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## **Robot Control for Medical Applications and Hair Transplantation**

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# MEDICAL ROBOTICS

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## × Telerobotics

- + Intuitive Surgical – Laparoscopic surgery
- + Hansen Medical – Catheter guidance

## × Robot Assist

- + Mako Surgical – Orthopedic surgery

## × Fully Automated

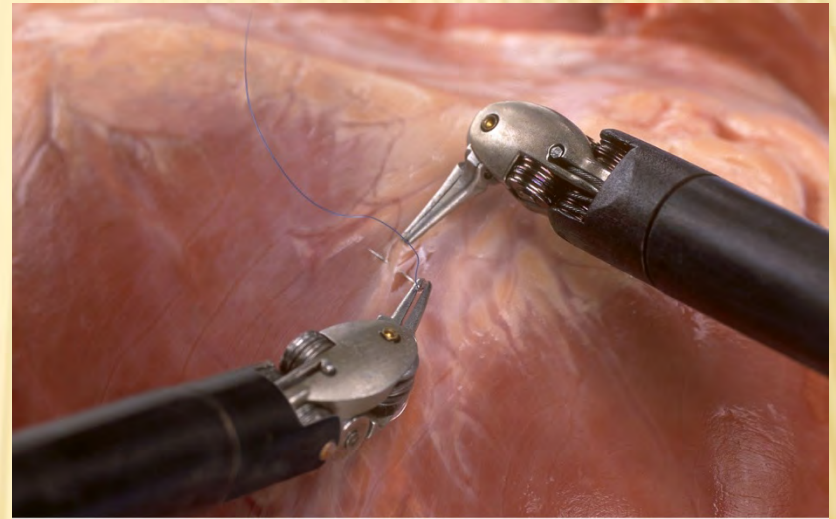
- + Accuray – RadioSurgery
- + Restoration Robotics – Hair Transplantation

# LAPAROSCOPIC SURGERY

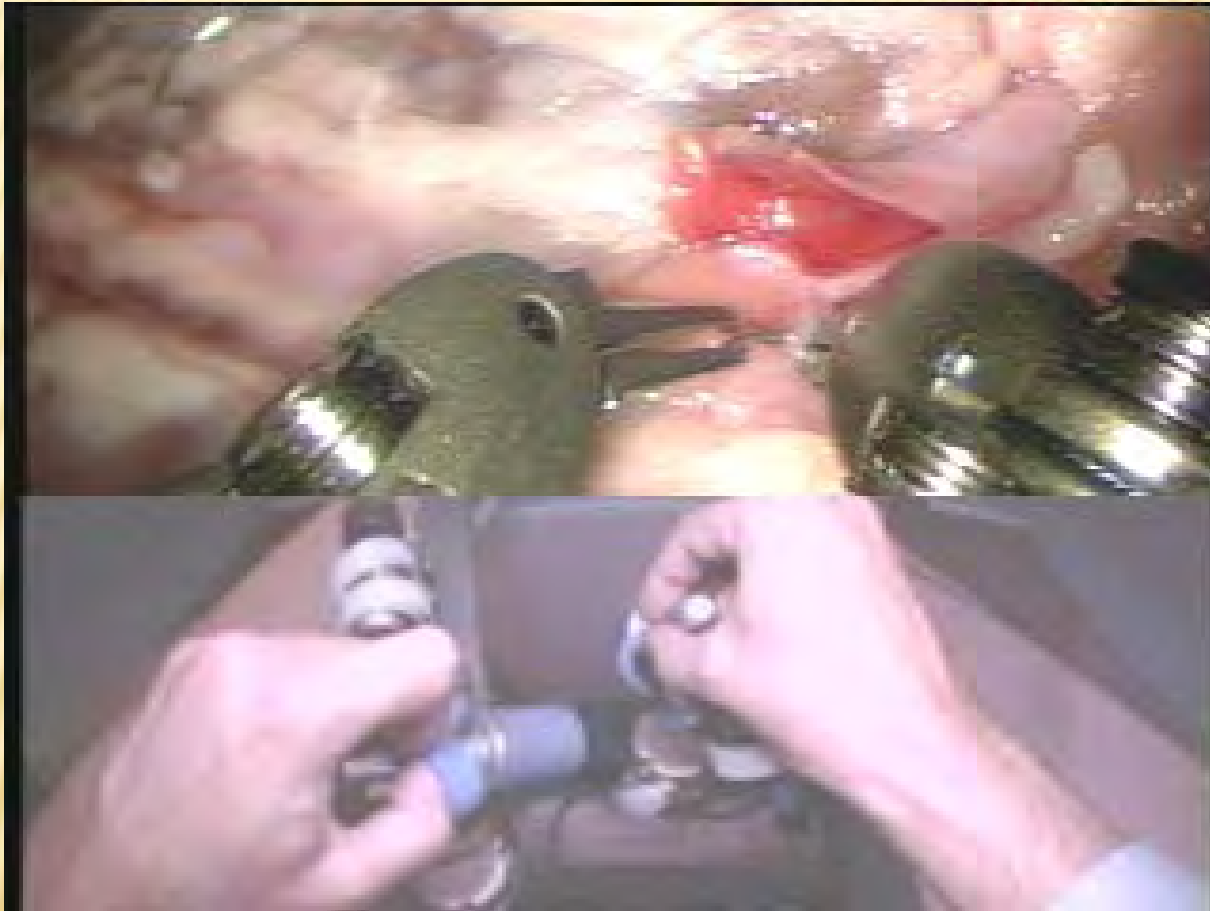
- ✘ Company: Intuitive Surgical, Sunnyvale, CA
- ✘ Product: Da Vinci
- ✘ Teleoperated
- ✘ Multiple Robotic arms
- ✘ Various instruments



# DA VINCI SURGICAL ROBOT SYSTEM

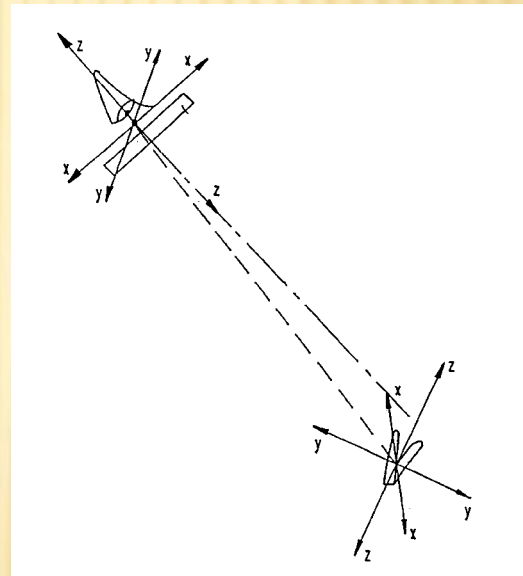


# SUTURING WITH DA VINCI

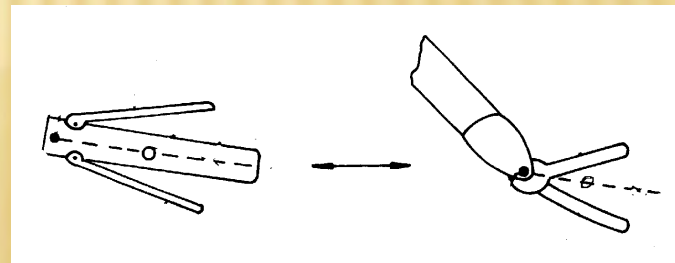


# DA VINCI – WHY “INTUITIVE”?

- ✘ 3x3 rotation matrix from camera to tool tip is identical to 3x3 rotation matrix from eye to handle.

