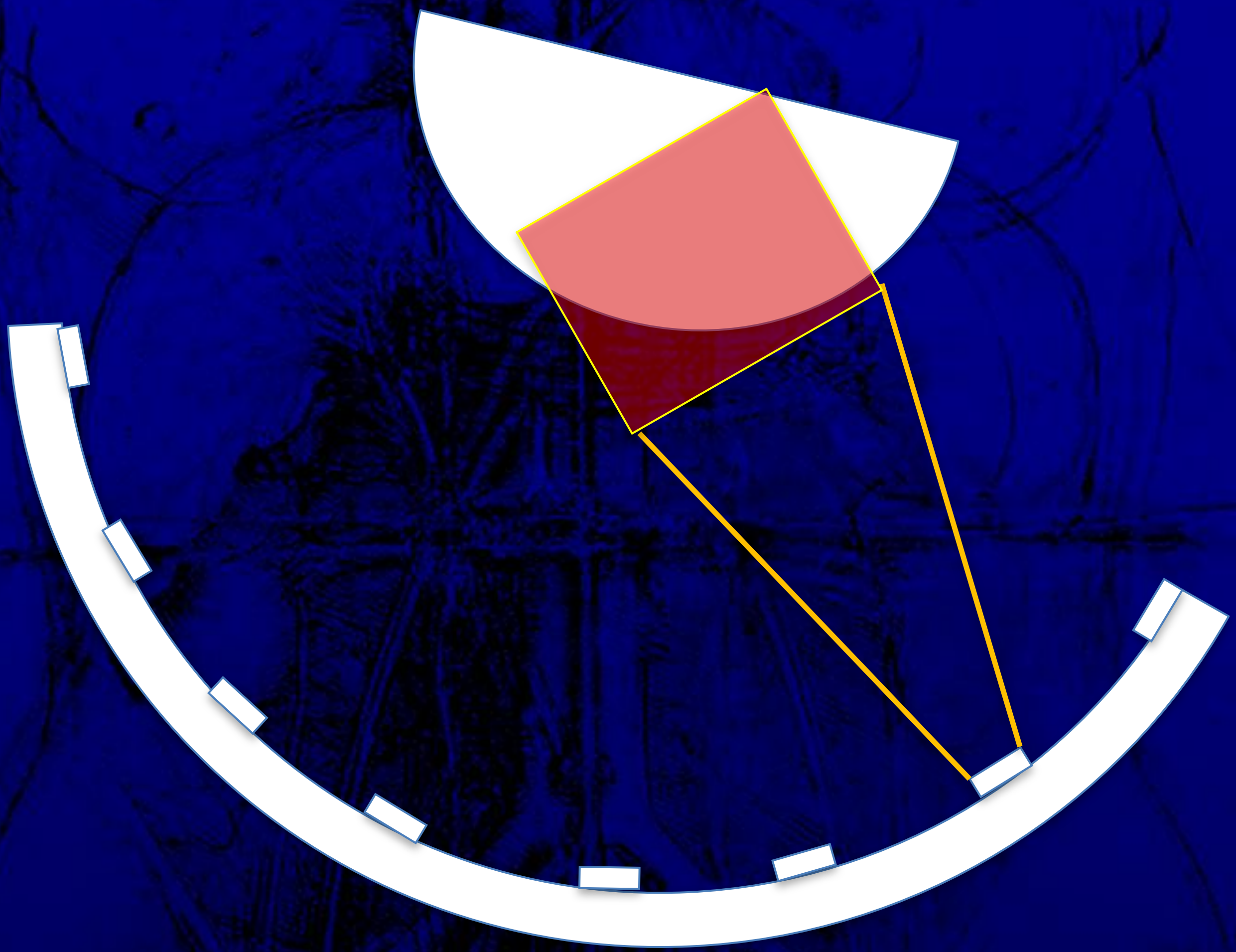
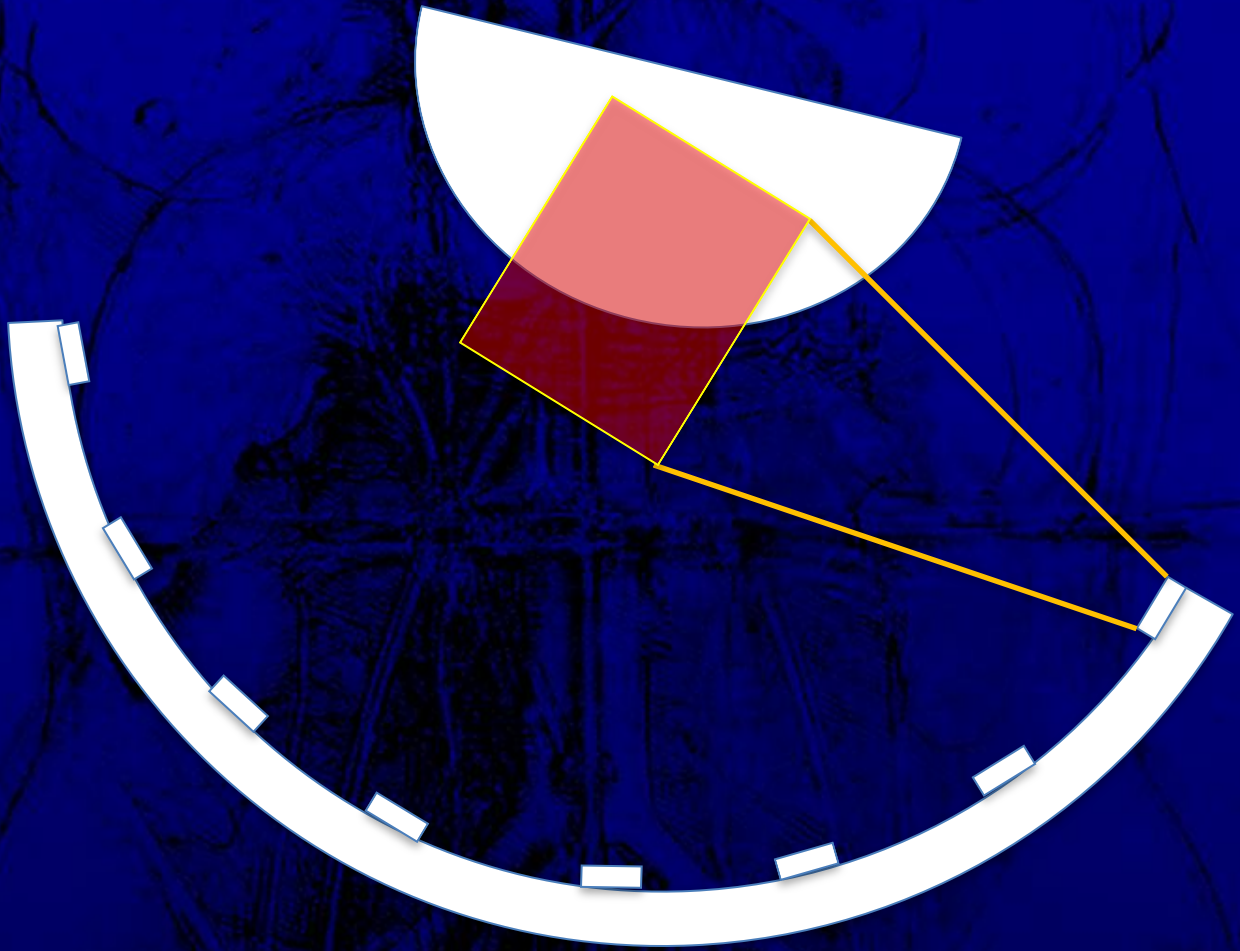


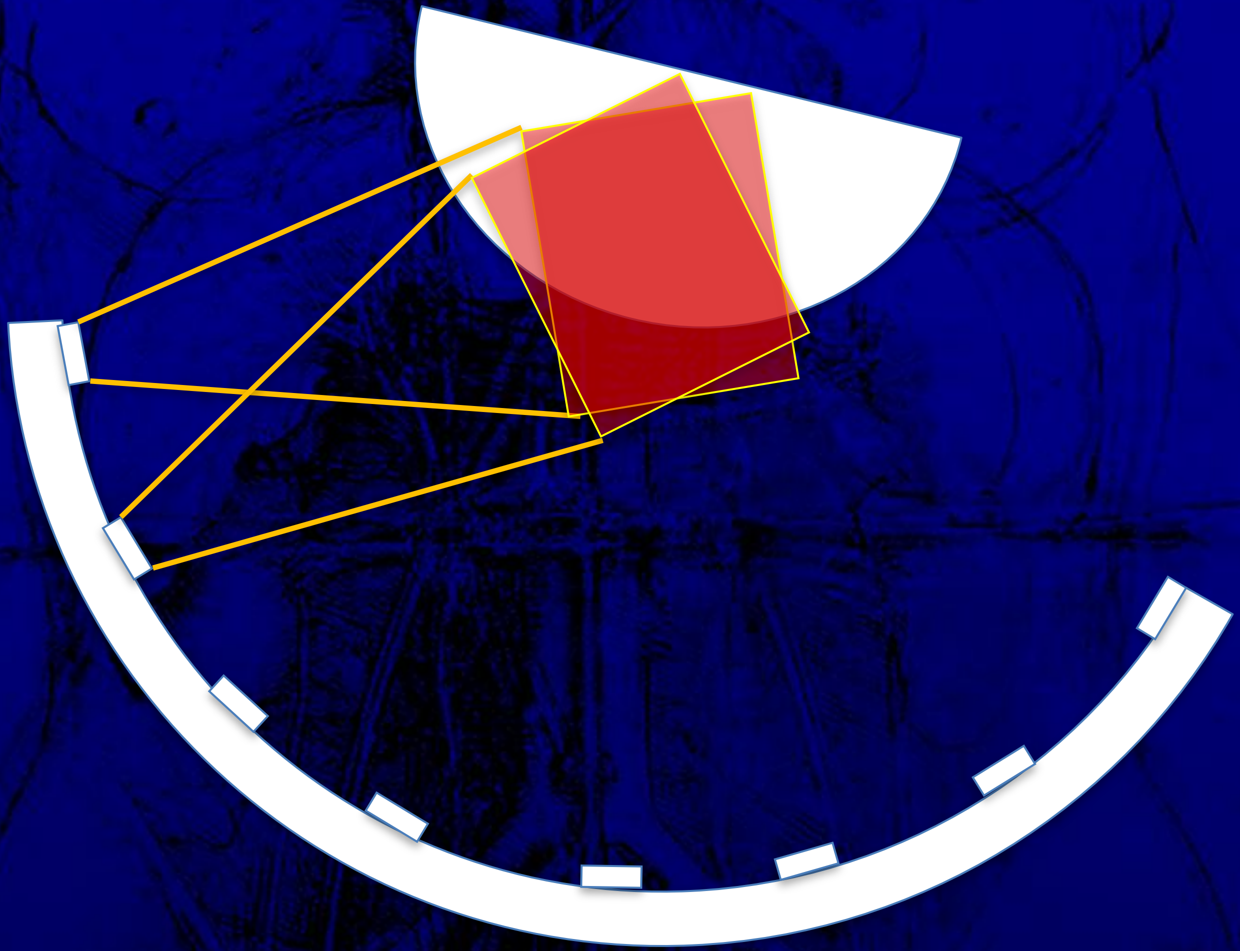
2) can acquire change of viewpoint without physical movement



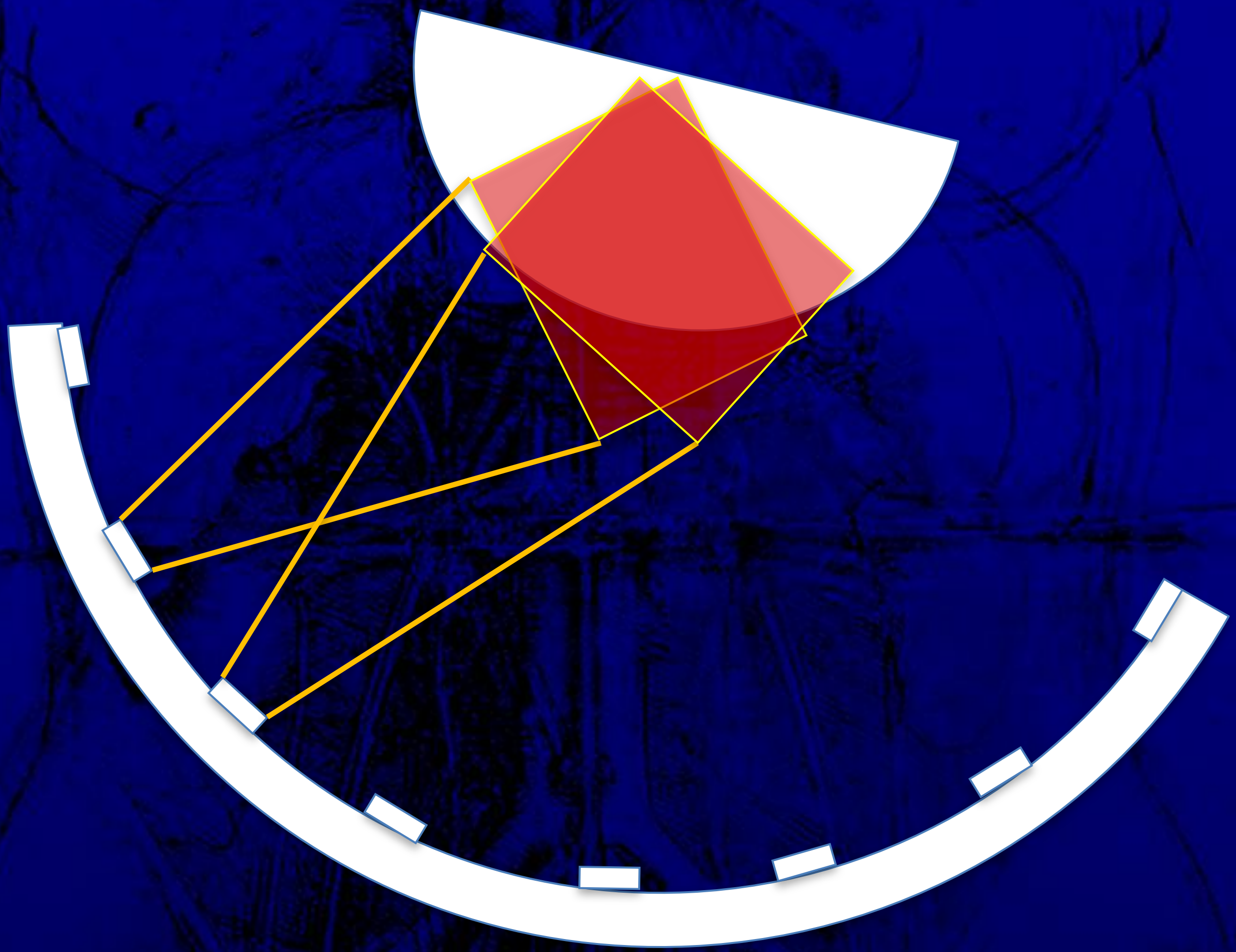
2) can acquire change of viewpoint without physical movement



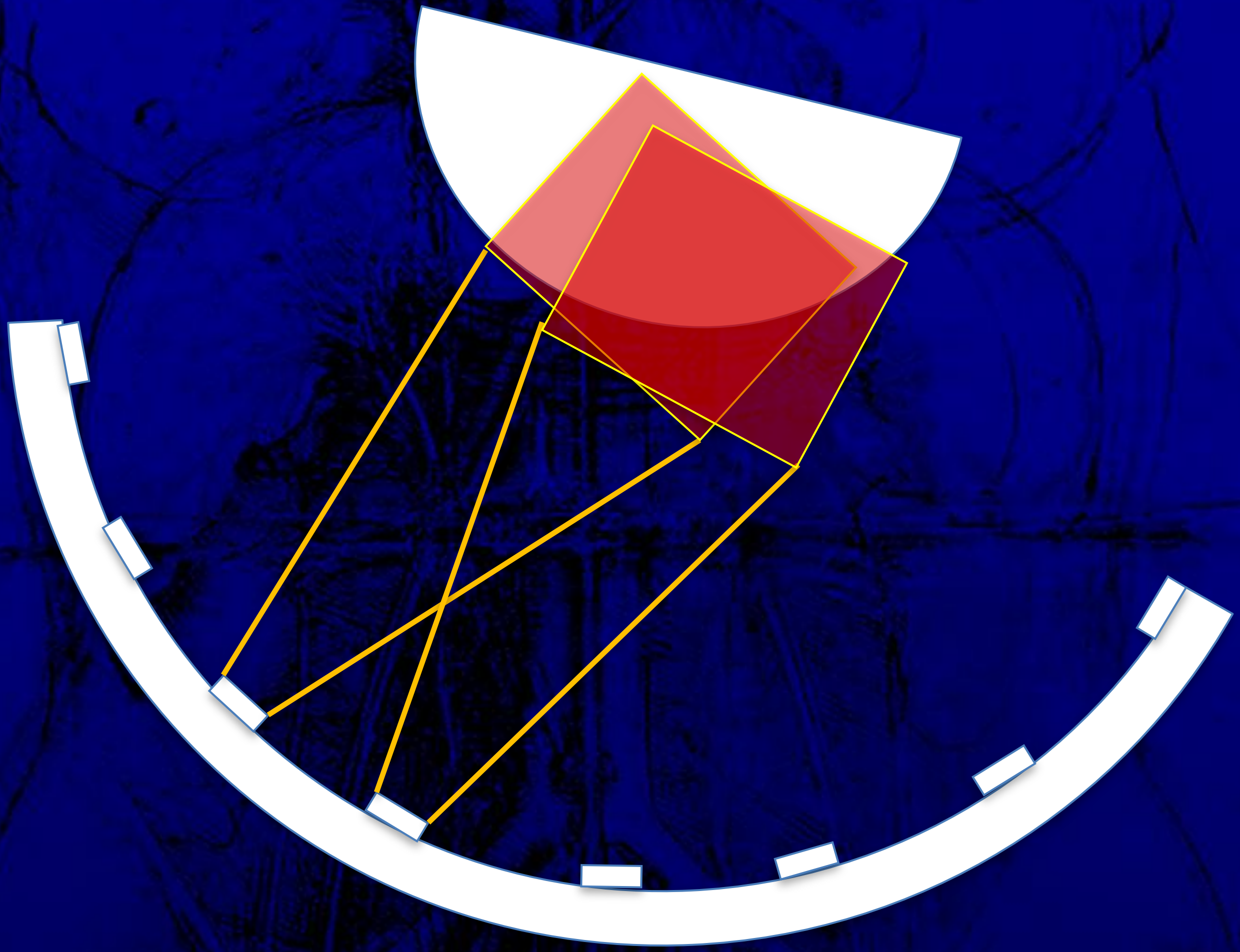
2) can acquire change of viewpoint without physical movement



