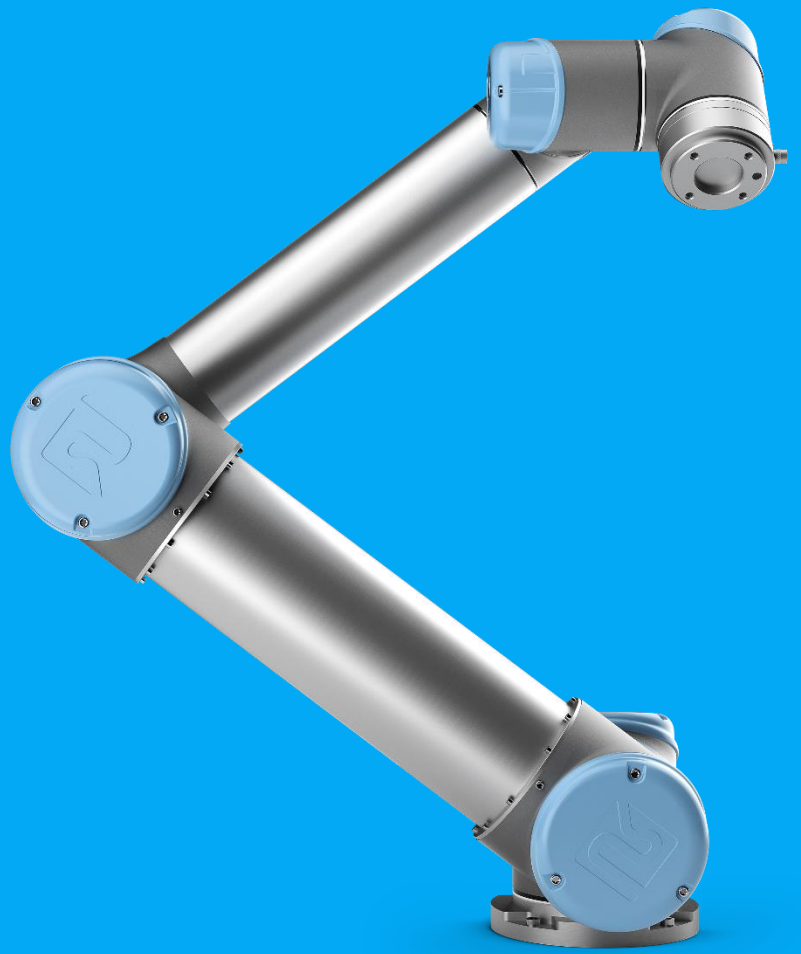
Robotic Ultrasound Assistance

via Hand-Over-Hand Control

Group 5:
Kevin Gilboy

Mentors:
Dr. Emad Boctor
Dr. Mahya Shahbazi



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Clinical Motivation

Ultrasound-guided procedures require **long periods of time** spent holding the probe in **static**, **contorted positions** and **applying large forces** [1]

63% - 91% of sonographers develop musculoskeletal disorders [2]

