Real-Time Soft-Tissue Imaging Concurrent with External Beam Radiation Therapy Delivery

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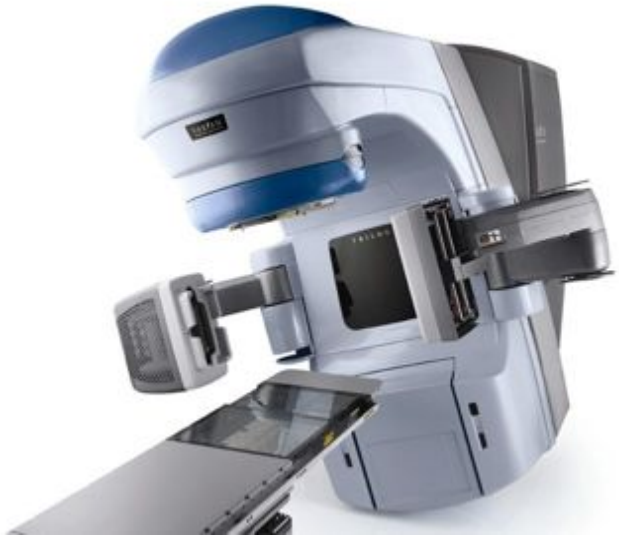
STANFORD ENGINEERING

Imaging During Beam Delivery

- Existing solutions are limited:

Radiographic x-ray



Electromagnetic

Real-time marker-less soft-tissue image guidance during beam delivery is an unmet challenge

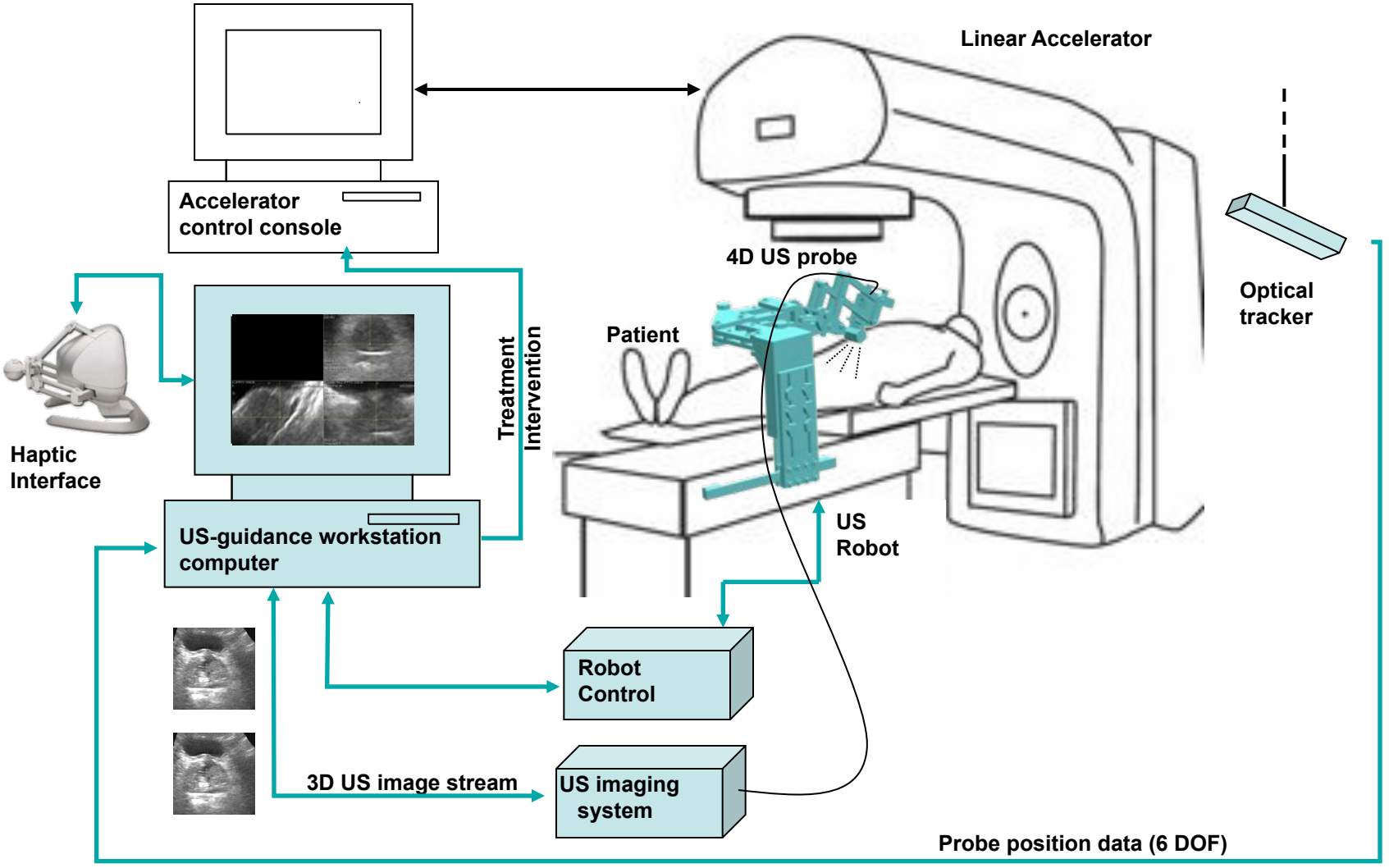
How about ultrasound?