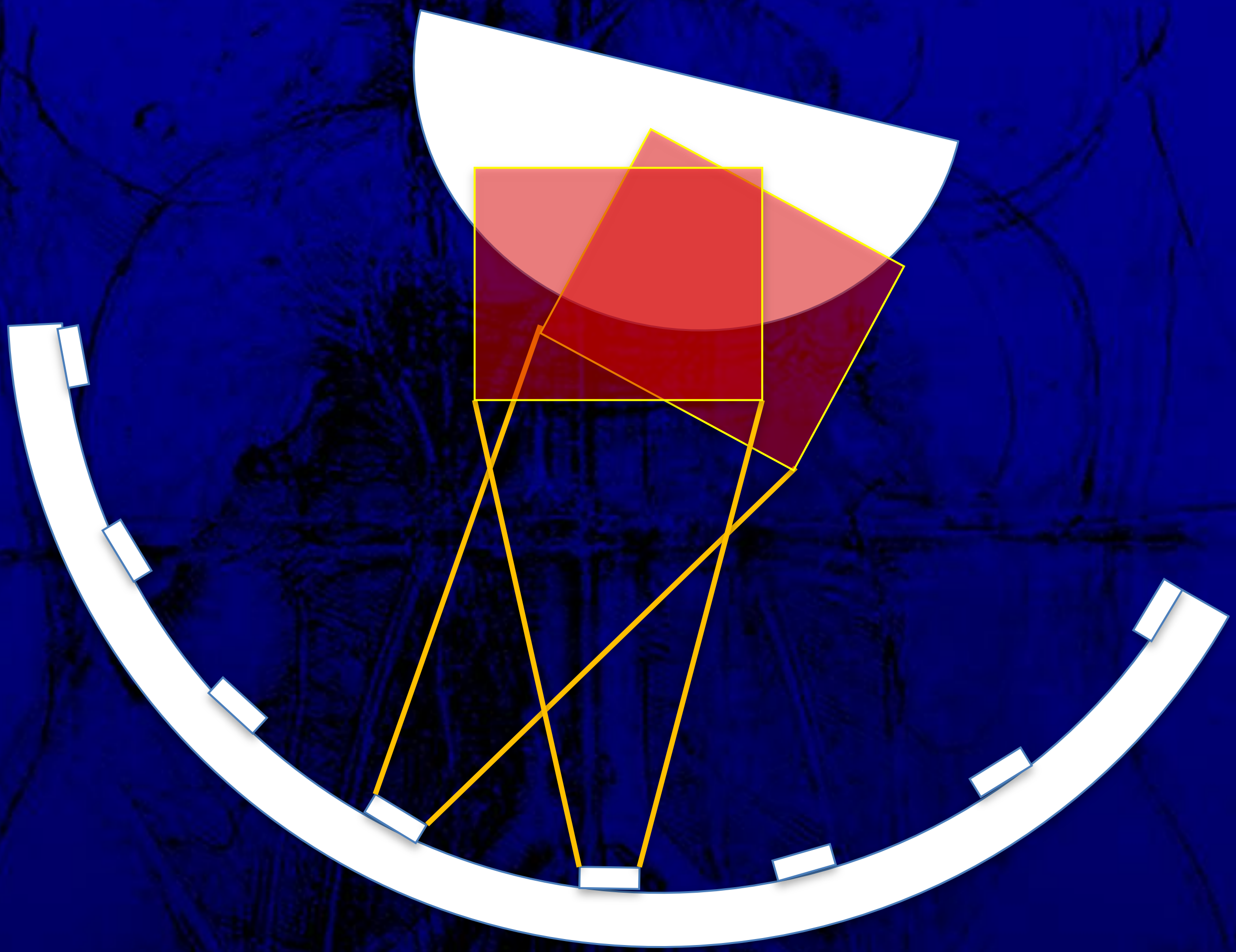
3) can acquire stereo view from any direction



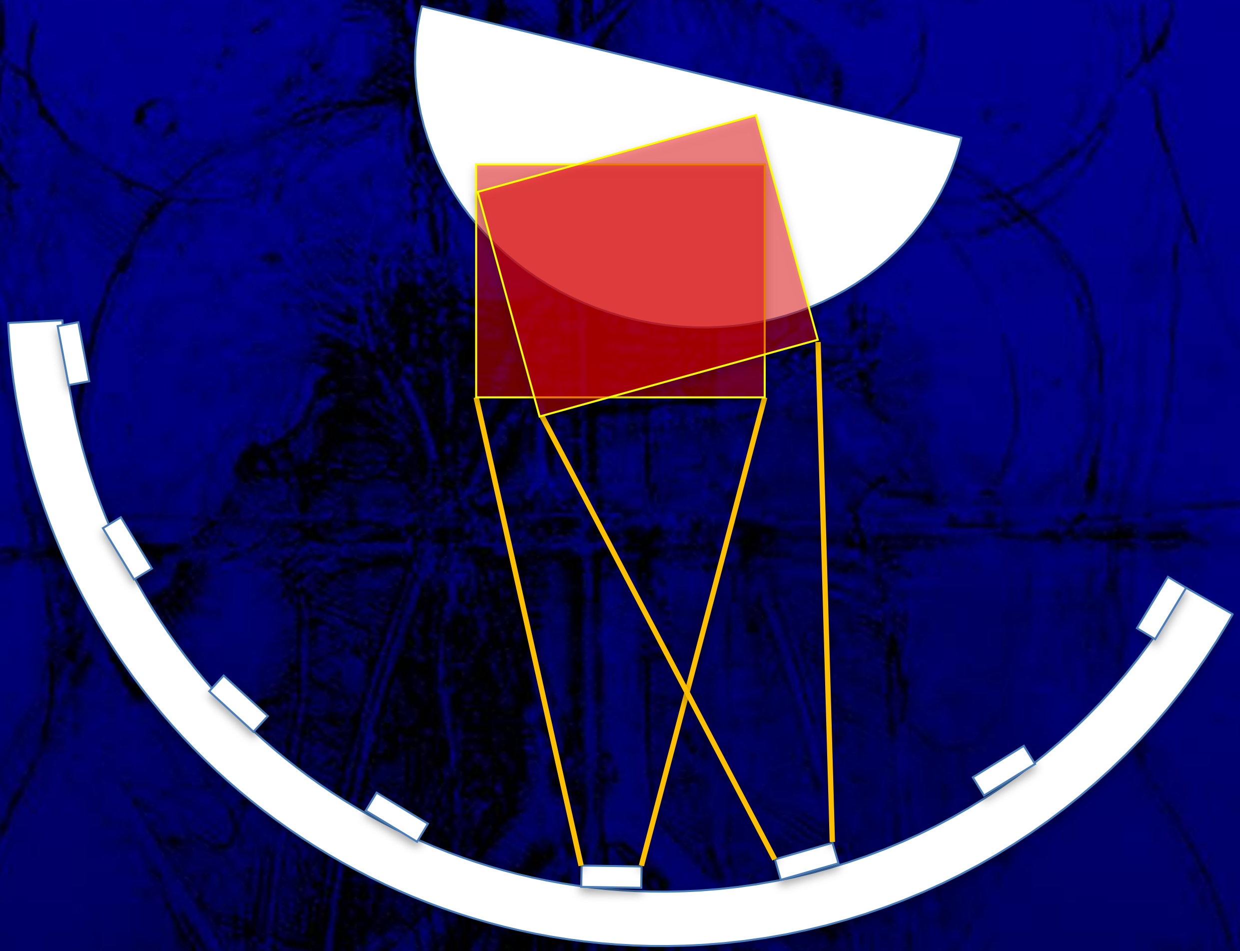
3) can acquire stereo view from any direction



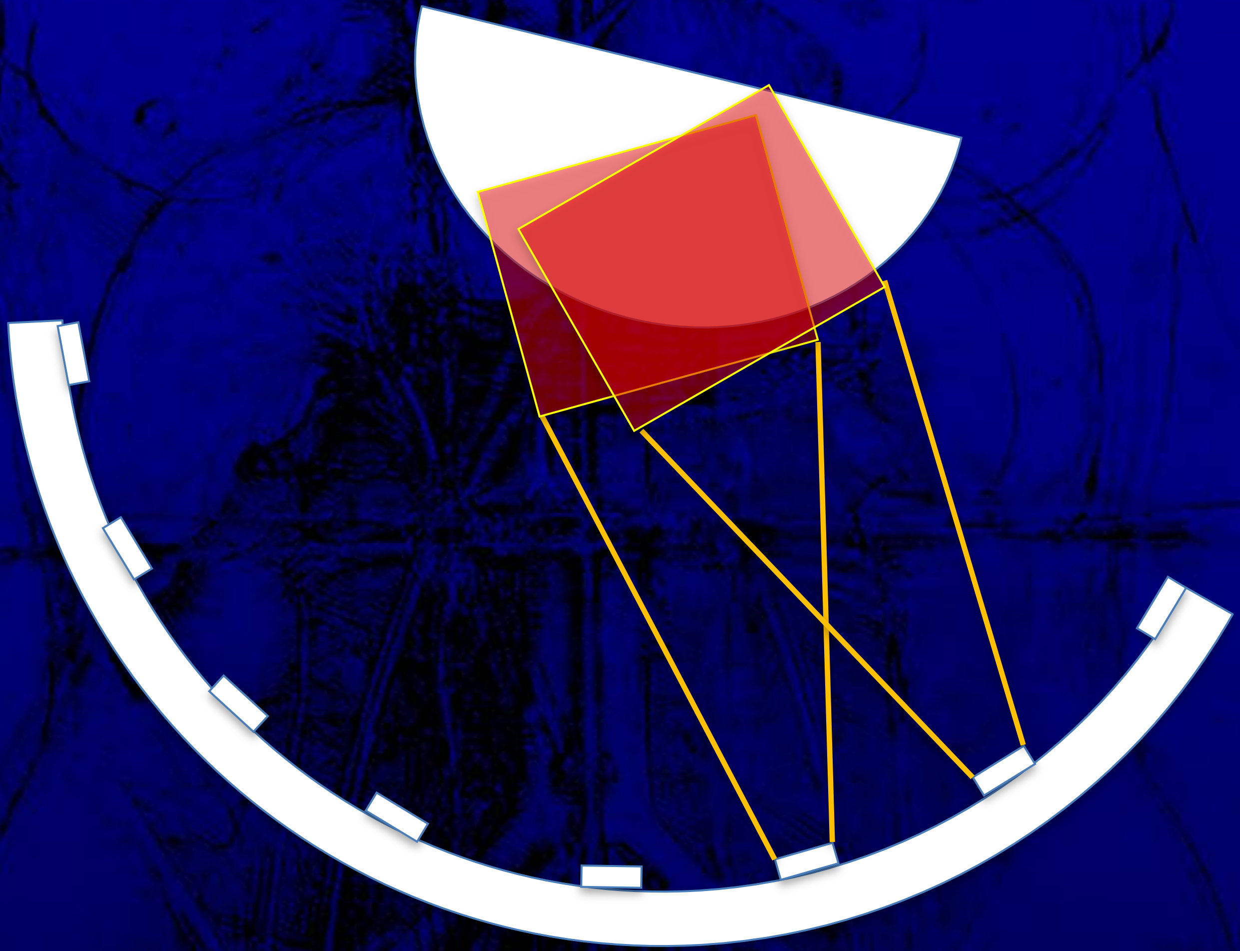
3) can acquire stereo view from any direction



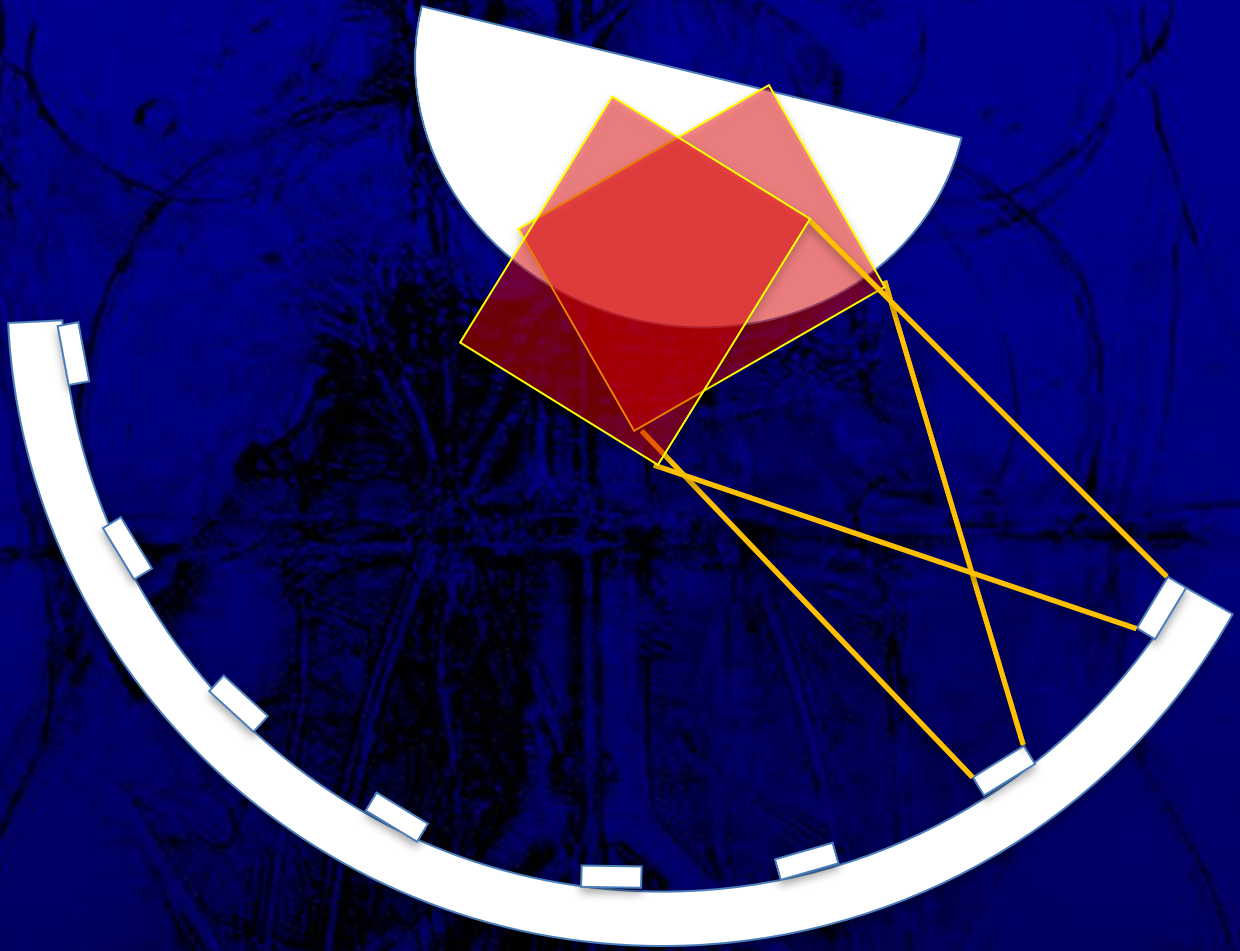
3) can acquire stereo view from any direction



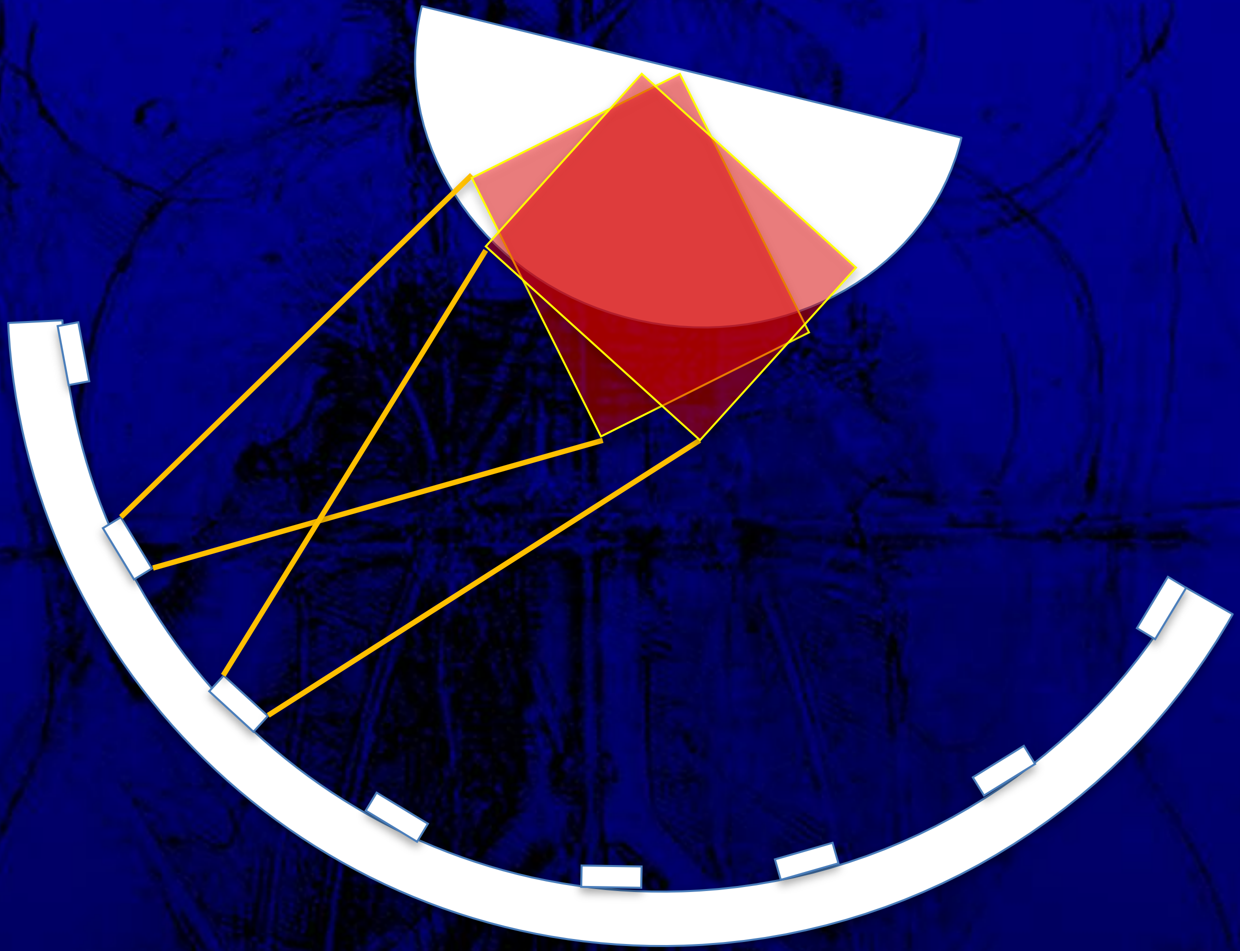
3) can acquire stereo view from any direction



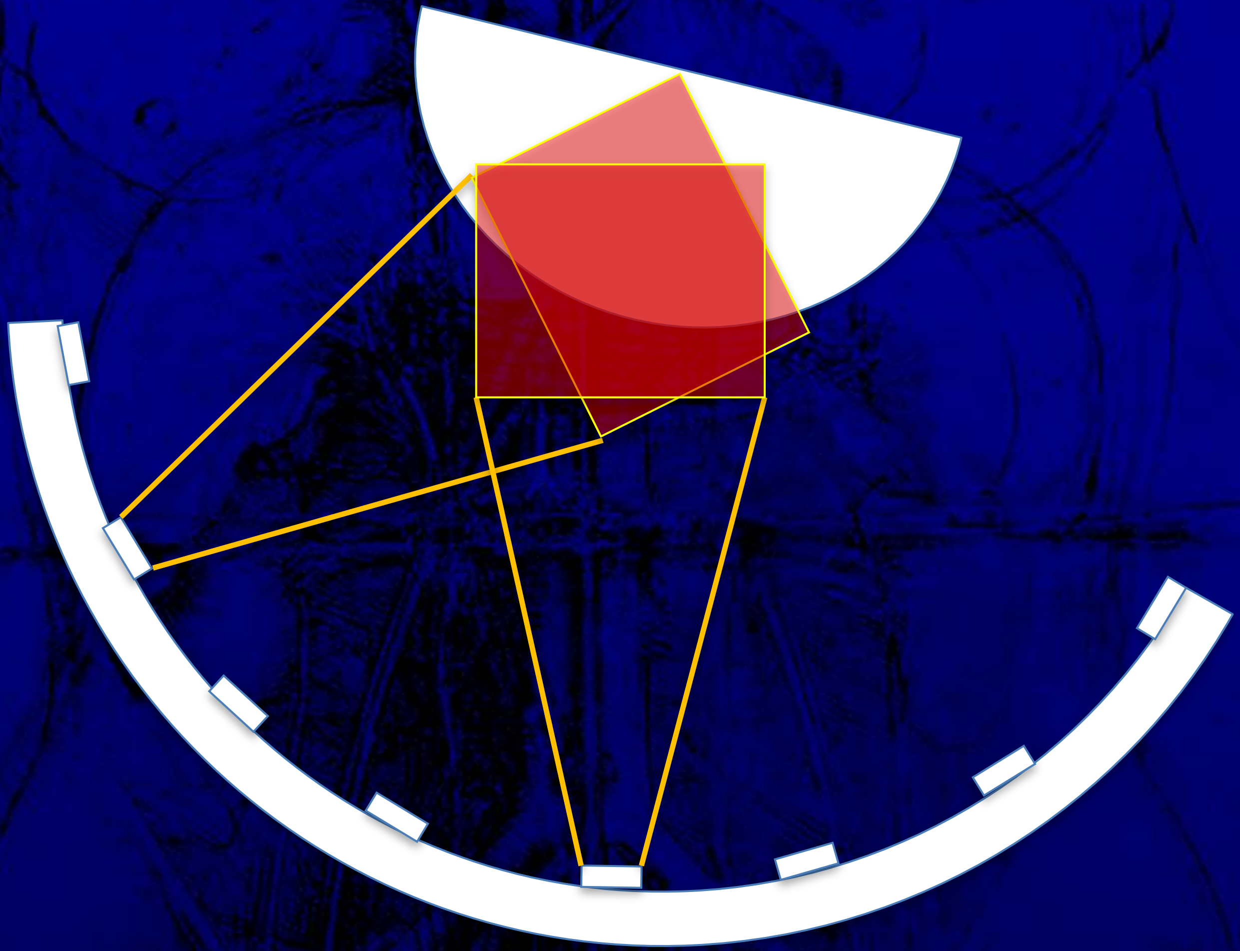
3) can acquire stereo view from any direction



