Design Process

Models of the Engineering Design Process

Engineering

Definition

"… Scientists discover the world that exists; Engineers create the world that never was …"

Theodore Von Karman, Aerospace engineer

"… Scientists dream about doing great things. Engineers do them…."

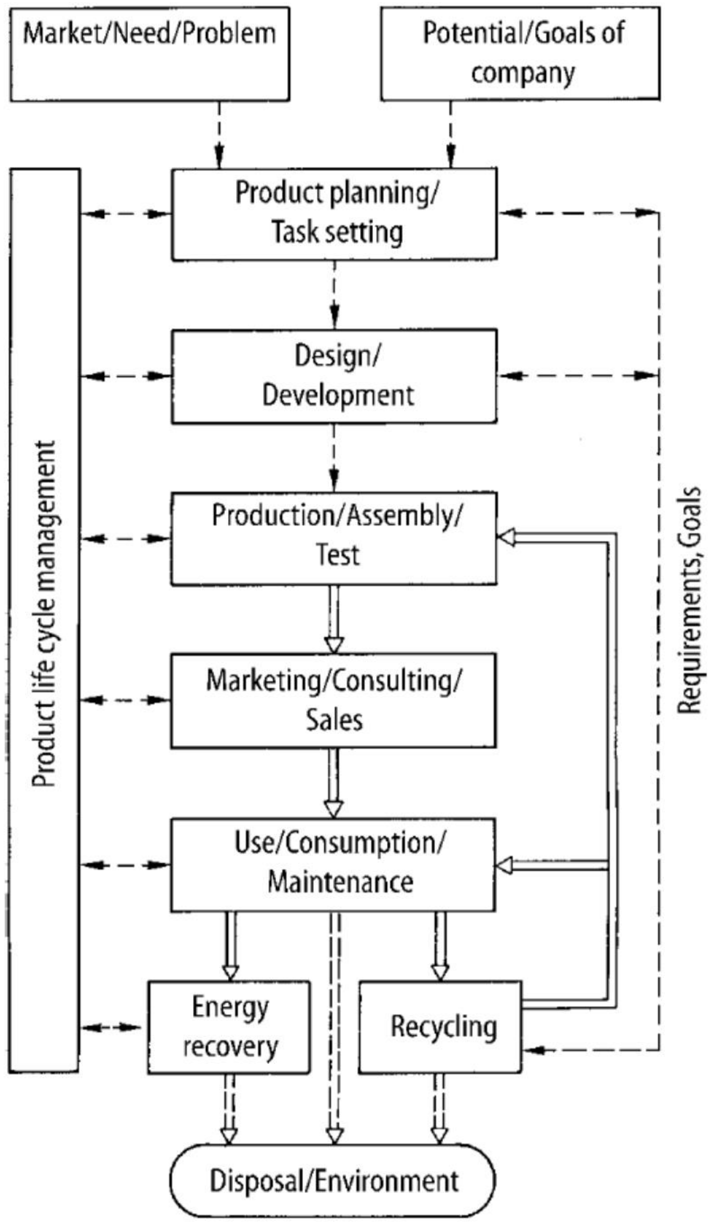
James A. Michener, Novelist

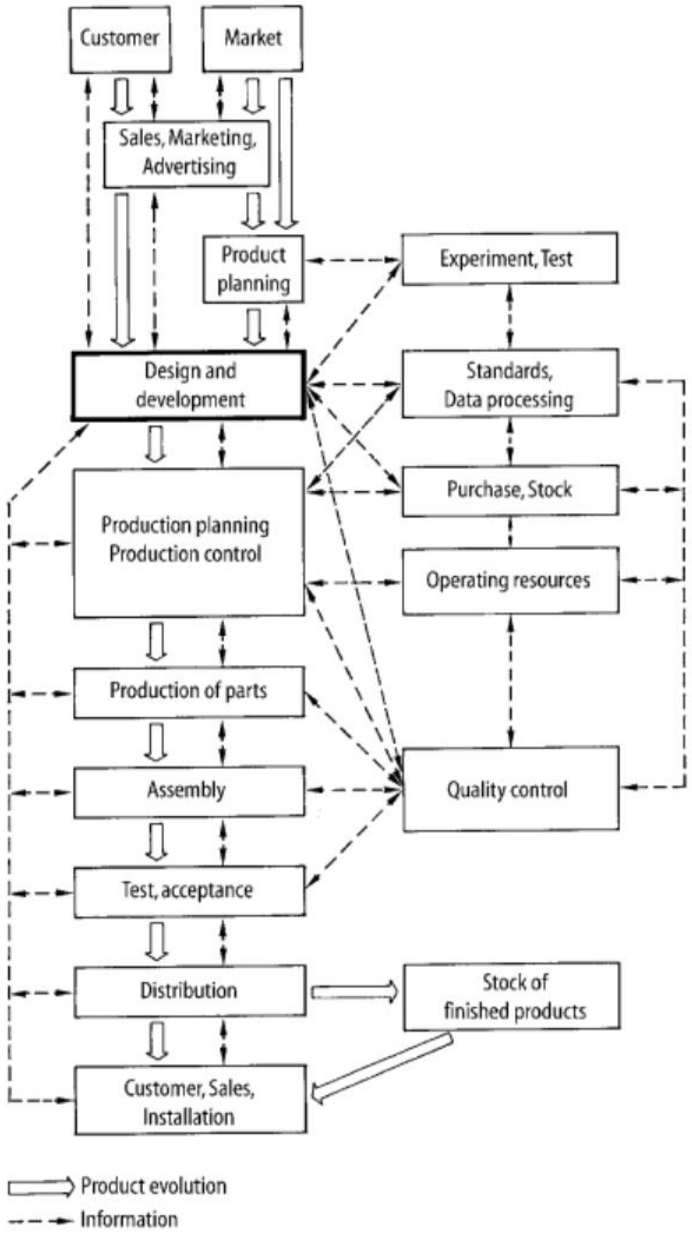
"... No profession unleashes the spirit of innovation like engineering. From research to real world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive effect on people's everyday lives. We are counting on engineers and their imaginations to help meet the needs of the 21st century ..."

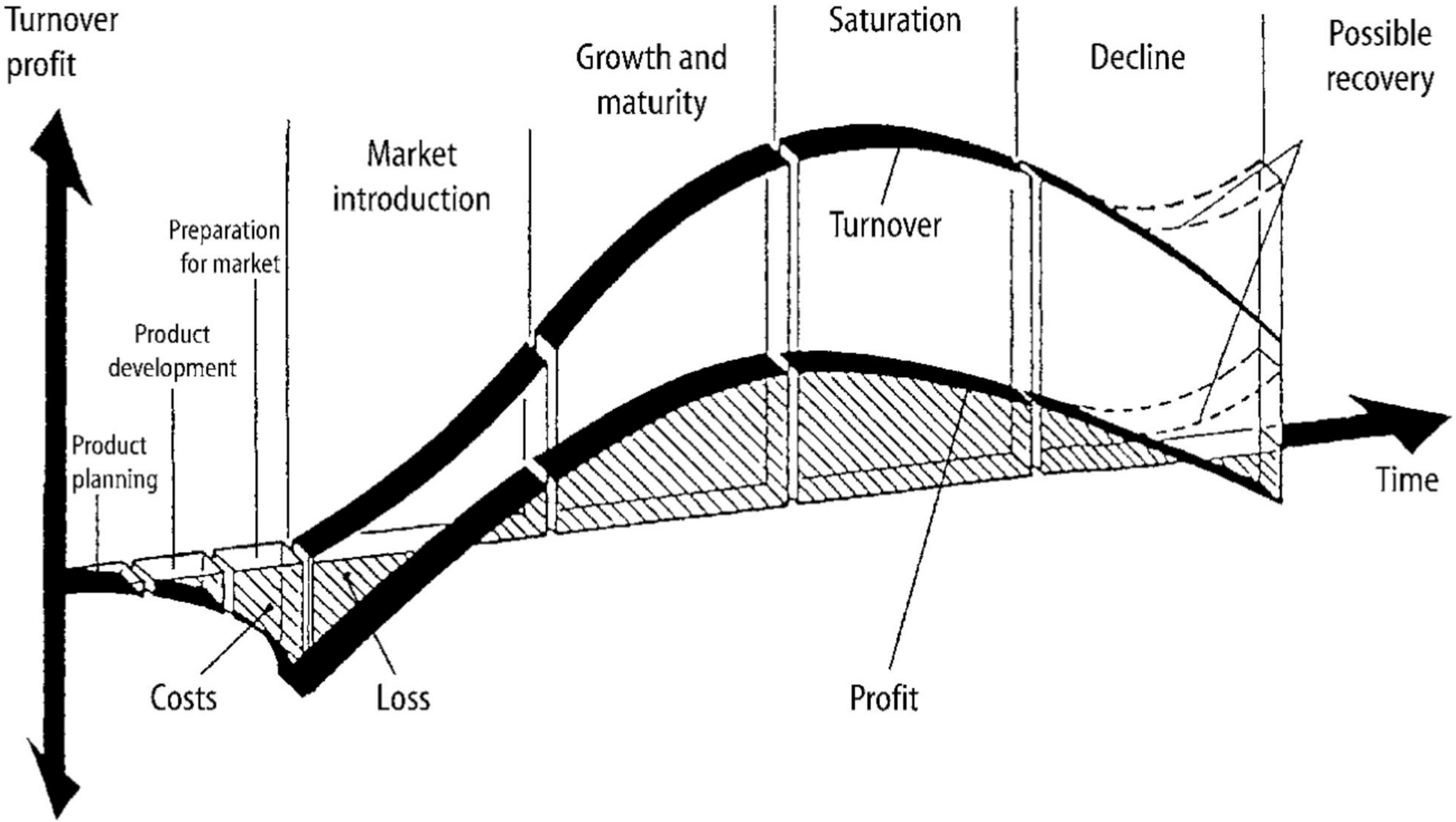
J. Sullivan

Life Cycle of a Product

Engineering


Market/Need/Problem
Potential/Goals of company
Product planning/ Task setting
Design/ Development
Production/Assembly/ Test
Marketing/Consulting/ Sales
Use/Consumption/ Maintenance
Energy recovery
Recycling
Disposal/Environment
Product life cycle management
Requirements, Goals


Customer
Market
Sales, Marketing, Advertising
Product planning
Experiment, Test
Design and development
Standards, Data processing
Purchase, Stock
Production planning Production control
Operating resources
Production of parts
Assembly
Quality control
Test, acceptance
Distribution
Stock of finished products
Customer, Sales, Installation
Product evolution
Information


Turnover
profit
Saturation
Growth and
maturity
Decline
Possible
recovery
Market
introduction
Preparation
for market
Turnover
Product
development
Product
planning
Time
Costs
Loss
Profit

UCLA

Design Process

Engineering

UCLA

Videos – Design Process

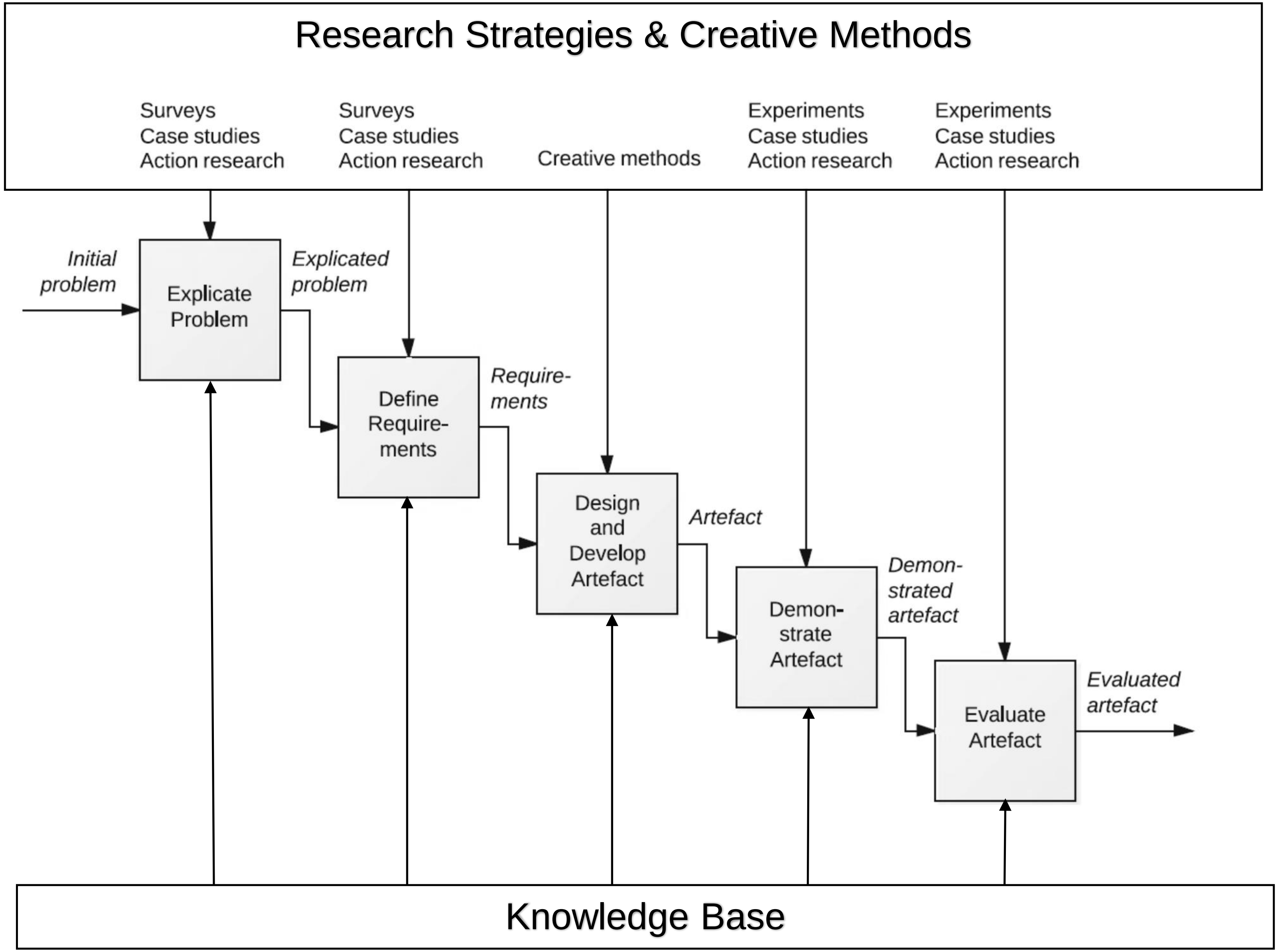
The Engineering Design Process: A Taco Party
https://youtu.be/MAhpfFt_mWM

Design Thinking Process
https://youtu.be/qyoZTUGzdGY

The Design Thinking Process – Cartoon
https://youtu.be/_r0VX-aU_T8

The Waterfall Model

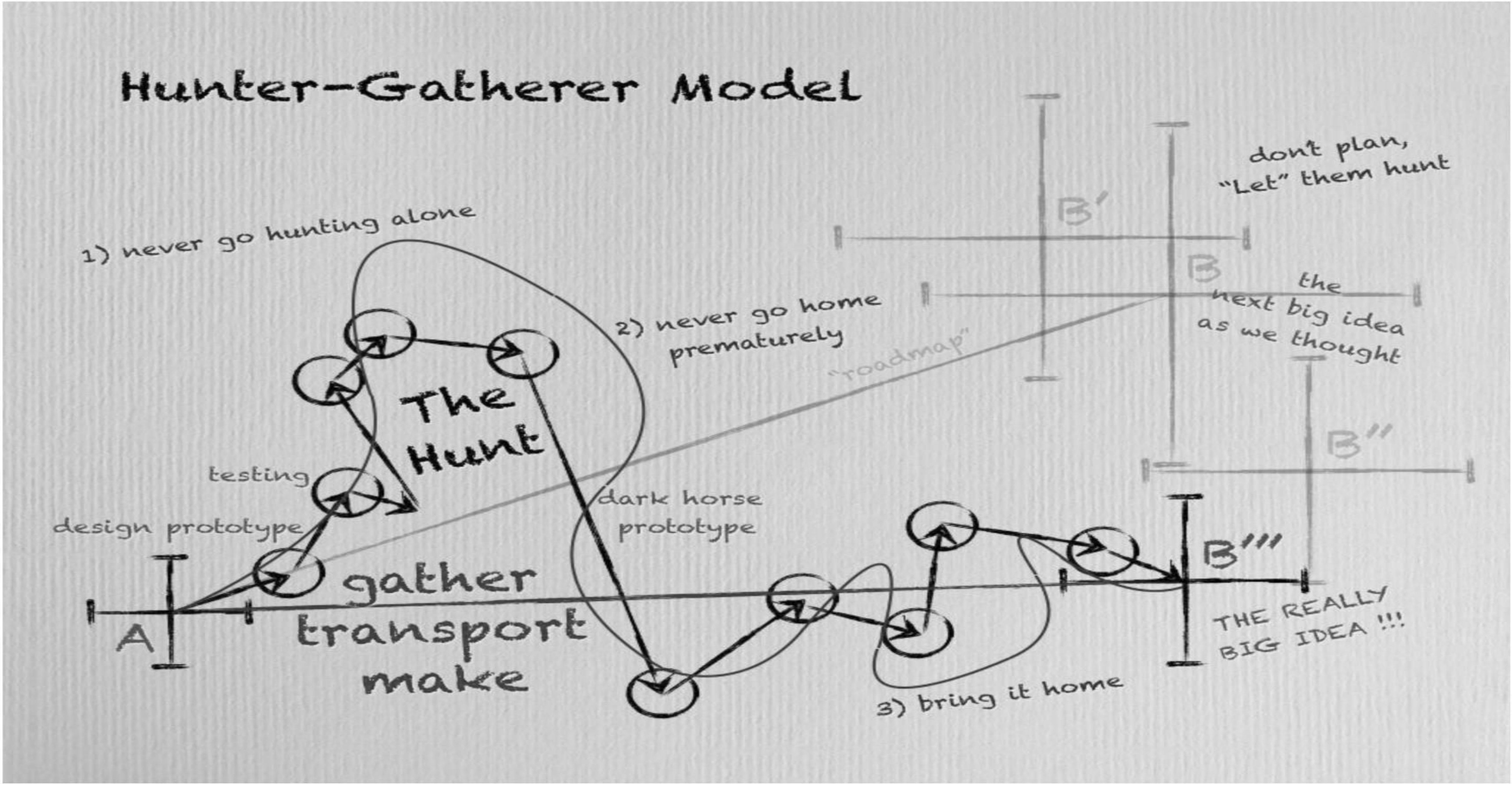
Engineering Design Process


Research Strategies & Creative Methods
Surveys
Case studies
Action research
Surveys
Case studies
Action research
Creative methods
Experiments
Case studies
Action research
Experiments
Case studies
Action research
Initial problem
Explicate Problem
Explicated problem
Define Require-ments
Require-ments
Design and Develop Artefact
Artefact
Demon-strate Artefact
Demon-strated artefact
Evaluate Artefact
Evaluated artefact
Knowledge Base

	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

The Hunter Model

Engineering Design Process



Hunter-Gatherer Model
1) never go hunting alone
2) never go home prematurely
3) bring it home
don't plan, "Let" them hunt
the next big idea as we thought
"roadmap"
The Hunt
testing
design prototype
dark horse prototype
gather
transport
make
A
B
B'
B''
B'''
THE REALLY BIG IDEA !!!

Videos – The Hunter Gatherer Model

YouTube

EDxConstitutionDrive 2012 - Martin Steinert - "Engineering Design: Creativity AND Analysis"

https://youtu.be/NybQMjOe9Ds

Trauma Pod
Fully Automated OR

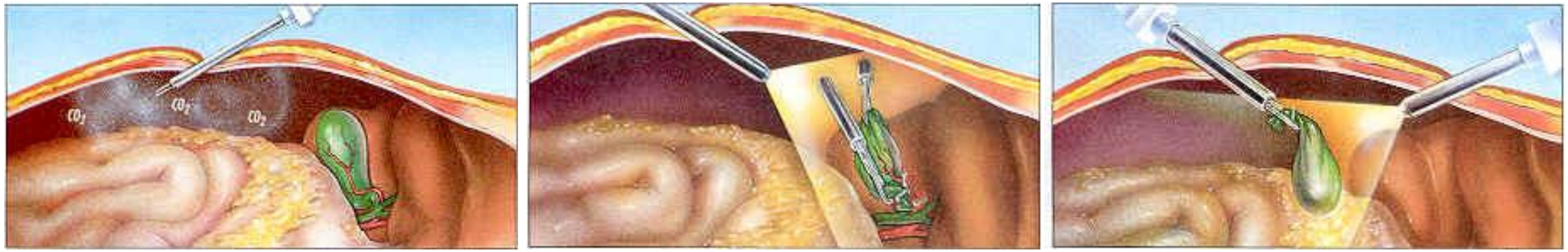
Demonstration of the Waterfall Model

Engineering Design Process

	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

Design Question

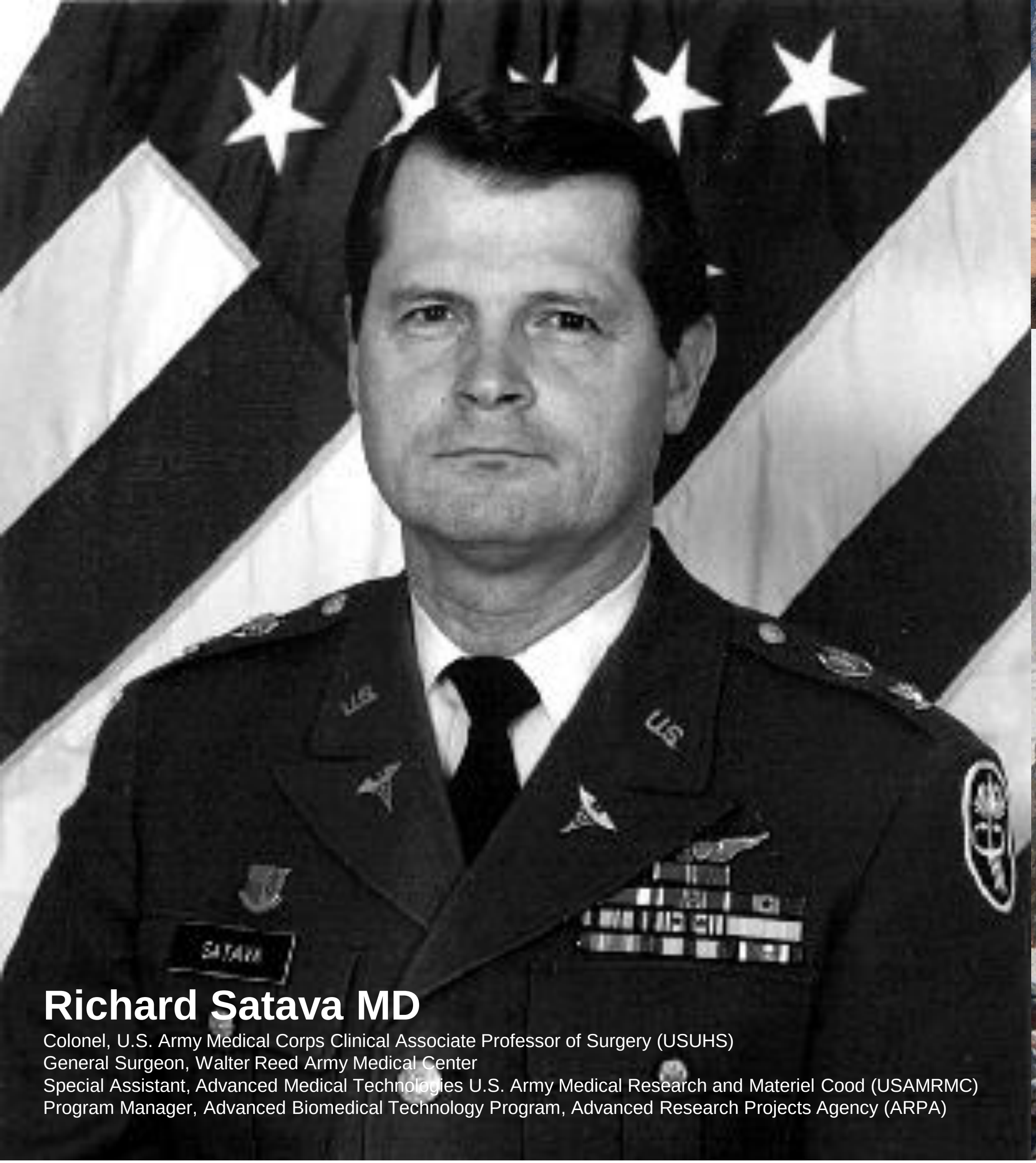
How is the Operating Room (OR) evolved


CO2
CO2
CO2

Design Question

The Operating Room (OR) in a military setting (Current) – Problem Definition

UCLA



Richard Satava MD

Colonel, U.S. Army Medical Corps Clinical Associate Professor of Surgery (USUHS)
General Surgeon, Walter Reed Army Medical Center
Special Assistant, Advanced Medical Technologies U.S. Army Medical Research and Materiel Cood (USAMRMC)
Program Manager, Advanced Biomedical Technology Program, Advanced Research Projects Agency (ARPA)

Dessert Storm 1991


F 20

Functions in the Operating Room

- **Surgeons**
  - Primary Surgeon
  - Secondary Surgeon

- **Nurses**
  - Scrub Nurse
  - Circulation Nurse

Design Question

What is the vision of the Operating Room (OR) in a military setting (Future)?

Videos - Trauma Pod Videos

Trauma Pod – Vision
https://youtu.be/diEDvxiWCCA

OR of the Future - Vision

Integration of an intelligent surgical robotic system into the unmanned and automated operating room.

- Full Body Scan
- Simulation
- Surgical Robotic Arm Extended Mobility
- Surgeon Teleoperation Workstation
- Tool Changer (Scrub Nurse)
- Equipment Dispenser (Circulation Nurse)
- High-Level Control and Monitoring Intelligence Layer
- Inventory Management Software

Design Question

How should the OR be arranged (Geometry)?

Videos - Trauma Pod Videos

Trauma Pod – Phase 1 – Final

https://youtu.be/Q0rcJCQESe8

Design Question

How to assemble a design group?

UCLA

Systems Breakdown

System	Organization
Supervisory Controller System (SCS)	SRI/U. Texas
Virtual Emulator System (VES)	SRI/U. Texas
Monitoring Station System (MSS)	SRI
Supplies Dispensing System (SDS)	General Dynamics; U.Maryland; Steris; Columbia U.
Scrub Nurse System (SNS)	Oak Ridge;U. Washington
Tool Rack System (TRS)	Oak Ridge;U. Washington
Tool Autoloader System (TAS)	Oak Ridge; U. Washington
Surgical Robot System (SRS)	Intuitive Surgical
Master Console System (MCS)	Intuitive Surgical
User Interface System (UIS)	SRI/Intuitive Surgical
Peripherals System (PS)	Storz
Patient Registration System (PRS)	Integrated Medical Systems
Global Registration System (GRS)	

UCLA

	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

Design Question

What are the requirements for the OR of the future?

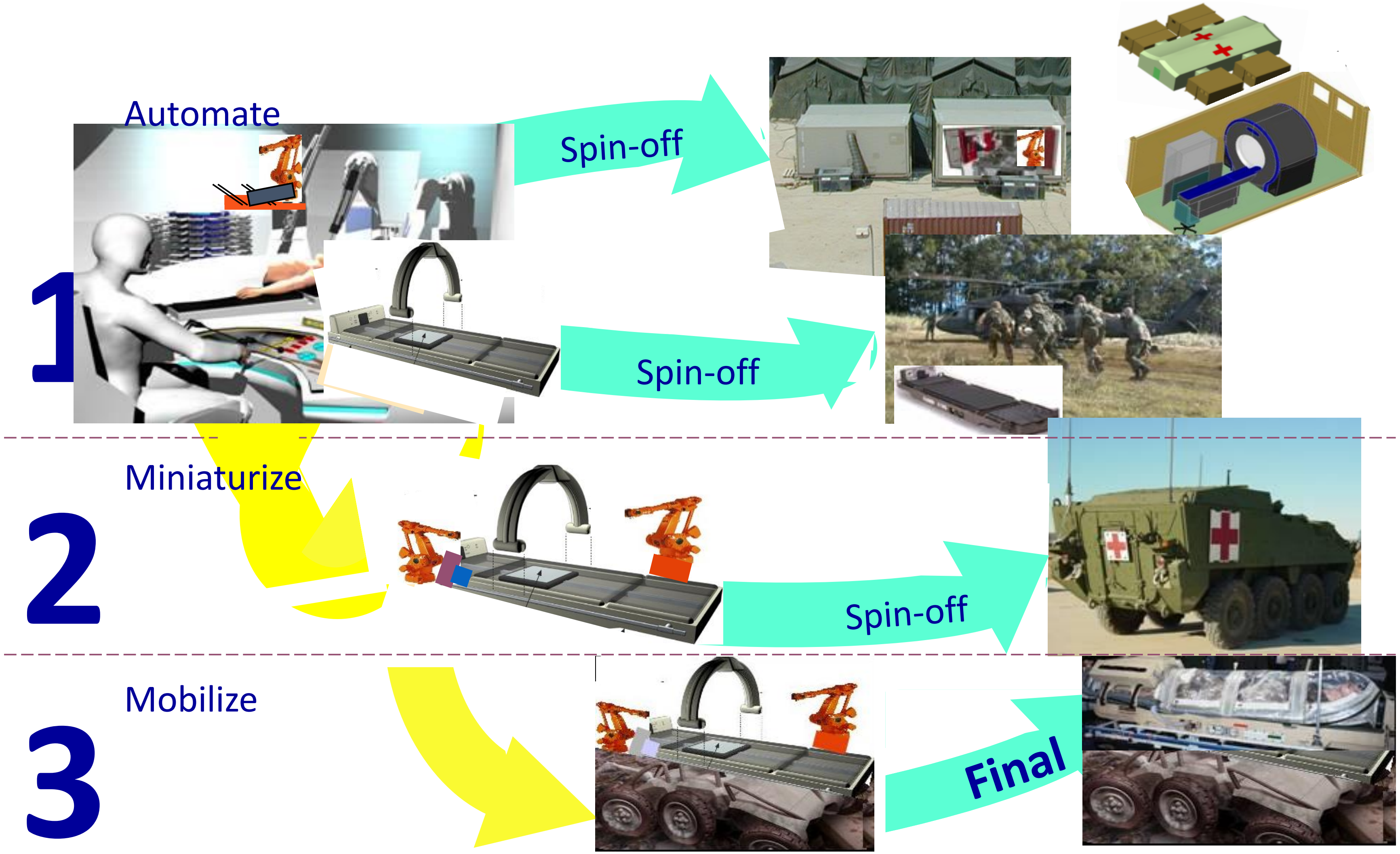
High Level Requirements

High Level Requirements

- Development of a robotic cell tele-surgical system the can perform a portion of a surgical procedure without nurses

- Demonstrate tool change and supply delivery within 10sec

Program Phases



UCLA

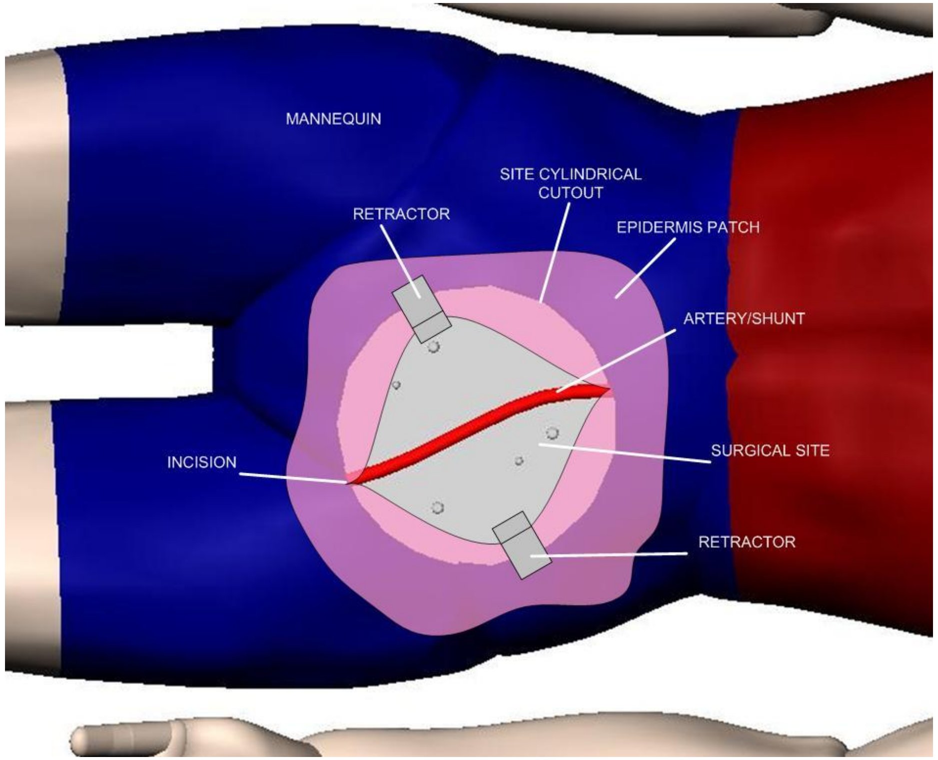
System Demo Desired Goal

- Demonstrate bowel resection and anastamoses
- Surgical Tasks:
  - Cutting
  - Suturing
  - Cauterizing
  - Irrigation and suction
  - Placing clamps
  - Removing tissue

- Automated Tasks:
  - Dispensing sutures and clamps
  - Changing needle holders, cautery scalpel, forceps, scissors

Trauma Pod Program
Phase 1 Demonstration

- Demonstrate placing a temporary shunt in the iliac vessel:
  - **This procedure addresses non-compressible vessel injuries which are causing deaths in the field**
  - **Being able to perform this type procedure would save lives in the battlefield**



UCLA

System Demo Pipe Dreams

- Extend the workspace and field of view of surgical robot
- Demonstrate more complete surgical procedure: Remove clothing, sterilize patient, perform laparotomy, place IV's
- Demonstrate system can be used in more than one patient without human assistance: Self cleaning and sterilization
- Add 'intelligence' to autonomous manipulators: More complex obstacle avoidance and path planning; learning algorithms; 3-D vision navigation
- Enhancing sensing to autonomous manipulators: Tactile and force sensing
- Demonstrate enabling miniature actuators or novel manipulators

Mid Level Requirements

System Functional Requirements

- The system shall be capable of conducting a portion of a teleoperated surgical procedure (TBD) requiring multiple supplies and surgical tools without the assistance of people in the operating environment
- The system shall be capable of cutting and dissecting tissue, cauterizing, and suturing including tying sutures
- The system shall be capable of handling a ONE patient without human intervention during the surgical procedure.
- (Failures in the operation of the system shall not result in a hazard for the patient safety.)
- The system shall generate a total record of the supplies and tools used and update the supply chain management system with re-supply requests.
- The architecture of the system shall be extendable to allow the miniaturization of the system to support the deployment in an appropriate military vehicle.

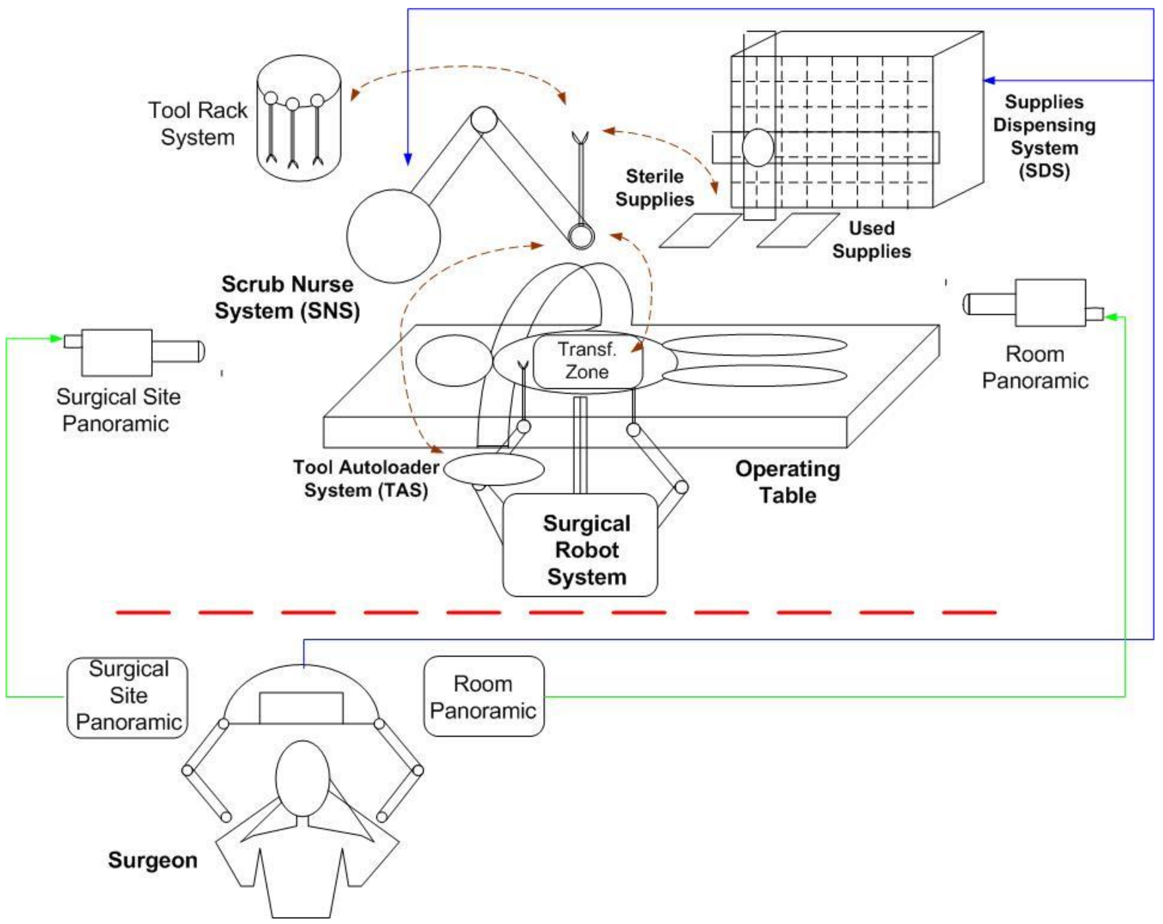
System Performance Requirements

- The length of an individual procedure shall be comparable to a procedure performed with human assistance: dispensing a supply will take no more than 10sec; Changing a tool will take no more than 10sec; Positioning a tool in the surgical site will take no more than 5sec from the tool change.
- The reliability of the operation shall be comparable to manual procedures: The system shall change 4 different tools with 100% accuracy and supply 10 different supplies with 100% correct supply and no collisions
- The system shall be able to operate in a surgical workspace of TBD cm^3
- (The system shall be capable of operating over a communication line with TBD bandwidth and TBD delay with minimal degradation.)

System Physical Requirements

- The system shall be operated by a single surgeon.
- (Tools in contact with the patient shall not be able to transmit more than TBD mA)
- (The system shall not generate introduce any toxic substances into the patient.)
- All the components of the system with the potential to interfere with the movement of the manipulators will have a means of being registered in a common three-dimensional coordinate system with a resolution of TBD and an accuracy of TBD one sigma in each dimension.
- (All equipment shall withstand cleaning and sterilization by commonly used methods without damage.)
- The total Trauma Pod system weight shall not exceed TBD pounds.
- The demonstration system shall be able to be installed within a military ISO container

System Layout

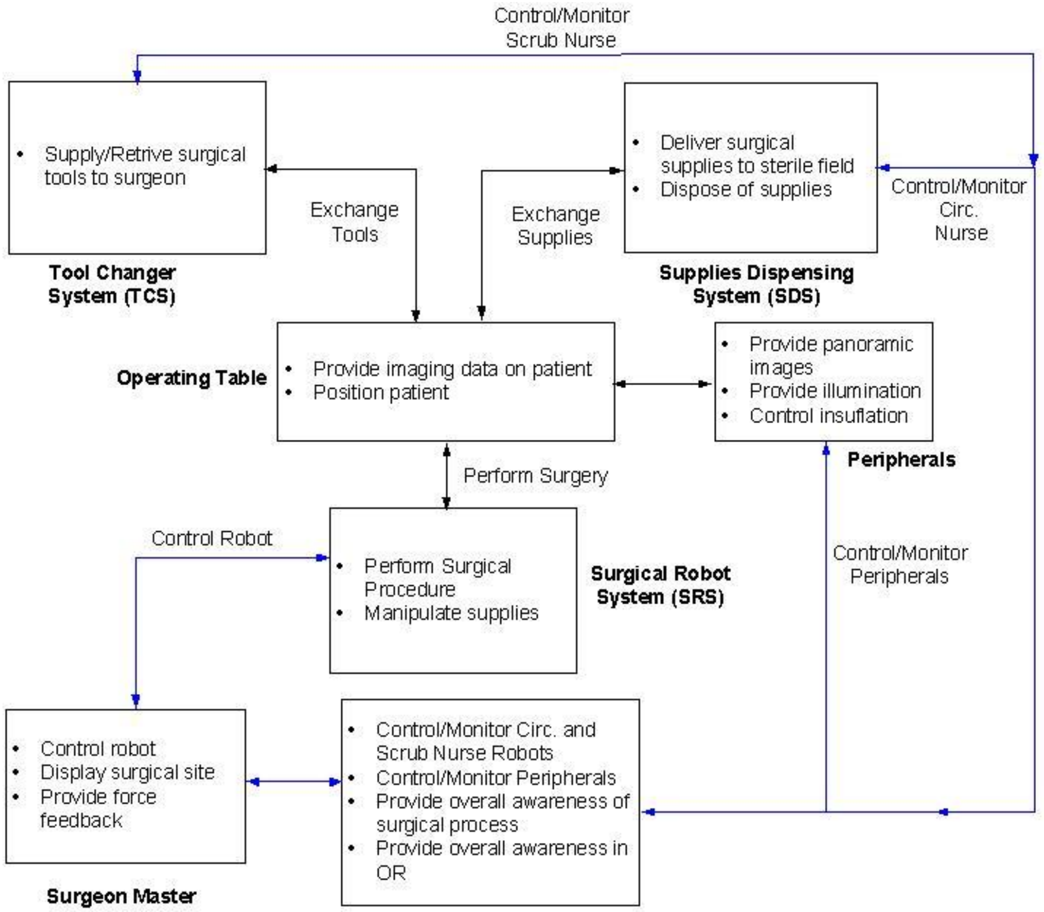


UCLA

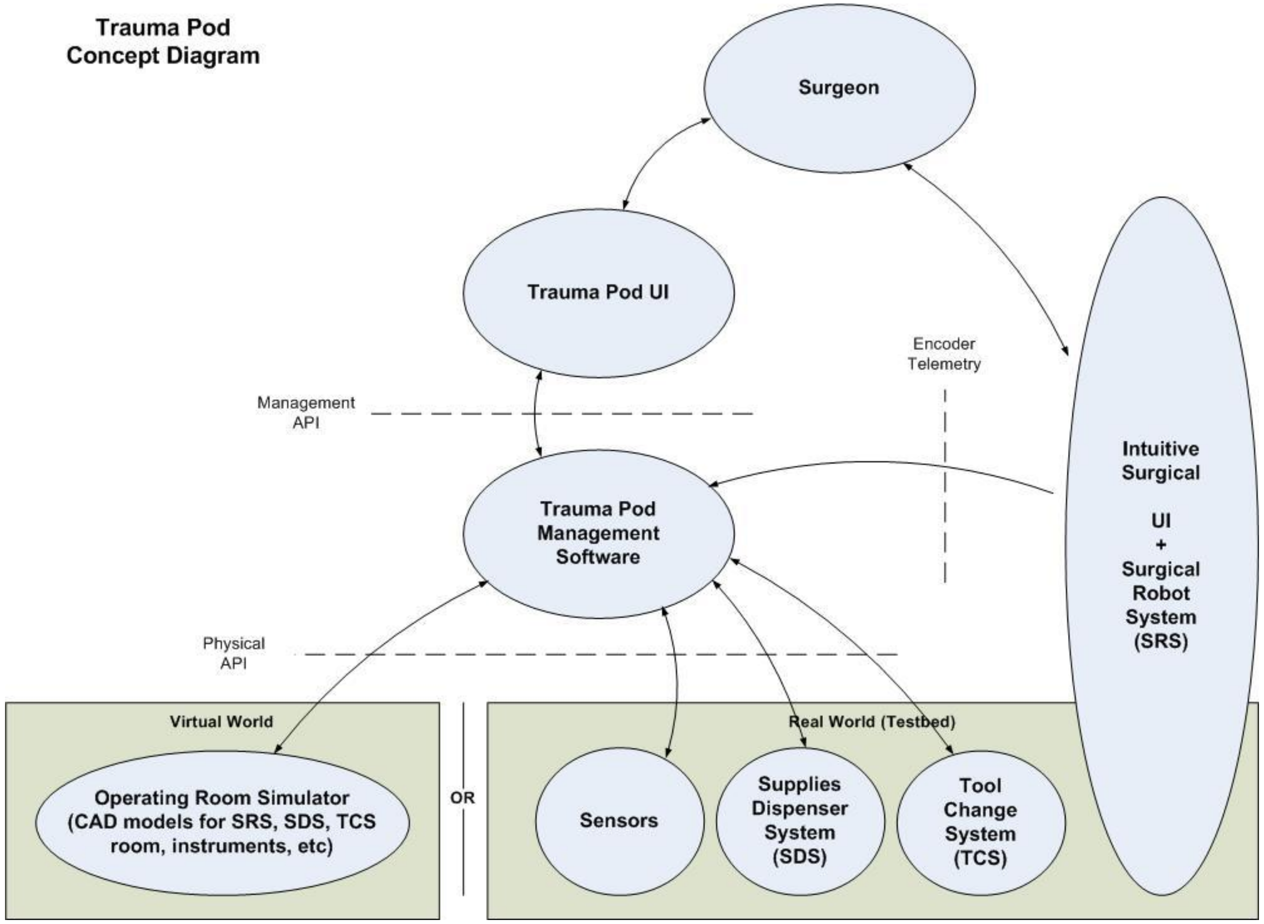
Design Question

How to develop hardware & software simultaneously

Functional Diagram



High-Level Architecture - Interfaces



UCLA

Trauma Pod Concept Diagram Definitions

Surgeon
- Human being in control of the operation
- Controls Trauma Pod UI and Surgical Robot System

Trauma Pod UI
- Surgeon's interface to all functions except Surgical Robot System (Intuitive Surgical)
- Several possible options
  - Voice control and feedback
  - Touch panel with menus

Intuitive Surgical Robot System
- A self-contained system that is controlled by its own user interface (i.e. a "black box")
- No external control interface available (true?)
- Provides telemetry on arms and effectors

Management API
- Programming interface for managing the Trauma Pod support functions
- Logically separates the UI from the management software
- Provides task selection, initiation, termination ("get me a scalpel")
- Provides task definition, scripting ("to get a scalpel, do need to do these things…")

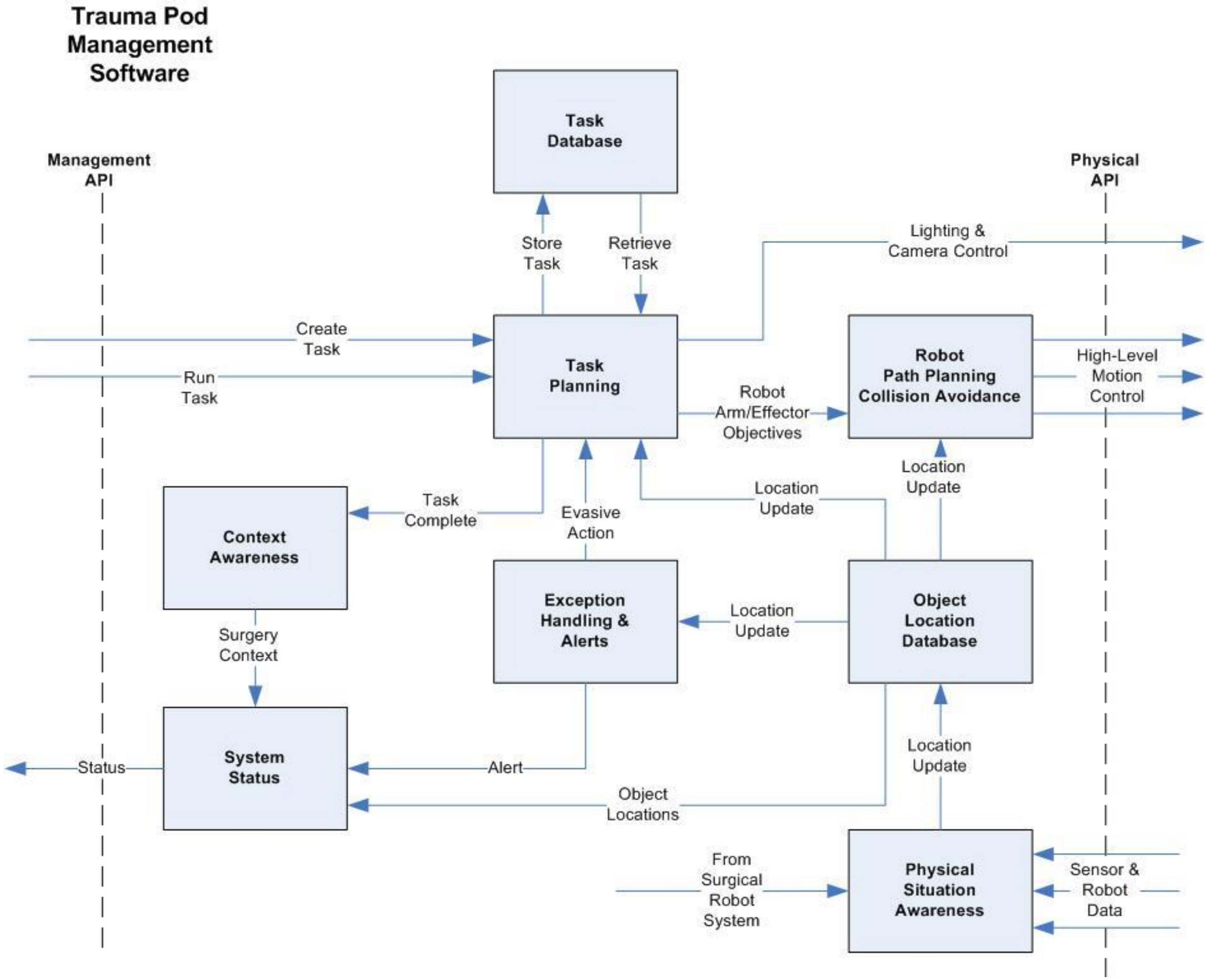
Trauma Pod Management Software
- Task planning algorithms
  - Lists of robot actions required to carry out a task
- Robot path planning and collision avoidance algorithms
  - Coordinates high-level movement of multiple robots
- System status, exception handling, alerts, evasive action
- Situation awareness: sensor monitoring, robot tracking
- Context tracking: surgery timeline, current step in surgery
- Object location database management
- ***Much, much more...***

Physical API
- Programming interface for controlling and tracking physical objects in the operating room
- Logically separates the actual operating room hardware from the management software
- Provides high-level motion control for individual robots except Surgical Robot System
- Provides sensor output for tracking physical objects

Real World
- A physical testbed containing all robot systems and supplies
- Collectively, the supply dispenser, tool changer, sensors, and the non-UI part of the SRS
- The final integration laboratory for all project participants

Virtual World
- Implements the Physical API so that it appears identical to the Real World
- Software programs model all robots (including Surgical Robot System) and sensors
- Used by project participants during development

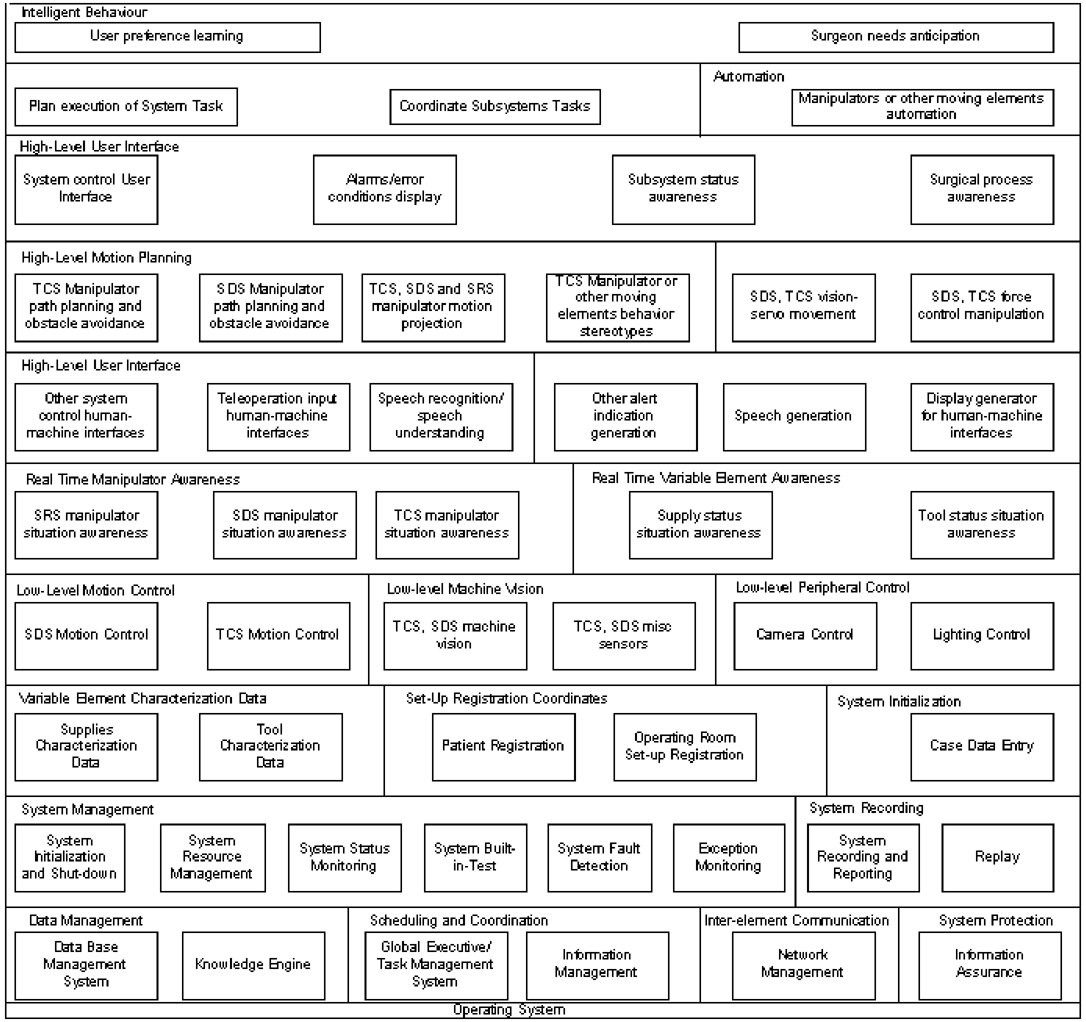
Management Software



Trauma Pod Management Software Definitions

- Task Planning
  - Breaks a high-level task ("get scalpel") into a set of robot objectives ("robot X move to here, robot Y does this")
  - Tasks can be created and defined via the Management API
  - Accepts tasks from
    - Surgeon
    - Exception Handling (safety)
- Task Database
  - Contains pre-defined tasks
  - Stores and retrieves tasks as required
- Path Planning & Collision Avoidance
  - Coordinates the movement of multiple robots according to the objectives set by Task Planning
  - Accounts for obstacles between robot current position and destination
  - Issues high-level motion control commands to each robot ("follow this set of linear segments, then follow an arc to here")
- Object Location Database
  - Keeps track of location for each physical object in the operating room
  - Includes
    - Fixed objects: tables, cabinet, etc
    - Movable objects: supplies, tools, etc
    - Robot arm, end geometry
    - Many, many other things...
- Context Awareness
  - Keeps the surgical procedure as a set of steps
  - Keeps track of the current step being performed
- Exception Handling & Alerts
  - Monitors the physical location of objects
  - Forms judgments about the safety of the current physical configuration
  - Issues exceptions to Task Planning for making current physical configuration safe
  - Issues alerts to inform the surgeon
- Physical Situation Awareness
  - Monitors robot movements and location
  - Monitors other object locations
  - Monitors supplies
  - Updates database as necessary
- System Status
  - Provides system and surgical status to surgeon

Software Components - Layered Diagram



UCLA

Low Level Requirements

Low Level Requirements

- Integrate robotic "cell"

  Collision avoidance, tool changing or dispensing — Accuracy = 100%

- Accurate registration and positioning of instrument

  Precisely place instrument in on a phantom after tool change — $\leq$ 1 mm

- Design interconnect for tool changer

  Change new 7 DOF tool or dispense new supply — $<$ 10 seconds

- Real time data acquisition of tools/supplies

  Recognize and dispense instruments/supplies — Accuracy = 100%

Some Open Issues

- System Level
  - What should the demo encompass as a goal?
  - Will there be a system to check for abnormal conditions besides sensors, such as camera?
  - If we use tools such as retractors that are not part of the robotic system we need to be able to track them and register them in space
- Supplies Dispenser System
  - How will the sterilization system avoid particles deposited on the supplies?
  - How will the supplies be packaged?
    - Packaged with no changes from today or packaged for automation? What penalty on cost are we prepared to take if packaged for automation?
  - How should the supplies be delivered and retrieved to/from the surgical site:
    - Through a special tool that can handle supplies
    - Through direct handling into the surgical site
    - Through a transfer zone outside the surgical area
  - Should be use MIS supplies, open surgery or both?
  - How are we going to keep track of all supplies: RF tagging, vision…
  - Is the SDS going to keep track of all the traffic of supplies and tools in the OR?

Some Open Issues

- Scrub Nurse System/ Tool Rack System/ Tool Autoloader System
  - Is the SNS arm going to be teleoperated to account for unexpected tasks, such as dropping a supply?
  - Is the tool rack going to be instrumented?
  - What are the assumptions for handling the tool rack in a sterile manner?
  - How are we going to load cautery tools that require electrical connections?
  - Shall we use retractors for open surgery?
  - How do we address the need to be able to sterilize the robotic arm end-effector and possibly bag some of it?
  - Will the end-effector be contaminated when it retrieves used supplies or tissue from the bowel? Do we need an end effector to supply and another to retrieve supplies?
- Surgical Robot System
  - Is the transfer zone inside or outside the surgical site? Are we going to need to extend the field of view and workspace of the robot?
  - How do we handle irrigation and suction?
  - Will we require a 4^{th} arm?

Supplies Dispensing System
List of Supplies

Name	Description	Purpose	Approx. Number Used per Case	Packaging, current practice	Packaging, Trauma Pod
“sponge”	A 4x4” piece of coarse gauze, folded from several layers	To blot up small amounts of blood	1- 100	10 per pack	TBD
“lap pad”	A 10x10” or 18x18” single piece of absorbent material, like a towel	To blot up large amounts of blood. To act as a dam to hold back intestines other structures	1-25	10 per pack	TBD
“peanut”	Peanut sized ball of gauze	Used on an instrument to delicately blot or sweep tissue	1-25	5 per pack	TBD
suture	Integral needle and thread	To sew structures together. To stop larger bleeders.	1-hundreds	Single/multiple per pack	TBD
tie	Thread	To tie off blood vessels	1-hundreds	On a reel in a single pack. In cut lengths multiple to a pack	TBD

Supplies Dispensing System
Approach for Supplies Design

- Design all supplies with common physical interface to a Supply Handling Tool
- The Supply Handling Tool will be able to be mounted on the daVinci arm or directed by the robot to the surgical site
- The common physical interface can be part of the disposable (I.e.: Capsule that contains sutures), or a re-usable carrier that can grasp or house the supply
- The supplies can be designed in reels that make it easy to open

Supplies Dispensing System Issues

- How will the sterilization system avoid particles deposited on the supplies?
- How will the supplies be packaged?
  - Packaged with no changes from today or packaged for automation? What penalty on cost are we prepared to take if packaged for automation?
- How should the supplies be delivered and retrieved to/from the surgical site:
  - Through a special tool that can handle supplies
  - Through direct handling into the surgical site
  - Through a transfer zone outside the surgical area
- Should be use MIS supplies, open surgery or both?
- How are we going to keep track of all supplies: RF tagging, vision…
- Is the SDS going to keep track of all the traffic of supplies and tools in the OR?