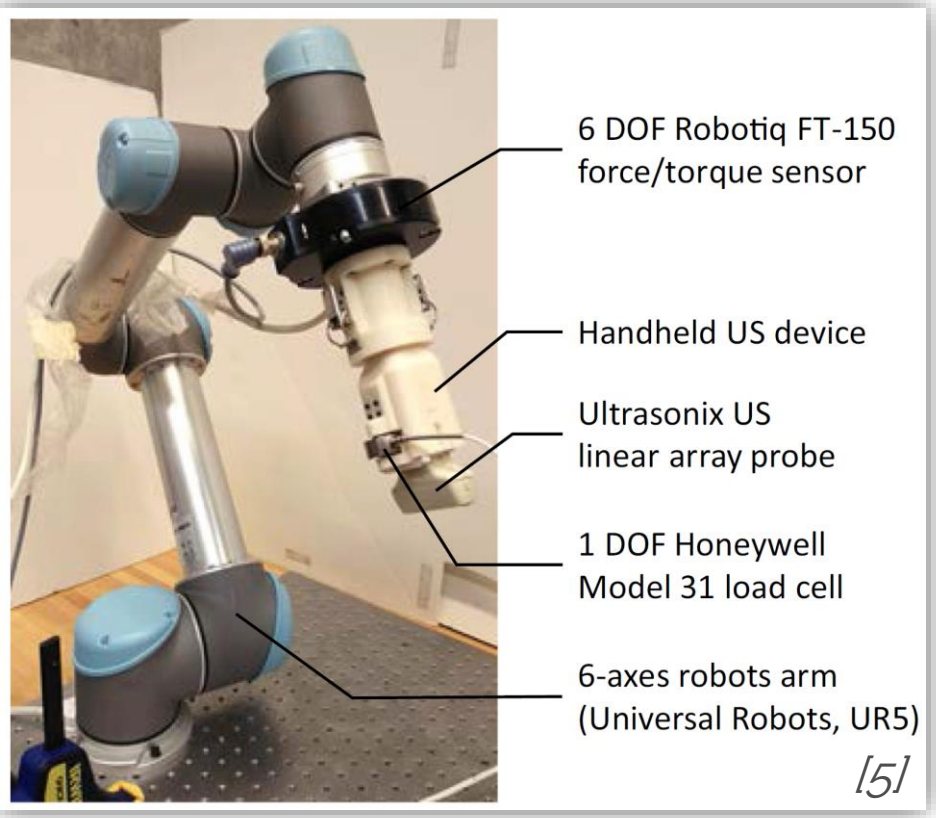
- General population: 13% - 22%

Vision: hand-guide an ultrasound-holding robot to a POI, and have the robot do all the strenuous holding!

[1] Schoenfeld, 1999
[2] Rousseau, 2013

Prior Work - JHU

- Finocchi Thesis ('16) [3,4]
  - Initial mechanical design
  - 1€ smoothing filter
  - Nonlinear Force→Velocity gains
  - Virtual fixtures for synthetic aperture
  - User study
- Fang CIS2 ('17) [5]
  - Improved probe holder



[3] Finocchi, 2016
[4] Finocchi, et al., 2017
[5] Fang, 2017

My Goal

- **Improve the transparency** of "power-steering" admittance control for a hand-over-hand, ultrasound-wielding robot (6 DOF)
- Use dual-force sensing to **maintain force profiles and virtual fixtures**

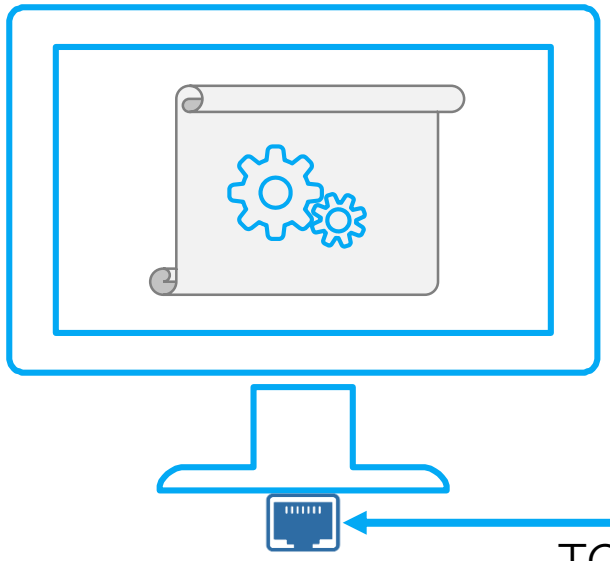
If successful…

Progression in **mitigating sonographer wrist issues**

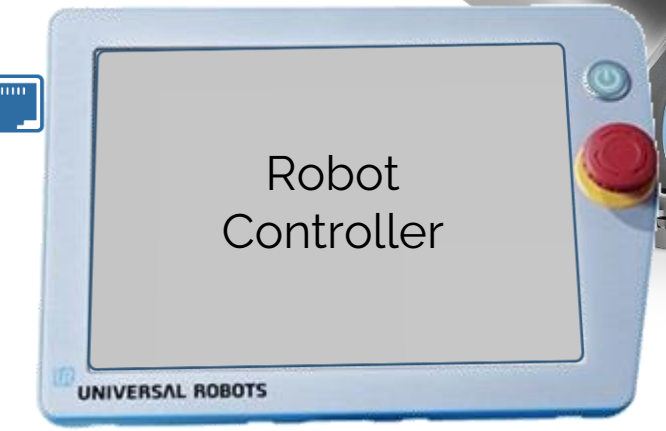
Important **"step 1"** for many robotic ultrasound procedures

