# Robotic Ultrasound Assistance

*via Hand-Over-Hand Control*


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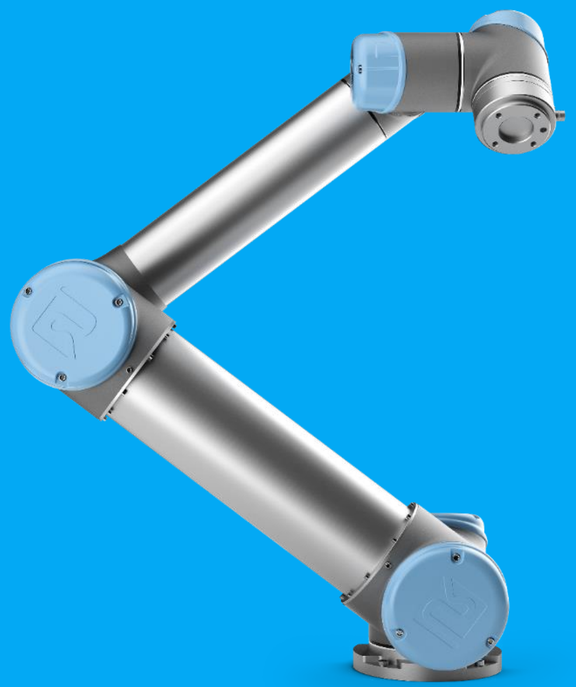

## Paper Critique

R. Finocchi, F. Aalamifar, T. Fang, R. Taylor and E. Boctor, "Co-robotic ultrasound imaging: a cooperative force control approach", *Medical Imaging 2017: Image-Guided Procedures, Robotic Interventions, and Modeling*, 2017. Available: 10.1117/12.2255271.

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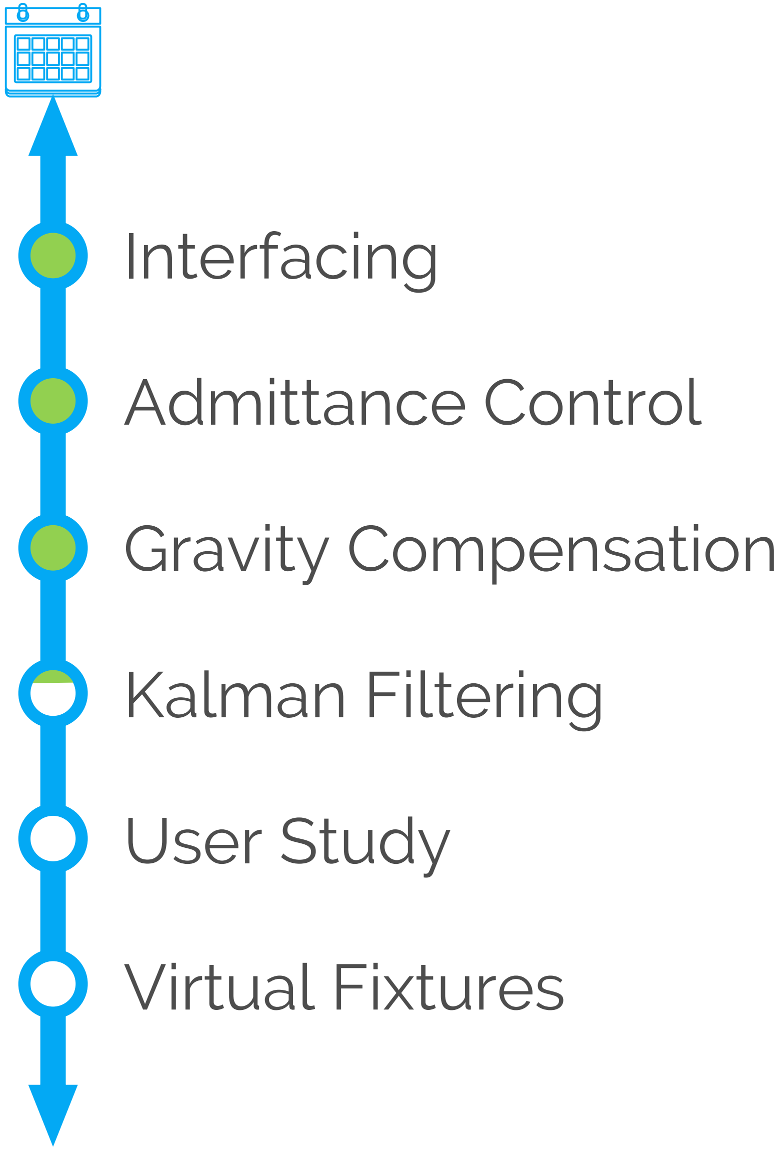
# Project Summary