Scrub Nurse System Approach

- Tool Handling:
  - Tool Autoloader System (TAS) allows a simple tool insertion task with very small external forces required
  - Tool Rack System (TRS) allows presenting the desired tool in a precise orientation for the SNS to grasp.
  - The TRS keeps track of the tool inventory
  - The Scrub Nurse System manipulator will have an end-effector that can tools
- Supply Handling:
  - Supplies are handled by a Supply Handling Tool compatible with the tool handling end-effector.

User Interface Requirements

- All Trauma Pod active systems controllable in real time from the Surgeon Master Console
- For Phase I demonstration, surgery set-up performed manually prior to operation
  - Patient positioning and registration
  - Supplies stocking
  - Robot position registration
  - (Other actions TBD)
- Allow surgeon to maintain hands and eyes on the surgical site to the maximum degree practical
- Minimum changes to the existing Intuitive Surgical surgeon direct interface physical configuration (displays, hand and foot controls)

User Interface Issues

- Will the surgeon be overloaded with control responsibilities?
- How do we provide system awareness without taking away attention from the surgical site?
- How do we make the surgeon aware of the choices without overwhelming the graphics with menus
- How are the overlaid graphics handled with the 3-D vision?
- What are the training requirements?

TRS - Elements

- Mechanism
  - Post/Case - Non-Sterile
  - Magazine (15 Tools) - Detachable - Sterile
- Actuators
  - Main: Step Motor - Spinning Magazine
  - Secondary: Solenoid / Linear Actuator (Tool Release)
- Sensors
  - Absolute Position Sensing (Shaft Encoder)
  - Tool in the Bay - Proximity sensor
  - Micro Switches: 1. Solenoid, 2. Magazine/Case
- Communication
  - Internal: RT OS / C
  - External: TCP/IP

EE - Elements

- Mechanism
  - Tool Gripping Jaws - Sterile (Detachable form the gripper)
- Actuator
  - Electric Linear gripper
- Sensors
  - Griping Force - Single axis double beam force sensor
  - Handling Force - Three axes F/T Sensor
  - Tool in the Gripper - Proximity sensor
  - RFID
- Communication
  - ORNL incorporated with the SNS

Project Challenges

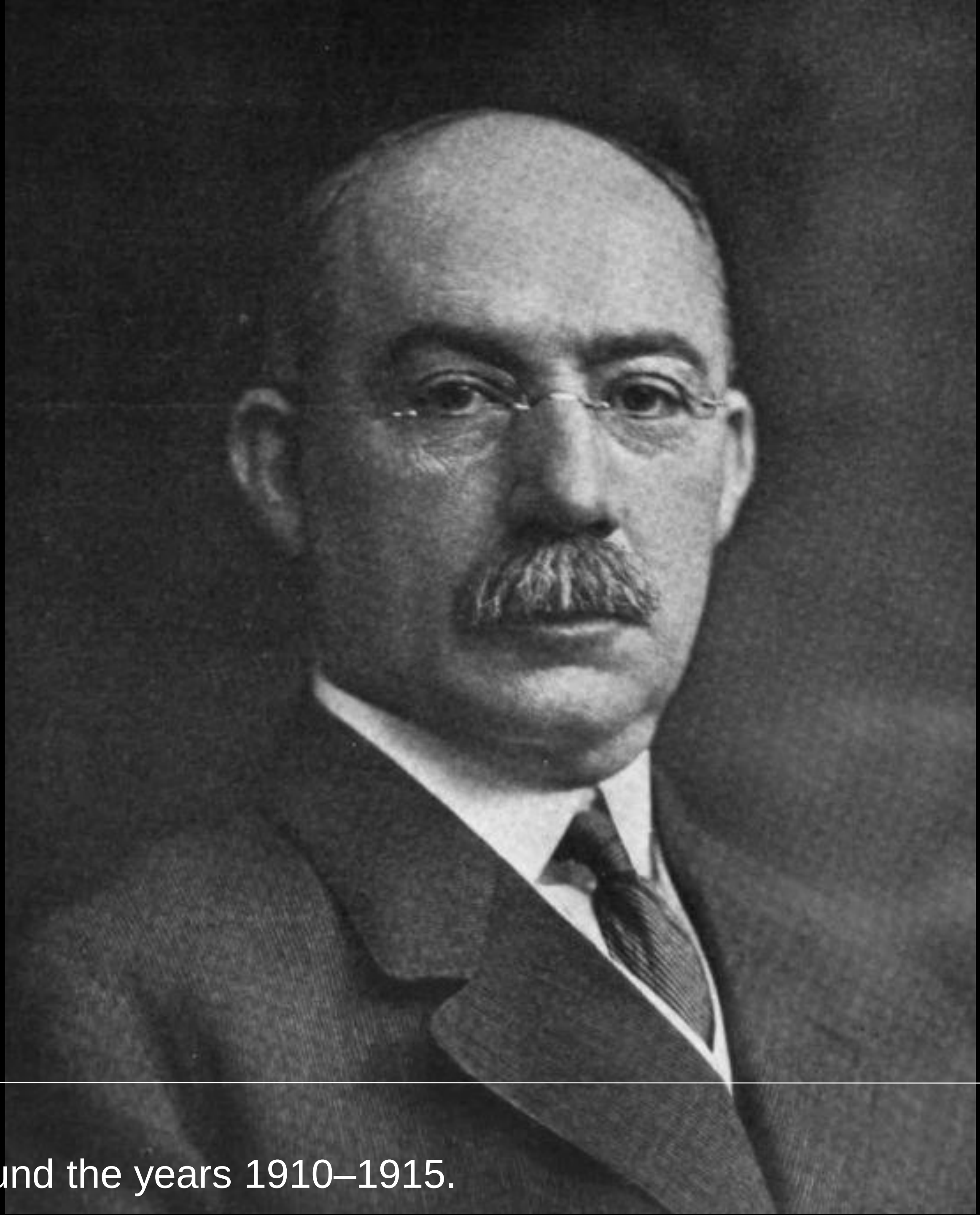
- Collaboration between autonomous and tele-operated systems
- Development of an advanced user interface that enables the surgeon to interact naturally with autonomous systems
- Automatic coordination of multiple robots in a very restricted space over a simulated patient
- Development of a system to store, manipulate and transfer sterile medical supplies that can be handled by robots
- Access tools from a compliant structure on the Surgical Robot
- Dispense tools and supplies within 10 seconds of command
- Track movement of supplies and events generating an automatic patient record
- Prove feasibility of field deployable CAT-Scan system
- Integrate subsystem developed by ten different organizations distributed around the country

Design Question

How to create a schedule?

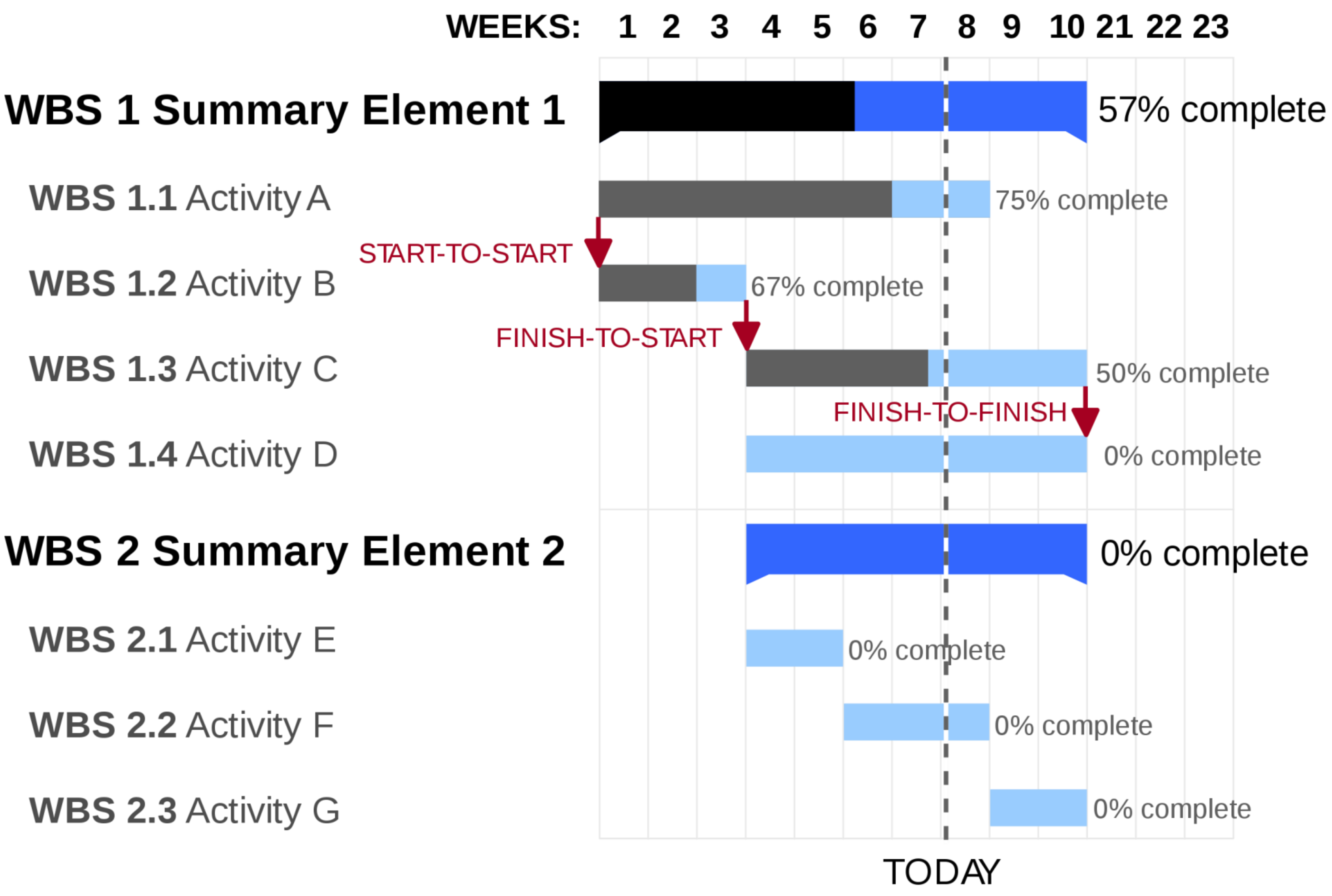
UCLA

Timetable / Scheduling / Milestones / Dependencies



Henry Gantt (1861–1919)

Designed such a chart around the years 1910–1915.

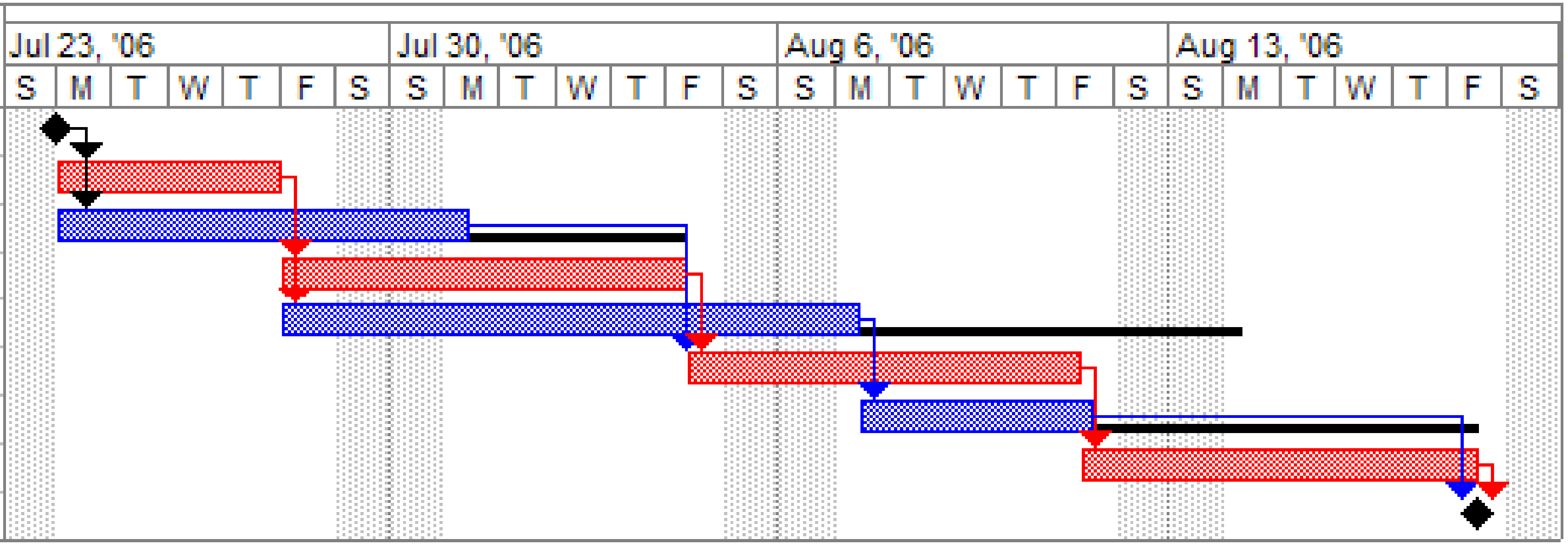

WEEKS: 1 2 3 4 5 6 7 8 9 10 21 22 23
WBS 1 Summary Element 1
57% complete
WBS 1.1 Activity A
75% complete
START-TO-START
WBS 1.2 Activity B
67% complete
FINISH-TO-START
WBS 1.3 Activity C
50% complete
FINISH-TO-FINISH
WBS 1.4 Activity D
0% complete
WBS 2 Summary Element 2
0% complete
WBS 2.1 Activity E
0% complete
WBS 2.2 Activity F
0% complete
WBS 2.3 Activity G
0% complete
TODAY

$$\mu(X) = \frac{a + 4b + c}{6}$$

$$\sigma(X) = \frac{c - a}{6}$$

Activity	Predecessor	Time estimates			Expected time (T_E) (O + 4M + P) ÷ 6
		Opt. (*O*)	Normal (*M*)	Pess. (*P*)	
a	—	2	4	6	4.00
b	—	3	5	9	5.33
c	*a*	4	5	7	5.17
d	*a*	4	6	10	6.33
e	*b*, *c*	4	5	7	5.17
f	*d*	3	4	8	4.50
g	*e*	3	5	8	5.17

ID	Task Name	Predecessors	Duration
1	Start		0 days
2	a	1	4 days
3	b	1	5.33 days
4	c	2	5.17 days
5	d	2	6.33 days
6	e	3,4	5.17 days
7	f	5	4.5 days
8	g	6	5.17 days
9	Finish	7,8	0 days



Master Plan Milestones

- 3 Months: System Definition and Specifications
- 6 Months: Detailed System Design – Start Fab
- 9 Months: Frozen Design
- 12 Month: Demo Subsystems Core Functionality; Software Emulator Ready to Interface with Subsystems
- 15 Month: Preliminary Subsystem Qualification Test
- 18 Month: Qualified Subsystems shipped to SRI
- 21 Month: Demo Integrated System Basic Functionality
- 24 Month: Run Final Demo

Master Plan Dependencies

- Month 1: Simulator CAD environment needs to be done before selecting manipulator and analyzing tasks.
- Month 1: The supplies package interface needs to be defined before the SNS end-effectors are designed.
- Month 1-3: Standards need to be in place before subs start writing code or defining the software architecture.
- Month 6-9: TAS and TRS need to be in tested and integrated before the SNS can be tested.
- Month 9-12: SNS software interface needs to be in place before SDS can finish the inventory tracking system
- Month 9-12: Obstacle avoidance and Path planning need to be in place to test SNS
- Month 12: Emulator package needs to be in place to test subsystems remotely
- Month 12: Subsystems software interfaces and communication need to be in place before they can be tested using the emulator

General Approach No. 1 - Phase 1

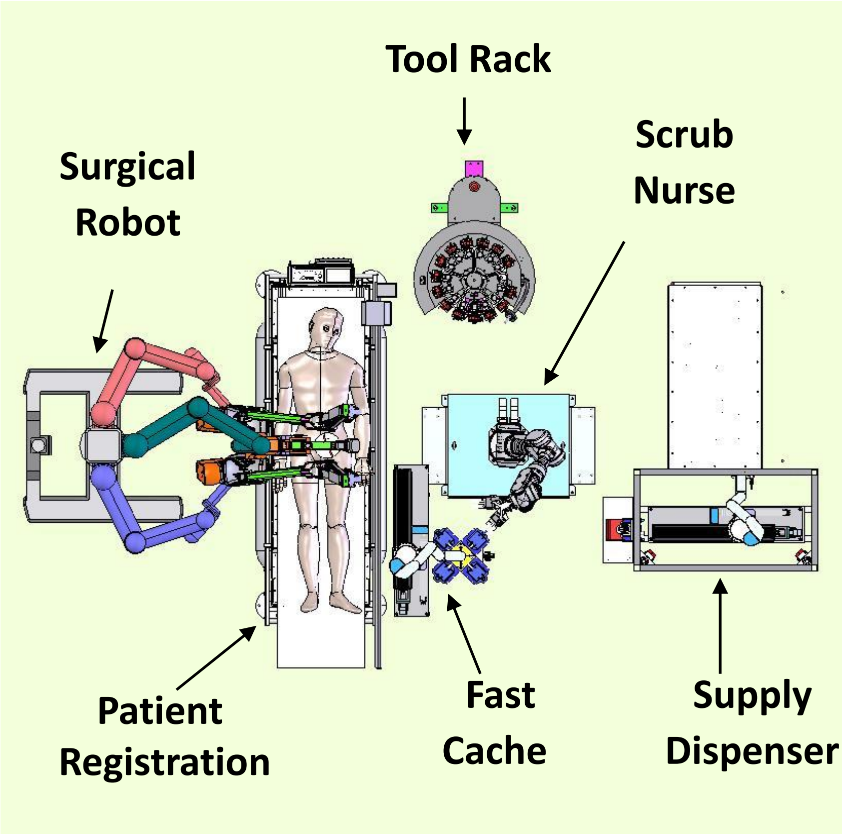


Fig 1 Top View of Robotic Cell

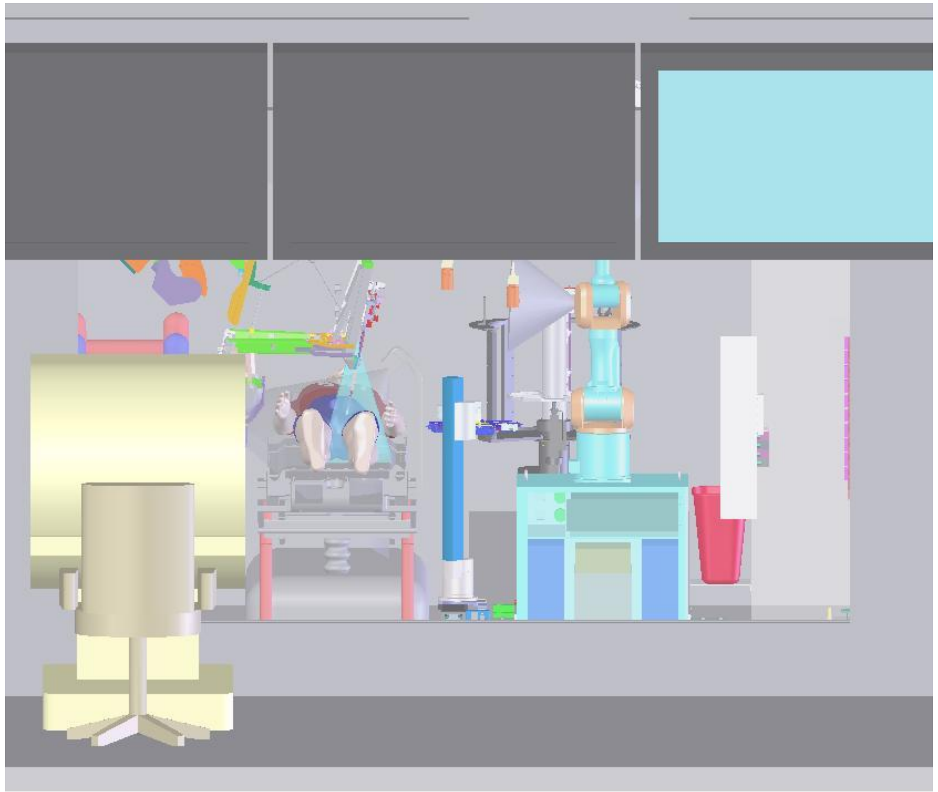


Fig 2 View from Control Room

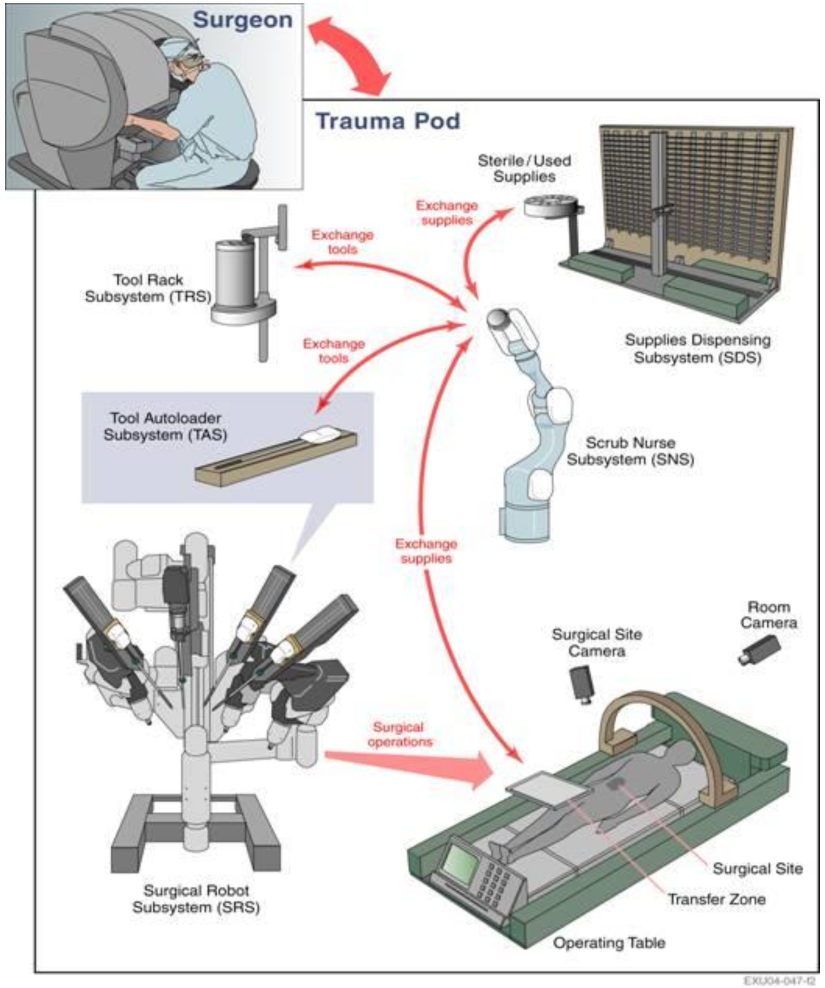
	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

Trauma Pod – Phase 1

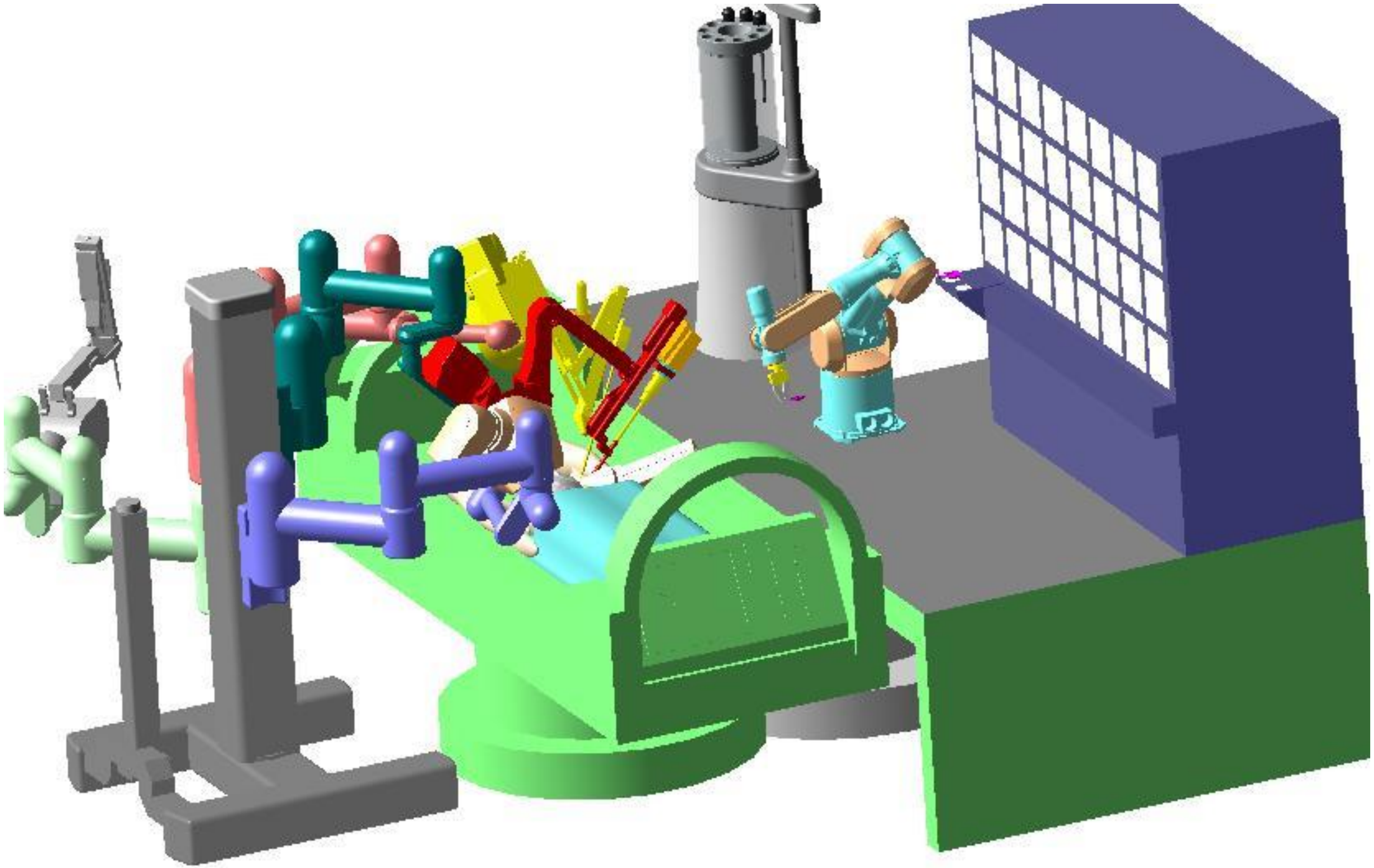
General Approach No. 1

General Approach No. 1 - Phase 1

- Adapted existing surgical robot and scrub nurse manipulator
- Adapted Life Support system used in the field
- Designed custom System
  - Tool changer
  - Supply dispenser
- Developed software to
  - Coordinate surgical tasks
  - Coordinate interaction between surgeon and system
- Developed flexible software architecture
  - Expandable
  - Scalable



UCLA



General Approach No. 1 - Phase 1

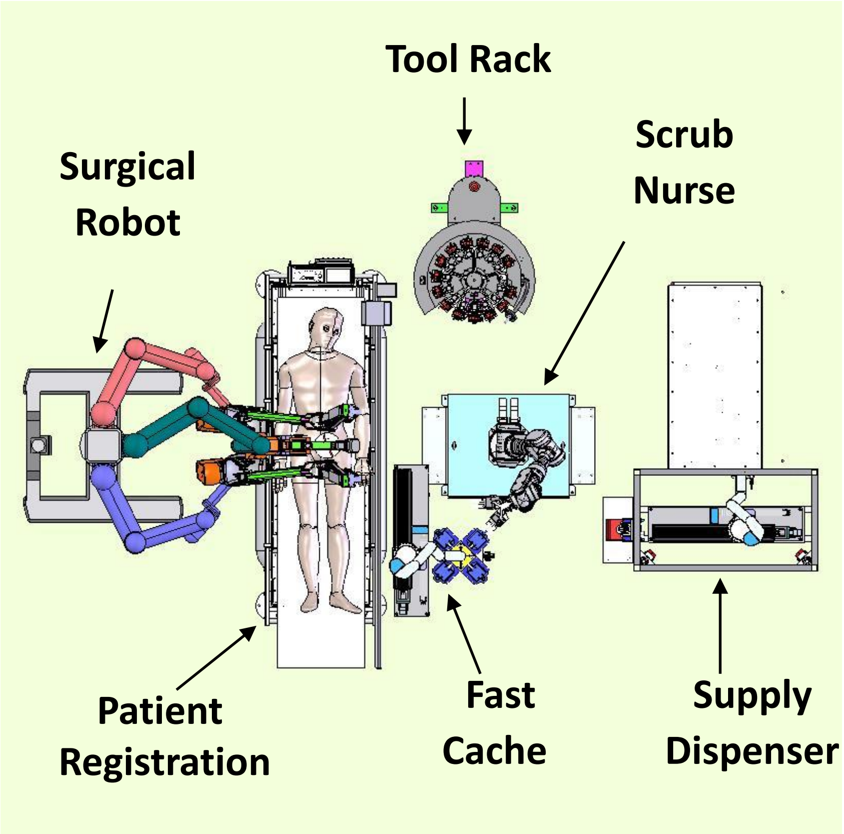


Fig 1 Top View of Robotic Cell

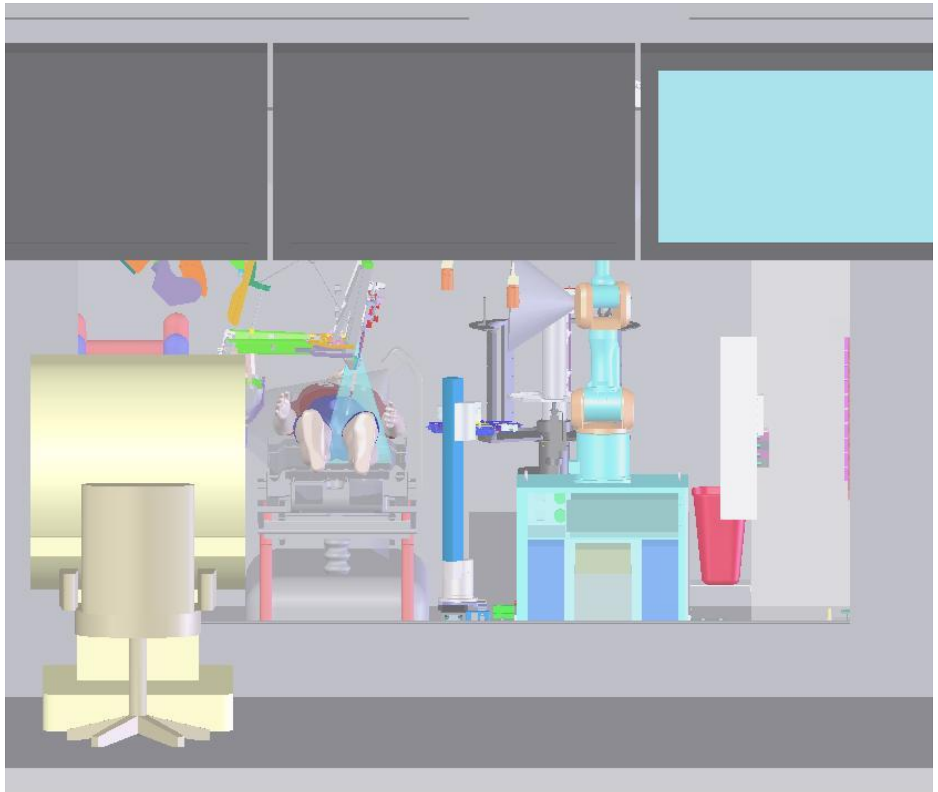
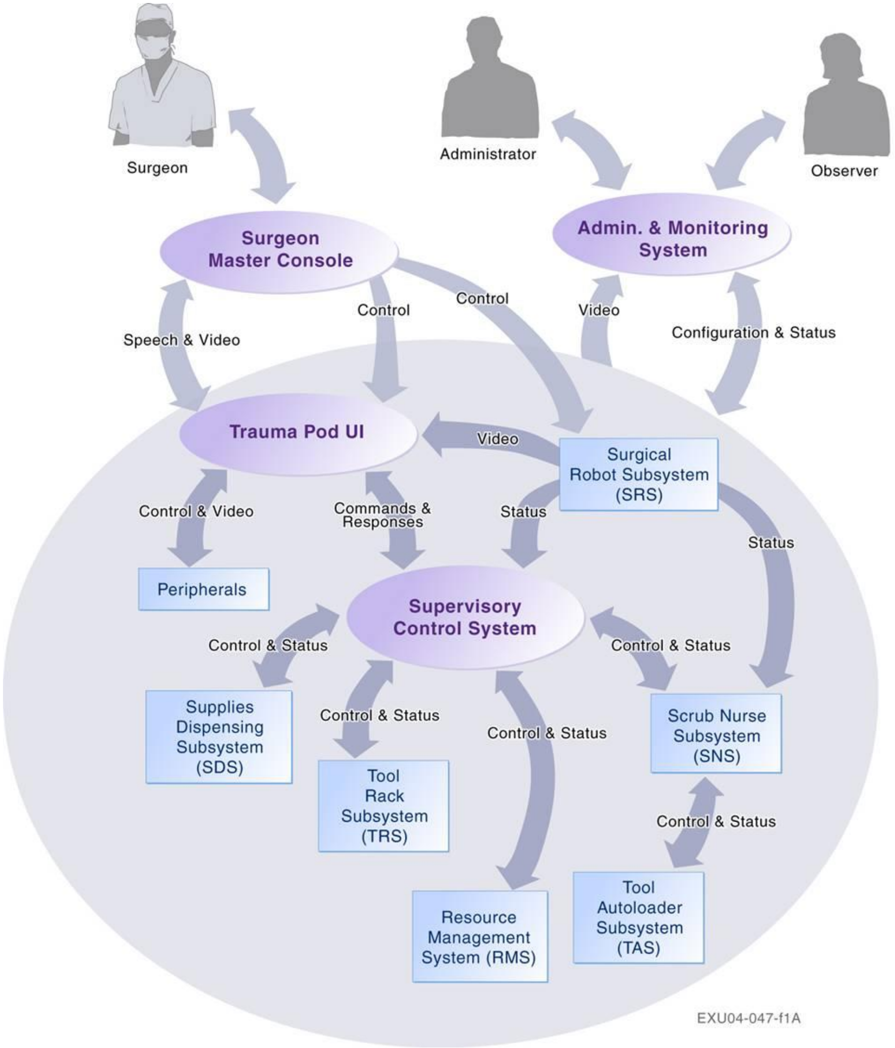


Fig 2 View from Control Room

Overall System Architecture



Trauma Pod – Phase 1

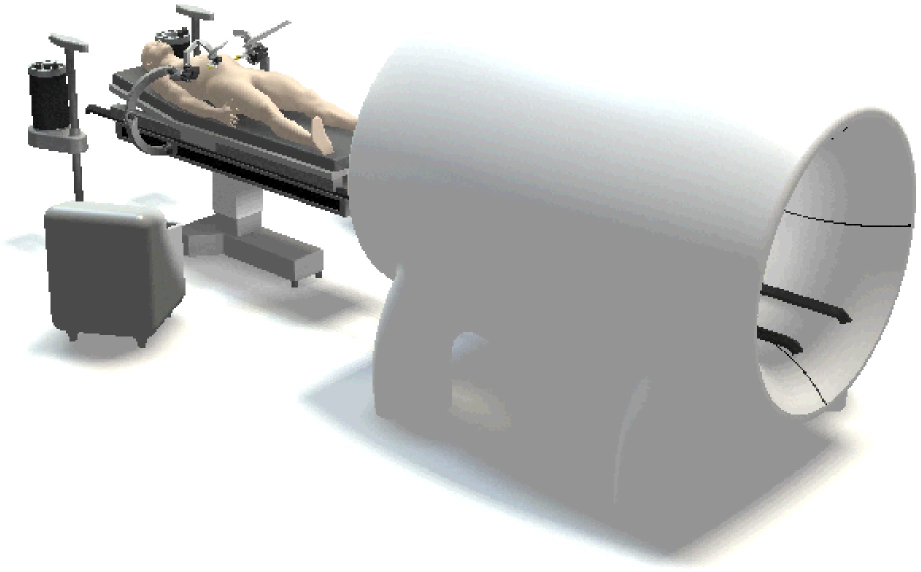
General Approach No. 2

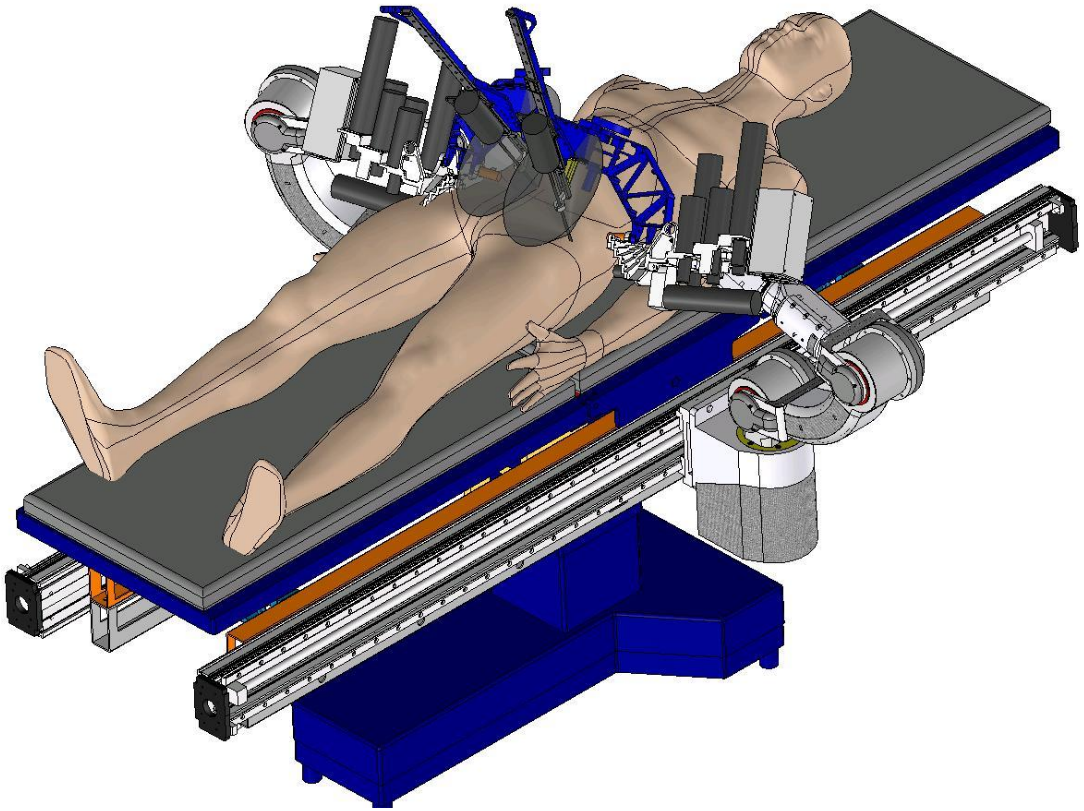
General Approach No. 2 - Phase 1

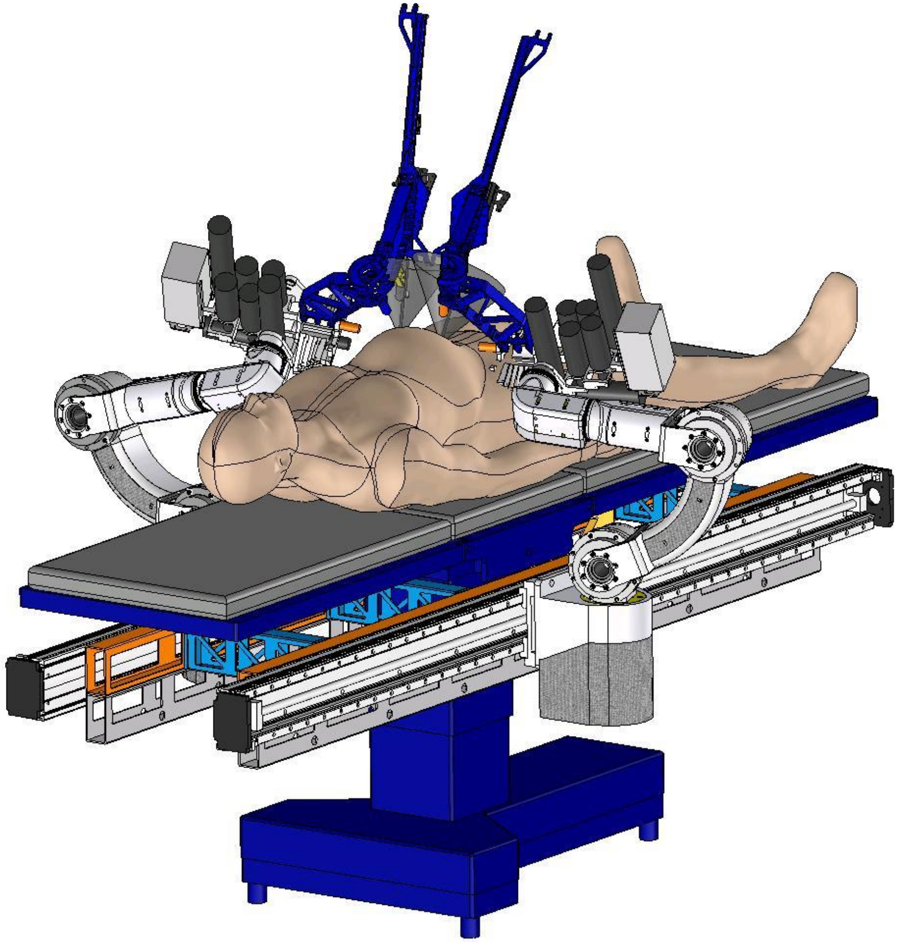
- **Research hypothesis**
  - Typical Surgery – 2 surgeons that are equal to
    - Four arms
    - Four eyes
  - Macro / Micro approach for surgical robotics
  - The human arm as an analogy of a surgical robotic arm
    - Shoulder elbow & wrist – Gross manipulation / Positioning – C-arm
    - Fingers -– Dexterous manipulation - Surgical robot
  - Distributed approach in occupying the surgical field with multiple arms
  - Surgical robotic arms attached to the OR bad
- **Future implications**
  - A surgical robotic arm that can serve itself (no need for surgical nurse)
  - Increasing the range of motion of each individual robotic arm
  - Avoiding arm-to-arm collisions

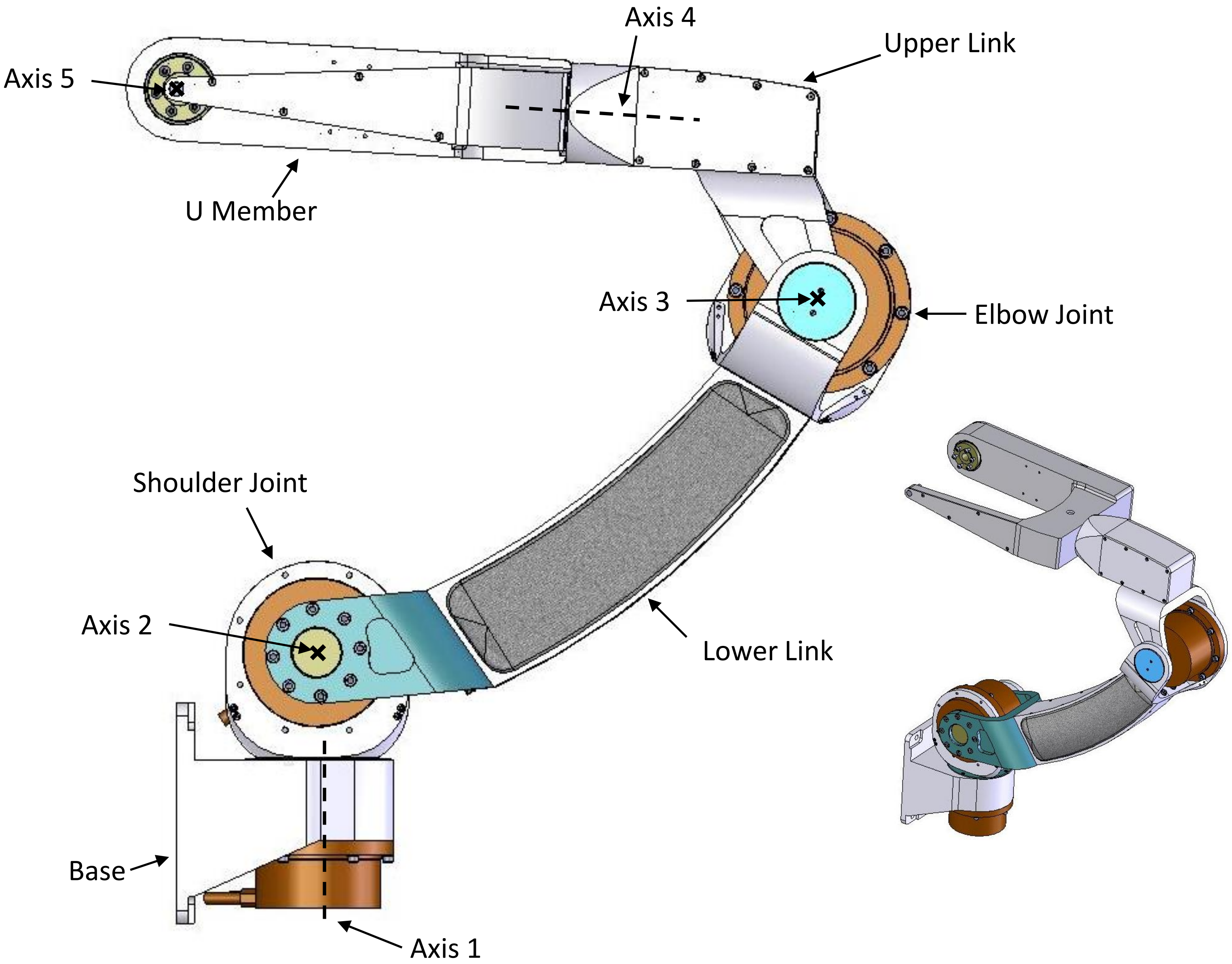
UCLA

General Approach No. 2 - Phase 1

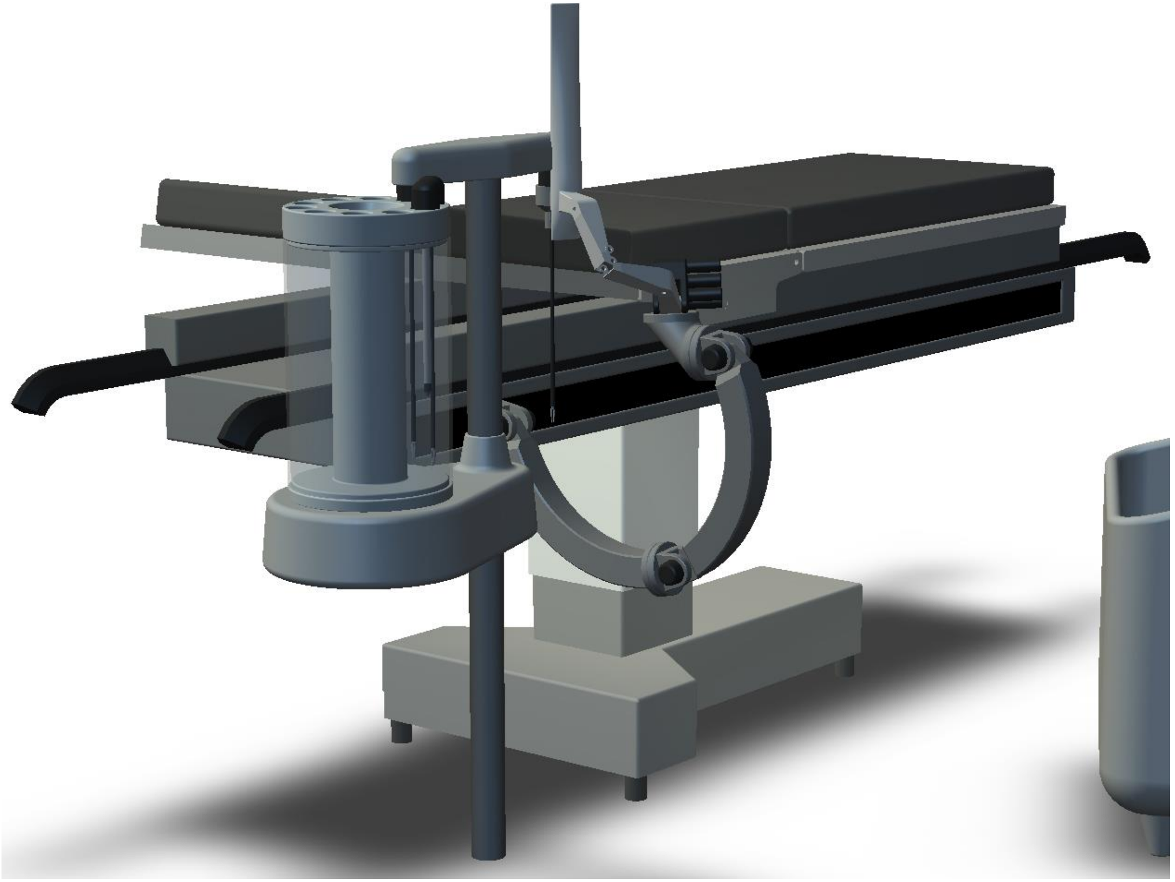




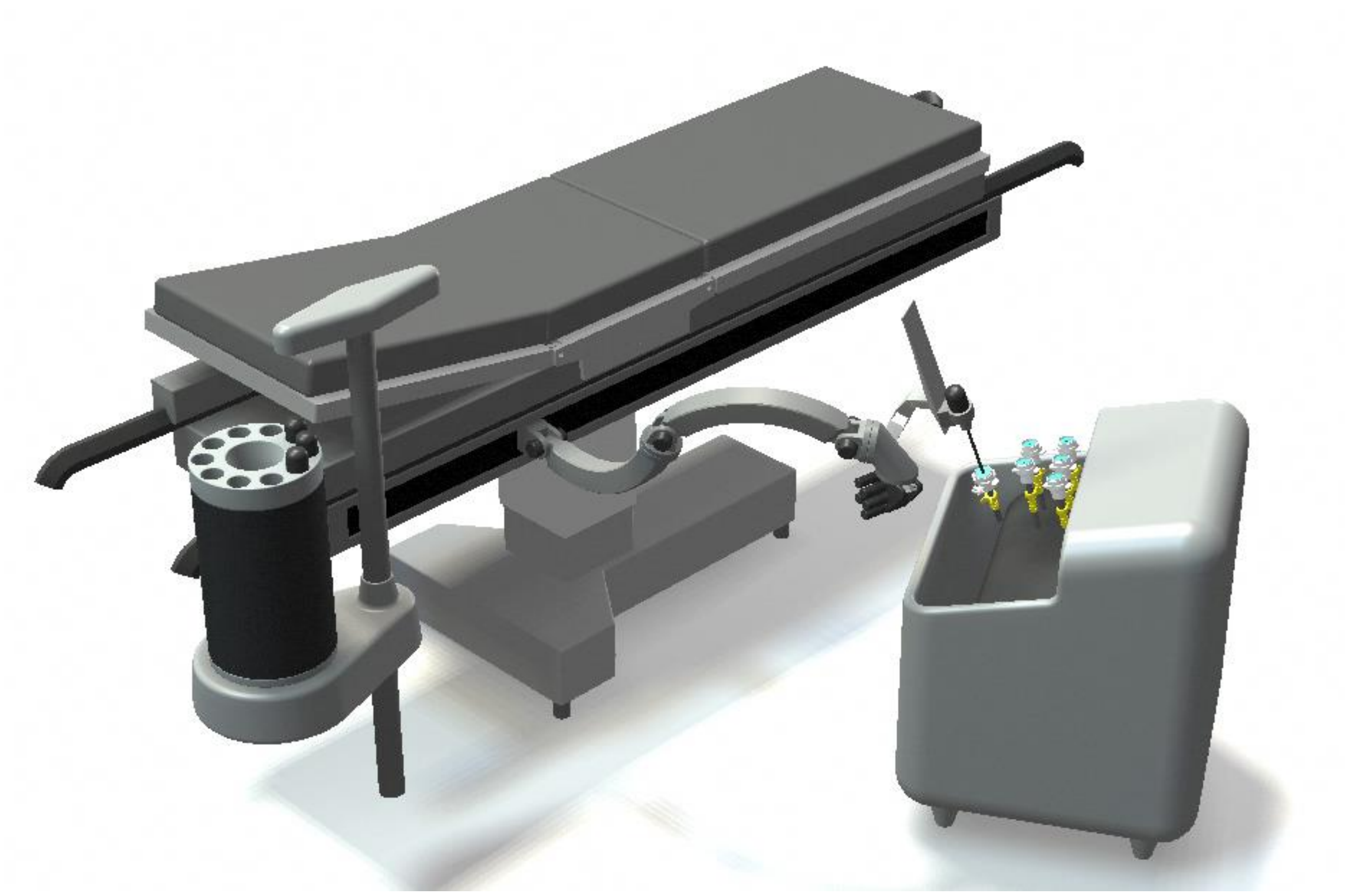


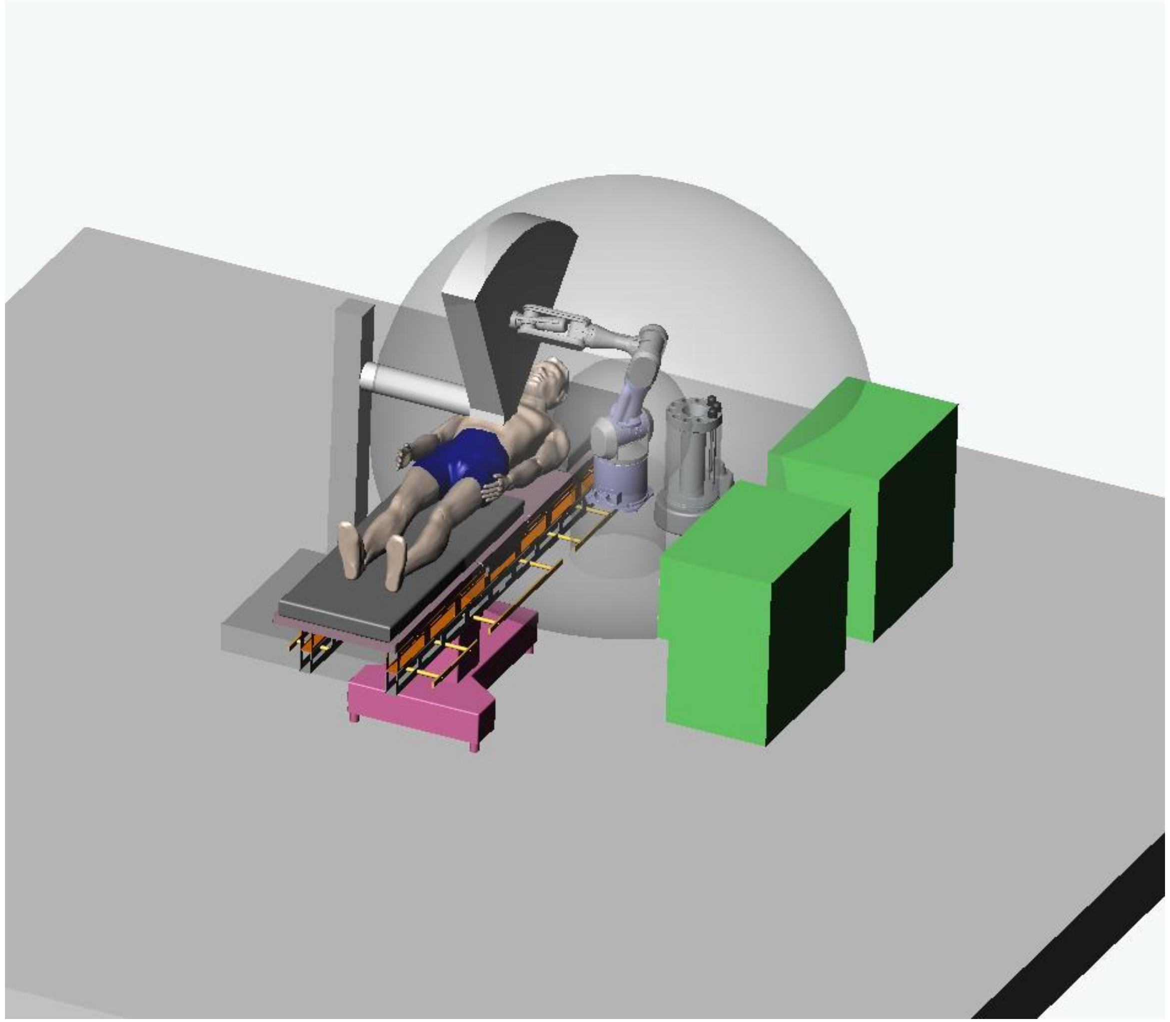

Axis 4
Upper Link
Axis 5
U Member
Axis 3
Elbow Joint
Shoulder Joint
Axis 2
Lower Link
Base
Axis 1