3) can acquire stereo view from any direction



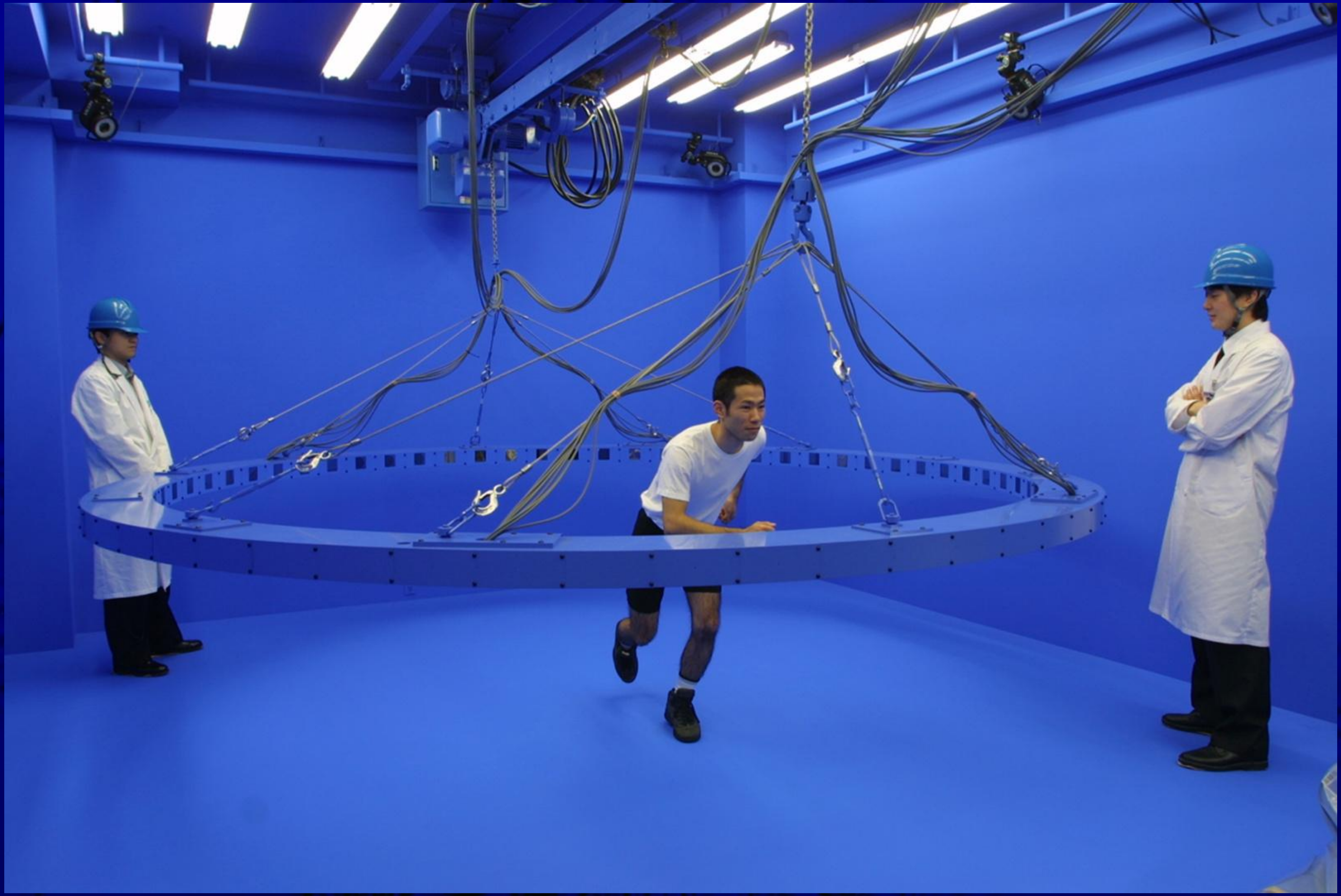
4) can enhance viewpoint in stereo view



4) can enhance viewpoint in stereo view

Basic research of this Project 3

Development of Large multi-view camera
(Clinical application to Orthopedics)

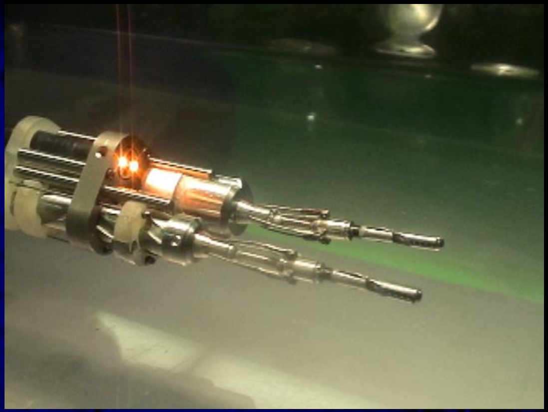


Our works related to this system

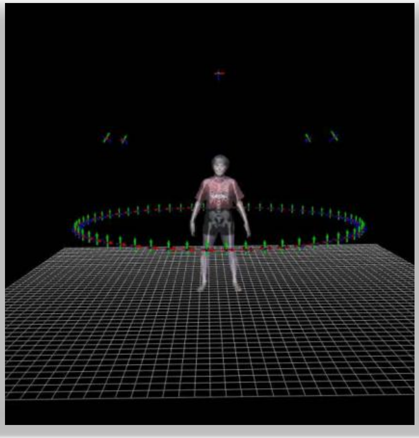
Open surgery simulation with haptic sensation
Laparoscopic surgery simulation
Robotic surgery simulation

Overlay system for navigation surgery
High-tech navigation operating room
Image-guided surgery using AR

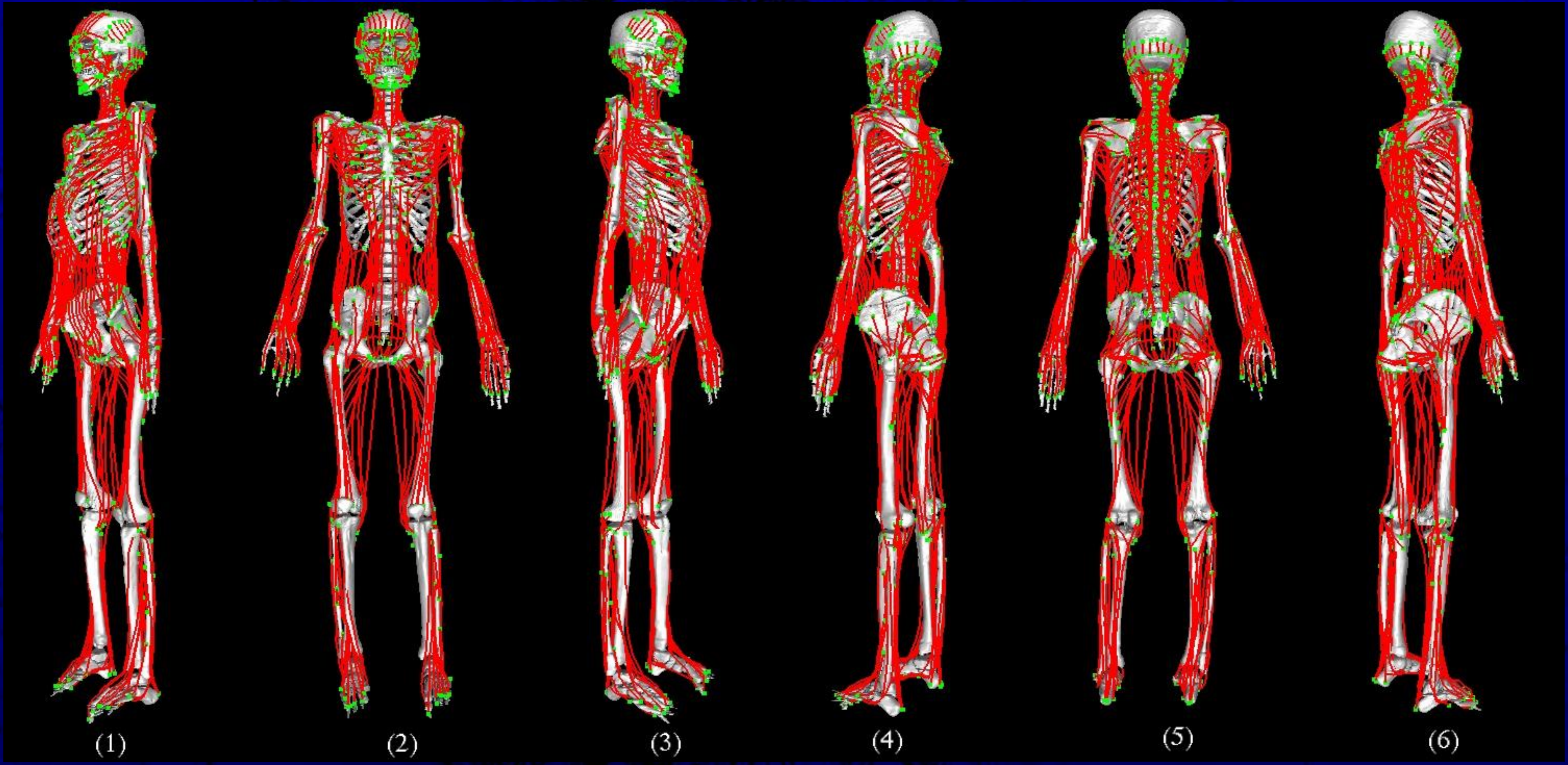
4D Analysis of Human Locomotion



Endoscopic surgical robot
Robot arm with haptic sensation
Surgeon's console enhanced by VR

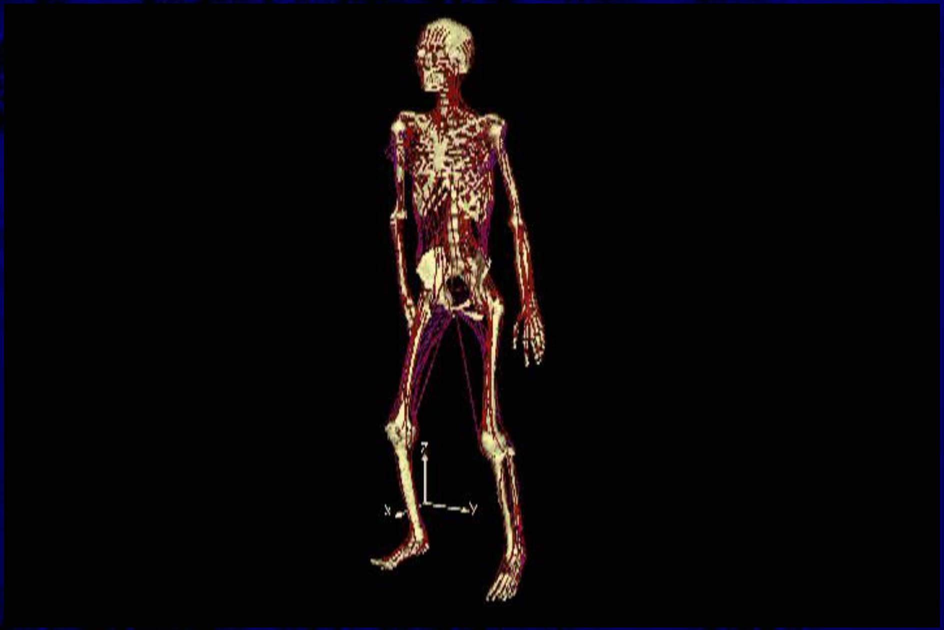


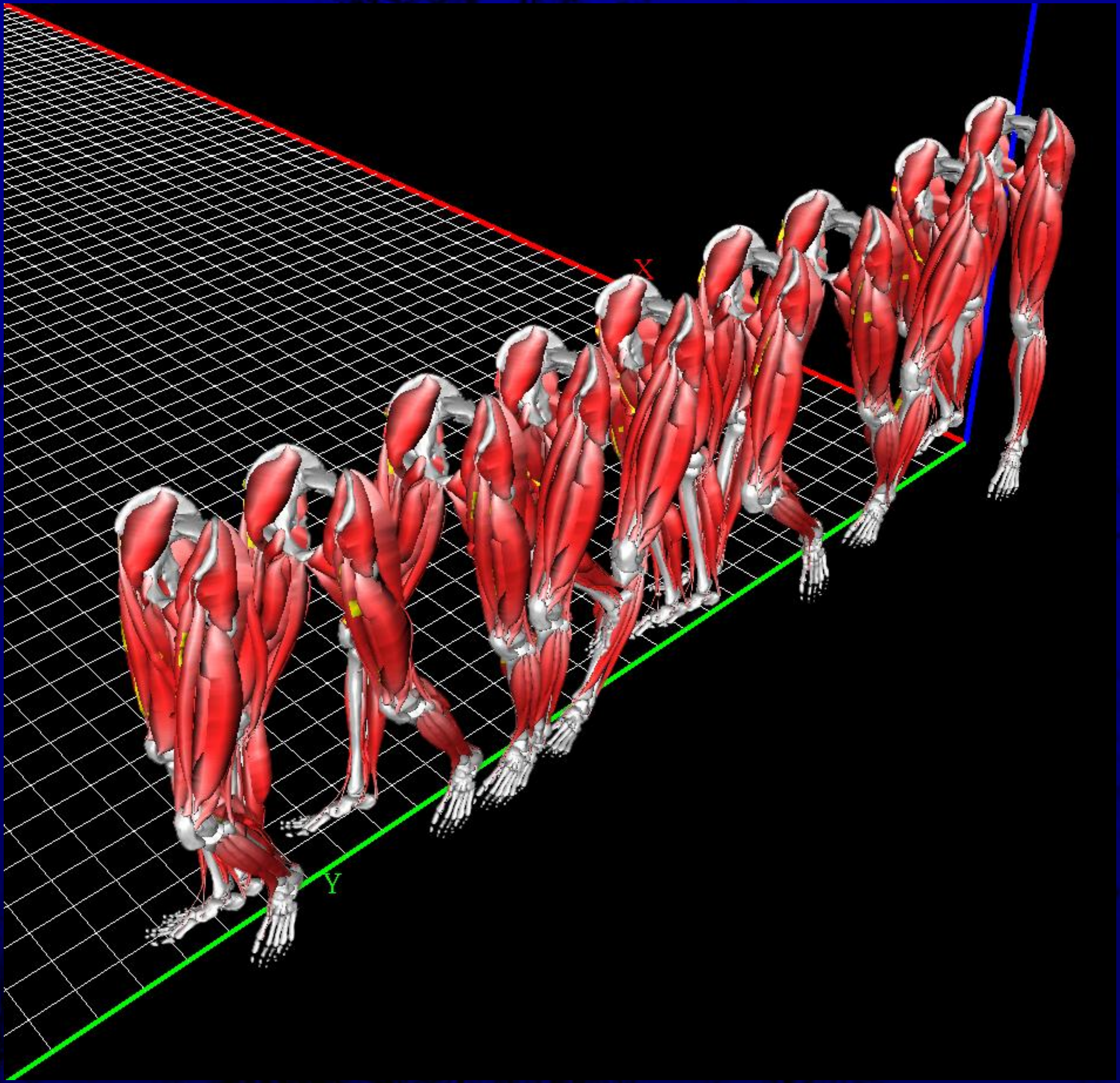
Visualization of whole body skeletal system
Time-spatial observation of human locomotion
Analysis of artificial joints



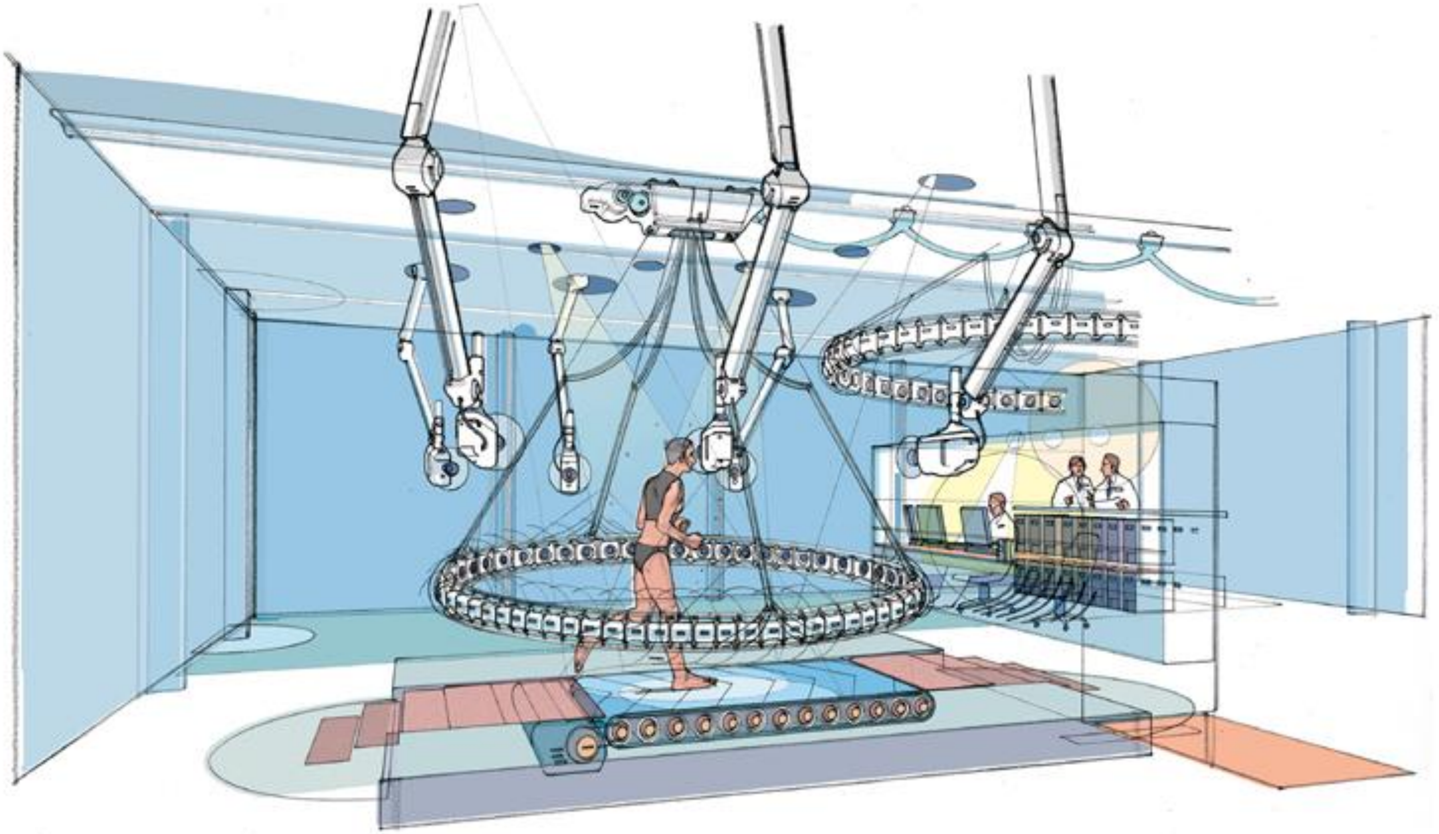
Skeletal and Muscular 3D Model of Whole Body


