Evaluation of a Telerobotic System Concept for Real-Time Soft-Tissue Image Guidance During Radiotherapy Delivery

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STANFORD ENGINEERING

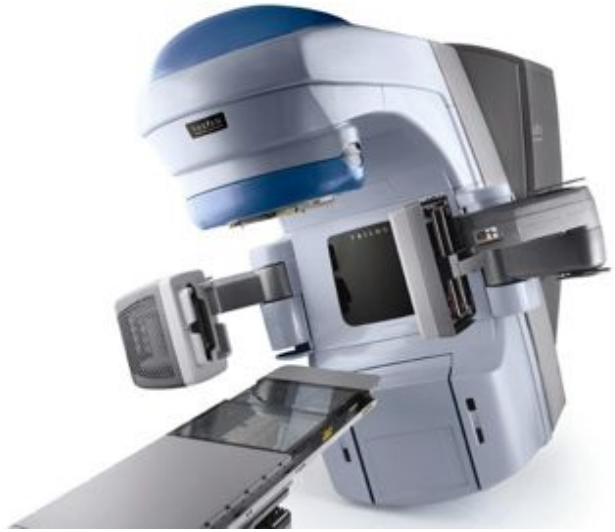
Conflict of Interest

- Nothing to disclose

Imaging During Beam Delivery

- Existing solutions are limited:

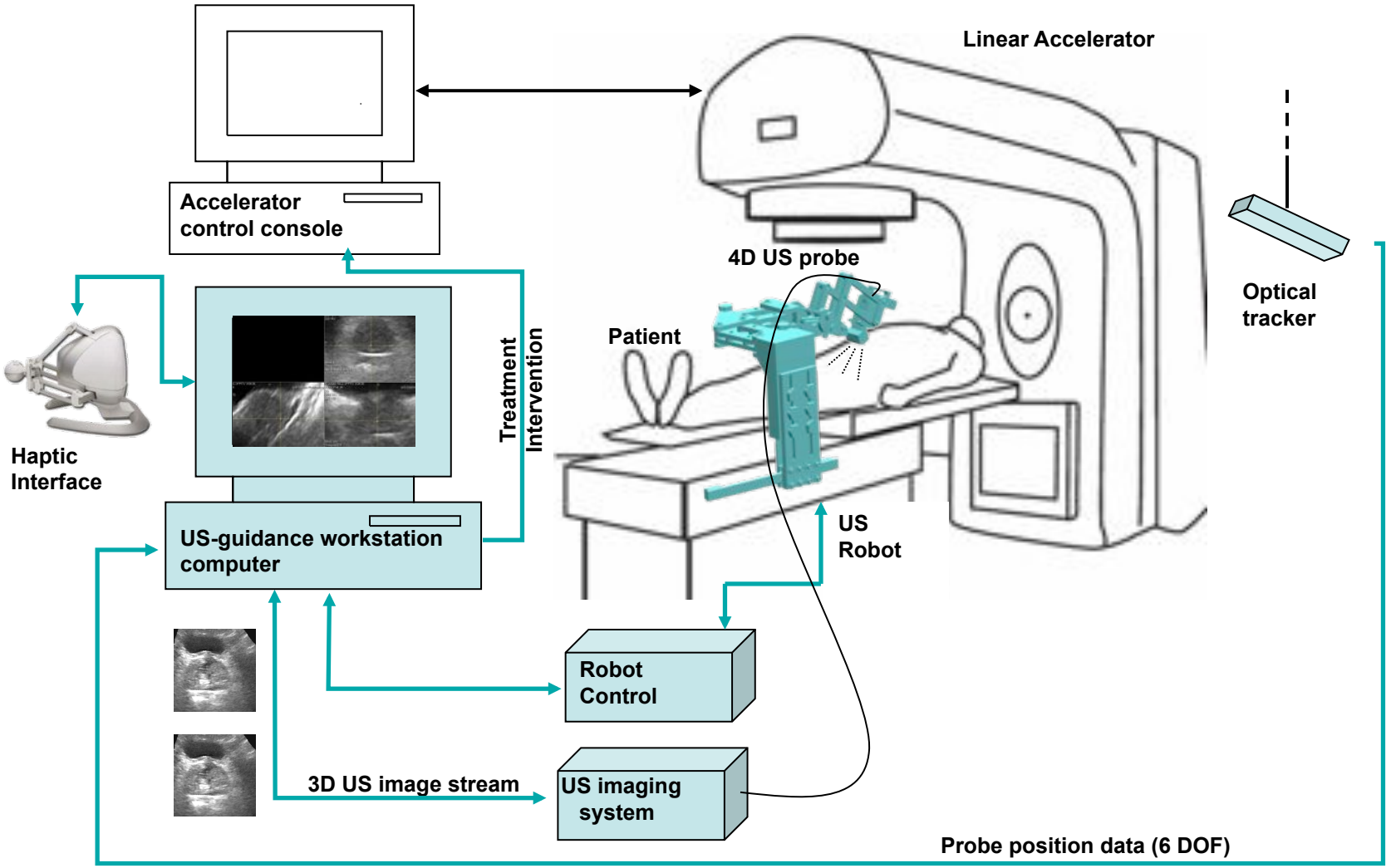
Radiographic x-ray



Electromagnetic

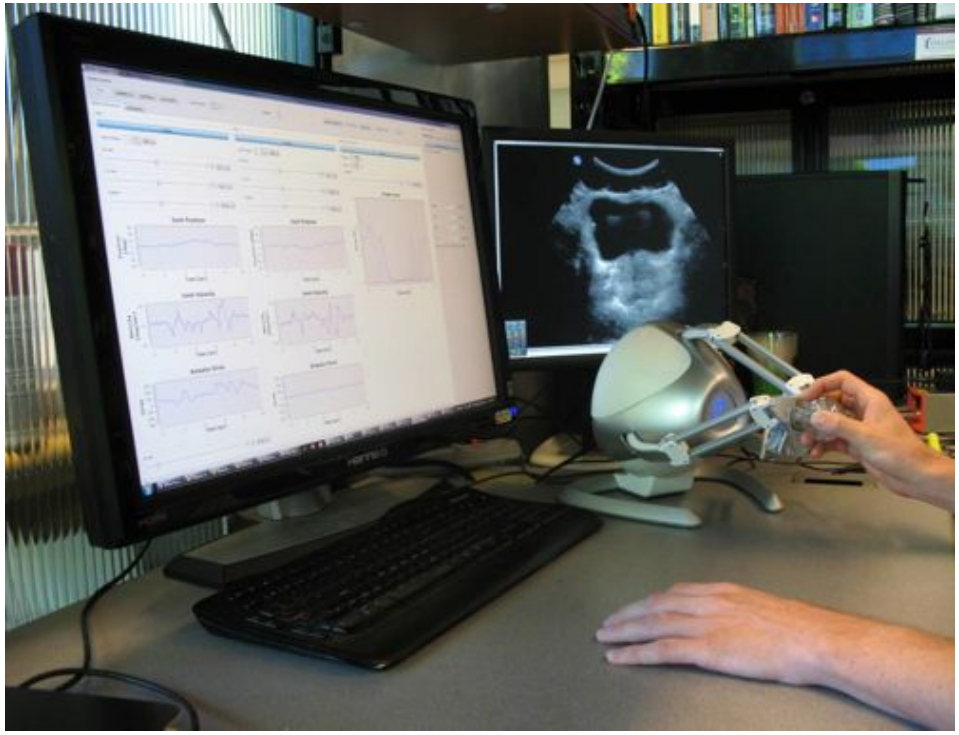
Real-time marker-less soft-tissue image guidance during beam delivery is an unmet challenge