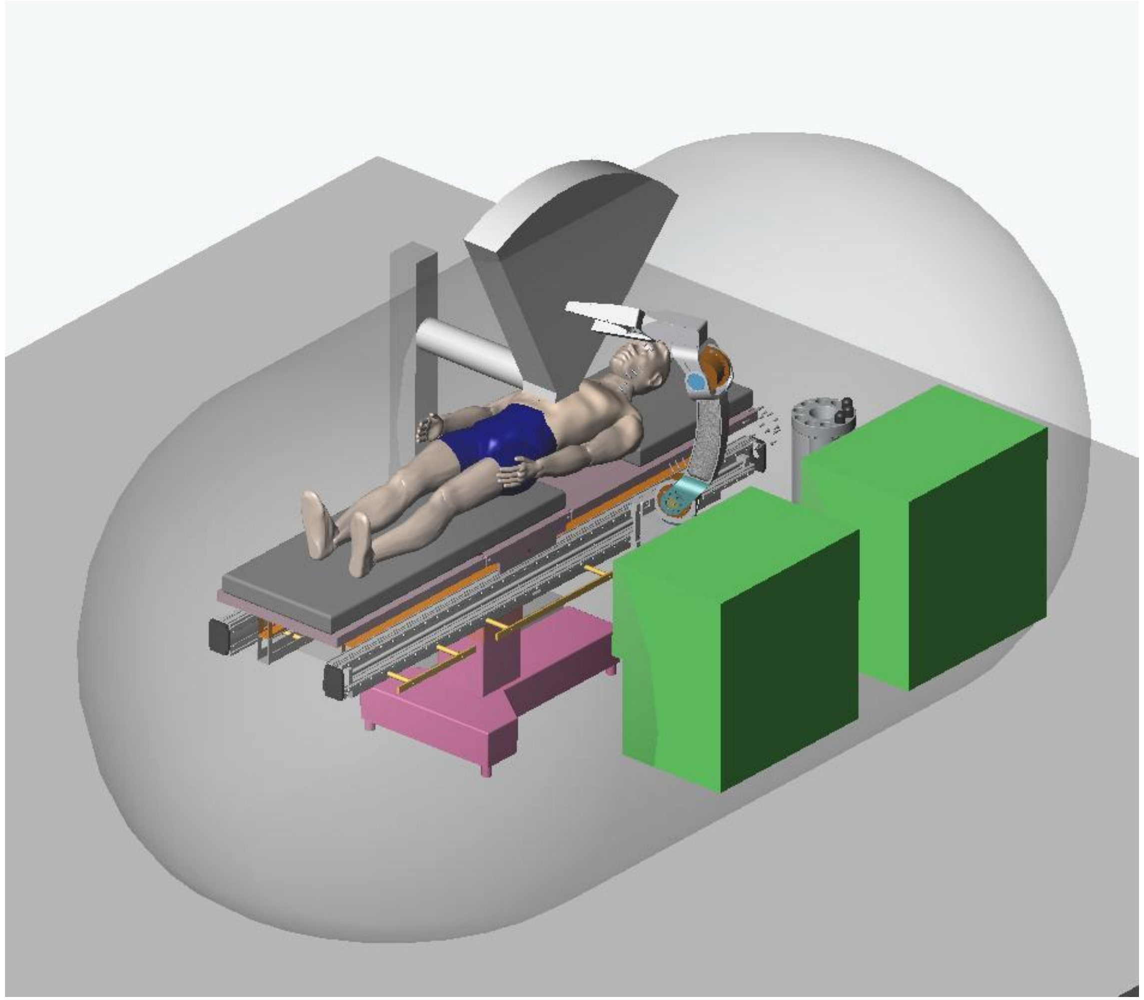
General Approach No. 2 - Phase 1
Tool Changer

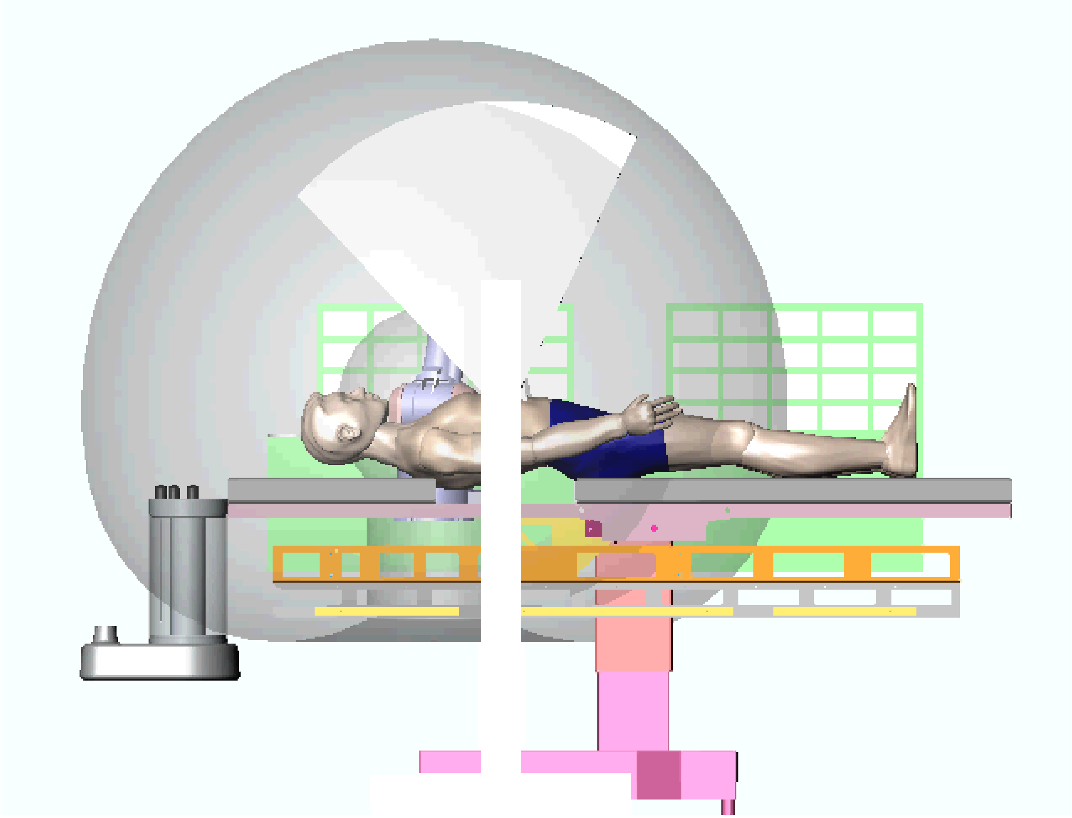


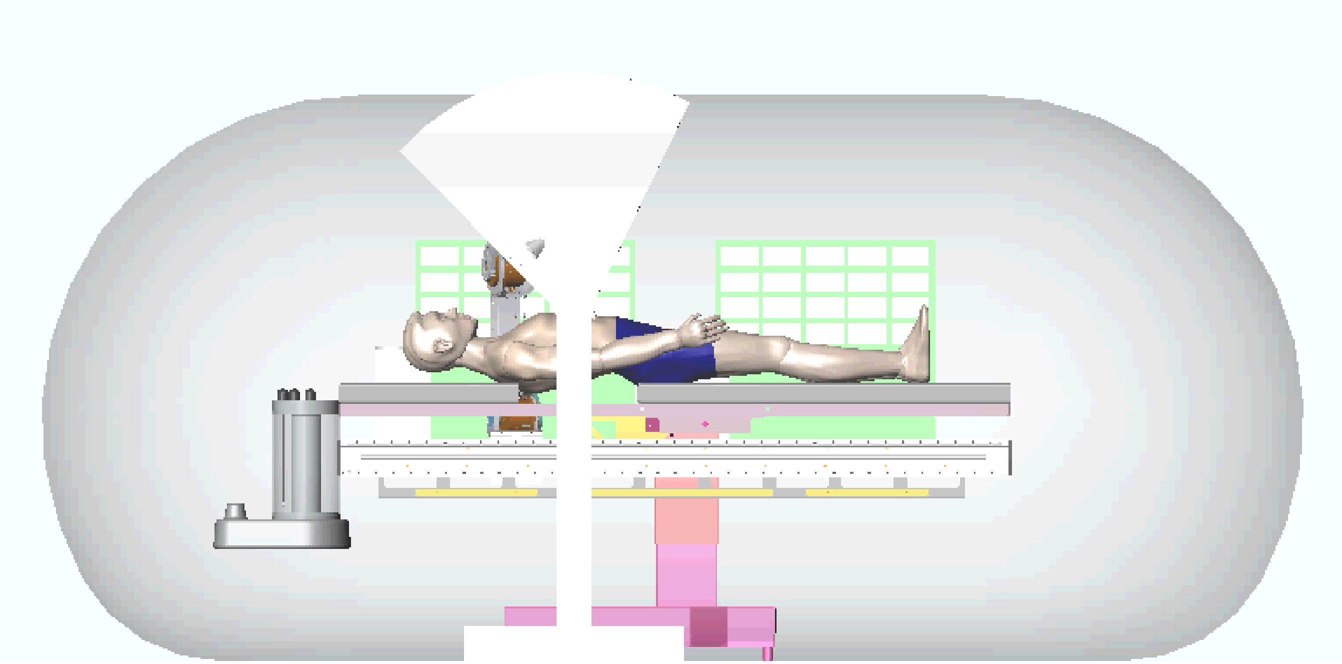
General Approach No. 2 - Phase 1 Equipment Dispenser





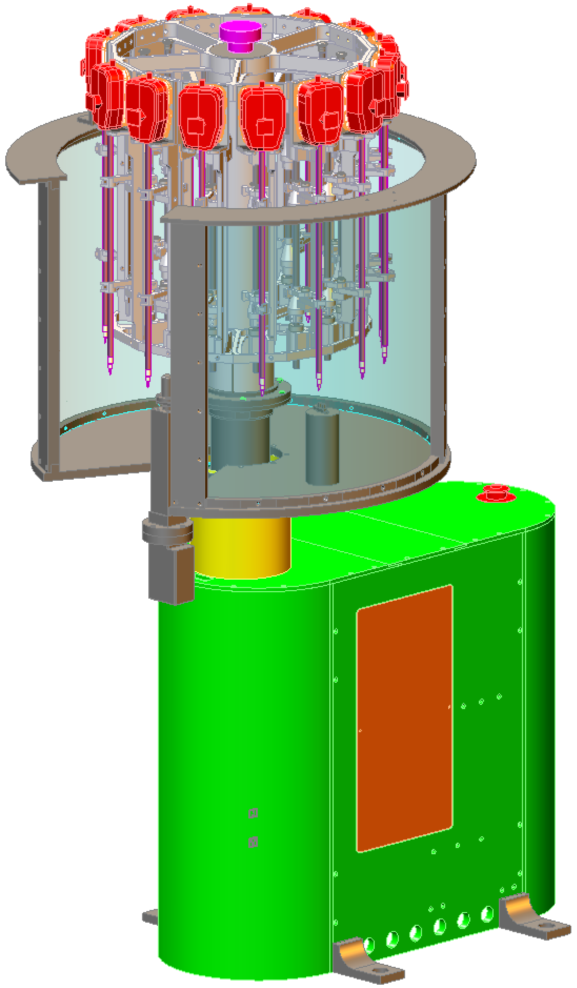






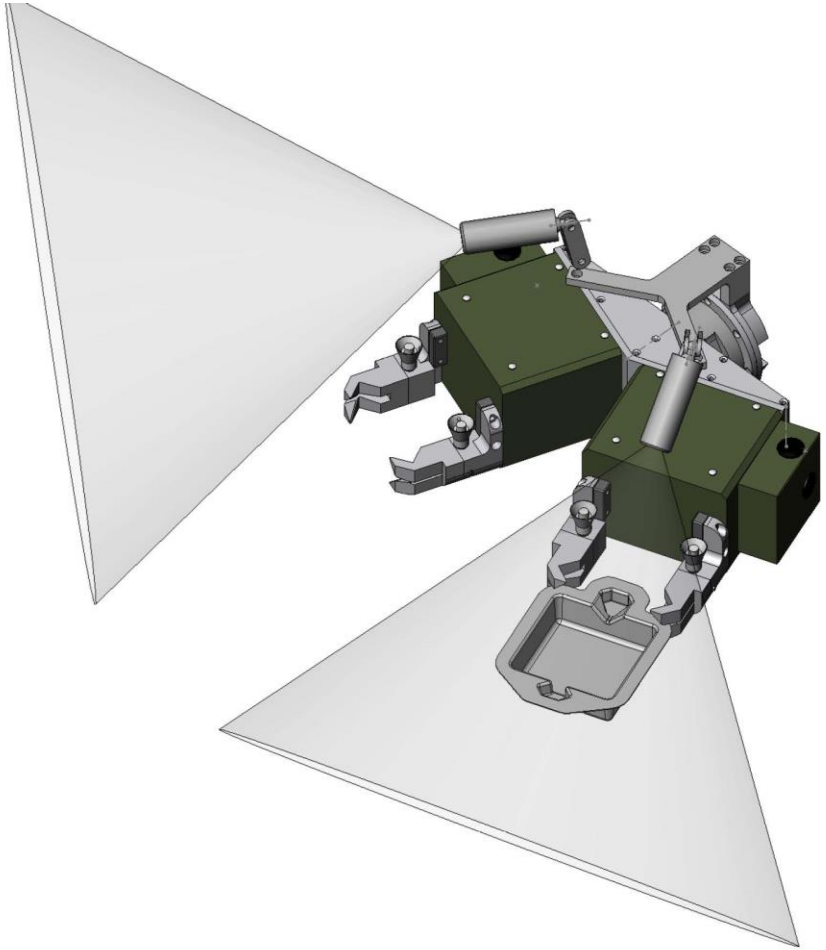
Tool Rack Subsystem (TRS)

- Function – The TRS hosts 10 sterilized tools (max 14) of the surgical robotic system in a spinning magazine that presents upon request the selected tool in a given position and ordination to be picked up by the SNS.
- System Architecture – The removable magazine grasp/release and spin by actuators located in the TRS stationary base. The entire electronic and computer control is located in the base. The system computer control its action maintain its inventory and communicate this information along with the system status to the pod central control system



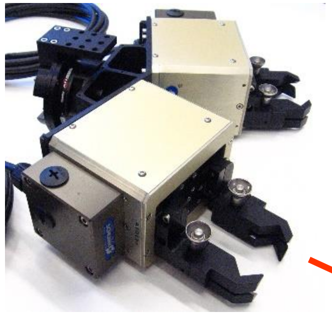
End Effector Subsystem

- Function – The EE is mounted on the surgical nurse system and with it unified actuated grapping fingers can gasp both surgical tools and trays including disposable equipment and deliver them to the surgical robot and the surgical site form their hosting subsystems and back.
- System Architecture – Two pneumatic actuators are attached to a custom made bracket enable a collision free approach to the subsystems and the surgical site. A force sensor monitor forces/torques that are developed as a result of the EE interaction with the subsystems. Two cameras allow to visually monitor the content of the tray and the interaction with the subsystems.



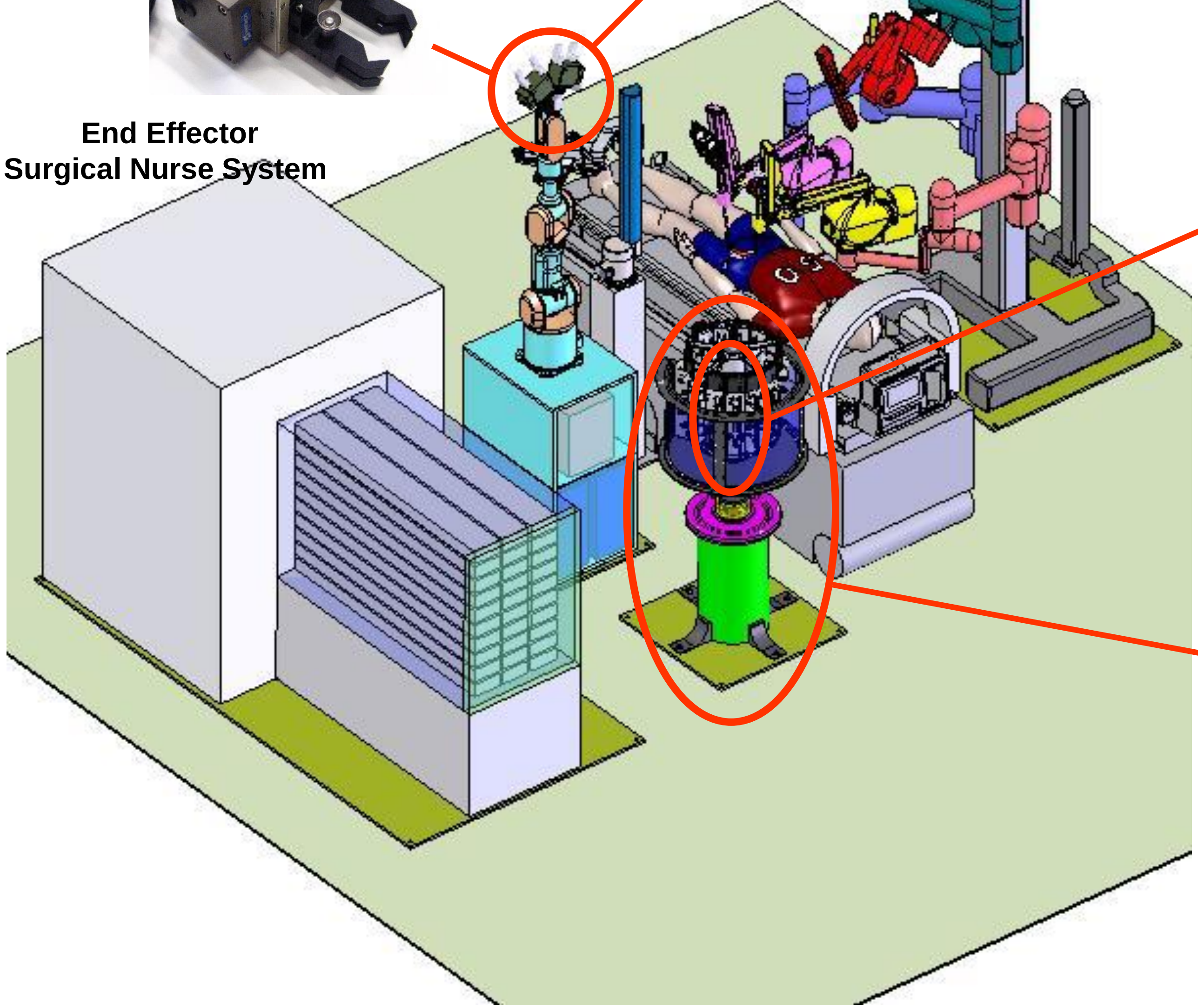
Design Step		Action	Outcome
Initial Problem	Problem Definition	Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition	Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development / Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
	Select the Best Design (Solution)	Optimization	Primary / Secondary Design
	Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration	Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate	Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting	Summary of the Design Process / Lesson Learned	Final Report
	Redesign		

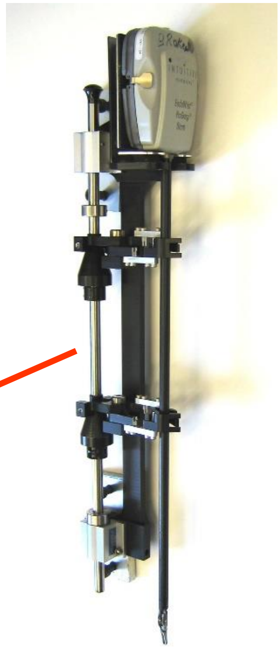
Design Step		Action	Outcome
Initial Problem			
Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
	Select the Best Design (Solution)	Optimization	Primary / Secondary Design
	Construct a Prototype	**Machining / Rapid Prototyping**	**Artifact / Fully functional System**
Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
Reporting		Summary of the Design Process / Lesson Learned	Final Report
Redesign			



End Effector Cameras
Surgical Nurse System

End Effector
Surgical Nurse System

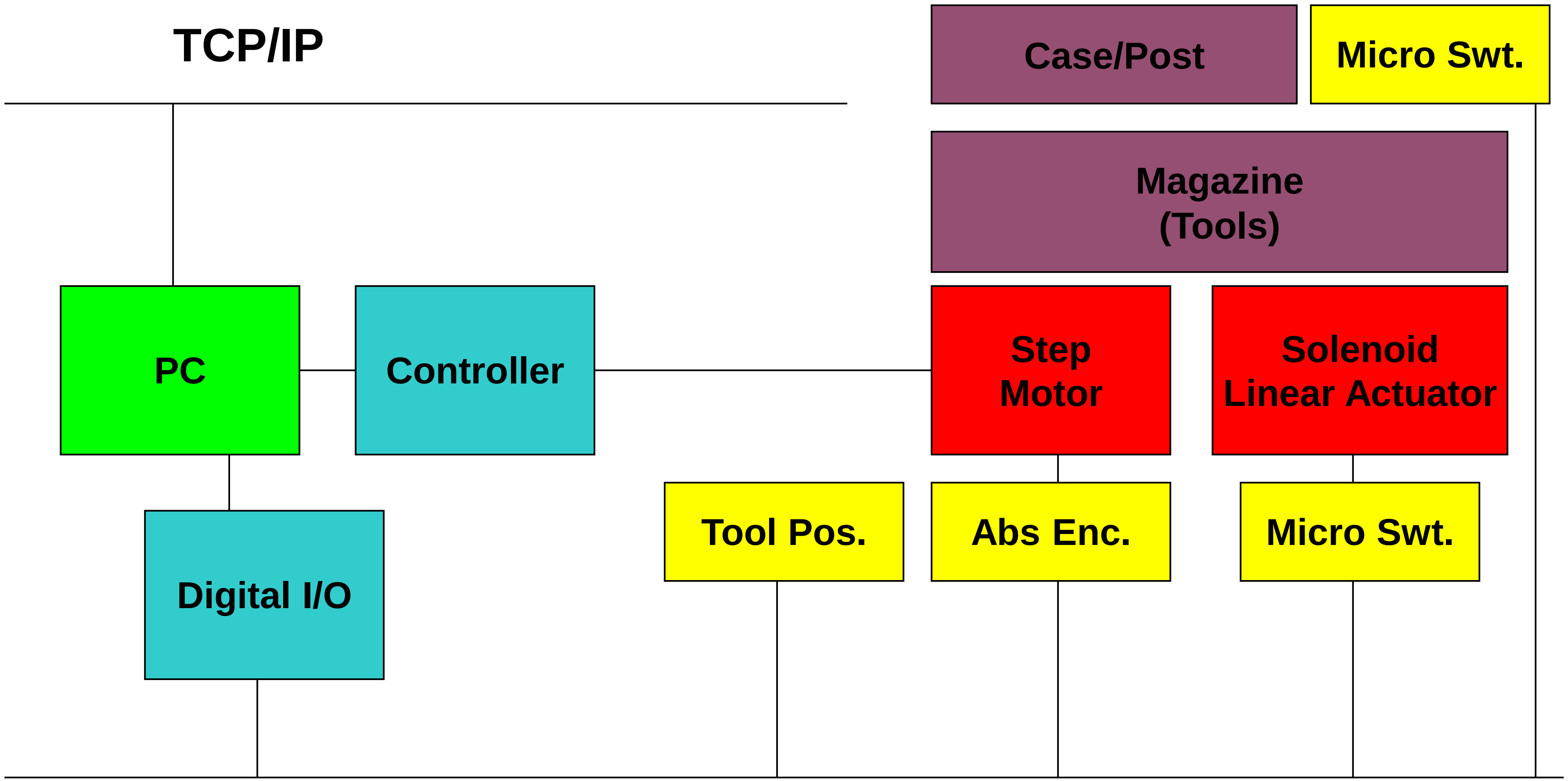


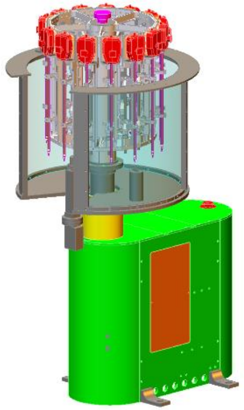


Tool Holder (x14)
Tool Rack System

Base
Tool Rack System

TRS - Architecture

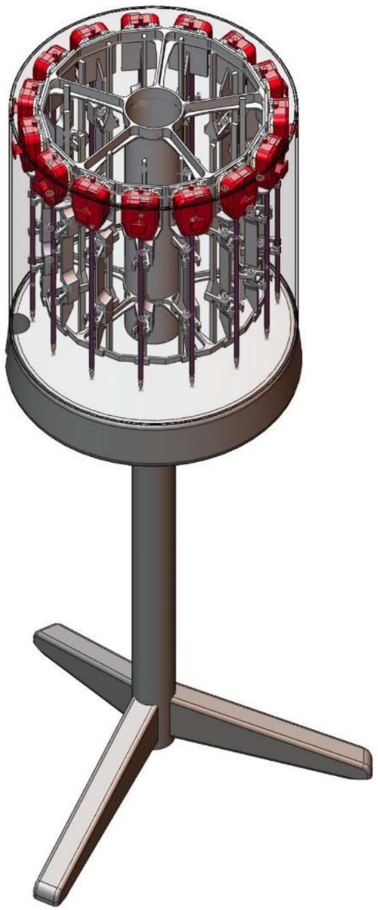


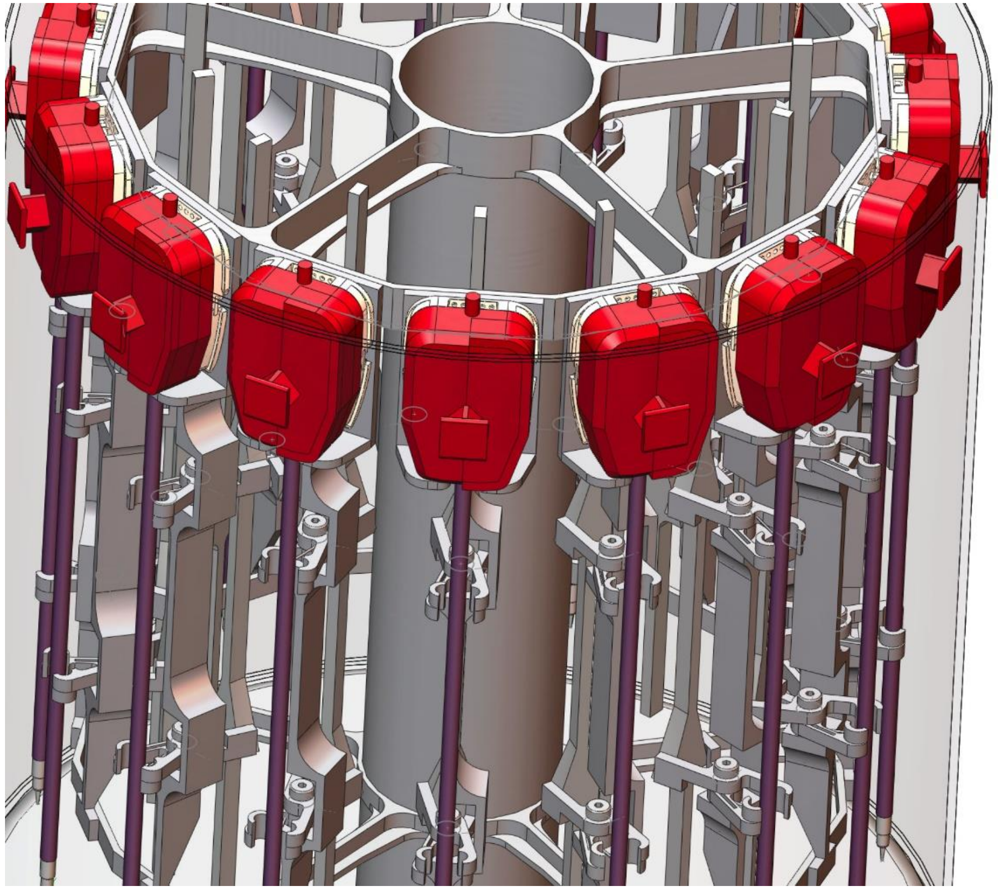


Design Question

How to Arrange the tools in the Tool Rack System (TRS)

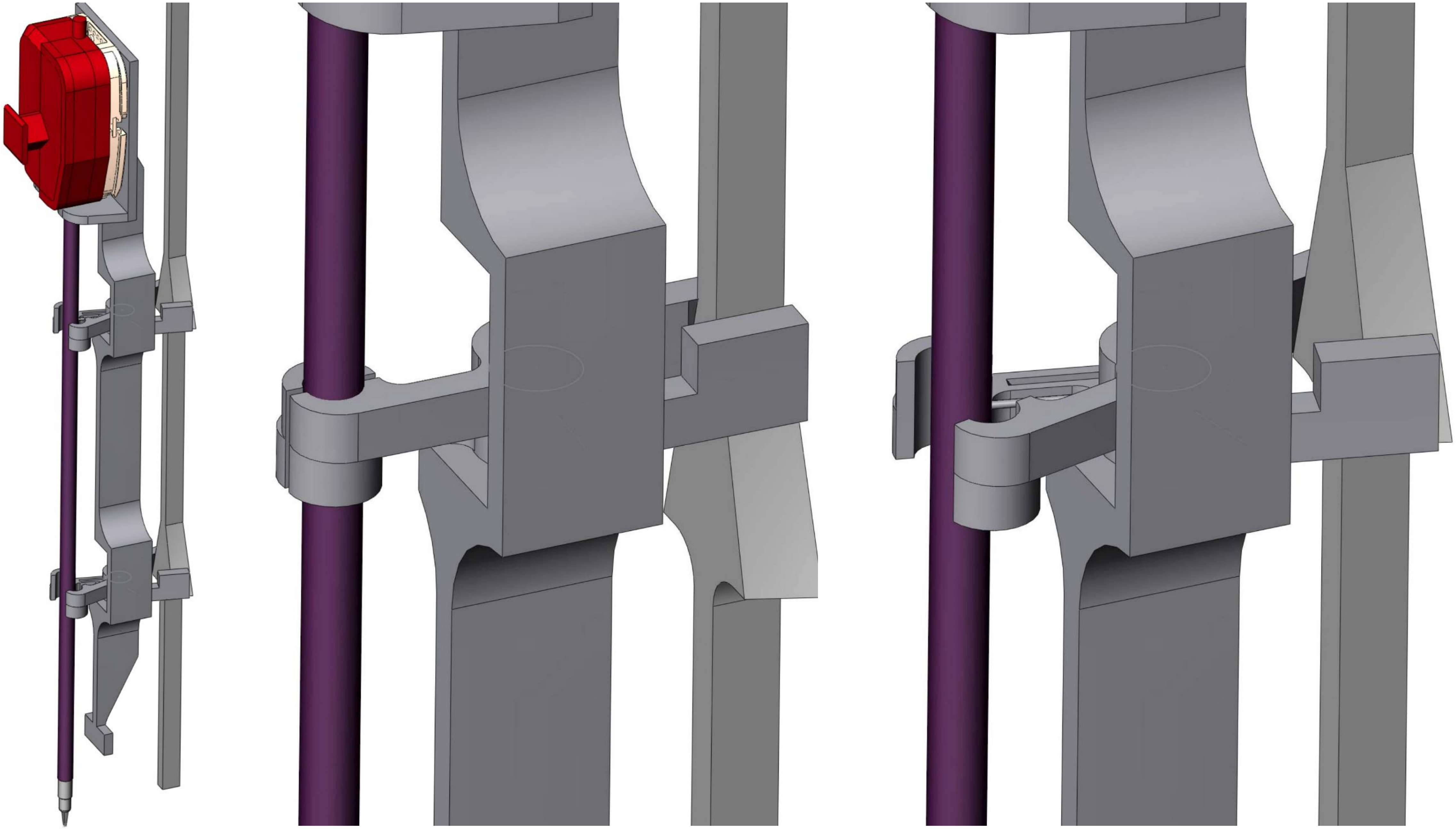
Tool Rack System (TRS) – Preliminary Concepts





Design Question

How to Attached the tools to the Tool Rack System (TRS)



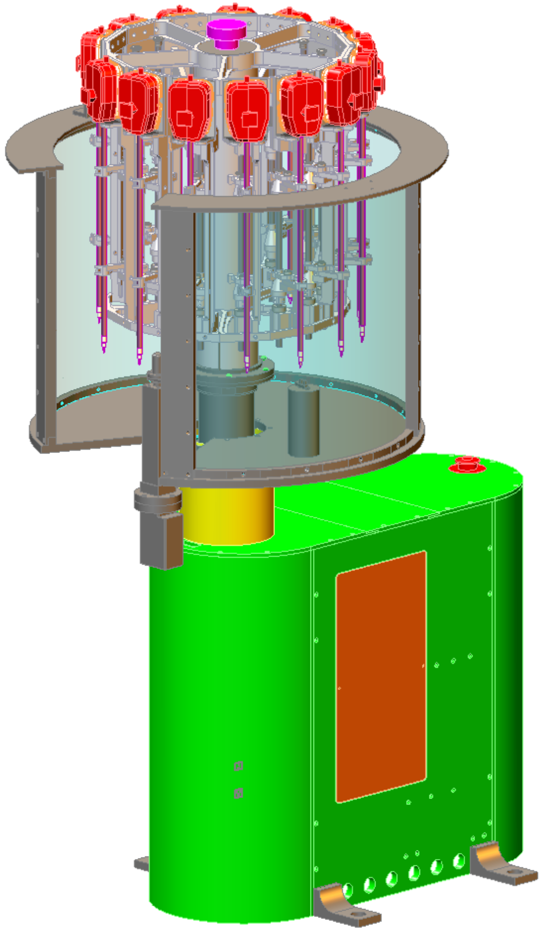
Design Question

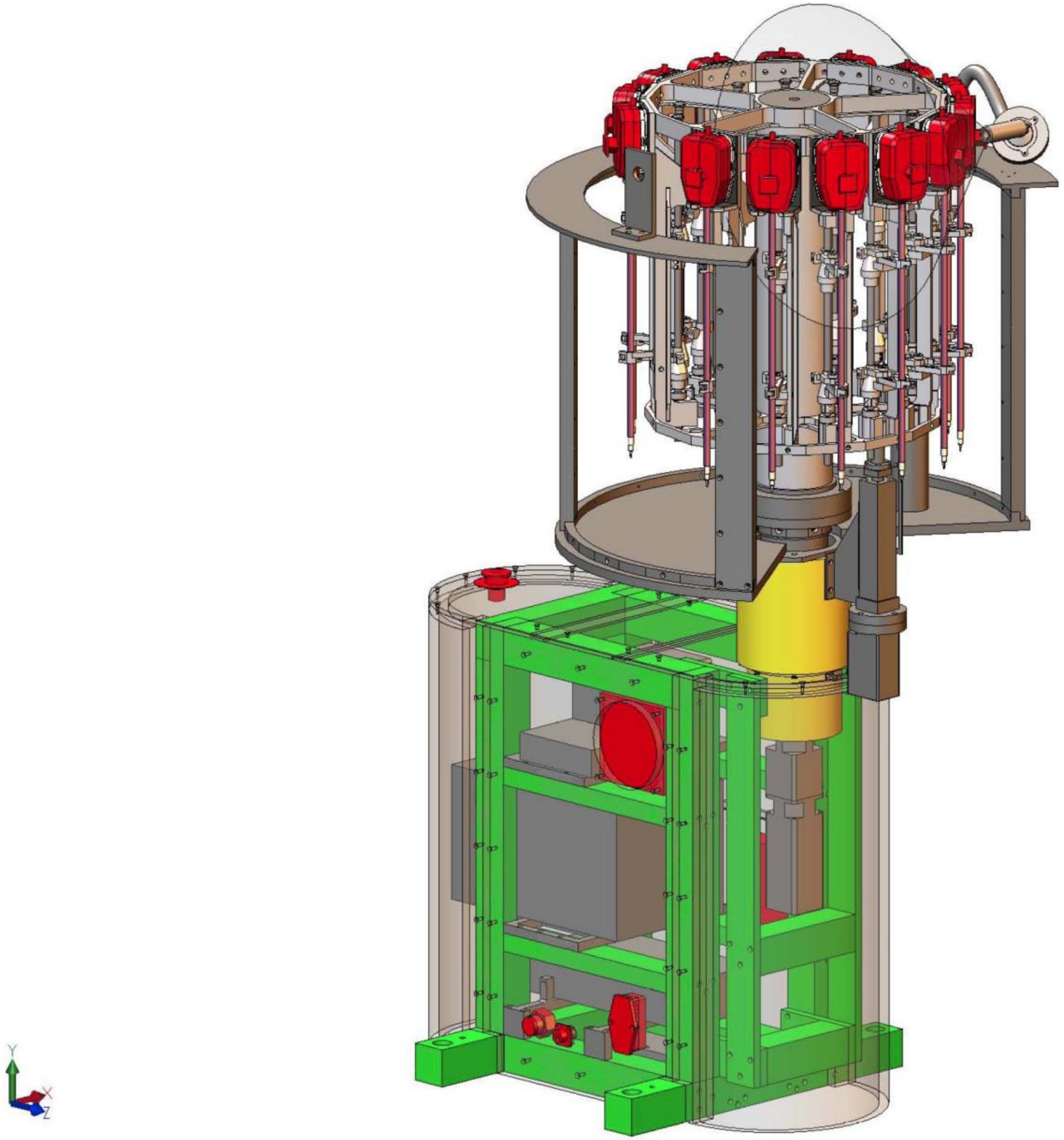
What are the problems with the initial design the Tool Rack System (TRS)

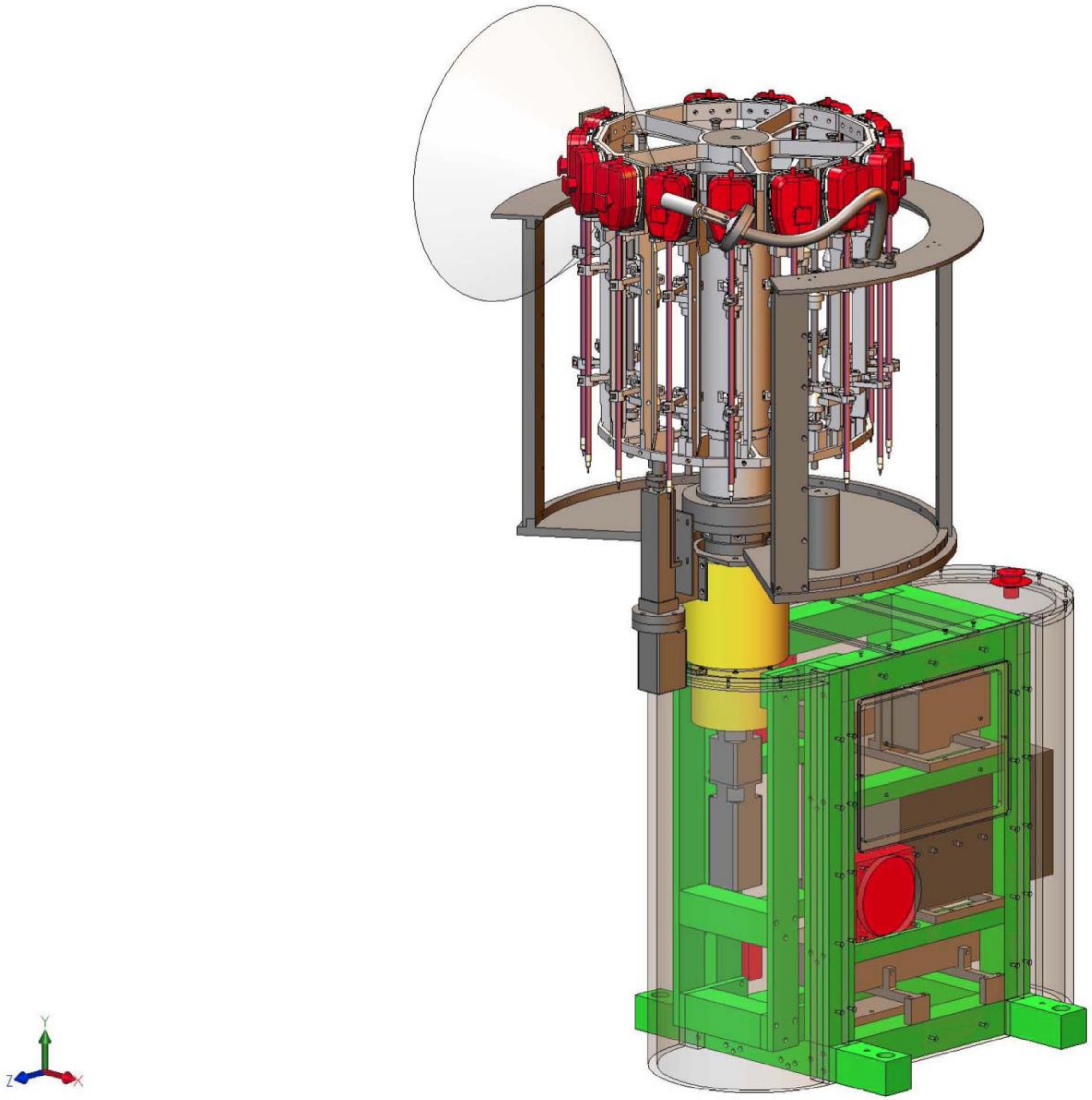
Design Question

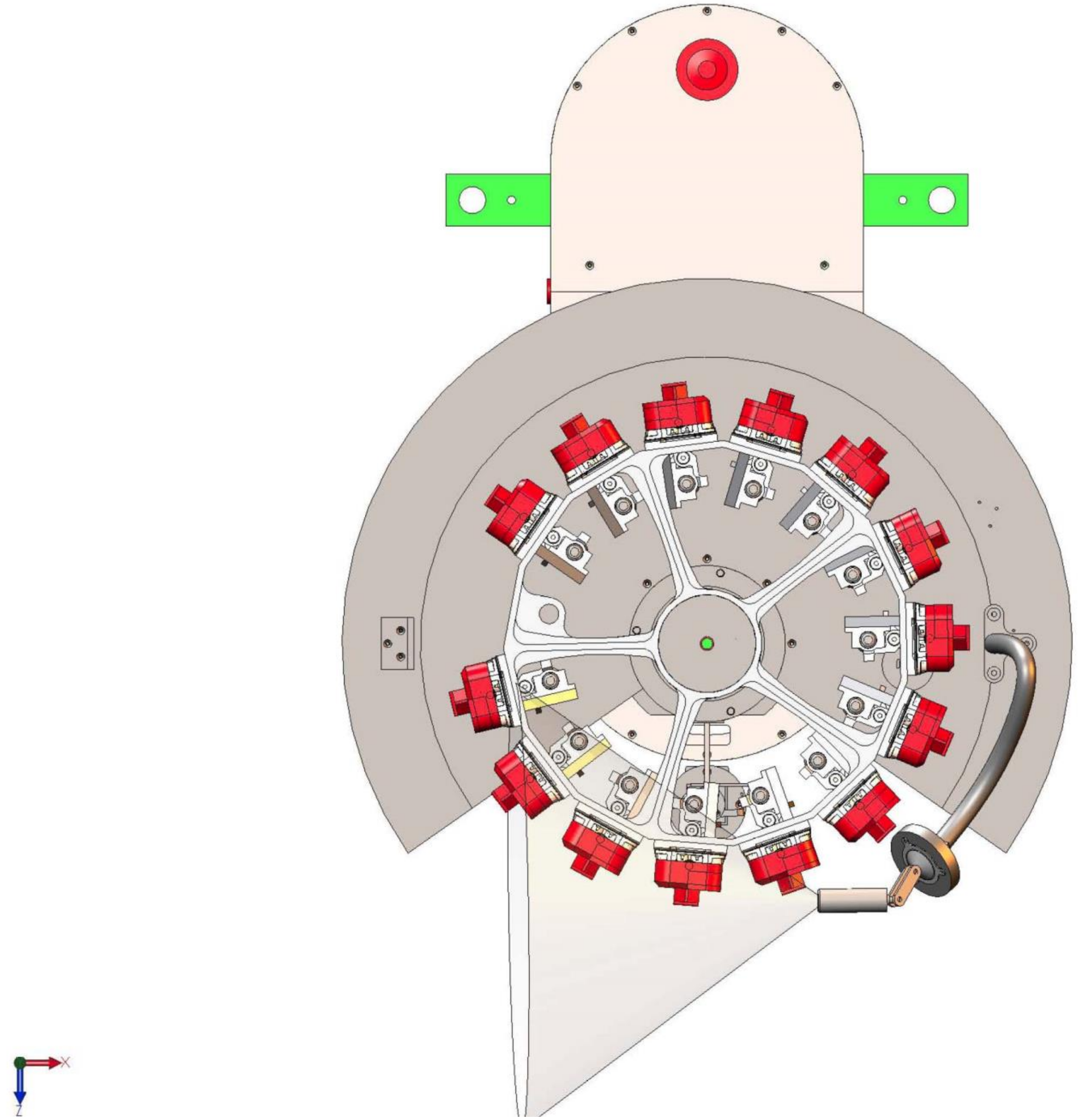
What are the potential solutions to the problem?