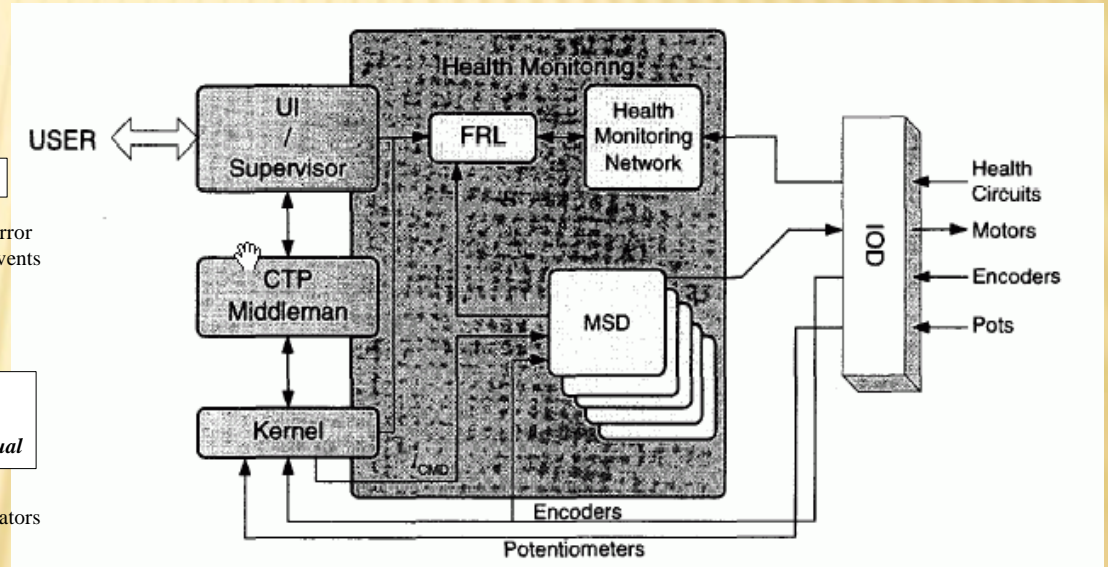
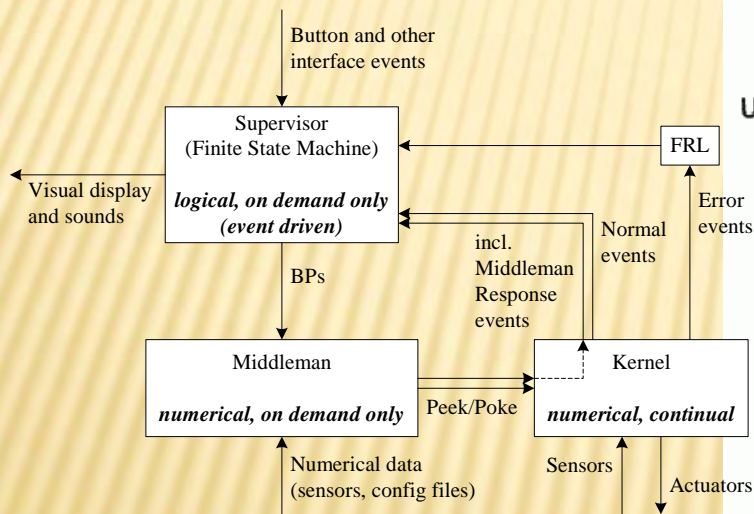


$$\begin{matrix} \langle \text{CAMERA} \rangle \\ \langle \text{TOOL TIP} \rangle \end{matrix} R = \begin{matrix} \langle \text{EYE} \rangle \\ \langle \text{HANDLE} \rangle \end{matrix} R$$



# DA VINCI: PERFORMANCE & RELIABILITY

- Finite state machine controls UI and app logic for reliable operation.
- Low-level high-performance distributed control systems.



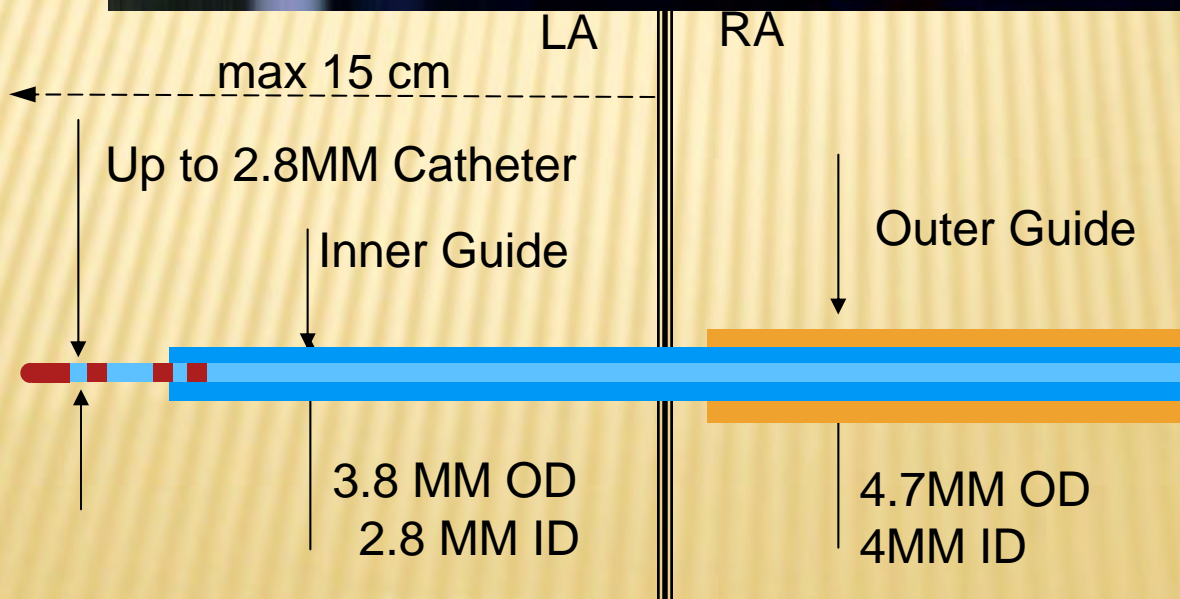
# CATHETER GUIDANCE

- ✘ Company: Hansen Medical, Mountain View, CA
- ✘ Product: Sensei Catheter System
- ✘ Teleoperated distal control of catheter