Novel Image Guidance Solution

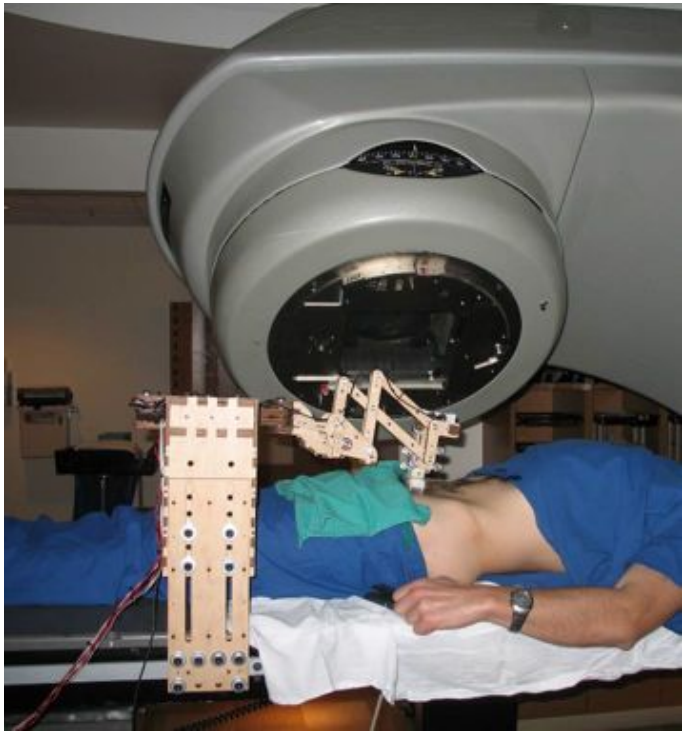


Telerobotic system enables remote probe control

Telerobotic Imaging



Remote Haptic Interface



Robot

Key Issues

- Remote ultrasound imaging during beam delivery
  - ✓Robotic manipulator design
  - ✓Treatment plan compatibility
  - ✓Performance during radiation exposure
  - – Imaging robustness for multiple treatment sites
- Image guidance
  - – Temporal calibration and time delay
  - – Spatial calibration and accuracy

✓ Details to appear in Medical Physics: Schlosser et al. (2010)

Telerobotic Imaging for Multiple Sites

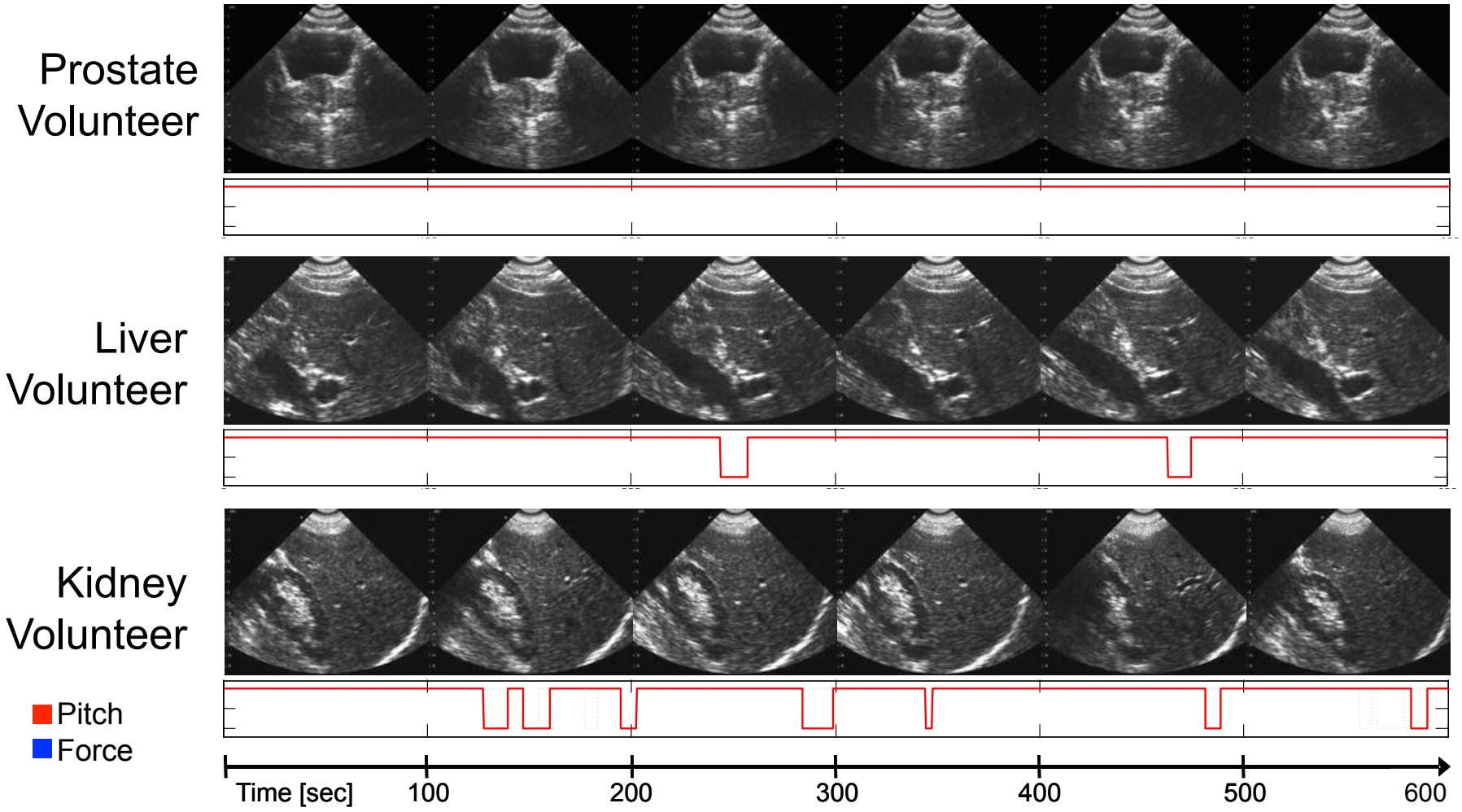
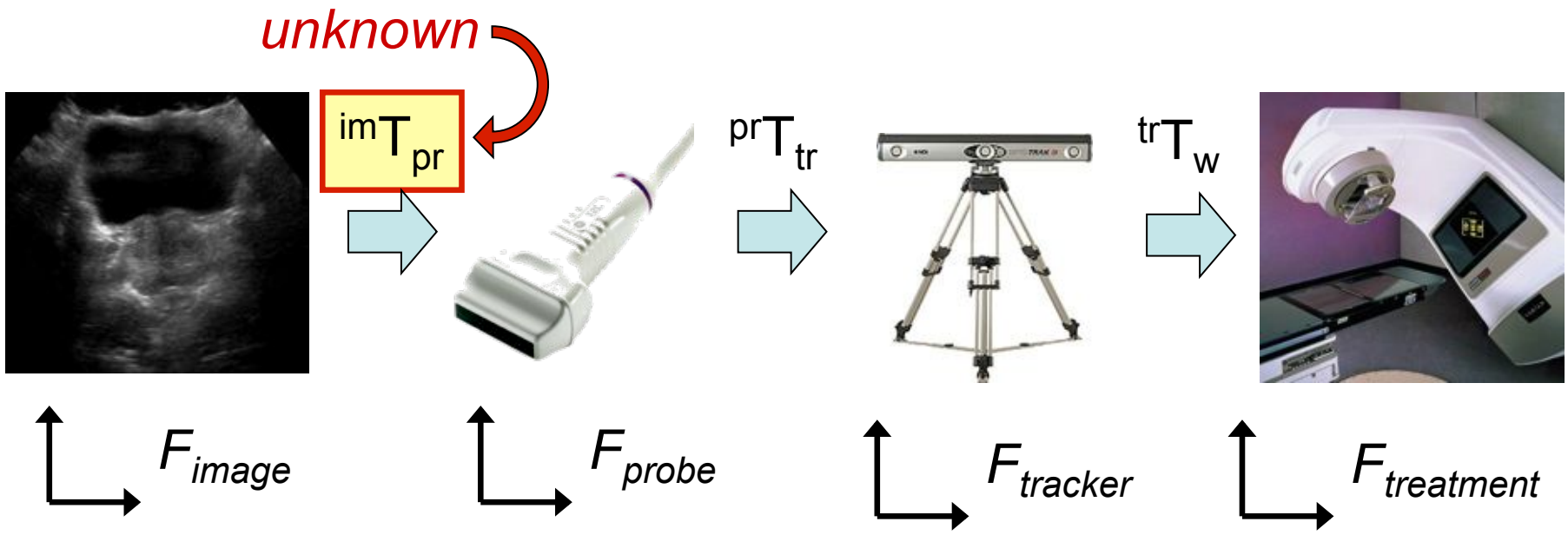


