Robotic Ultrasound Power-Steering via Hand-Over-Hand Control

Computer Integrated Surgery II - Spring, 2019

Kevin Gilboy*, advised by Dr. Mahya Shahbazi, Dr. Emad Boctor**

*kevingilboy@jhu.edu, **eboctor1@jhmi.edu

Introduction

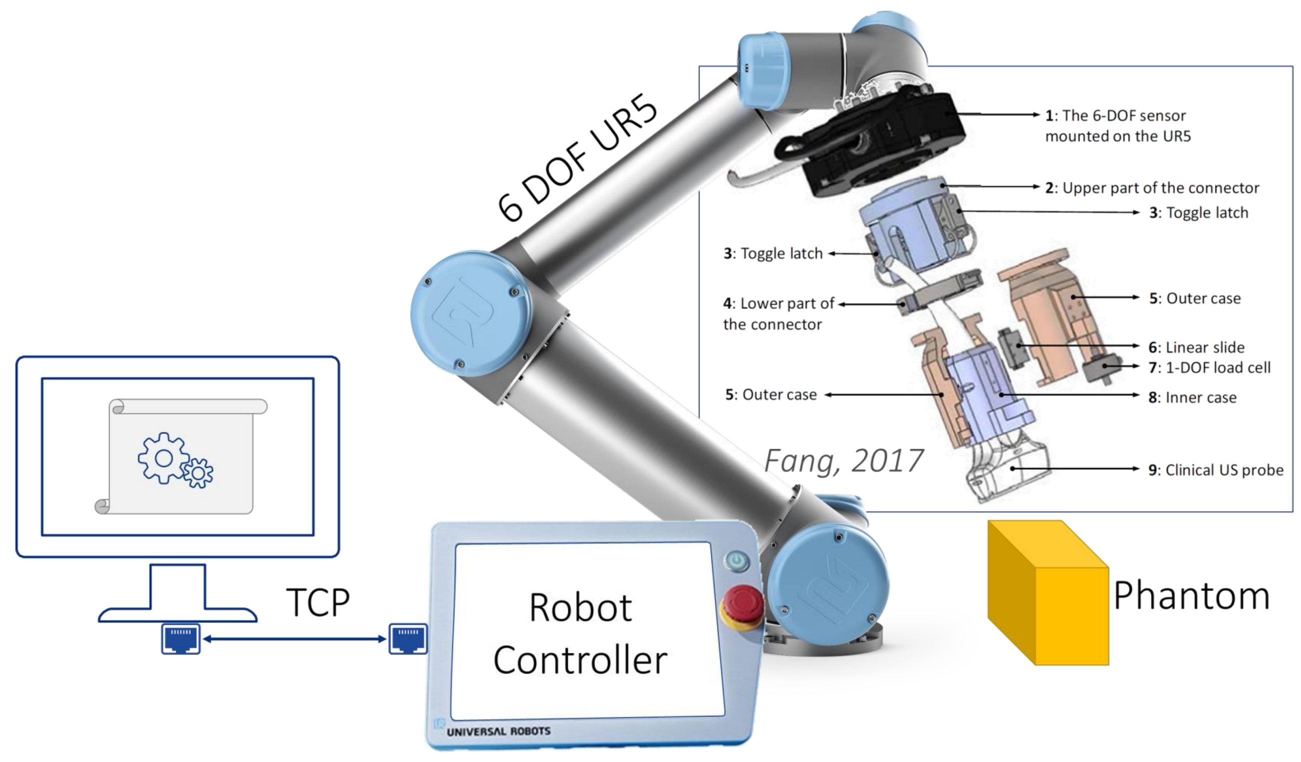
- **Implemented admittance control** for a UR5 robot to assist and ease ultrasound (US) scanning
- Improved upon a previous attempt by using observer-based **Kalman filtering to infer/smooth force readings** and produce more transparent motion

This was done in an effort to **reduce sonographer exertion while scanning**, as well as **enable future robot-assisted US procedures** that could benefit from user hand-guidance.

The Problem and Prior Work

Up to 90% of sonographers experience occupation-related musculoskeletal disorders [1] from holding US probes in contorted positions while applying large forces.