# GYMNASTIC CATHETERIZATION

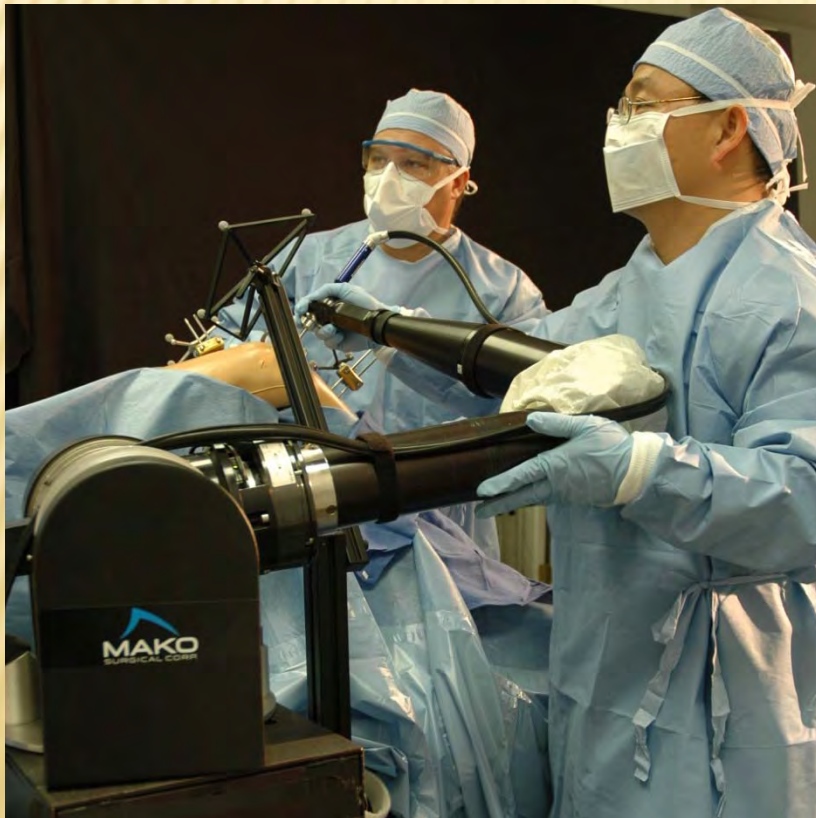


# INSTINCTIVE CATHETER CONTROL



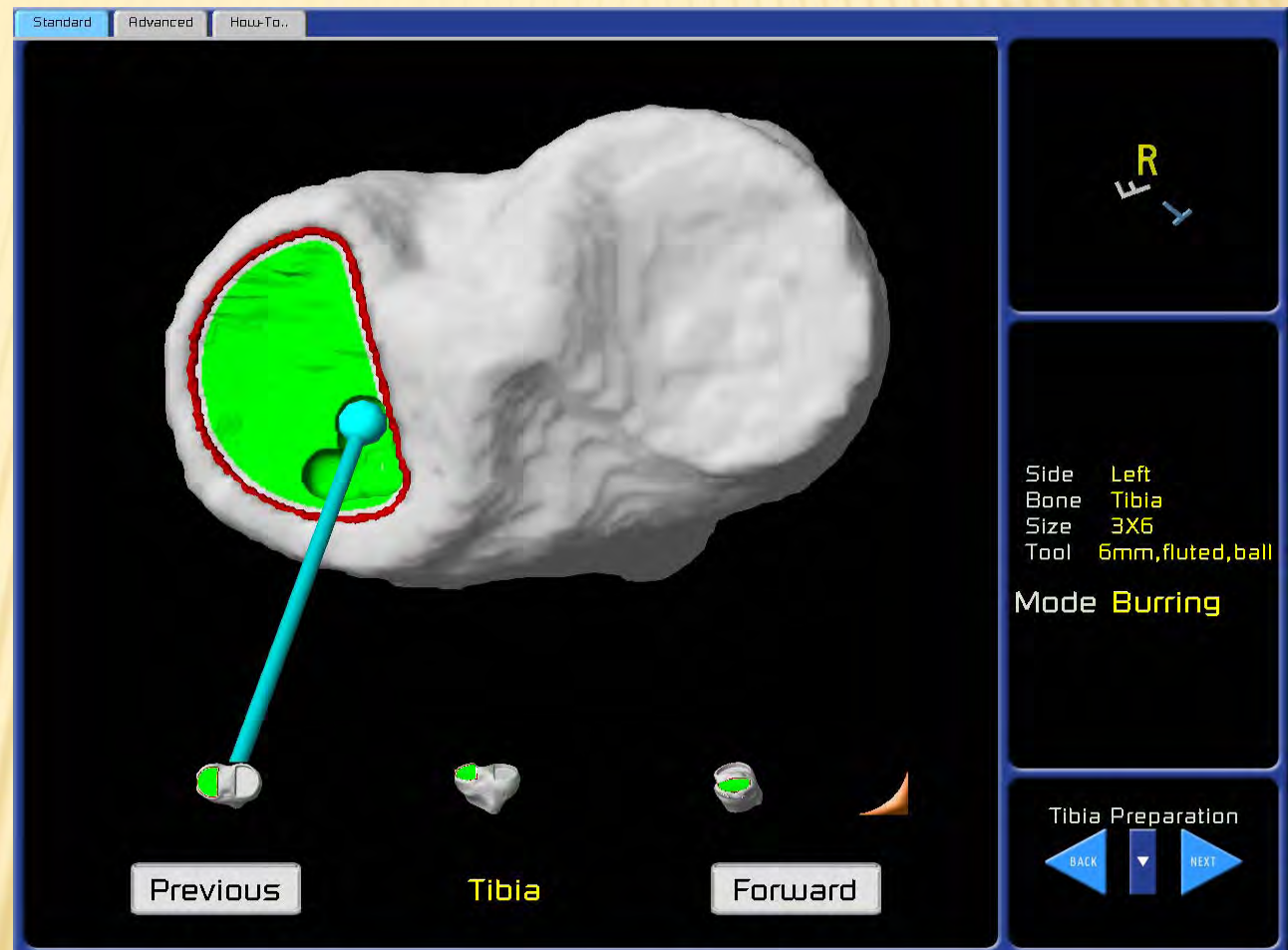
# ORTHOPEDIC SURGERY

- ✘ Company: Mako Surgical, Ft. Lauderdale, FL
- ✘ Robot-assisted jigless partial-knee surgery