z
x
y

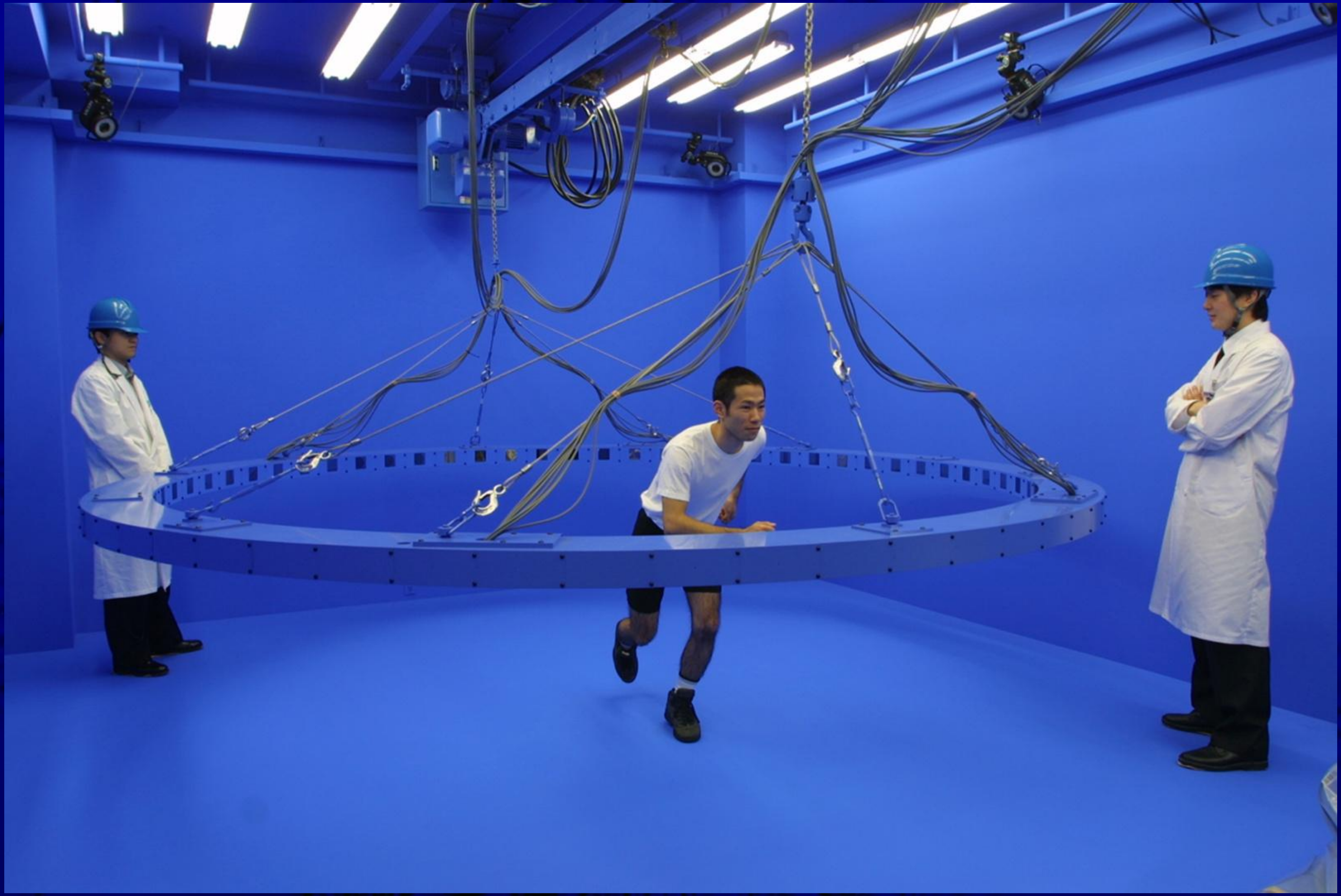

z
x
y


X
Y

Development of
Dynamic Spatial Video Camera (DSVC) for
4D observation, analysis
and modeling of human body locomotion



平成13年度文部科学省私大整備事業ハイテクリサーチセンター 四次元動作計測室
東京慈恵会医科大学 総合医科学研究センター 高次元医用画像工学研究所内

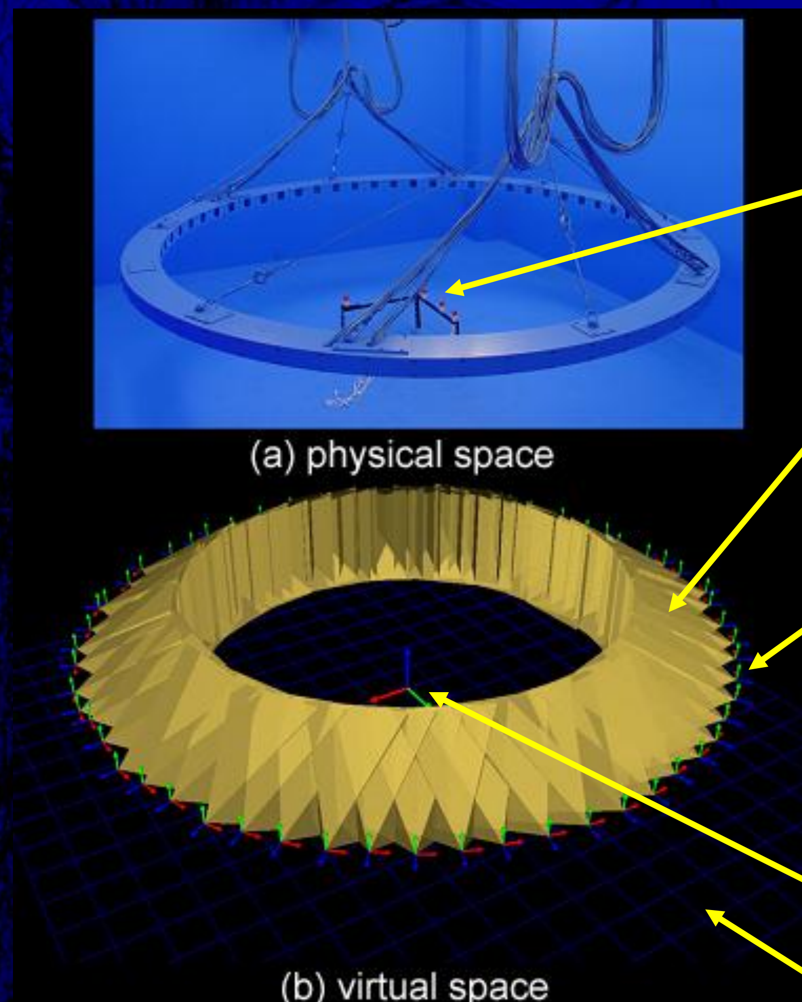


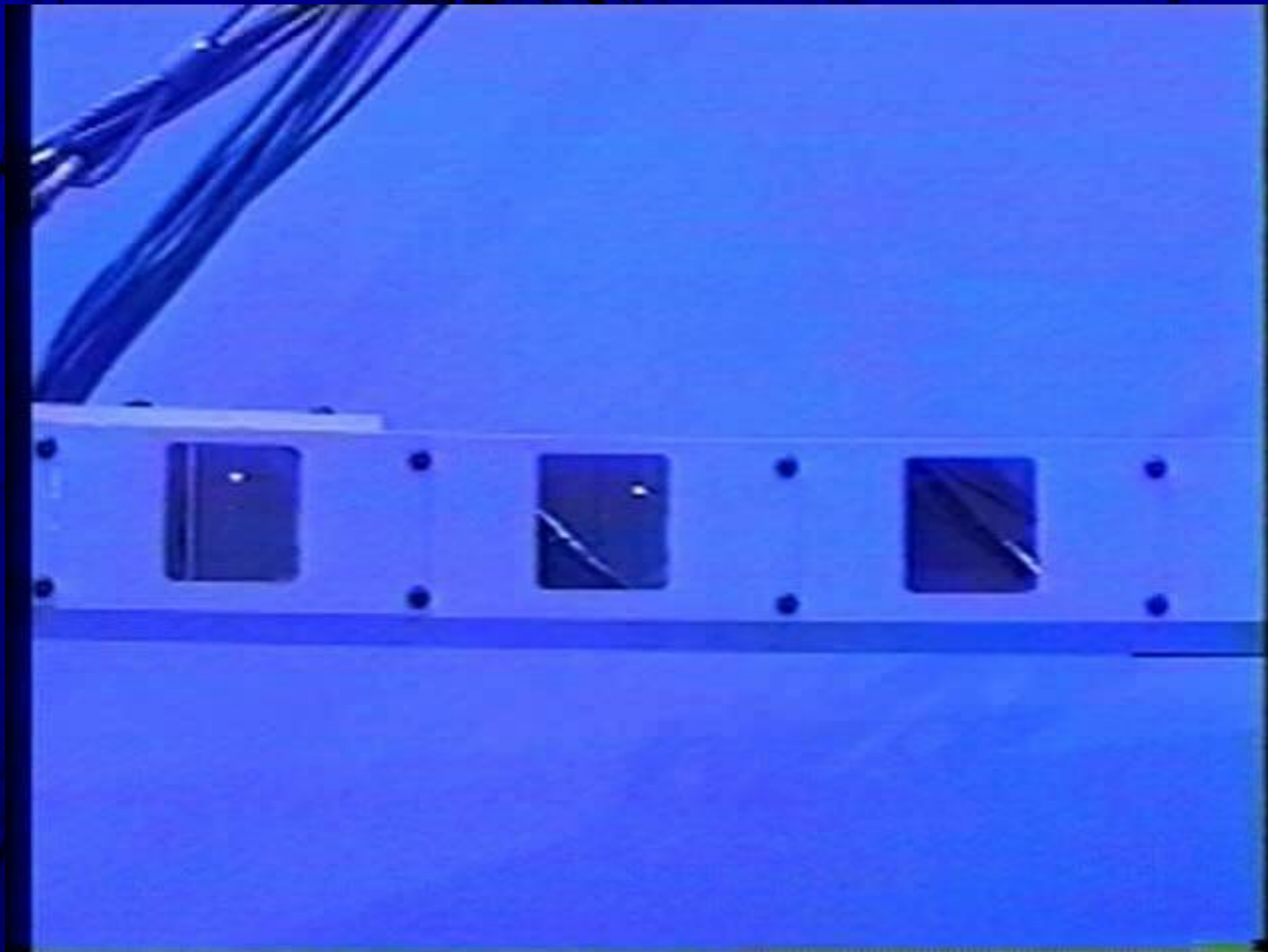
The appearance of the constructed DSVC system

Camera Calibration

Before filming, the location and direction of each camera was calibrated for the precise reconstruction of a 4D model of the human body movement.

Each cameras’ position and angle was reproduced in virtual space by the camera calibration based on the theory of the self-calibration method.



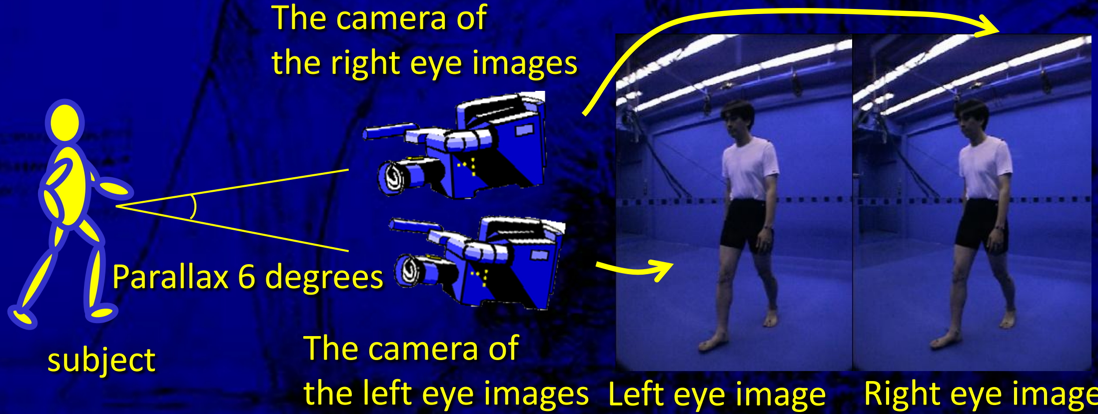


The free observation in viewpoints

An example of the free observation in view points during the subject is freezing.

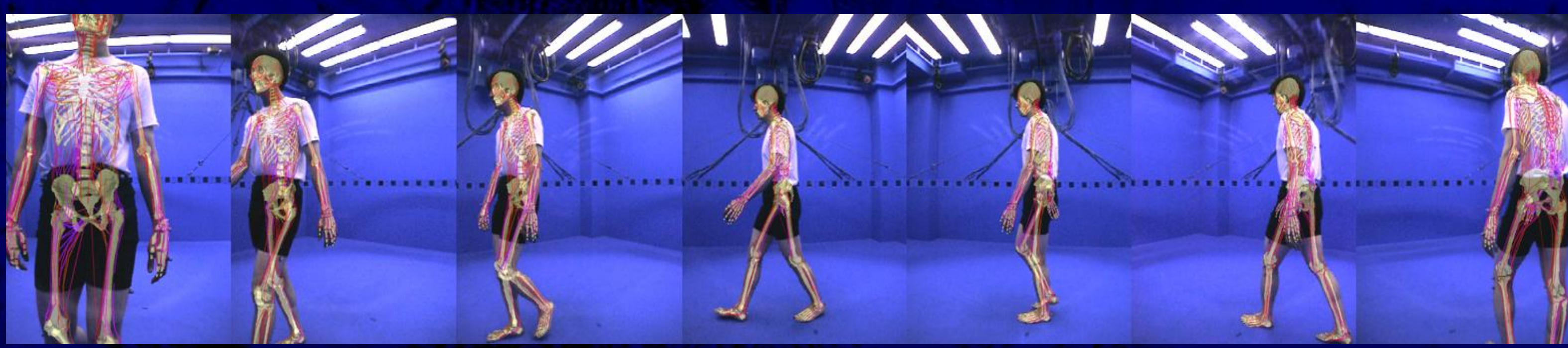
Time sequential image when the user try to observe the rhythmic sportive gymnastics locomotion by rotating the viewpoint clockwise.

Stereo view and Visualization of the inner structures



Enabling the stereo observation by indicating the neighboring camera image at each eyes.

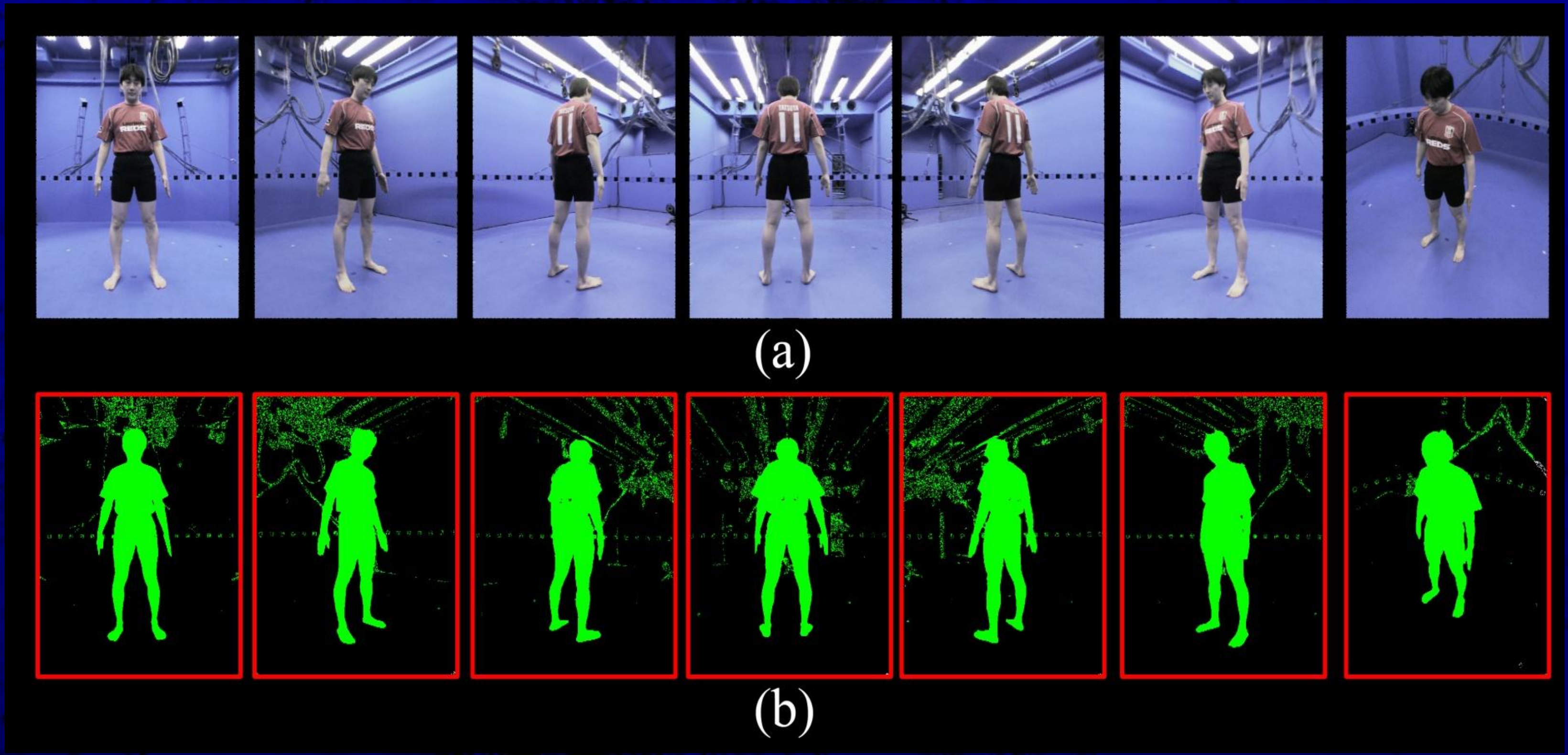
The inner structure of the subject was previously reconstructed from MRI data set and this image was super imposed to the live video image in all directions. The user is able to observe the condition of joints of bones or muscle in an interactive way.



Superimposed image of the subject’s skeletal and muscular system conditions while the subject is walking.

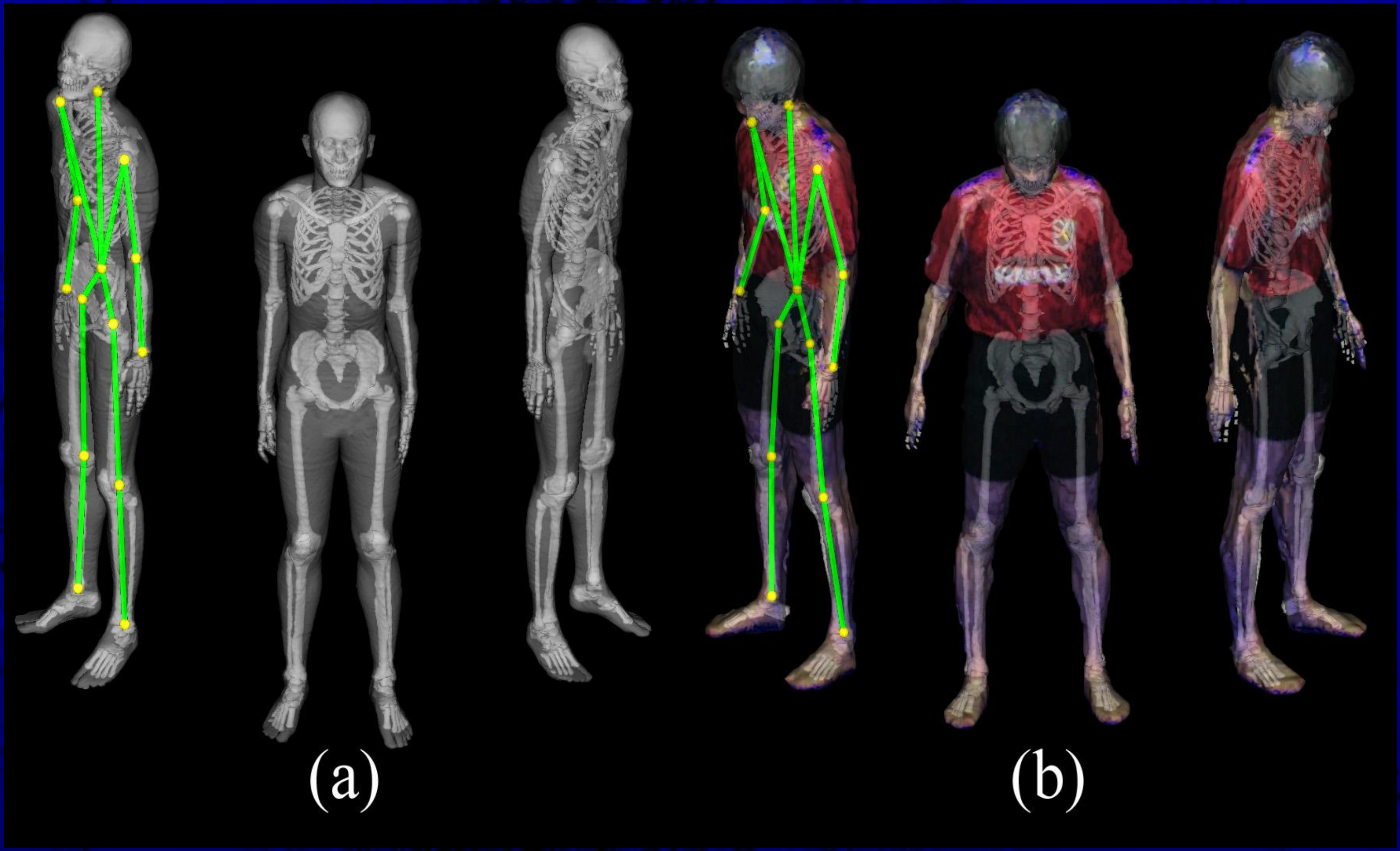
Extraction of subject’s shapes from captured images

Subject’s shapes in images are extracted from captured images by difference of pre-captured background images.