- Previous investigations use imaging prior to delivery, or imaging in phantoms
  - A. Hsu, N. R. Miller, P. M. Evans et al., "Feasibility of using ultrasound for real-time tracking during radiotherapy," Medical physics 32 (6), 1500-1512 (2005).
  - Q. Xu and R. J. Hamilton, "A novel respiratory detection method based on automated analysis of ultrasound diaphragm video," Medical physics 33 (4), 916-921 (2006).
  - E. J. Harris, N. R. Miller, J. C. Bamber et al., "Performance of ultrasound based measurement of 3D displacement using a curvilinear probe for organ motion tracking," Physics in medicine and biology 52 (18), 5683-5703 (2007).
  - A. Sawada, K. Yoda, M. Kokubo et al., "A technique for noninvasive respiratory gated radiation treatment system based on a real time 3D ultrasound image correlation: a phantom study," Medical physics 31 (2), 245-250 (2004).
  - F. Jacso, A. Kouznetsov, and W. L. Smith, "Development and evaluation of an ultrasound-guided tracking and gating system for hepatic radiotherapy," Med Phys 36 (12), 5633-5640 (2009).

Unresolved Question:

➡ ***How can we control the US imaging process during beam delivery from outside the treatment room?***

Novel Image Guidance Solution



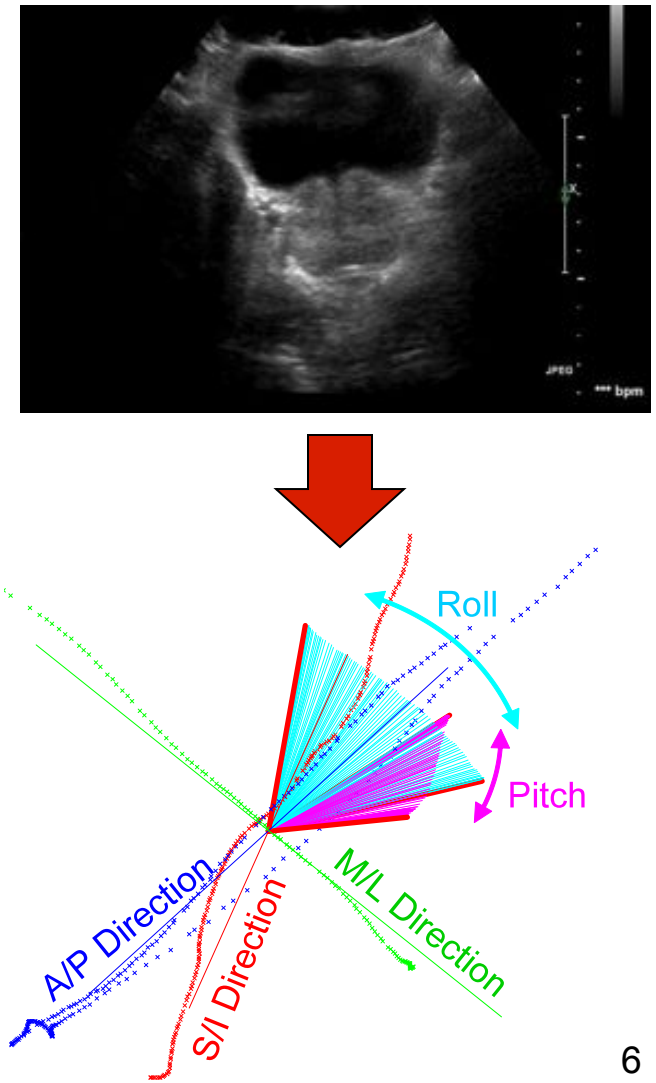
Telerobotic system enables remote probe control