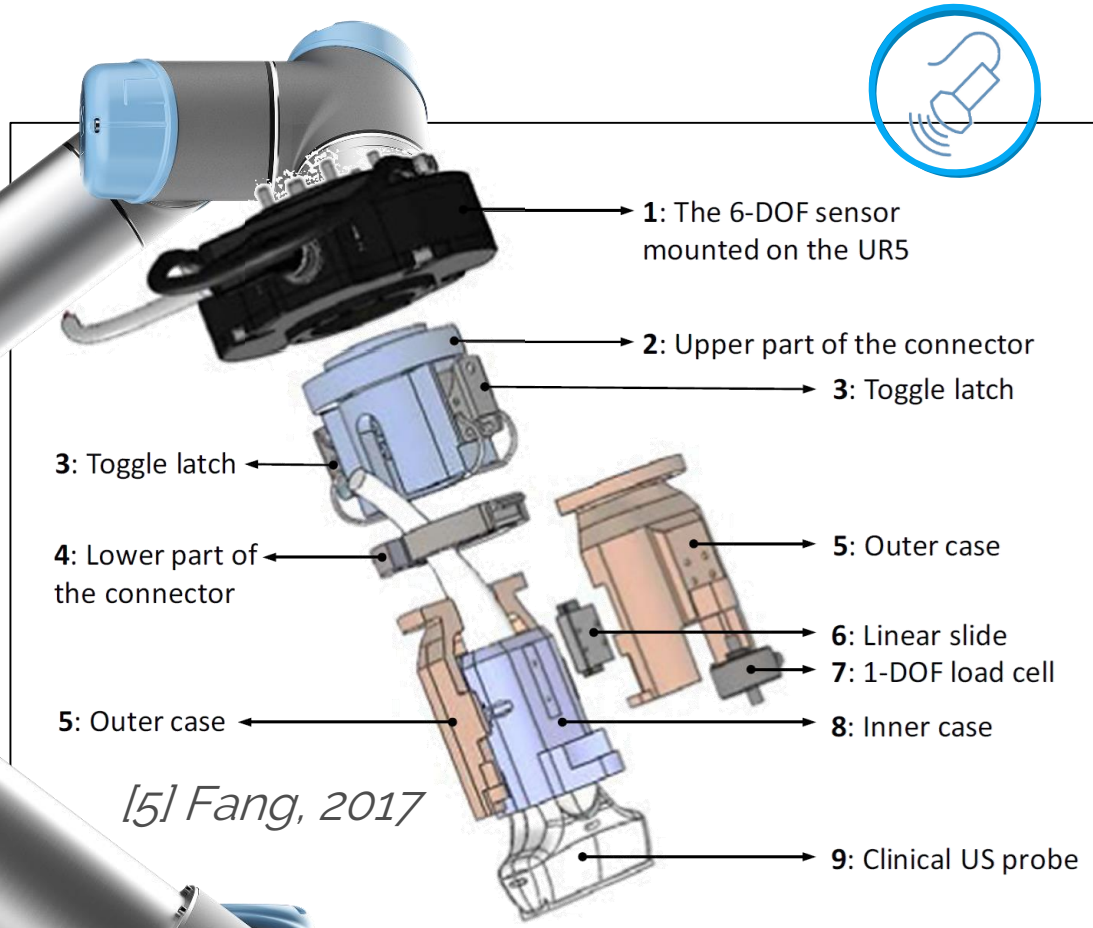
- Repeatable biopsy, synthetic aperture…
- US Tomography – my thesis ☺

General Setup

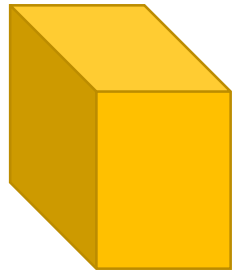


TCP





[5] Fang, 2017



Phantom

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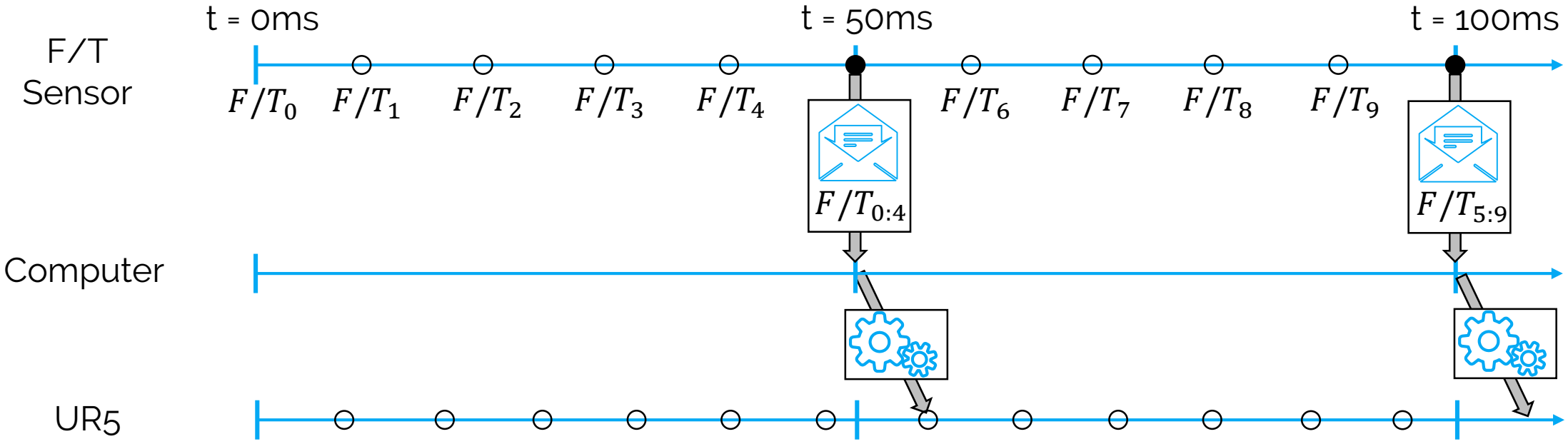
Technical Approach [1/2] - Controls

