# Standard and Metrology Needs for Surgical Robotics

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# Surgical Robotic Revolution



Enhance dexterity and precision of Minimally Invasive Surgery (MIS)

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# Minimally Invasive Surgery (MIS)


- Small 1cm incisions
- Inflate abdomen with $CO_2$
- Endoscope visualization
- Long shafted instruments

Shortens hospital stay, quicker recovery, <u>less $</u>

Difficult to perform

# Teleoperated Robotic Surgery

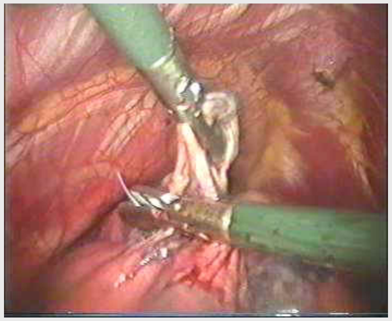
- Fly-by-wire systems
  - Surgeon console outside sterile field
  - Robotic instruments interact with patient

- Sometimes called *master-slave* or *surgeon assistants* systems
- Surgeon is *“in-the-loop”* with the robot

# Advantage of Surgical Robots

- Instruments move like the human hand but are *smaller* *(< 10mm)*

- Motion scaling and smoothing
- Better visualization
- Future applications:
  - *Surgical simulation*
  - *Image-guided surgery*
  - *Telesurgery*



# Commercially Available Robotic Systems

*Currently only one choice:* daVinci from Intuitive Surgical

- Hundreds sold worldwide
- Thousands of cases performed annually

# Previously Available System

Zeus System from Computer Motion

Zeus Robot Arms

Zeus Console

# Current Clinical Applications

Urology
- Radical prostatectomy, pyeloplasty, cystectomy, nephrectomy, ureteral reimplantation

Cardiothoracic
- Mitral valve repair, endoscopic atrial septal defect closure, Internal mammary artery mobilization and cardiac tissue ablation

OB/GYN
- Hysterectomy and myomectom

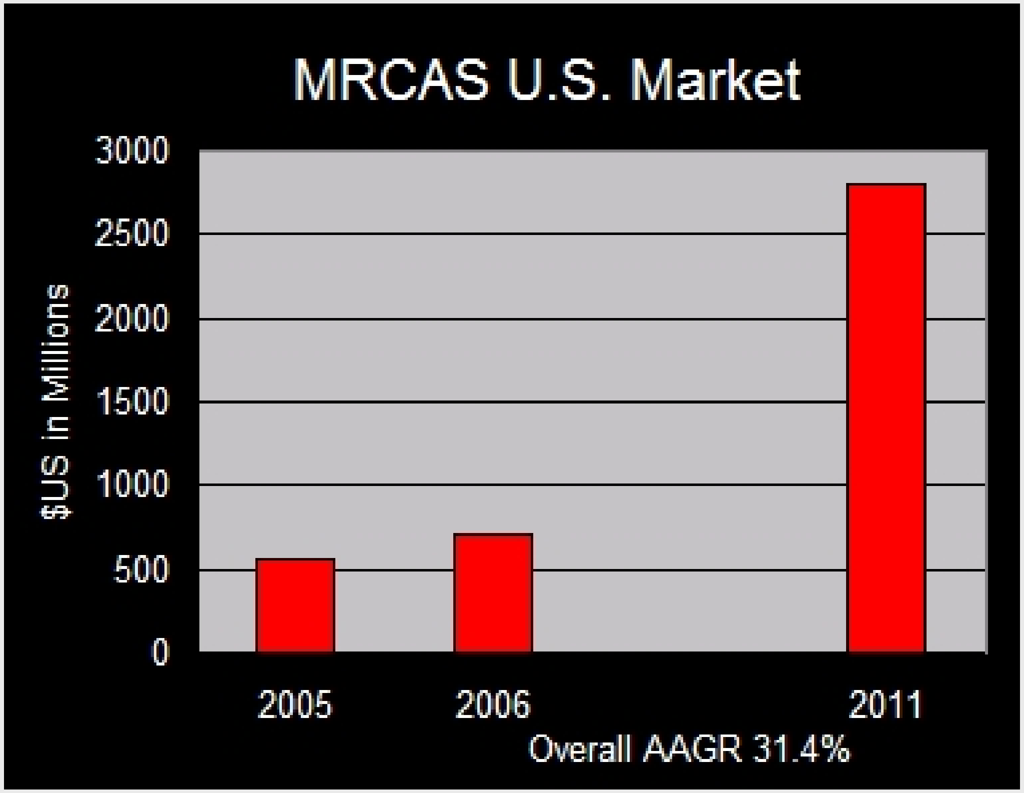
Pediatrics
- pyeloplasty for ureteropelvic junction obstruction, gastroesophageal repair GERD, ligation of patent ductus arteriosus