Key Issues

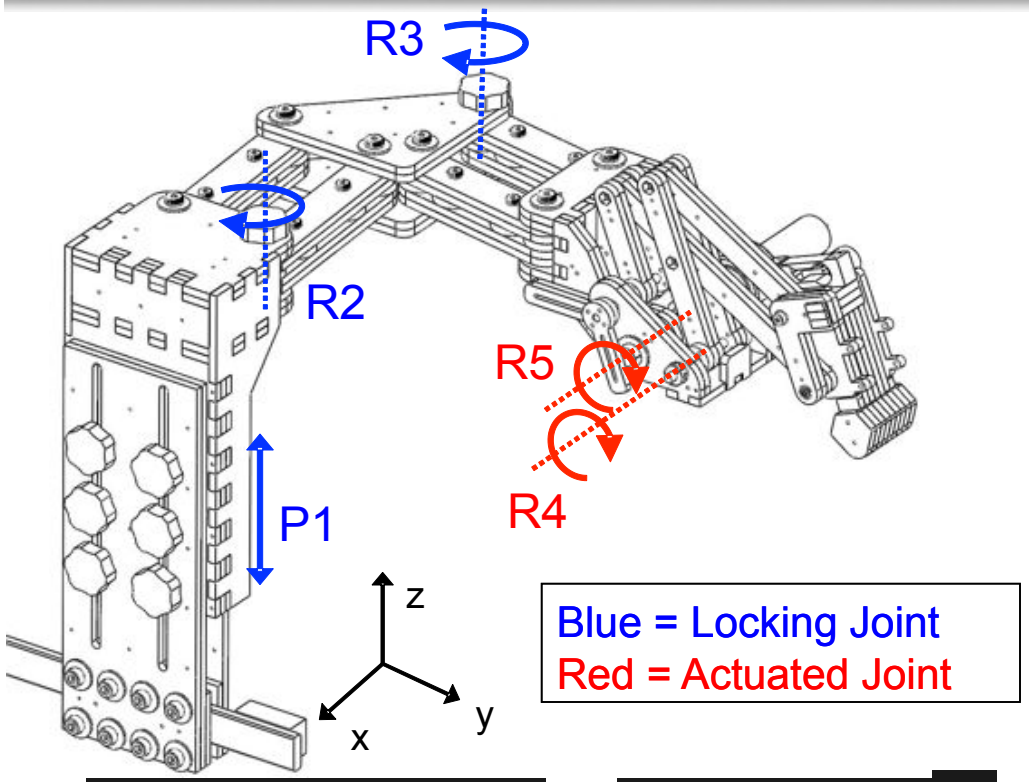
- Design of customized robotic manipulator
  - Range of motion
  - Radiotherapy environment constraints
  - Human safety
- Robustness of telerobotic human imaging
- Treatment plan compatibility
- Performance during radiation exposure