- Previous work focused on smoothing F/T measurements (1€ filter) [3,4]
- Data sparsity, latency, and wasted cycles is an equally large issue…
  - 100 Hz of F/T data received at 20 Hz

[3] Finocchi, 2016
[4] Finocchi, et al., 2017



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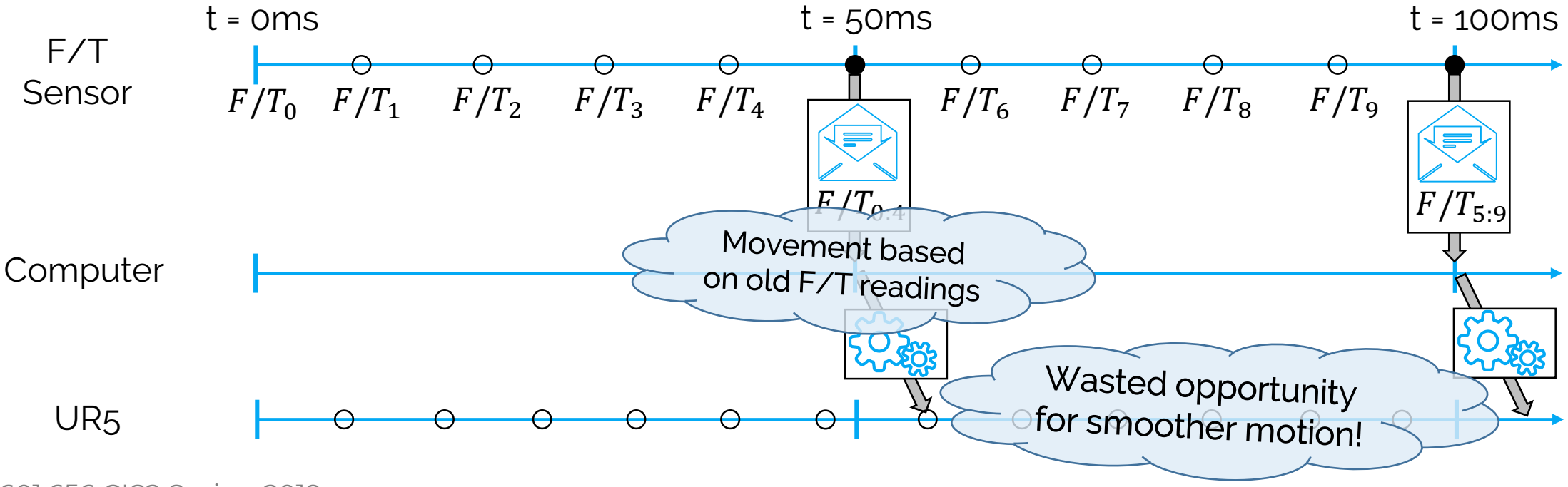