Tool Rack System (TRS) – Final Concept

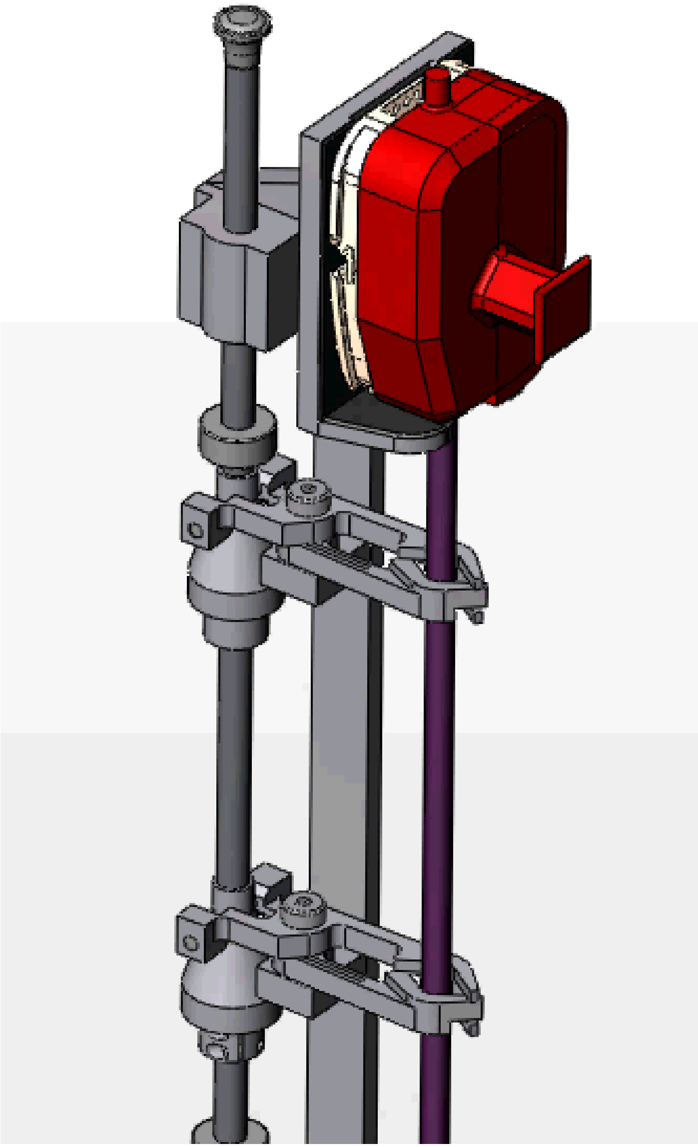


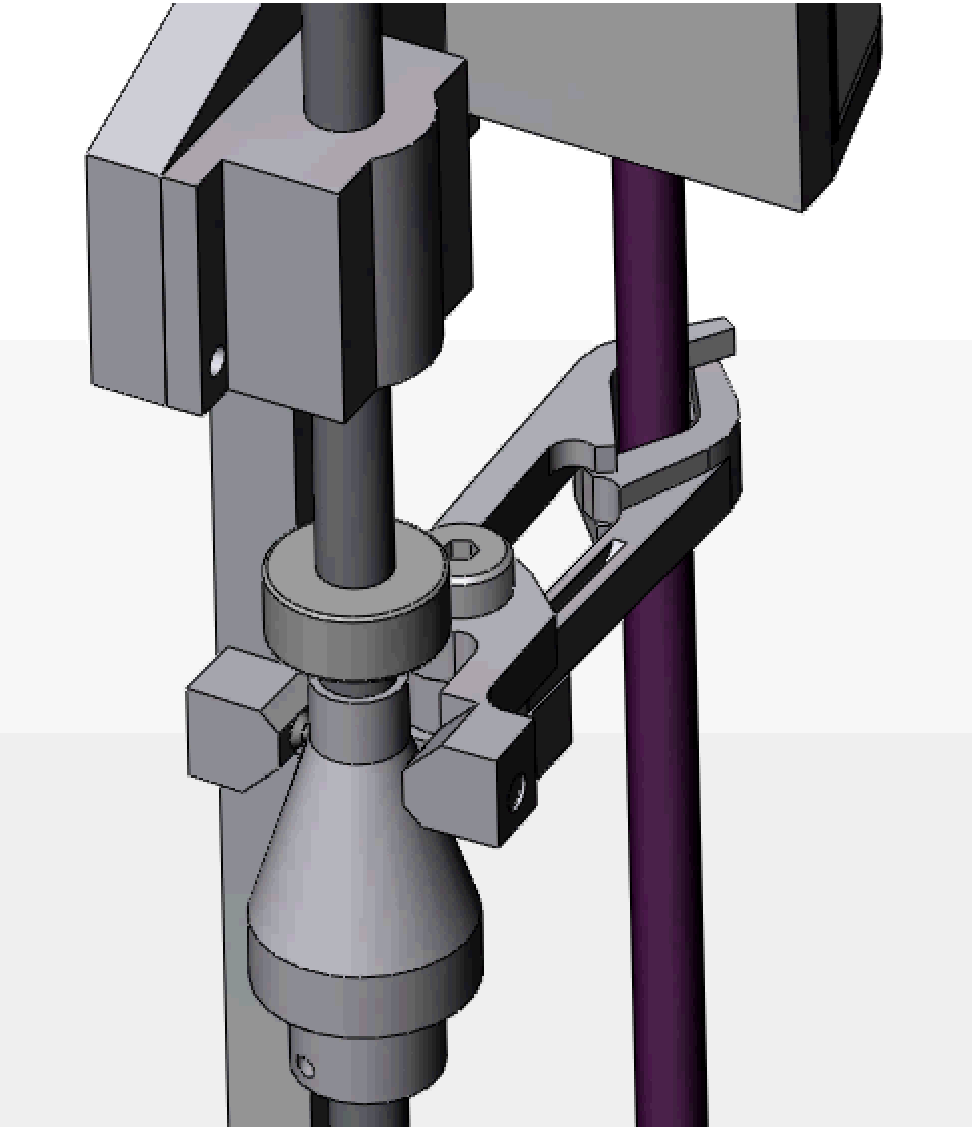


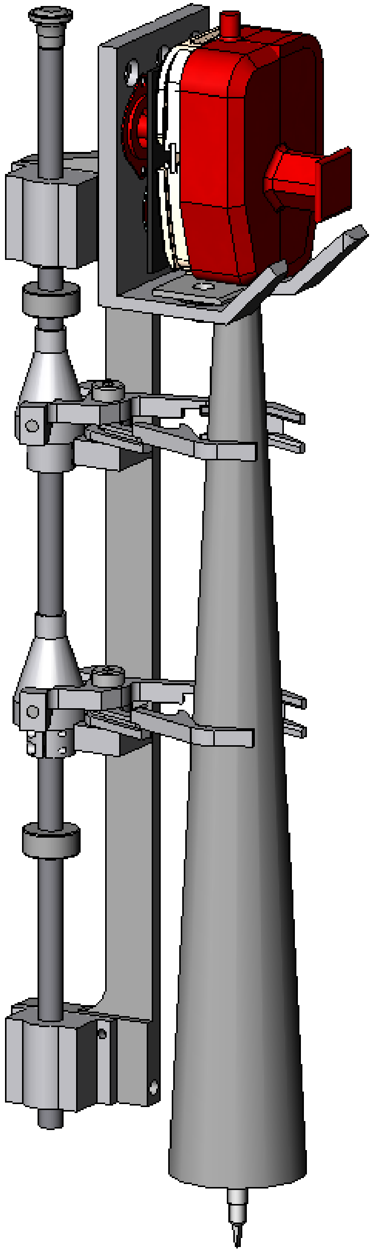

Y
Z
X

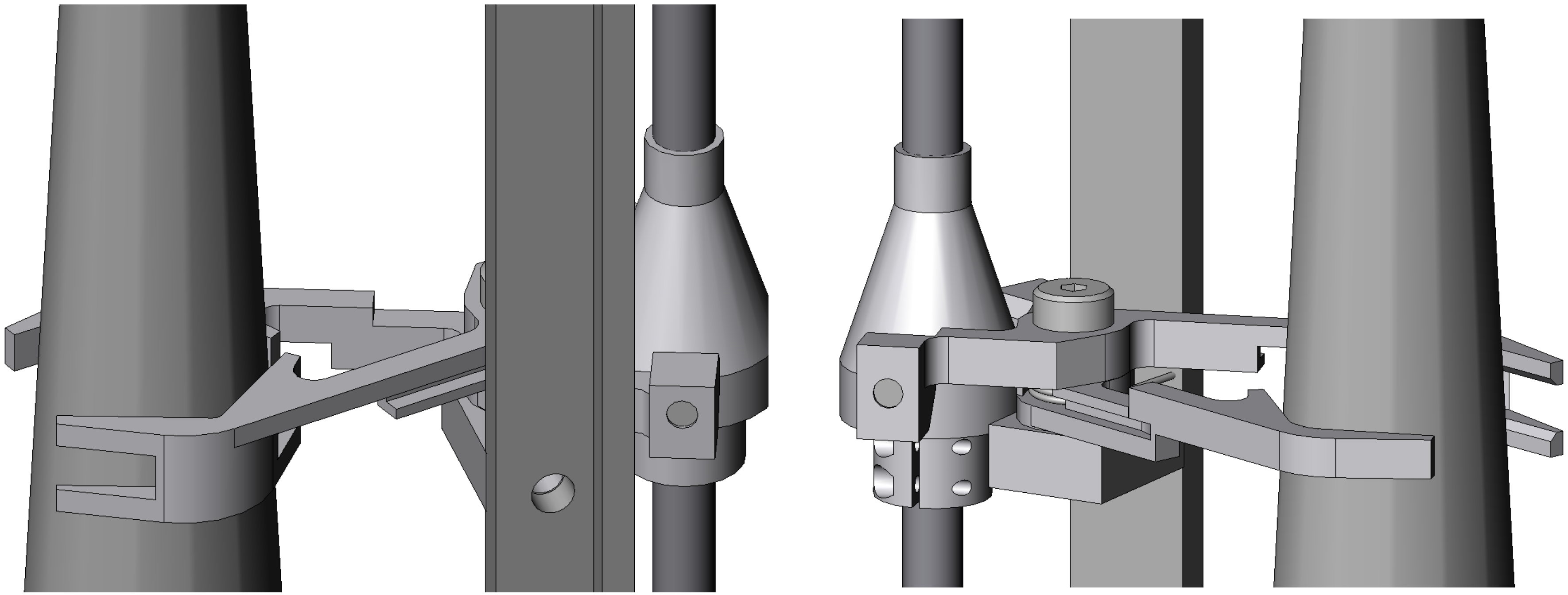


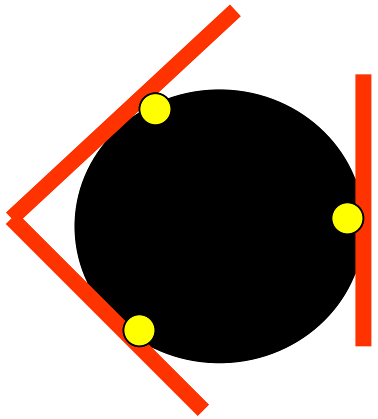
UCLA

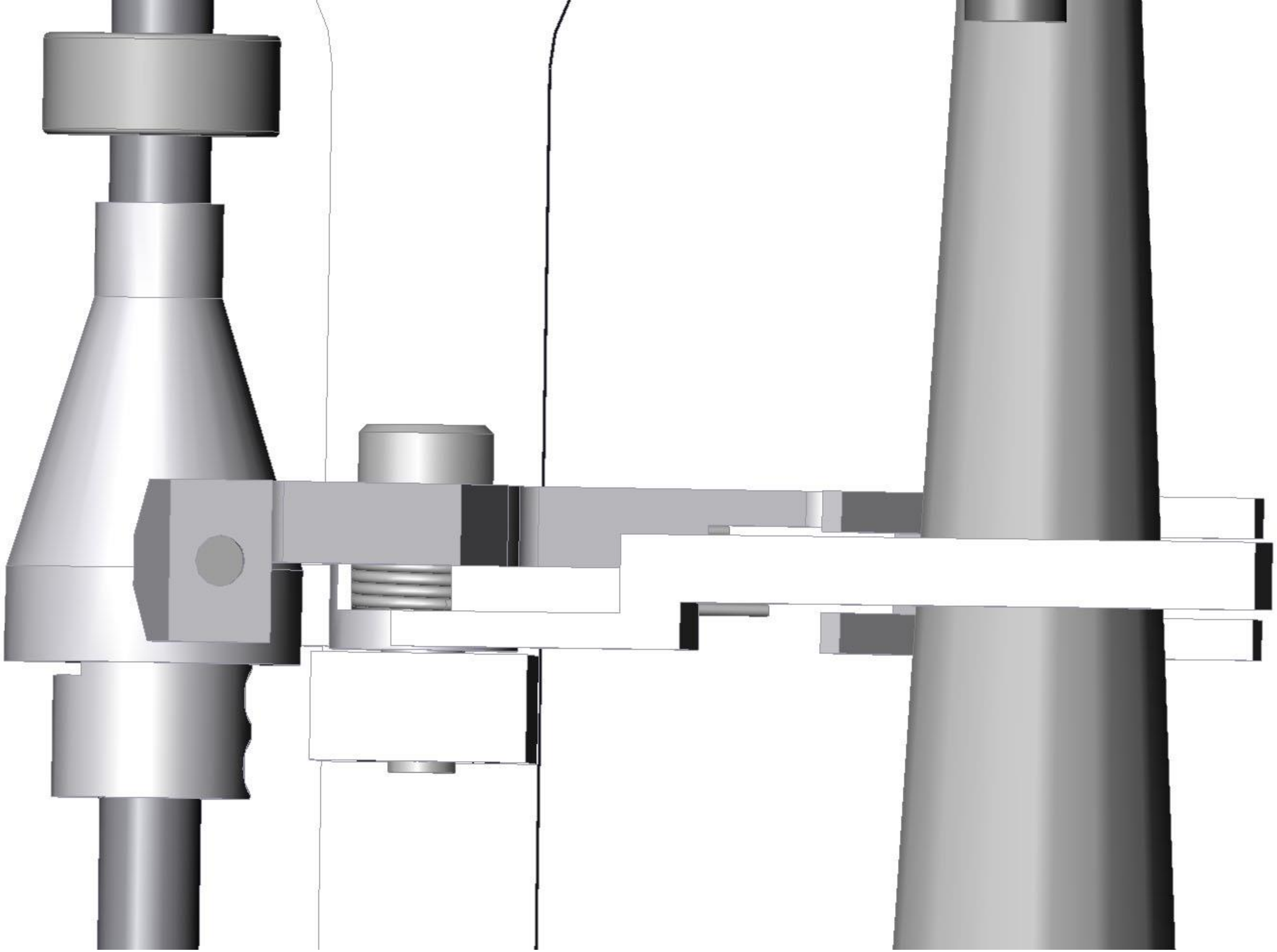




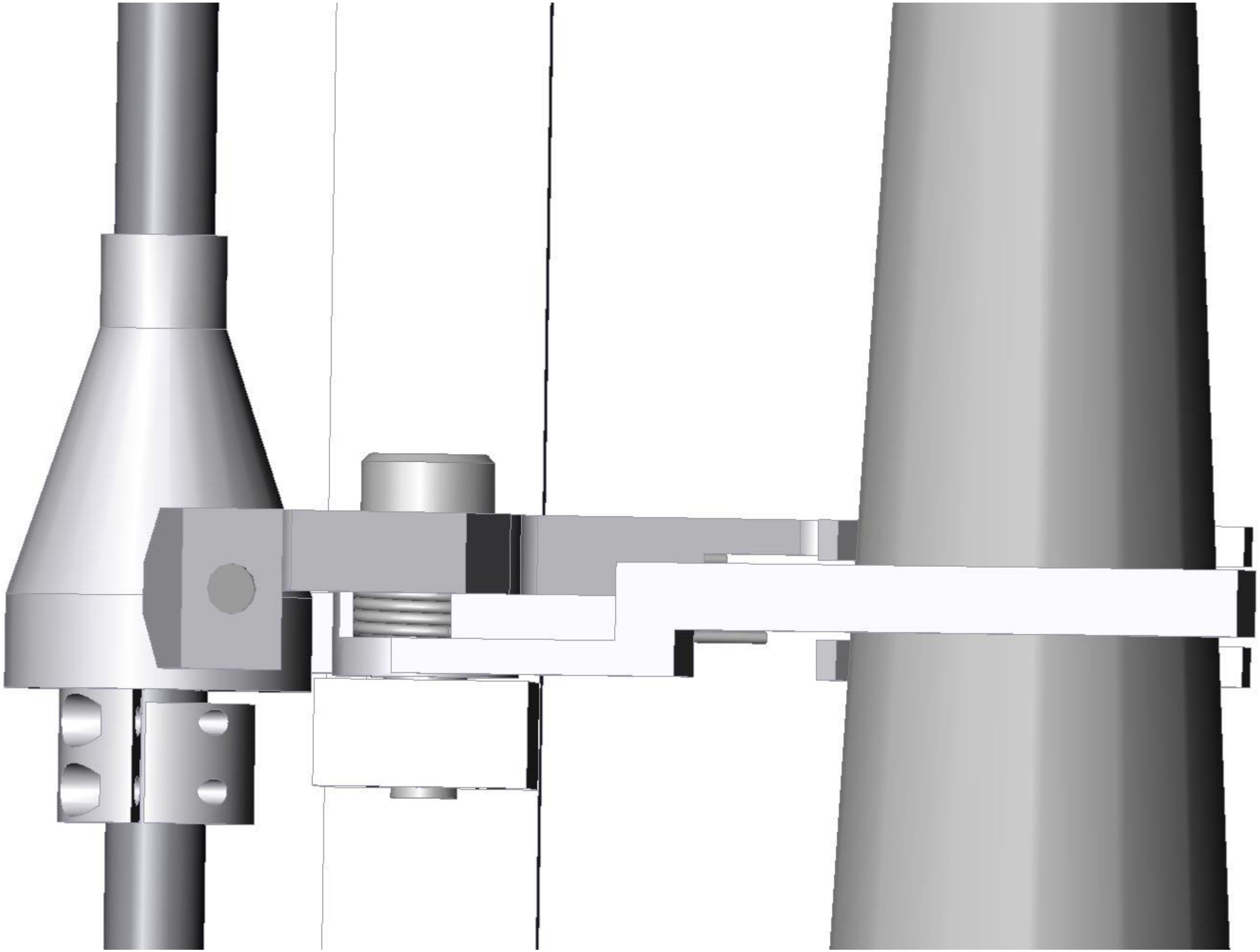


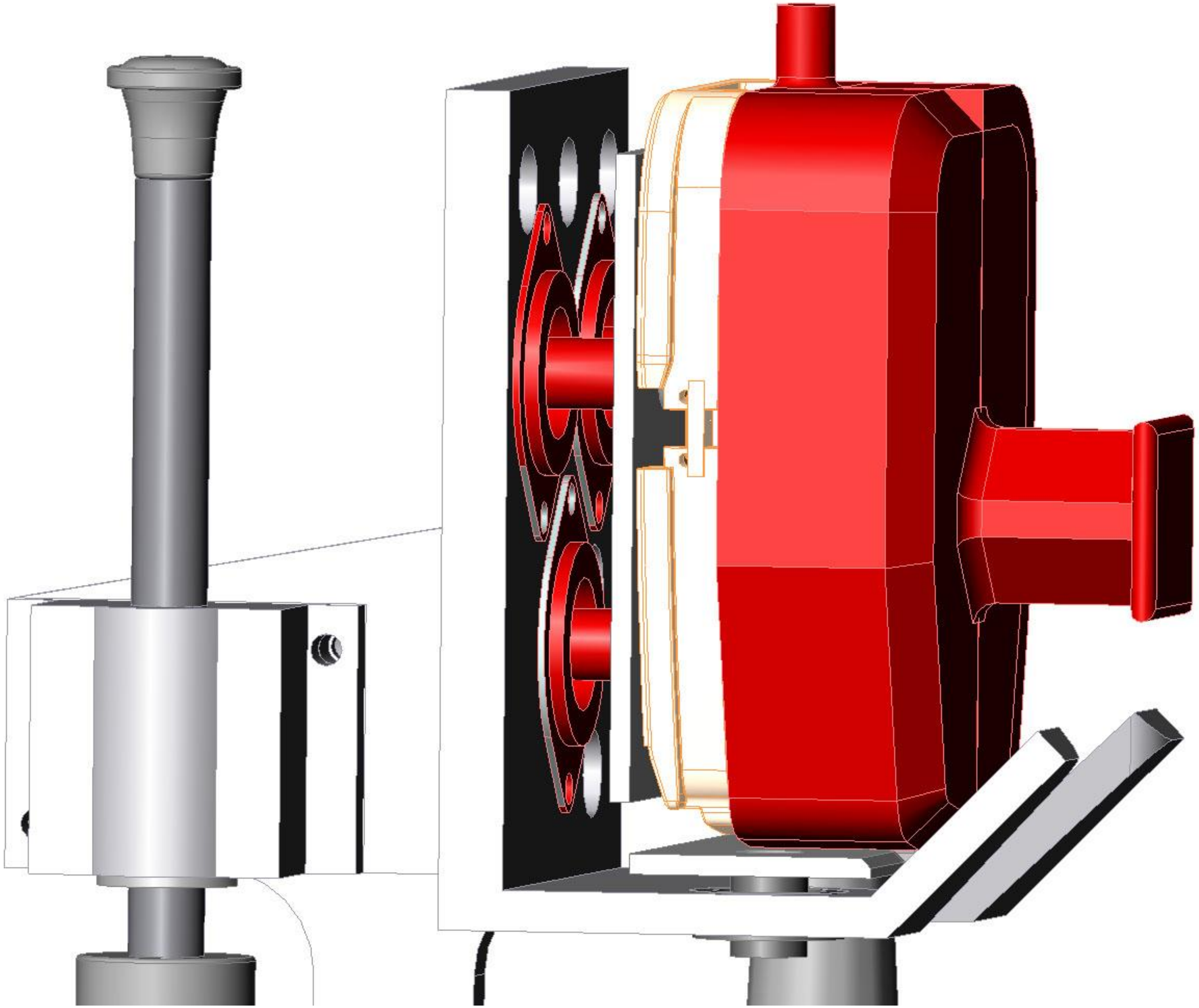




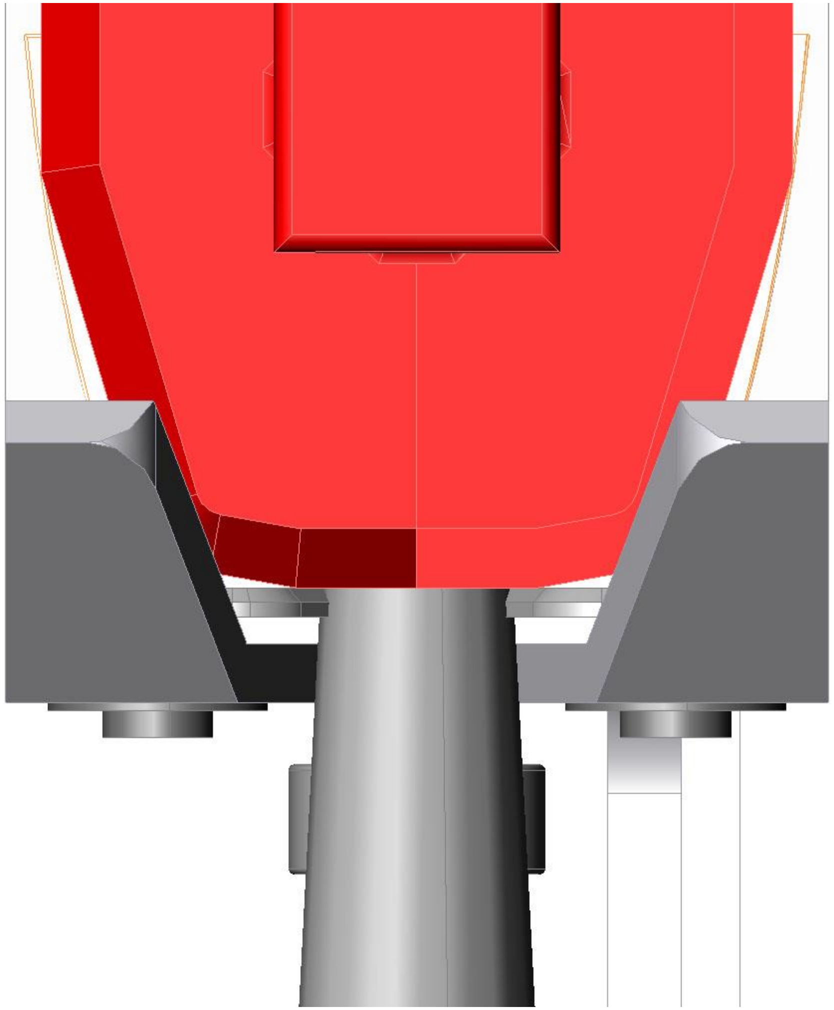


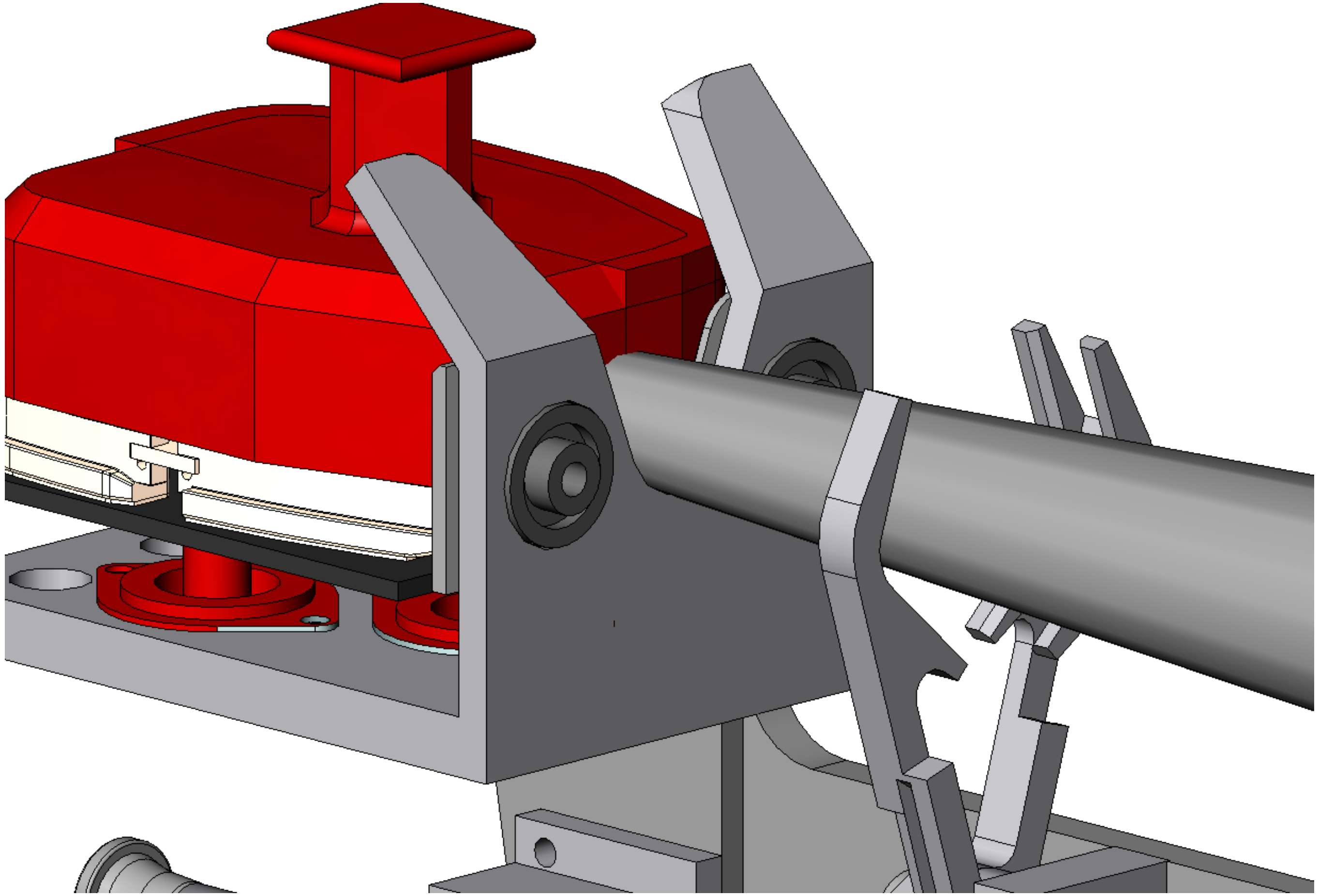
UCLA

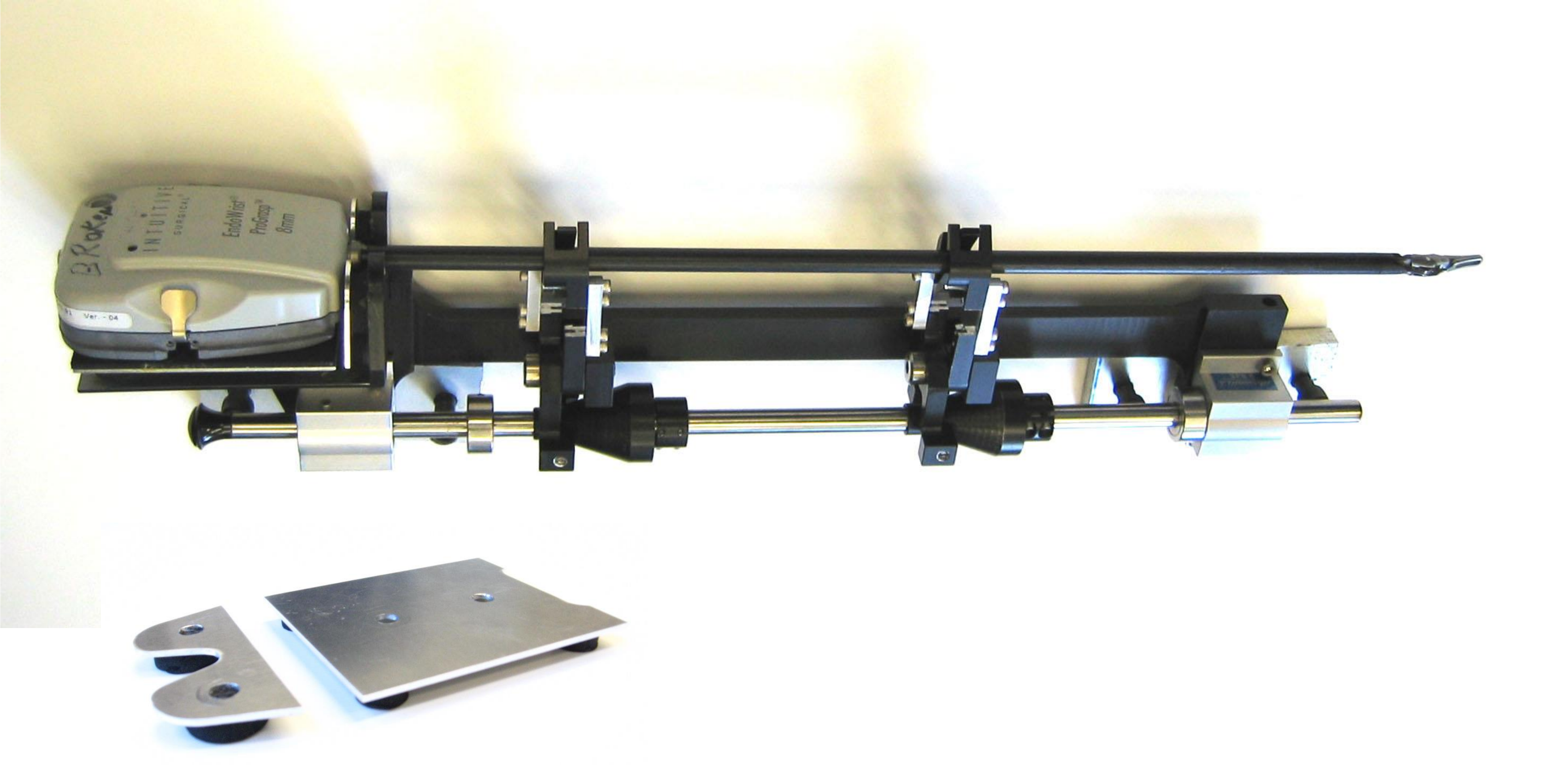


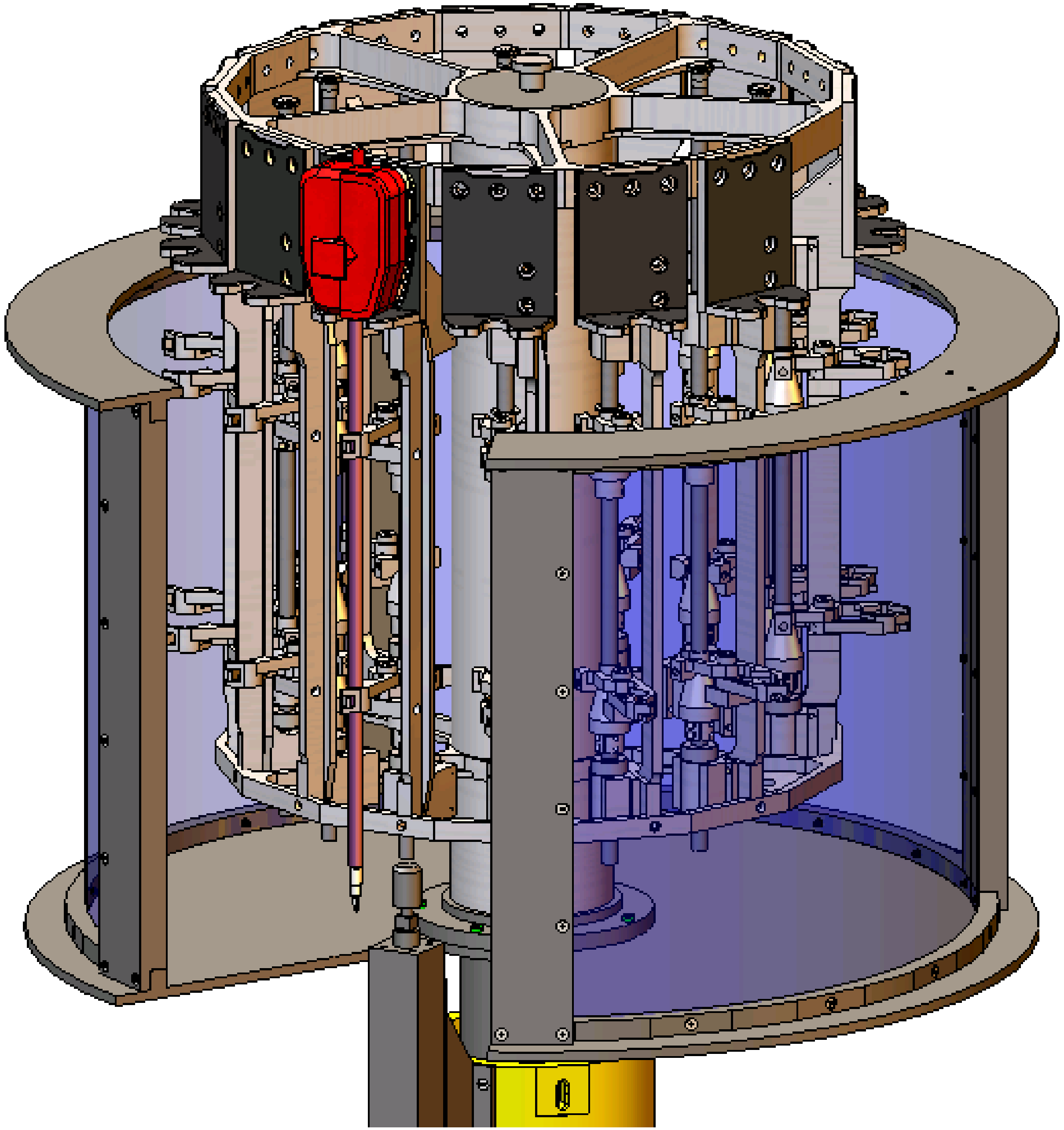


UCLA






INTUITIVE SURGICAL
EndoWrist ProGrasp 8mm
Ver. - 04



UCLA

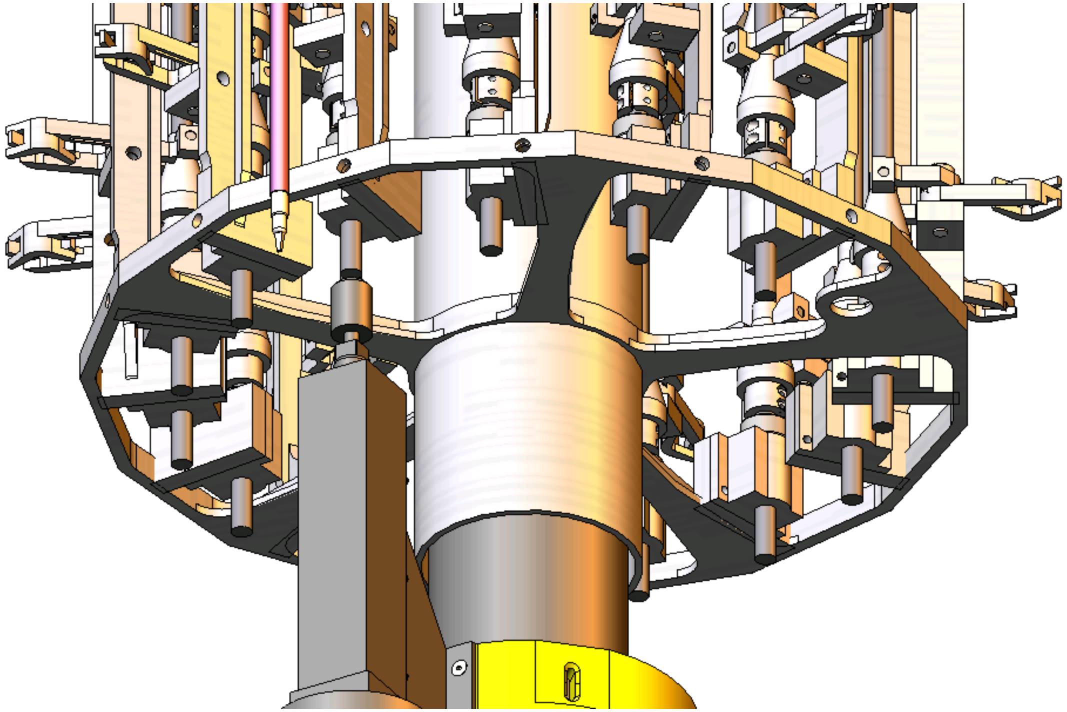
Design Question

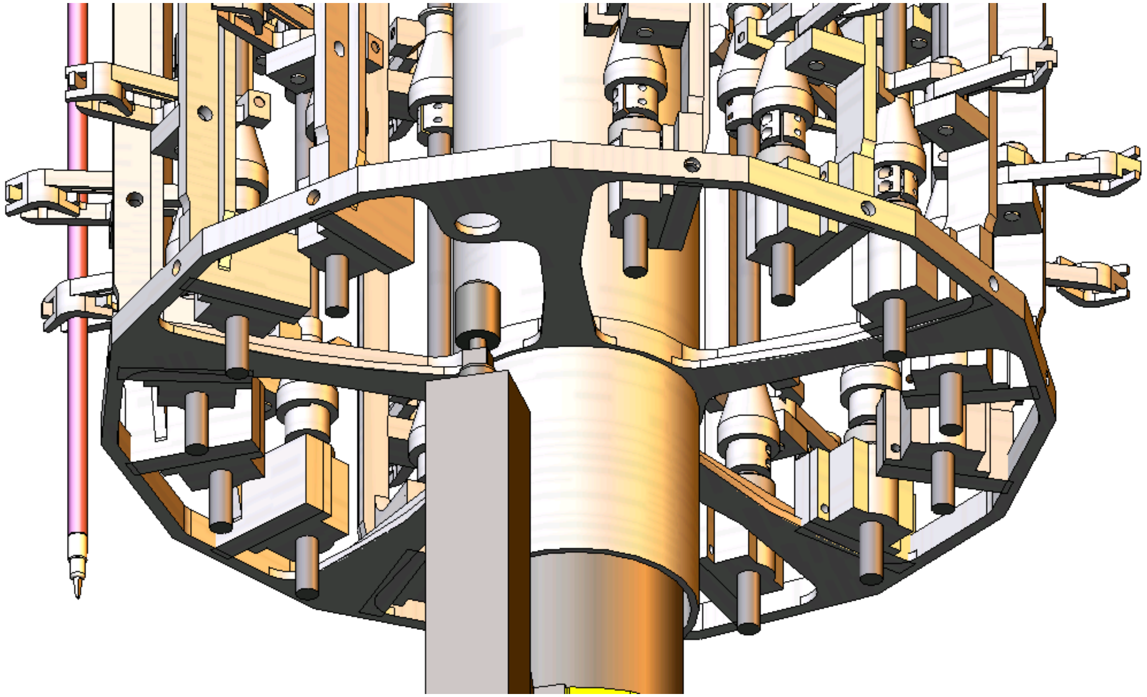
How should be the Tool Rack System (TRS) actuated?

Actuators and Sensors

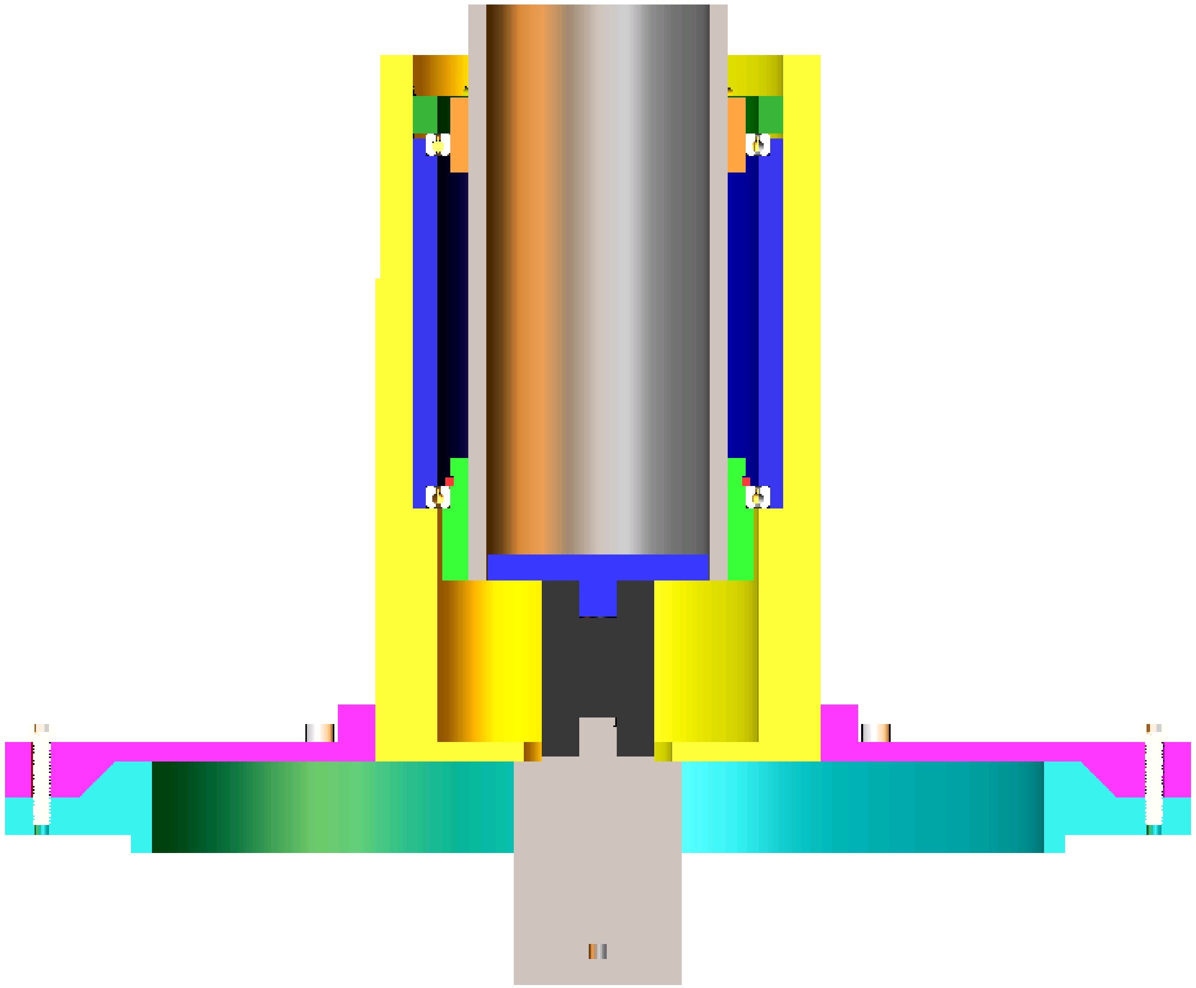
- Actuators
  - Magazine Spinning - DC Motor & Brake
  - Tool Grasping – DC Motor
- Sensors
  - Position sensor
    - Relative Position - Encoders
    - Absolute position – Optical Indicators
  - RFID Reader / Tag (on each tool)
- Camera – Pointing towards the tool head

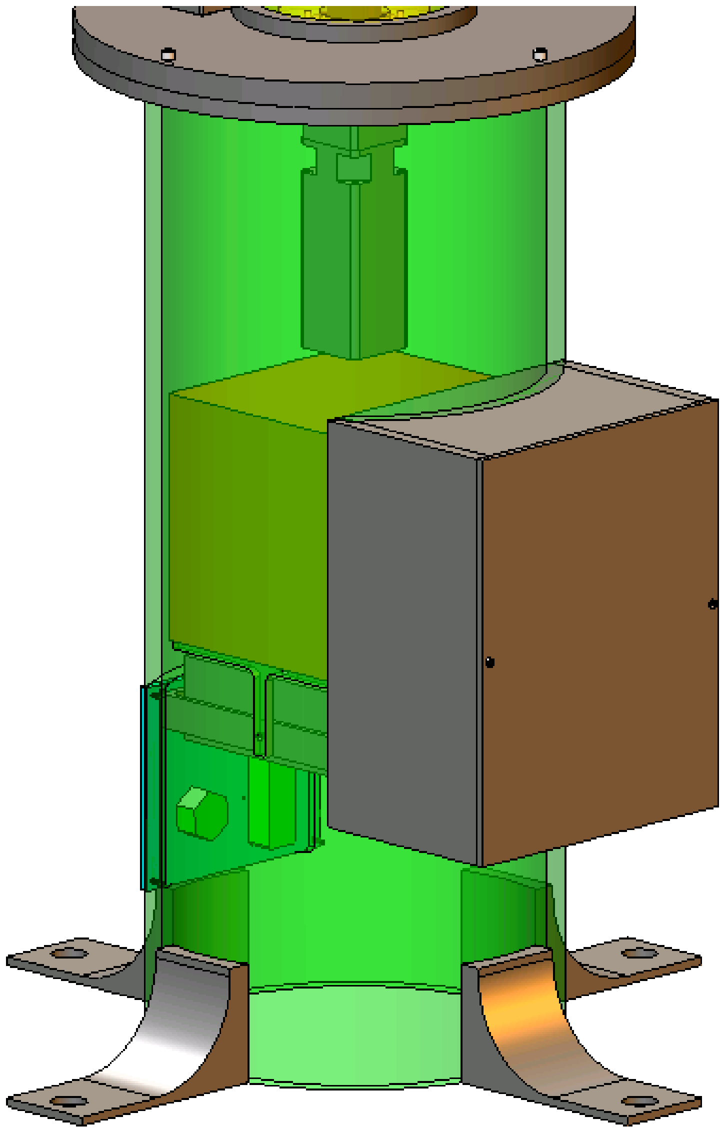
Linear Actuator

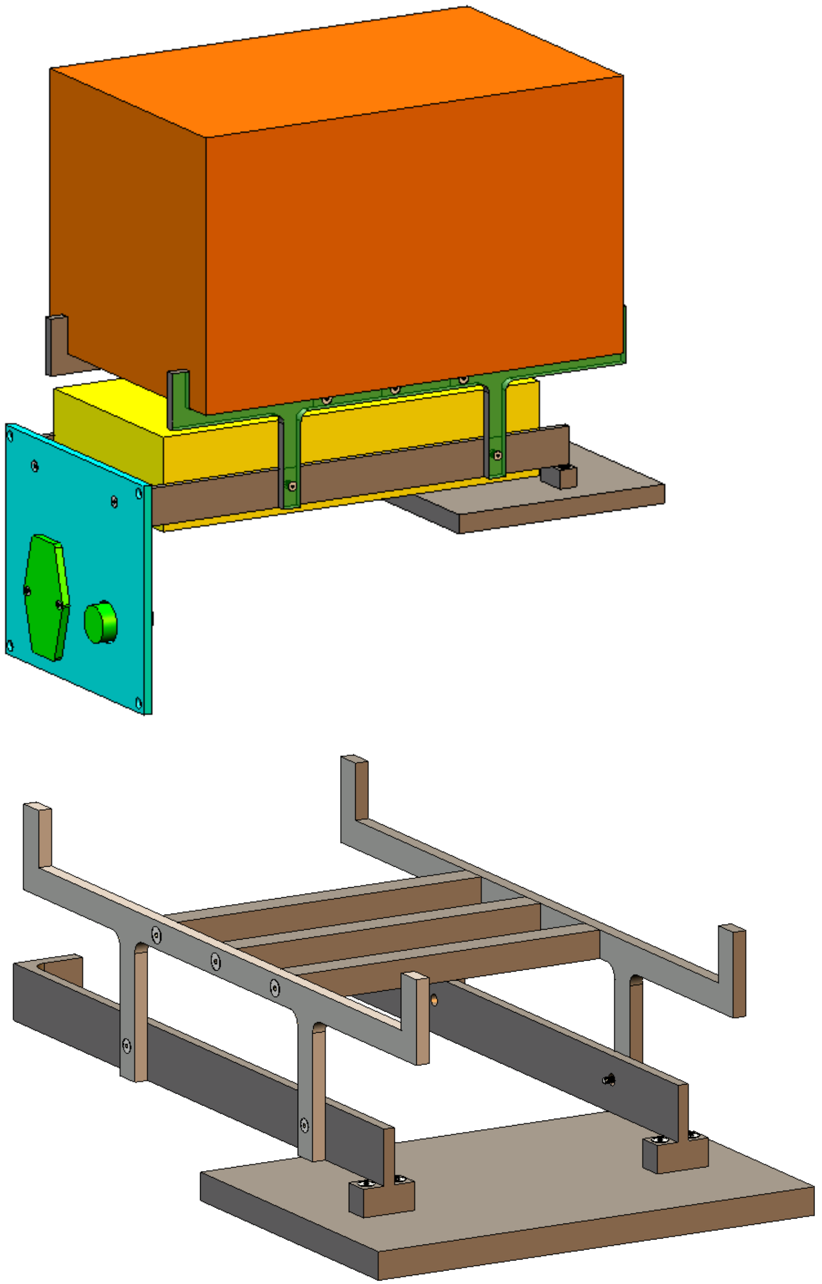


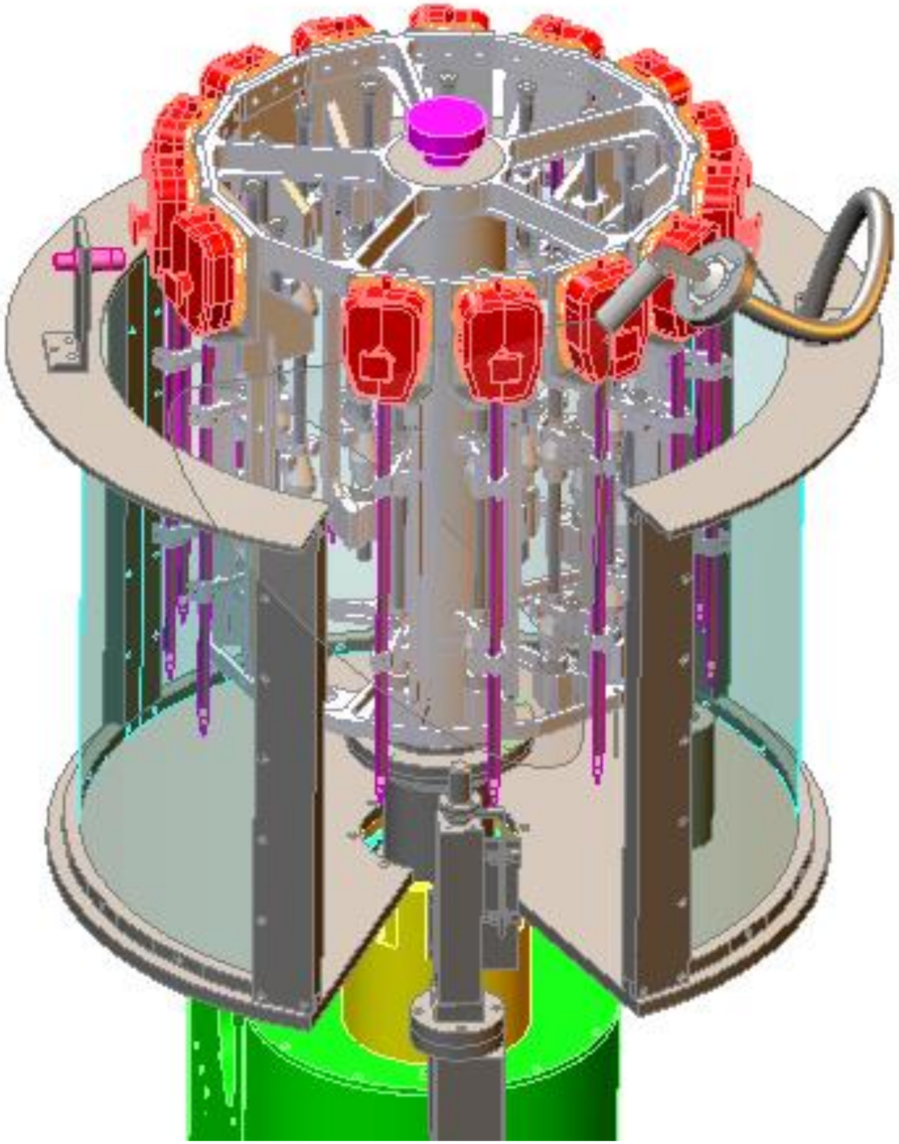


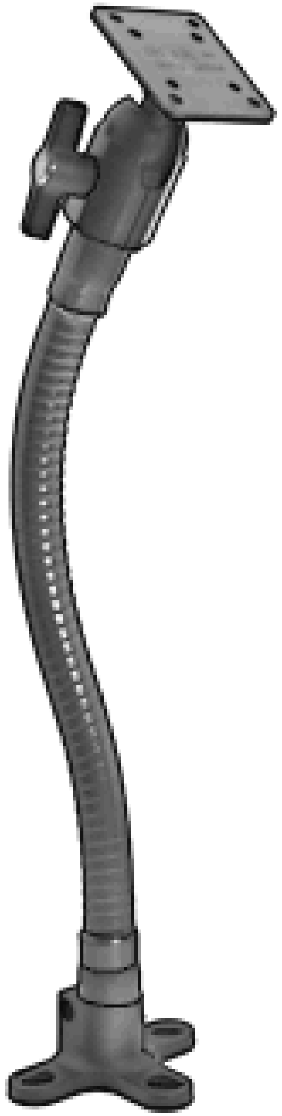
Bearing Assembly (TRS)







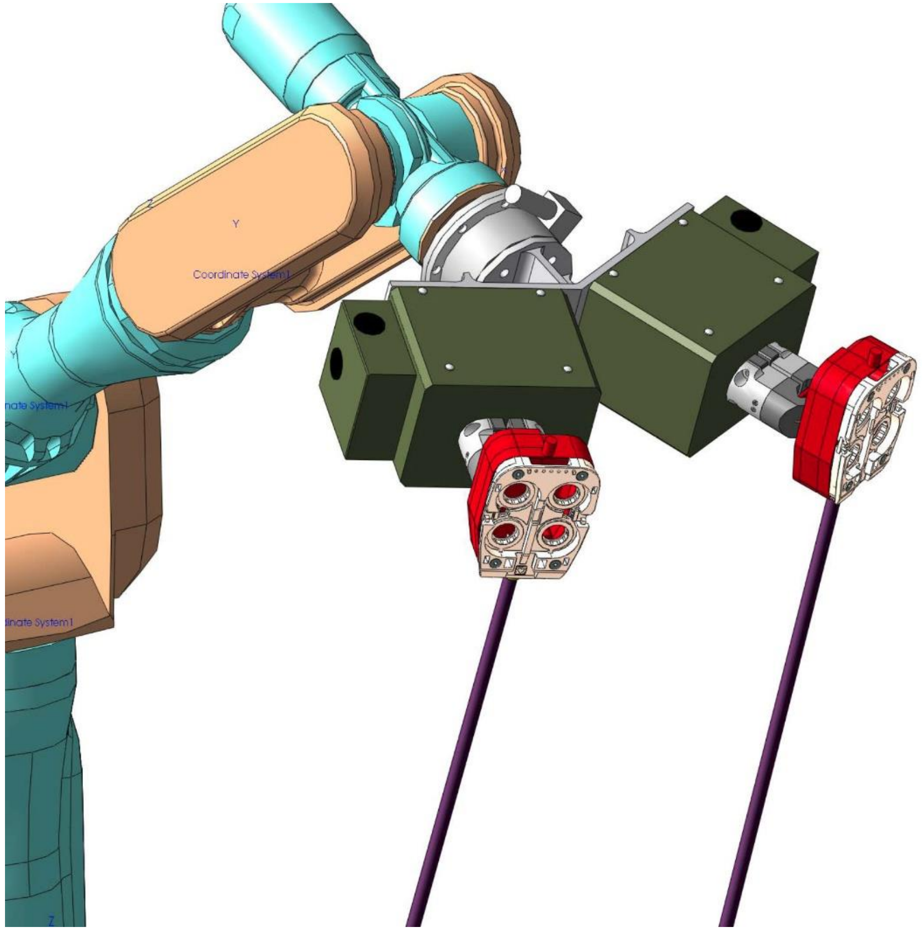


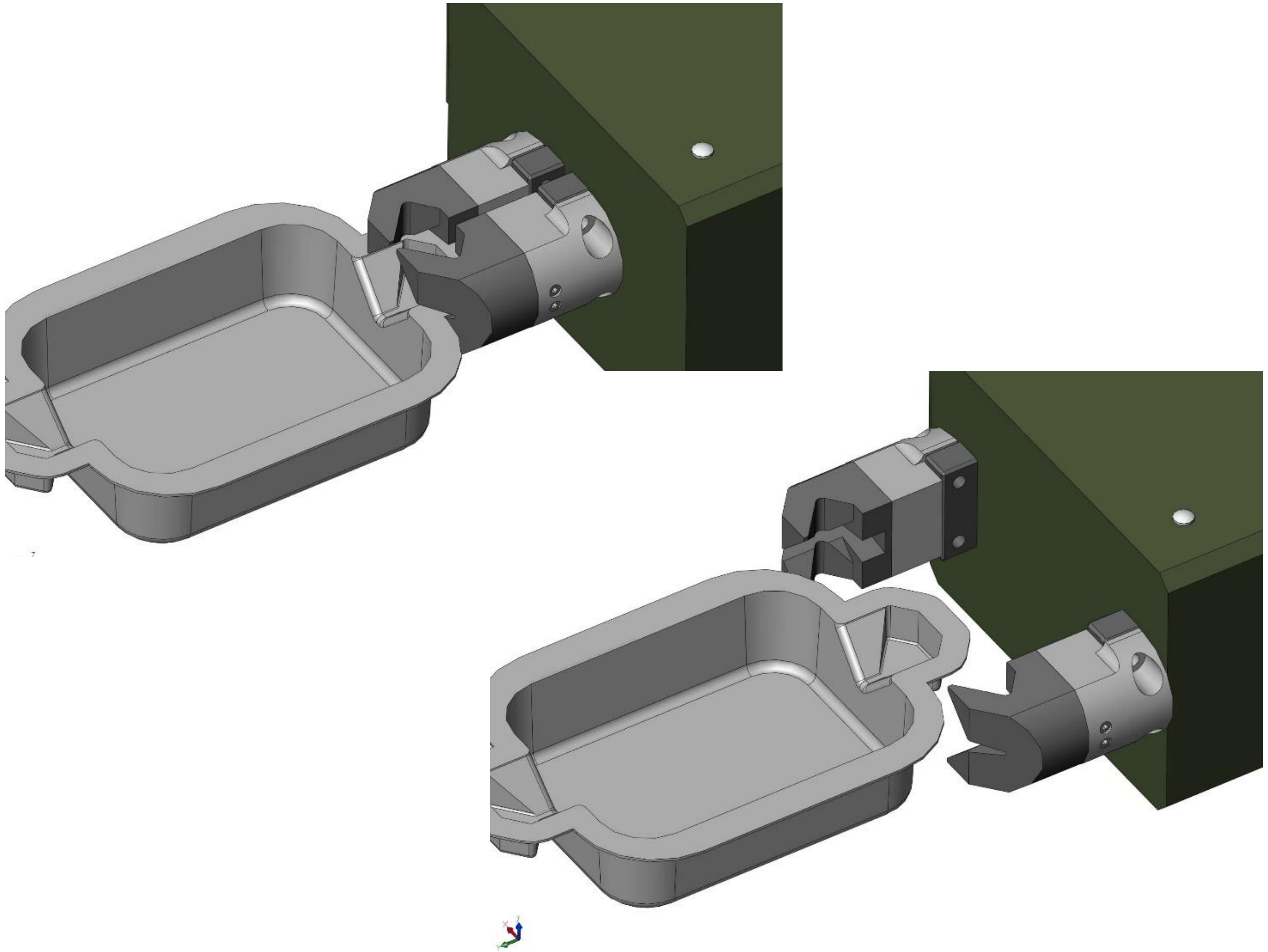


Design Question

How to design the End Effector of the Scrub Nurse ?

End Effector (EE)



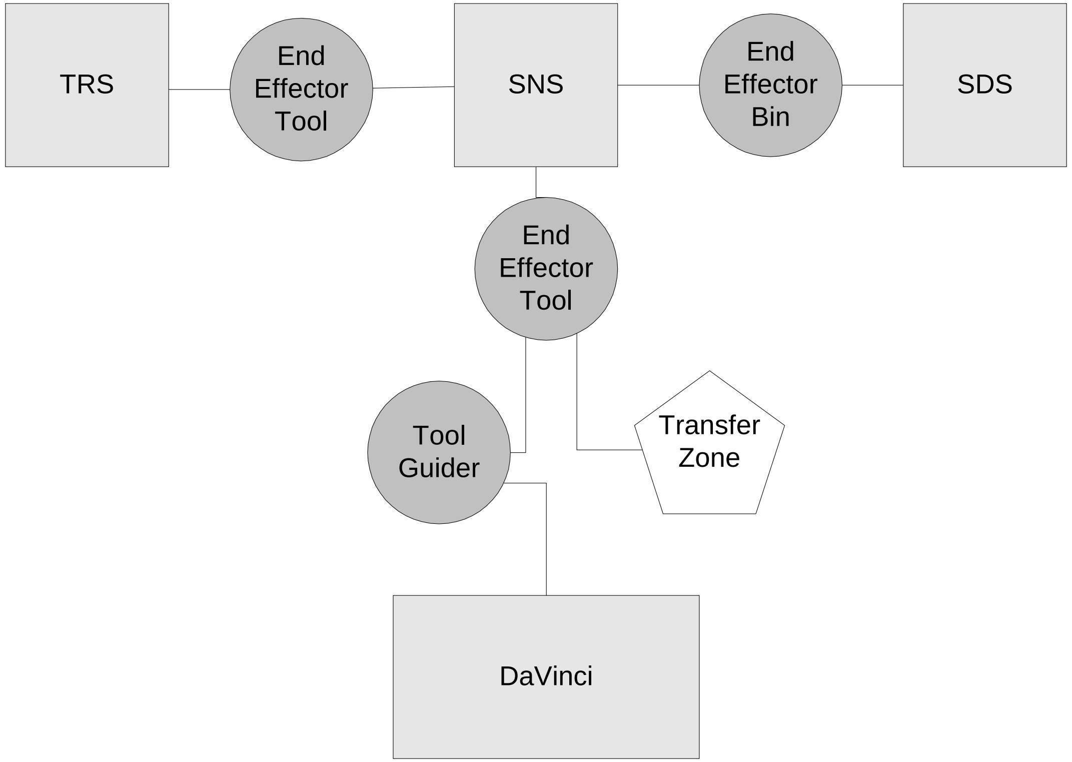


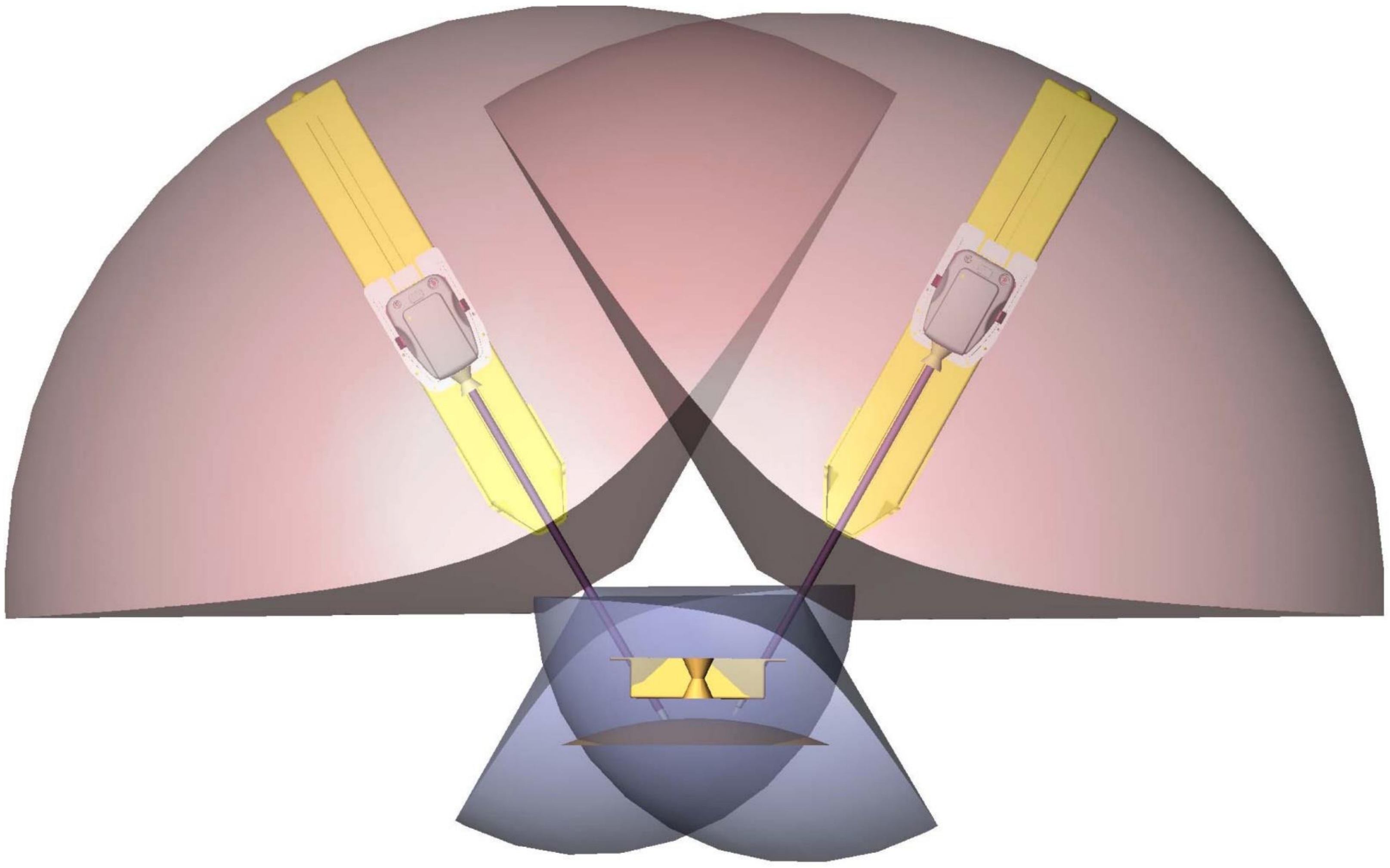
UCLA

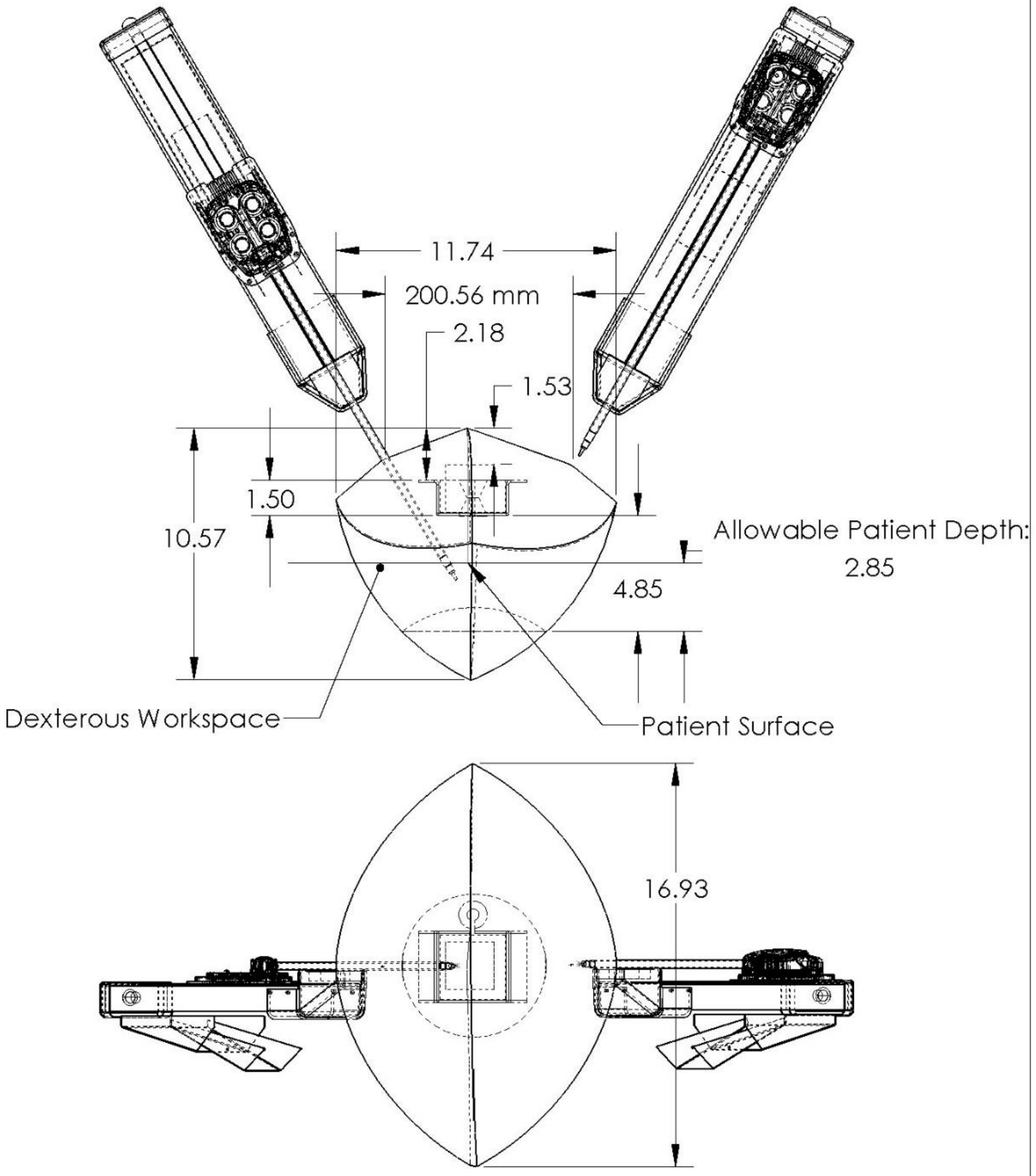
EE Interfaces

- Tray
  - Surgical Site -> Patient /Tray/Surgical Robot System (SRS)
  - Supplied Dispensing Subsystem SDS -> Tray

- Tool
  - Tool Rack Subsystem (TRS) -> Tool
  - Tool Autoloader Subsystem -> Tool






11.74
200.56 mm
2.18
1.53
1.50
10.57
Allowable Patient Depth:
2.85
4.85
Dexterous Workspace
Patient Surface
16.93