Image quality remotely maintained over 10 minutes

Image Guidance: Spatial Calibration

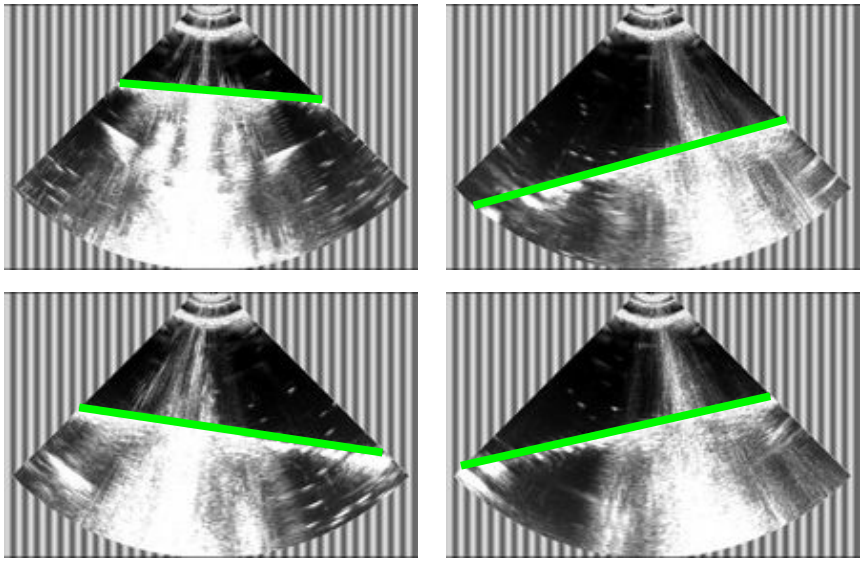


- Goal: find $^{im}T_{pr}$
- Variation of planar fit method from Hartov et. al*

*Hartov et al., “Adaptive spatial calibration of a 3D ultrasound system,” Med. Phys., 2010

Image Guidance: Spatial Calibration

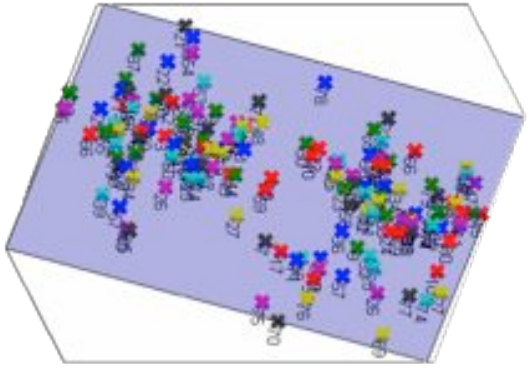
(1) Collect images of plate



(2) Extract points on plane

$$ {}^{w}\mathbf{p} = {}^{w}\mathbf{T}_{tr} * {}^{tr}\mathbf{T}_{pr} * {}^{pr}\mathbf{T}_{im} * {}^{im}\mathbf{p} $$

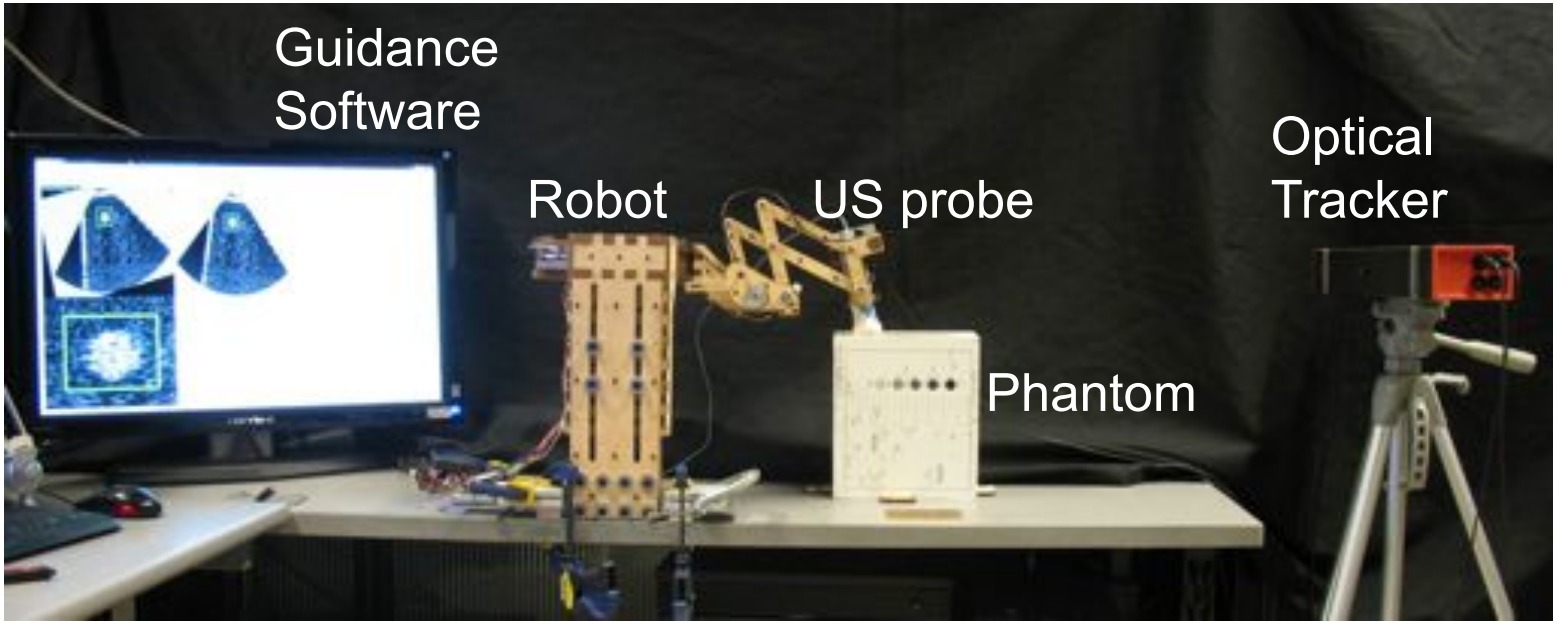
(3) Convert to world frame



(4) Optimize planar data fit

Temporal Calibration and System Evaluation: Experimental Method

- Image static target in US phantom
- Vary probe pitch or pressure
- Track target in real-time using NCC
- Use transformation chain to register in world frame