Robot Design Specs

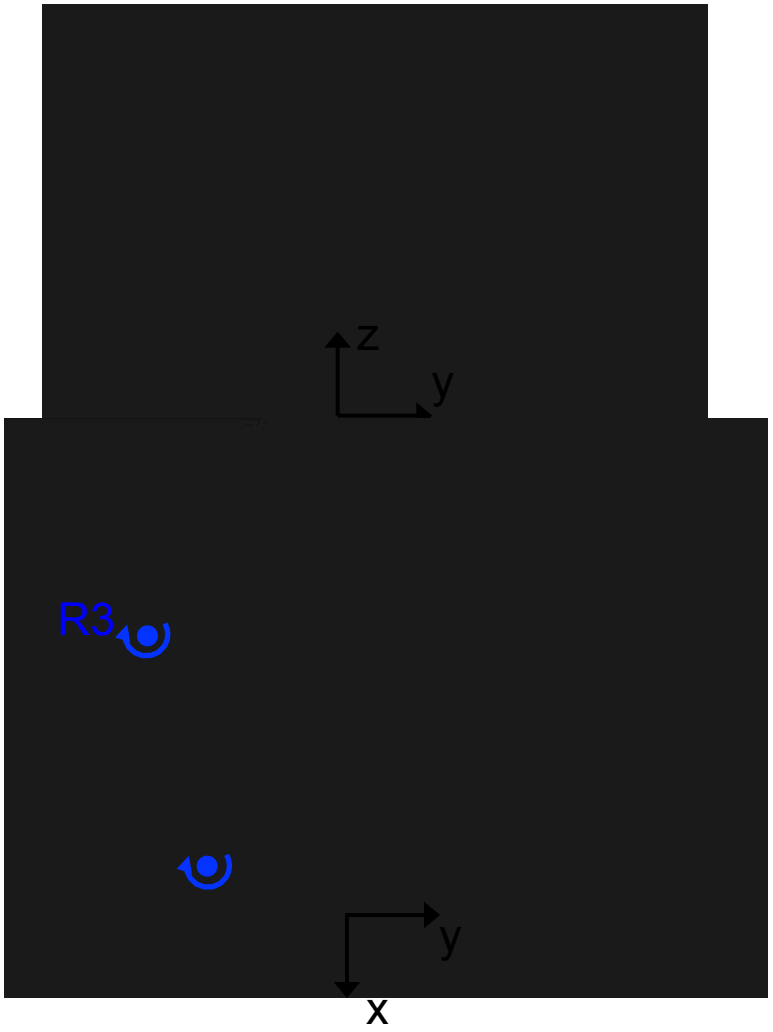
- Range of motion
  - Optical tracking
  - Probe pitch critical: 0-45°
- Radiotherapy environment constraints
  - 360 degree gantry rotation
  - Limited mounting areas on treatment couch
  - Limited clearance between patient and LINAC head