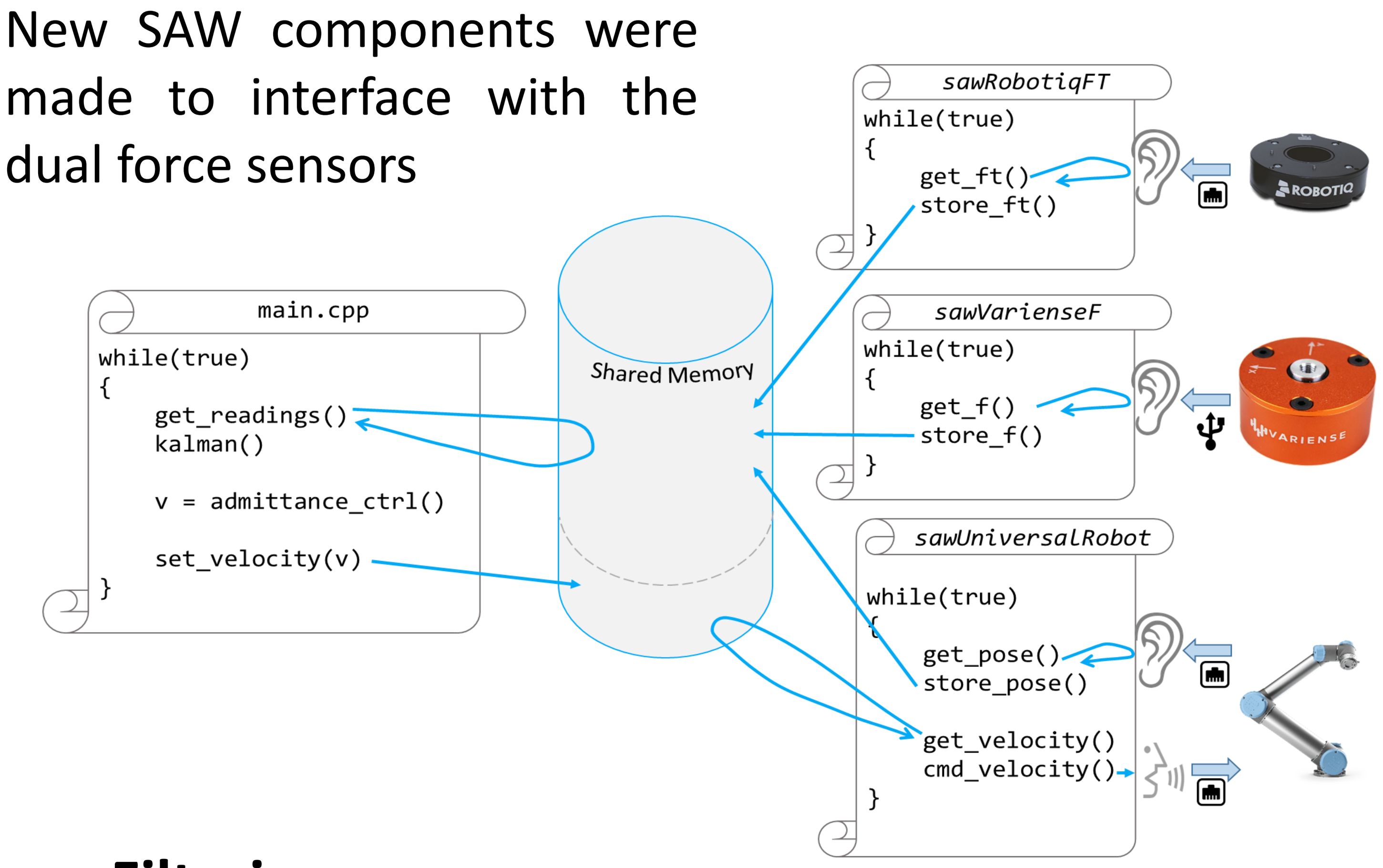
Previous work by Finnochi [2] and Fang [3] used frequency-domain force filtering and nonlinear admittance control gains to implement hand-over-hand control in MATLAB, however the motion was non-transparent to the user.