General Surgery
- Cholecystectomy, Nissen fundoplication, Heller myotomy, gastric bypass, donor nephrectomy, adrenalectomy, splenectomy and bowel resection

*[Source: Intuitive Surgical Website]*

# Projected Market of MRCAS

## (Medical Robotics and Computer Aided Surgery)




Surgical robots are the fastest growing U.S. market segment, with a projected AAGR of over 43% between 2006 and 2011.

The total *worldwide* market for MRCAS devices and equipment is expected to be $1.3 billion in 2006 and $5.7 billion by 2011, an AAGR of 34.7%.

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# Room for Improvement

daVinci is a first generation system

- *High initial cost ($1.5MM)*
- *High per procedure costs (~$2K)*
- *Large size in OR and sterile field*
- *Lack of haptic feedback*
- *Required training not defined*

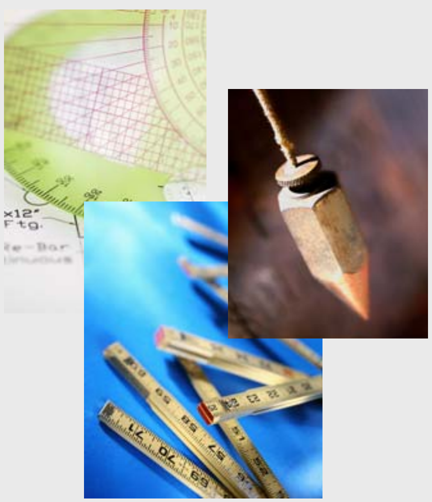
Current economics are not favorable for widespread adoption

*(radical prostatectomy is one exception)*

# Standards and Metrology for Surgical Robotics

Surgical robotics is in its infancy:

**<u>Now</u> is the time to discuss the standard and metrology needs!**



- Consistent evaluation metrics will aid device development and safety
- Standards will stimulate the industry and facilitate system integration

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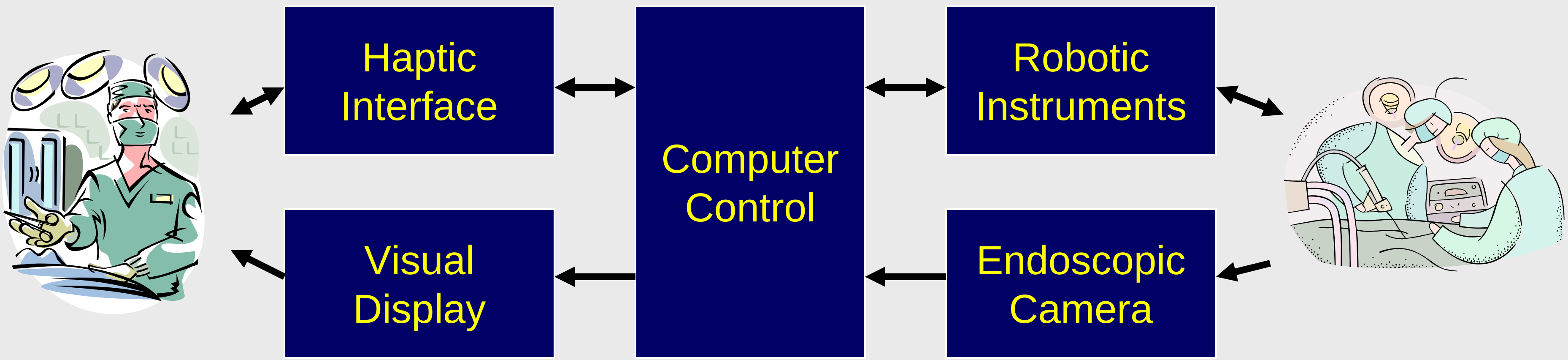
# Challenge of Human-Machine Interface Design