Manipulator Design

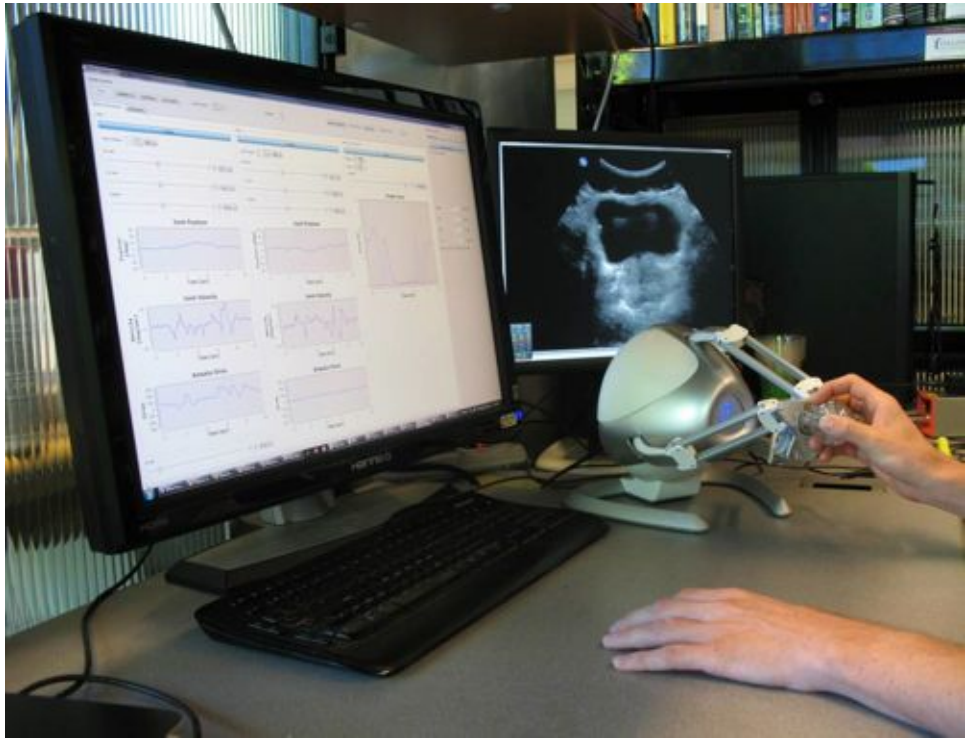


Blue = Locking Joint
Red = Actuated Joint

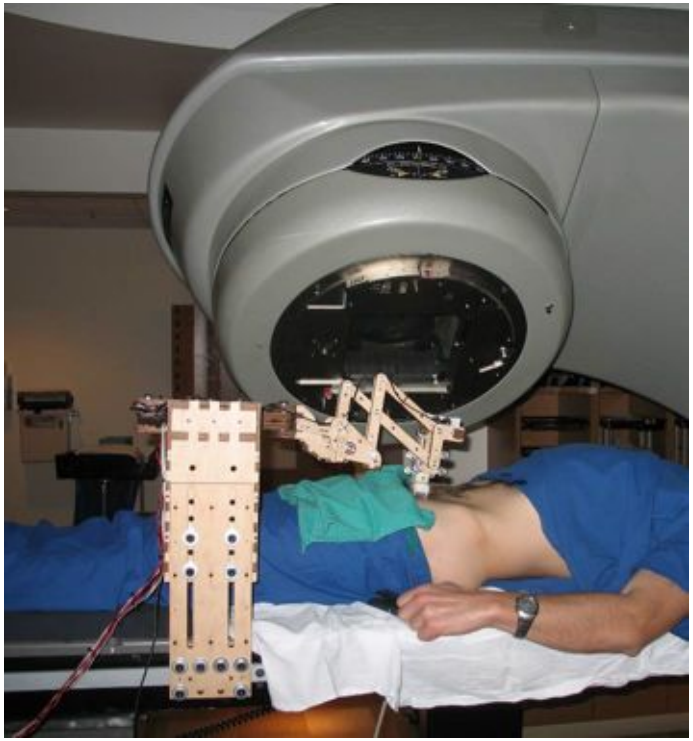


➡ ***Critical motions are actively controlled during treatment***