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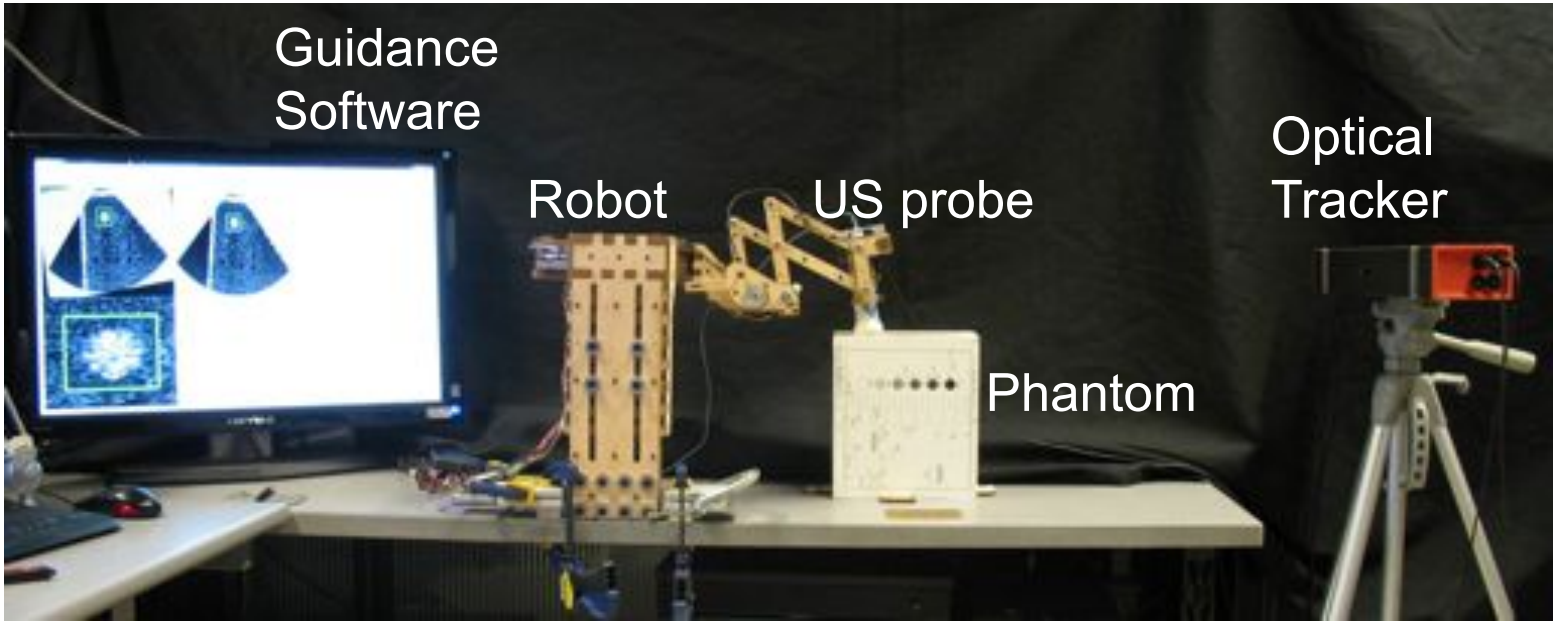

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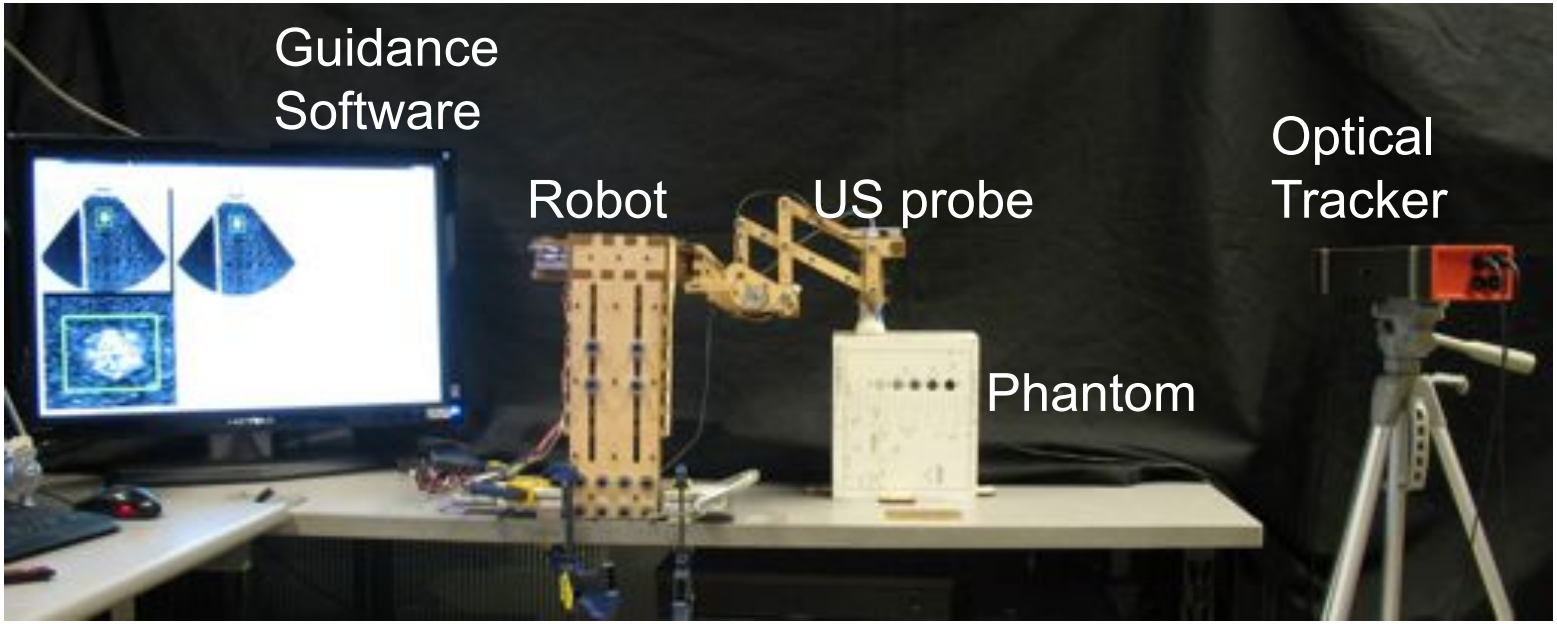

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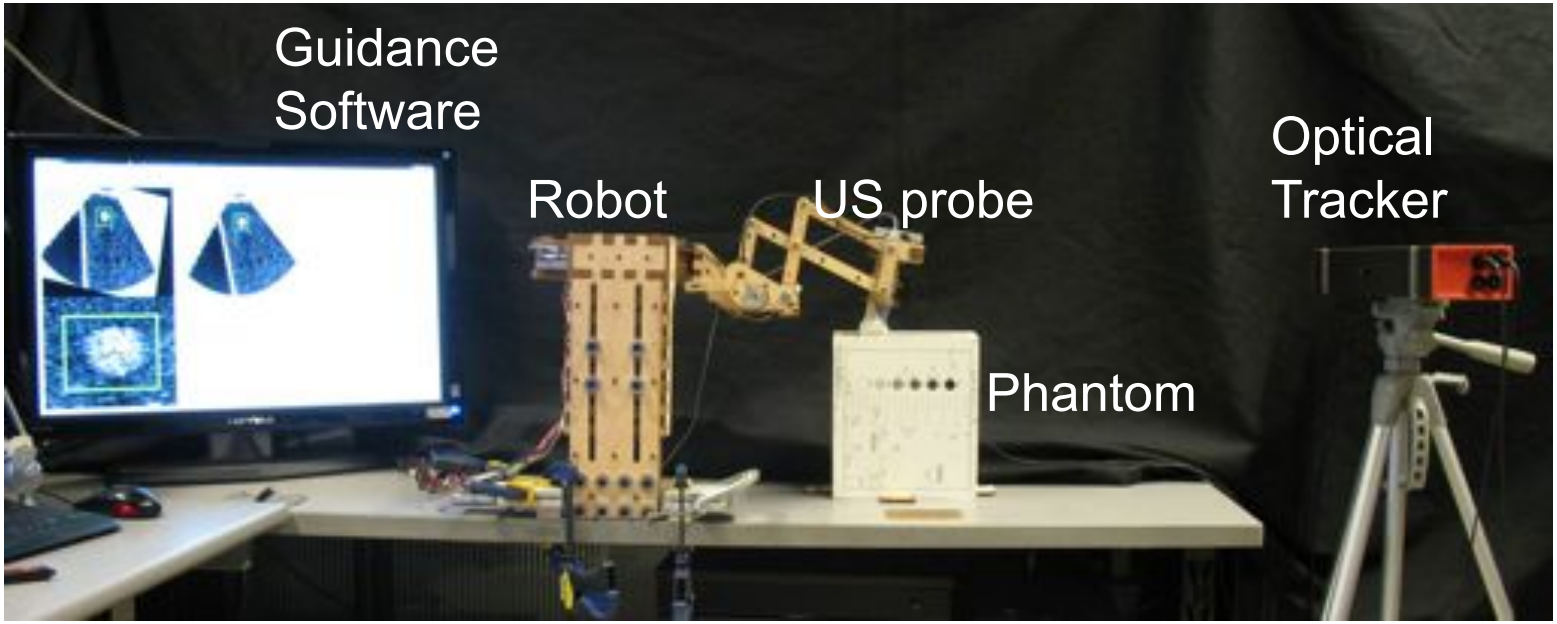