The Solution

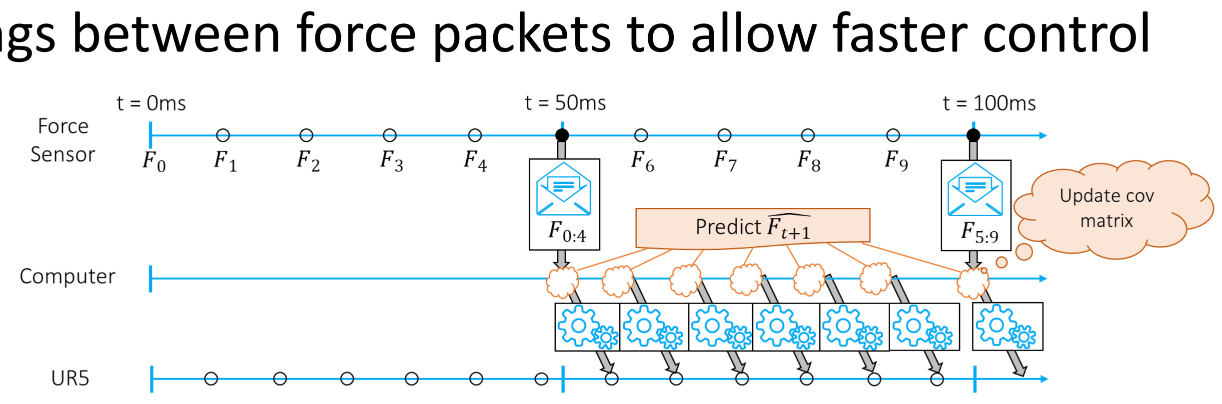
Extensible Software Implementation with CISST/SAW

- New SAW components were made to interface with the dual force sensors



Kalman Filtering

- Used to smooth noise, predict future force values, and infer readings between force packets to allow faster control

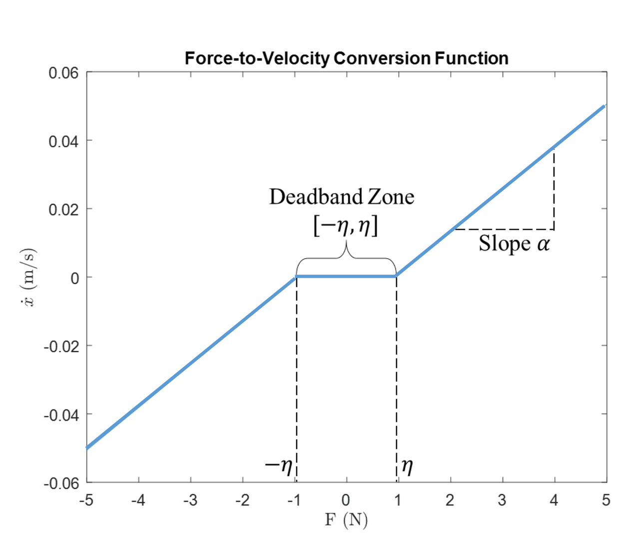


Admittance Control Gains

- Piecewise linear with slope α and deadband between noise range $[-\eta, \eta]$

$$\dot{x} = \begin{cases} 0 & |\tilde{F}_{hand}| \le \eta \\ sgn(\tilde{F}_{hand}) \cdot \alpha\left(|\tilde{F}_{hand}| - \eta\right) & |\tilde{F}_{hand}| > \eta \end{cases}$$