Telerobotic Imaging



Remote Haptic Interface



Robot

Telerobotic Imaging

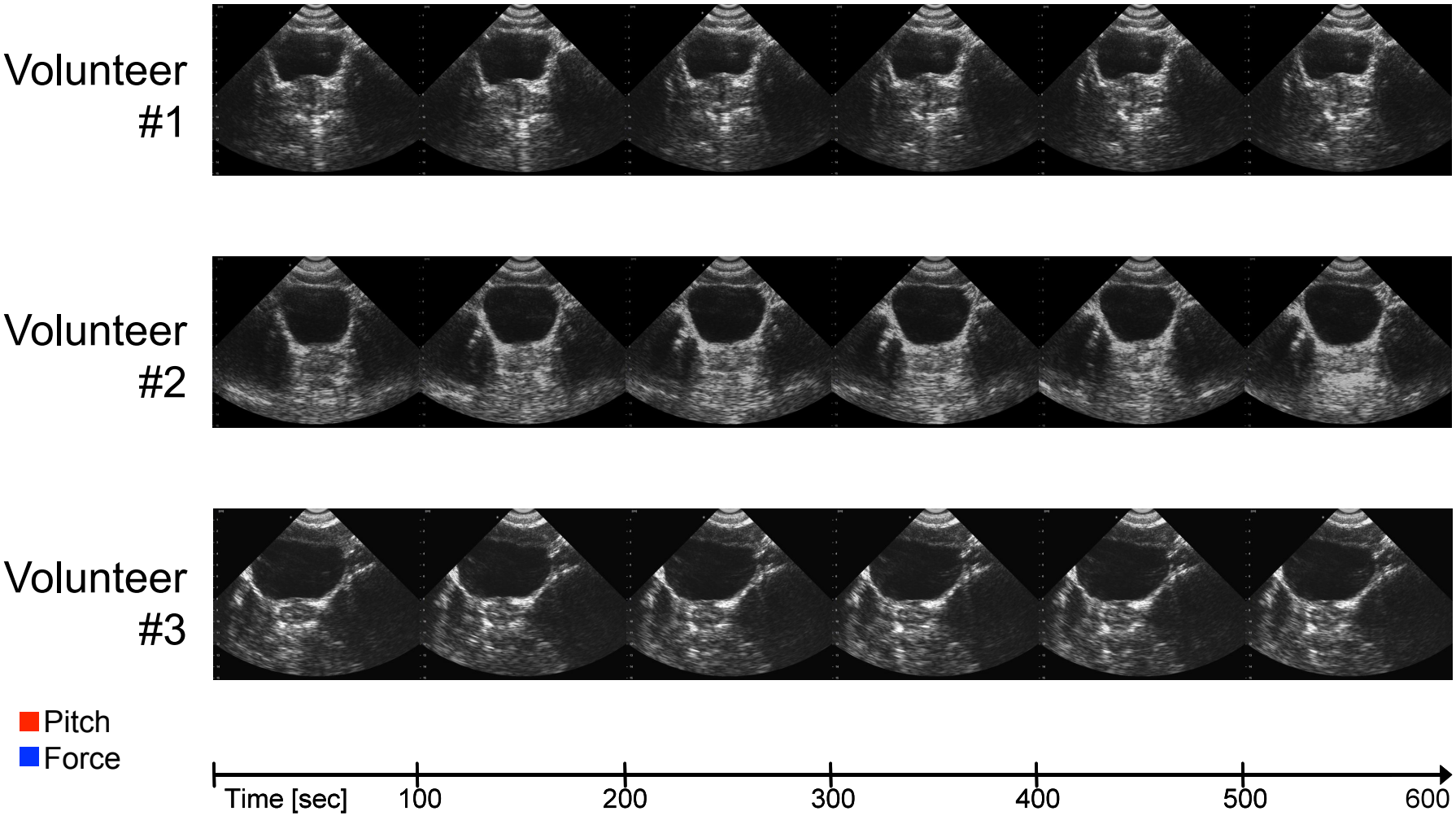
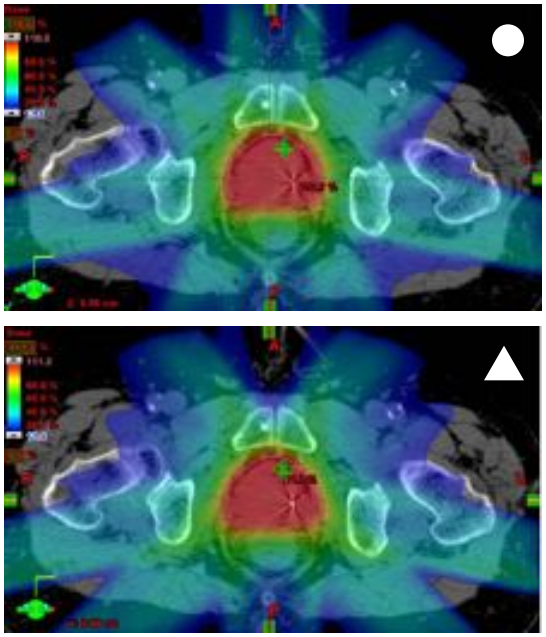
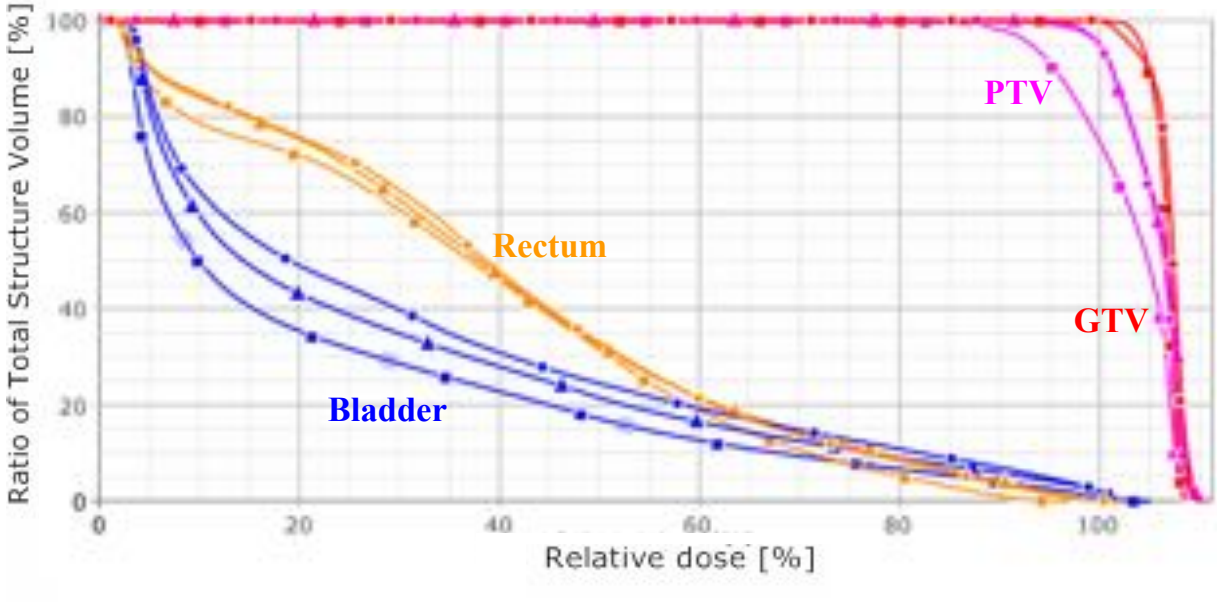