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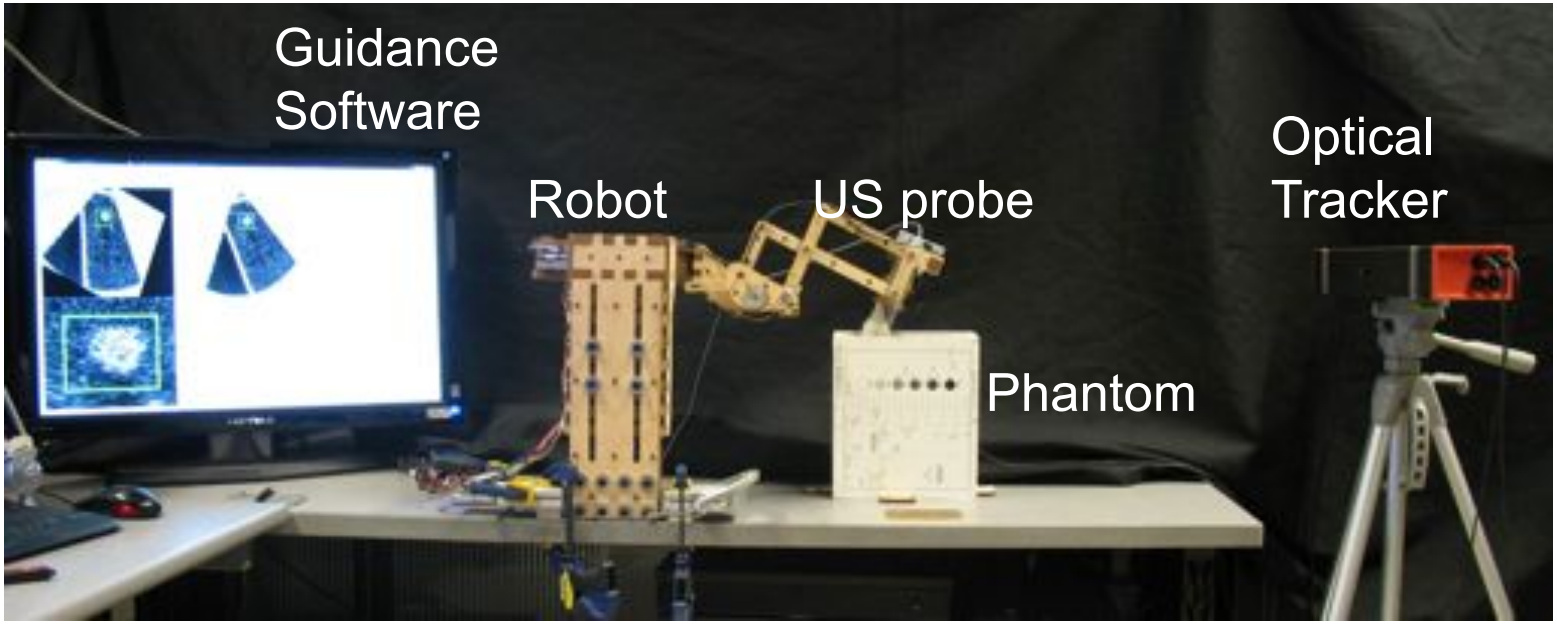
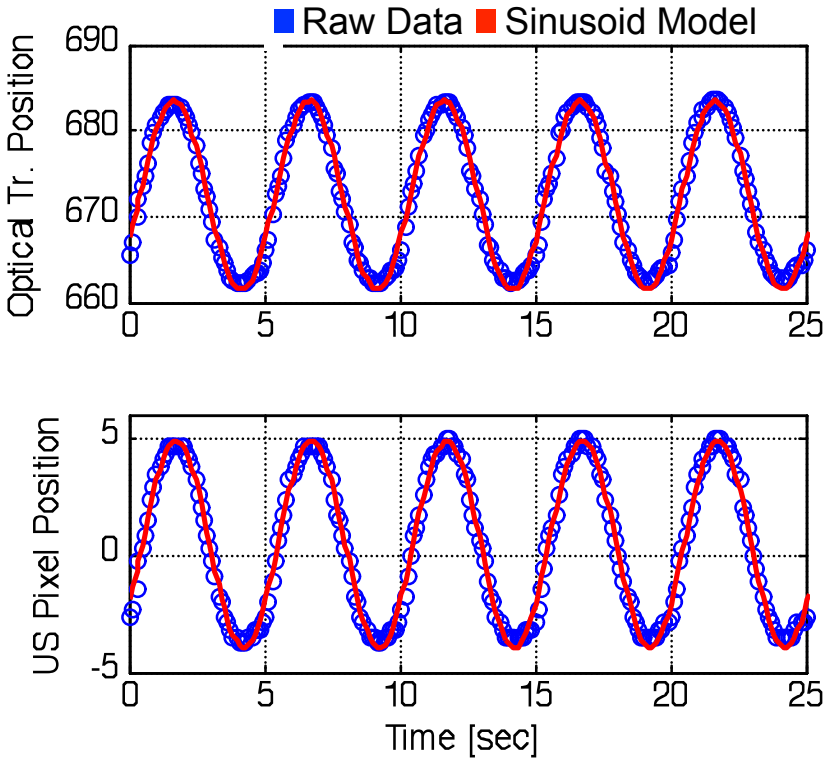
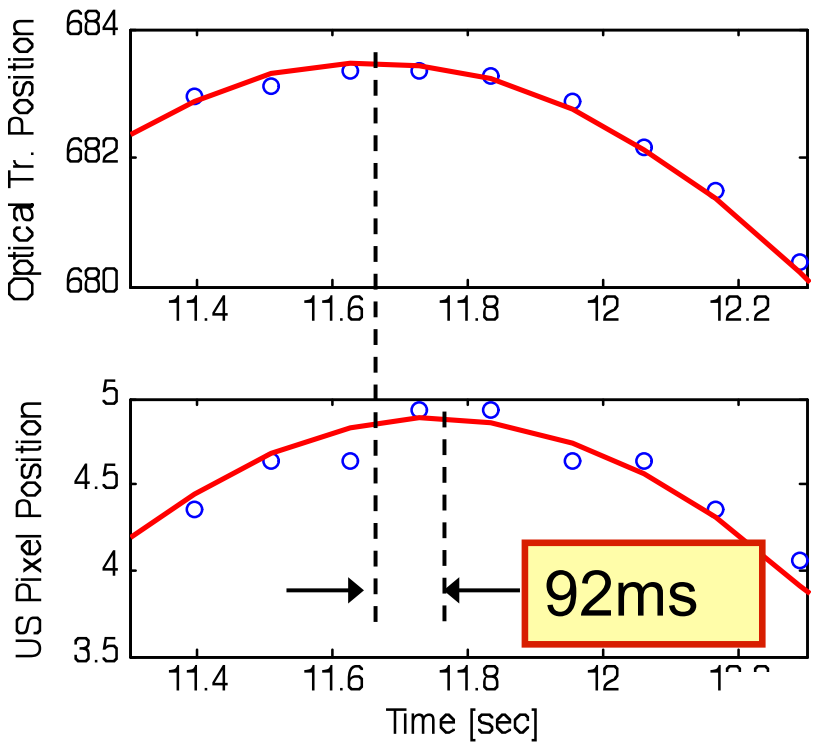