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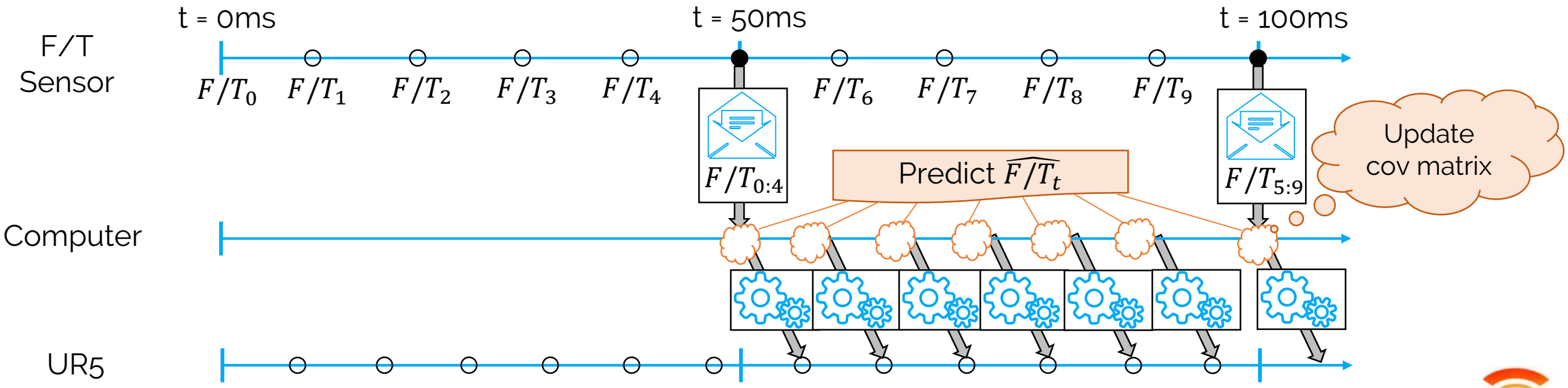
Technical Approach [1/2] - Controls

- Will develop an adaptive Kalman filter observer to predict inter-packet F/T readings, reduce the effects of F/T, TCP latency
  - Adaptive since it compares real observations with previous predictions to adjust covariances and improve future predictions



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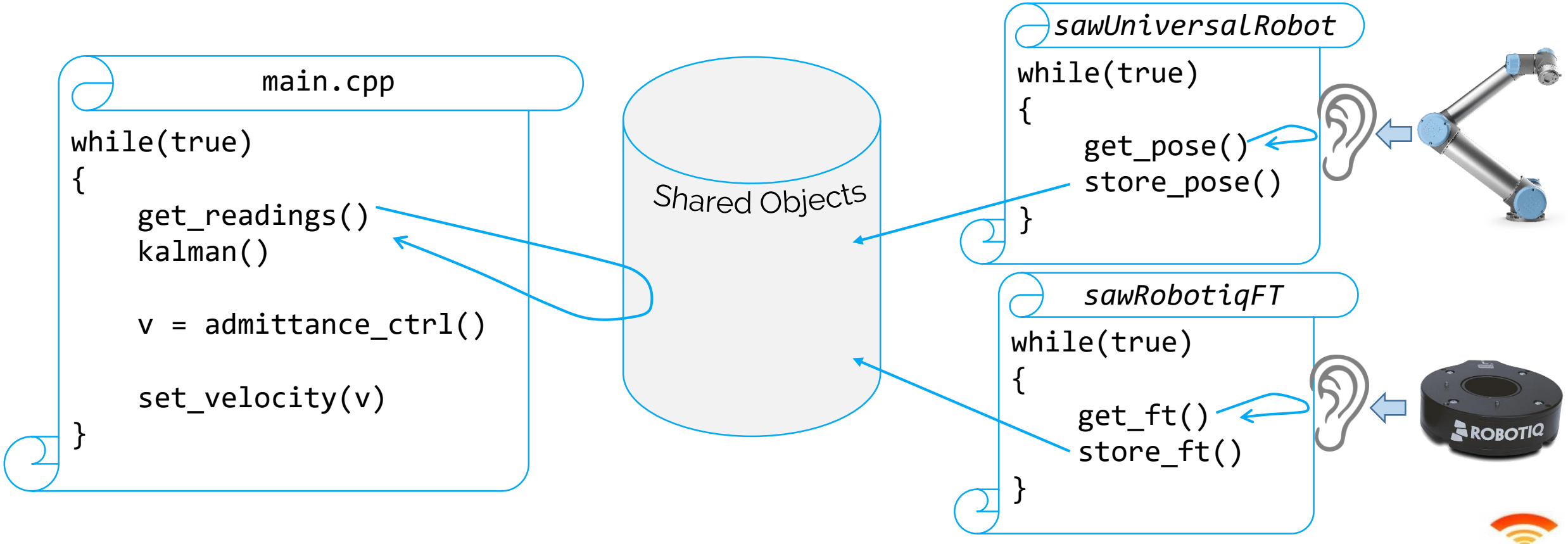
Technical Approach [2/2] – Program Optimization

- Previous work was a great proof-of-concept, but inherently slow
  - Used MATLAB scripting
  - Used UR5 as a TCP client

Speedup Opportunities?