Image quality remotely maintained over 10 minutes

Impact on Treatment Plan

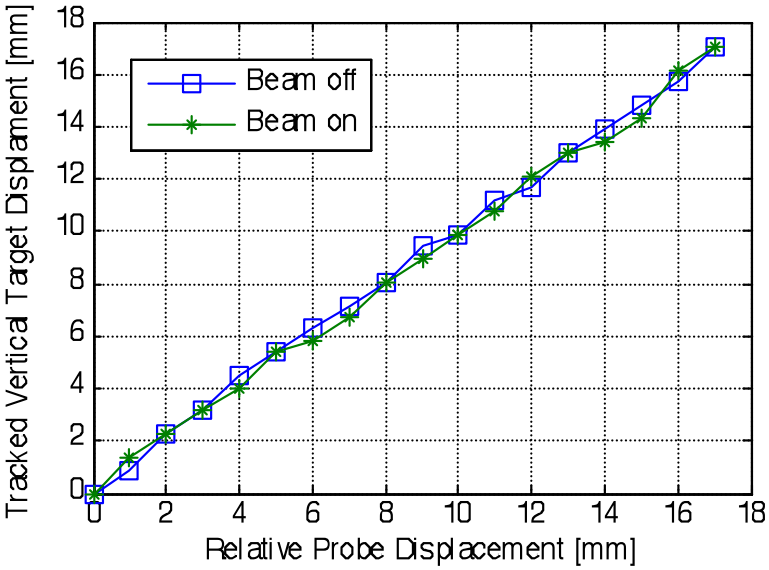


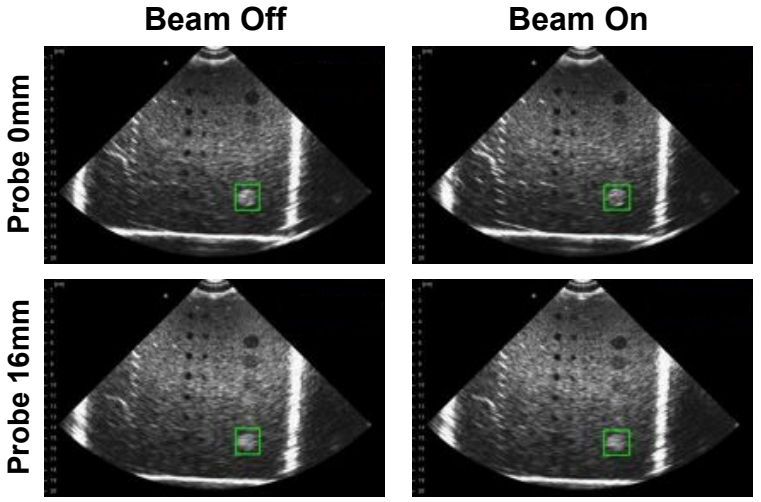


- ● Clinical prostate IMRT plan
- ▲ Re-optimized IMRT plan with restricted beam angles to avoid US probe and robot links
- ■ Re-optimized plan with 2mm margin reduction as potentially enabled by real-time image guidance