The Extraction of Subject’s shapes from captured images
(a: Captured images from DSVC, b: Extracted subject’s shapes)

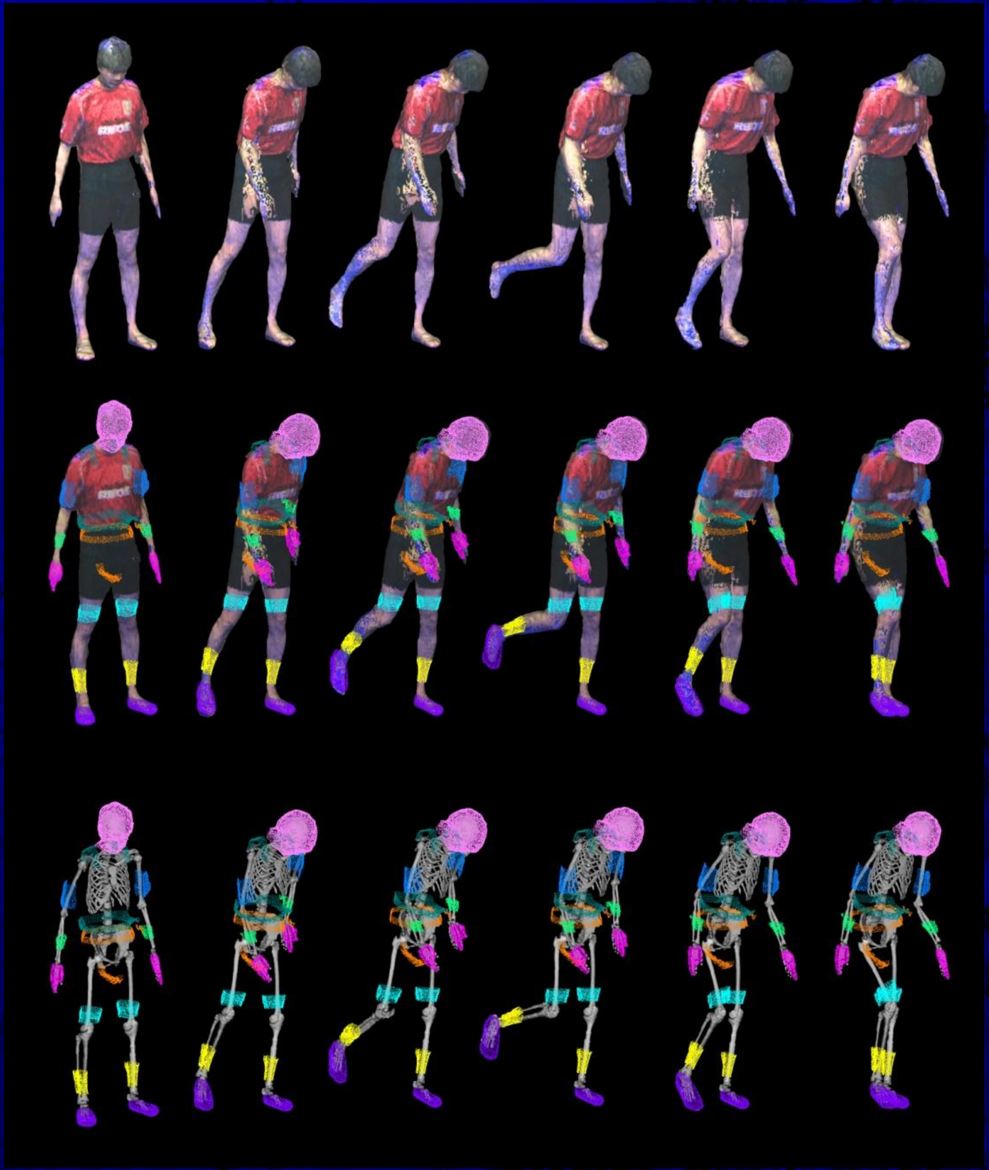
Resizing of the skeletal model with standard proportion



Resizing of the skeletal model
(a: skeletal model with standard proportion, b: constructed subject's skeletal model)

The subject's skeletal model was constructed by resizing the skeletal structure of the standard 4D human model based on distance differences between joints.

Tracking body surface movements in motion



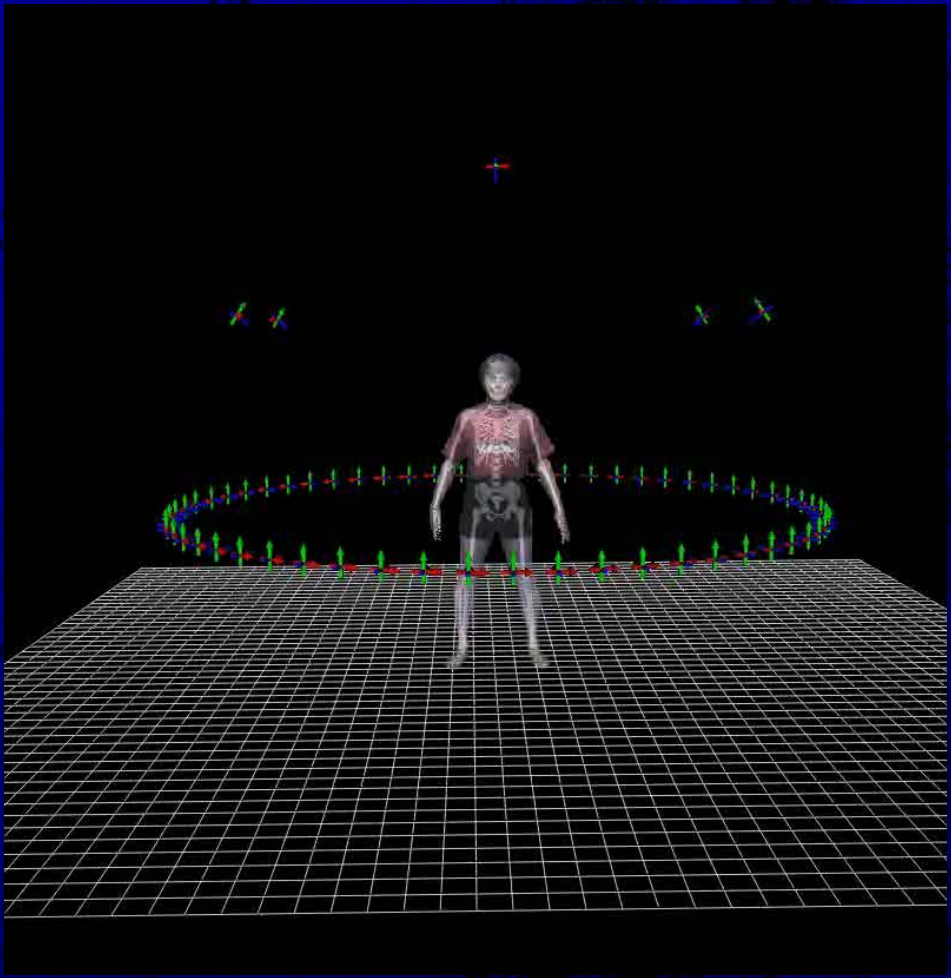
Time-series constructed from subject's body surface models during foot swing motion

Tracking of body surface movements based on geometrical changes of body surface shapes

Estimated dynamic skeletal structure in motion by tracking body surface movements

An estimation of 4D skeletal structure in foot swing motion

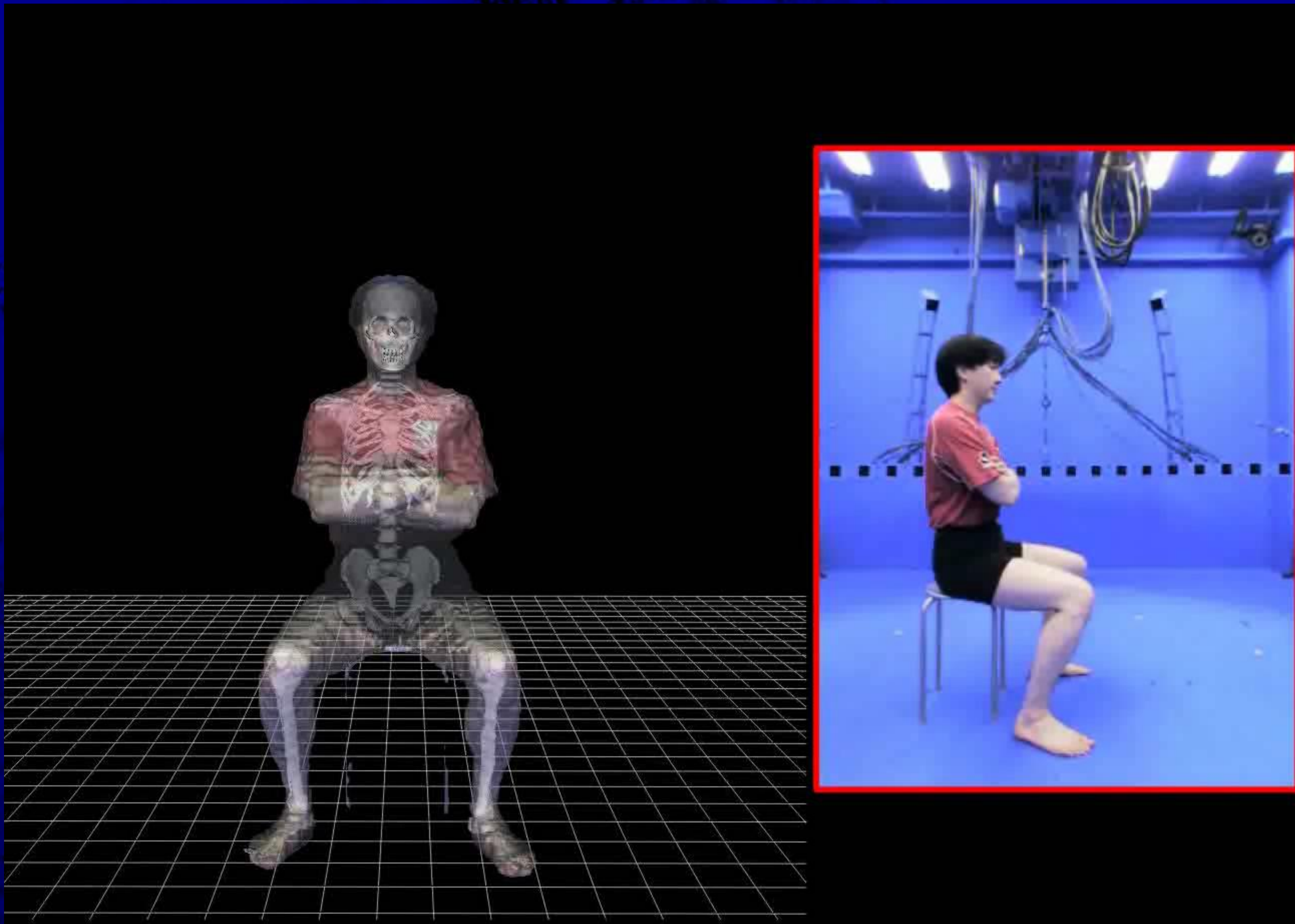
An estimation of 4D skeletal structure in motion

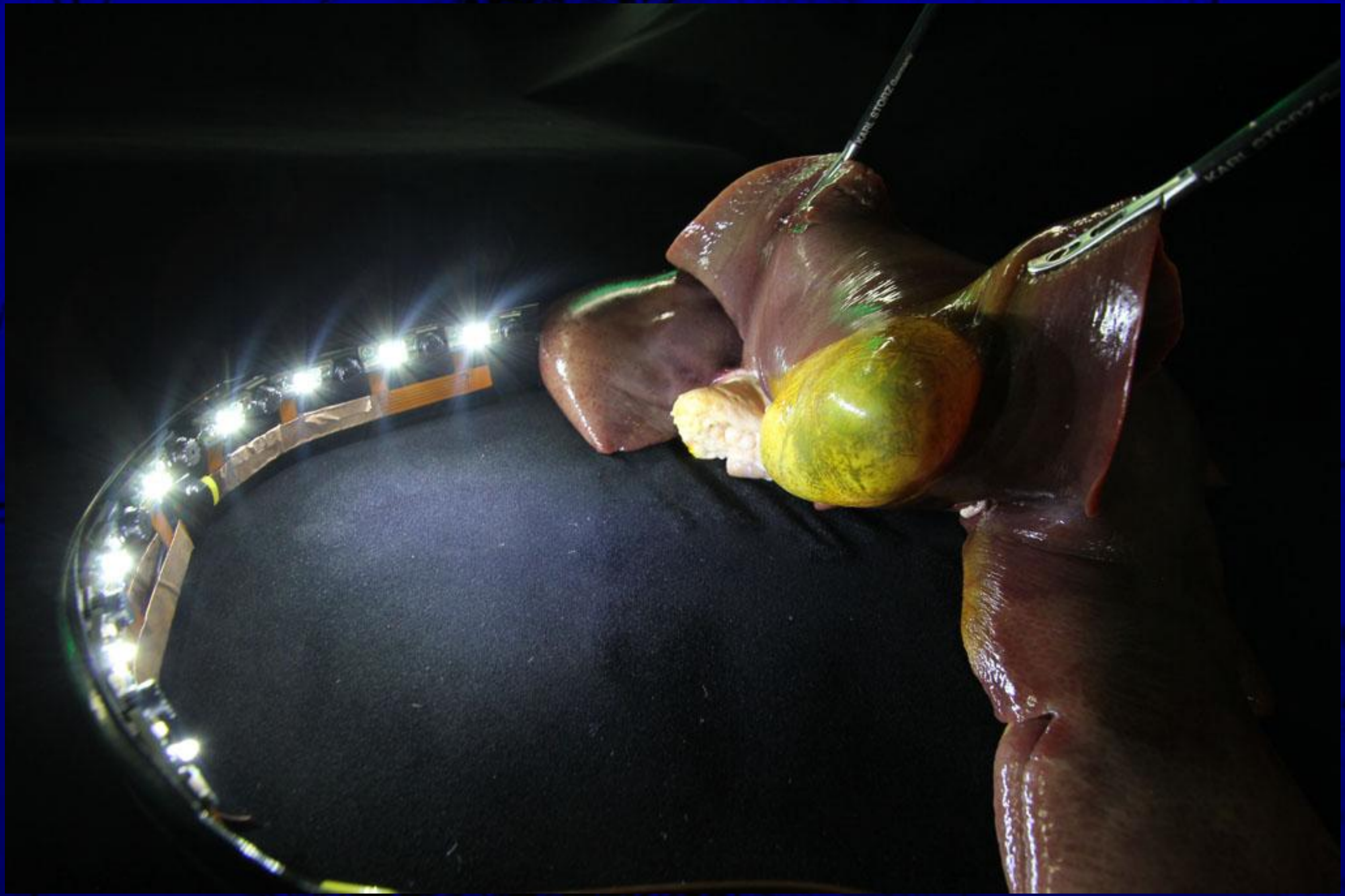


The dynamic skeletal state of the swinging foot was visualized by applying tracking data and constructed subject's skeletal model data.

Observations of the dynamic skeletal state could be made from any viewpoint and at any time with the developed software.

Observing the results of estimated dynamic skeletal state in motion superposed on a 4D body surface model