# PLANNING AND GUIDANCE

- ✘ Fast recovery
- ✘ Smaller incisions
- ✘ Dynamic planning changes
- ✘ Surgeon assist



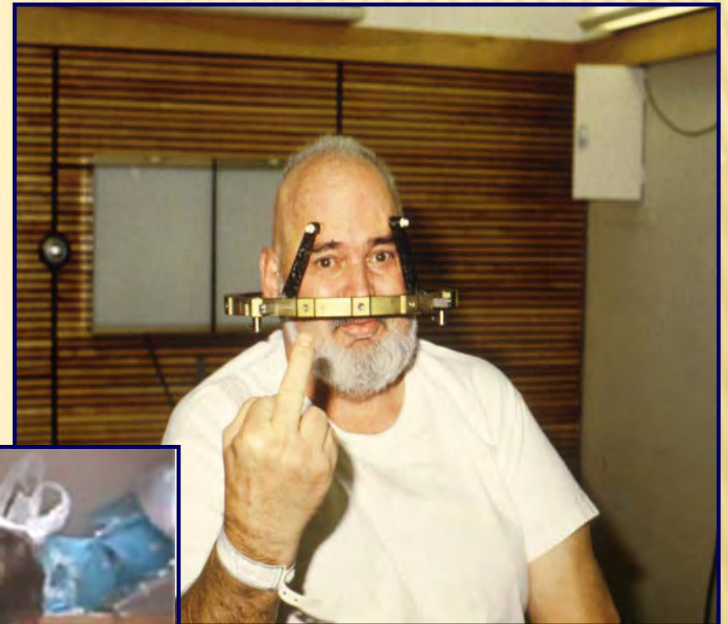
# RADIOSURGERY

- ✘ Company: Accuray, Sunnyvale, CA
- ✘ Product: CyberKnife
- ✘ Noninvasive, fully automated.



# CONVENTIONAL RADIOSURGERY

- ✘ Many beams crossfire
- ✘ Frame based
- ✘ Limited to cranium
- ✘ Isocentric treatments
- ✘ Painful



# CYBERKNIFE RADIOSURGERY SYSTEM



# CYBERKNIFE PROCEDURE

MultiPlan®

Load Fuse Contour Align Plan Visualize Plan QA Settings Help

Setup Isocentric Conformal Evaluate Finetune

Evaluation

- Contour correction
- High resolution
- Calculate

Prescription

Rx Dose (cGy)

Rx (%)

Prescribe

Reference Point

- Use max. dose point
- Dose (cGy)
- Point:
- 
- Set to Cross-Hair Point

Save Plan

Save Plan

Layouts

3D  DVH  3D  A

A  Dose  S  C

Standard Display

ACCURAY®

Target Volume: PTV

584 mm³ 82.00%(3500cGy)Dose\_97.11%Vol

Volume

0 10 20 30 40 50 60 70 80 90 100% Dose

Critical Volume: All Critical Regions

30472 mm³

Volume

0 10 20 30 40 50 60 70 80 90 100% Dose

Soft Tissues

2061409 mm³

Volume

0 10 20 30 40 50 60 70 80 90 100% Dose

Nodes	69	Total MU	7725.43
Beams	79	Min. MU	33.40
Max. Dose(cGy)	4268.29	Max. MU	203.68

Dose Statistic Table

VOI	Min( cGy )	Max( cGy )	CI	nCI	HI	Coverage
Right Eye	0.00	2.97	n/a	n/a	n/a	n/a
PTV	3347.21	4268.29	1.30	1.34	1.22	97.11%
Right Optic N	0.00	21.28	n/a	n/a	n/a	n/a
Left Eye	0.00	1.79	n/a	n/a	n/a	n/a
Left Optic Ne	0.00	0.00	n/a	n/a	n/a	n/a
Optic Chiasr	0.00	23.58	n/a	n/a	n/a	n/a
Brain Stem	0.00	375.22	n/a	n/a	n/a	n/a

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X 225 Y 256 Z 36 Value 1604



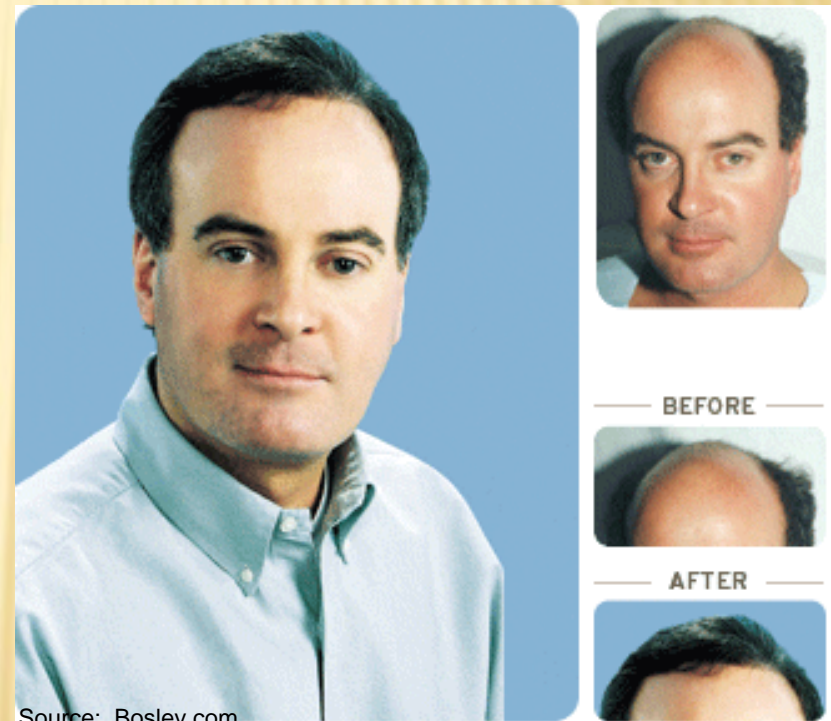
# HAIR TRANSPLANTATION

- ✘ Company: Restoraton Robotics, Mountain View
- ✘ Fully automated hair dissection



# HAIR TRANSPLANTATION IS AN EFFECTIVE PROCEDURE

- ✘ Current techniques are capable of excellent aesthetic, natural results
- ✘ Disadvantages
  - + Labor intensive, tedious, long
  - + Staff recruitment, training, retention
  - + No standardization
  - + Invasive (strip excision)
  - + Stigma of past techniques, results
  - + Limited knowledge of procedure by potential patients
  - + Credibility of hair restoration field