- Problem
  Sonographers develop work-related musculoskeletal issues [1] by holding probe in static, contorted positions and applying large forces [2]

- Overall Goal
  Provide sonographers with a hand-guidable, ultrasound wielding robot to hold probe for them

- Personal Goal
  Improve the "transparency" of robot motion from previous prototypes




*[1] Rousseau, et al., 2013*
*[2] Schoenfeld, et al., 1999*

# Paper

R. Finocchi, F. Aalamifar, T. Fang, R. Taylor and E. Boctor, "Co-robotic ultrasound imaging: a cooperative force control approach", *Medical Imaging 2017: Image-Guided Procedures, Robotic Interventions, and Modeling*, 2017. Available: 10.1117/12.2255271.

- First prototype of robotic ultrasound assistance at JHU
- Very relevant to my work (which is improving Finocchi's methods)
  - Will use the same physical setup: robot, sensor housing, . . .
  - Can use algorithms as starting point
    - Filtering
    - Force/Torque (F/T) → velocity conversion
  - Results can be directly compared to gauge my success



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# Co-robotic ultrasound imaging: a cooperative force control approach

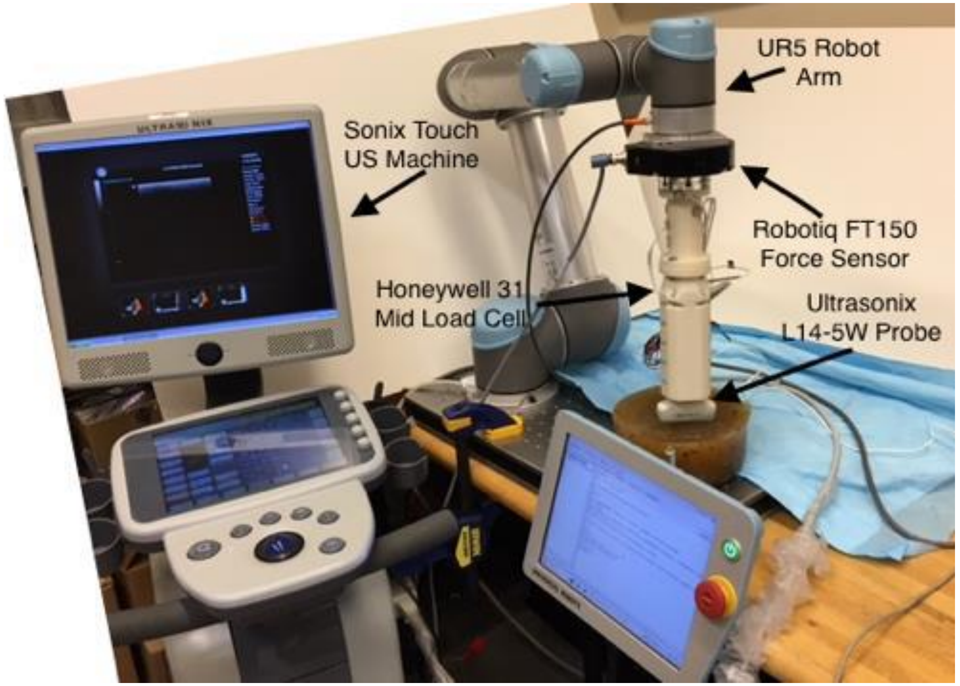
R. Finocchi, F. Aalamifar, T. Fang, R. Taylor and E. Boctor

Johns Hopkins University

R. Finocchi, F. Aalamifar, T. Fang, R. Taylor and E. Boctor, "Co-robotic ultrasound imaging: a cooperative force control approach", *Medical Imaging 2017: Image-Guided Procedures, Robotic Interventions, and Modeling*, 2017. Available: 10.1117/12.2255271.

# Summary

- **Design & develop robotic ultrasound assist prototype**
- User study on **strenuousness**, contact force **stability**, image **quality**




*[3] Finocchi, et al., 2013*

# Key Results

- Robotic assist system was **less strenuous**, allowed **more stable** contact force and therefore **better image quality**
- Alleviated hand tremor, minimized hand readjustments due to fatigue



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# Significance

**Human factors**

Lowered strenuousness

- Fewer sonographic acquisition-related injuries
- Potentially longer careers for sonographers

**Ultrasound Capabilities**

Better image stability

- Better resolution in synthetic aperture imaging
  - Zhang, et al., 2016 [4]
- Better tomographic reconstruction
  - Aalimafar, et al., 2016 [5]

# Necessary Background

- <u>Admittance control</u>: translating forces at robot's end effector (EE) into Cartesian linear and rotational EE velocities

