Checkpoint Presentation

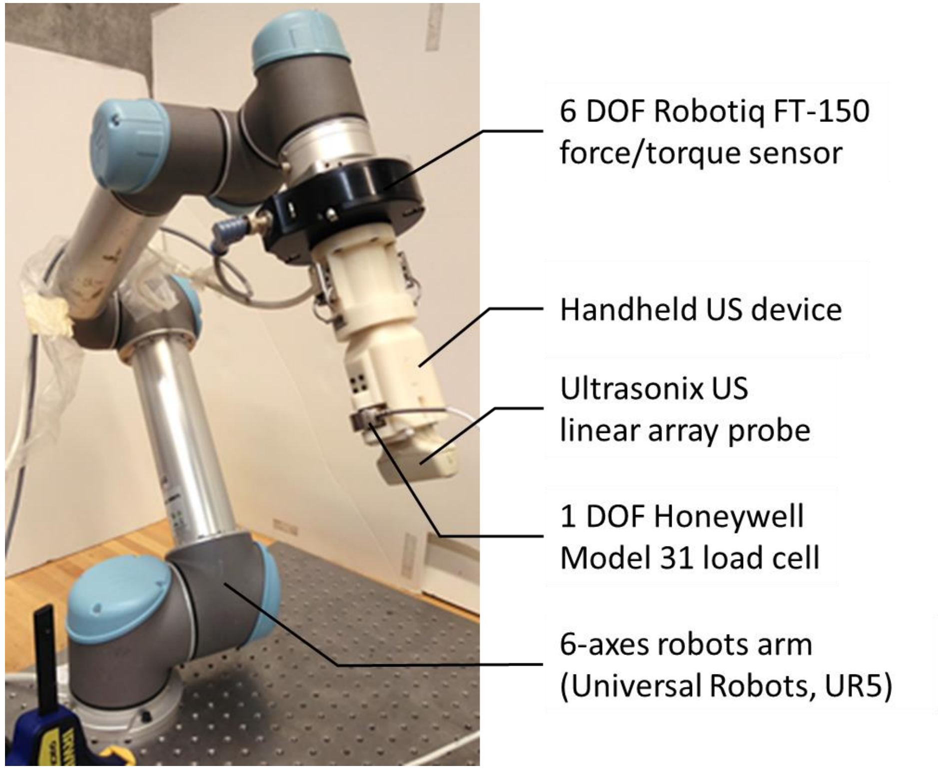
Co-robotic Ultrasound Imaging System

Group7
Ting-Yun (Angel) Fang
Weiqi (Rocky) Wang

Mentors: H. Kai Zhang, Dr. Taylor, Dr. Boctor

Project Summary

- Build a robot system (using UR5) to assist the ultrasound scanning procedure
- Integrate the system with synthetic tracked aperture ultrasound imaging algorithm
- Validate STRATUS in multiple direction through phantom study and in vivo studies
- Extend the existing system to a higher dexterity



Deliverables

Minimum: (expected 3/18)

1. Design an animal (pig) experiment protocol and submit to ACUC for approval
2. Design an IRB protocol for human factor study and human imaging study
3. Implement virtual fixture features to the system
4. Integrate STRATUS algorithm with the system (2D in-plane scanning)

Expected: (expected 4/15)

1. System validation using a phantom (probably a general US phantom or a female uterus phantom)
2. Extended synthetic tracked aperture (SA) from 2D to 3D and perform out-of-plane scanning
3. Experiment with the extended SA using a phantom

Maximum: (expected 5/9)

1. Design a GUI for real-time interface to visualize collected US data
2. Apply one or more of imaging protocol on in vivo subjects
3. Replace the 1-DOF load cell with a multi-axis force sensor for higher dexterity
4. Upgrade the current mechanical design of the US probe holder

Updated Deliverables

Minimum: (expected 3/18)

1. ~~Design an animal (pig) experiment protocol and submit to ACUC for approval~~
2. ~~Design an IRB protocol for human factor study and human imaging study~~
3. ~~Design a new US attachment for the convex probe~~
4. Implement virtual fixture features to the system
5. ~~Integrate STRATUS algorithm with the system (2D in-plane scanning)~~