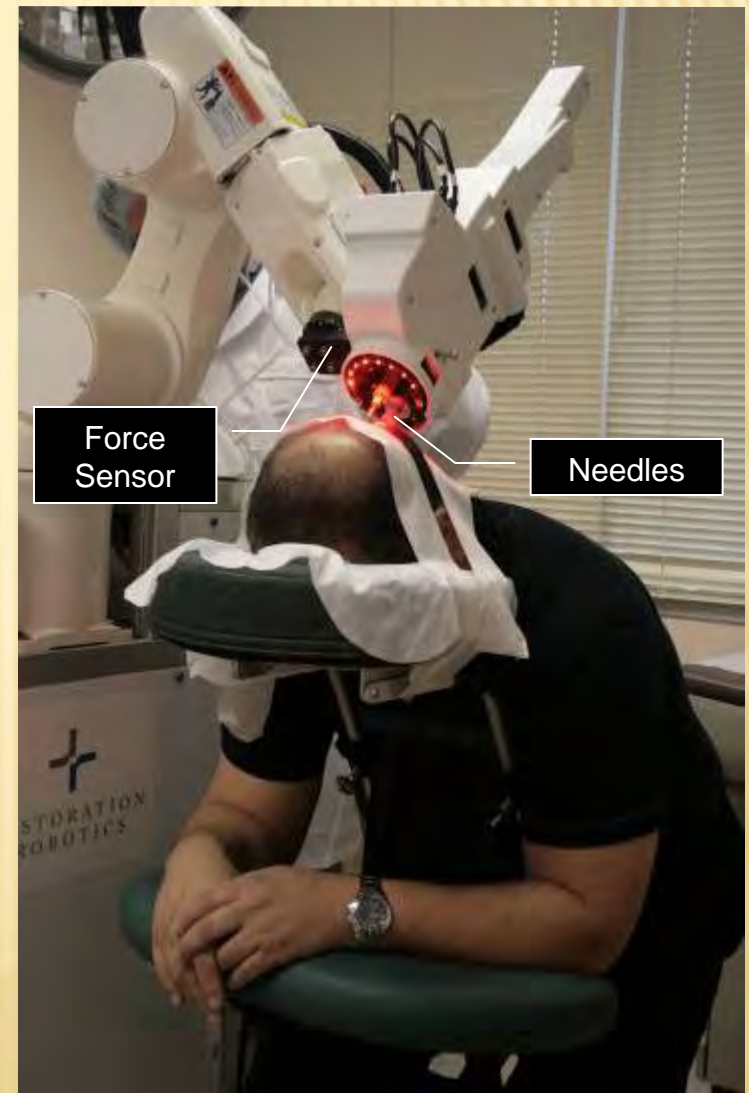
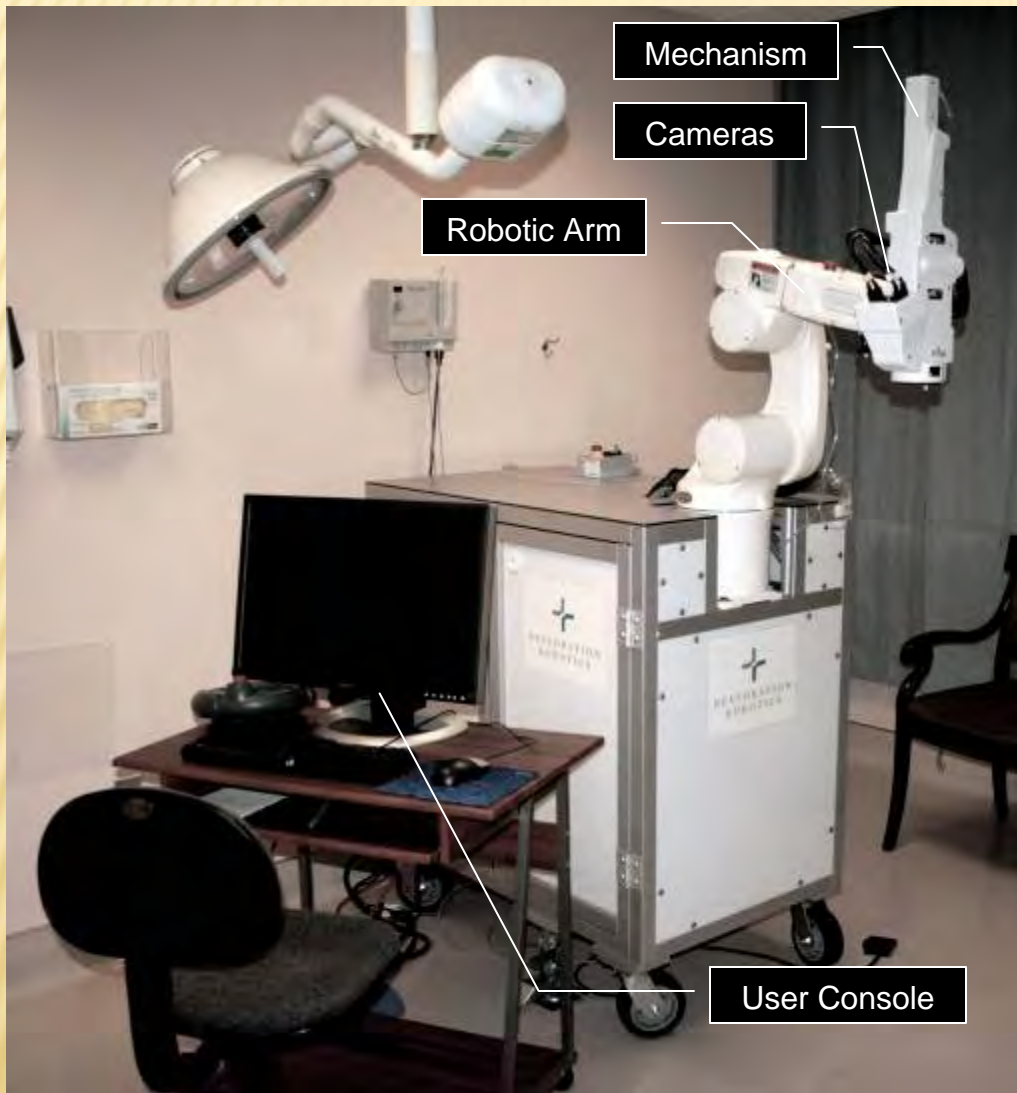
# SHIFT TO FOLLICULAR UNITS IN LATE 1990S

- ✘ More refined approach
- ✘ Hair follicles naturally grow in clusters (F1, F2, F3+) - follicular units (FUs)
- ✘ FU grafts are small (~1mm dia.)
- ✘ Enable an aesthetic approach
  - + F1, F2, F3 distribution
  - + Angles, patterns, spacing of FU implants