Technical Approach [2/2] – Program Optimization

- Will solely use **C++** running on a desktop, no client queries
- **CISST/SAW** libraries for interfacing



** diagram very simplified ☺*

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V&V Testing Approach

- **Verification** – is *it* doing *it* right?
  - Questionnaire for sonographers regarding **perceived wrist strain** with and without the robotic assist
  - Will need some **quantitative test** for "improved transparency." Finocchi [3,4] used strain gauges on the probe handle.

- **Validation** – is *it* the right *it*?
  - Questionnaire for sonographers regarding **clinical usability** of the robotic assist in its final state

[3] Finocchi, 2016
[4] Finocchi, et al.,2017

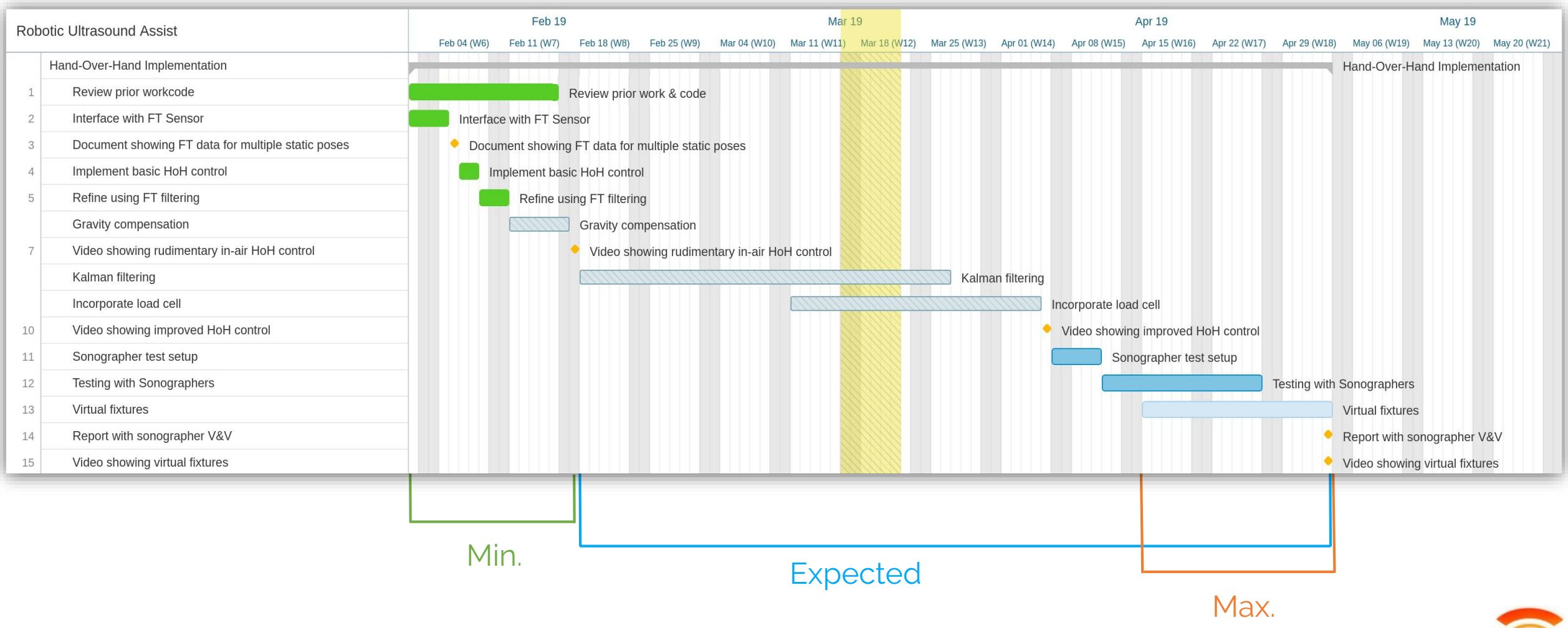
Key Activities and Deliverables

	Activity	Deliverable
Min.	C++ interface with robot and dual force sensors to collect data	Datasets for multiple static poses
	Implement rudimentary in-air admittance control, gravity compensation	Video of functionality, graphs showing compensation, code
Expected	Implement improved admittance control incorporating probe-pt. force feedback	Video of functionality, code
	Qualitatively & quantitatively evaluate the system with test subjects	Report with graphs and statistical validation
Max.	Virtual fixtures	Video of functionality, code