Computer-assisted surgery introduces many questions and measurement needs…

# Presentation Outline

1. **Limitations of current robotic systems**
2. **Standard and Metrology needs:**
   - *Motion control and precision*
   - *Training systems*
   - *Haptic feedback*
3. **Next generation systems**
   - *Image-guided robotic surgery*
   - *Telesurgery*
   - *Endoluminal robotic systems*
4. **Conclusions and Priorities**

# Limitations of Current Robotic Systems

*daVinci is a first generation device…*


- Too expensive ($1.5MM) for many hospitals

# Large Footprint in OR

- Requires large OR and dedicated staff
- Significant draping and setup

# What do these limitations have to do with metrology needs?

- Next generation systems will be smaller and cheaper
- This may reduce the precision and utility
- What performance is "good enough"?

**Metrology!**

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# Defining Adequate Performance

- Complex answer… depends on
  - Surgical procedure
  - Human in-the-loop
  - Surgeon preference and skill

→Developing quantitative evaluation metrics of system performance is still needed!

# ***Personal Example:***

# Development of Laprotek Robotic System

# EndoVia Laprotek System

- Same intended use as daVinci
- Teleoperated surgical robot
- R & L hands for manipulation
- 7 DOF instruments with wrist
- 7 DOF force reflecting master
- Target cost:  $250K

# Laprotek Clinical Trials


- Successfully completed laparoscopic cholecystectomy on 10 patients in Germany
- Obtained UL and CE mark
- Approved for sale in Europe

# EndoVia Laprotek System

- Portable console (master)
- Utilize hospital's existing laparoscopic equipment
- Monitor for visualization
- Built in storage space
- Handle based interface
- Capable of force feedback

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# EndoVia Laprotek System

- Instrument arms (slave) mount to OR table
- Minimize space in sterile field
- Simplified setup
- Disposable instruments