Follicular unit grafts

# RESTORATION ROBOTICS TECHNOLOGY

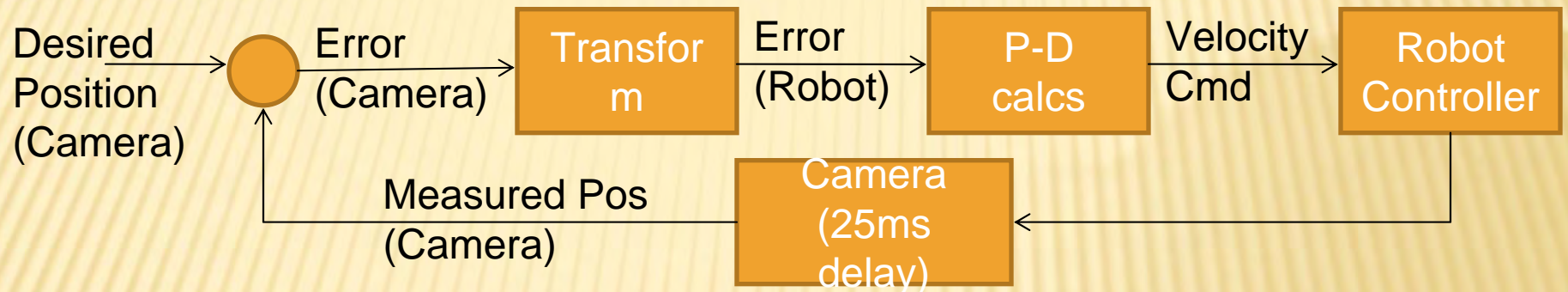


# CONTROL TECHNOLOGY

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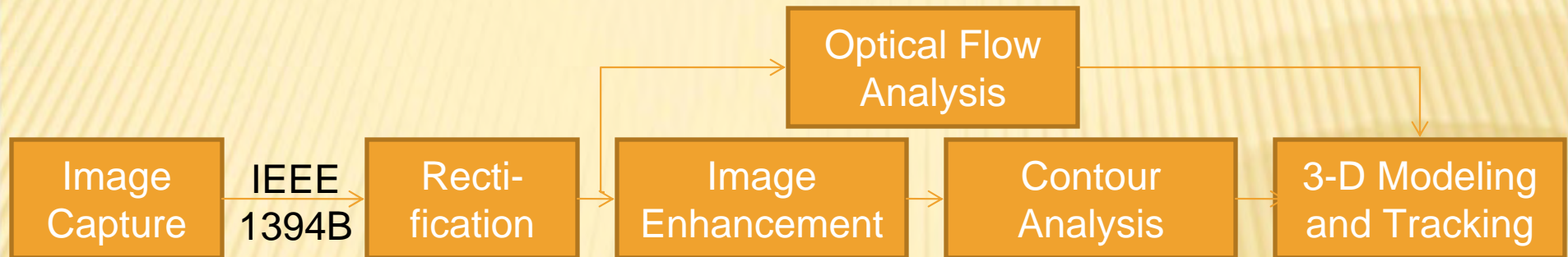
- ✘ Standard Robot Control: Staubli TX60 robot with off-the-shelf controller.
- ✘ Industrial PC with Windows 7 for high-level machine control, with embedded controllers in robot, power distribution, and needle mech.
- ✘ Visual Servo Control: Two pairs of stereo cameras—one 35mm FOV, one 15mm FOV—running at 50Hz. Considering move to 150Hz.
- ✘ Force Control: Six-axis force sensing used for gross positioning by physician.

# CONTROL LOOP



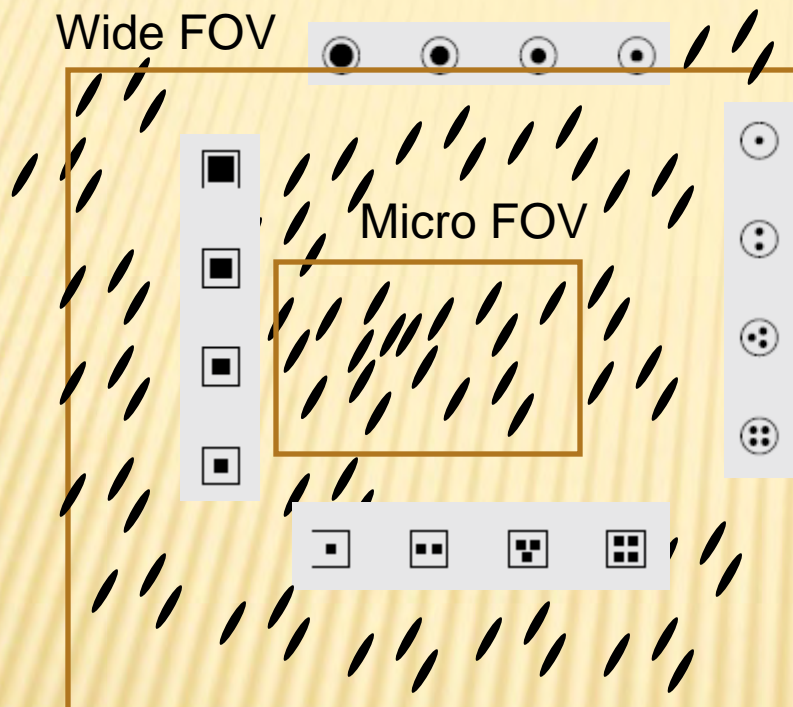
- ✘ Goal: To provide 100 micron dissection accuracy at 16 hairs/min.
- ✘ Disturbances: Patient breathing and other motion
- ✘ Delays due to
  - Image acquisition and transfer to PC
  - Image processing
  - Communication with robot
  - Robot trajectory generation (25Hz low-pass trajectory filter)

# VISUAL SERVO CONTROL



- Rectification simplifies the ‘correspondence problem’ by undistorting and transforming images into a common plane
- Image enhancement is performed to minimize effects of glare and shadow.
- Contour analysis establishes outlines for 3-D hair creation and measurement.
- Optical flow is used to assist in tracking hairs across frames.
- Using OpenCV for image processing.
- No longer using CUDA for GPU-accelerated vision processing.