Dependencies

Dependency	Need	Status	Followup	Contingency Plan	Planned Deadline	Hard Deadline
Robot	Quite obvious ;)	Have a working UR5	N/A	If breaks, could seek continued permission to use UR3 in B08	2/1	2/1
6DOF F/T Sensor	Admittance control input	Have a working Robotiq FT-150	N/A	If breaks, look to order another through the MUSiiC Lab	2/1	2/1
Load Cell	Decouples force from probe on pt.	Have an untested Honeywell Model 31	Must test the load cell asap	If broken, look to order another through the MUSiiC Lab	2/12	2/28
Ultrasound Probe	Key component for realistic testing	Have a curved probe, several others available in our lab pod	N/A	If disappears, seek permission to use another probe available in lab pod	2/1	4/1
Phantom (non-anatomical)	Something to test the probe on	Un-acquired, several available in our lab pod	Seek permission from Dr. Boctor to use phantoms in lab pod	If unable to acquire, test on easily available surfaces like polyethylene foam	2/1	4/1
HIRB Approval	Testing with sonographers	Unsubmitted, untrained for human subjects testing, HIPPA	Undergo training, revise and submit plan from Nov '16	If unapproved, test on non-sonographers	2/22	3/1

Timeline – HoH Control



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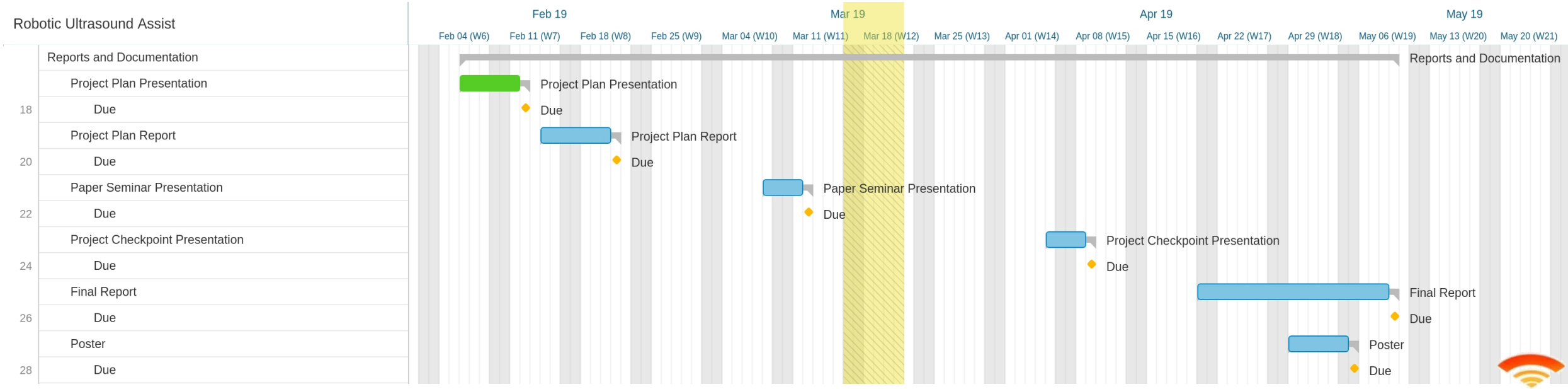
Timeline – TL&DR

	Key Activity Milestones	Deliverables
Min.	• 2/4 Sensor interfacing • 2/16 Gravity compensation	• 2/5 Document of static sensor readings for multiple poses • 2/17 Video of in-air HoH control
Expected	• 3/27 Kalman filtering • 4/4 Load cell • 4/26 Sonographer testing	• 4/5 Video of functionality • 5/3 Document of test results
Max.	• 4/26 Virtual fixtures	• 5/3 Video of functionality

Timeline – Dependency Resolution

Timeline – Reports and Documentation



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Roles and Responsibility

The Team:

Kevin Gilboy: Sole responsibility for all tasks

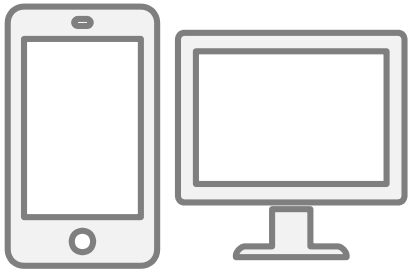
Mentors:

Dr. Emad Boctor: Ultrasound, CIS, JHMI connections, “the vision”