# Positional Accuracy of Laprotek

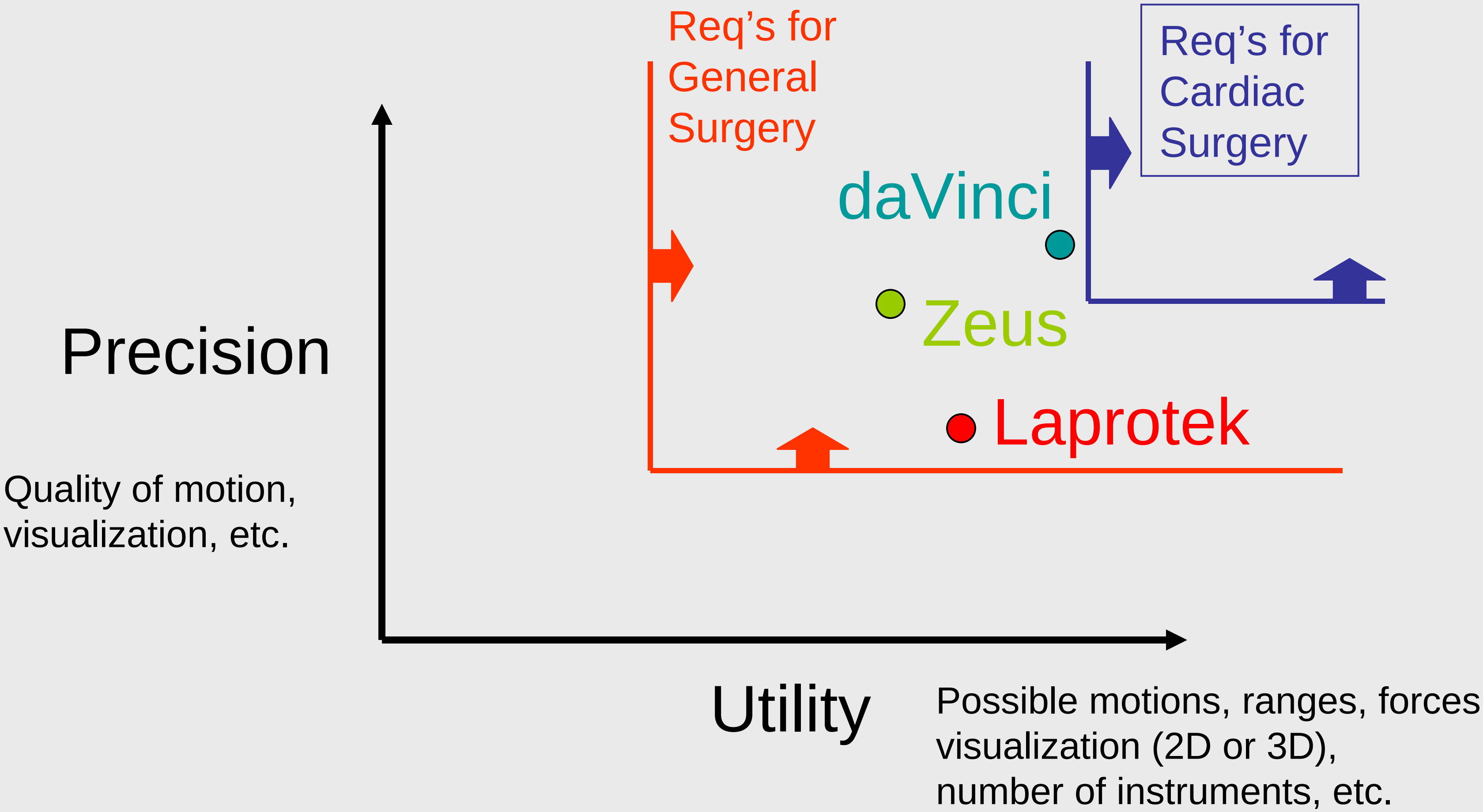
**Not as good as daVinci…**

but adequate for lap cholecystectomy.

Causes:

- Multiple mechanical connections (slop)
- Flexible, disposable instruments
- Deflection of support structure
- Friction and cable stretch
- Variations due to manufacturing

# Precision and Utility




Cost is possible 3rd dimension of graph…

# Metrology Need for Motion

Measure overall input vs. output motion

*Input Motion*

$\Delta X_i$ $\Delta Y_i$ $\Delta Z_i$
$\Delta \theta_i$ $\Delta \varphi_i$ $\Delta \psi_i$

*Output Motion*

$\Delta X_o$ $\Delta Y_o$ $\Delta Z_o$
$\Delta \theta_o$ $\Delta \varphi_o$ $\Delta \psi_o$

Need new measurement systems and performance metrics…

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# Metrology Need for Motion

- Develop generic measurement system to quantify motion of any teleoperated surgical system
  - *Attaches to master handle and instrument tip*

- Analyze data to determine:
  - *Precision of motion tracking*
  - *Quantify latency, slop, motion limits, nonlinearities*
  - *Determine coupling between joints*
  - *Quantify smoothness*

# Metrology Need for Motion

- Consistent motion performance metrics could be tied to required precision for specific procedures
- Not Easy!   Need to understand human perception and adaptability