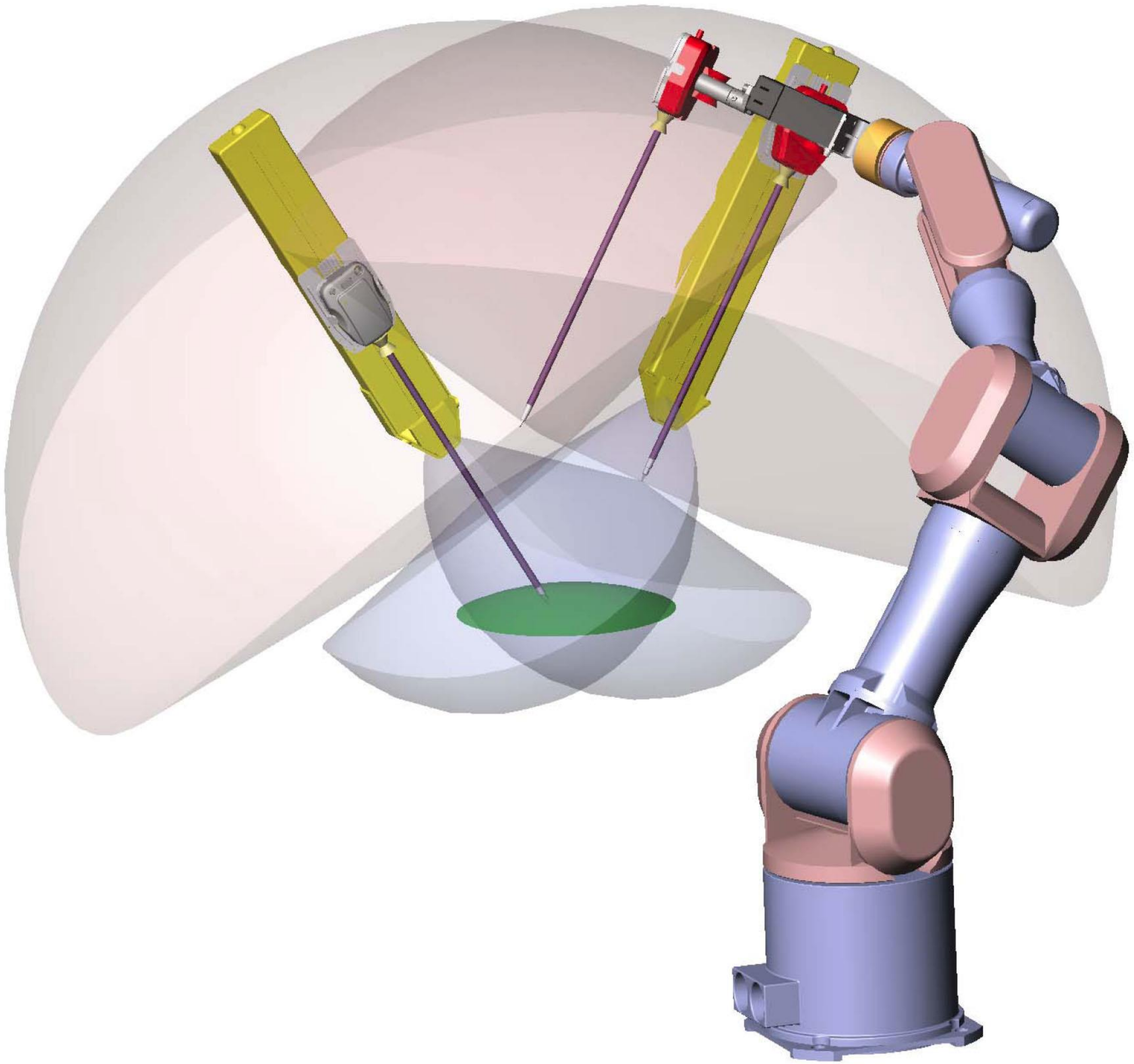
UCLA

Workspace Analysis

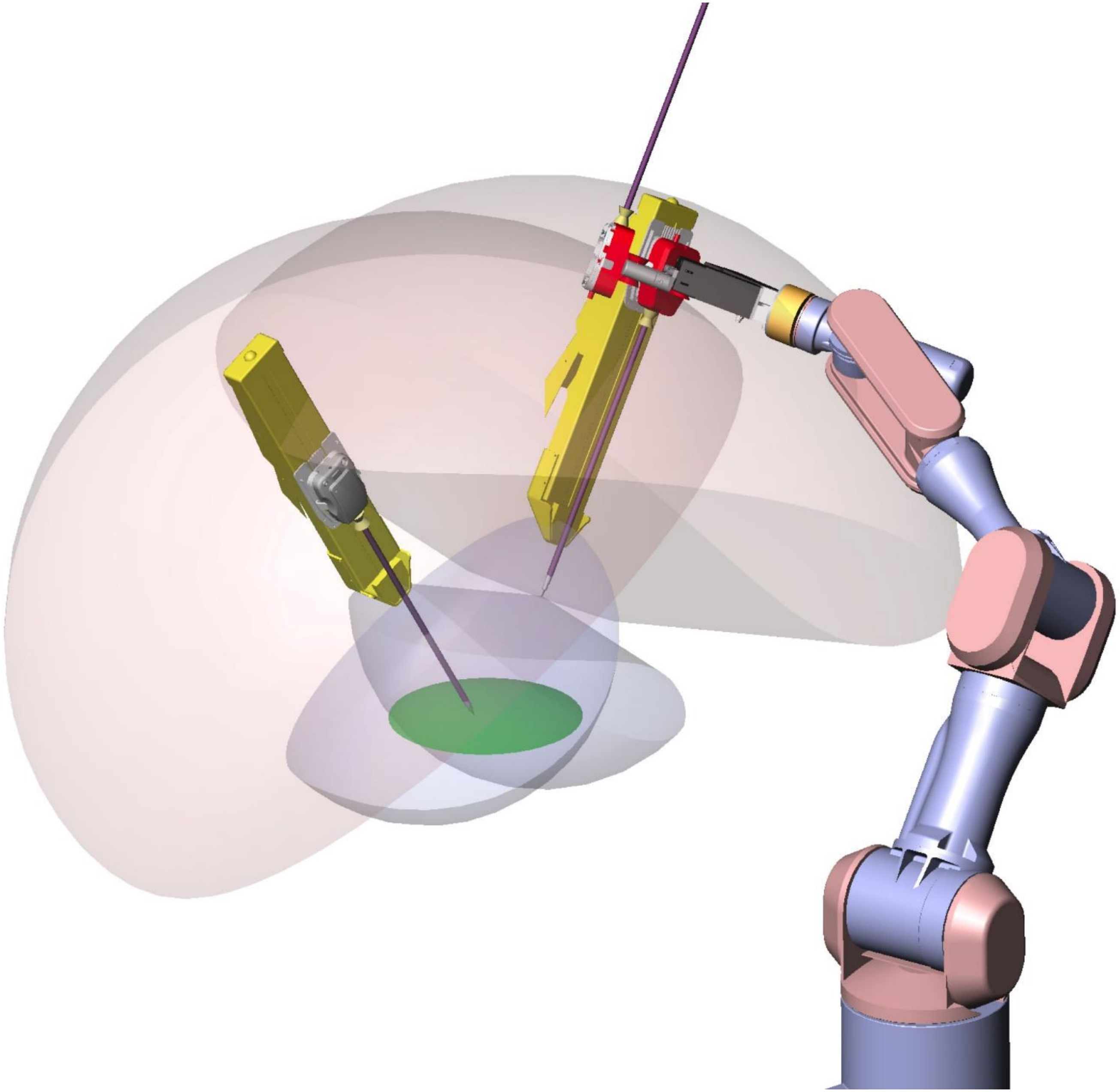
- Surgical Site & Arm Configuration
  - Distance between pivot points – 200 mm
  - Surgical Site Diameter – 146 mm (6”)
  - Nominal angle between the tools – 60 Deg
  - Distance between the pivot point and the surgical site – 150mm (half the length of the surgical tool)

- Arm workspace
  - Left/right +/-80 Deg = 160 Deg
  - Forward Backward +/-60 Deg = 120 Deg

- Tray size – 127 mm (5”) x 127 mm (5”) x 25.4 mm (1”)

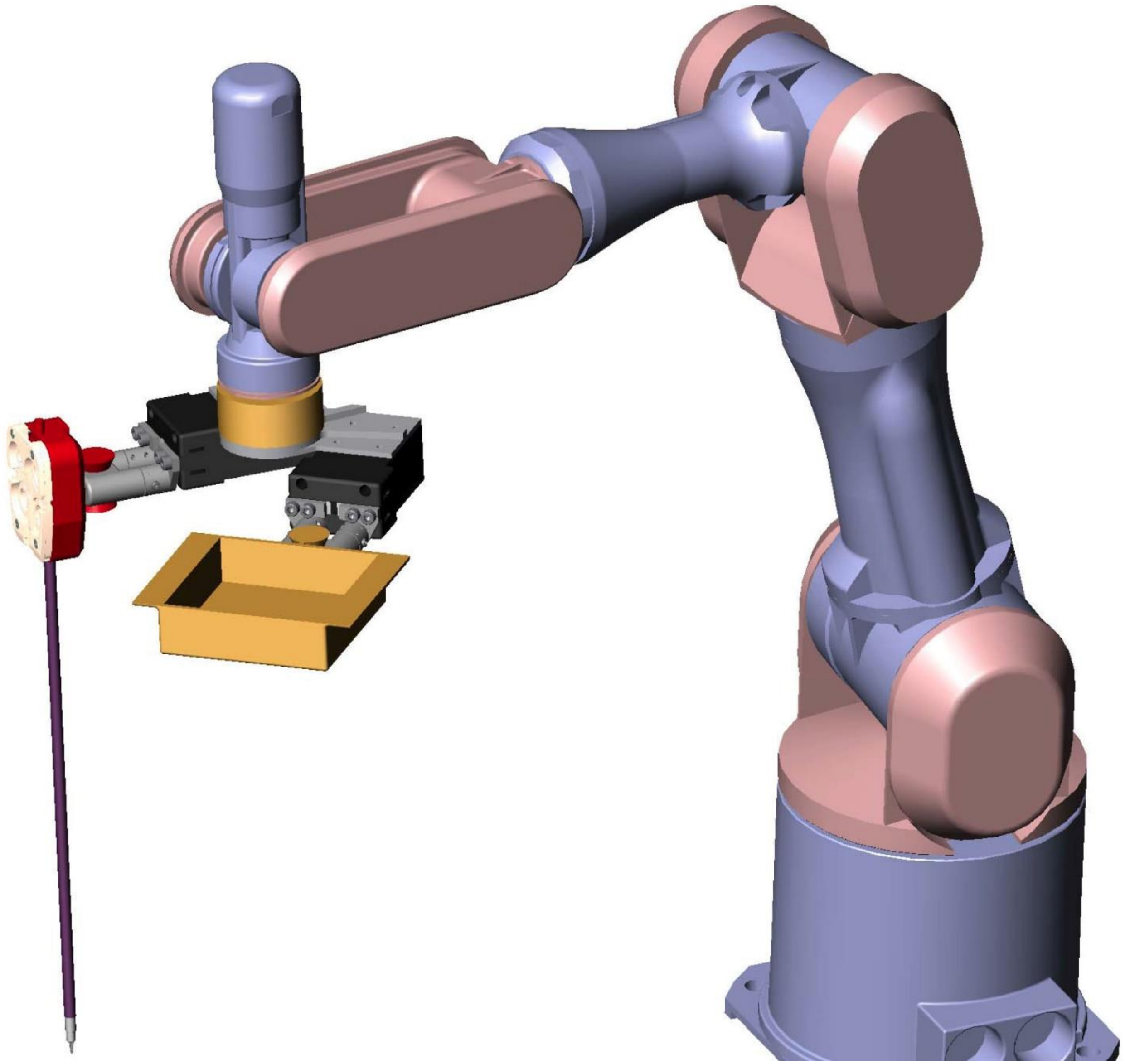


V- Shaped

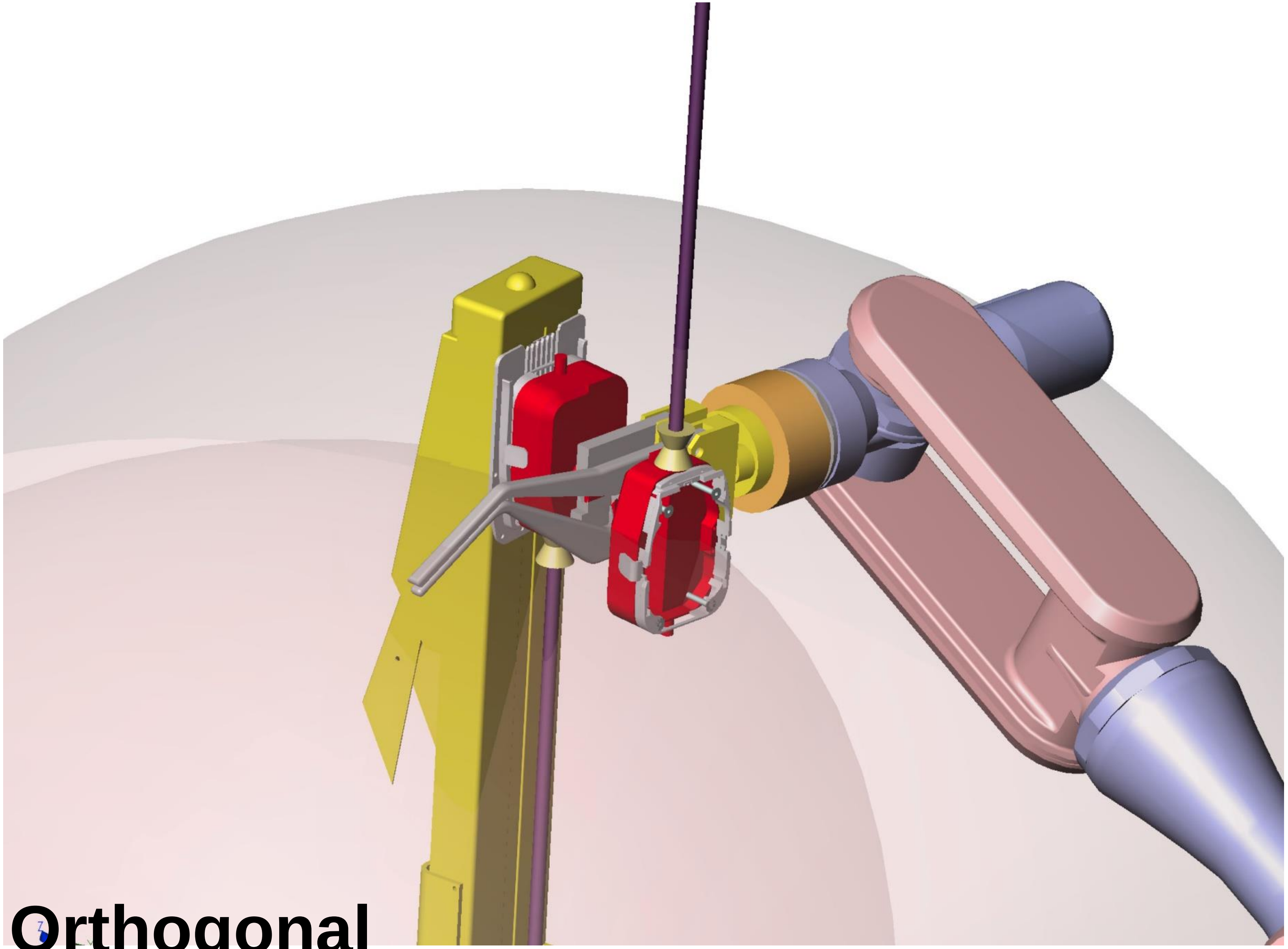


V- Shaped (Flipped)

UCLA

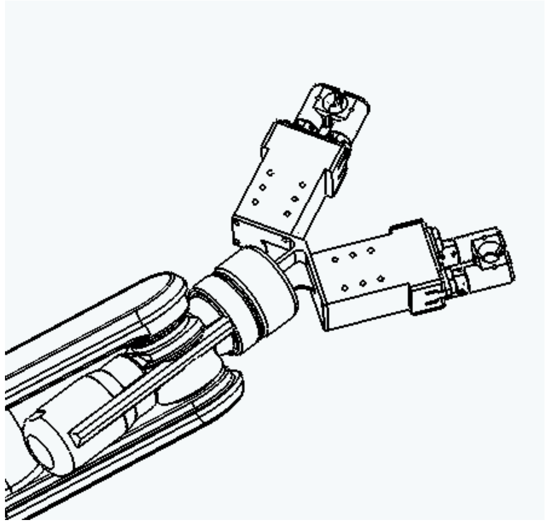


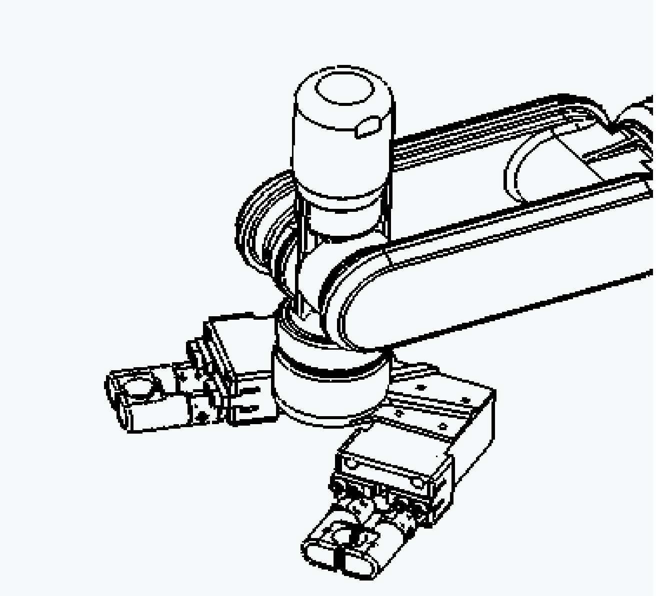
V- Shaped – 90 Deg

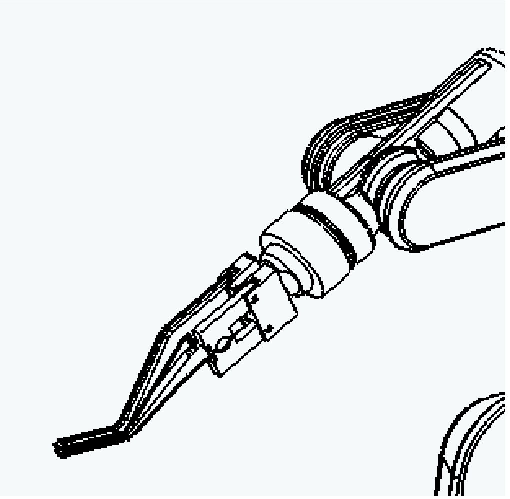


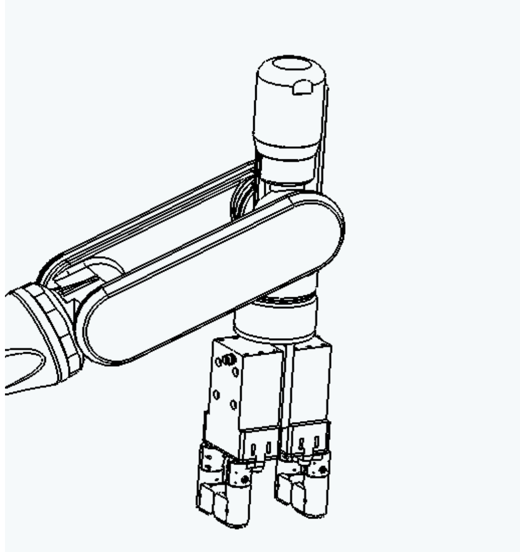
Back to Back – Orthogonal

Scrub Nurse - End Effector



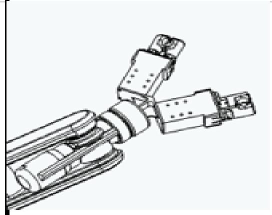
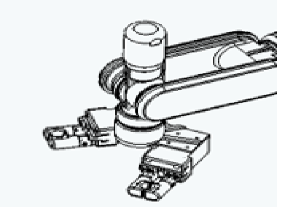
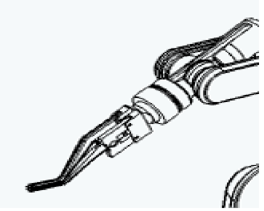
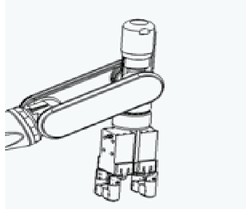






Design Question

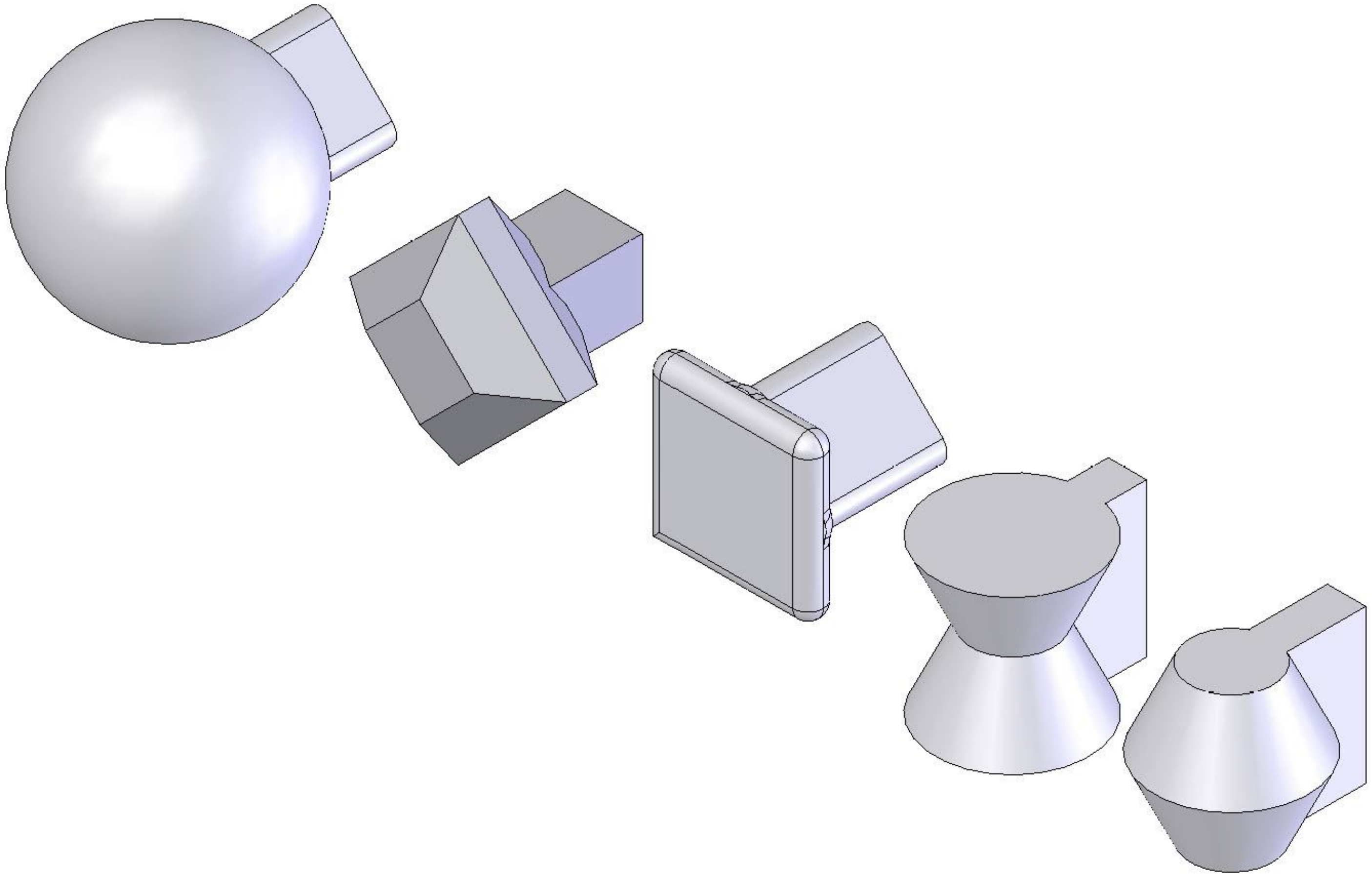
What is the best design of the End Effector of the Scrub Nurse ?

		V-hand	90 degree v-hand	long nose gripper	back-to-back
					
EE PHY 1.0	The EE geometry shall allow the surgeon to see the contents of the supply trays.	4	2	3	1
Manufacturability	aggregates several requirements which effect the general feasibility of fabrication, including use if pre- existing components, reliance on tight tolerances, and cost of manufacture.	4	4	3	4
Stiffness	Natural frequency of equally loaded grippers with respect to the Mitsubishi arm. A qualitative inspection of the stiffness of each SNS-EE design is sufficient.	2	3	1	4
TAS – Tool	See EE PHY 2.0, EE PHY 5.0, & EE PHY 10.0	4	3	2	1
Surgical site – Tray interference	See EE PHY 2.0, EE PHY 5.0, & EE PHY 10.0	4	3	1	2
Tool Rack – Tool interference	See EE PHY 2.0 & EE PHY 9.0	2	3	1	4
Supplies dispenser – Tray interference	See EE PHY 2.0	2	3	1	4
Workspace volume	the volume occupied by all possible positions of	1	3	2	4
Dual-direction interference	Problems with interference when tools are mounted in different directions	4	3	2	1
Switchability	Easy with which the SNS can re-configure to switch between tools	3	4	4	4
SNS Workspace	Utilizing the SNS Workspace	4	3	4	3
Sum		34	34	24	32

Design Question

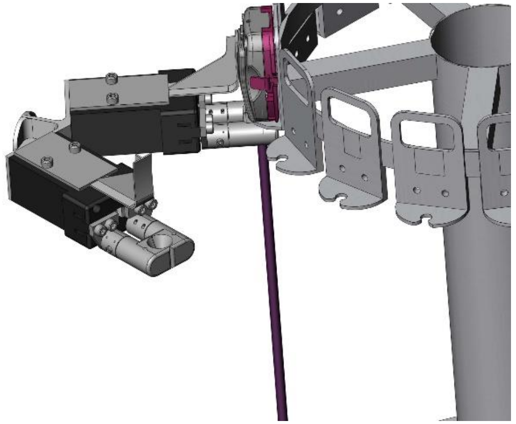
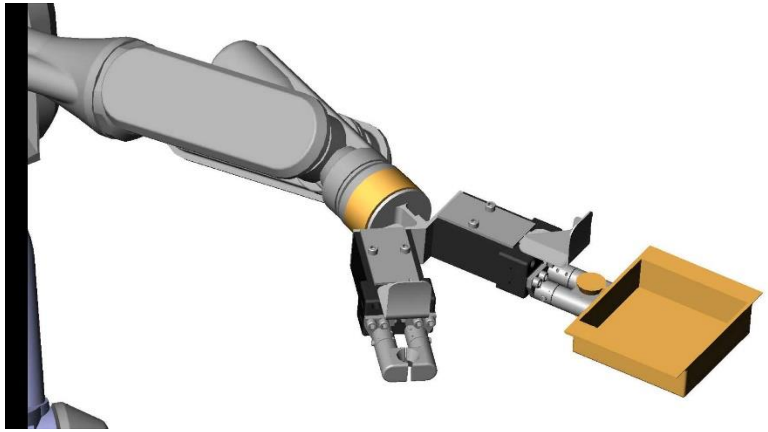
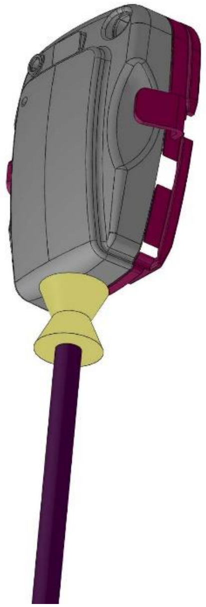
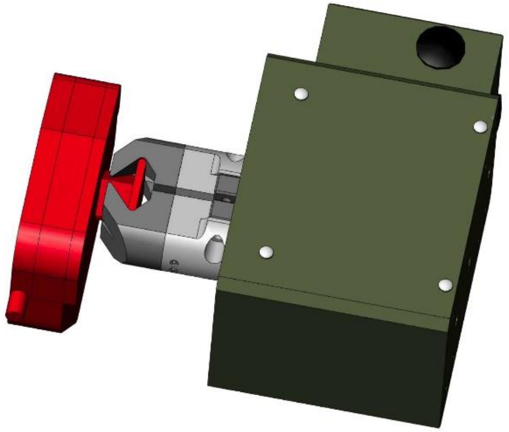
What should be the physical interface between the the End Effector of the Scrub Nurse and the tool / tray ?

Tool / Tray – Lug



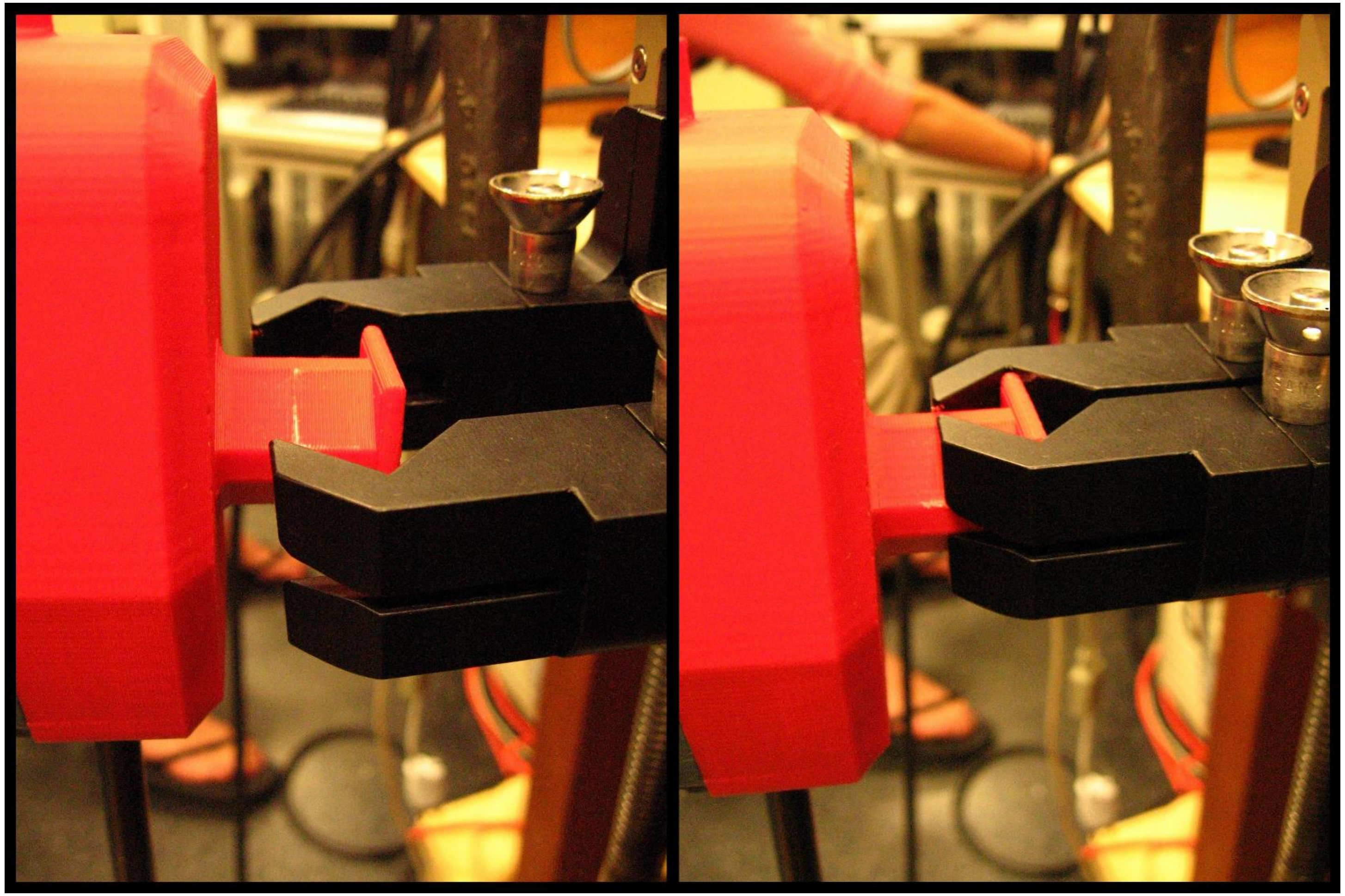
Design Question

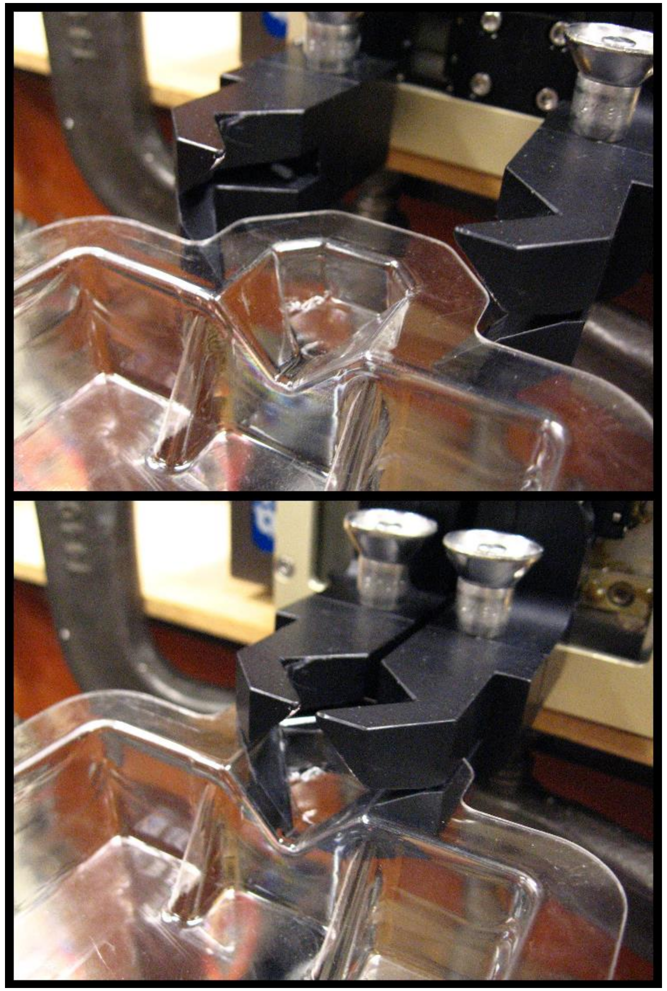
Which Lug is the best interface between the End Effector of the Scrub Nurse and the tool / tray ?

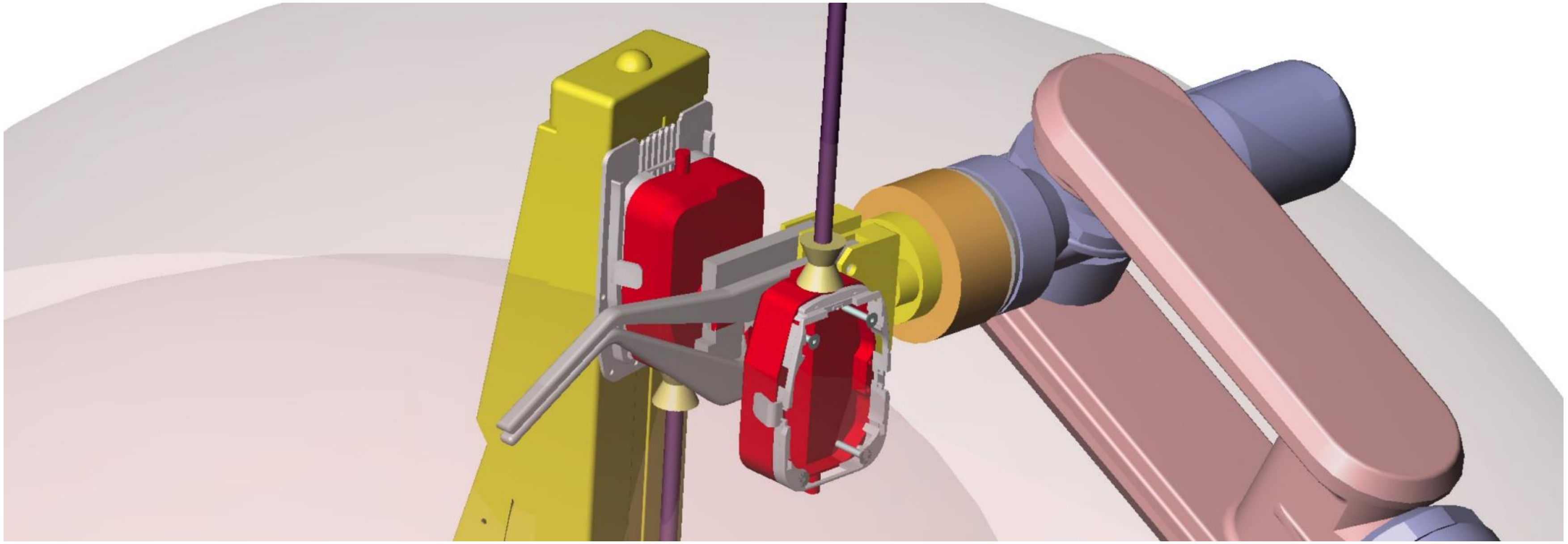





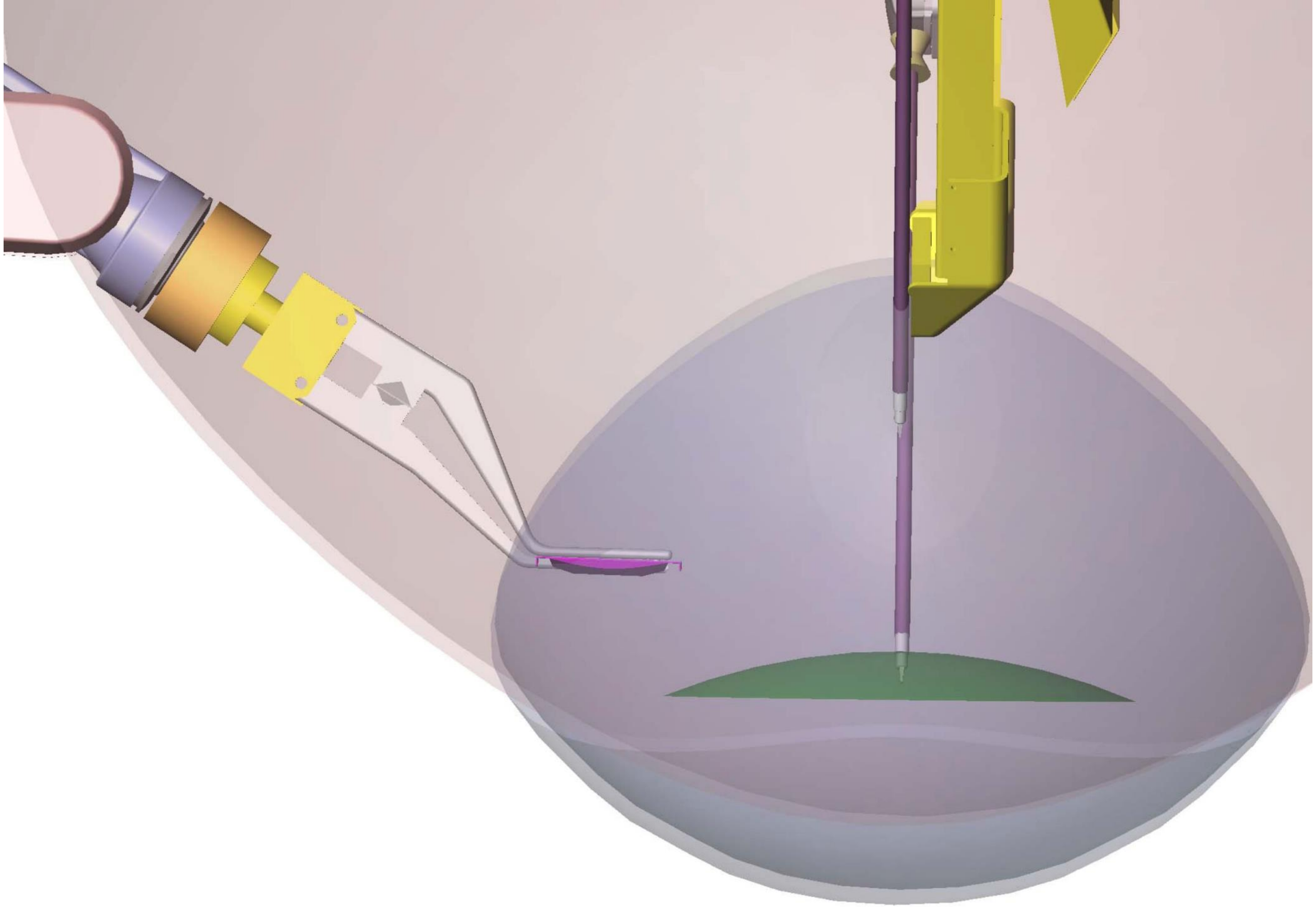
Design Question

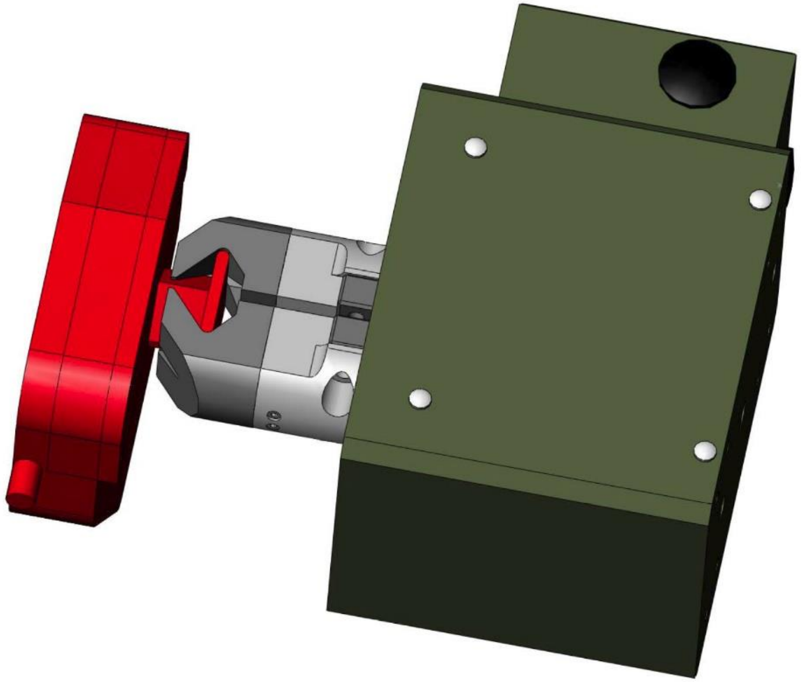
How to unify the gripper of the End Effector (EE) such that it can grasp both the tool and the tray ?

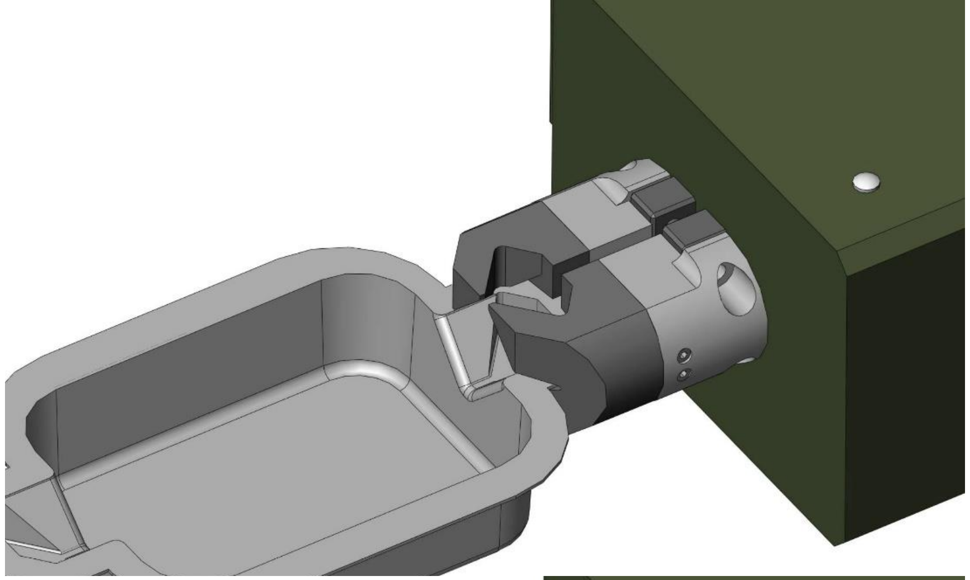


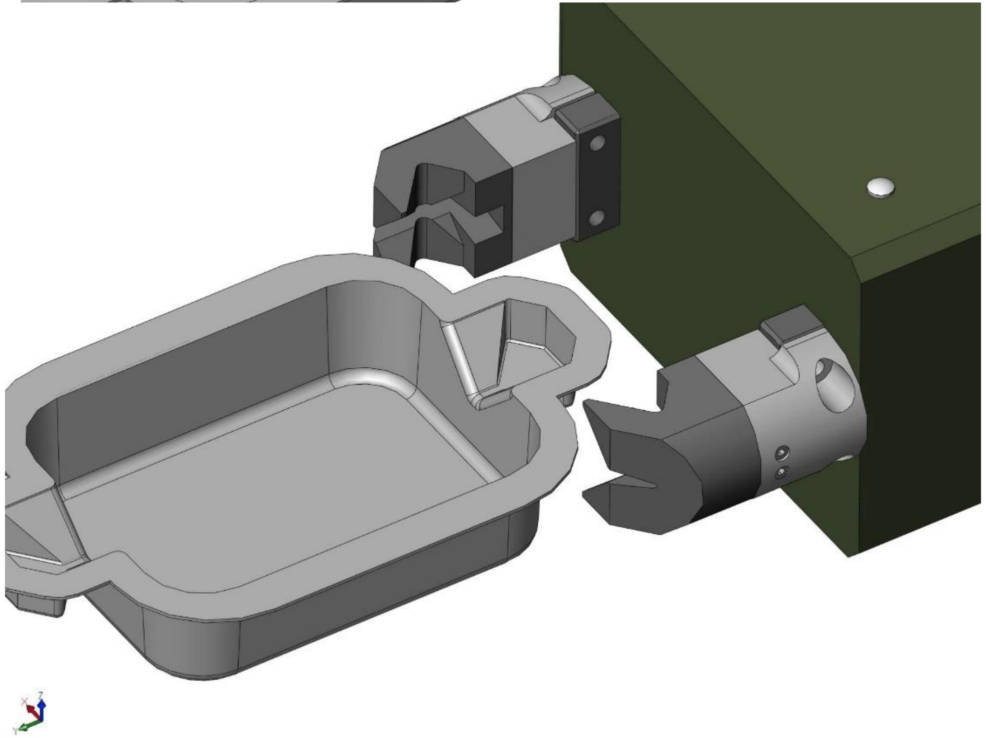










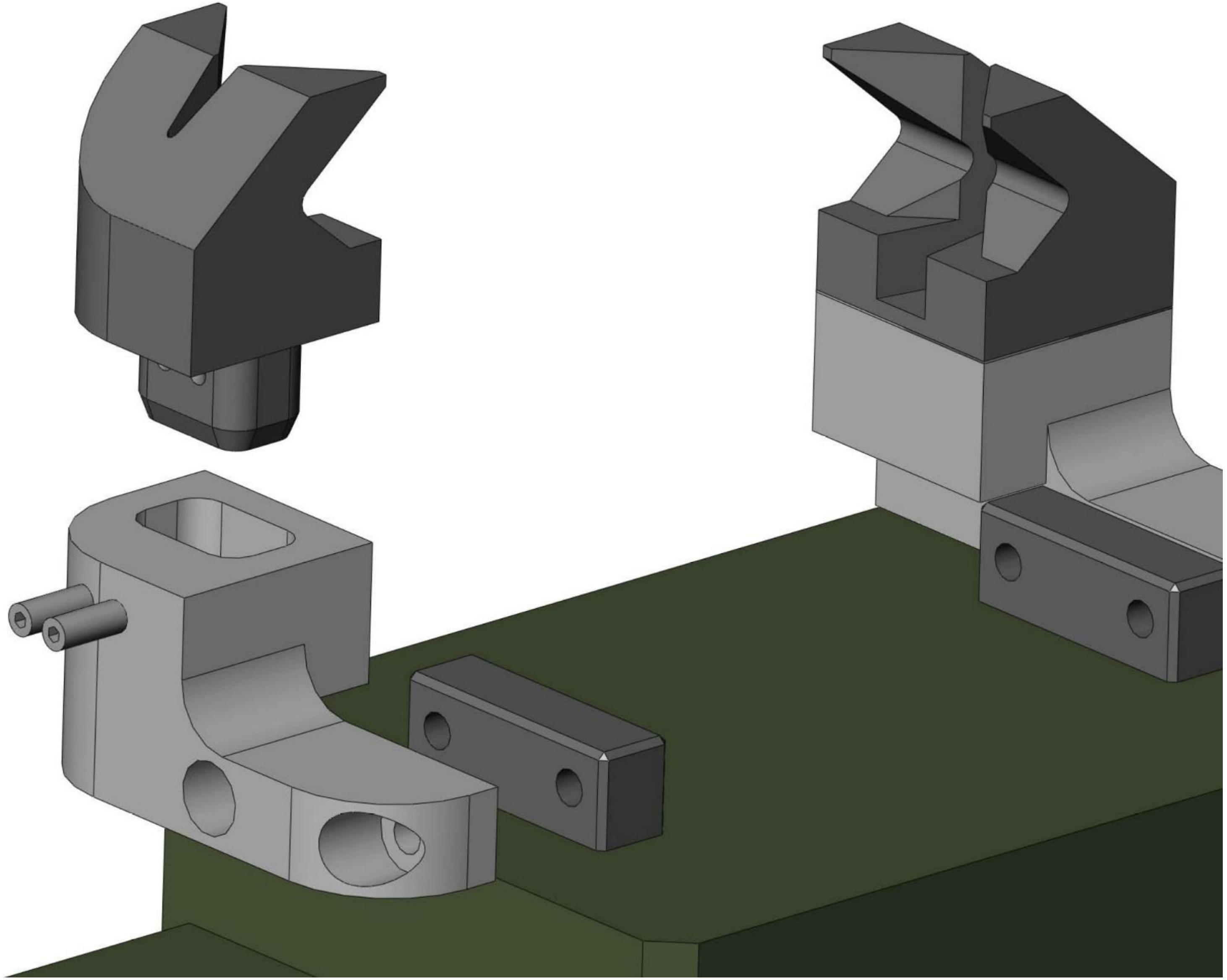


Design Question

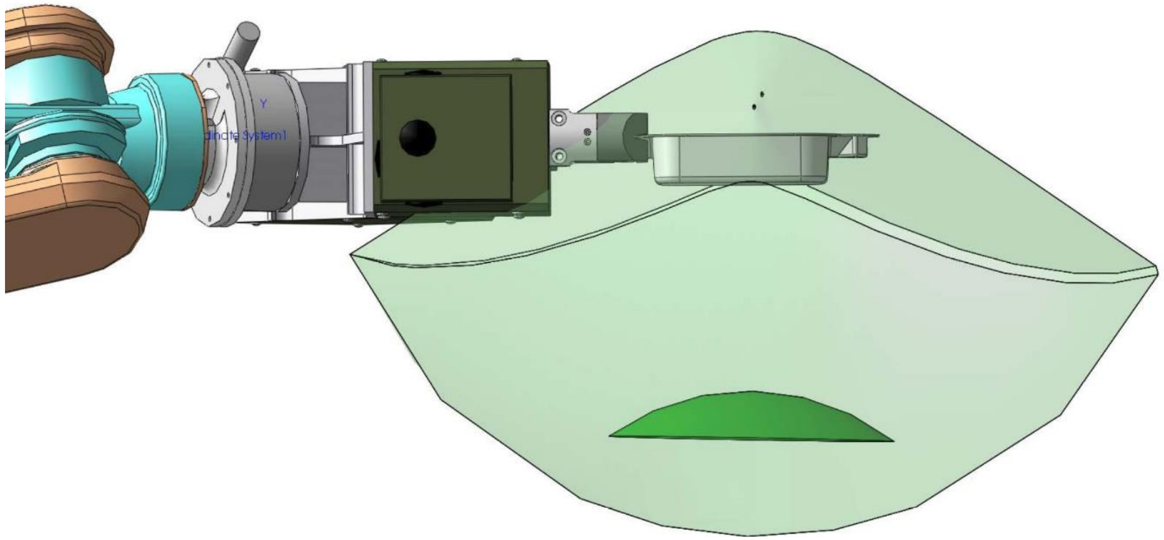
How to avoid the fact that the tray may get stuck in the EE jaws