Dr. Mahya Shahbazi: Control systems design, CIS, robot kinematics

Management Plan

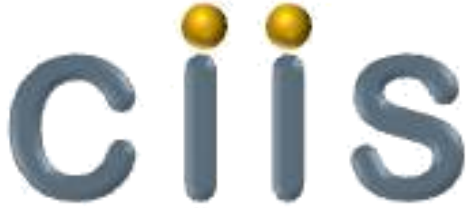
- Meetings
  - Weekly meetings with Dr. Boctor
  - Ad-hoc, likely weekly, meetings with Dr. Shahbazi



Communication

Code
(private)

Reports



Final Reports and Presentations

Reading List

Older

H. K. **Zhang**, R. Finocchi, K. Apkarian and E. M. Boctor, "Co-robotic synthetic tracked aperture ultrasound imaging with cross-correlation based dynamic error compensation and virtual fixture control," *2016 IEEE International Ultrasonics Symposium (IUS)*, Tours, 2016, pp. 1-4. Available: 10.1109/ULTSYM.2016.7728522

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.

R. **Finocchi**, "Co-robotic ultrasound imaging: a cooperative force control approach", The Johns Hopkins University, 2016.

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.

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.

S. **Farsoni**, C. Landi, F. Ferraguti, C. Secchi and M. Bonfe, "Compensation of Load Dynamics for Admittance Controlled Interactive Industrial Robots Using a Quaternion-Based Kalman Filter", *IEEE Robotics and Automation Letters*, vol. 2, no. 2, pp. 672-679, 2017. Available: 10.1109/lra.2017.2651393.

Newer

Additional References

[1] 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.

[2] 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.

[3] R. Finocchi, "Co-robotic ultrasound imaging: a cooperative force control approach", The Johns Hopkins University, 2016.

[4] 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.

[5] 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

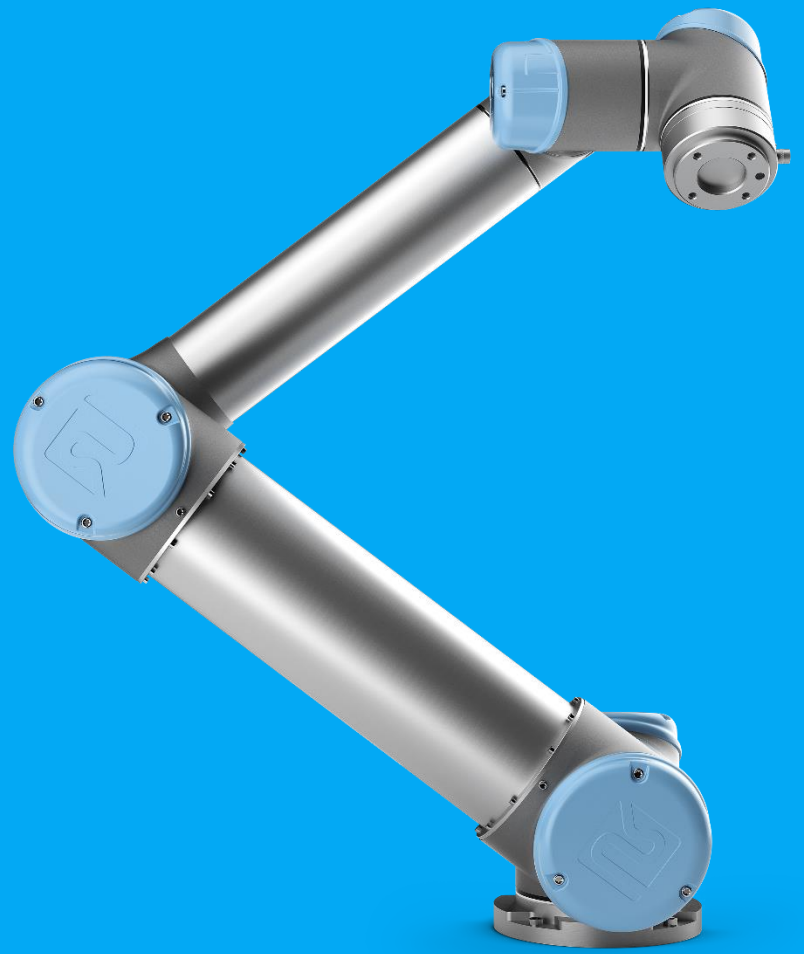
General Setup
https://thenounproject.com/
https://www.universal-robots.com

Program Optimization
https://www.universal-robots.com
https://robotiq.com/
https://www.pngarts.com/

Management Plan
https://git-scm.com/
https://overleaf.com/
https://ciis.lcsr.jhu.edu/

Thank you!

Questions?



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Appendix: Full HoH Gantt