1. Multiply EE F/T by gains to get EE velocity

$$\acute{x}_e = K\left(\begin{bmatrix} F_e \\ T_e \end{bmatrix}\right)$$

2. Resolve velocity to world frame

$$\acute{x}_w = Ad_{g_{we}} \acute{x}_e$$

3. Calculate individual joint velocities via constrained optimization problem

$$\acute{x}_w = J\acute{q}_w$$

Optionally constrained by:

$$H\dot{q}_w \leq h$$

$$\begin{bmatrix} -I_{6x6} \\ I_{6x6} \end{bmatrix} \dot{q}_w \leq \begin{bmatrix} \dot{q}_{low} \\ \dot{q}_{up} \end{bmatrix}$$



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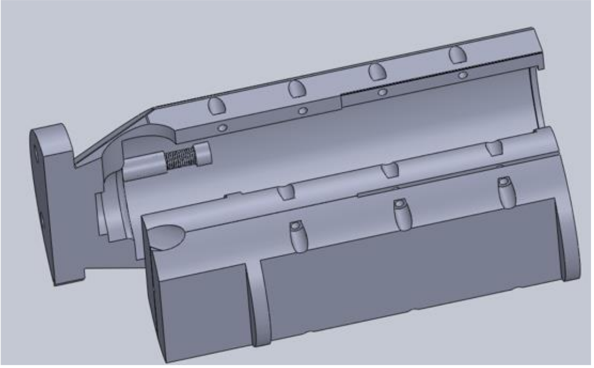
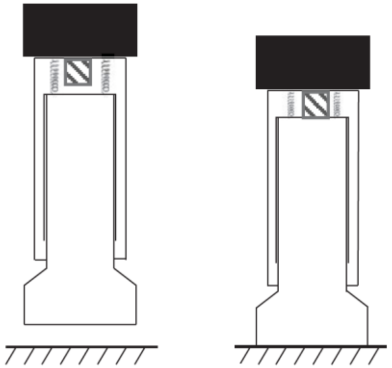
# Contributions