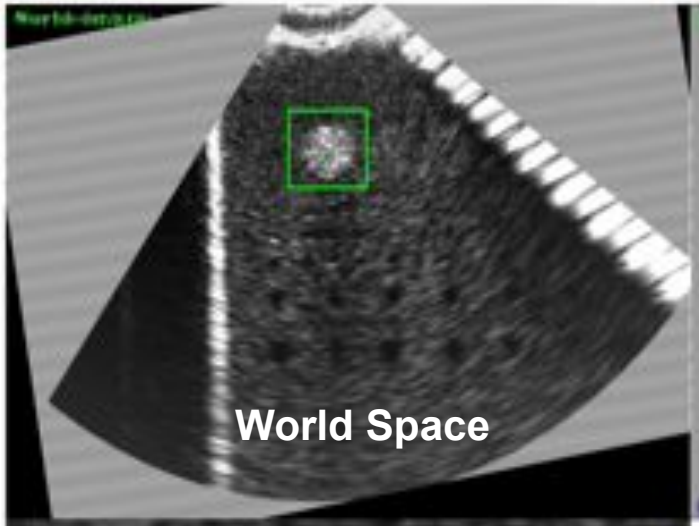
Temporal Calibration

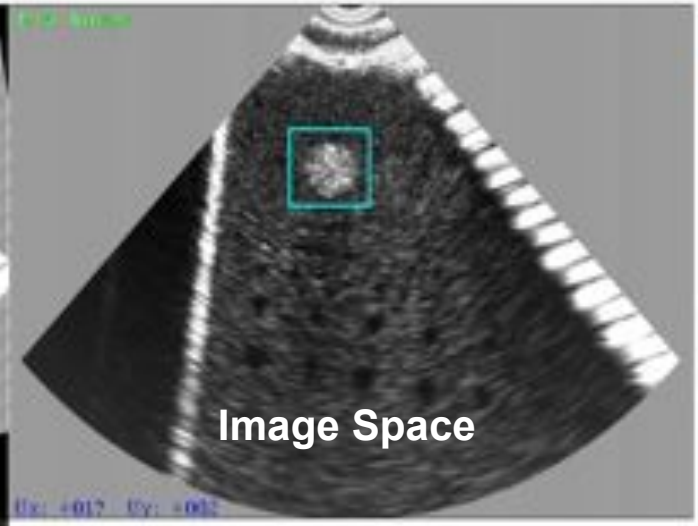
- Novel procedure:
  - Robot pitches US probe w/ sinusoidal motion
  - Static target imaged and tracked using NCC
  - Optical tracker data compared to US pixel data

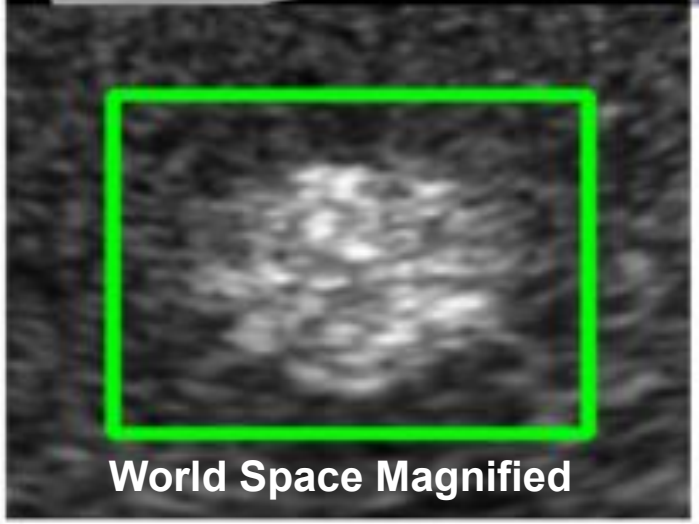




Evaluation: Spatial Localization Error







Variable	**Pitch**	**Pressure**
Experimental Parameters	-5 to 5° 0.4 Hz	0 to 12N
Tracking Error	**0.4±** **0.2 mm**	**0.6±** **0.3mm**
Max Tracking Error	0.8 mm	1.3 mm

➡ ***Real-time phantom localization error < 1mm***

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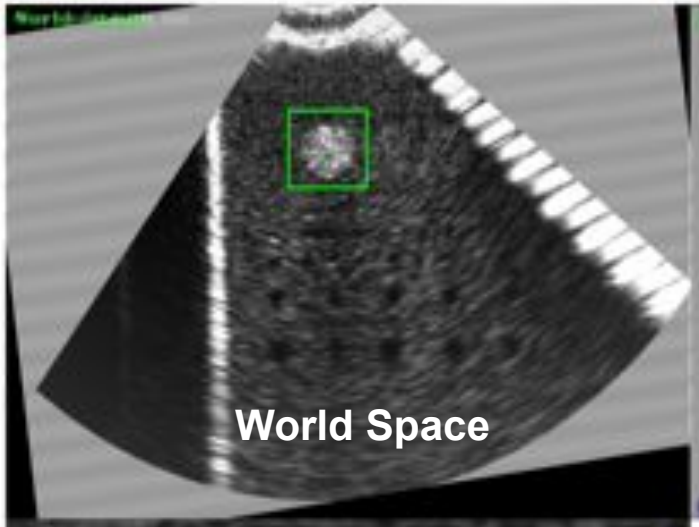