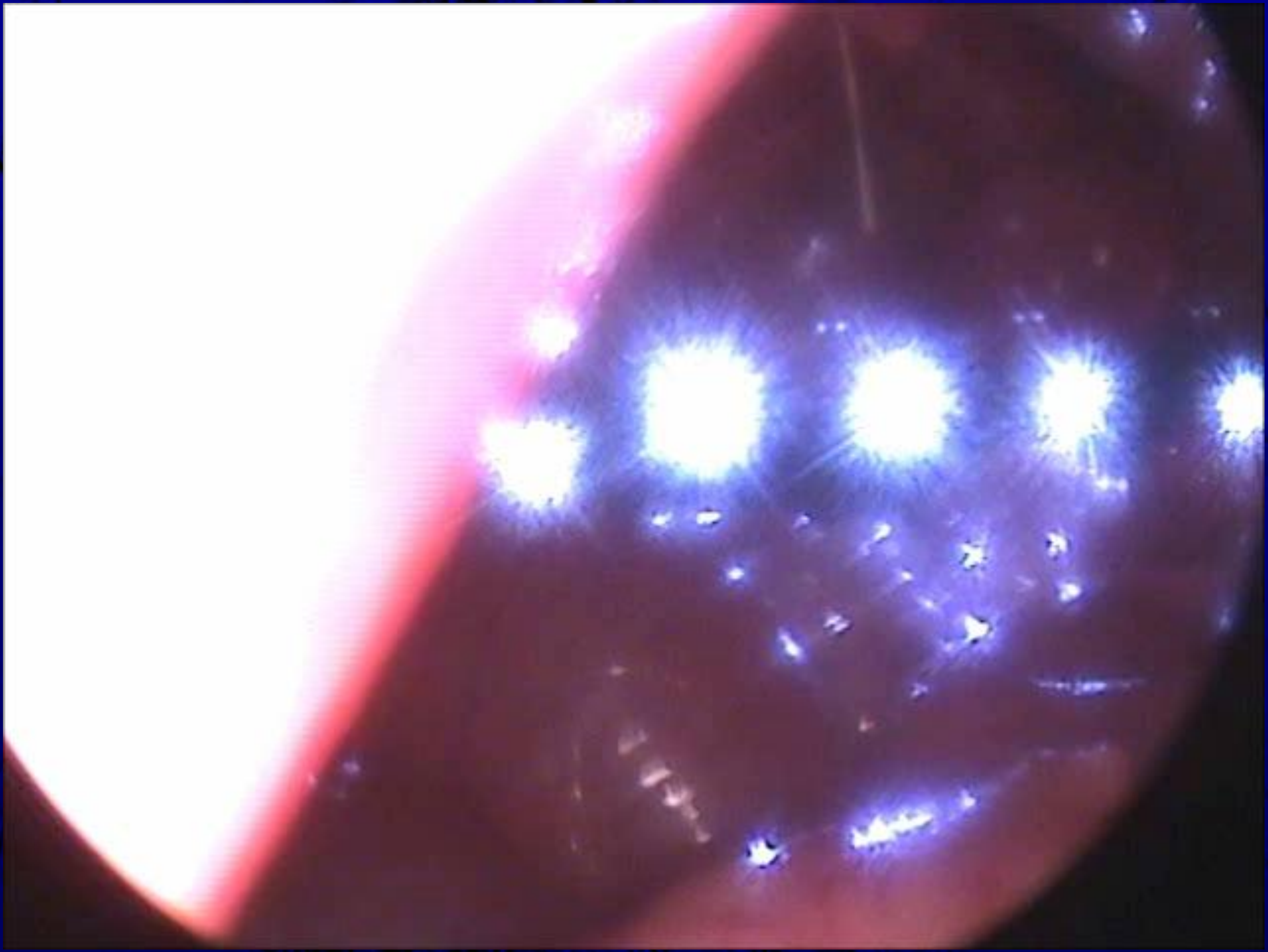


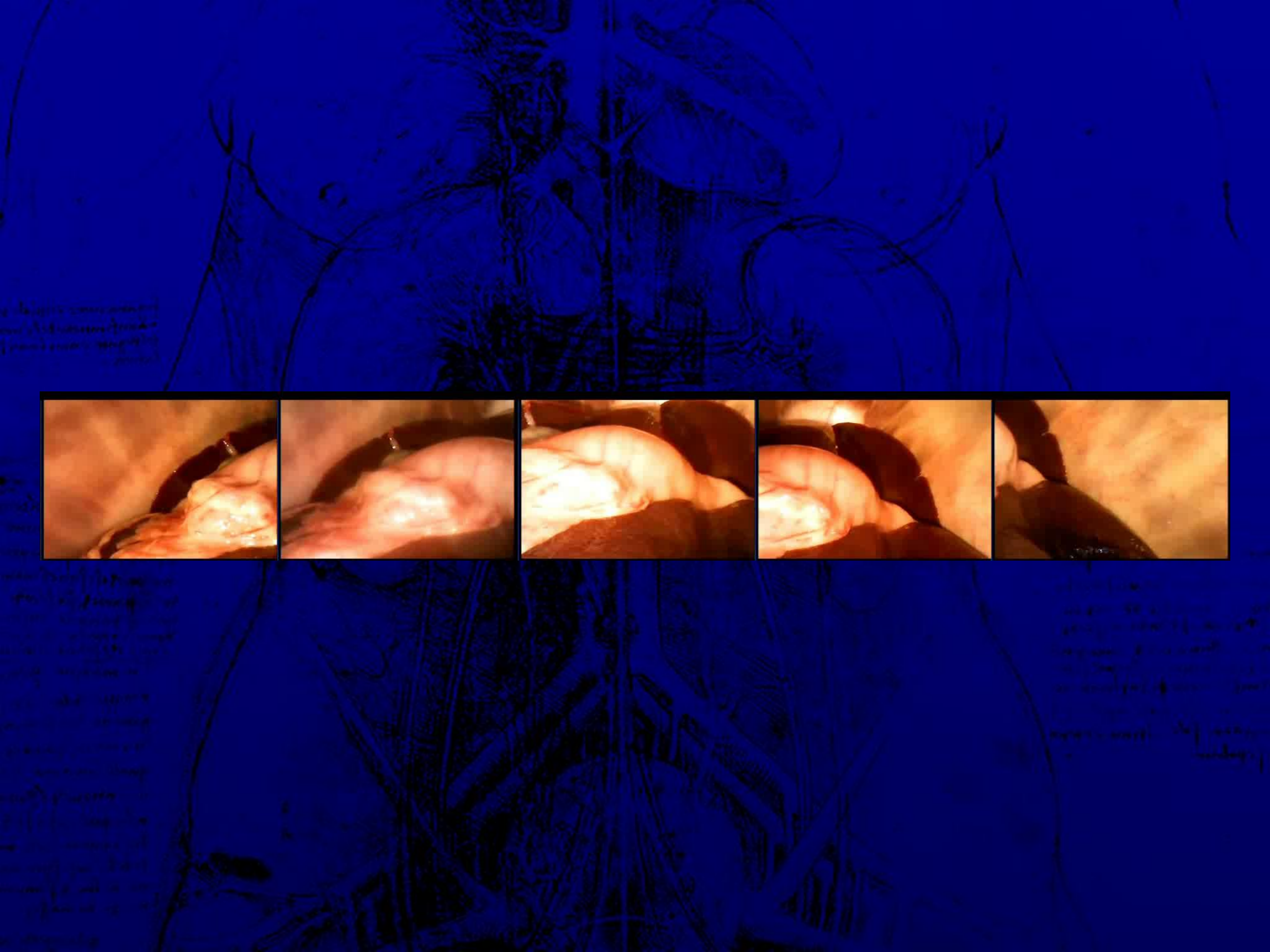


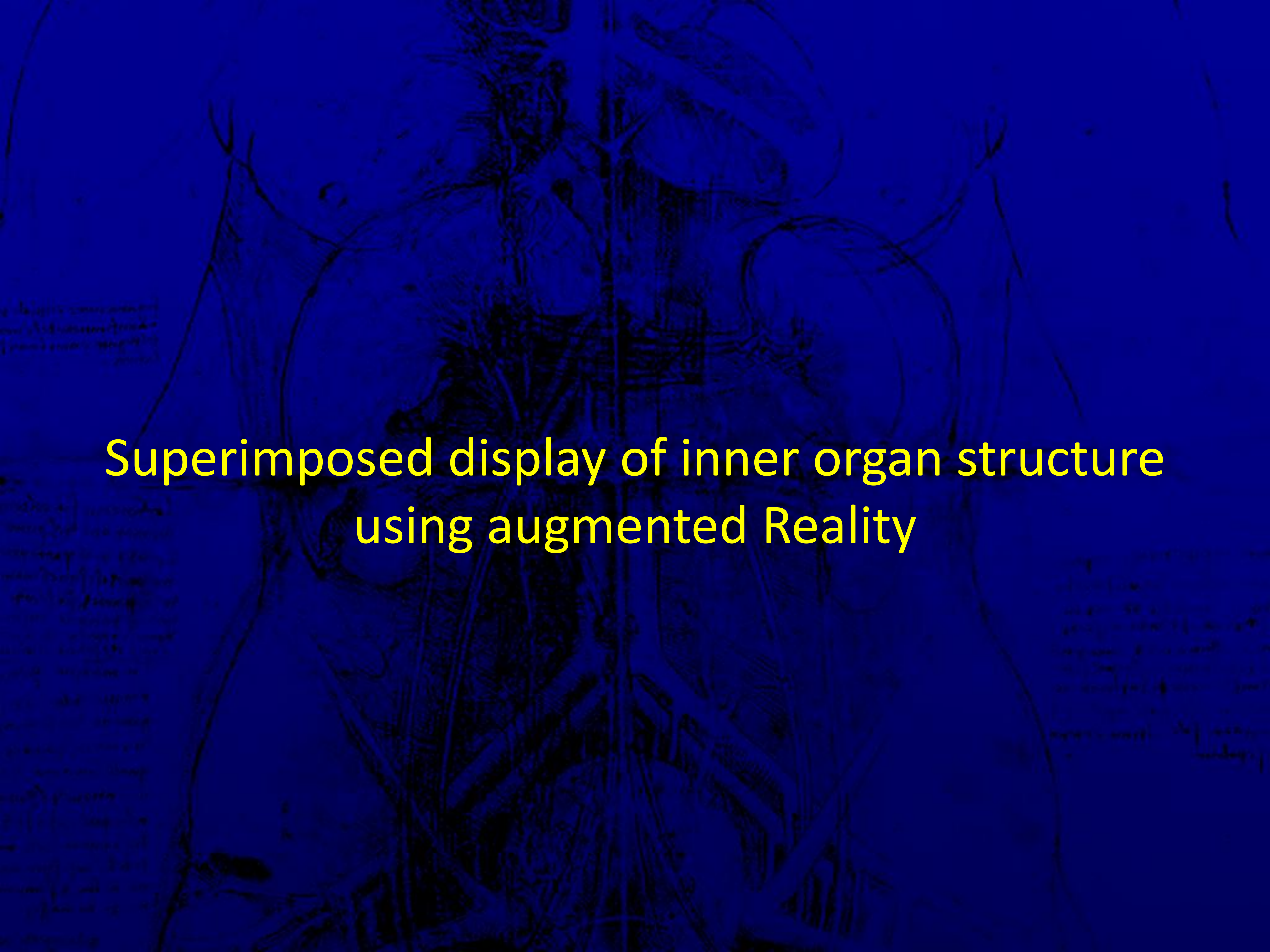
Multi-view camera system in an experiment using extracted liver with gall bladder

Obtaining intraperitoneal images from animal experiment

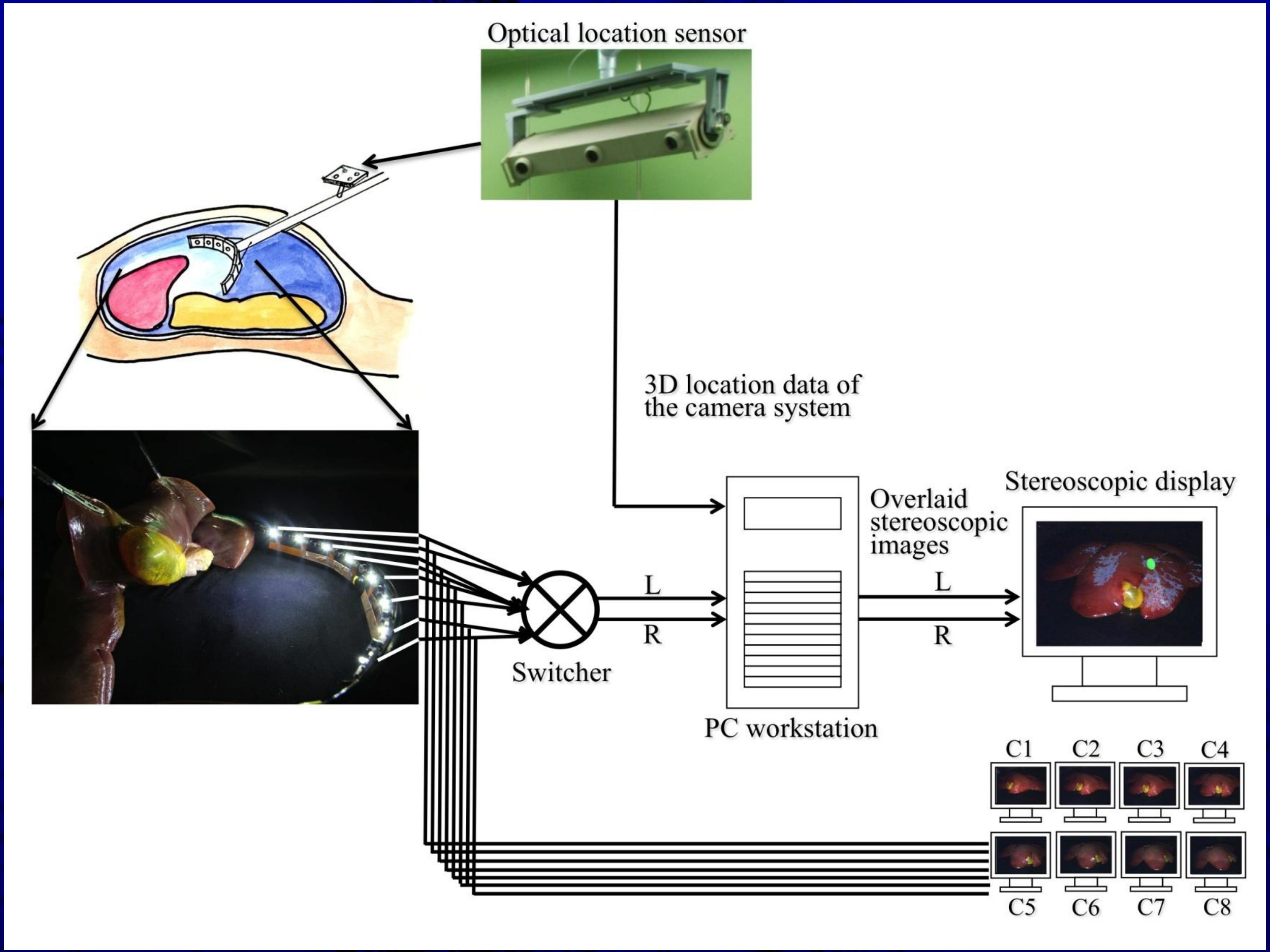
We conducted verification experiment of the function under in vivo environment. Using 4 swines weighing 35 to 40 kg, we inserted this system in the abdominal cavity under anesthetic conditions.



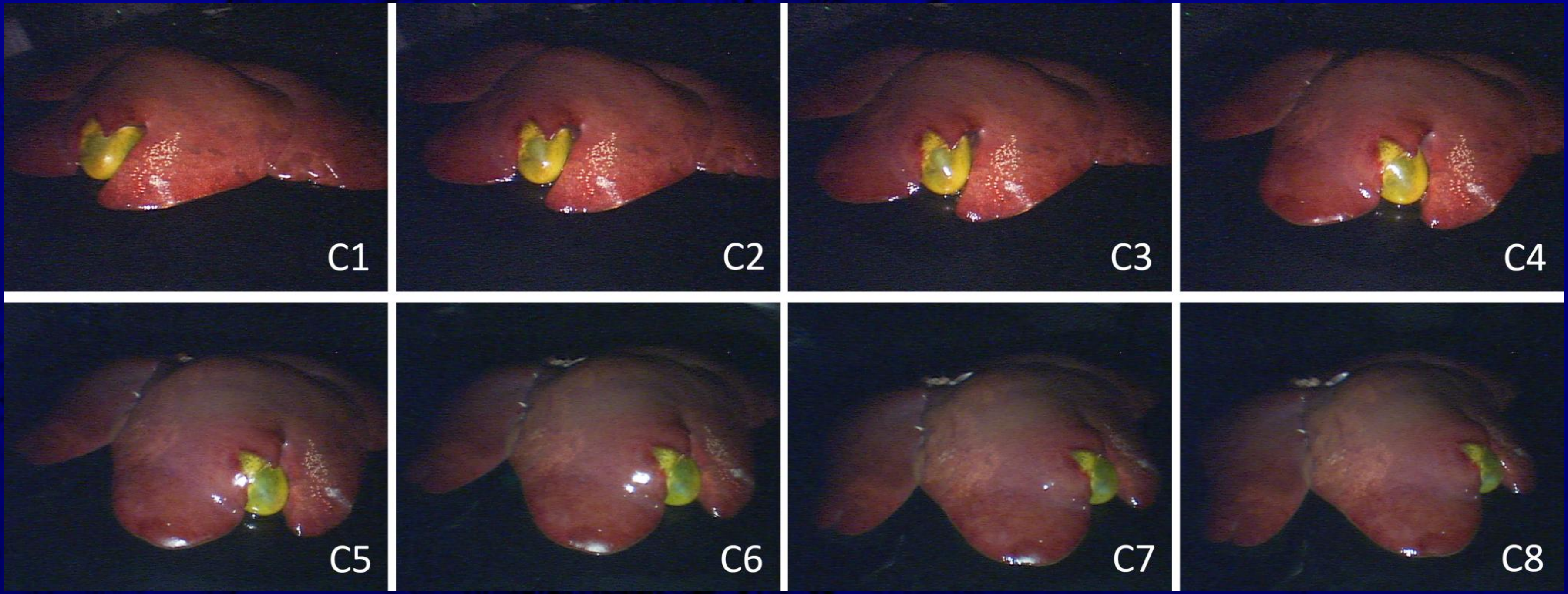




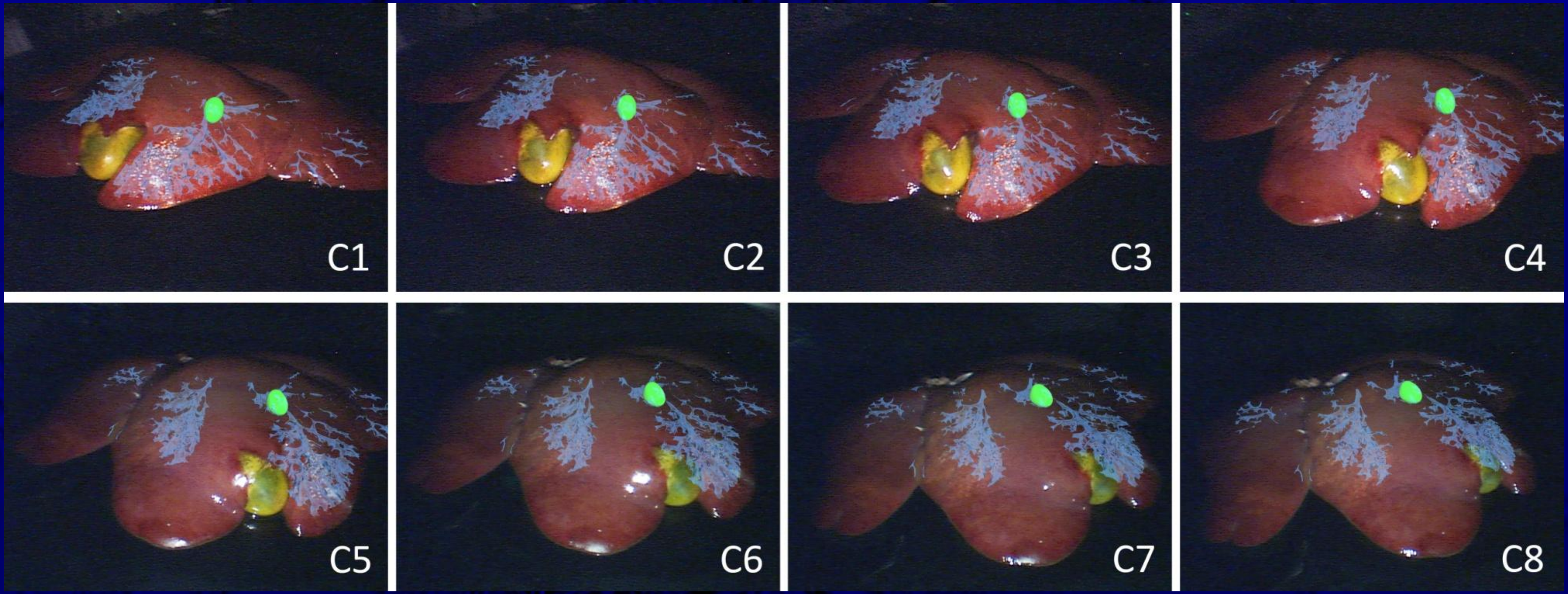
Superimposed display of inner organ structure using augmented Reality



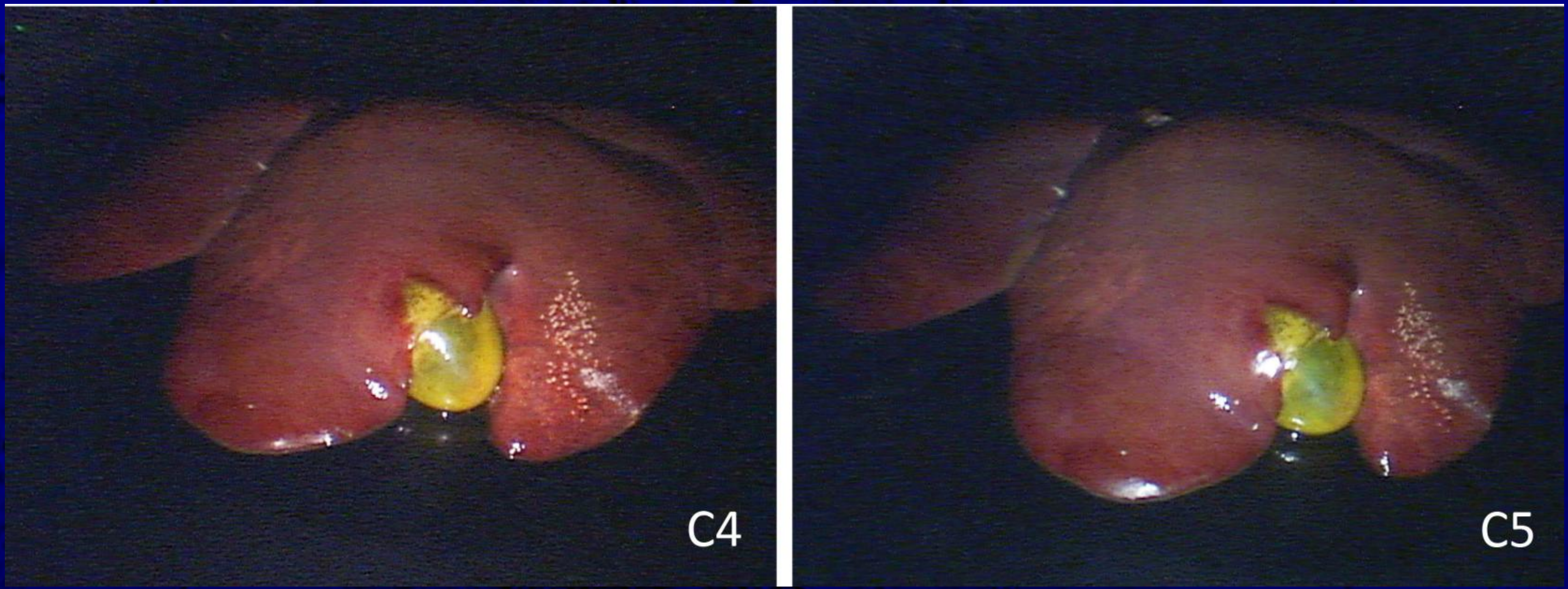
Device composition of the system



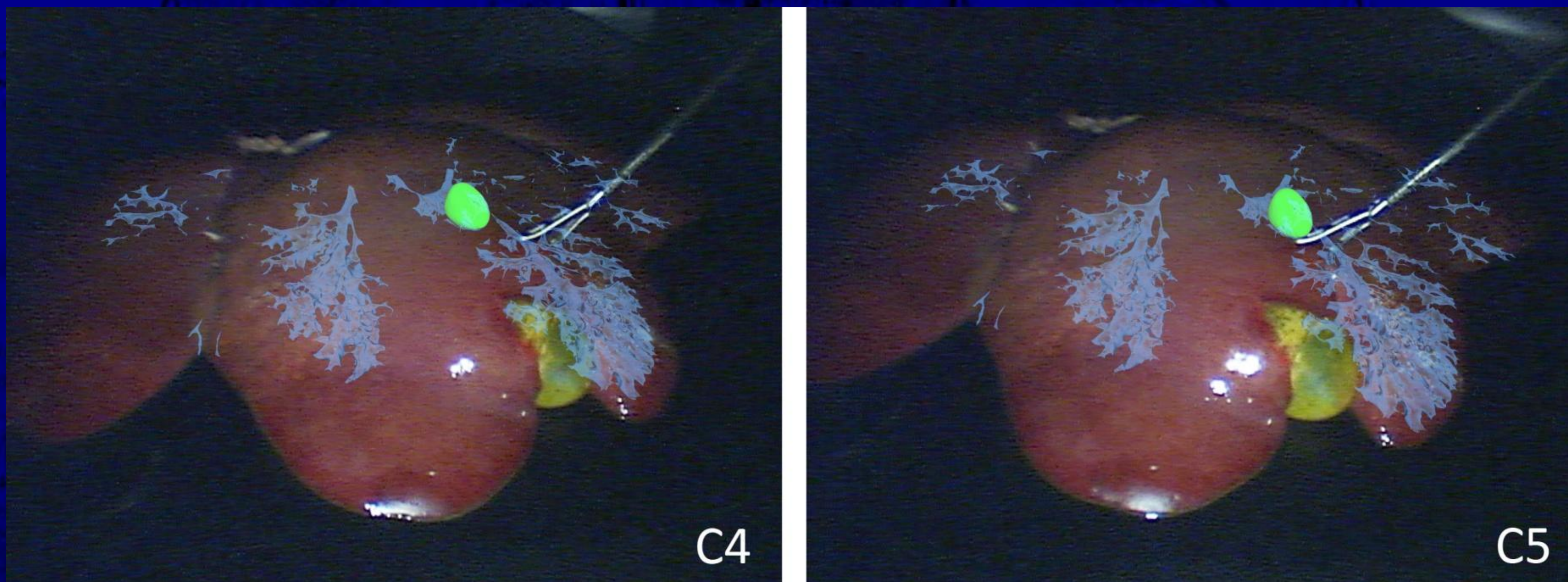
Images obtained from each viewpoint when the camera system surrounds the extracted swine liver with gall bladder