## 1. Probe and force/torque (F/T) sensor housing

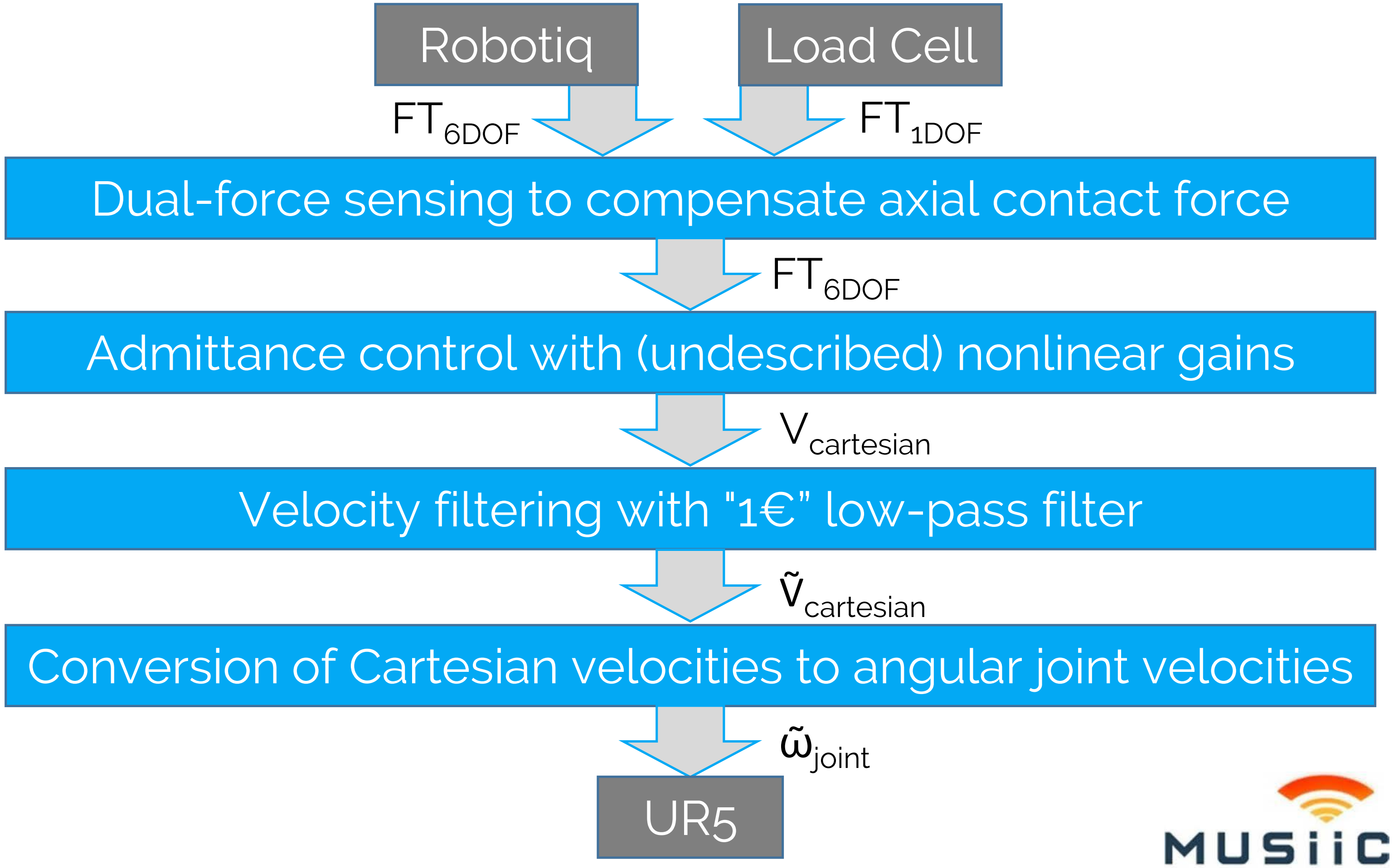


*[3] Finocchi, et al., 2013*



*[3] Finocchi, et al., 2013*

## 2. Admittance control workflow

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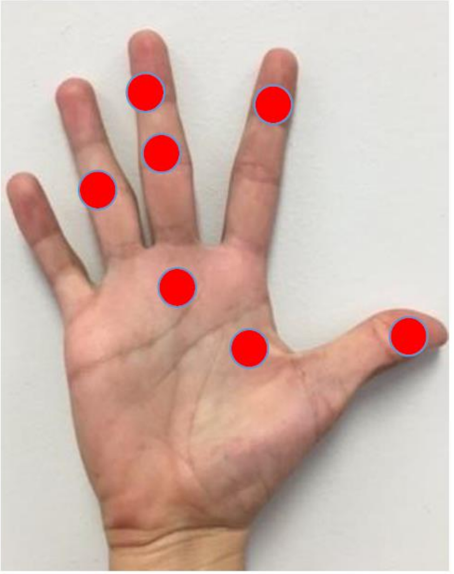
# User Study Experiment [1/2]

- Measuring: - grip force via FlexiForce film in 7 locations
  - perceived strenuousness via questionnaire
- Participants apply steady 5N, 15N, 25N, 35N, 45N force against a phantom for 10 sec with and without robotic assist, while given visual feedback




*[3] Finocchi, et al., 2013*



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# User Study Experiment [2/2]

- Measuring: ultrasound image stability via sum of square differences (SSD)

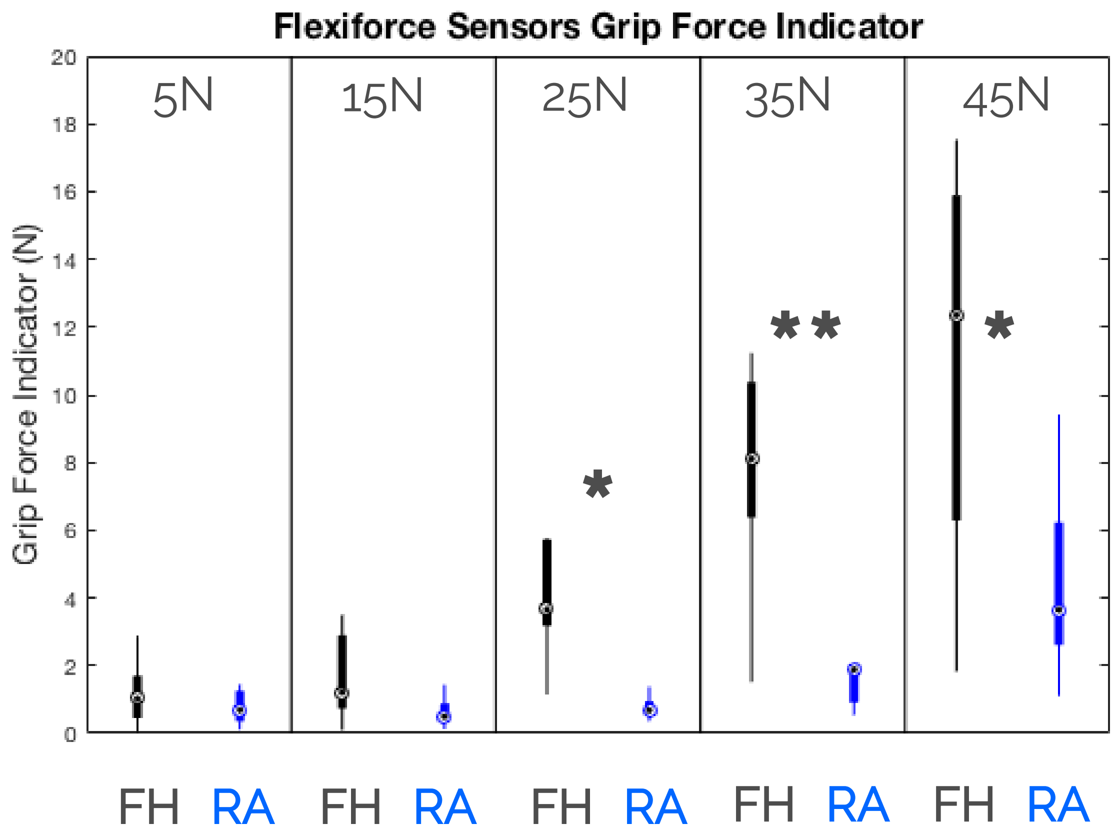
$$SSD = \sum_m \sum_n (I_{ref} - A_i)^2$$