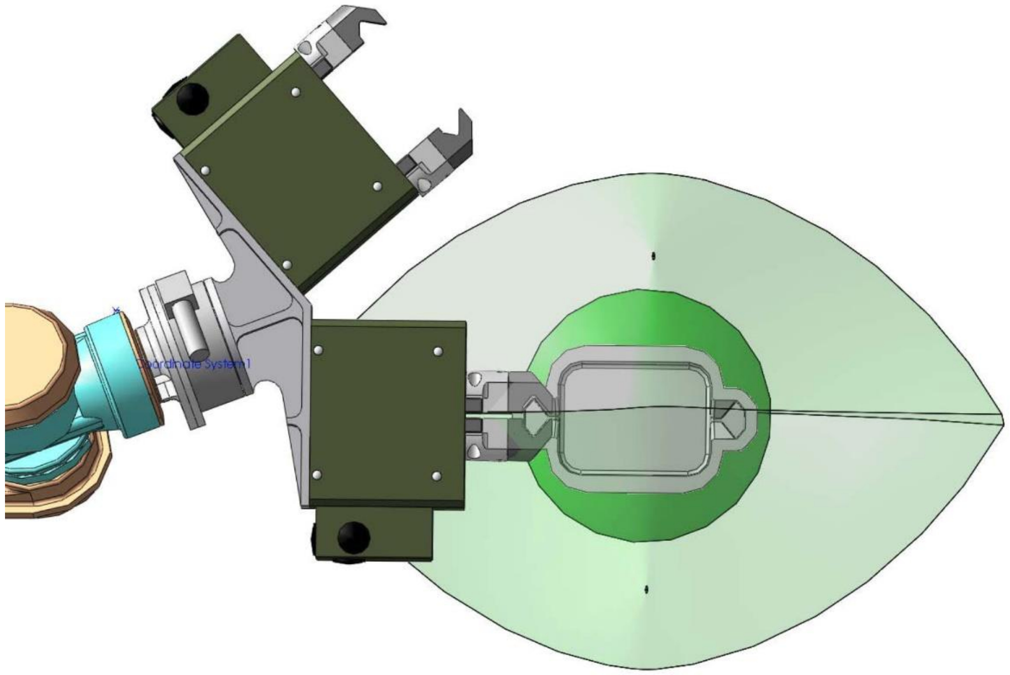
Design Question

How to address sterility of the EE jaws

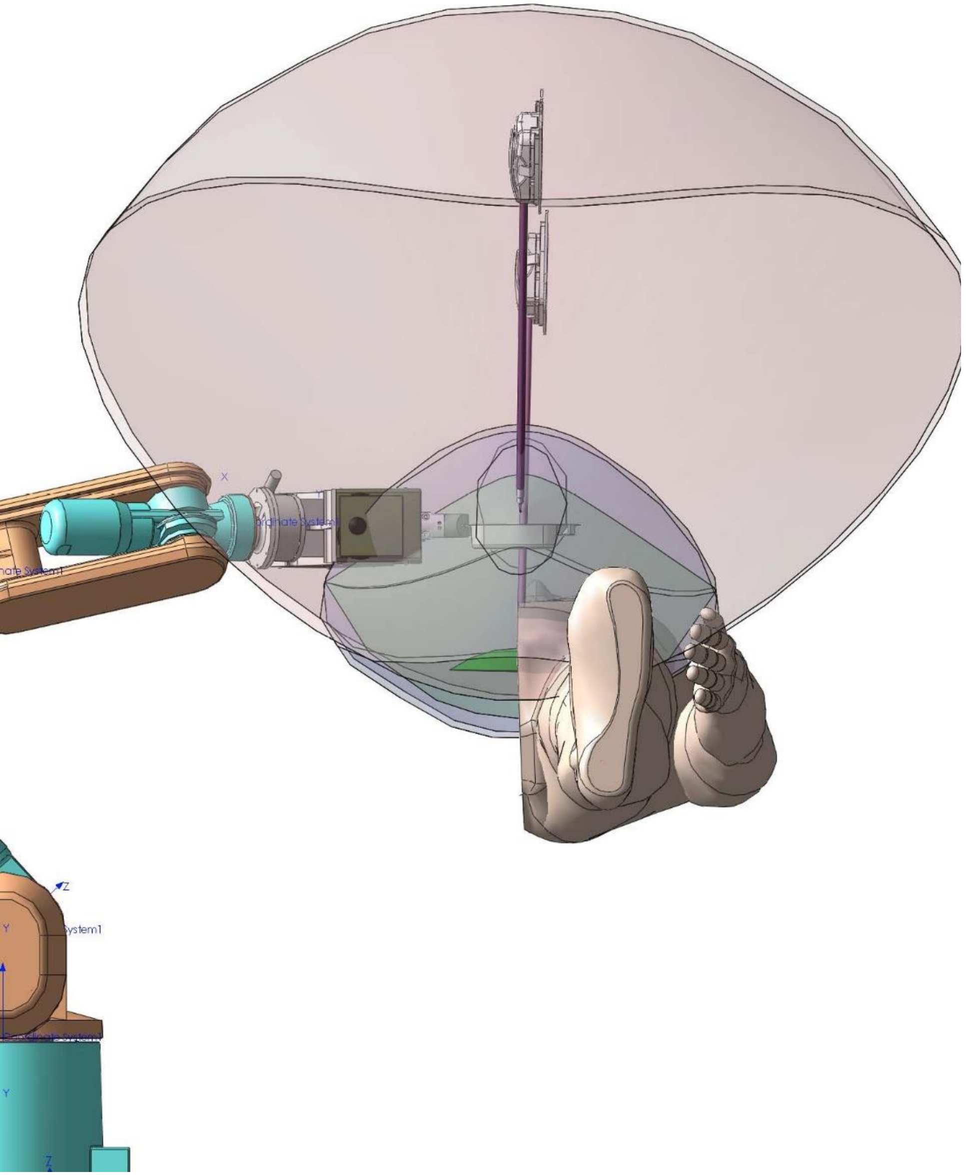


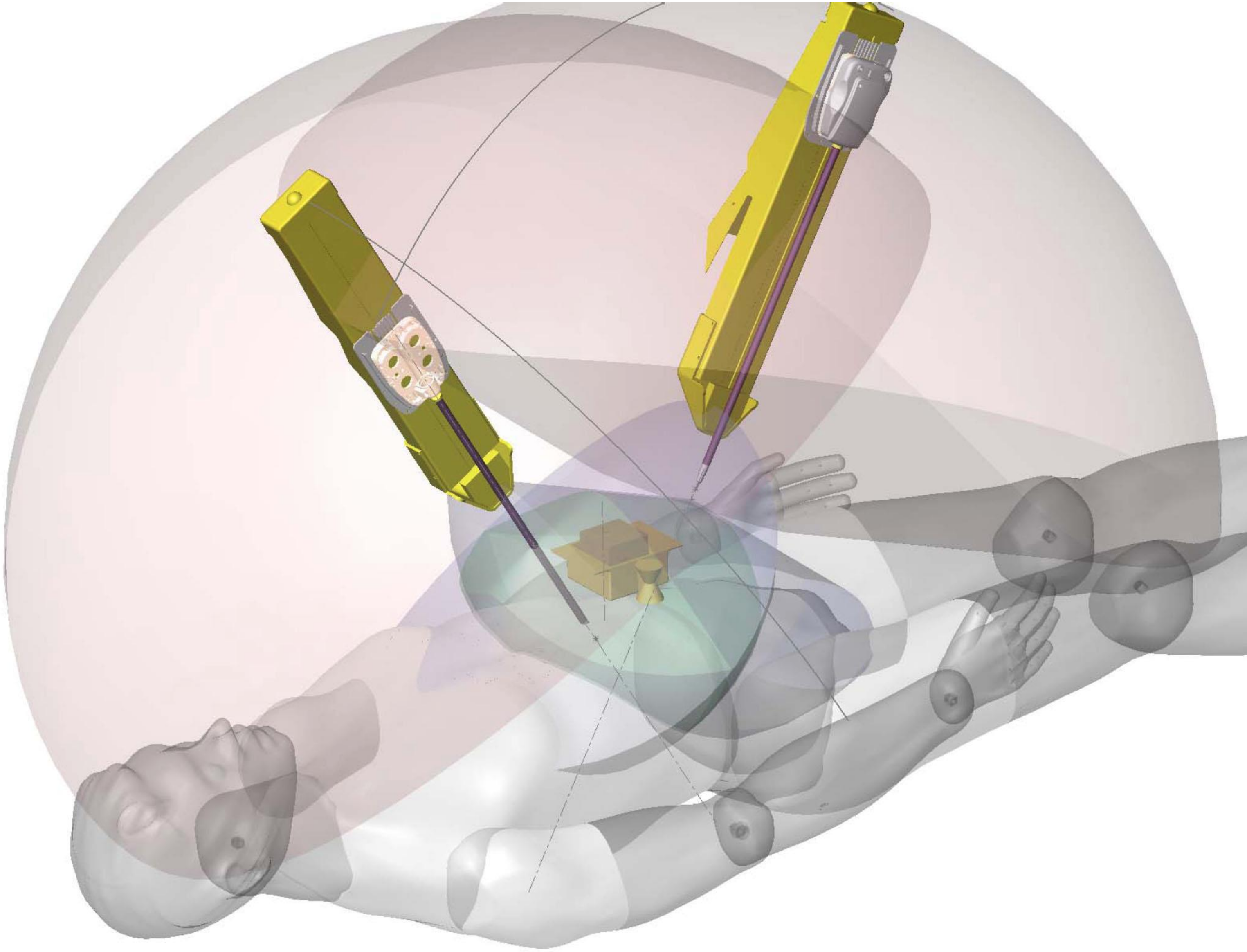
UCLA

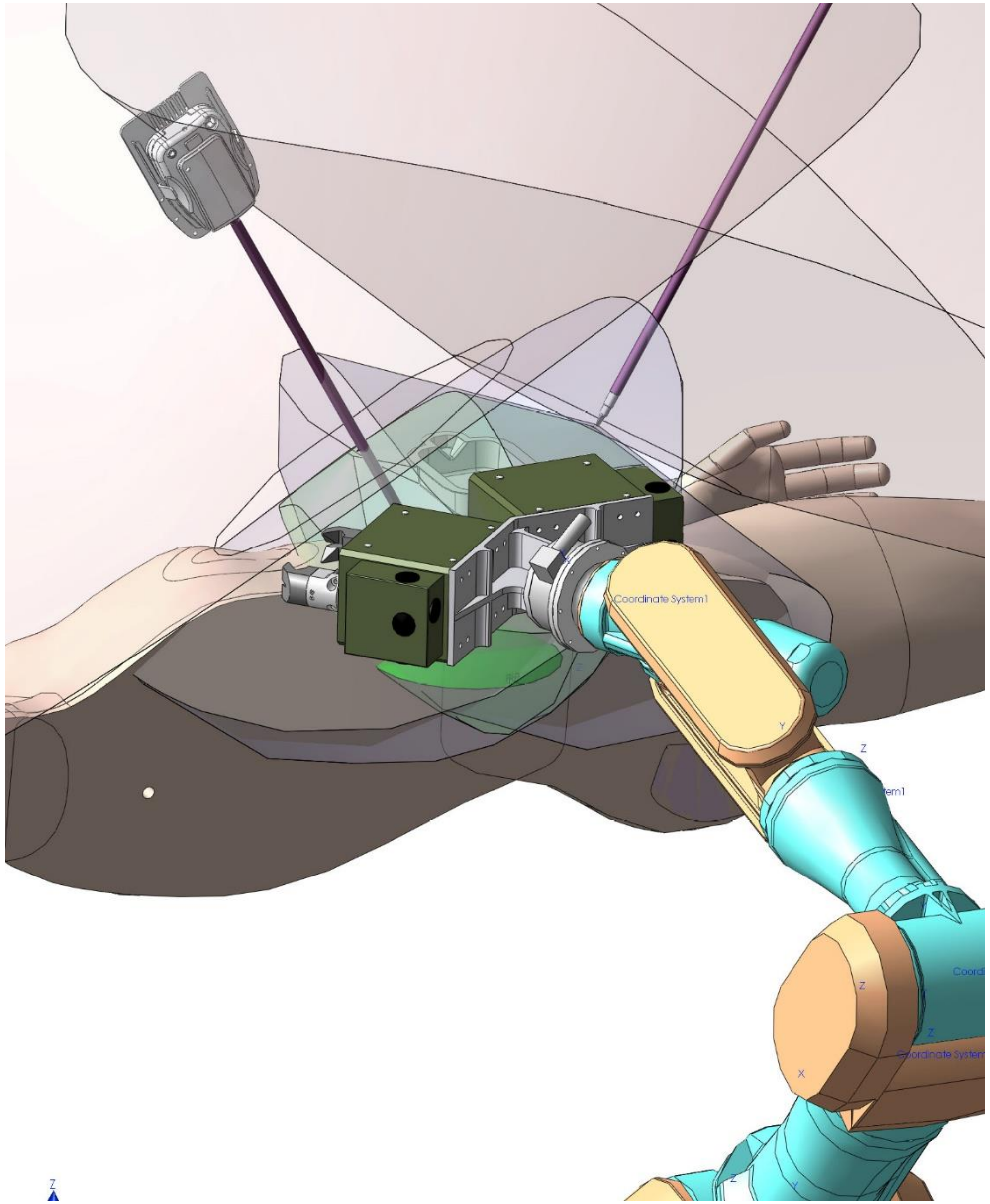




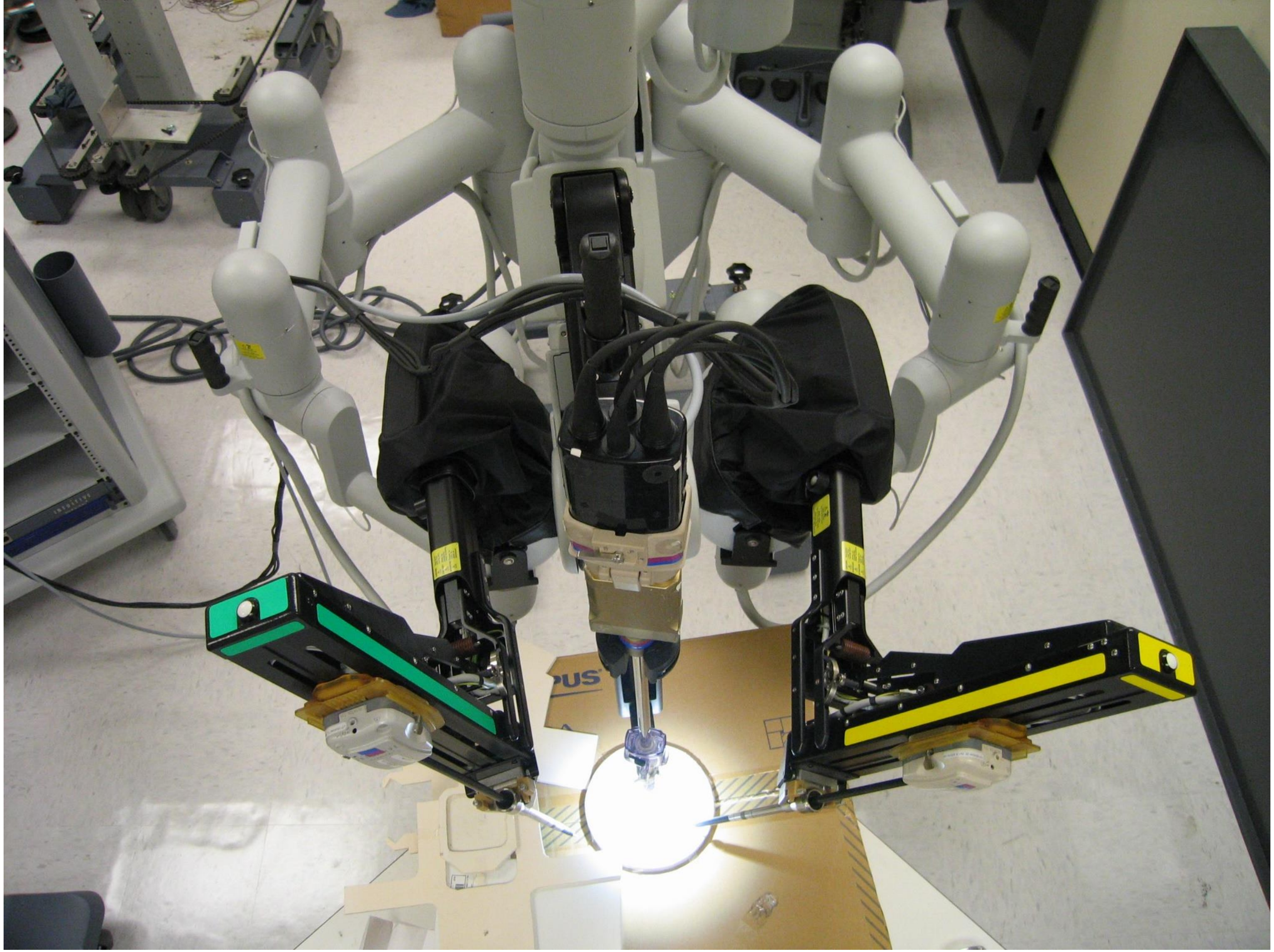
UCLA

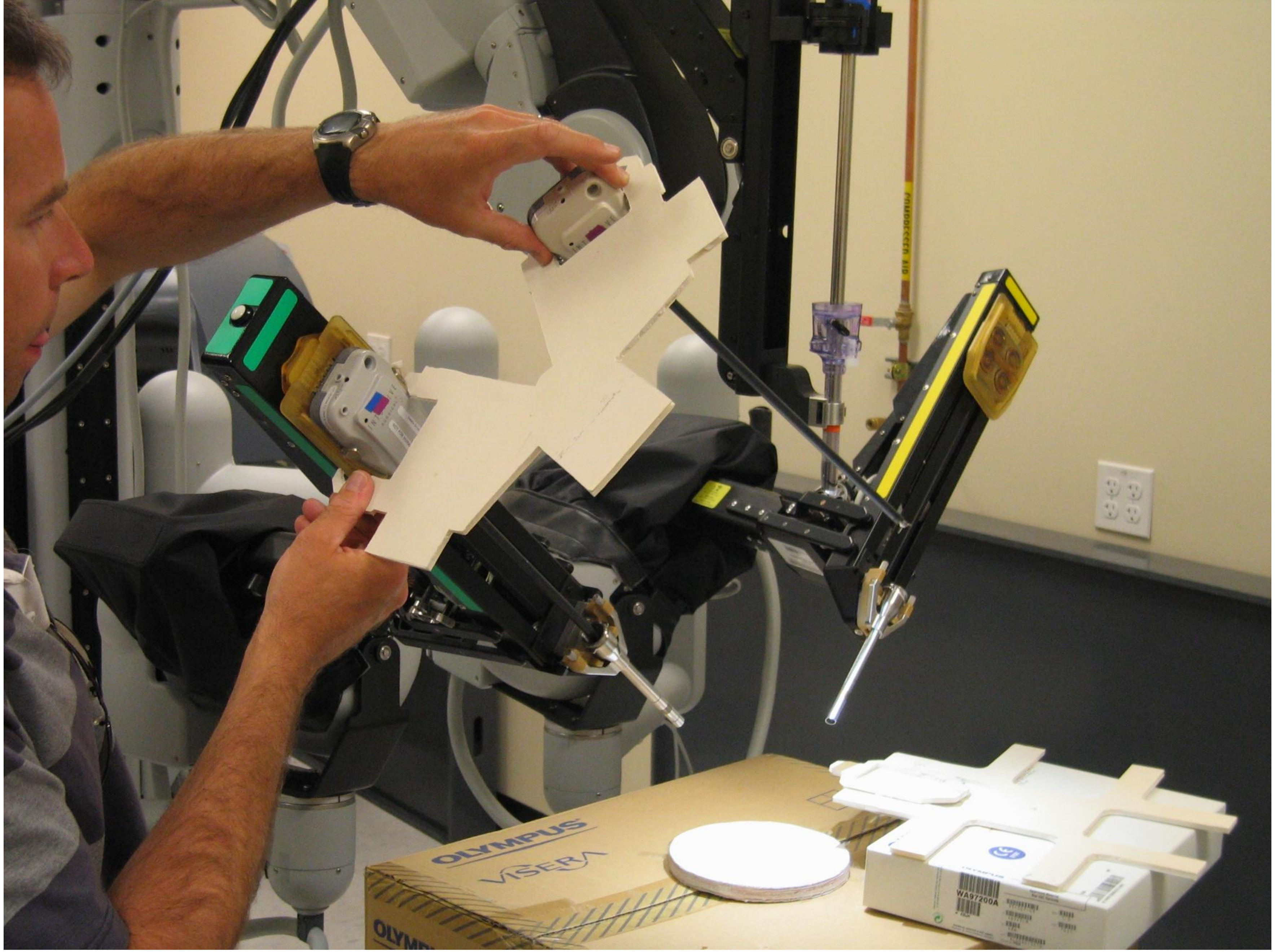






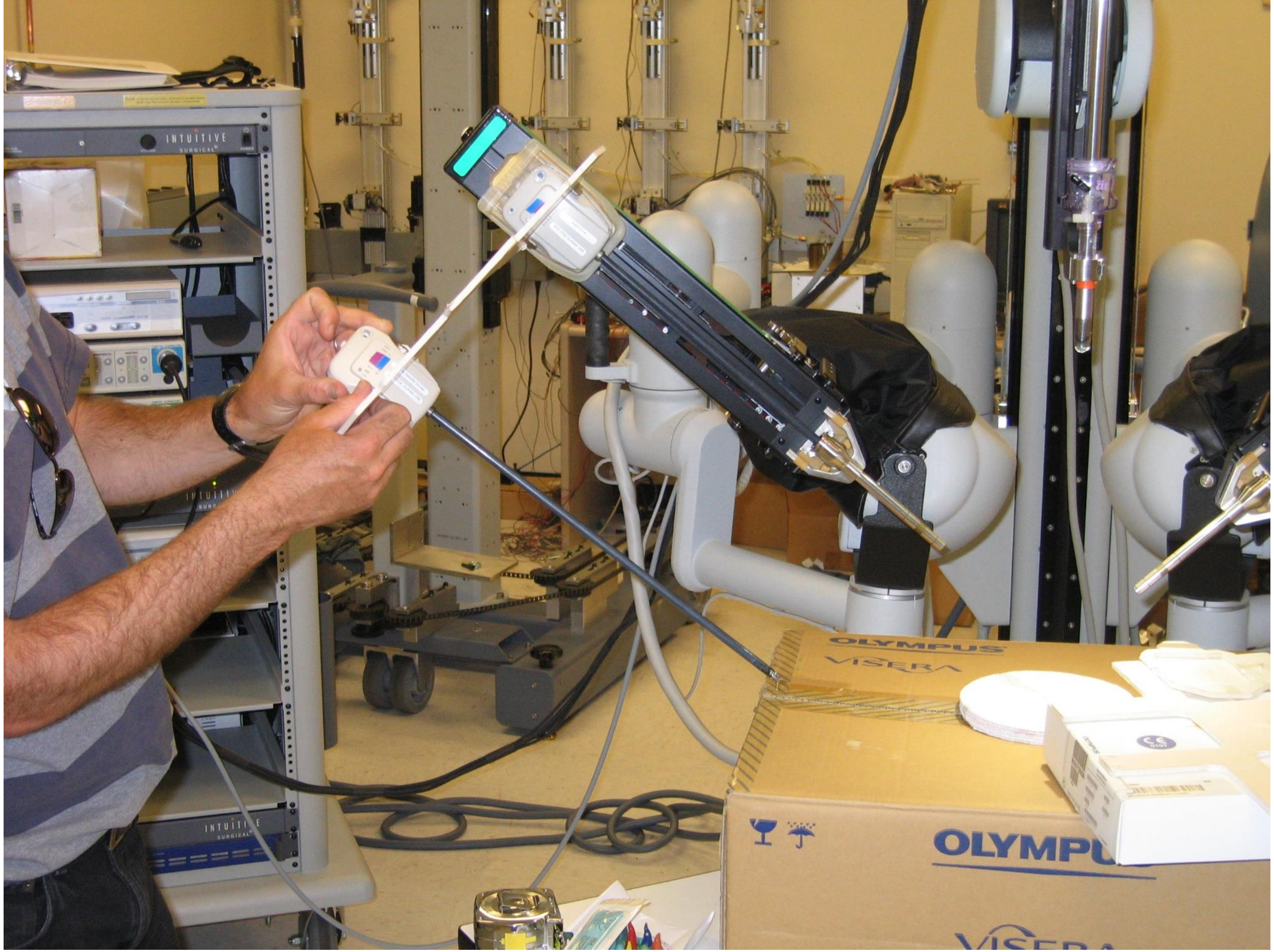
UCLA


PUS

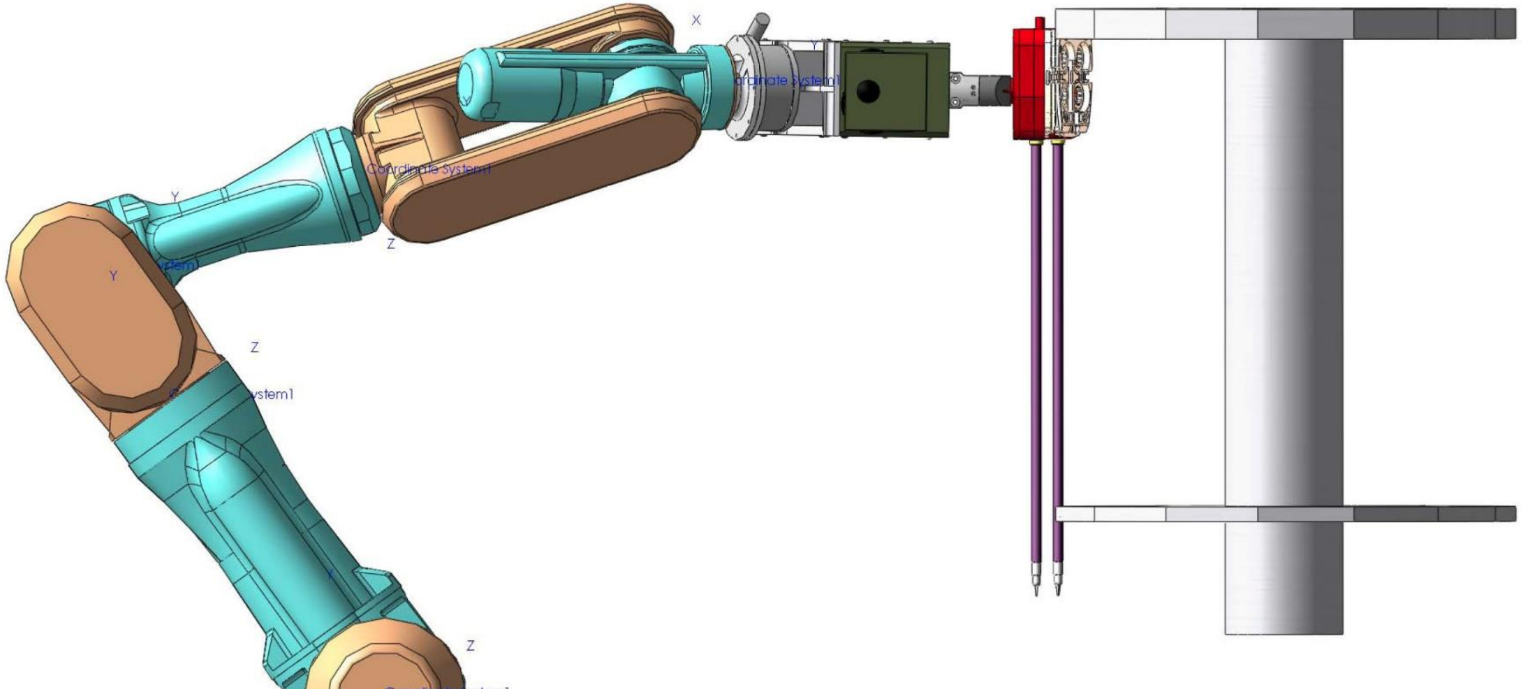


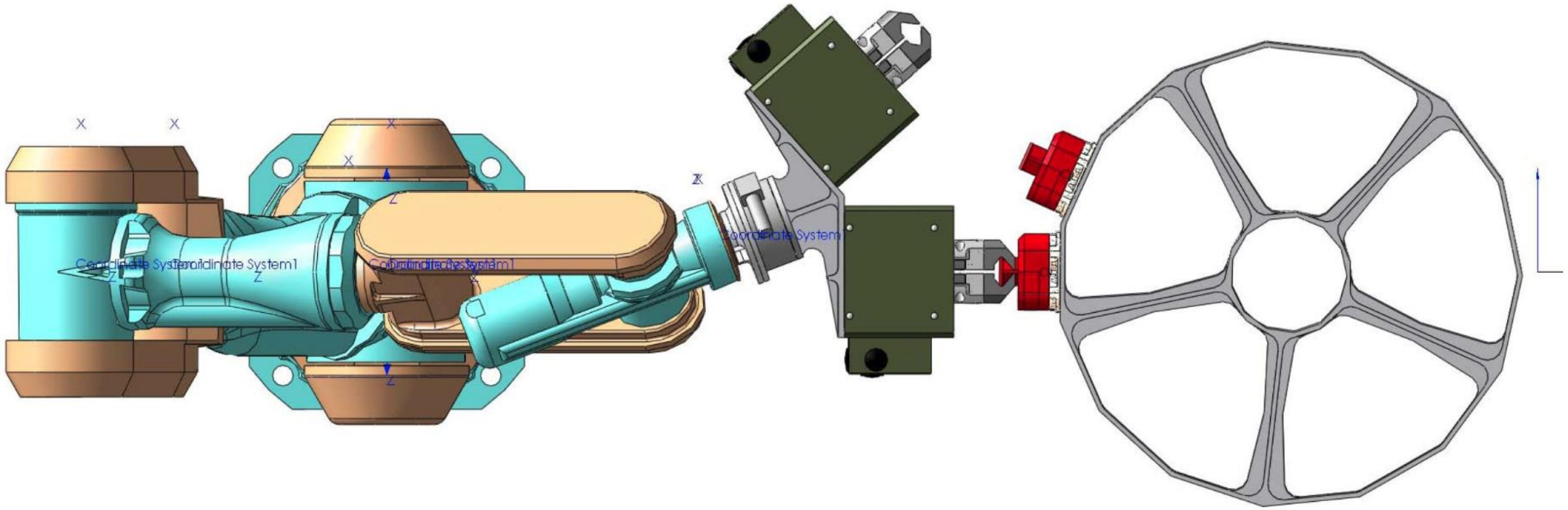
UCLA

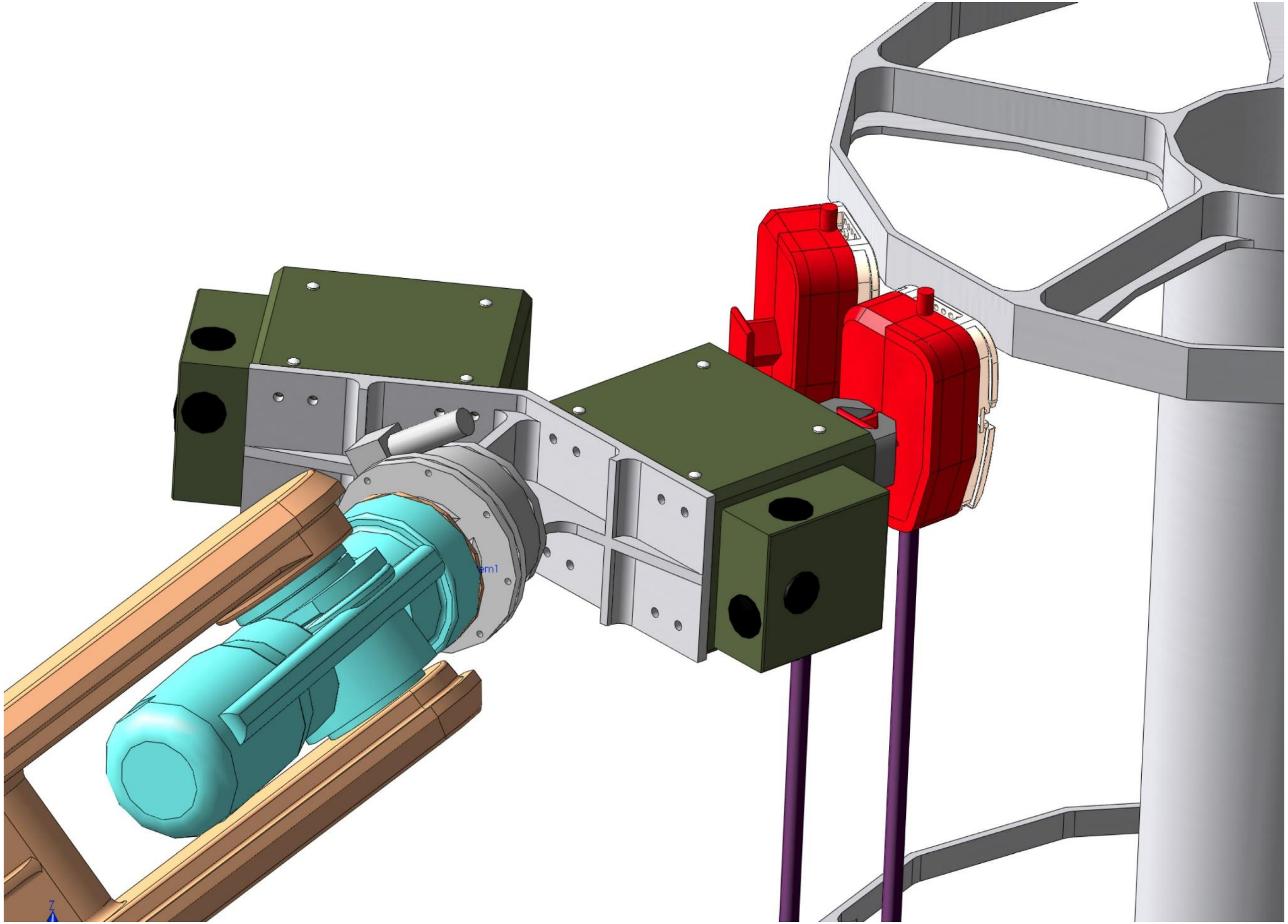
UCLA


INTUITIVE
SURGICAL
OLYMPUS
VISERA
OLYMPUS
INTUITIVE
SURGICAL


OLYMPUS
VISERA



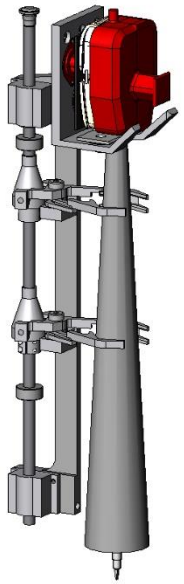

Coordinate System1



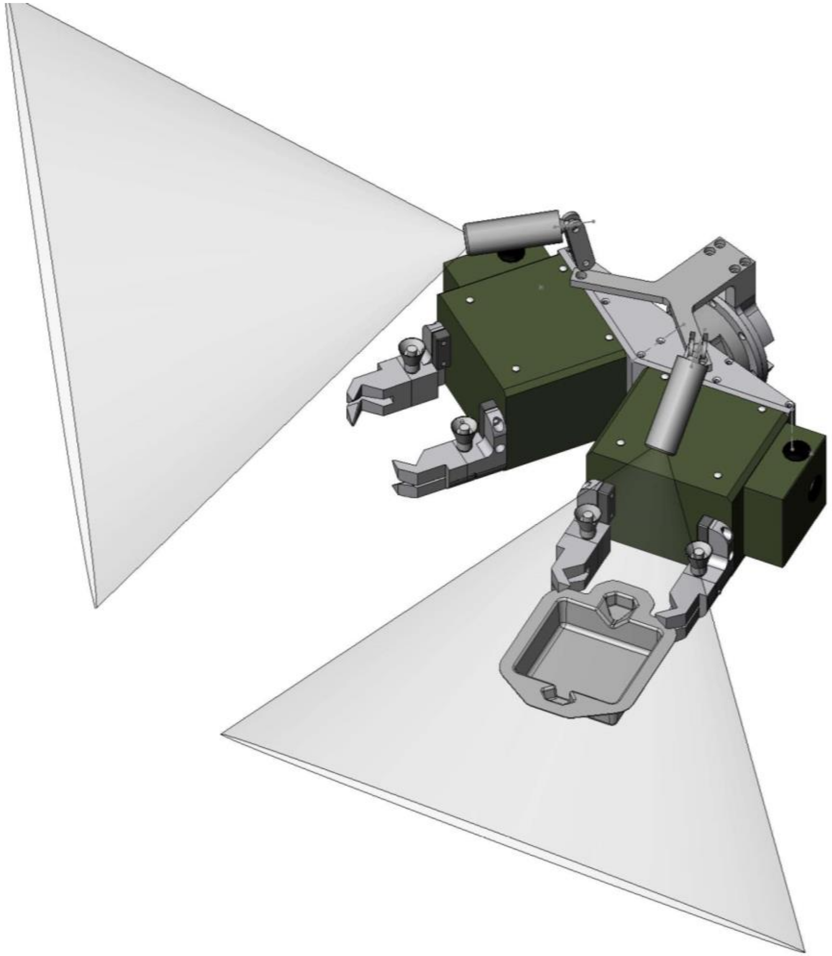
UCLA

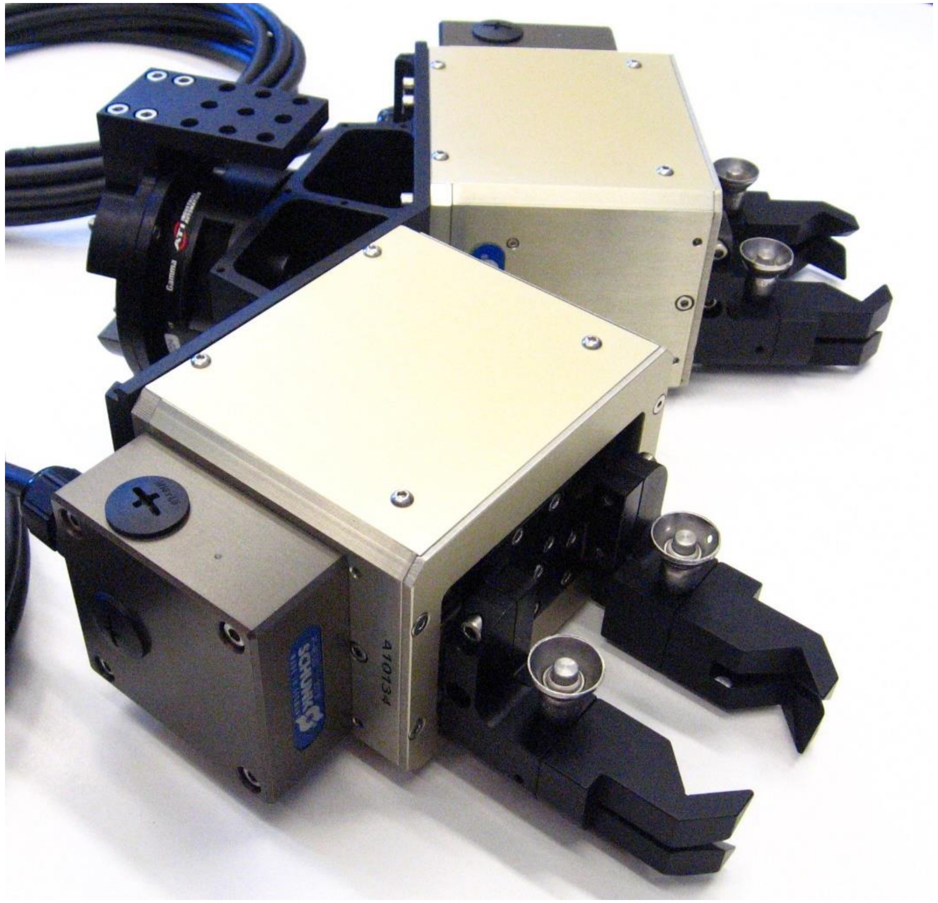
Tool Rack System (TRS)

- Developed custom tool rack for 16 surgical tools
- Tools are presented in less than 1 sec from receipt of command



End Effector (EE) – Ver. 1

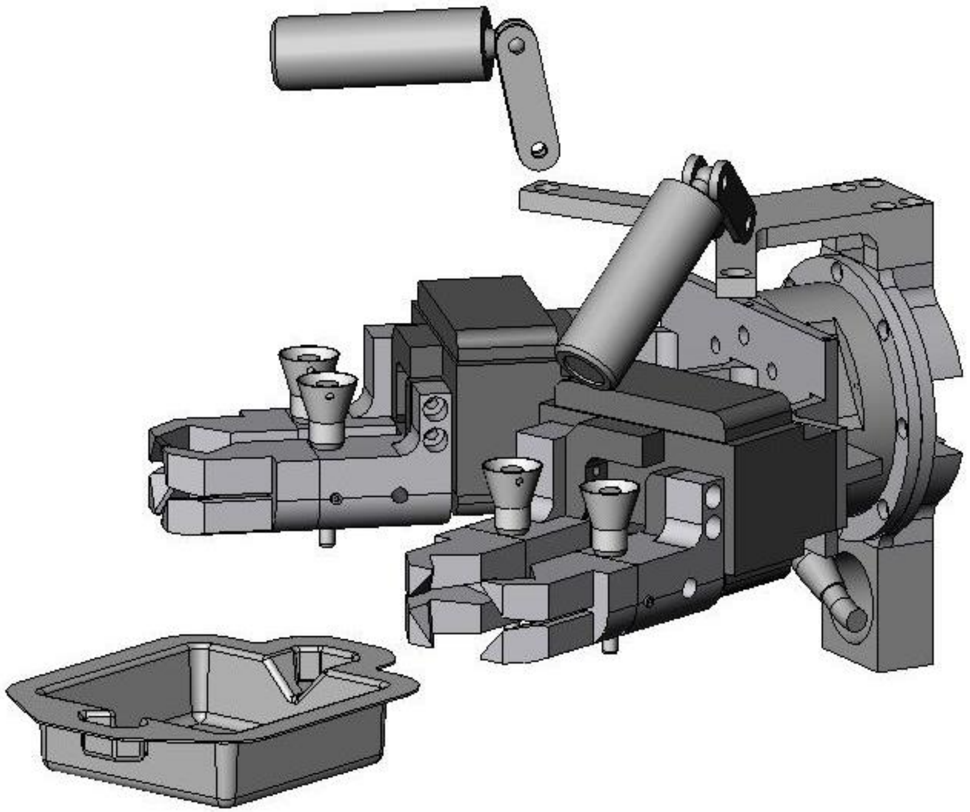


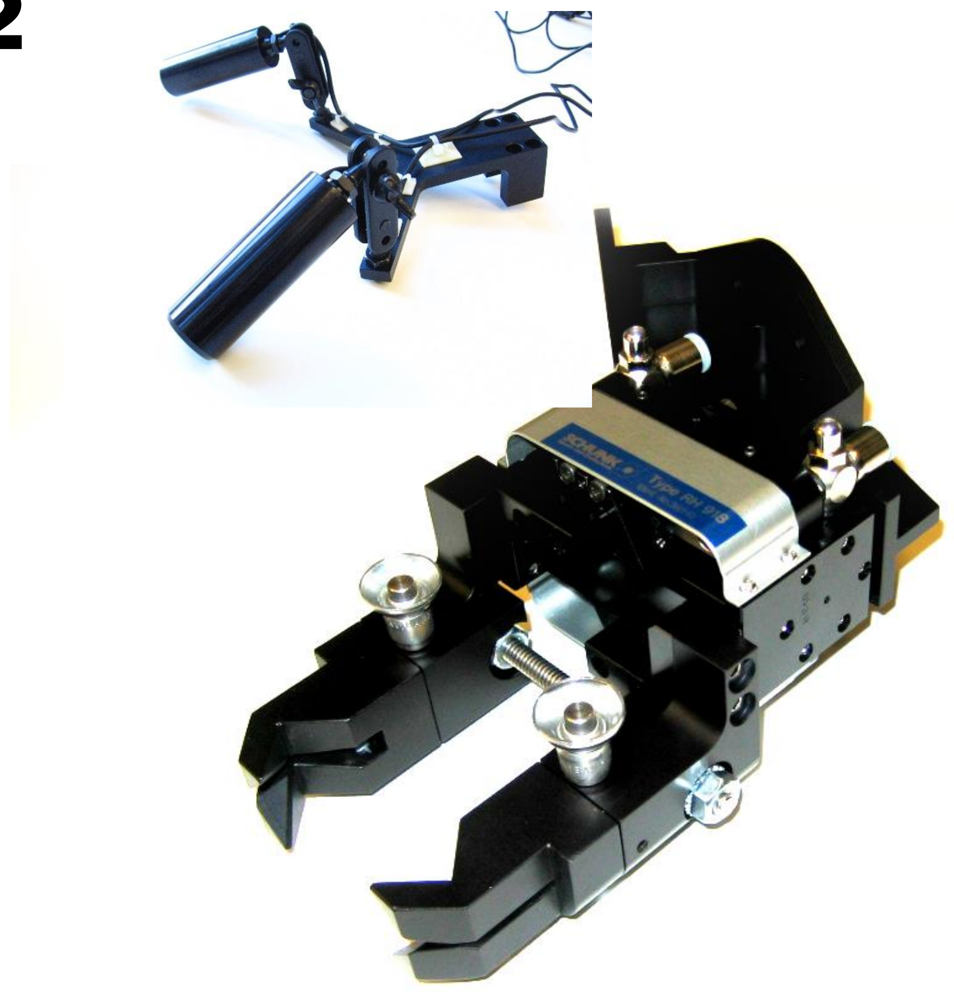


Design Question

How to change the design if the gripper doesn't grasp fast enough

End Effector (EE) – Ver. 2





Supply Dispensing System (SDS)

- Developed custom cabinet to store and de-package sterile supplies
- Supply trays are presented in less than 5 sec from receipt of command

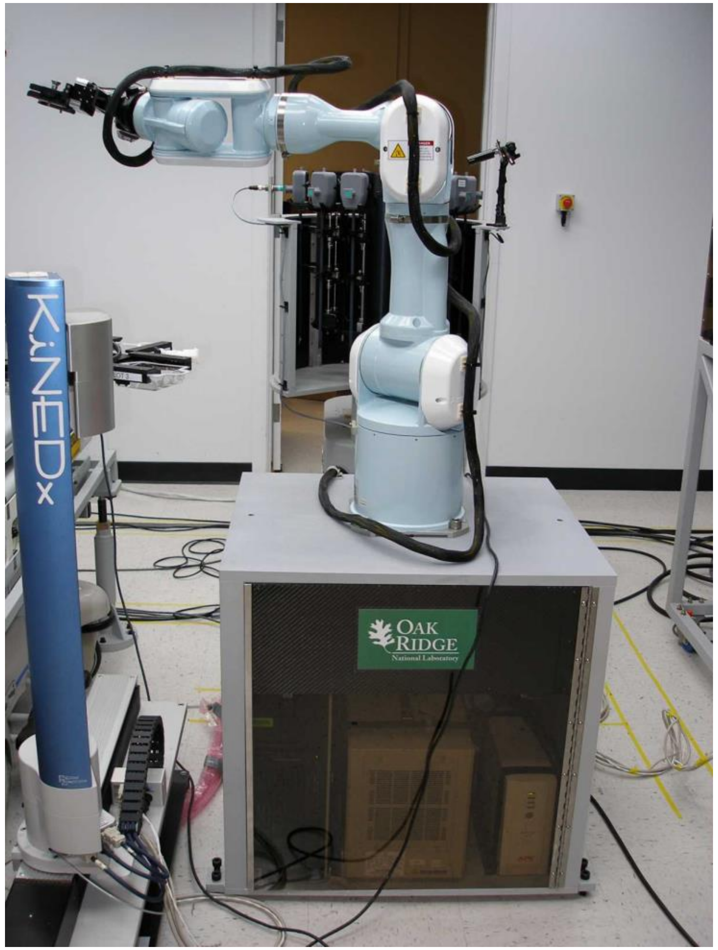
Fig 1 Supply Dispensing Cabinet

Fig 2 Fast Cache

Fig 3 Supply Trays

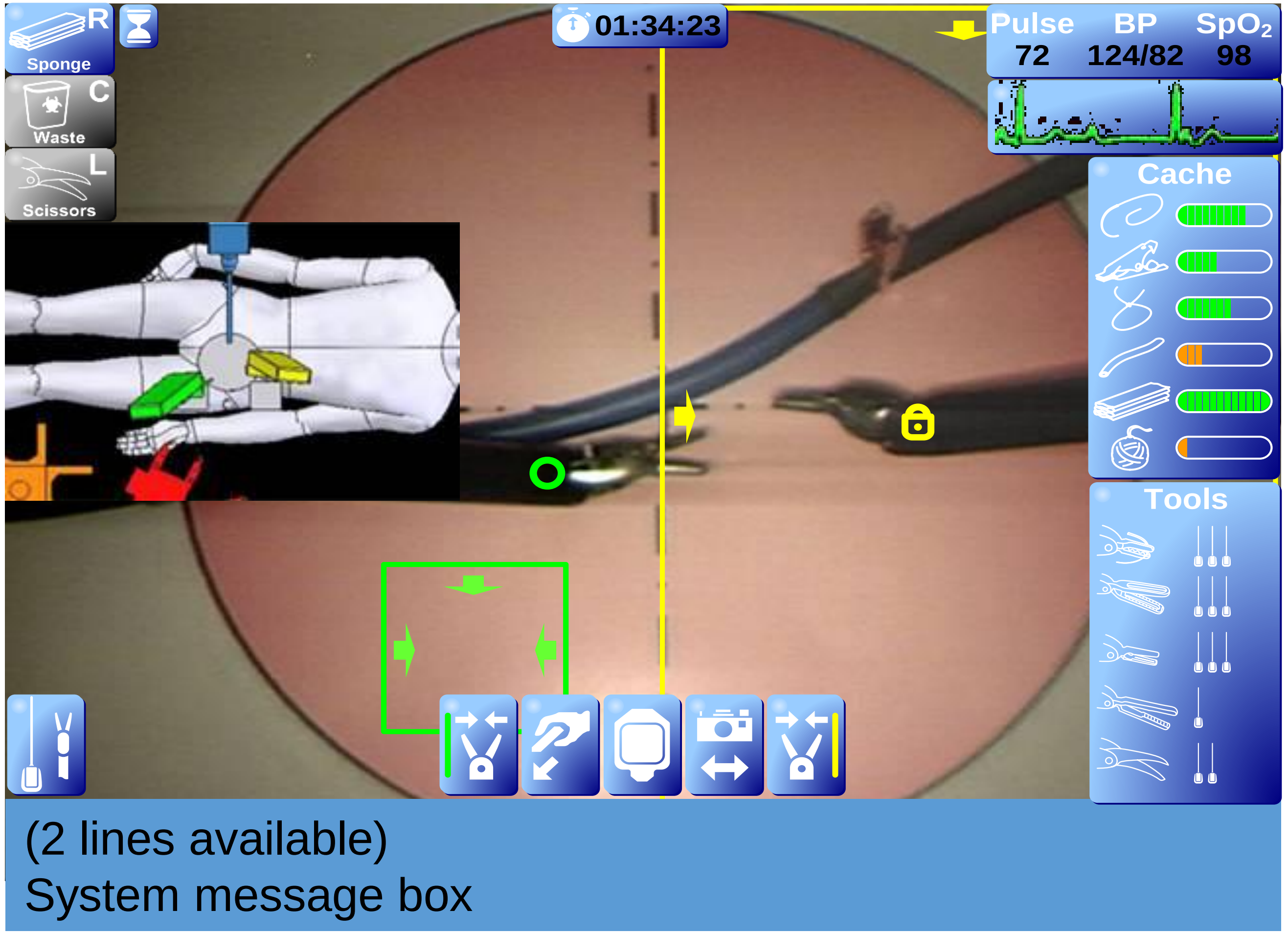
Scrub Nurse System (SNS)

- Adapted off-the-shelf industrial robot with 7 degrees-of-freedom
- Capable of changing tools and dispensing supplies in less than 11sec
- Custom software performs path planning, collision detection and obstacle avoidance in a surgical environment



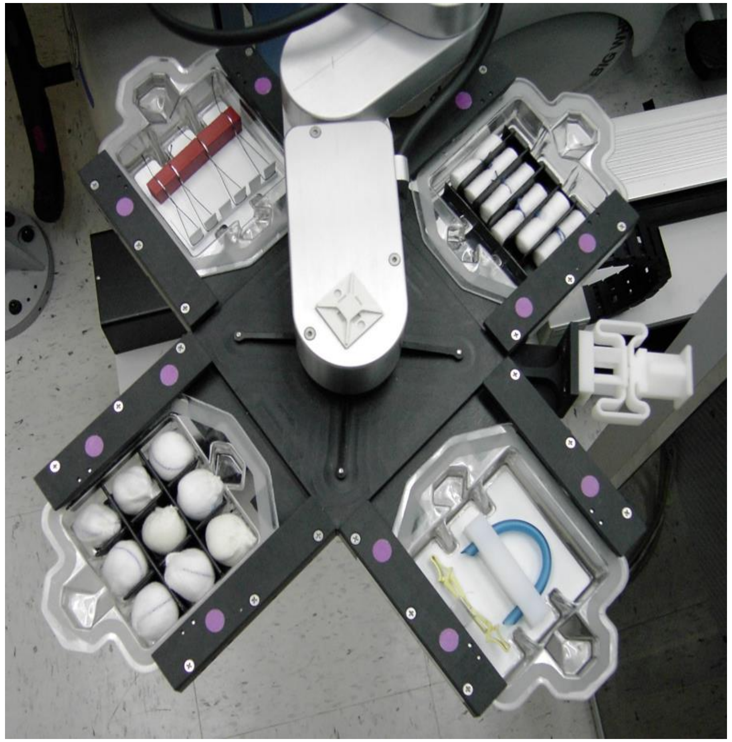
User Interface System

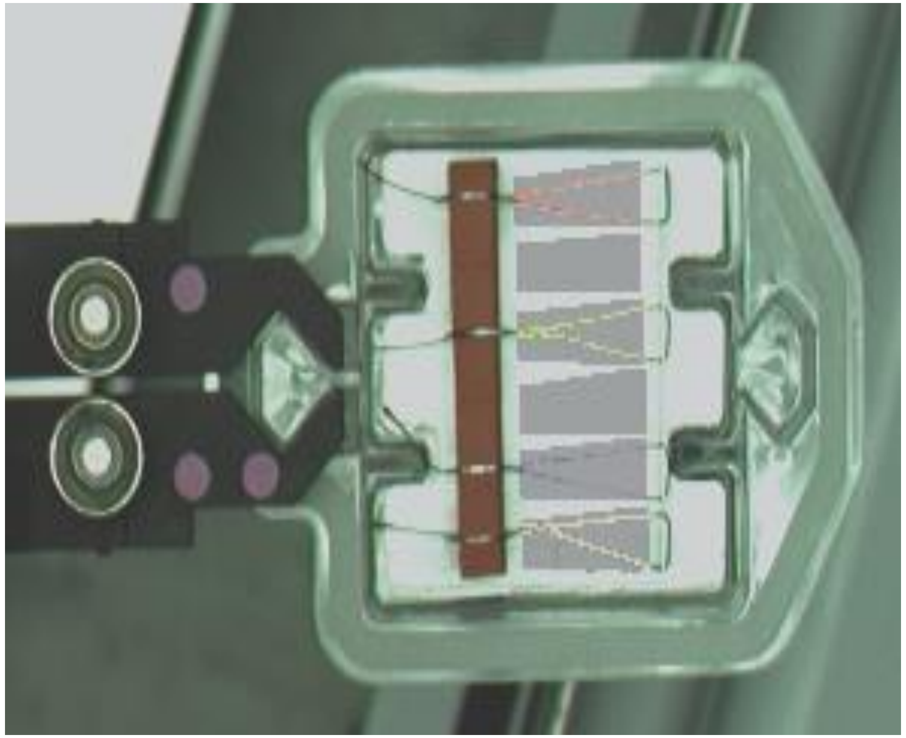
- Integrated speech recognition
- Developed prototype that interacts with emulator
- Gathered feedback from surgeons using the system



Machine Vision System

- Overhead system automatically counts supplies inside trays

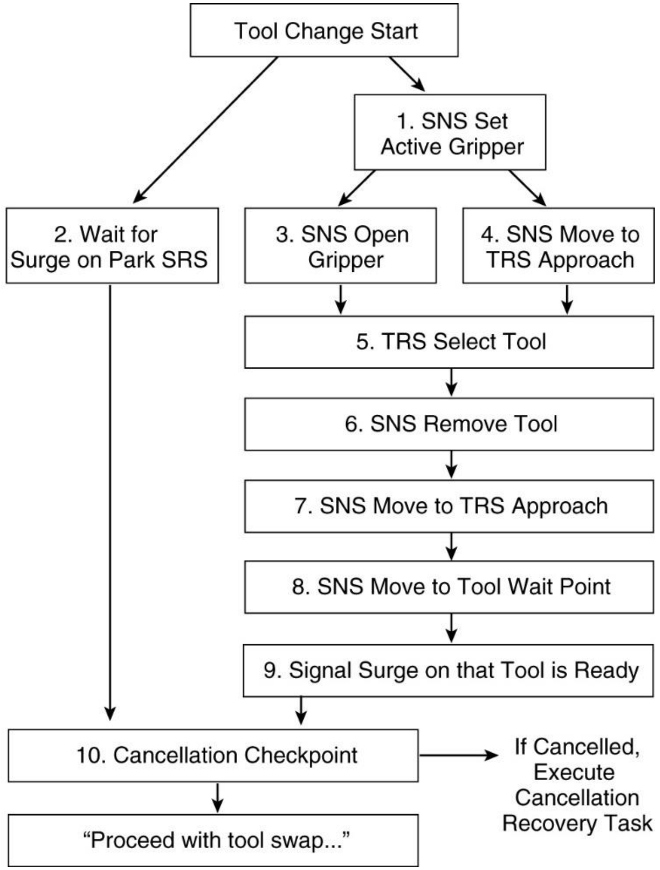




UCLA

Supervisory Controller System

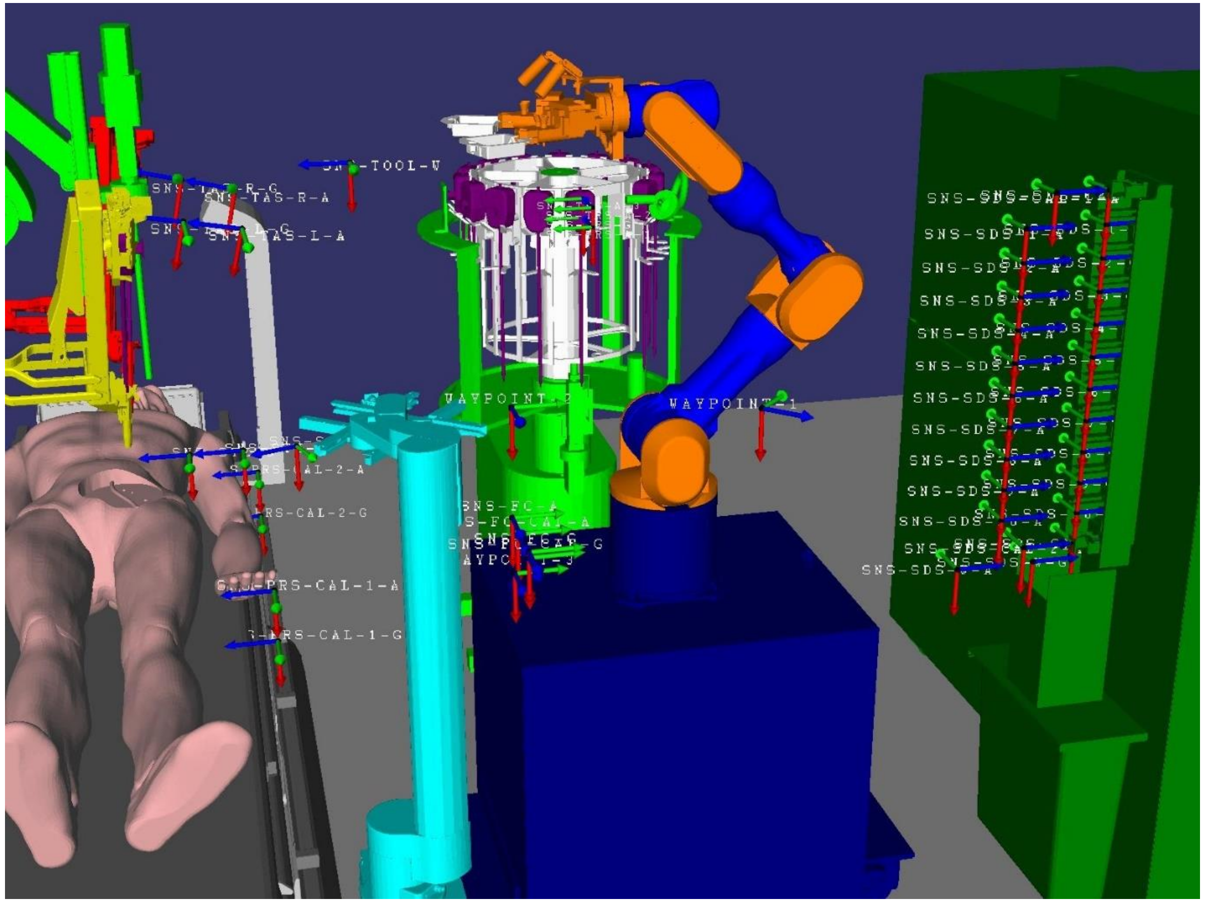
- Coordinates all subsystems to execute task requested



TYPE	TASK	DESCRIPTION
Surgical	Change tool	Swap tool on SRS arm with new tool from TRS
	Dispense supply	Provide supply to surgeon from the SDS or fast cache
Debug	Park all	Park all subsystems
	Recover SNS	Recover SNS error automatically
Surgical Pre/Post Operative	Empty slots	Remove trays from slots and place in waste bin
	Empty SRS arm	Remove tools from SRS and return to TRS
	Populate slots	Populate supply slots with specified supply types
	Populate SRS arm	Populate SRS arms with specified tools
Calibration	Calibrate (automatically or manually)	Calibrate locations of subsystem (PRS, SRS, TRS, SDS, fast cache)

Simulator Systems

- World model driven by sensory data in the robotic cell
- Served as development tool to analyze layout
- Used by collision detection systems during the operation

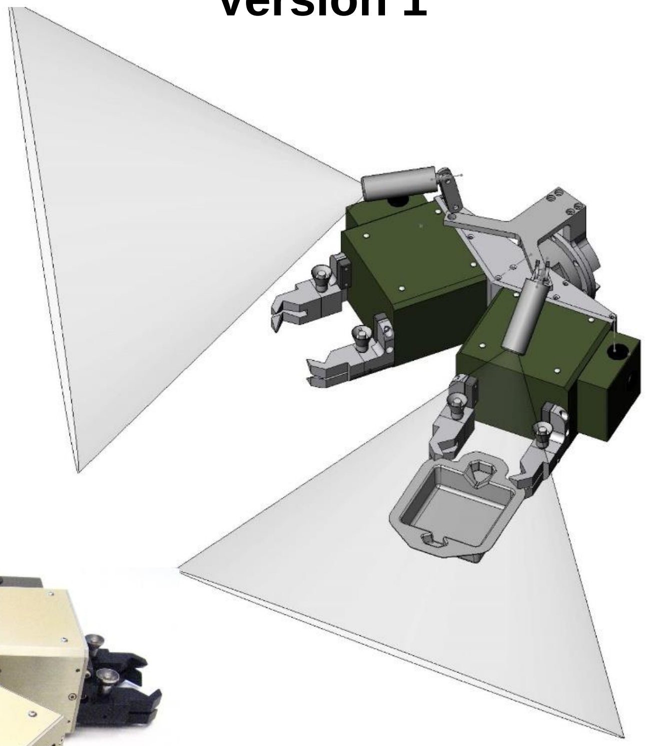


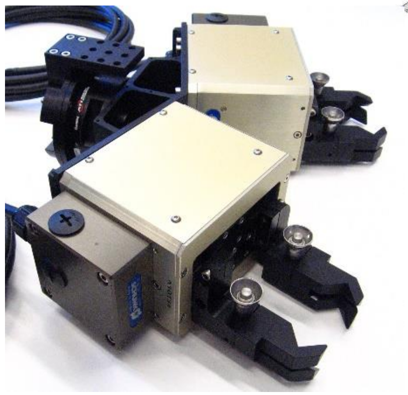
UCLA

	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

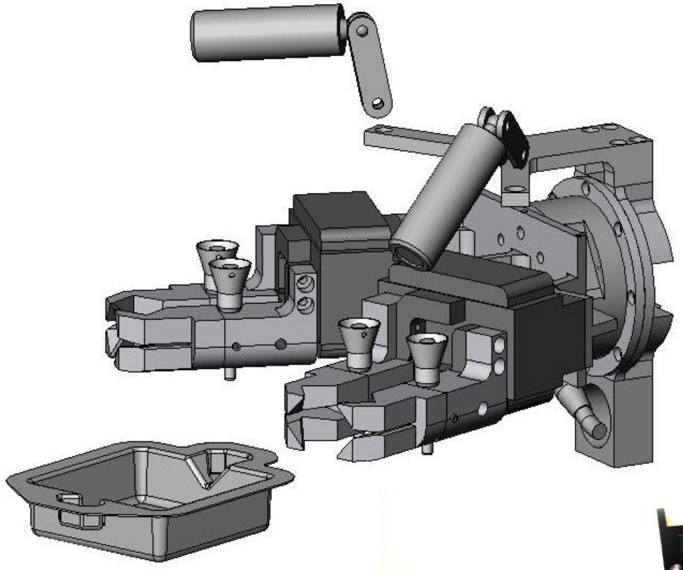
End Effector Version

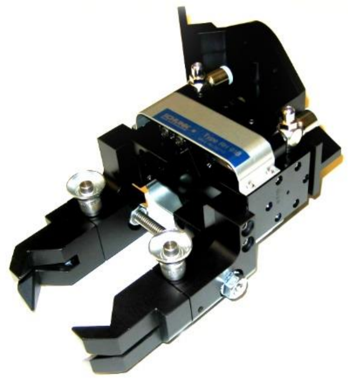
Version 1





Version 2



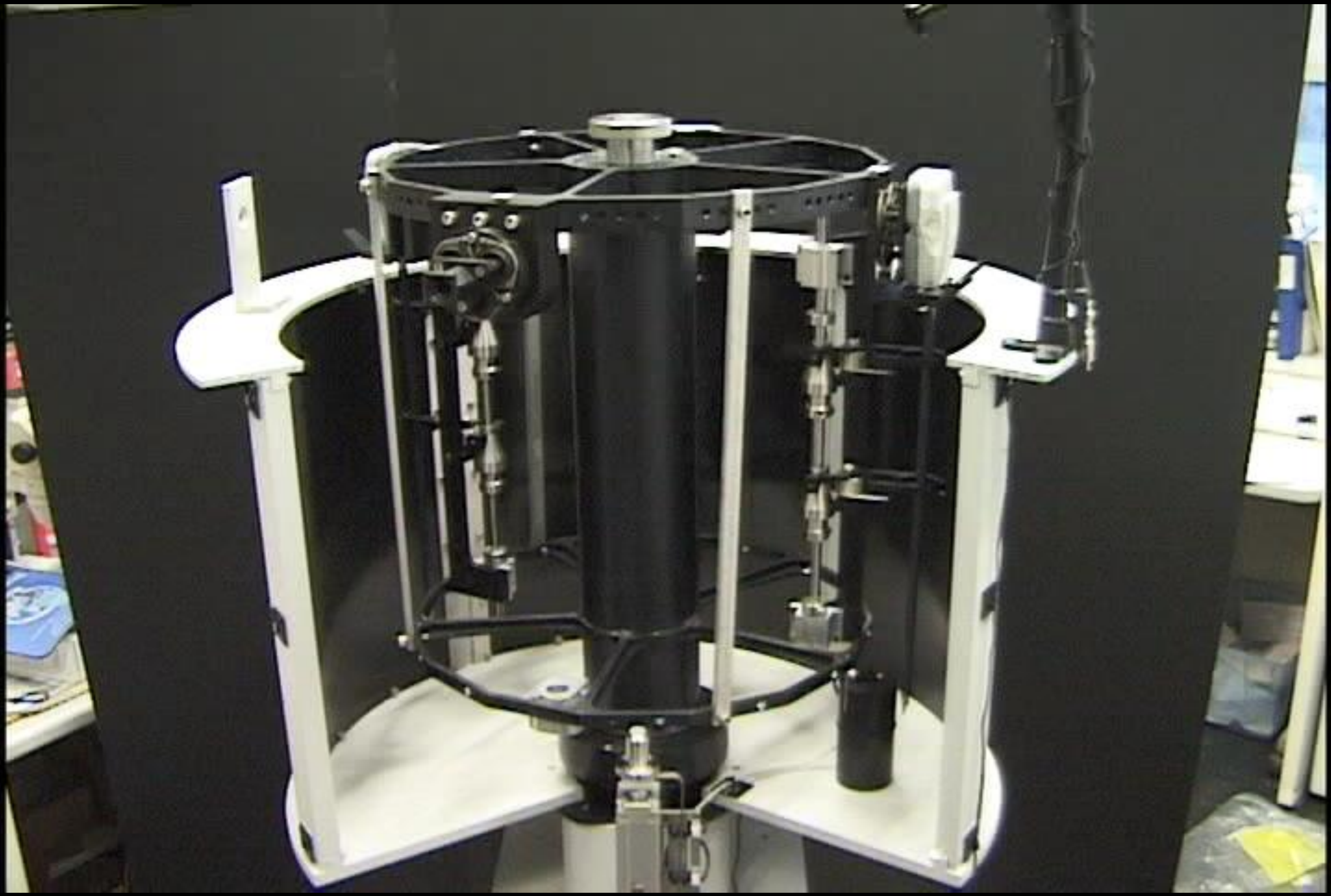


UCLA

End Effector Spec

EE Version	1	2	Requirements
Actuator	Electric (Servo) Schunk PT-AP 70	Pneumatic Schunk RH 918	*
Time open/close [s]	0.63 - 0.75	0.4 (Stroke 60 mm) 0.28 (Stroke 42 mm)	0.4 Timing Analysis CTL-023-R02
Stroke [mm]	70	60	42
Grasping Force [N]	200	5 -100	15 -100
Weight – Actuator [Kg]	1.4 (2.8)	0.480 (0.960)	*
Weight – V-Head [Kg]	0.684	0.239	*
Weight – Total [Kg]	4.522	2.263	7.5 -10

TRS Overview

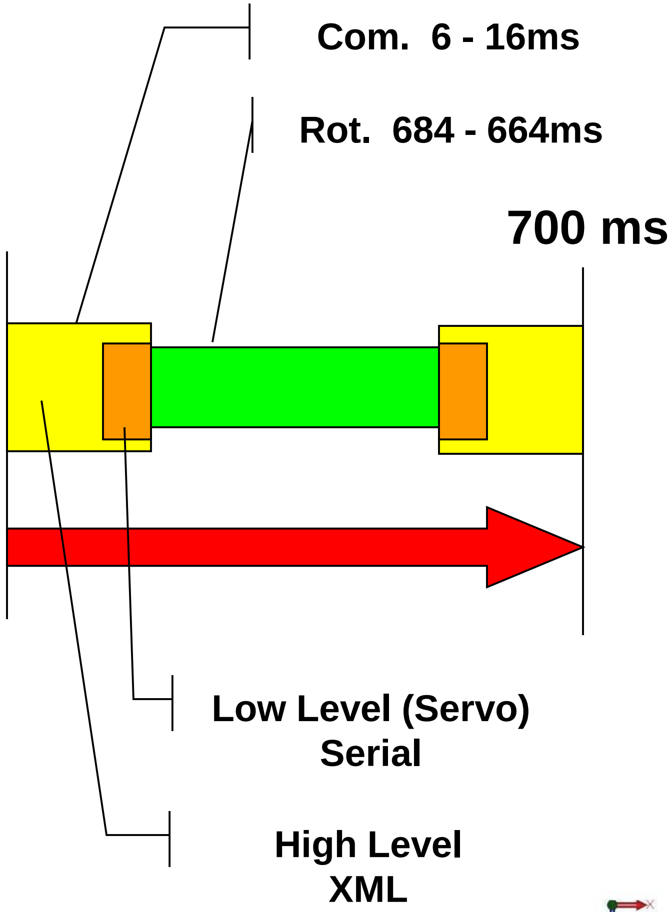


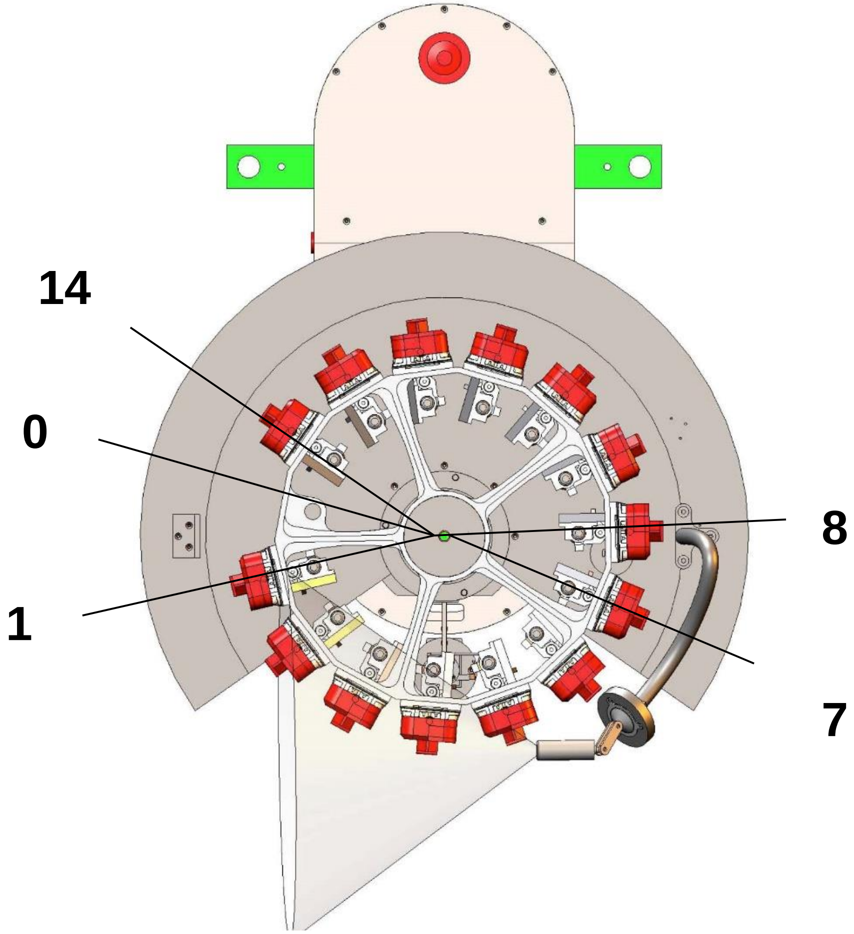
TRS Performance - TRS PER 1.0

- **Requirement** - The TRS shall be able to present any SRS tool in its rack for acquisition with a maximum of 0.7 s of receipt of command.