Superimposed display of images obtained from each view-point of part of the vessels and artificial tumor inside liver using extracted swine liver



Stereoscopic images from a view-point when the camera system surrounds the extracted swine liver with gall bladder



Stereoscopic images from cameras next to each other (camera 4 and 5) of part of the vessels and artificial tumor inside liver using extracted swine liver. Surgeon bringing laparoscopic surgical forceps close to the artificial tumor depending on superimposed display images.

Obtaining more unrestricted view

1) 3D comprehension of the operative field by unrestricted view

2) Observe the inner structure in the 3D surface configuration by the unrestricted view approach

Real-time acquisition of 3D surface configuration and it's spatial composition with the inner structure

1) Obtain surface configuration by calculating disparity map and point cloud of the organ surface by using 2 neighboring cameras.
2) The point cloud of organ surface is fed color texture acquired from camera images.
3) Compose point cloud and inner structure model constructed from X-ray CT data in 3D space

Basic research of this Project 4

Acquisition of real time 3D information
in surgical field

Application for Laparoscopic Surgery

2004

System configuration

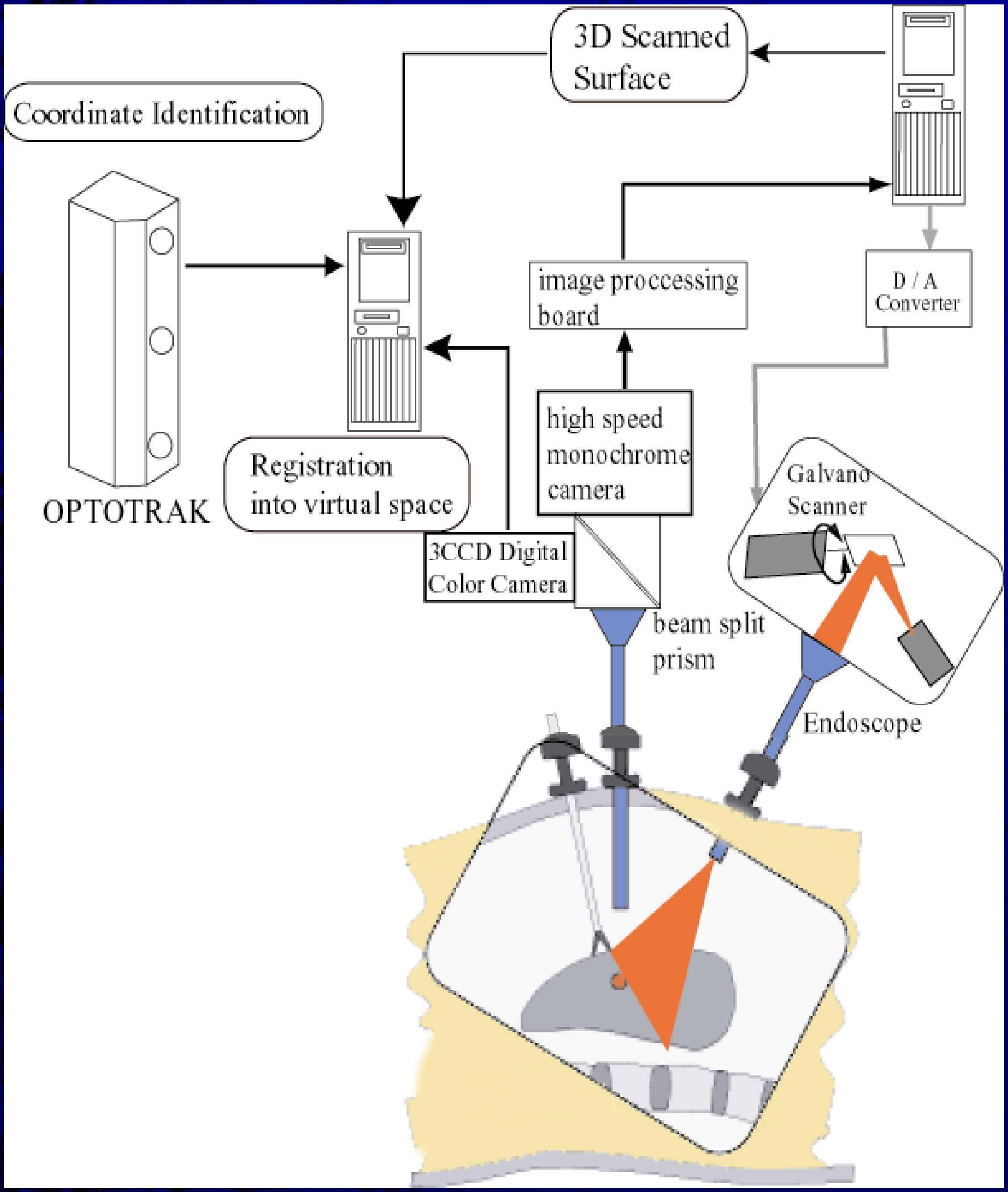
Laser scan control
Fast image processing

3D geometric measurement
Signal synchronization with shared memory board

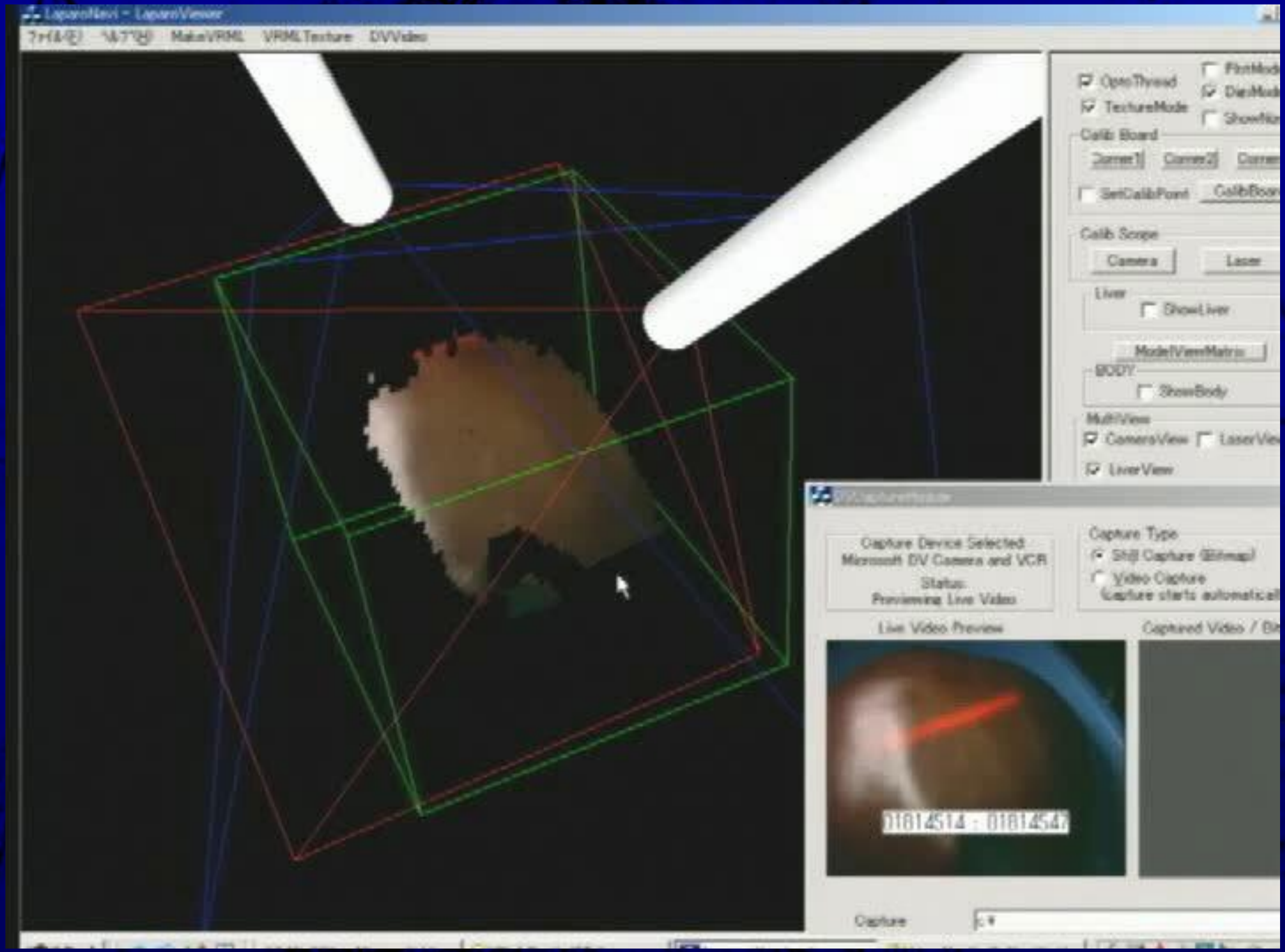
Real-time measurement and visualization

Coordinate identification
Texture rendering

Image-based rendering
Information display



Real-time imaging of a deformable organ

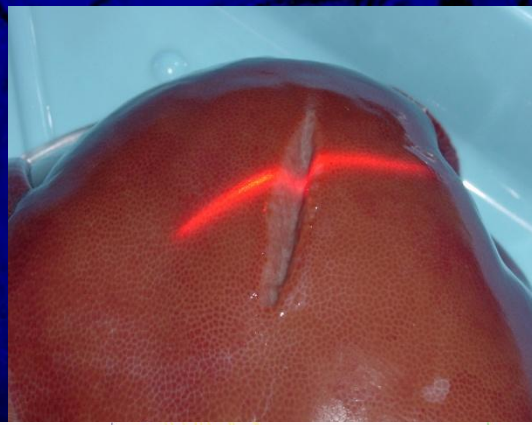


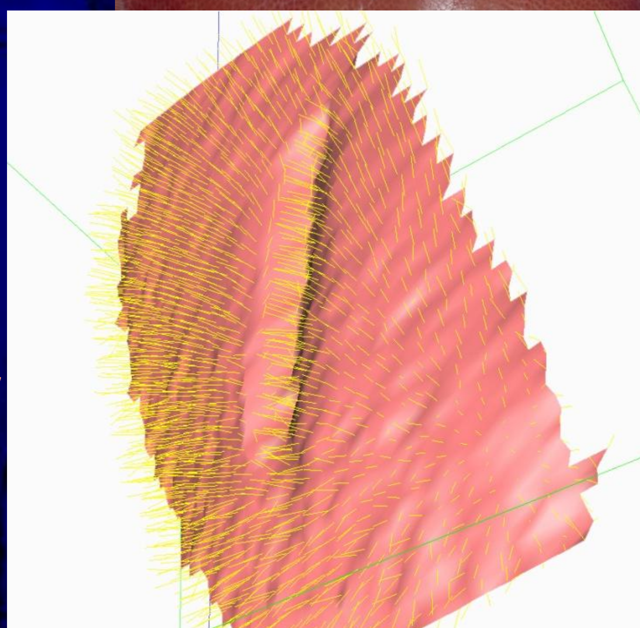
Measurement of an isolated pig liver surface

At present, the frame rate of shape visualization is 4 ~ 5 fps if 20 lines are used for surface reconstruction.

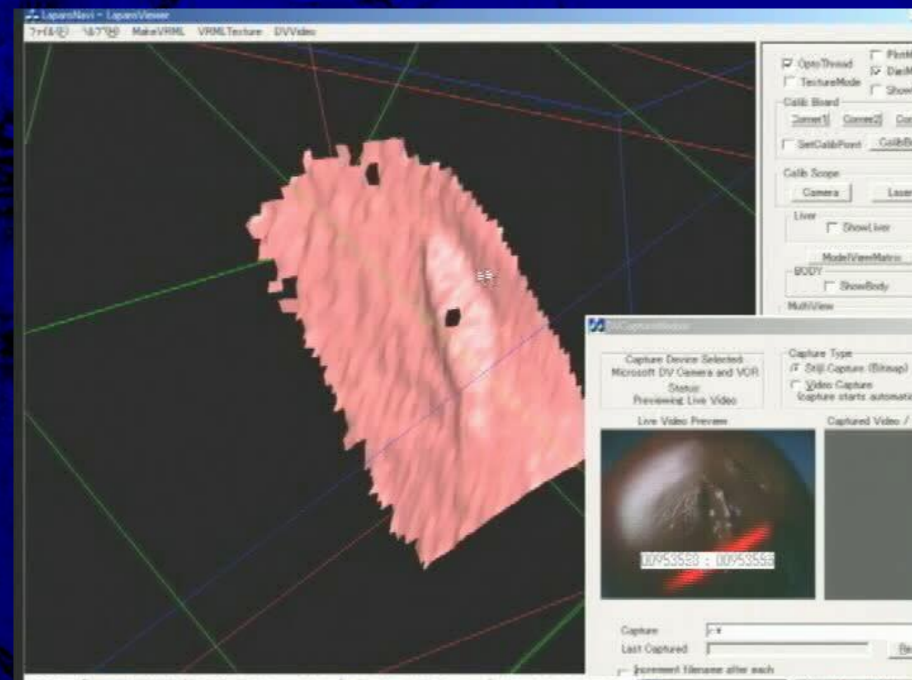
Measurement of incisions on liver surface

depth
7mm
length
44mm





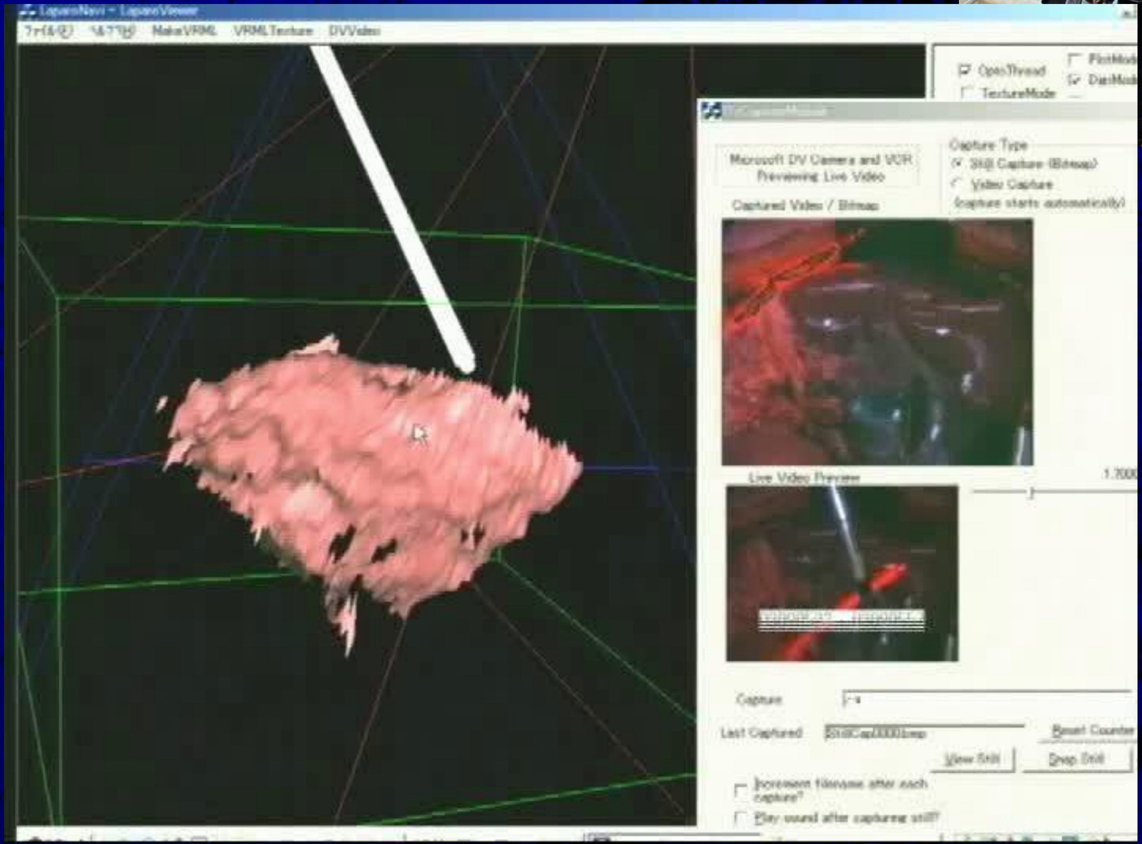
Yellow lines show normal vectors



The shape and texture of the incision on the liver are measured.

Incisions on the surface of a pig liver were measured successfully.