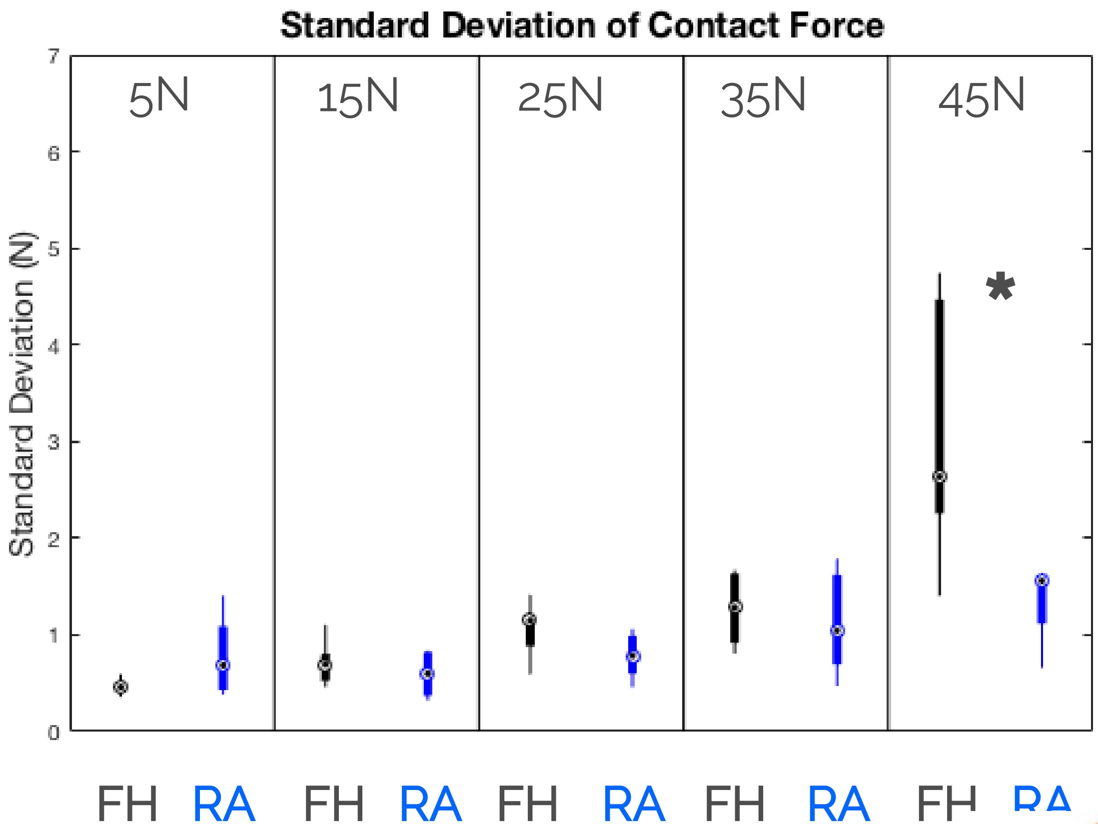
- Asked participants to apply steady 20N against a phantom for 20 sec

1. Freehand
2. With robotic assist, variable admittance
3. With robotic assist, maximum allowed force of 20N

# Results [1/2]: Grip Force Indicator

- **Comparing Freehand (FH) versus Robot Assisted (RA) grip force**, n=6
- Robot assist: ↓ avg grip force, ↓ contact force std dev (above 5N)