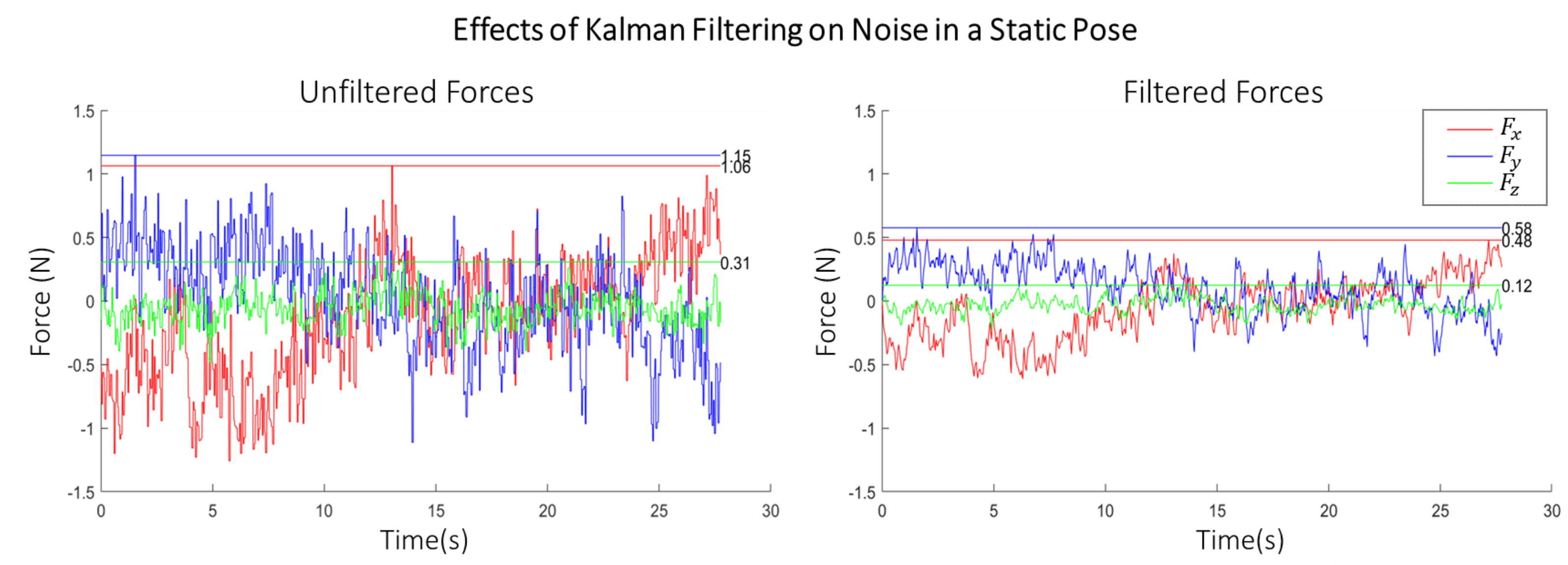
- Tuned for optimal responsiveness and noise rejection