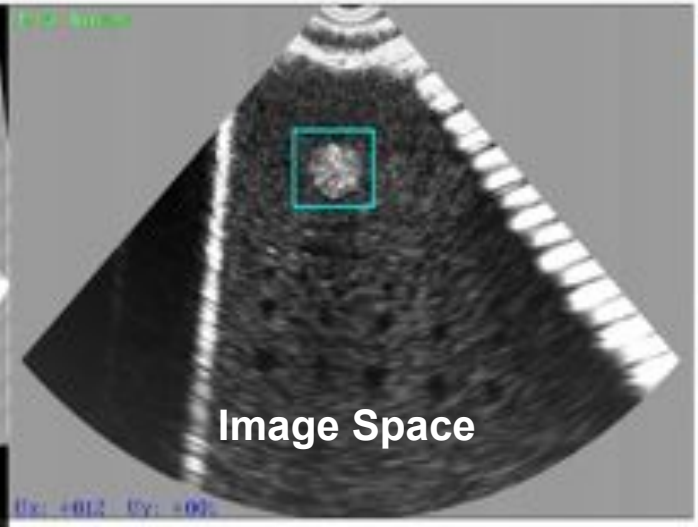

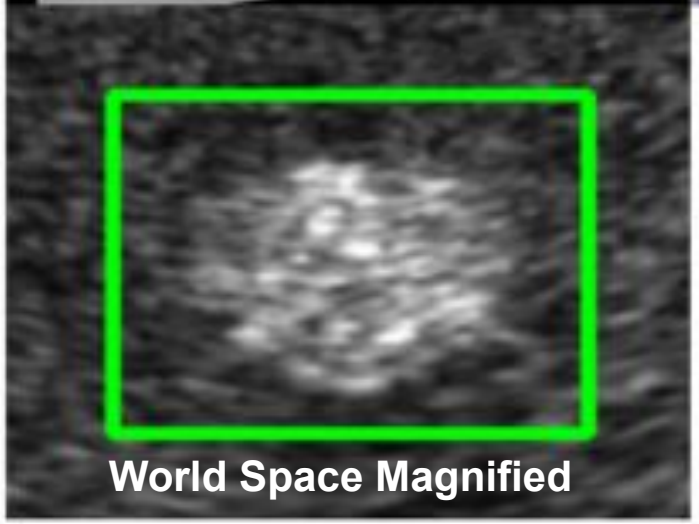

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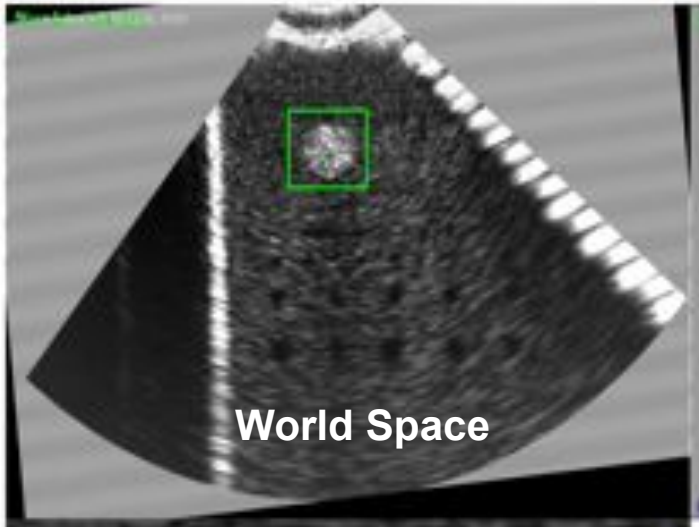

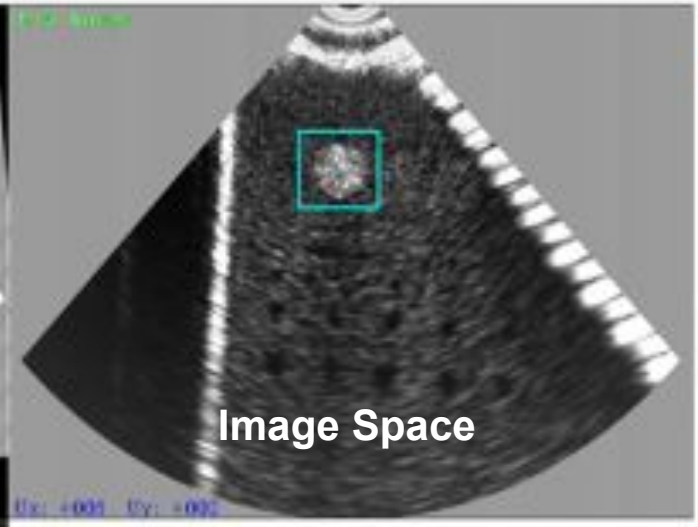

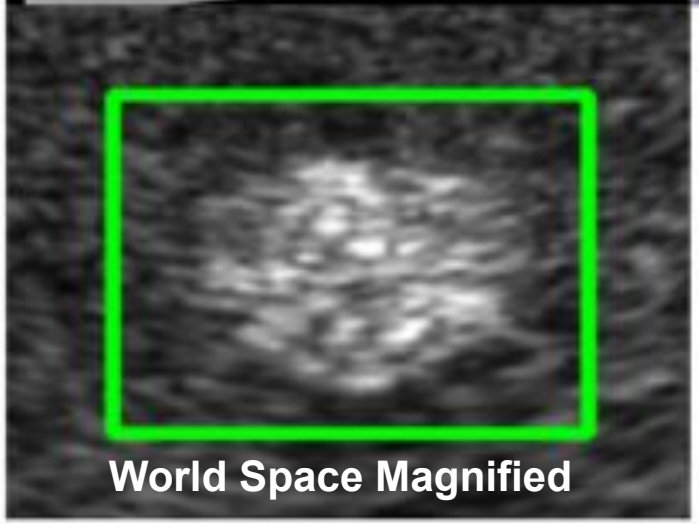

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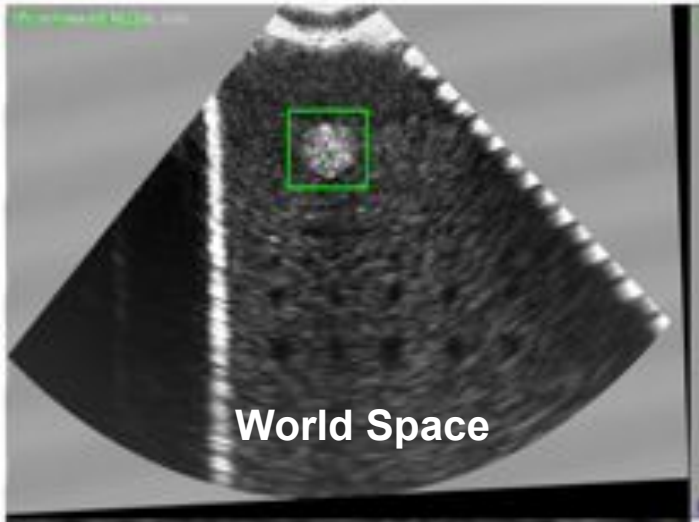