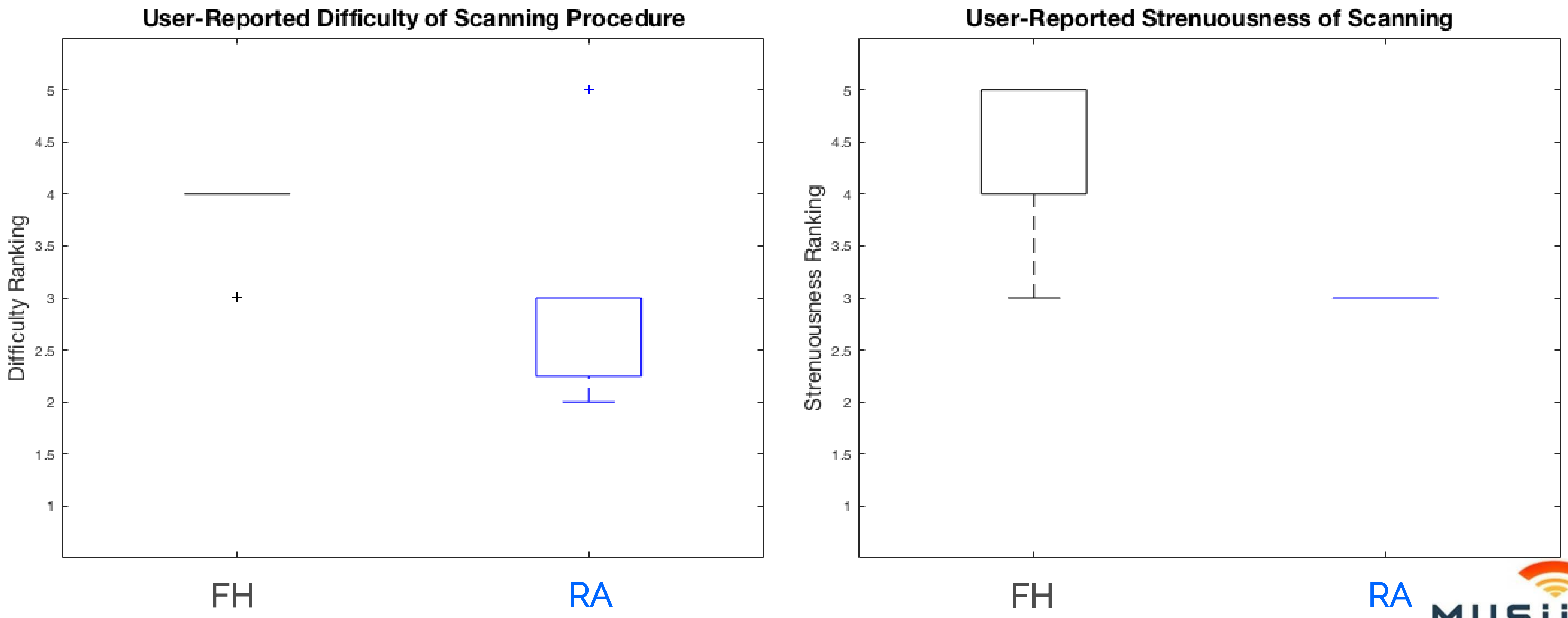




* = $p<0.05$ ** = $p<0.01$

[3] *Finocchi, et al., 2013*

# Results [1/2]: Questionnaire

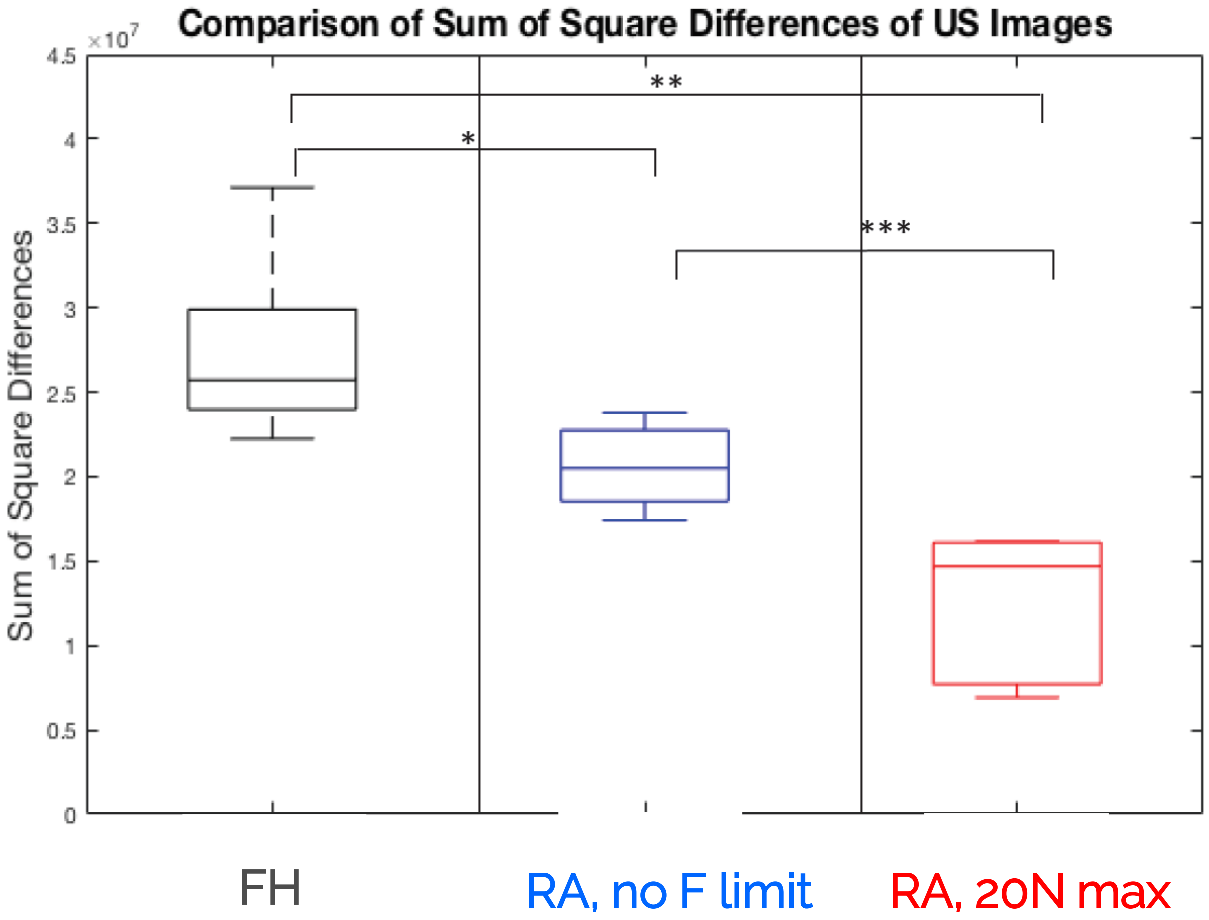
- **Comparing FH vs RA operator reported difficulty and strenuousness**, n=6
- Robot assist: ↓ difficulty (one outlier), ↓ strenuous




[3] *Finocchi, et al., 2013*

# Results [2/2]: Image Stability

- **Comparing FH vs RA image stability via SSD** of frames with first frame
- Robot assist: ↑ stability, further improved with 20N max limit




* = p<0.05
** = p<0.01
*** = p<0.001

*[3] Finocchi, et al., 2013*

# Assessment – Results

Promising for high force sonographic tasks

- ✓ Lowered strenuousness
- ✓ Lower mean grip force
- ✓ Lower standard deviation of contact force
- ✓ Higher image stability

# Paper Assessment – The Good and Bad

Good

- Strong demonstration of robot kinematic knowledge
- Good presentation of results

Bad

- Unclear pictures
  - Cluttered experimental image
  - No "cross-section" of probe holder showing usage
- Not reproducible
  - No discussion of gravity compensation
  - No discussion of nonlinear F/T → velocity conversion
- Not much description of the programmatic implementation



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# Research Assessment – The Good and Bad

**Good**

- Accomplished full implementation of an admittance controlled system
- Good mechanical clamshell design to allow dual force sensing

**Bad**

- Only compensated axial forces of probe