# Robotic Surgery Training Systems

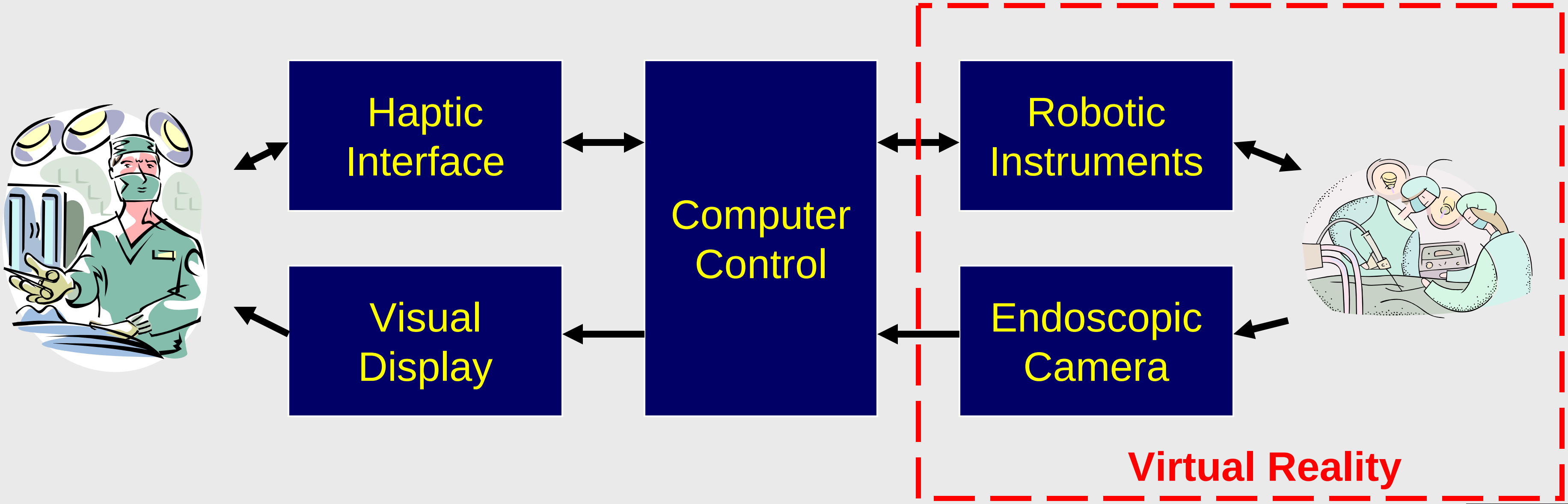
As a surgeon, how do you know when you are ready to do your first robotic case?

Robotic surgery is a big change from MIS…

- Cases 1-10: STEEP learning curve
- Cases 11-100: Patient specific learning
- Cases 100-700+: Still learning!

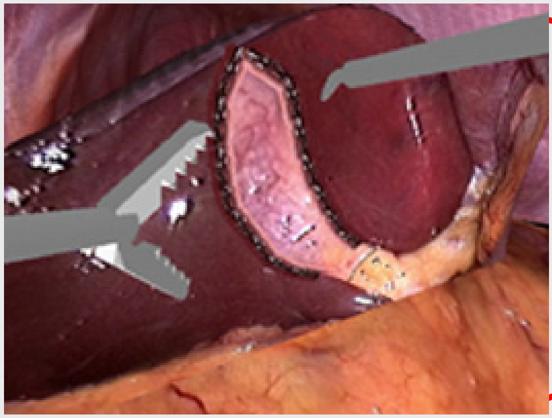
# Surgical Robotic Simulators

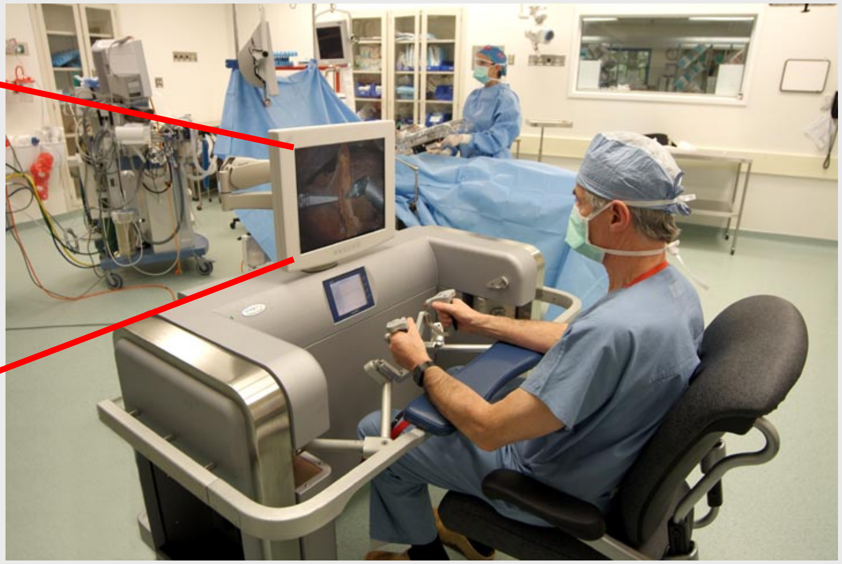
- Fly-by-wire architecture makes surgical simulators possible
- Create virtual patient and slave robot



# Surgical Robotic Simulators

- Surgeon uses same haptic interface
- Endoscopic images replaced with computer generated visualizations





# Surgical Robotic Simulators

- Improper training can lead to safety hazards
- Need Standards and Metrology to qualify and validate training systems
- Again, LOTS of questions since a human is in the loop…

# Surgical Robotic Simulators

- What is adequate simulation performance?
- How faithfully do tissues need to deform?
- How geometrically accurate do the organs models need to be?
- What dynamics or update rates are required?