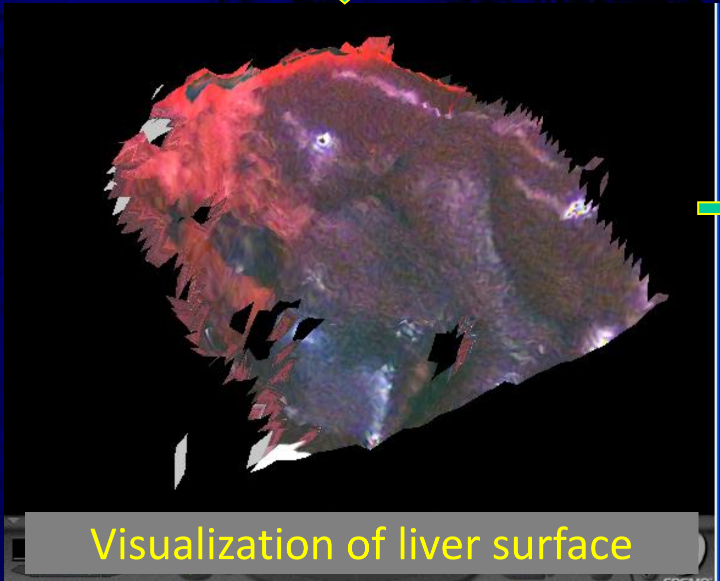
Warning by sound
to give a depth perception



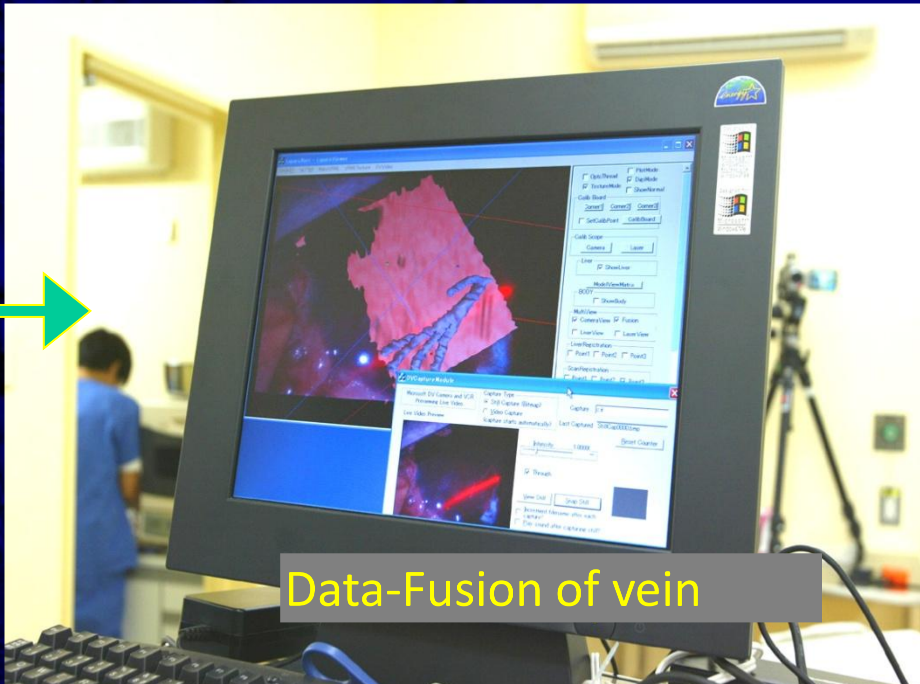
In-vivo experiment using pig liver

In-vivo experiment

Abdominal CT scans using contrast medium



Visualization of liver surface



Data-Fusion of vein

In-vivo experiment using pig liver

Obtaining more unrestricted view

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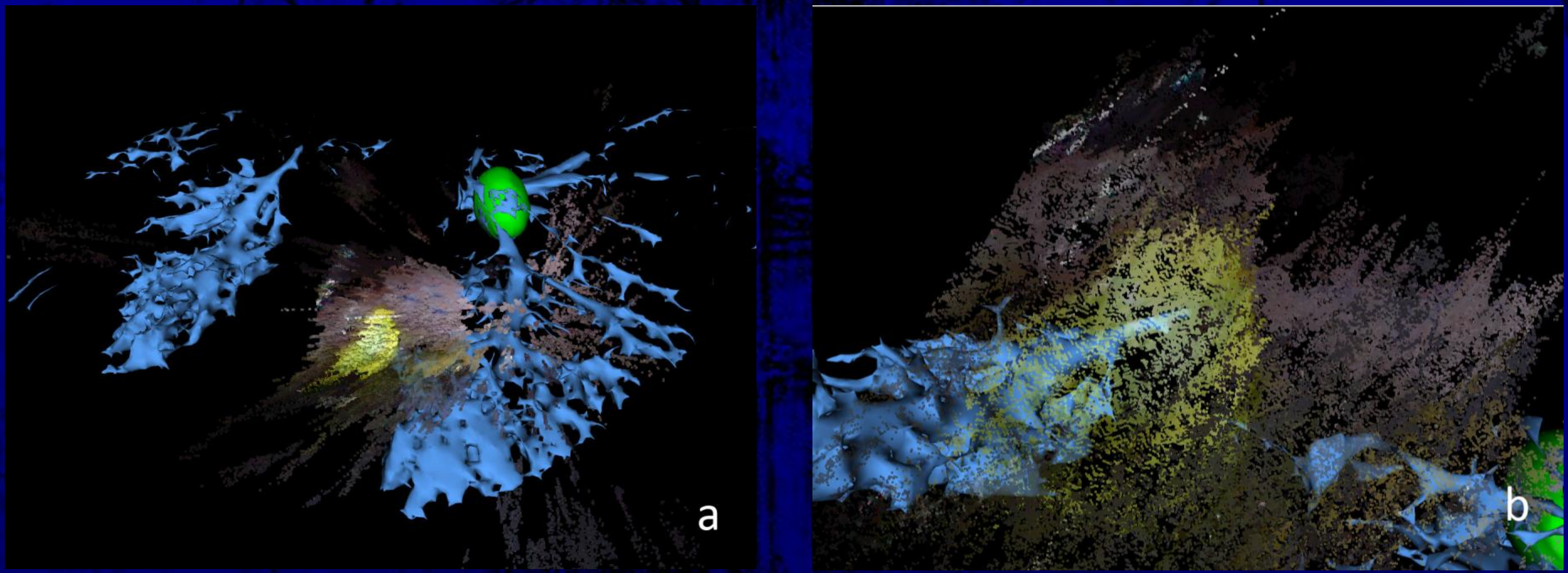
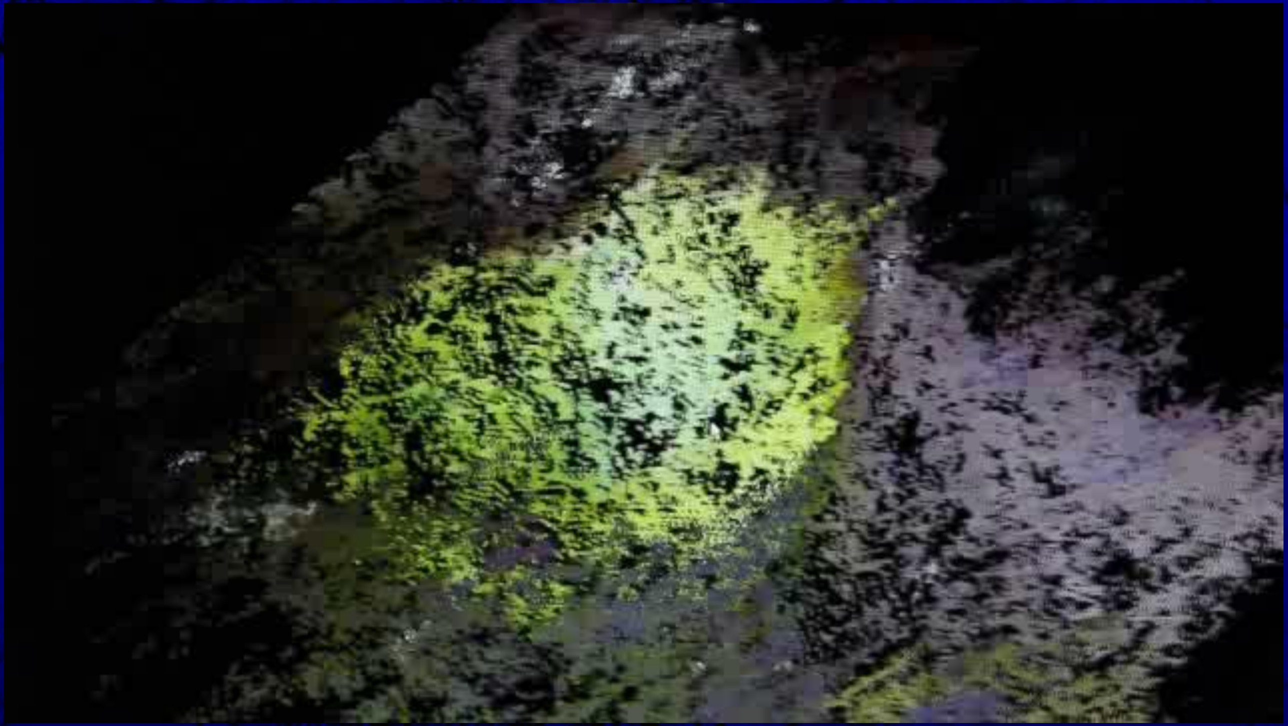
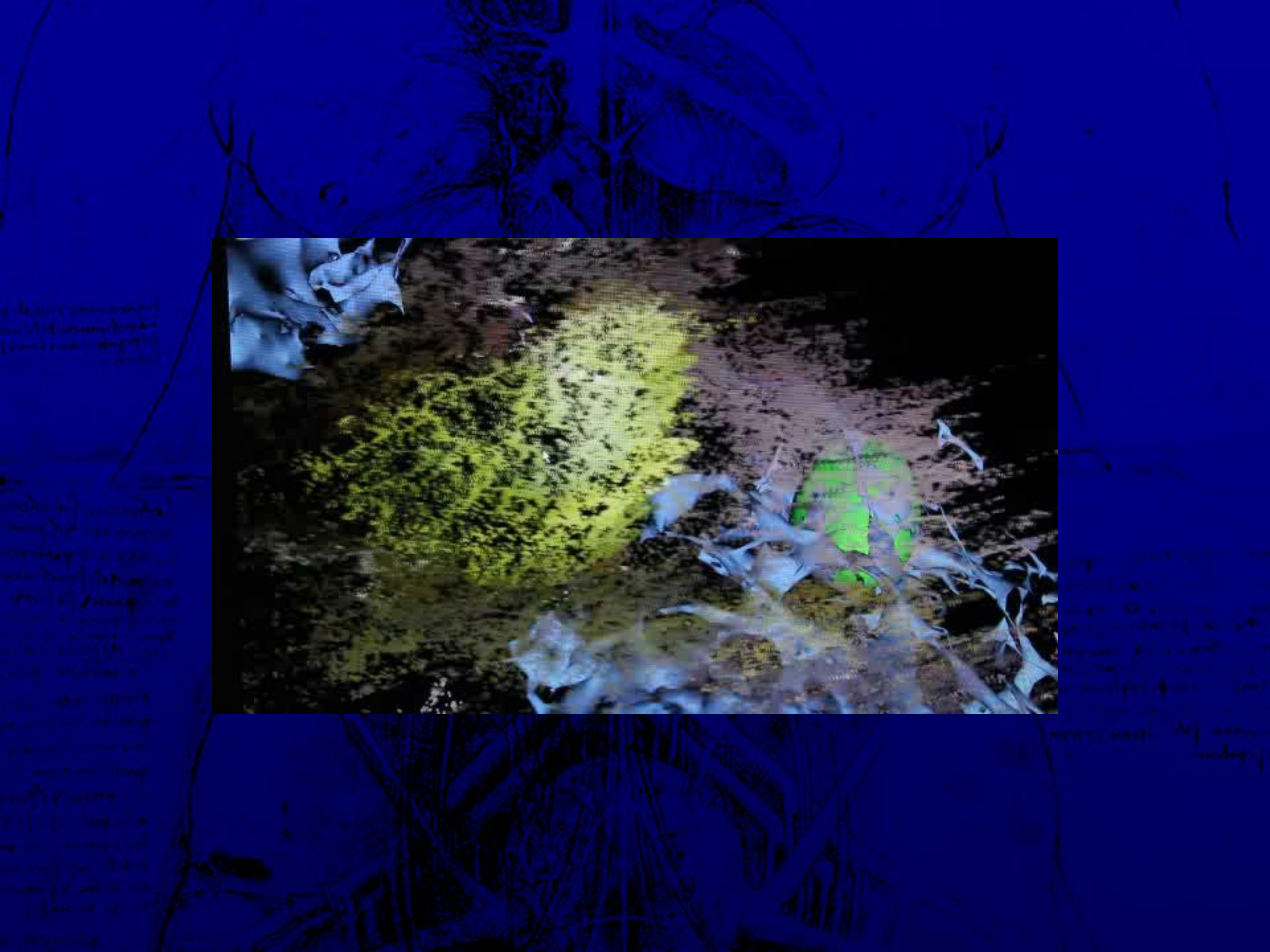
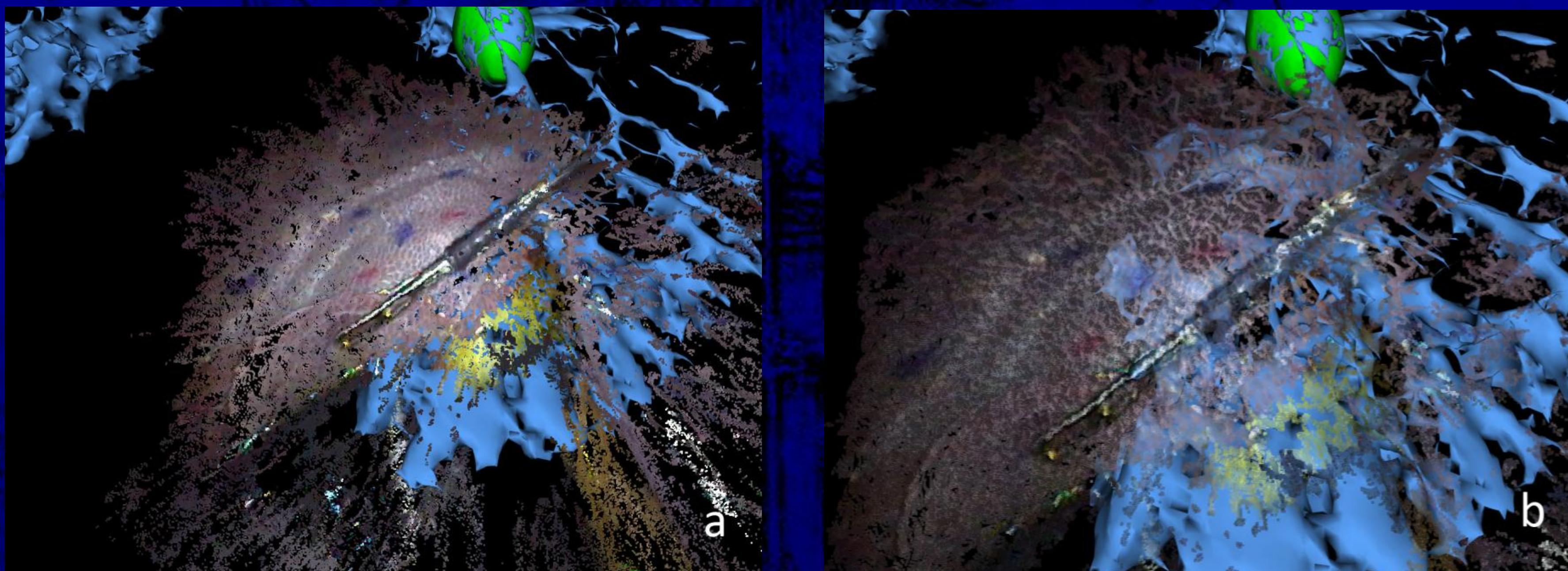
3) Compose point cloud and inner structure model constructed from X-ray CT data in 3D space



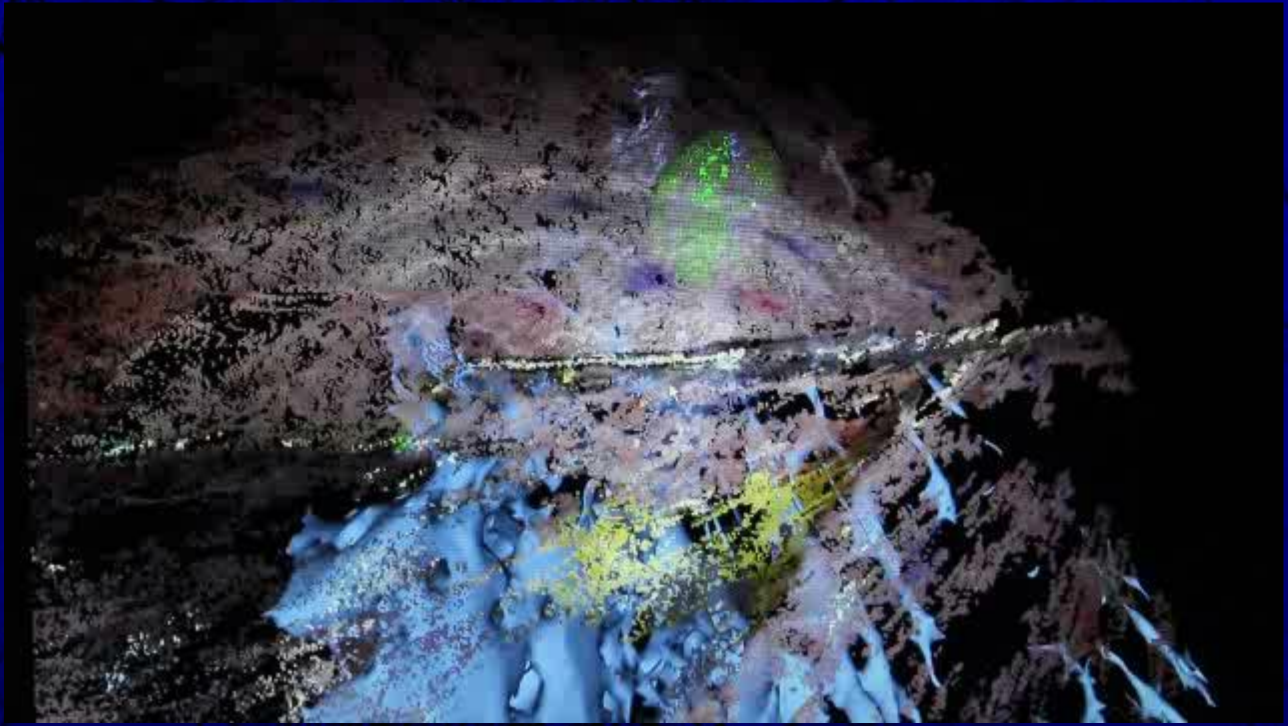
Spatial composed image of reconstructed liver surface near the gall bladder and the 3D models of the inner vascular structure (blue) and artificial tumor (green).







Spatial composed image of reconstructed liver surface near the gall bladder and the 3D models of the inner vascular structure and artificial tumor. The forceps grasping the liver are also reconstructed in 3D.



Conclusion 1

- The most important function of this system is that it can move viewpoints of images (mono / stereo) without physically moving the camera.

- It also is able to view targeted parts from various viewpoints which realizes different kinds of observation using augumented reality techniques.

- It prevents clashes of soft tisses with laparoscopes or surgical tool where conventional laparoscopes could not see.

Conclusion 2

We found that it is possible to observe the inner structure that corresponds to the organ surface changes including surgical apparatus position during surgery.

But,

One pair of stereo images can only reconstruct a small area of liver surface configuration.

It tends to be difficult in calculating disparity map from stereo image by lacking characteristics in liver surface texture.

Future solutions

One pair of stereo images can only reconstruct a small area of liver surface configuration

Update the liver surface configuration in the operative field using more than one pair of stereo images

It tends to be difficult in calculating disparity map from stereo image by lacking characteristics in liver surface texture

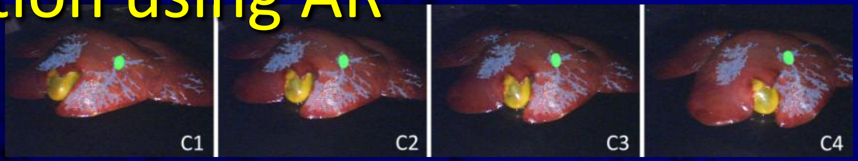
Make it easier to construct disparity map by enhancing the features of minute liver surface patterns and anatomical characteristics of peripheral zone

Use obtained images for different purposes

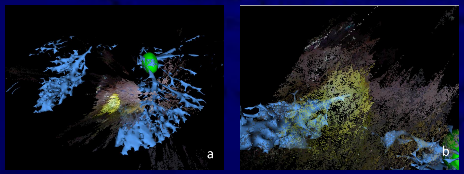
1) Images used for actual surgery under unrestricted environment

- Acquire visuals putting surgeon's experience into use

2) Strengthening visual information using AR



3) Obtain greater field of view without restriction of camera viewpoint



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Grasp entire situation of the abdomen, carryout safety control

Our goal is to formulate new Laparoscopic imaging system with augmented reality functions that could be used in next generation laparoscopic and robotic surgeries.