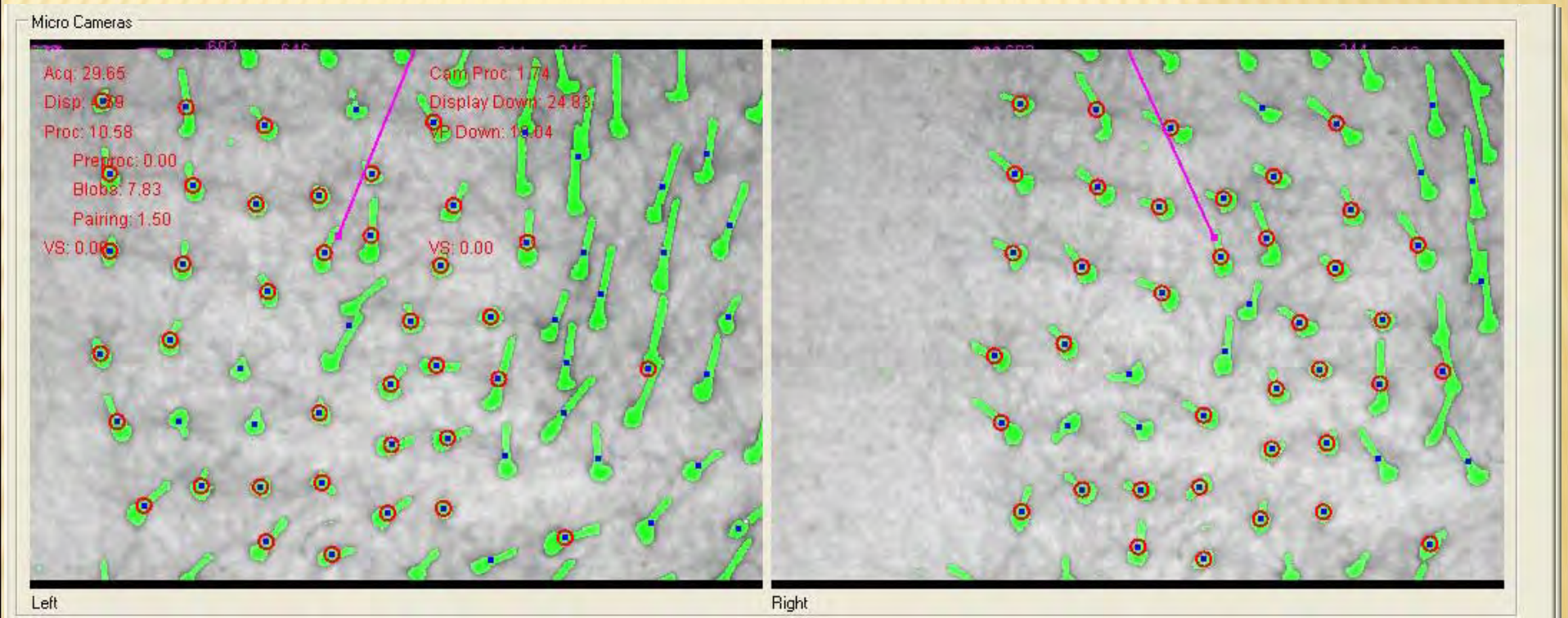
# AUTOMATION



- Fiducial markings on skin tensioner used to plan back-and-forth path across tensioner.
- Harvesting occurs at a rate of about 15 hairs/minute.



# TECHNOLOGY - IMAGING ANALYSIS



# TECHNOLOGY - SOFTWARE

The screenshot displays a software interface for a robotic system. The main window shows a top-down view of a surgical instrument with a tissue sample. The interface includes a status bar at the top with the following information: 01, 01; test01; 11/18/2010 02:26:00; 2 58 27 47. The control panel on the right features a power button, two camera views, and several function buttons: Center, Force Drag, Tensioner, Mouse, Saline, Lights, and Utility. A large red STOP button is prominently displayed, with an 'Away 40' indicator below it. The 'Fast Harvest' section includes a table of parameters:

PD	CD	Ang	RPM	FC
5	8	50	400	0

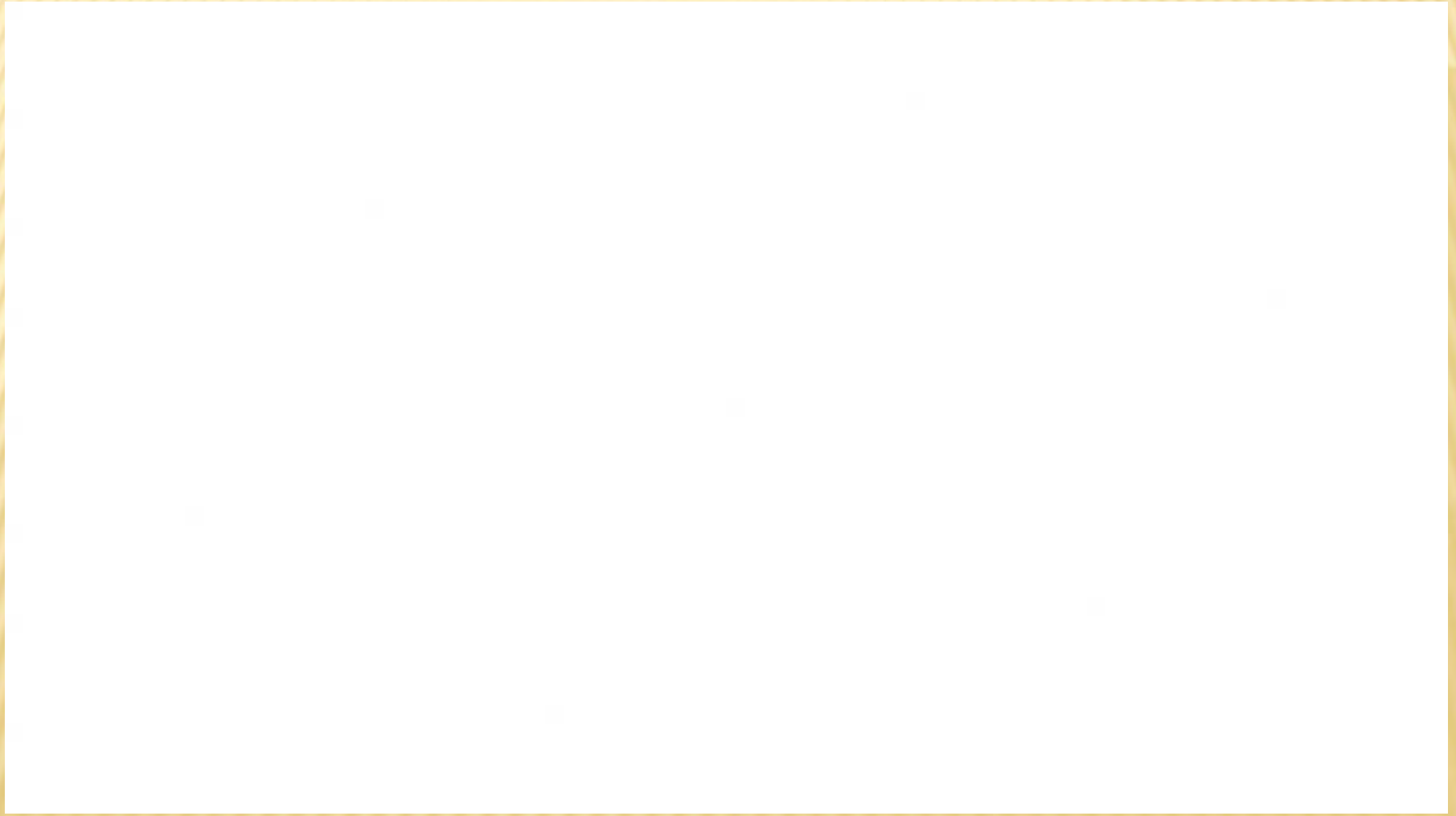
Below the table is an 'Automation' section with 'Begin' and 'Safe Position' buttons. The bottom of the interface shows the 'Restoration Robotics, Inc.' logo and a row of system icons.