Obviously, answers depend on training goals…

# Surgical Robotic Simulators

Some Possibilities:

- Is procedure specific training possible?
- Can we teach the difference between proper and improper robot performance?
- Can we determine common mistakes and feedback improvements into future robot designs?
- Can telementoring augment simulation?

# Metrology Needs for Haptic and Force Feedback

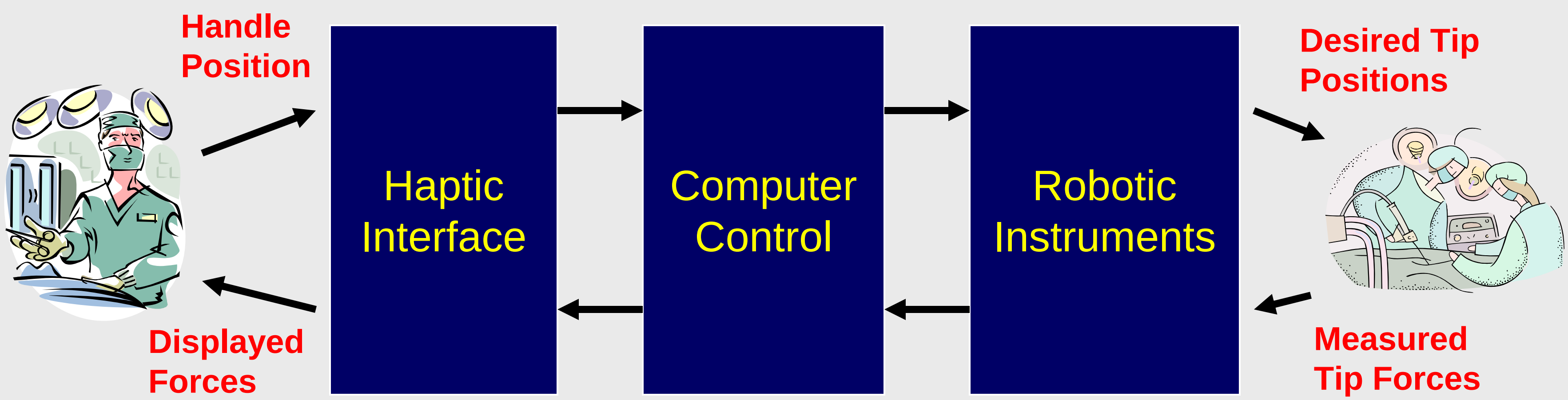
- Current robotic systems lack force feedback
- Many researchers are working on this…
- Haptic feedback introduces many challenges

→ Need for Metrology and Standards

# Implementing Force Feedback

## Bilateral Control Architecture:

- Positions (master → slave)
- Forces (slave → master)




Depending on gains and environment,

system can go unstable!!!

# Metrology Needs for Haptic Feedback

- Consistently quantifying haptic performance will facilitate evaluation and development
- Many questions since there is a human in the loop…

# Metrology Needs for Haptic Feedback

- How do you guarantee stability with an undefined environment and operator?
- What range / sensitivity / resolution of forces are needed be displayed?
- How many directions or DOF of forces/torques are needed?
- How faithful do the displayed forces need to be (direction and magnitude)?

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# Metrology Needs for Haptic Feedback

- How do you reliably measure instrument tip forces at a low cost?
- Are sensory substitution methods acceptable?
- How do you safely implement automatic motions? (Virtual constraints only?)
- Adding distributed contact pressure measurements have the same questions…

# The Future of Robotic Surgery
# Next Generation Devices

Brining tissue manipulation under computer-assisted control enables endless possibilities…