- User study with N=6 and N=7
- Uncertain relation of grip force and “exerted effort”
- Grip force measurement completely ignores typical sonographer grips. No sonographer feedback




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# Assessment – Future Work

Future improvements

- More user testing
- Use second 6DOF F/T to measure nonaxial probe forces
- Investigate better ways to characterize sonographer “exertion”

Future applications

- Virtual fixtures
- Synthetic tracked aperture ultrasound (STRATUS) imaging
- Tomography
- Catheter tracking
- “Repeatable biopsies”



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# Conclusion – Relevance to Me

Adopting:

- Physical setup (with slight housing mod by Fang, 2017 [6])
- Nonlinear admittance control gains (to start with)

Modifying:

- Load cell to be 6DoF F/T sensor to compensate non-axial probe forces
- User study to include sEMG sensing for quantifying exertion regardless of grip

Changing:

- Filtering to be done by adaptive Kalman filter instead of 1€ filter to infer inter-packet F/T values and command the robot faster



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# Additional References


[1] T. Rousseau, N. Mottet, G. Mace, C. Franceschini and P. Sagot, "Practice Guidelines for Prevention of Musculoskeletal Disorders in Obstetric Sonography", *Journal of Ultrasound in Medicine*, vol. 32, no. 1, pp. 157-164, 2013. Available: 10.7863/jum.2013.32.1.157.