- **Performance** - Max – 648 +/- 8 ms

TRS Performance - TRS PER 1.0

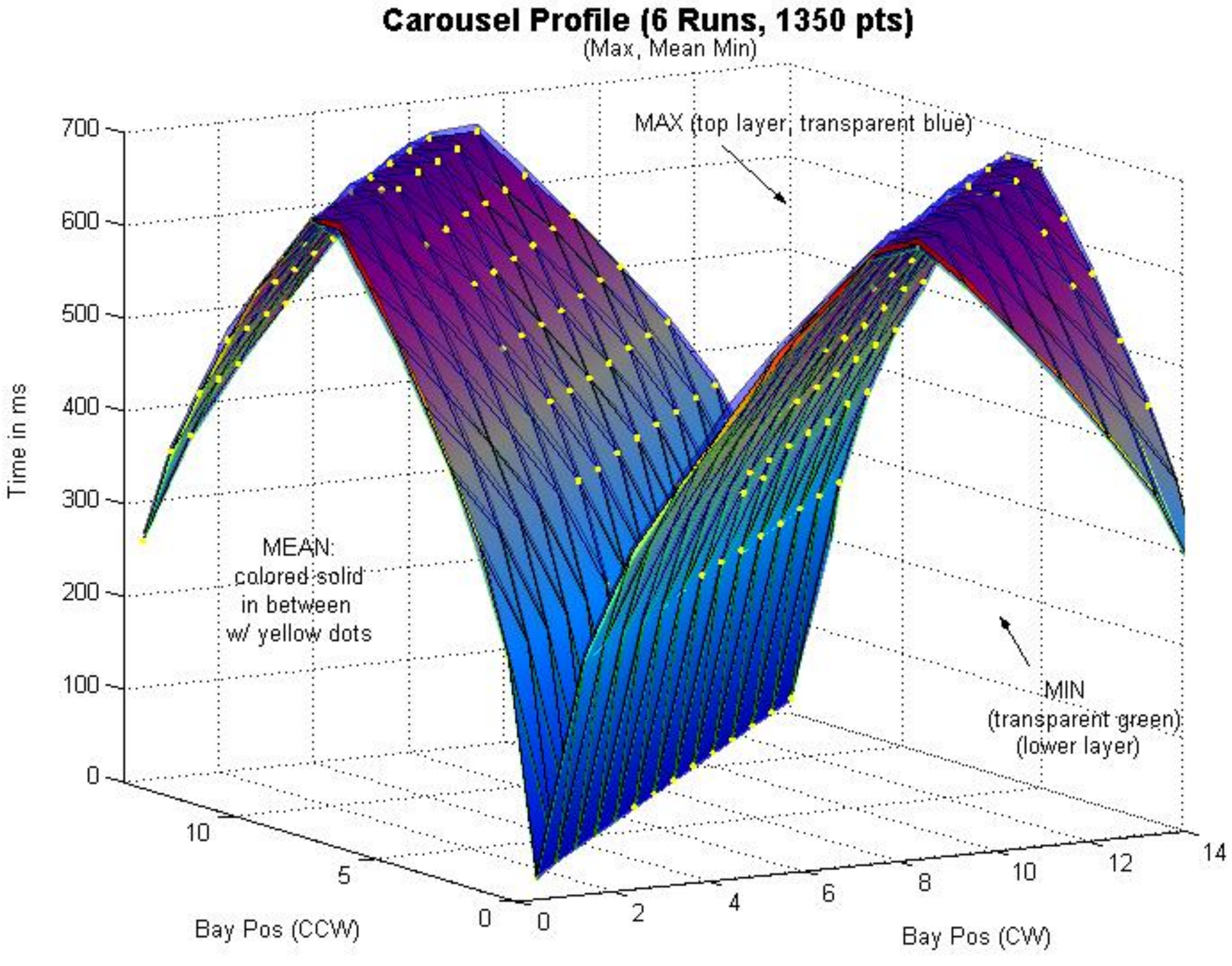




TRS Performance - TRS PER 1.0

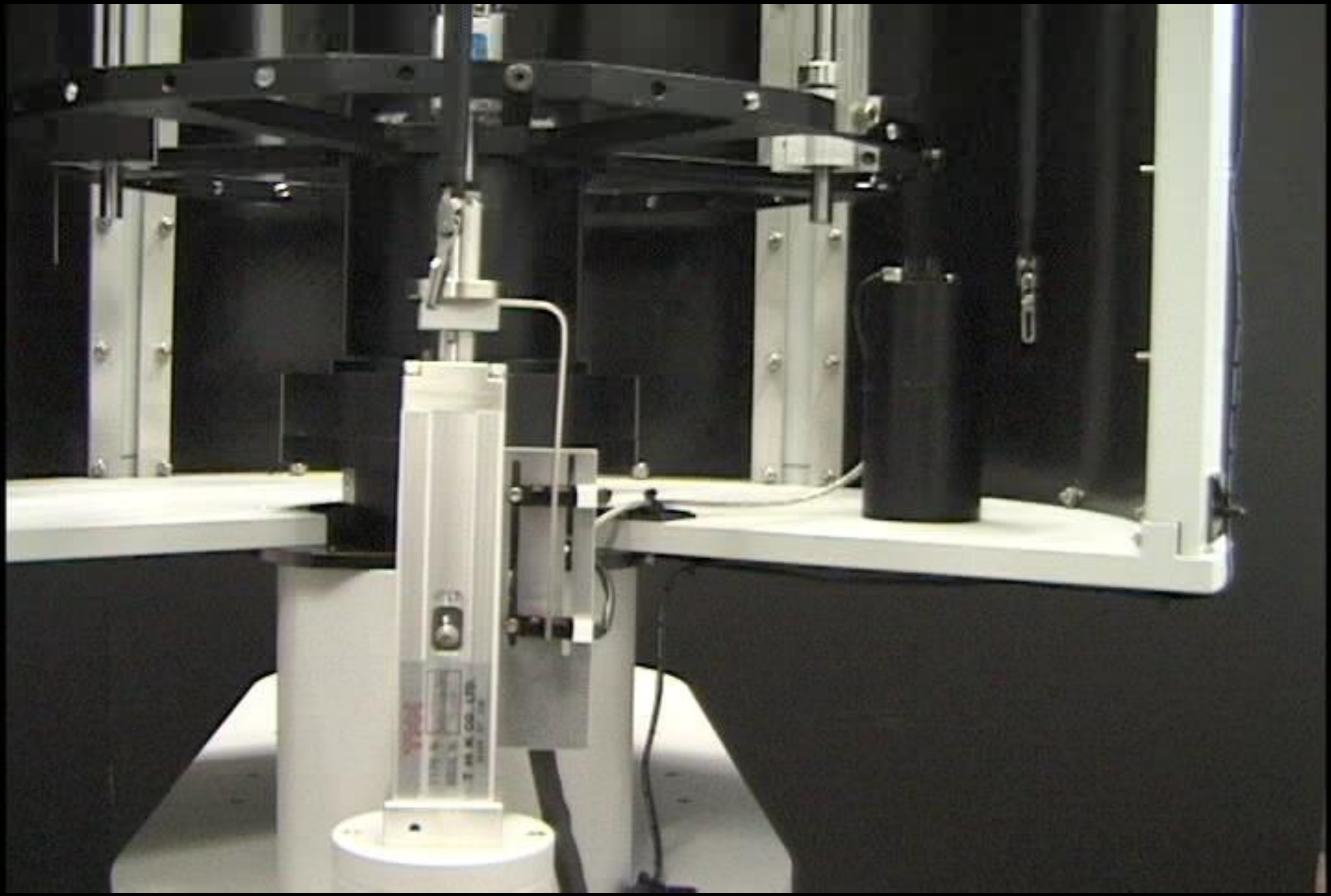
Average Time for Presenting a Tool [ms]
6 trials – 1350 Transitions
Max – 648 +/- 8 ms

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	13.33	242.17	350.00	417.33	480.83	544.17	594.00	642.17	648.83	600.83	546.00	486.83	419.50	350.67	243.33
1	240.67	14.00	242.67	348.67	425.50	481.33	547.33	594.00	644.17	644.00	600.00	544.83	485.50	423.33	354.00
2	348.17	240.67	14.67	242.67	346.67	422.00	484.00	548.17	594.00	642.00	648.17	598.17	545.33	487.33	425.33
3	418.67	349.33	240.67	14.67	240.83	349.33	420.83	486.67	543.33	594.17	642.83	644.67	600.00	550.00	486.00
4	483.33	422.83	348.67	241.33	14.67	240.67	348.00	421.33	481.50	546.67	593.33	645.33	645.33	598.67	548.67
5	544.17	482.67	420.17	349.33	242.00	14.67	242.83	348.33	421.50	484.67	545.33	596.00	644.00	644.67	598.83
6	592.67	543.50	484.67	418.67	346.67	244.17	14.00	244.00	348.67	420.00	482.83	545.33	593.33	647.67	647.50
7	643.33	593.33	543.50	484.83	422.67	347.33	242.67	14.00	244.00	347.33	420.67	482.00	546.17	596.17	646.67
8	645.33	642.17	592.00	546.17	485.50	423.50	345.33	240.67	14.67	241.33	348.67	420.17	486.17	549.33	595.50
9	596.17	644.67	644.17	592.83	546.17	485.33	420.67	348.00	240.17	14.67	242.83	348.00	422.00	492.17	546.83
10	549.33	596.83	646.67	644.17	595.33	544.00	482.67	419.33	349.33	241.33	14.00	241.33	345.33	422.67	484.83
11	488.83	546.00	602.17	647.33	648.00	597.33	544.00	482.67	420.83	349.33	242.83	14.67	242.67	350.00	424.67
12	422.17	487.50	544.67	599.33	648.00	644.67	594.00	544.17	484.00	422.67	348.00	243.50	14.67	242.00	348.67
13	350.83	423.33	487.33	548.17	600.17	647.33	644.00	594.00	547.33	486.67	422.00	349.50	241.50	14.67	241.50
14	245.33	354.00	425.33	484.67	549.33	596.00	646.17	648.00	595.33	546.00	486.00	421.33	348.00	242.67	16.00


Carousel Profile (6 Runs, 1350 pts)
(Max, Mean Min)
MAX (top layer, transparent blue)
MEAN:
colored solid
in between
w/ yellow dots
MIN
(transparent green)
(lower layer)
Time in ms
0
100
200
300
400
500
600
700
Bay Pos (CCW)
0
5
10
Bay Pos (CW)
0
2
4
6
8
10
12
14

UCLA

TRS Calibration



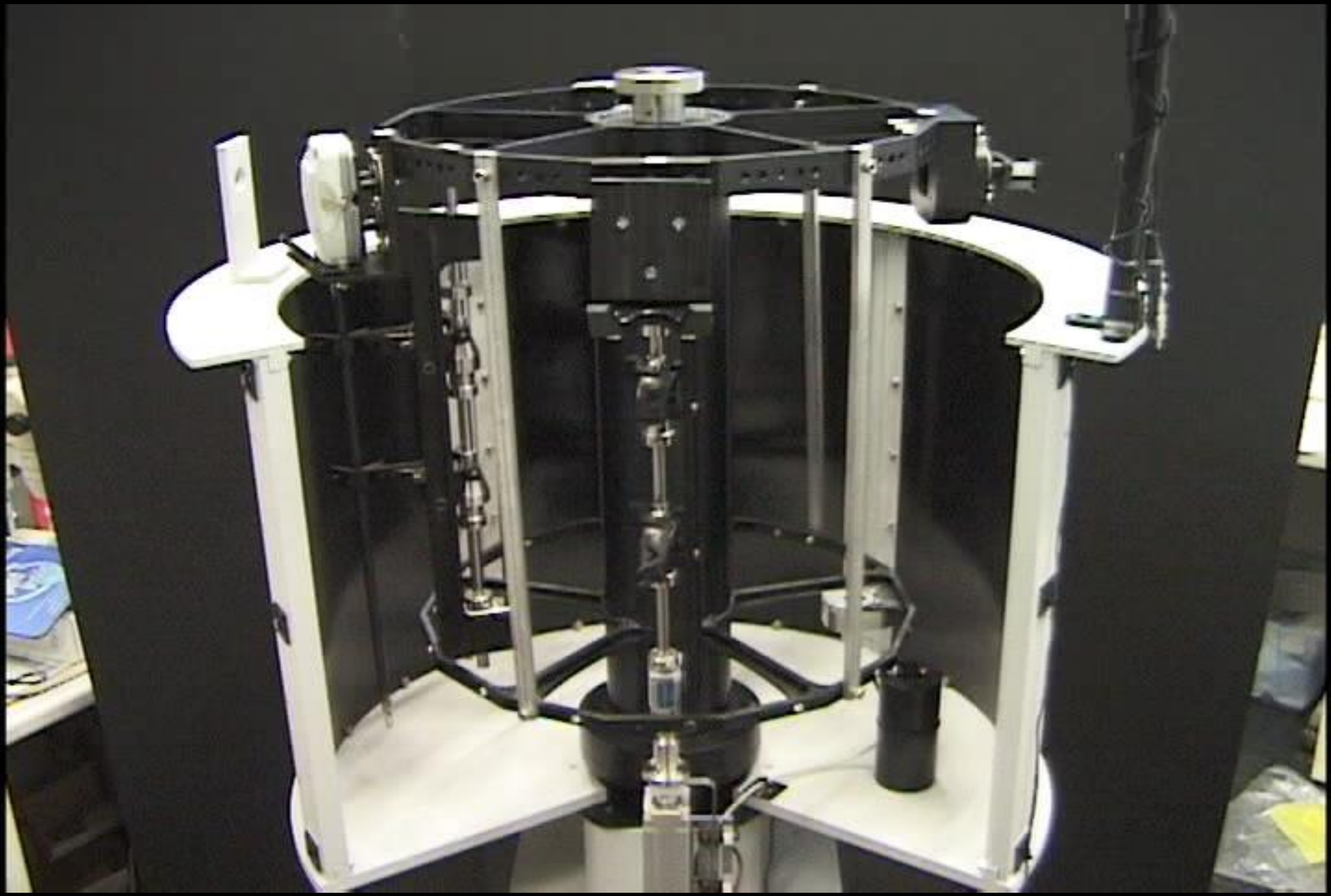
TRS Spinning

TRS Performance - TRS PER 2.0/3.0

- Requirement - The TRS shall receive / release and lock / unlock in SRS tools in 0.1 seconds (goal) with a maximum of 0.3 seconds within receipt of command.

- Performance
  - Release Tool – 0.088 s
  - Receive Tool – 0.076 s

TRS Load/Unload Tools



TRS Performance - TRS PER 4.0

- **Requirement** - The TRS shall be able to present any SRS tool in its rack for acquisition by the SNS with a position accuracy and repeatability of +/-0.65mm and orientation accuracy and repeatability of +/-0.2deg.

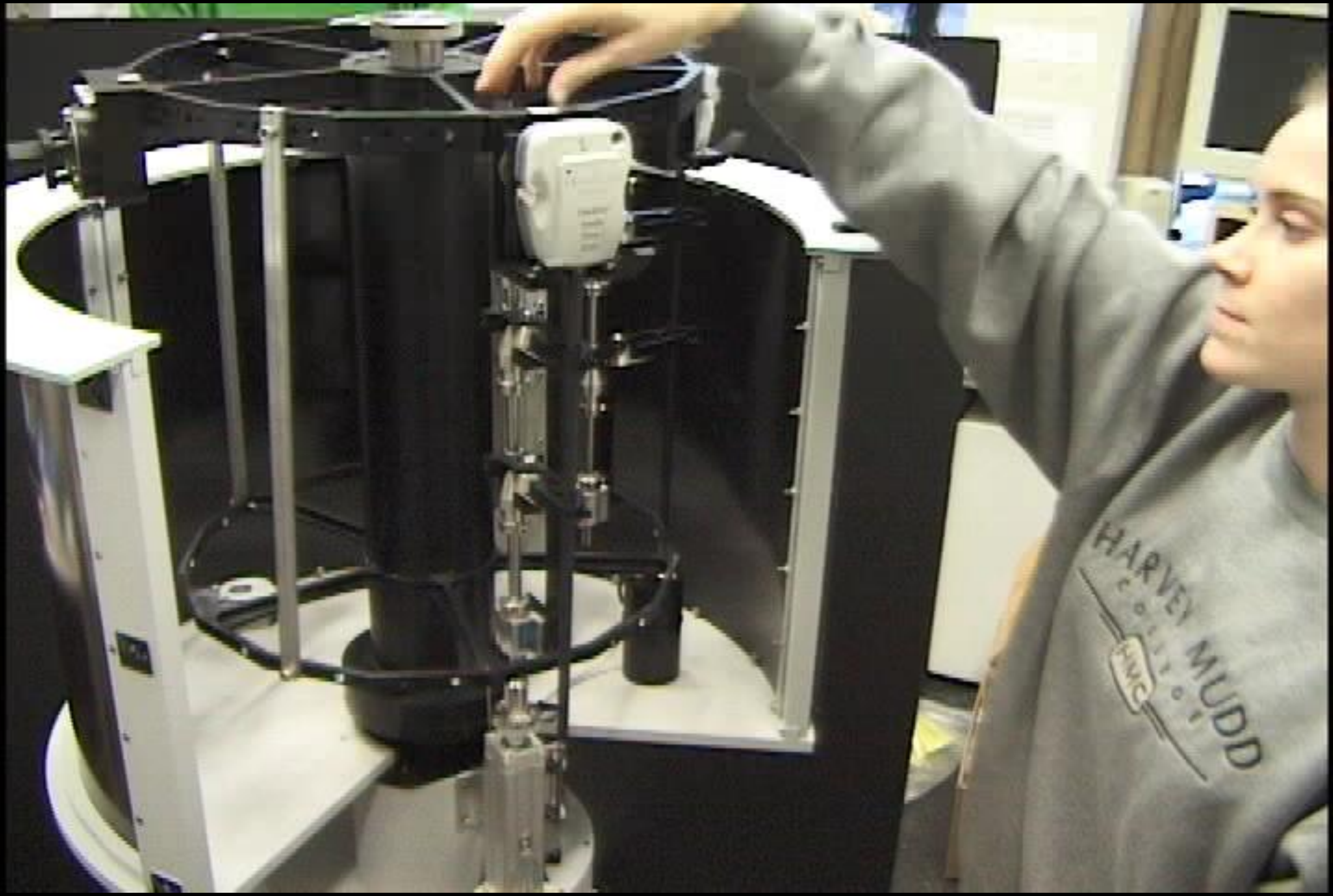
- **Performance** - Repeatability of +/-0.177 deg

TRS Performance - TRS PER 8.0

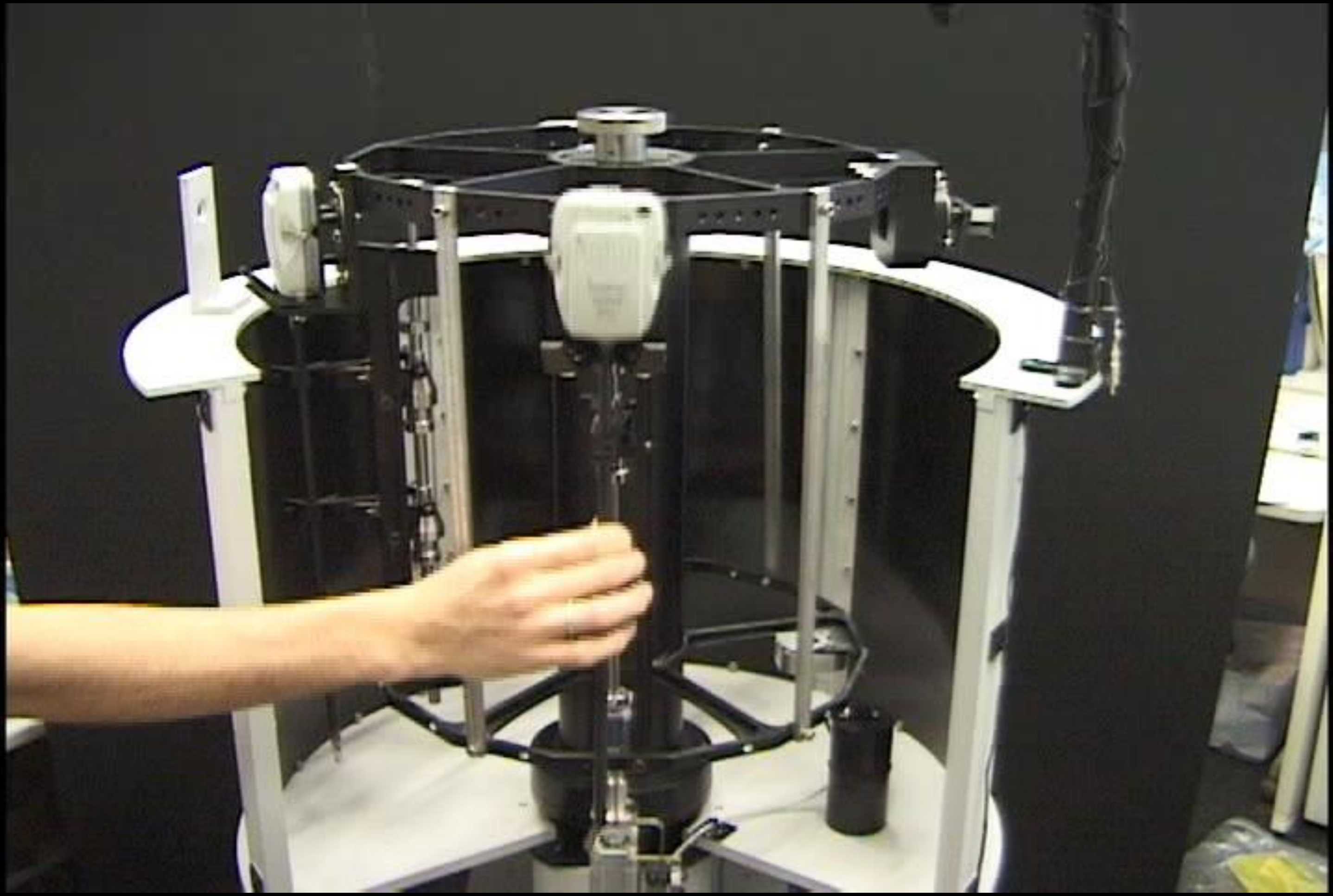
- **Requirement** - The TRS shall have removal forces (what the SNS/EE must overcome for tool placement or removal) of less than 1lb

- **Performance** – Releasing Force
  - Pinchers Open – 0 N
  - Pinchers Close - 12 N
    Overcoming the active passive grasping

TRS Load/Unload Tools



TRS Tool Pulling



TRS Performance - TRS FUN 12.0

- **Goal:** The TRS shall be capable of sustaining autoclave-based cleaning and sterilization with tools installed

TRS Magazine Removal

UCLA

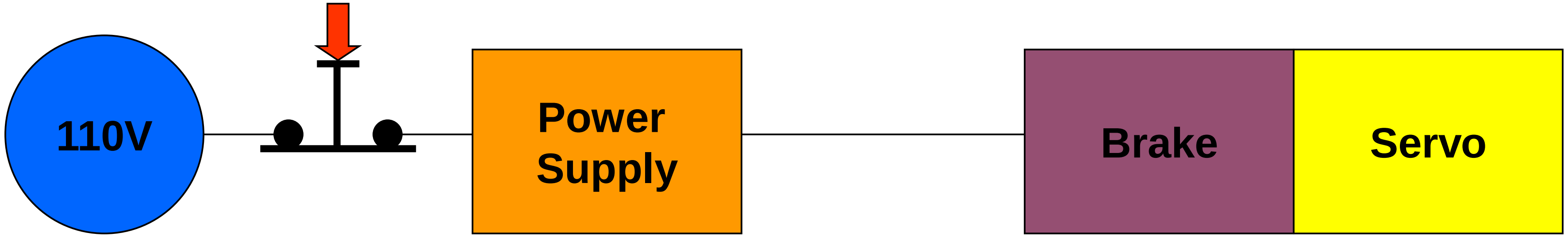
TRS Performance - TRS INT 4.0

- **Requirement** - The TRS will include an external E-Stop connection that will bring halt all motorized movements.

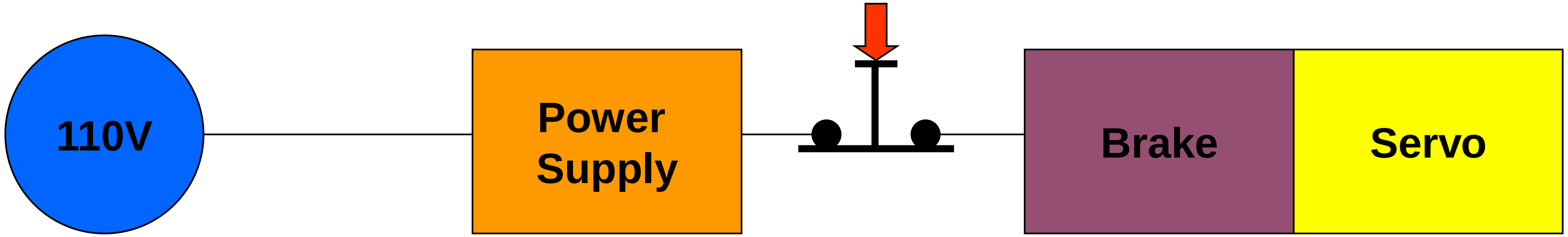
- **Performance** –
  - Rotation
  - Load / unload Tool
  - Idle

TRS Performance - TRS INT 4.0

Option 1



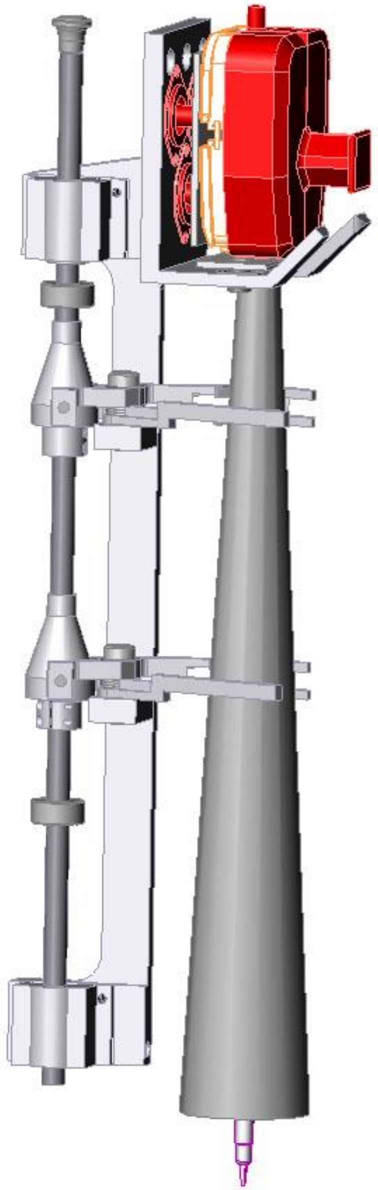
Option 2

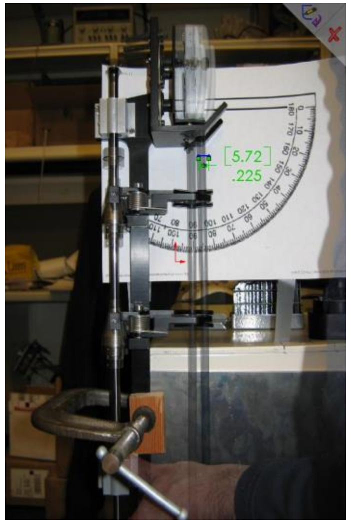


TRS E-Stop

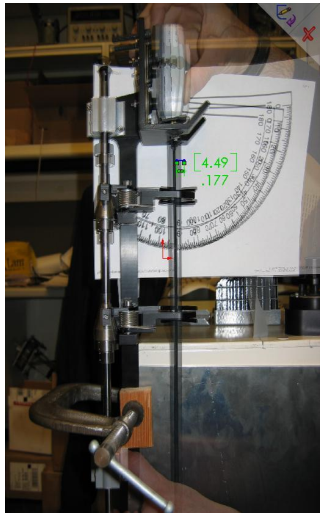
TRS Performance - TRS PER 6.0

- **Requirement** - The TRS shall incorporate passive compliance to accommodate a misalignment with the SNS end-effector of +/-4mm in any direction axes and +/- 2.8 degrees in any rotational axes, while inserting a tool or picking it from the TRS.

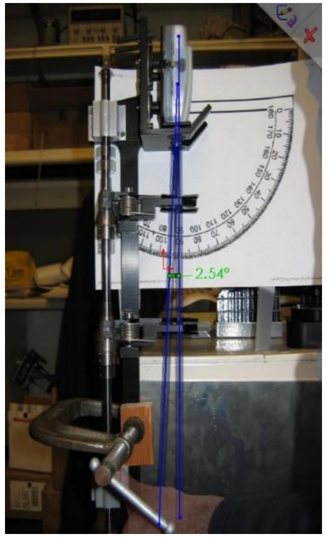




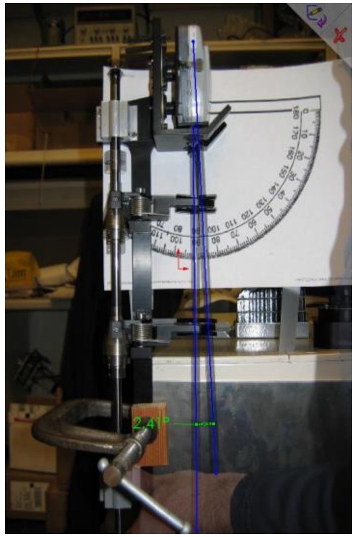
Tool Displacement Forward



Tool Displacement Backward



Tool Rotation Backward



Tool Rotation Forward

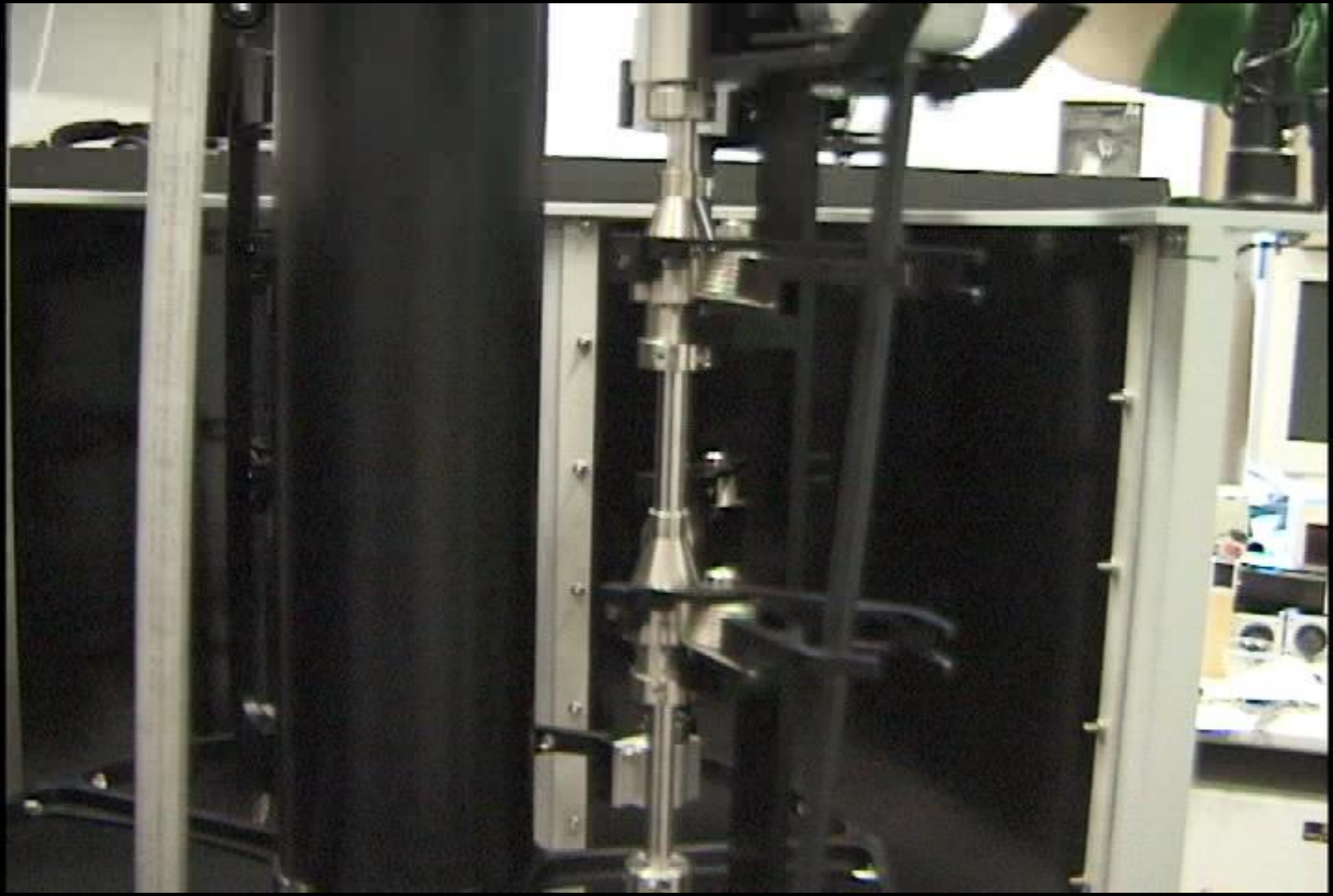
Tool Rotation Left

Tool Misalignment

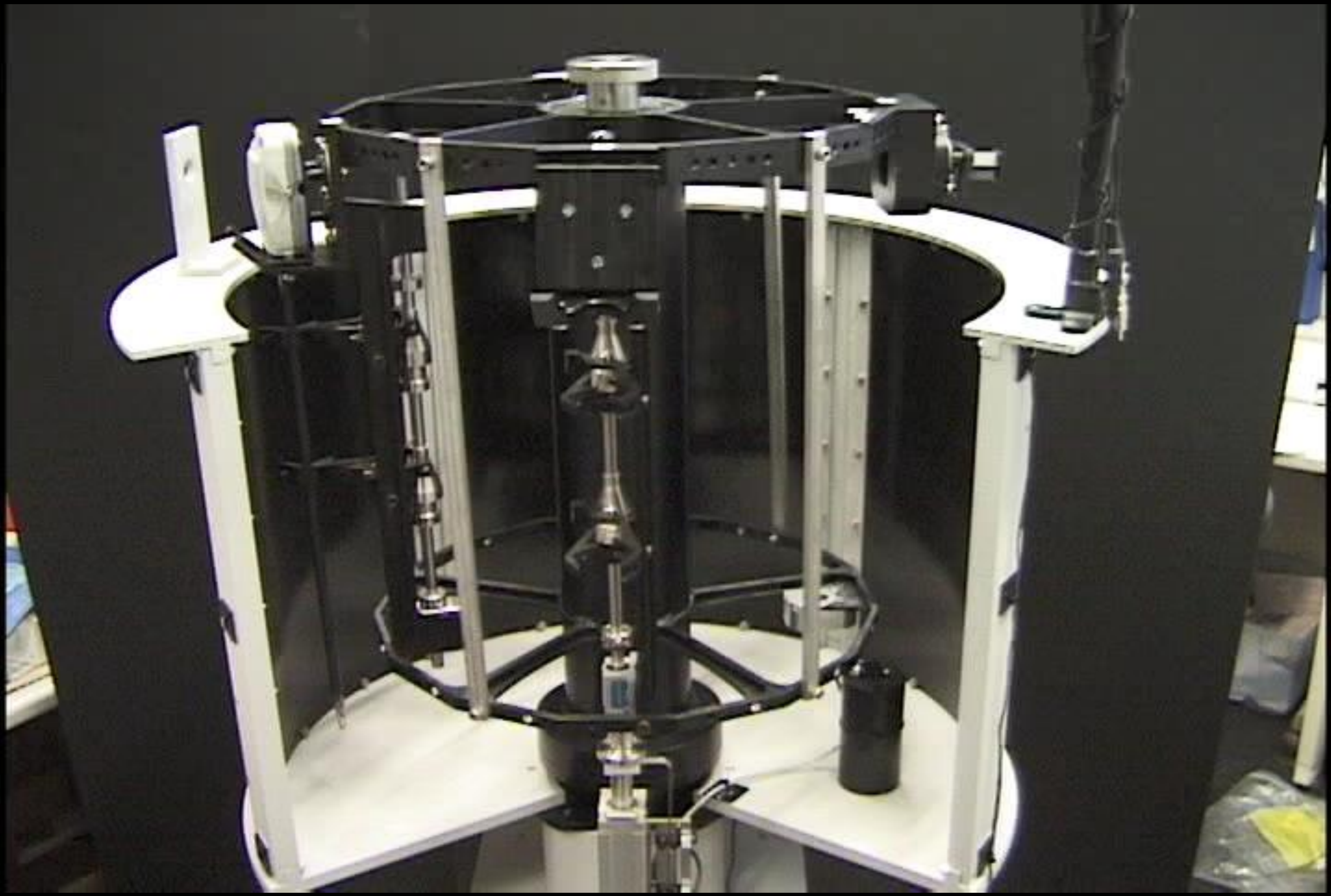
Displacement or Rotation		Specified	Measured
Displaced to the side	$\pm\Delta X$	2 mm	3.10 mm
Displaced Forward	$+\Delta Y$	2 mm	5.72 mm
Displaced Back	$-\Delta Y$	2 mm	4.49 mm
Displaced Down	$-\Delta Z$	2 mm	2.50 mm
Displaced Up	$+\Delta Z$	2 mm	Unlimited
Rotated Forward	$+\Delta\theta_x$	1.4 deg	2.41 deg
Rotated Back	$-\Delta\theta_x$	1.4 deg	5.21 deg
Rotated Left/Right	$\pm\Delta\theta_y$	1.4 deg	2.39 deg
Rotated Along the Shaft	$\pm\Delta\theta_Z$	1.4 deg	21 deg

UCLA

TRS Tool Misalignments



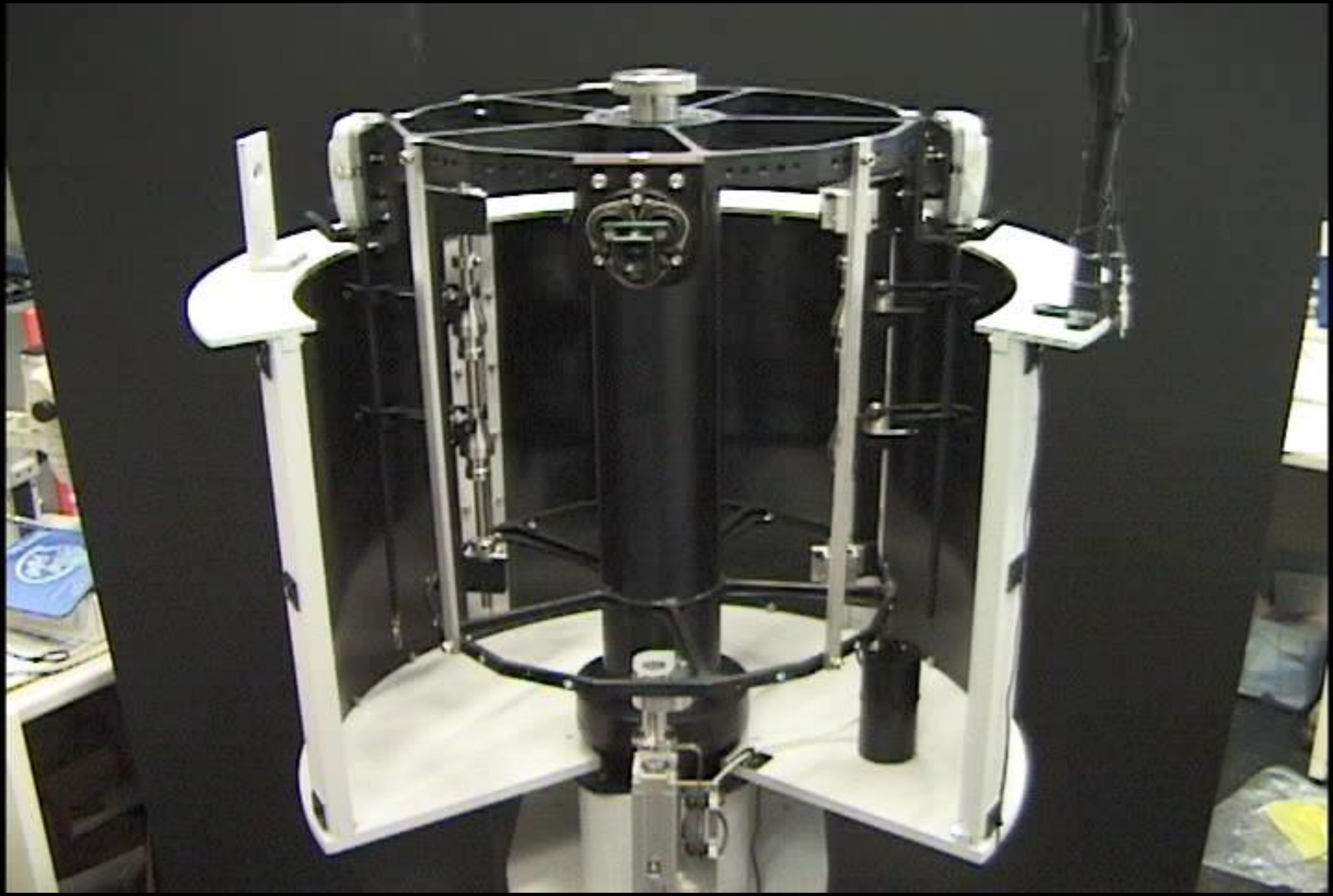
TRS Tool Load - Robustness



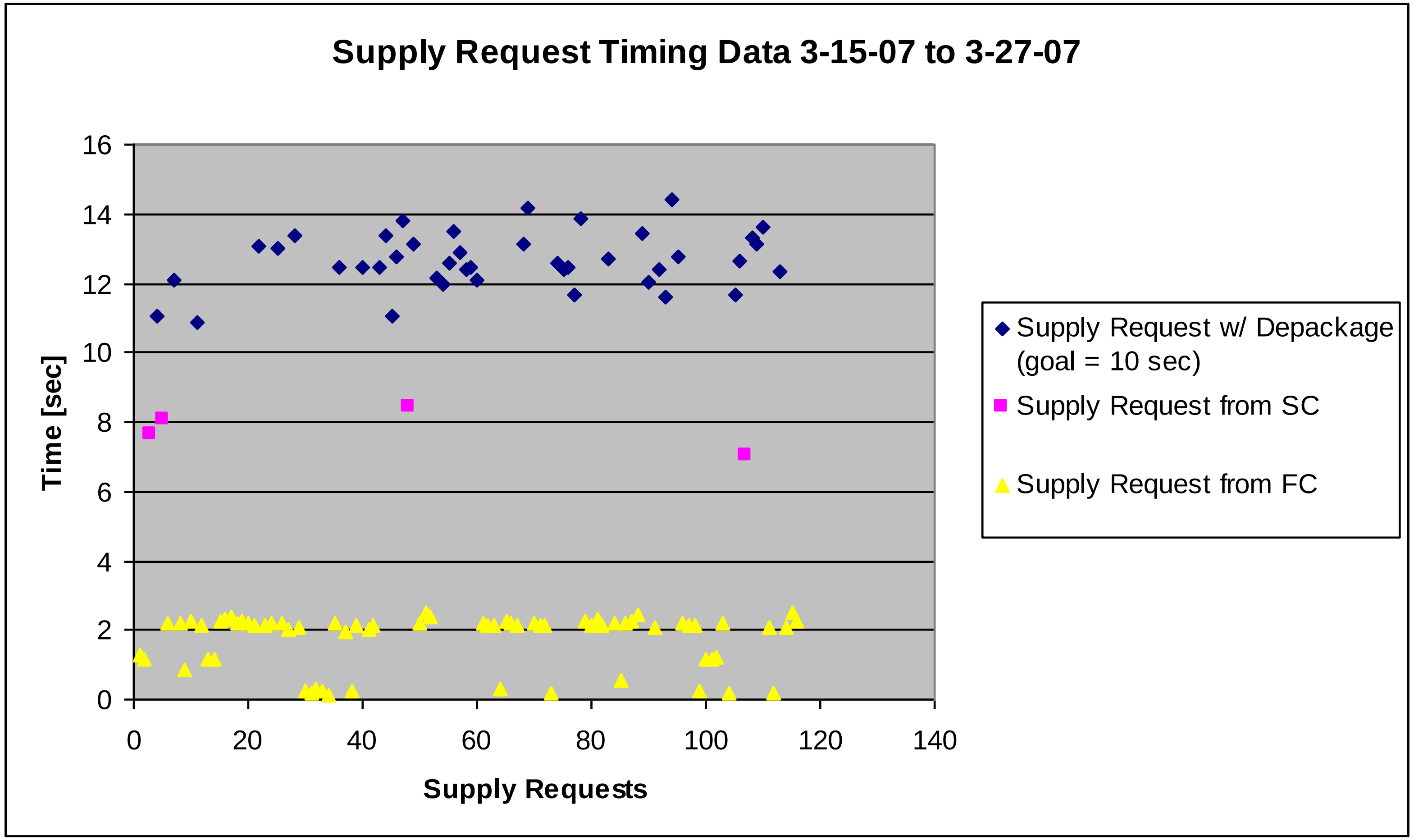
TRS Performance - TRS FUN 7.0

- **Requirement** - The TRS shall be able to sense how many SRS tools there are, location of specific tools and whether they have been used.