All of these can be improved and shaped by standards and metrology…

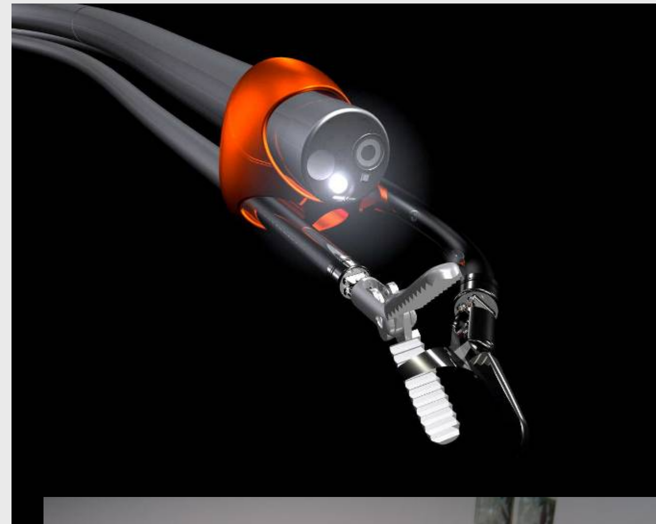
# Image-Guided Robotic Surgery

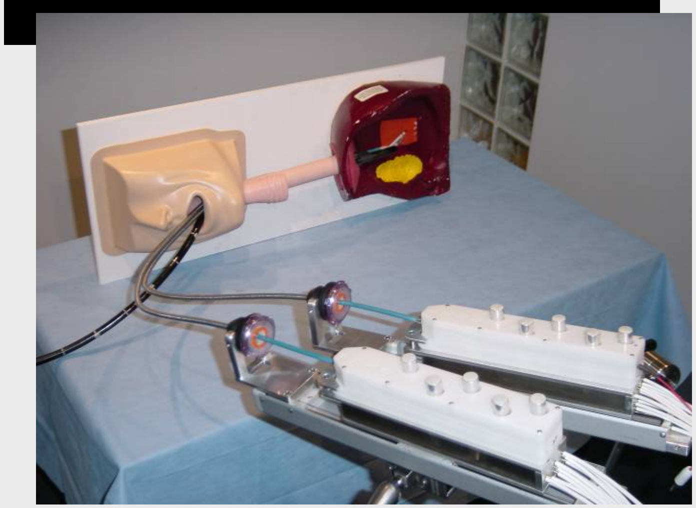
- Combine the positional accuracy of a robot with the 3D medical imaging patient “map”
- Provide enhanced geometric displays of the anatomy and real-time tool locations
- Create haptic “keep out” zones or virtual constraints to avoid delicate tissues

# Robotic Telesurgery

- Teleoperation over a distance
- Surgeon and patient can be miles apart
- A few cases have been successful
- Military applications (Trauma Pod)
- Many new safety concerns arise
  - Communication channel delays or failure
  - Setup, training, and overall patient safety

# Endoluminal Robotics



# Endoluminal Robotics

- Create tools enabling new procedures
- Procedure development will take time

- Applications in bariatrics, upper/lower GI
- Transgastric Surgery

**“This is the next generation of surgery.**
**…There is no other tool that can do this.”**

**Dr. Jeffrey Ponsky**
**Surgical Endoscopist,**
**Cleveland Clinic**

# Transforming Healthcare…

Computer Aided Surgery adds complexity, but has great potential to…

- Improve patient outcomes and safety
- Reduce costs and minimize trauma
- Synthesize informatics with intervention
- Push healthcare toward prevention

***Standards and metrology can greatly facilitate these goals!***

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# Standard and Metrology Needs for Teleoperated Surgical Robotic Systems

# Suggested Priorities

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# Priority 1

- Develop system to measure overall Input / Output motion performance of teleoperated surgical robots.
  - Passive position sensing mechanical arm
  - Optical tracking
  - Magnetic tracking
  - Should not require any modifications to robot

# Priority 2

- Develop performance metrics to evaluate the overall Input / Output motion of teleoperated surgical robots.
  - Quantify dead band, dexterity, motion limits
  - Evaluate synchronization to visualization
  - Quantify dynamic behavior and smoothness
  - Characterize nonlinearity and deformation under loading

# Priority 3

- Determine critical performance metrics for robotic surgical simulators.
  - Quantify virtual instrument motion versus actual robot motion
  - Quantify accuracy of virtual tissue motion versus real tissue
  - Help standardize surgeon evaluation metrics