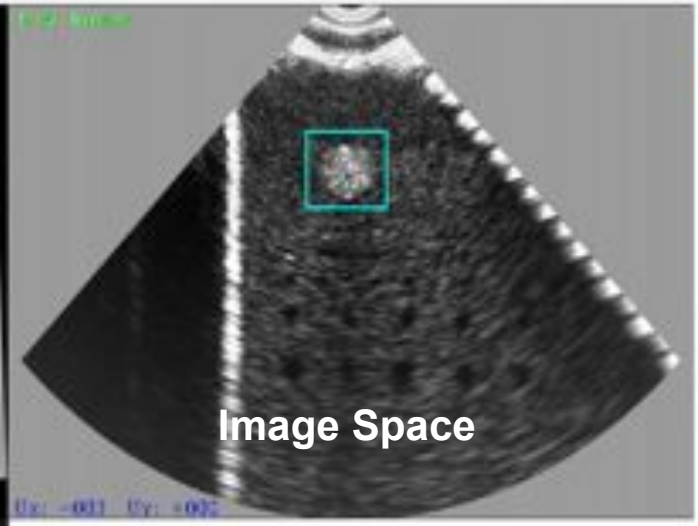

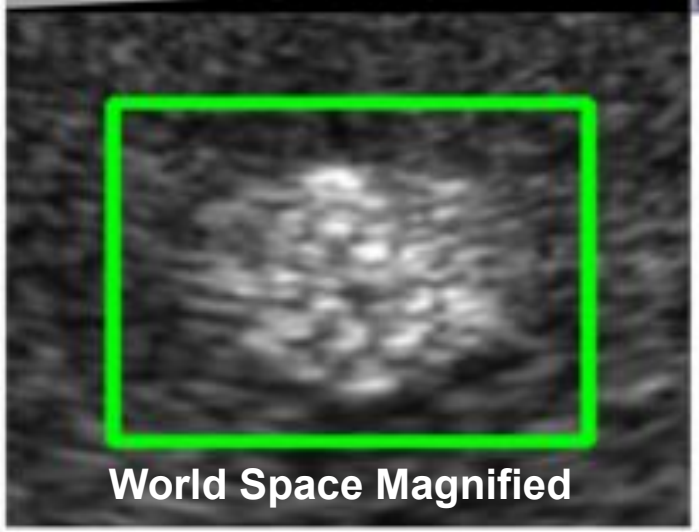

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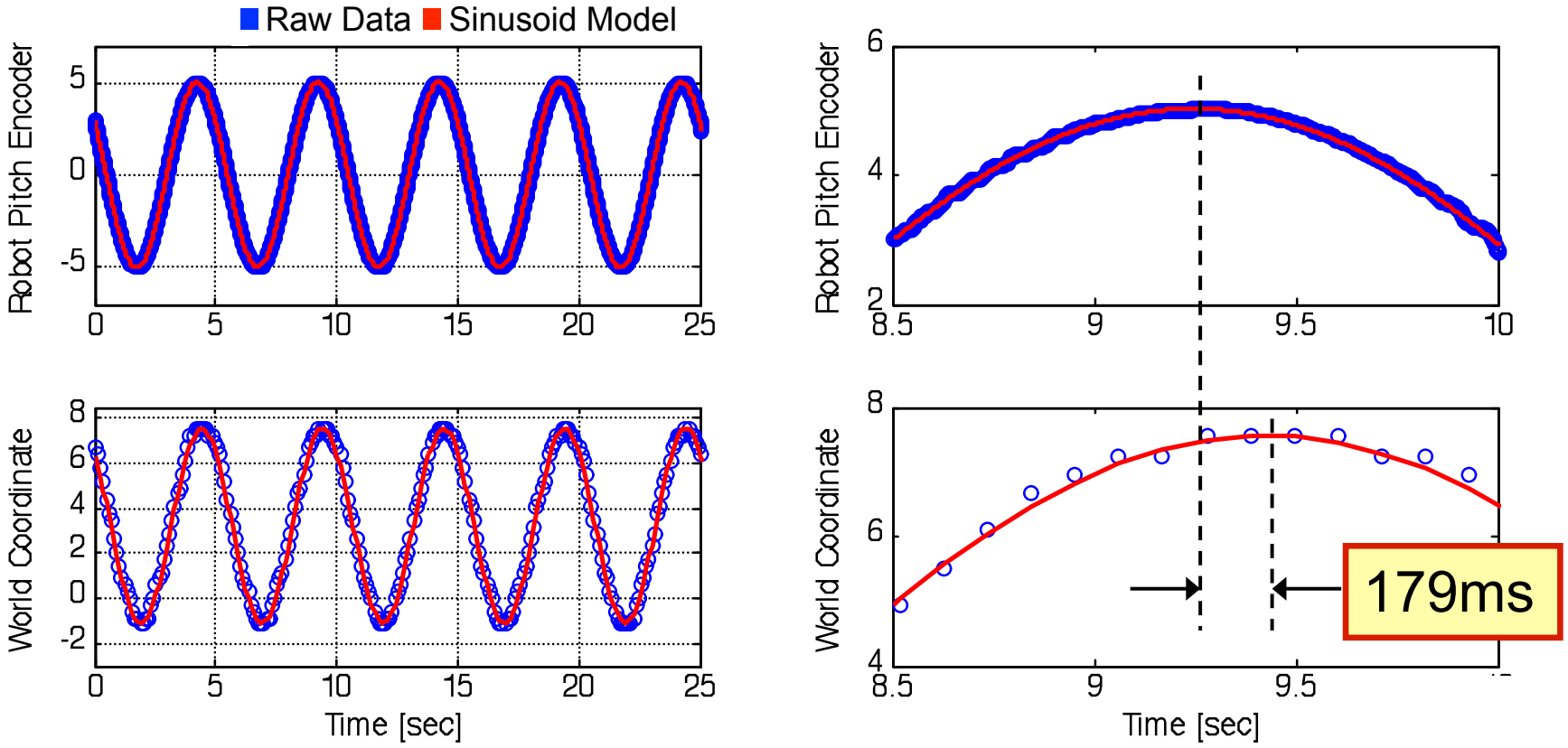
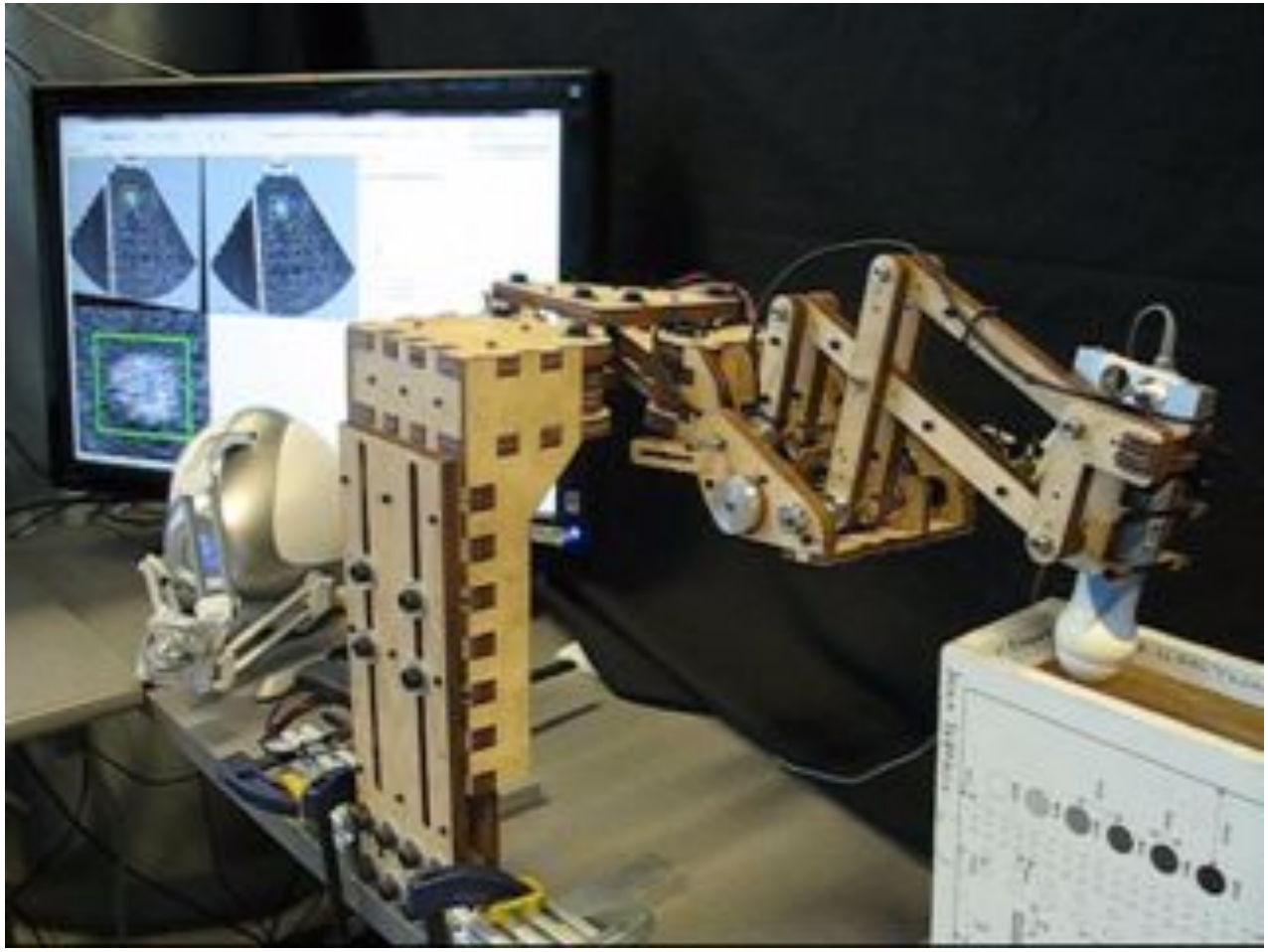
Evaluation: Time Lag

- Experimental method:
  - Similar to time calibration
  - Robot trajectory (1000Hz) compared to target trajectory in ultrasound sequence



Real-Time Guidance at 5 Hz and Sub-millimeter Localization Accuracy



Conclusions

- Remotely-controlled soft-tissue imaging in the treatment vault is feasible for multiple abdominal sites
- Sub-millimeter targeting accuracy with 2D imaging indicates feasibility for accurate real-time 3D ultrasound guidance
- Telerobotic US guidance system could offer non-invasive localization for IGRT that truly reflects soft-tissue anatomy

Questions?

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