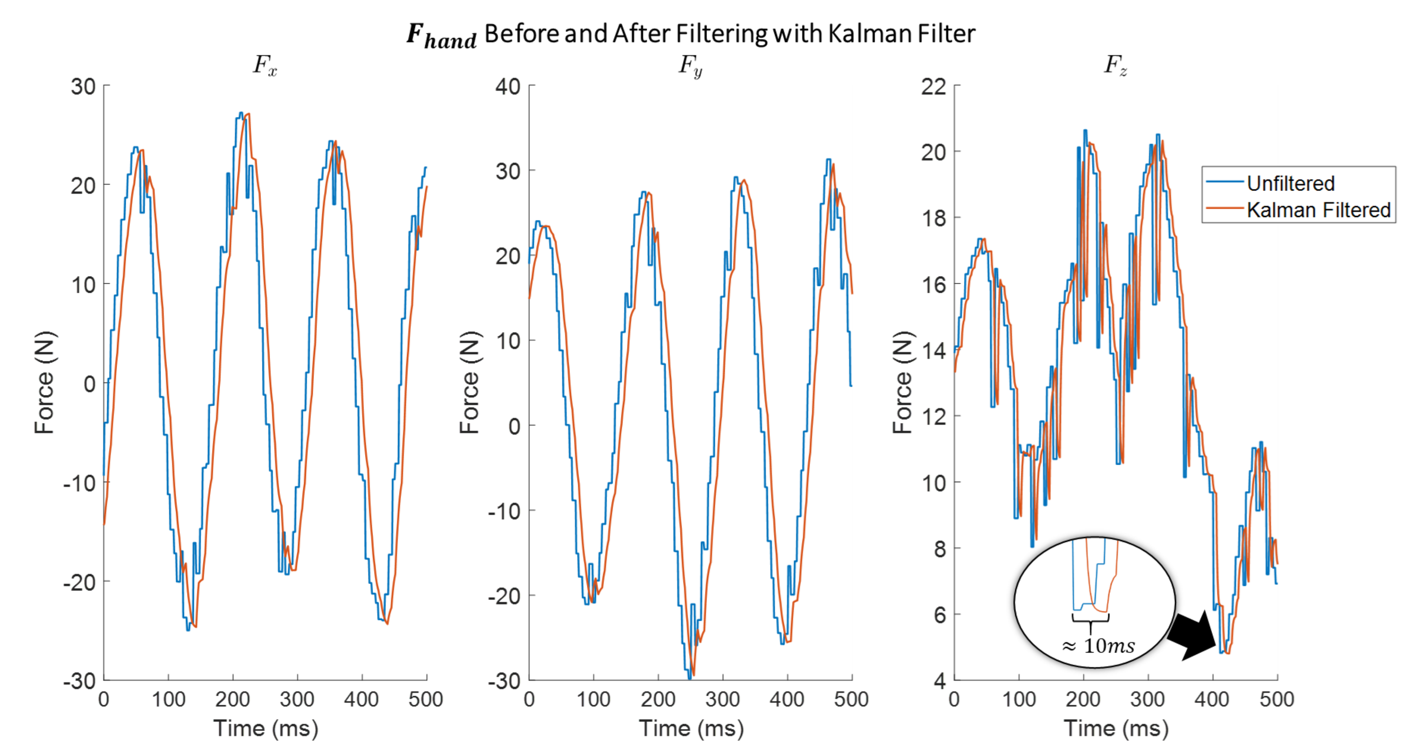
Results

Kalman Filtering

- Successful sensor noise reduction of 2x when in a static pose



- Smoothed readings w/ minimal phase-lag and over/undershoot



Admittance Control

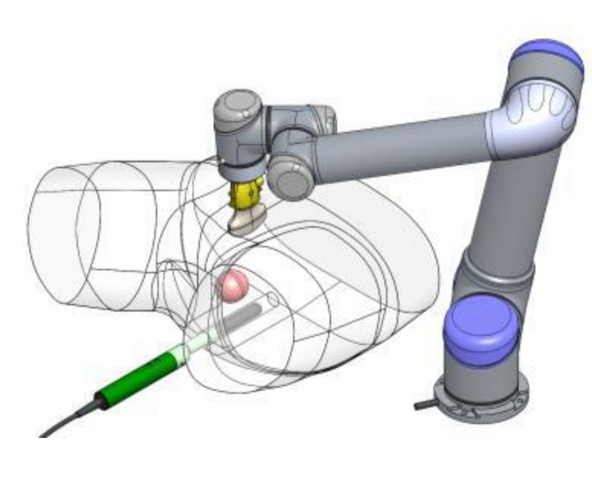
- Linear gains worked better than sigmoidal gains used in [2,3]
- Was qualitatively smooth to users in informal pilot study
- Due to hardware issues preventing probe contact force compensation, a quantitative user study had to be postponed

Lessons and Future Directions

This project touched upon many different technical aspects: robot programming in C++, interfacing with serial and analog hardware, robot kinematics, admittance control, tool-weight compensation, filtering techniques/tuning, and using neural networks for characterizing nonlinear systems.

Future work will first require a redesign of the probe contact force sensor housing and a user study for validation.

Afterward, work will be aimed at a **novel co-robotic application** of this framework **to US tomography** of the prostate for cancer diagnosis, in which a robot-held transabdominal probe will track the rotations of a freehand transrectal probe to capture an array of transmission US images necessary for tomographic reconstruction.



Support and Acknowledgements

In addition to the project's official mentors, we would like to thank **Dr. Russell Taylor** for his weekly feedback on this project and **Dr. Peter Kazanzides** for graciously providing us with a UR5 robot when ours broke during the final week.

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] 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.

[3] 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.