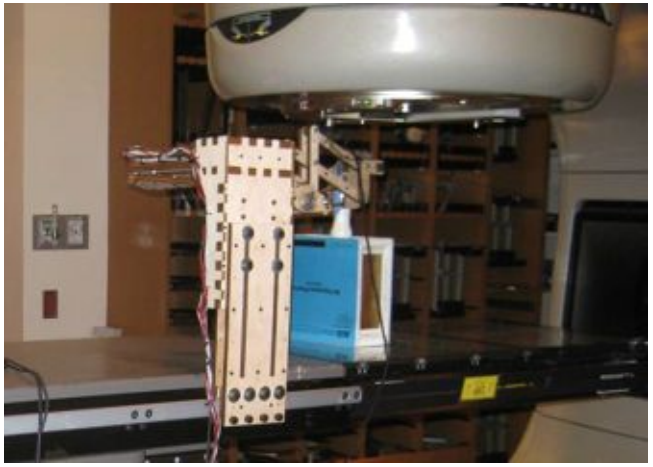
Plans are nearly identical. Potential margin reduction from real-time guidance is beneficial.

Performance During Delivery





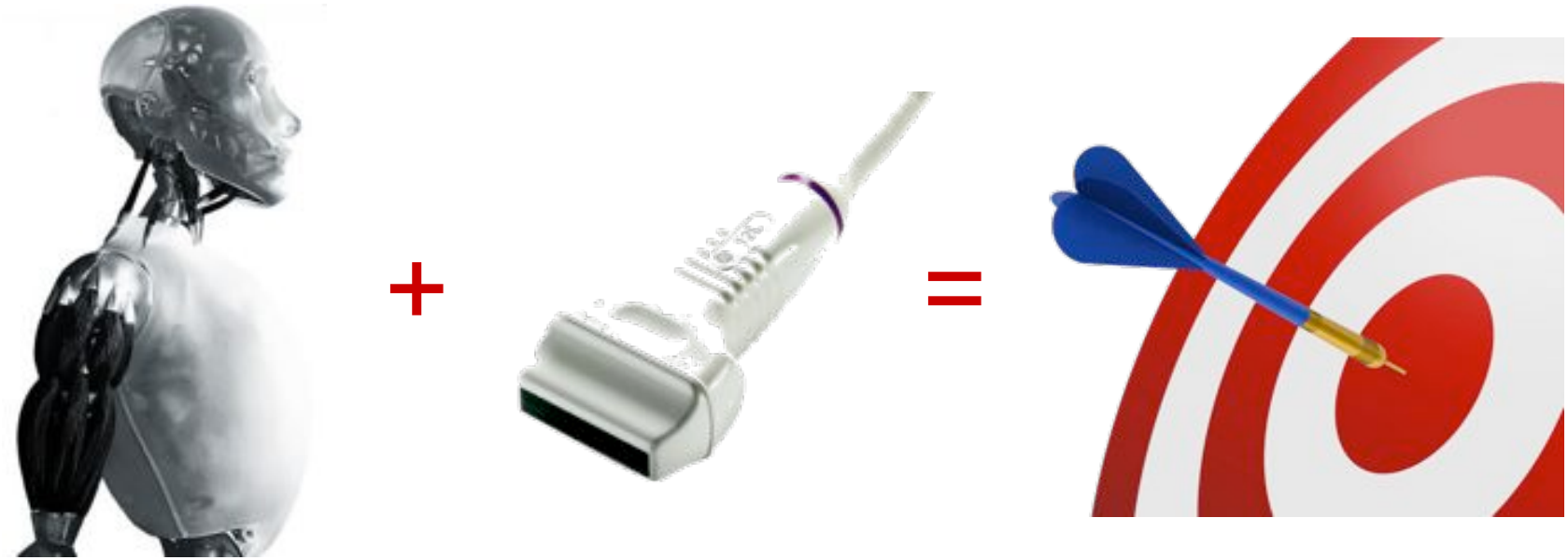
	p-Value
Servo cycle interval	0.99
Force control	0.46
Pitch tracking error	0.47
US tracking error	0.68



LINAC interference inconsequential for robot and US

Conclusion

Telerobotic ultrasound imaging is feasible during beam delivery



Could provide non-invasive guidance that truly reflects soft tissue anatomy

Questions?

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