[2] A. Schoenfeld, J. Goverman, D. Weiss and I. Meizner, "Transducer user syndrome: an occupational hazard of the ultrasonographer", *European Journal of Ultrasound*, vol. 10, no. 1, pp. 41-45, 1999. Available: 10.1016/s0929-8266(99)00031-2.

[3] R. Finocchi, F. Aalamifar, T. Fang, R. Taylor and E. Boctor, "Co-robotic ultrasound imaging: a cooperative force control approach*", Medical Imaging 2017: Image-Guided Procedures, Robotic Interventions, and Modeling*, 2017. Available: 10.1117/12.2255271.

[4] H. Zhang, A. Cheng, N. Bottenus, X. Guo, G. Trahey and E. Boctor, "Synthetic tracked aperture ultrasound imaging: design, simulation, and experimental evaluation", *Journal of Medical Imaging*, vol. 3, no. 2, p. 027001, 2016. Available: 10.1117/1.jmi.3.2.027001.

[5] [3]F. Aalamifar, H. Zhang, A. Rahmim and E. Boctor, "Image reconstruction for robot assisted ultrasound tomography", *Medical Imaging 2016: Ultrasonic Imaging and Tomography*, 2016. Available: 10.1117/12.2216518.

[6] T. Fang, H. Zhang, R. Finocchi, R. Taylor and E. Boctor, "Force-assisted ultrasound imaging system through dual force sensing and admittance robot control", *International Journal of Computer Assisted Radiology and Surgery*, vol. 12, no. 6, pp. 983-991, 2017. Available: 10.1007/s11548-017-1566-9.

# Image References

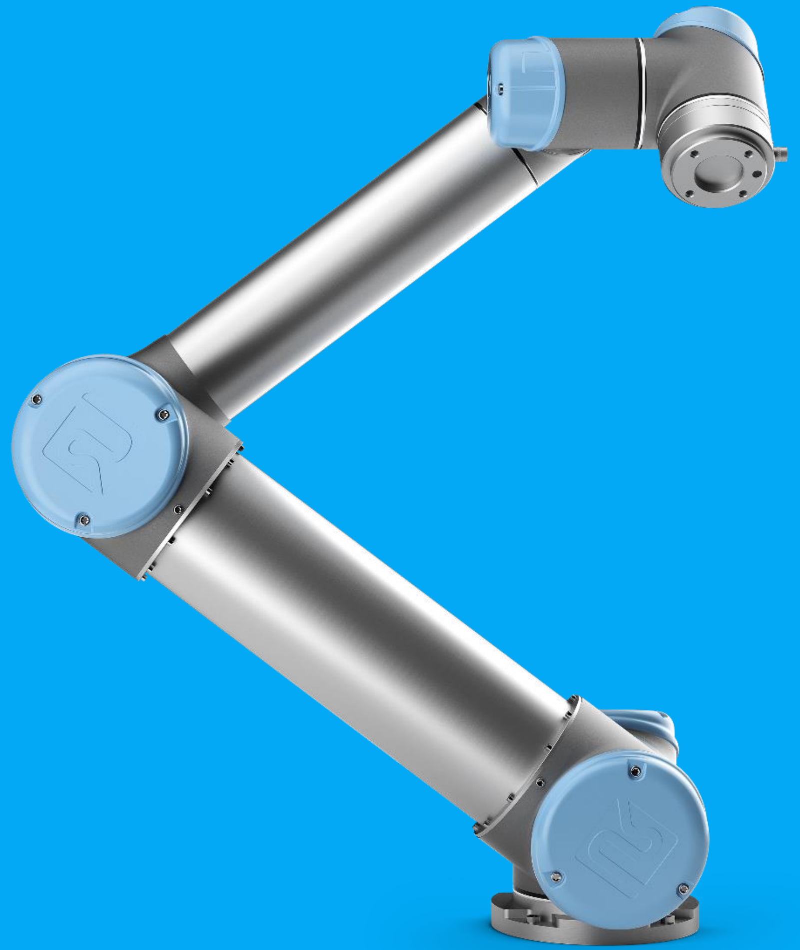
Title
https://www.universal-robots.com

Ultrasound Probe
https://www.radiology.ca/services/ultrasound

Check mark
https://en.wikipedia.org/

# Thank you!

Questions?



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