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# Priority 4

- Determine critical performance metrics of force and haptic feedback for surgical robotic systems.
  - Develop new (disposable?) sensors to measure applied forces at the instrument tip
  - Develop system to measure overall Input / Output force feedback performance
  - Determine metrics to evaluate virtual constraints and haptic “keep out” zones

# Priority 5

- Develop communication and data standards to link surgical robots with medical imaging systems.
  - Allow connections between systems in OR
  - Include safety mechanisms to minimize any one component's (i.e. company's) liability
  - May have application to telesurgery

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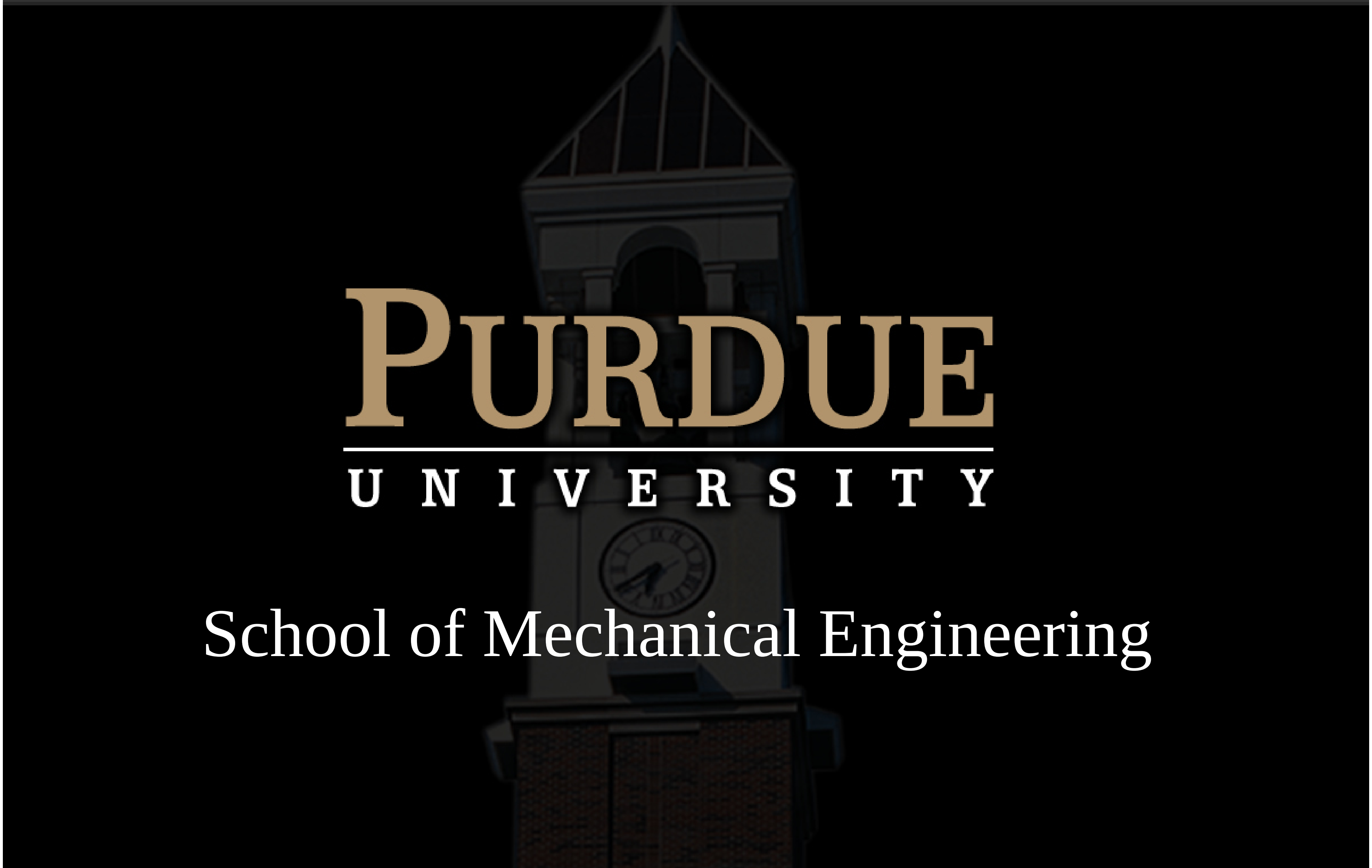
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