TRS RFID Reading Sequence

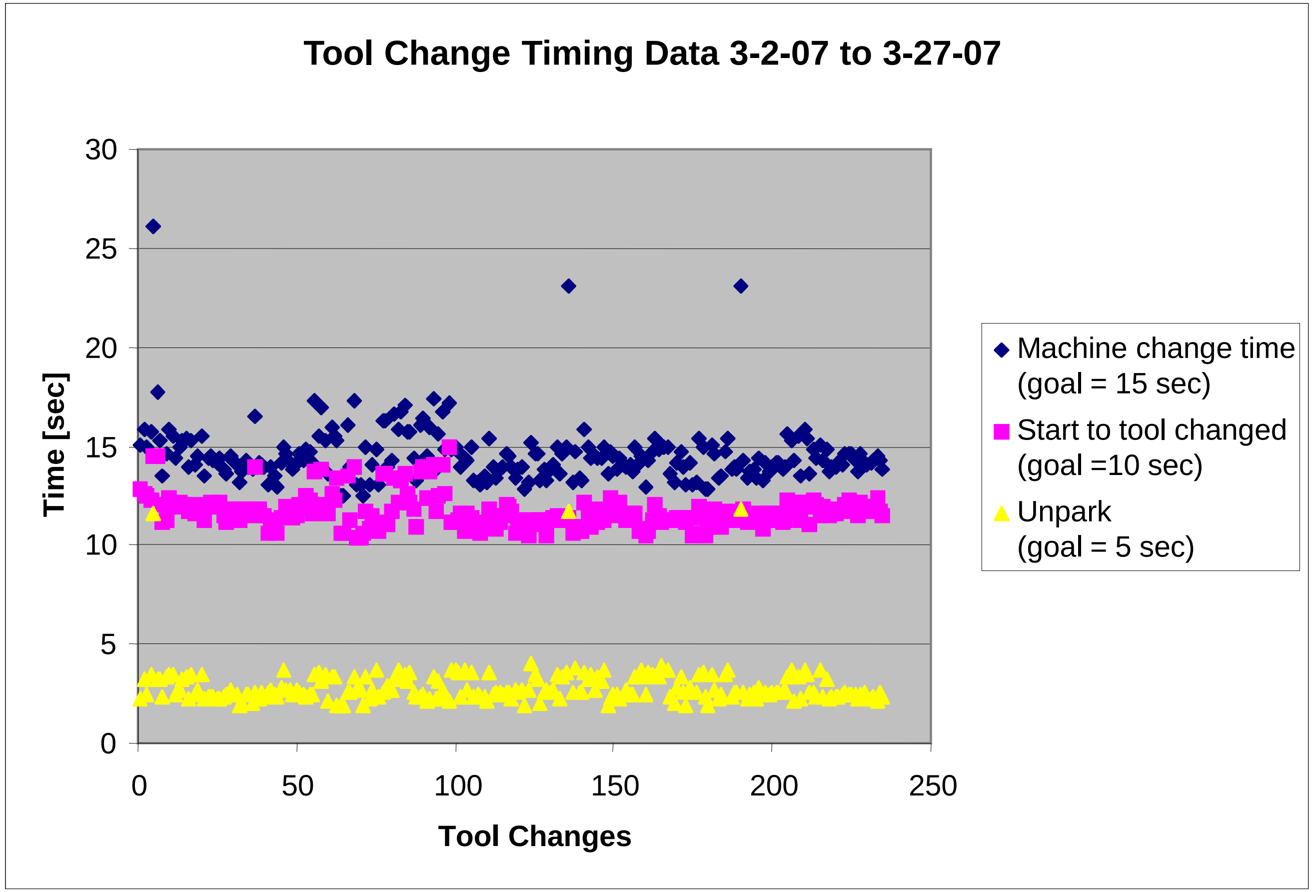


Supply Dispensing Time –Cumulative



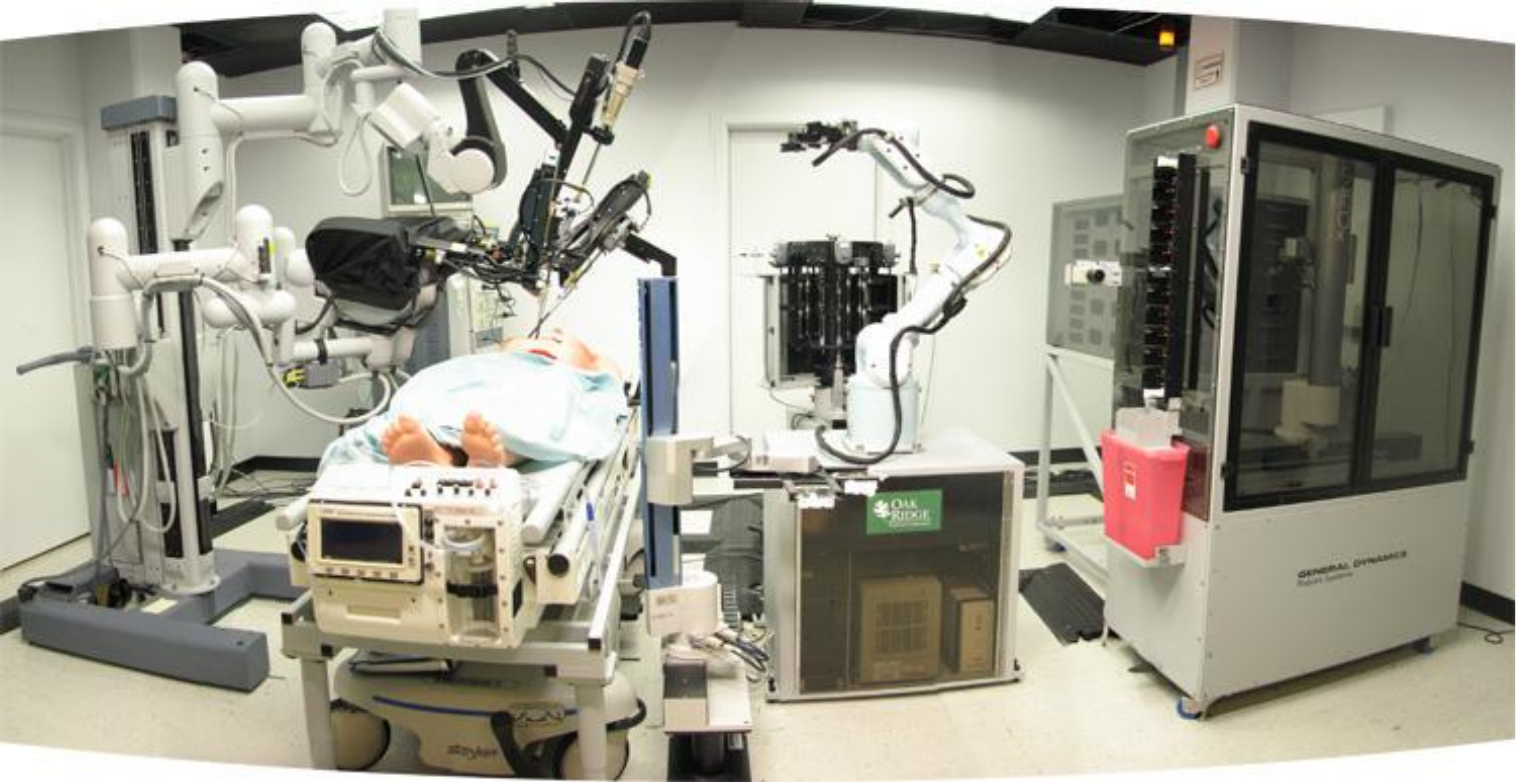
UCLA

Tool Change Time - Cumulative



High Level Requirements – Deliverable (Phase 1)

Deliverable	Status
Development of a robotic cell tele-surgical system the can perform a portion of a surgical procedure without nurses	Demonstrated basic surgical tasks
Demonstrate tool change and supply delivery within 10sec	Tool change 11sec; Supply delivery 5-12sec

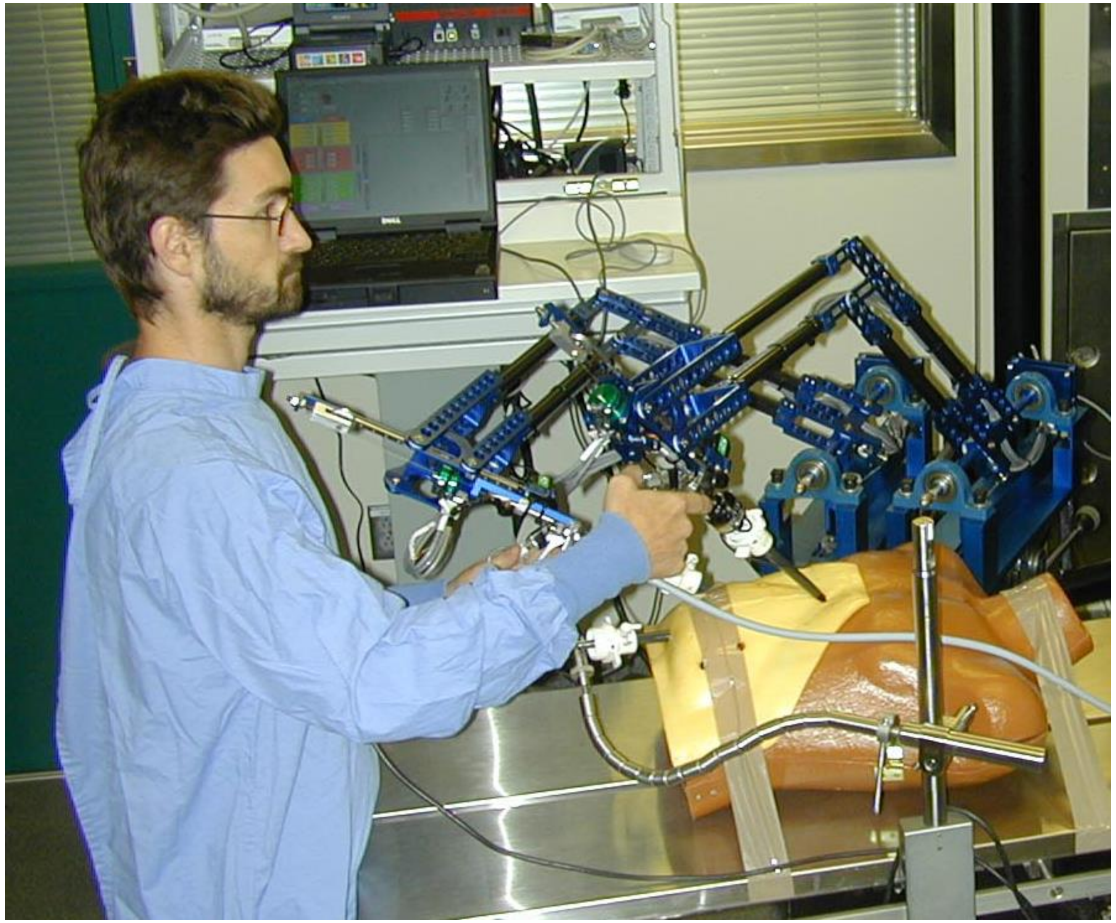

OAK RIDGE
GENERAL DYNAMICS
stryker


SRI

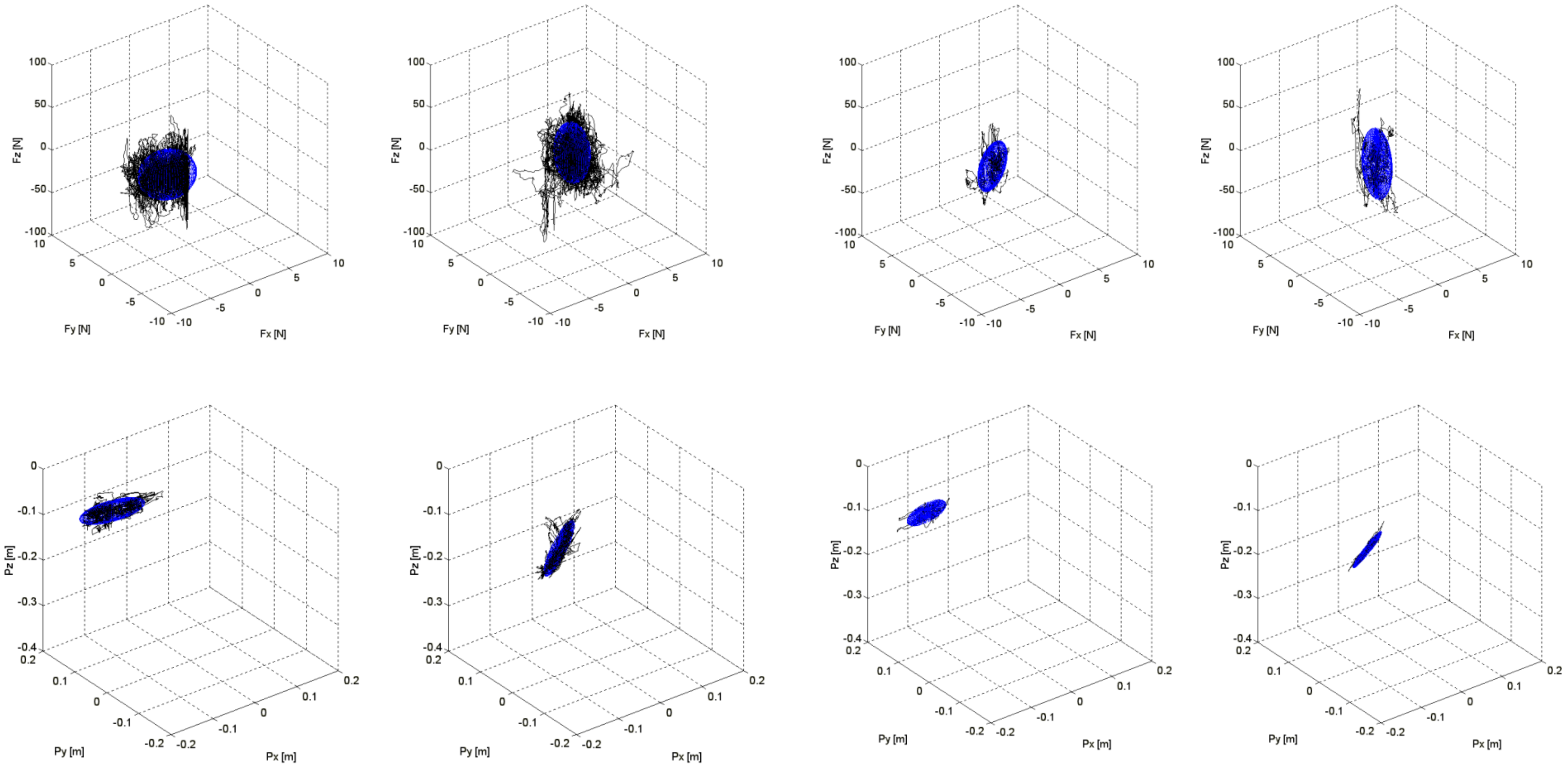
	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

The Blue Dragon



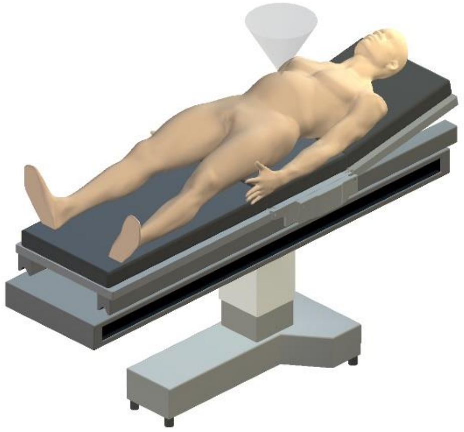
BlueDRAGON - Data



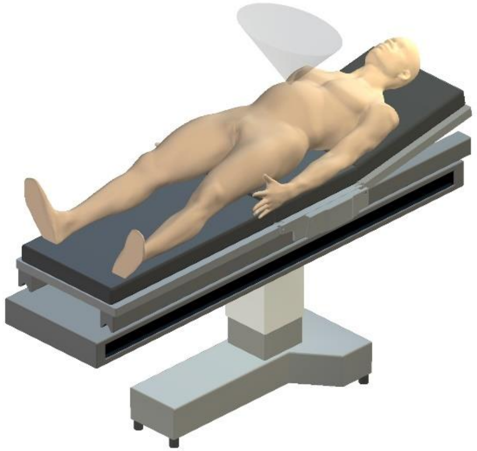
UCLA

Mechanism Kinematic Optimization

- Dexterous Work Space (DWS)
  - High dexterity region defined by a right circular cone with a vertex angel of 60º
  - Contains 95% of the tool motions based on in-vivo measurements.



- Extended Dexterous Work Space (EDWS)
  - The workspace required to reach the entire abdominal cavity with MIS instruments and defined by a cone with an elliptical cross section created by two orthogonal vertex angels of 60º and 90º.

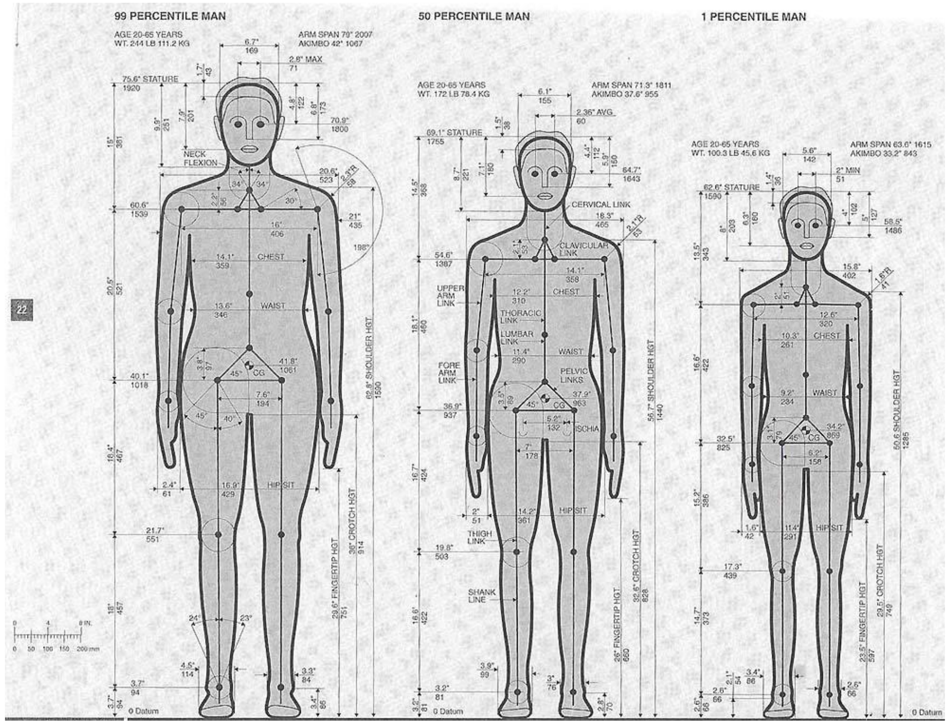


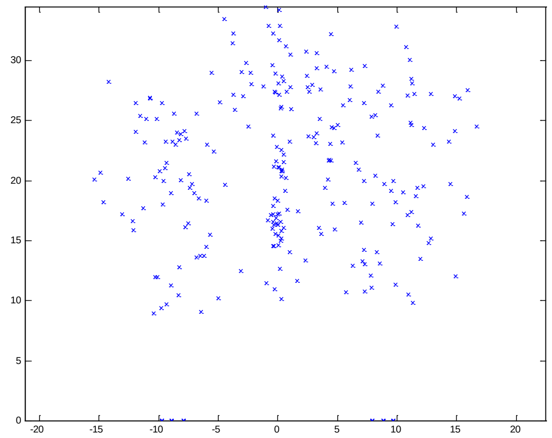
Engineering Specifications - BlueDRAGON

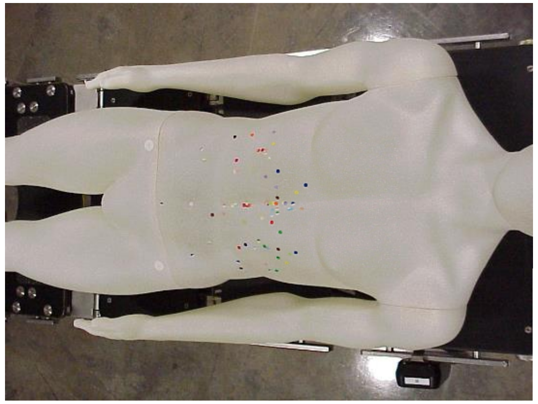
Device				DRAGON	UC Berkeley	UC Berkeley	UC Berkeley	DeVinchi	Zeus
Generation				R1 - E (95%)		1	2		
Referance					Measured	Traget	Obtained		
Base	Overall Geomtery	Shaft Diameter	[m]			0.01 - 0.015	0.01 - 0.015	0.01	0.005
	Position / Oriantataion	Delta Theta x	[Deg]	53.8047				+/-60	
		Delta Theta y	[Deg]	36.3807				+/-80	
		Delta Theta z	[Deg]	148.0986	90	180-270	720	+/-180	
		R	[m]	0.1027				0.2	
		Grasping Jaw s	[Deg]	24.0819				200	
		Grasping Jaw s	[m]	*	0.006	0.002-0.003	0.008 min		
		Delta X	[m]	0.1026					
		Delta Y	[m]	0.0815					
		Delta Z	[m]	0.0877					
	Velocity (Angular Linear)	Wx	[Rad/sec]	0.432					
		Wy	[Rad/sec]	0.486					
		Wz	[Rad/sec]	1.053			9.4 min		
		VR	[m/sec]	0.072					
		Wg	[Rad/sec]	0.0468					
	Force	Fx	[N]	14.7299					
		Fy	[N]	13.1981					
		Fz	[N]	184.3919					
		Fg	[N]	41.6085	15	5 min	40 min		
	Torque	Tx	[Nm]	2.3941					
		Ty	[Nm]	1.6011					
		Tz	[Nm]	0.0464	0.088	0.022			

Port Locations Analysis

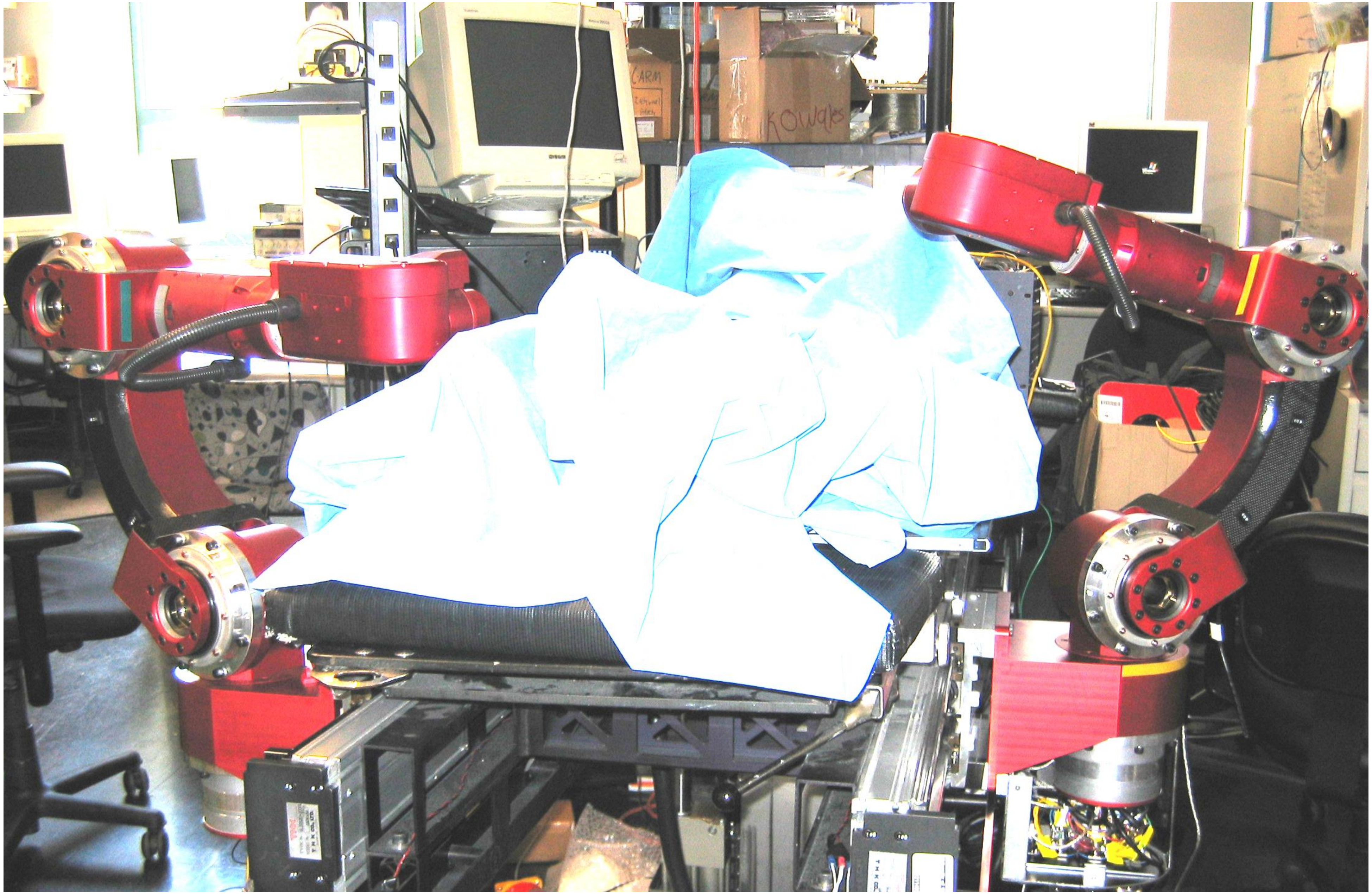
- Aortal Access
- Gastrectomy
- Left and Right Adrenalectomy
- Cholesystectomy
- Nissen Fundoplication
- Liver Access
- Left Nephrectomy
- Pelvic Access
- Colon
- Small Bowel Resection





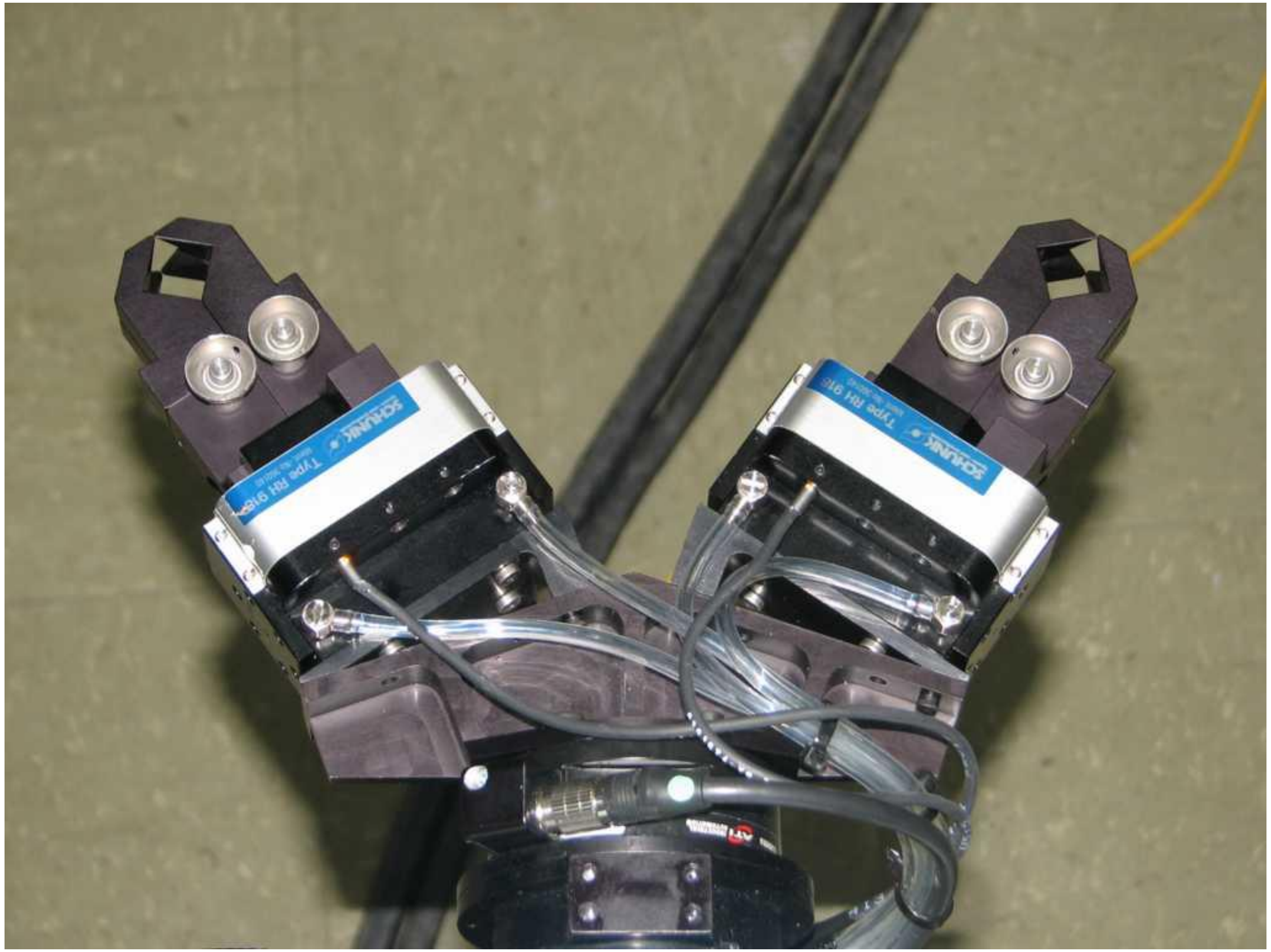


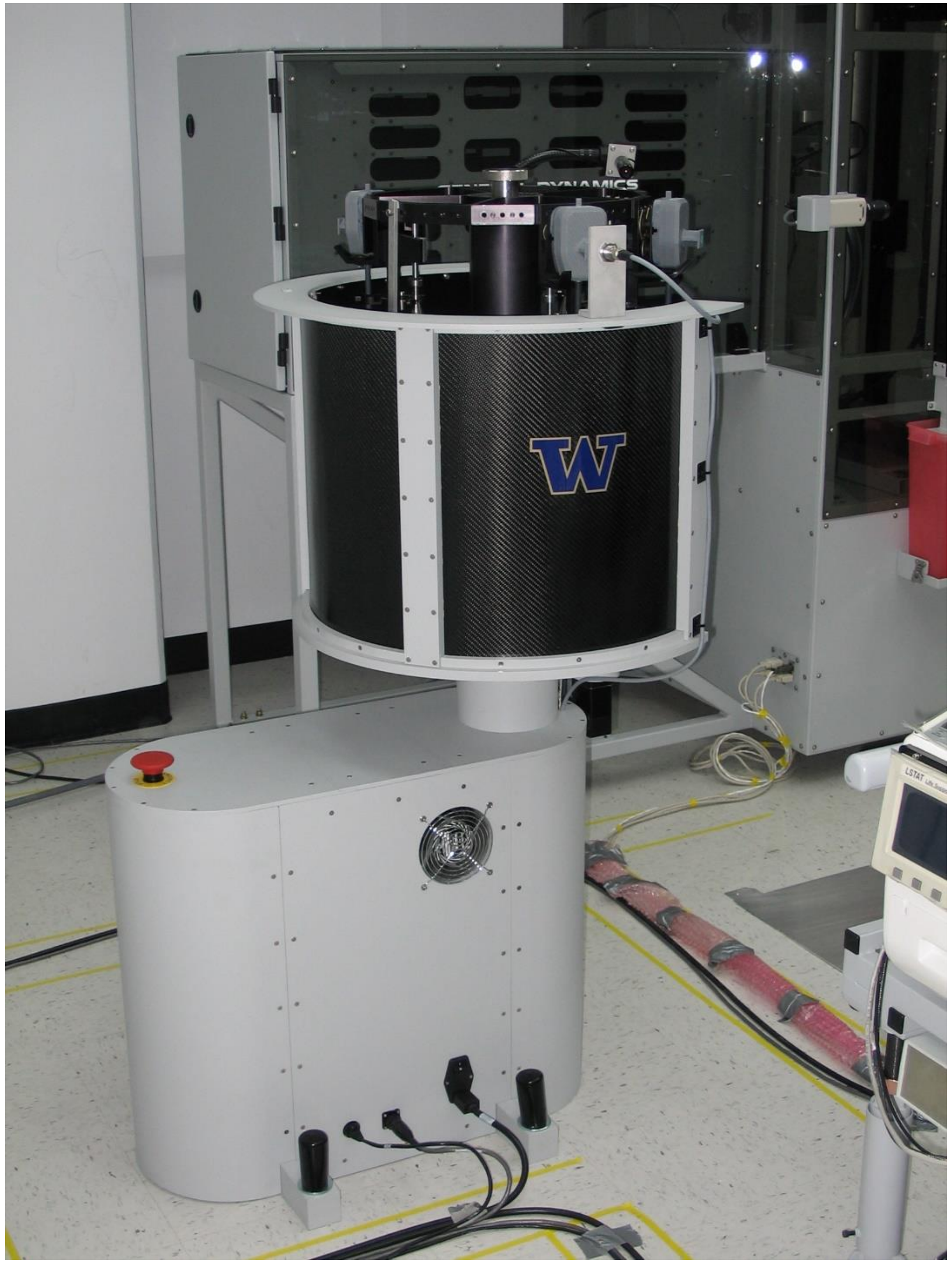
UCLA



UCLA

Scrub Nurse - End Effector





UCLA

Publications

- [CP30] Friedman Diana, Jesse Dosher, Timothy M. Kowalewski, Jacob Rosen, Blake Hannaford, Automated Tool Handling for the Trauma pod Surgical Robot, International Conference of Robotics and Automation (ICRA 07), Rome, Italy
- [JP20] Pablo Garcia, Jacob Rosen, Chetan Kapoor, Mark Noakes, Greg Elbert, Michael Treat, Tim Ganous, Matt Hanson, Joe Manak, Chris Hasser, David Rohler, Richard Satava, Trauma Pod: a semi-automated telerobotic surgical system, The International Journal of Medical Robotics and Computer Assisted Surgery, Vol. 5, No. 2, pp. 136-146, June, 2009

The Follow-ups and The Aftermath

Operation @ Home Appendectomy Kit

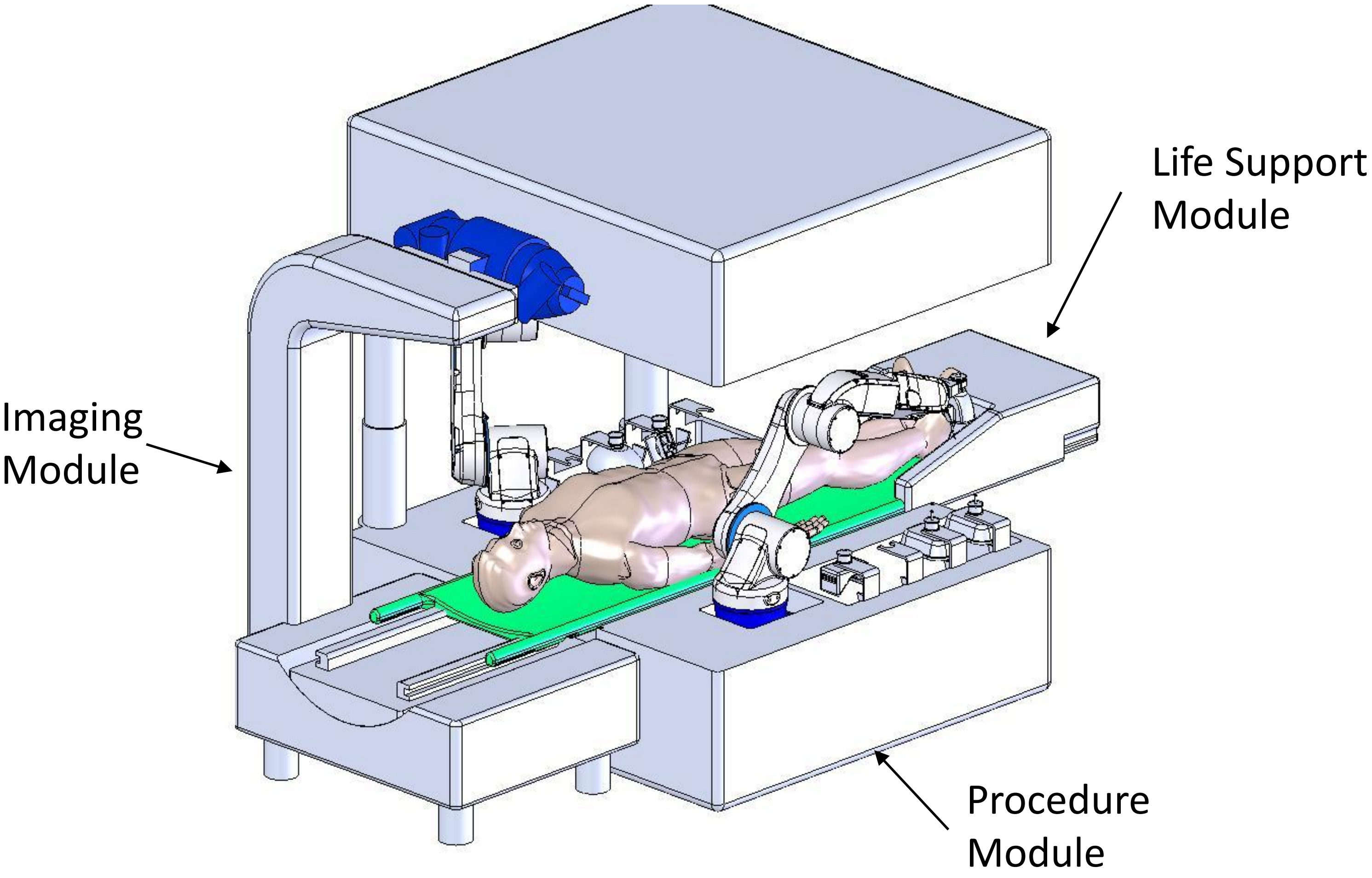
Real Surgery Performed Telerobotically by Real Surgeons at Half the Price!

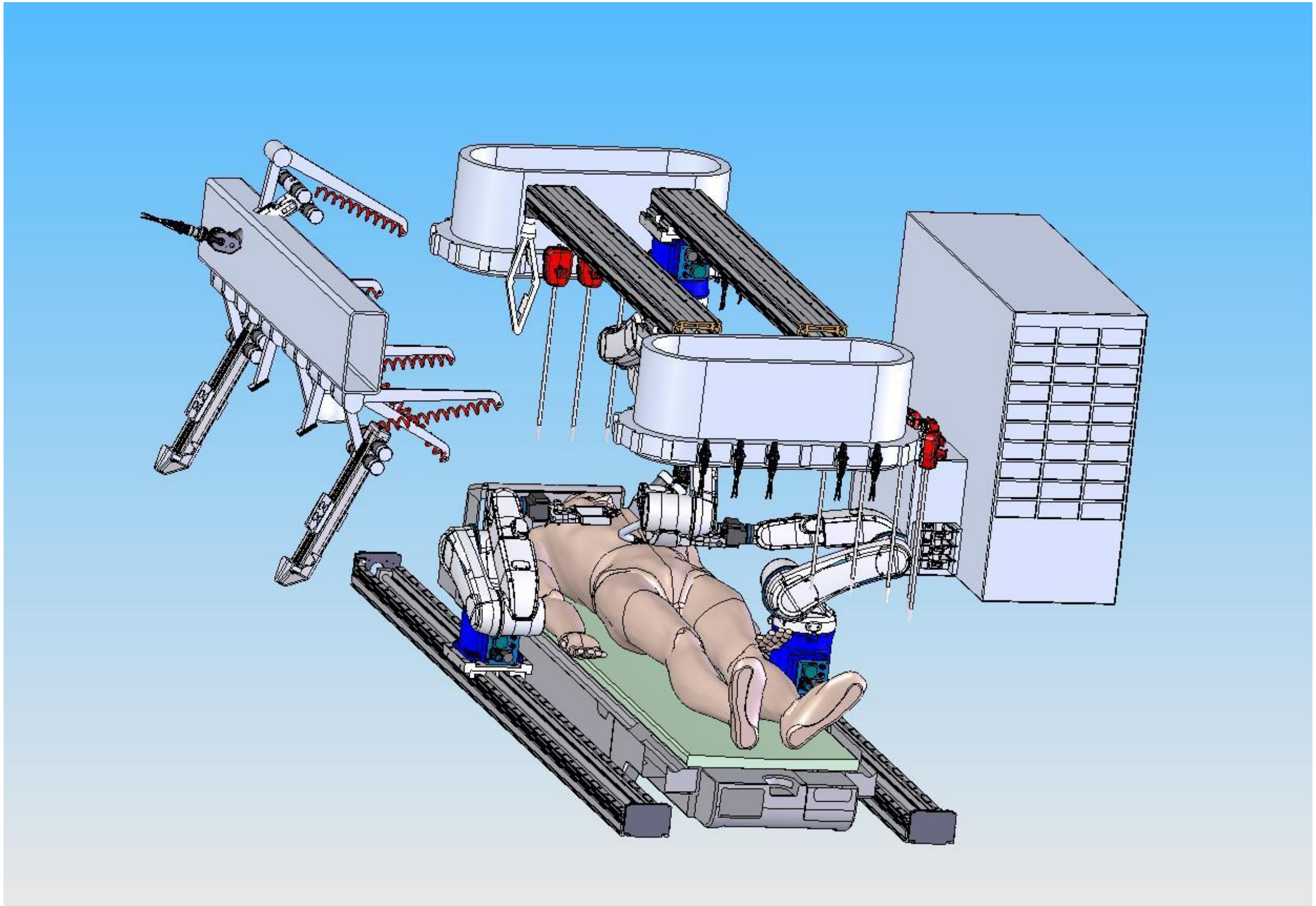
30% Lower Infection Rate Then Hospitals

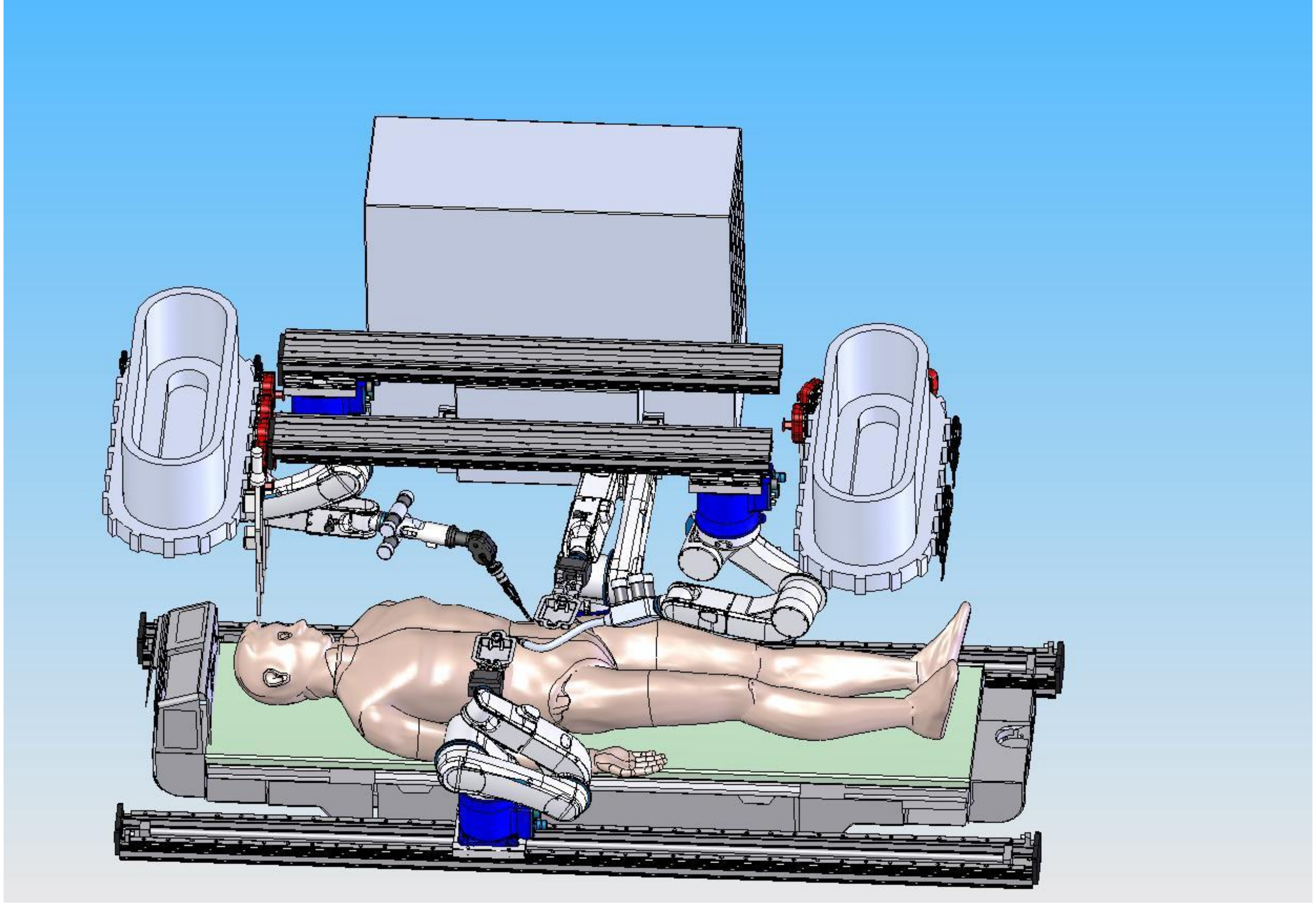
Wired Magazine - January 2005

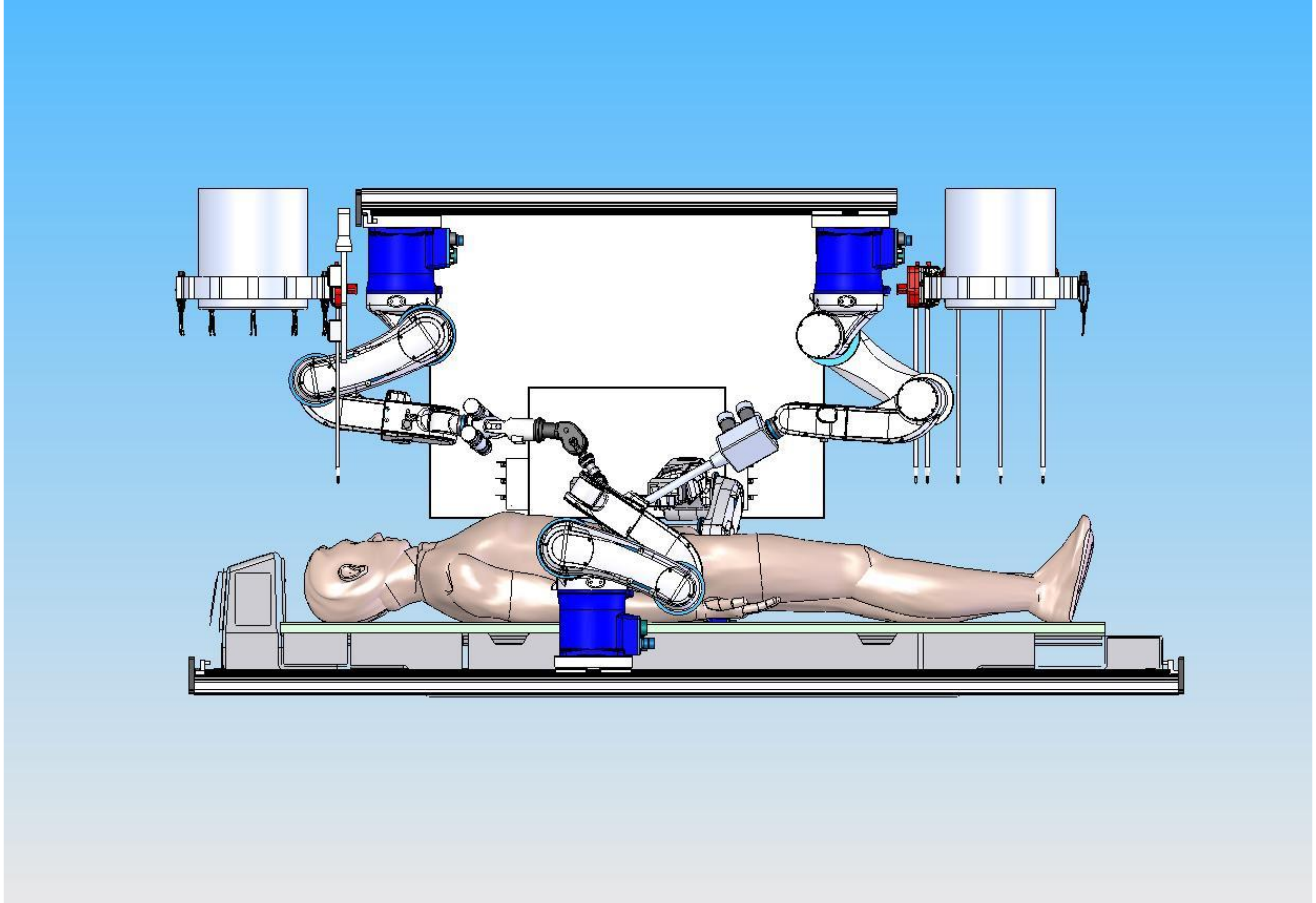
Trauma Pod – Phase II

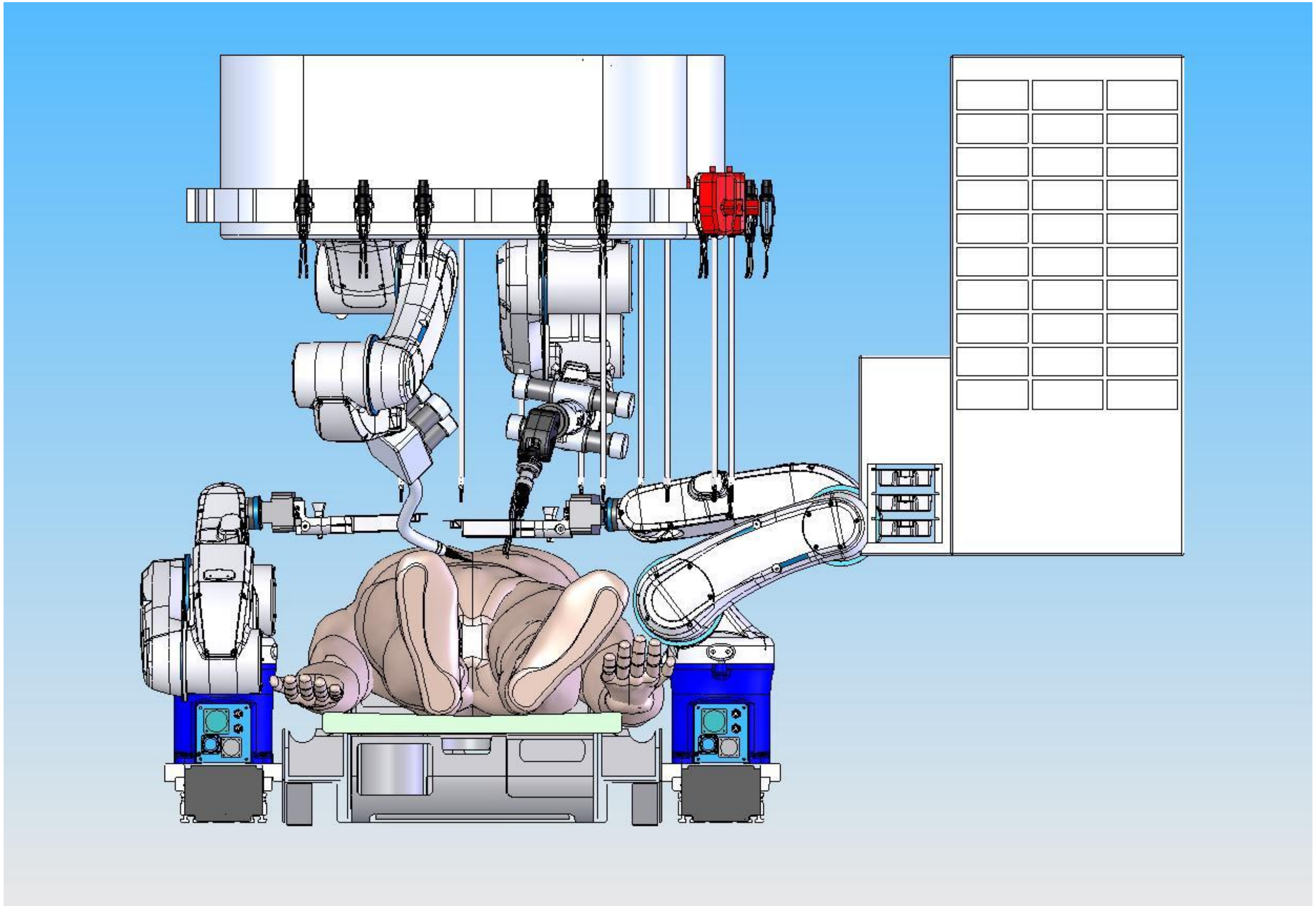
Vision for Phase II

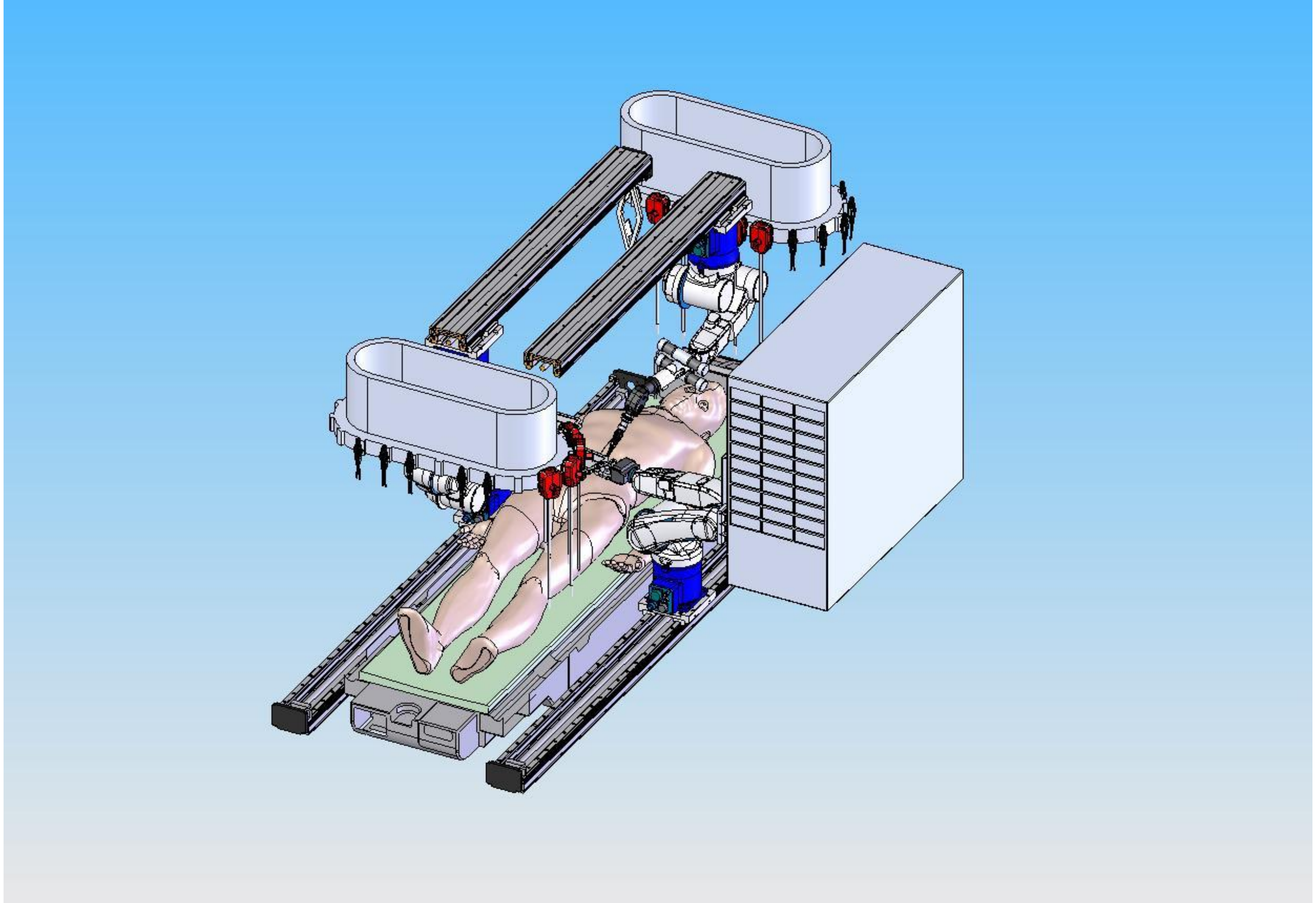


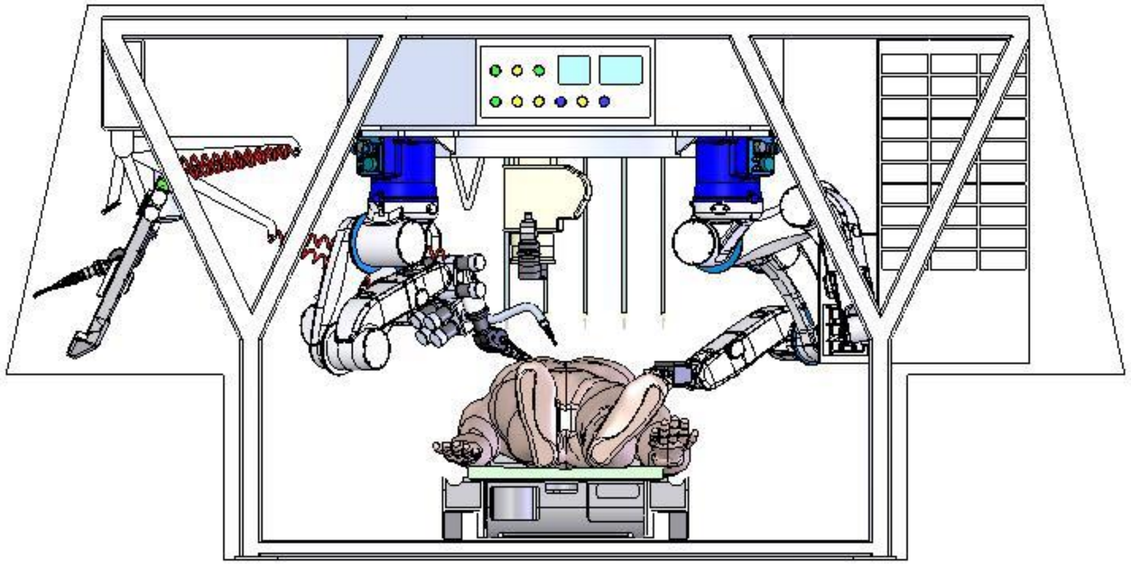


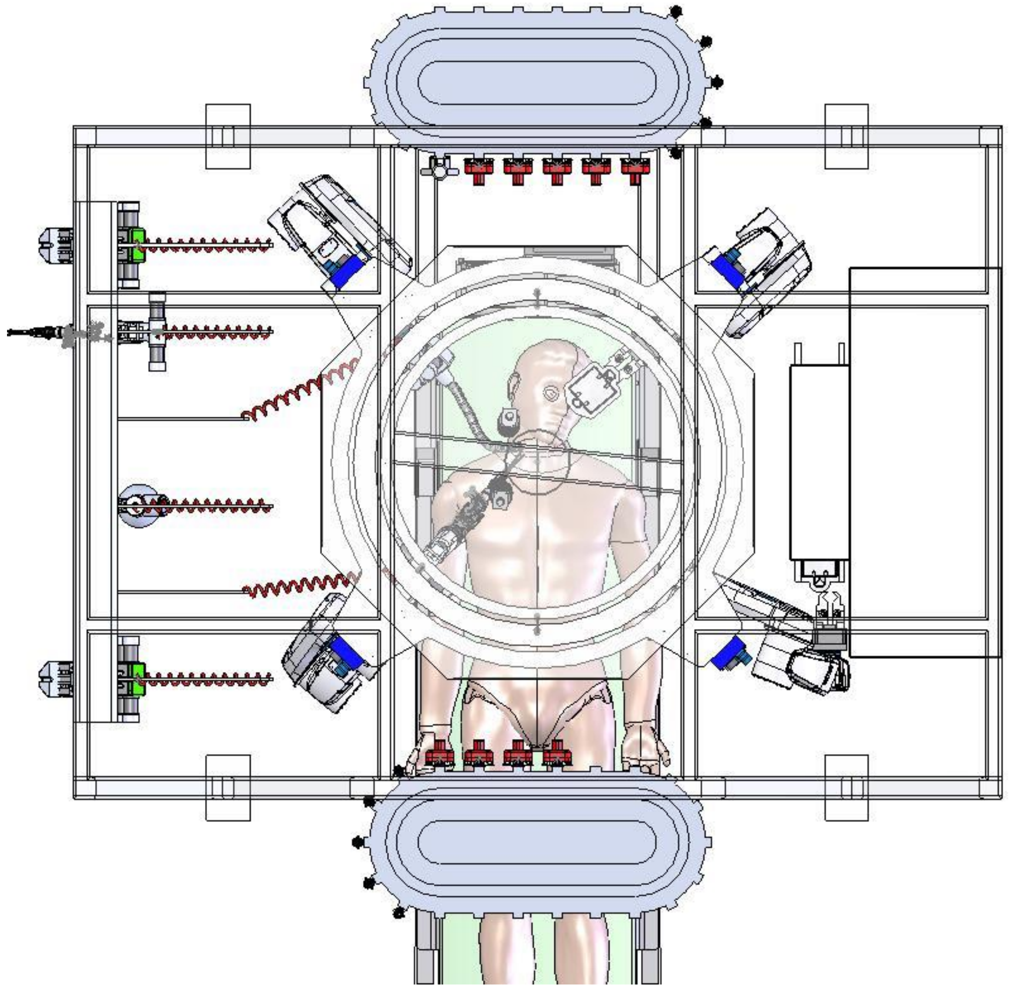


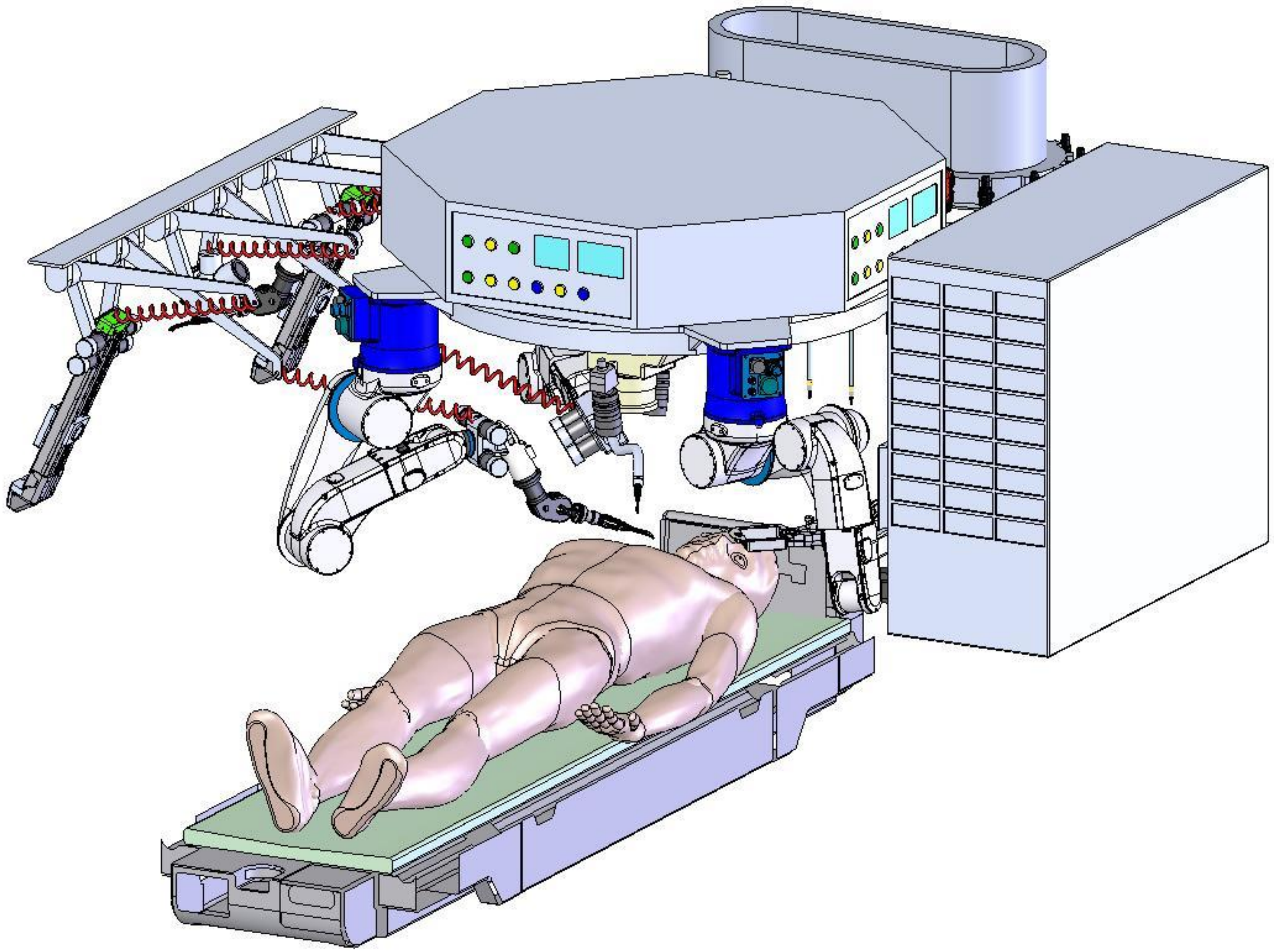








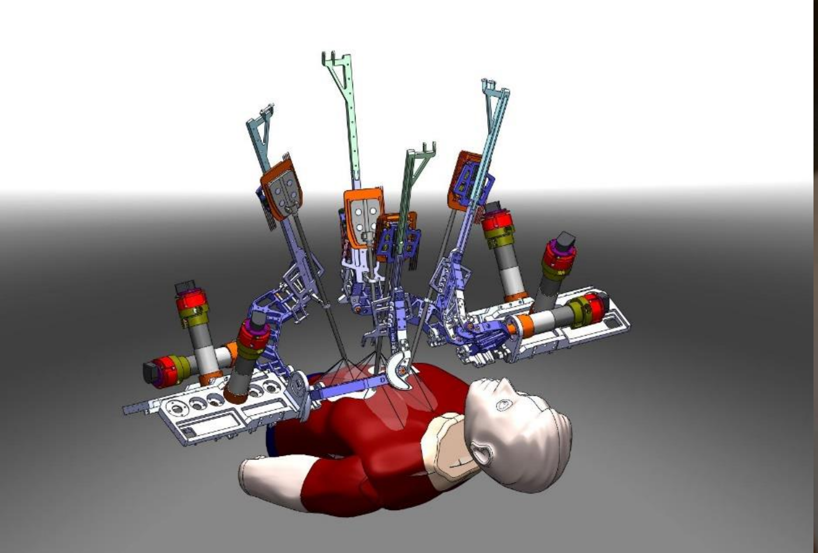




UCLA

Raven IV


MARYLAND
BIPOLAR
FORCEPS
7
6
2
0937 A
HEDM-5540 B02



Automation in Surgery