# SAFETY FEATURES

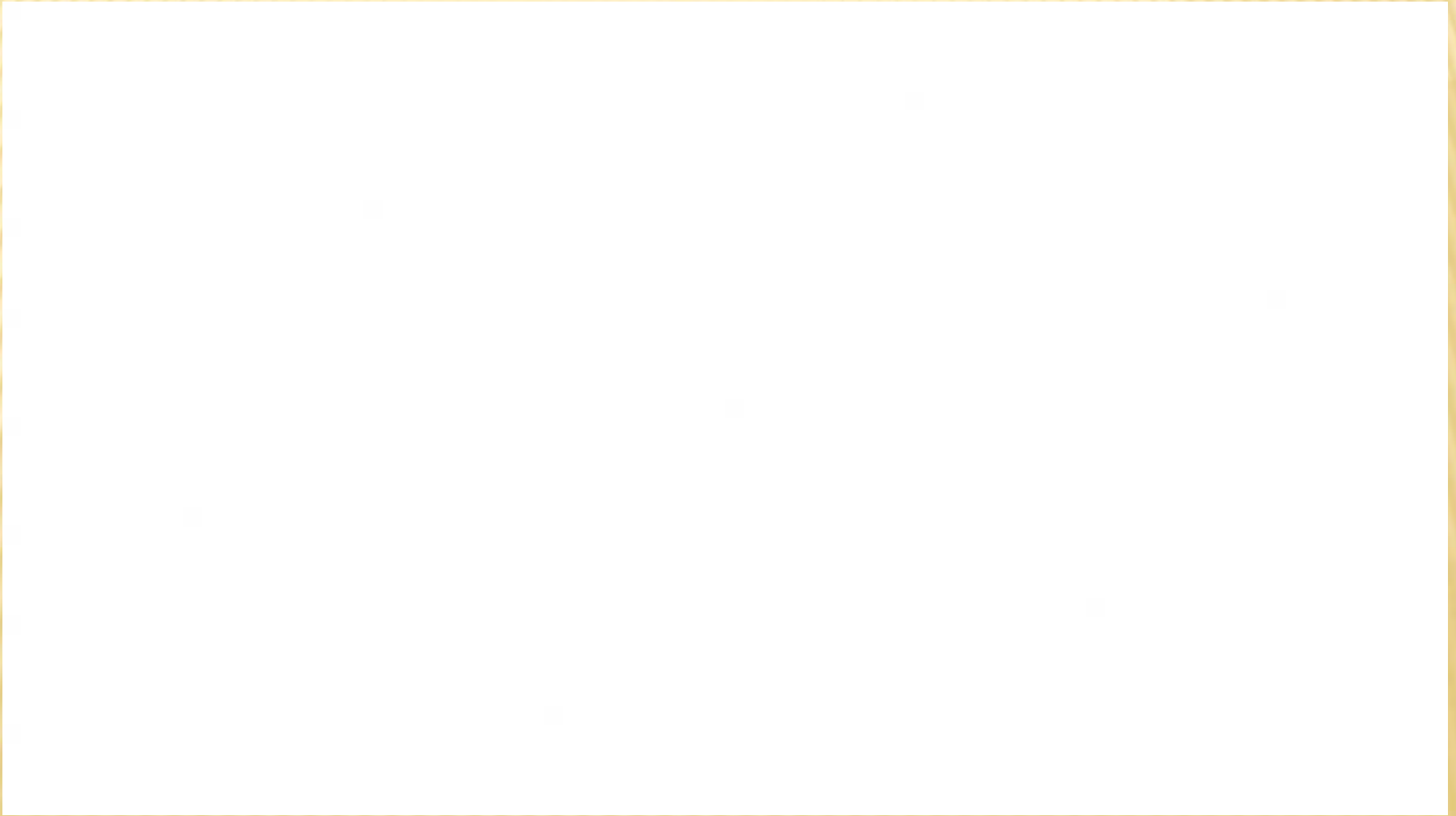
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- ✘ 3-D Model of robot, needle mechanism, and cart used in real-time collision prediction and avoidance.
- ✘ Software protection to avoid measured location of head.
- ✘ Several mechanical touch sensors on needle mechanism.
- ✘ Force sensor on needle mechanism.
- ✘ Limited depth of field of vision system.
- ✘ Standard E-stop and EPO switches.

# ROBOTIC SYSTEM - FORCE CONTROL




# ROBOTIC SYSTEM - HARVESTING



# ROBOTIC SYSTEM - AUTOMATION

# TECHNOLOGY – TREATMENT PLANNING

**Treatment Planning System Demo**



The image shows a 3D model of a male head with a hair simulation. The hair is dark brown and styled in a short, textured cut. Several blue arrows point to specific areas on the hair, likely indicating control points for the simulation. The background is a plain, light gray.

**Load Head Model**  
Norwood Type 3

**Apply Solution**

**Hide Hair Controls**  
 Position  Angle

**Density:**   
**Randomness:**


**Hairline Controls**  
**Modulation:**   
**Hairline Zone:**

**Show Sites**

**Hide Solution**

**Highlight Solution**

**Hair Count**  
**Solution:** 3124  
**Elements:** 542

  
RESTORATION  
ROBOTICS

# TECHNOLOGY – SAFETY SYSTEM

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- ✘ Continuous feedback
  - + Cameras measure the distance between the needle and the scalp at every frame
  - + Cameras have limited depth-of-field, robot cannot automatically move past scalp plane.
- ✘ Redundant safety devices
  - + Force Sensor
  - + E-stop buttons
  - + User overrides
- ✘ Watchdog checks throughout software and electronics



# STATUS

- ✘ Clinical Trials
  - + Successfully concluded
- ✘ FDA Clearance
  - + 510k submission complete
- ✘ Product Release in 2011



# CONCLUSIONS

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- ✘ Medical Robotics is an exciting and growing field. Mechanical Design, Control Systems, and Software Engineering are crucial in making these devices successful.
- ✘ Restoration Robotics is making a key contribution to the world of medical robotics: first product to fully automate surgery with patient contact
- ✘ Stereo vision, faster CPU's and faster camera technology makes visual servoing increasingly feasible in a variety of applications.