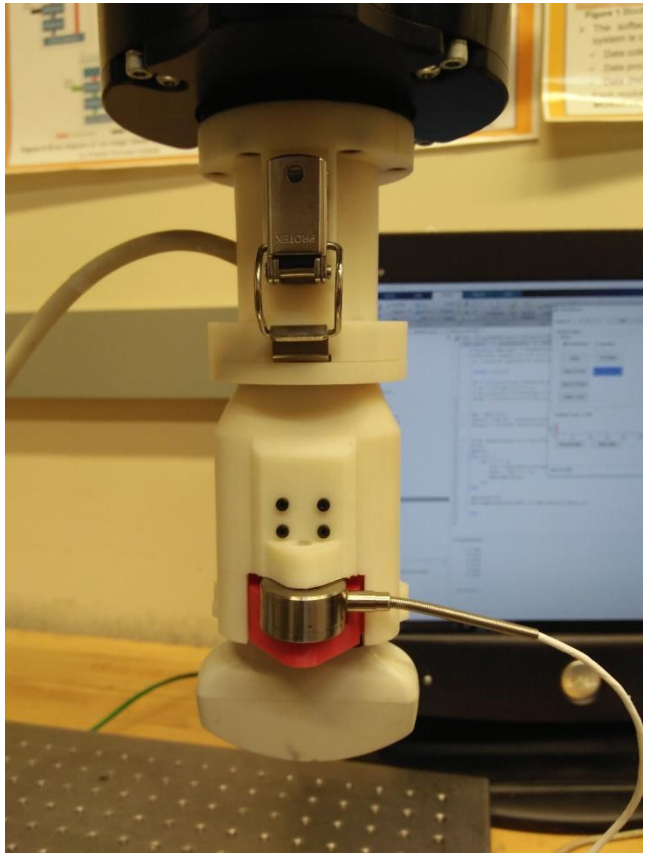
Expected: (expected 4/15)

1. ~~Perform US calibration for the new attachment~~
2. ~~System validation using a phantom (probably a general US phantom or a female uterus phantom)~~
3. Extended synthetic tracked aperture (SA) from 2D to 3D and perform out-of-plane scanning
4. Experiment with the extended SA using a phantom

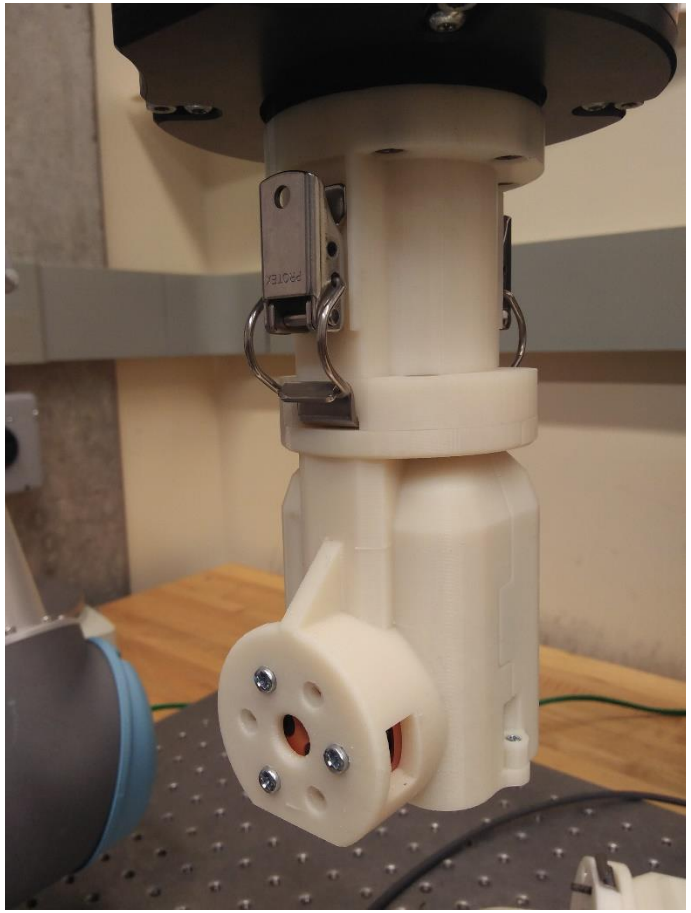
Maximum: (expected 5/9)

1. Design a GUI for real-time interface to visualize collected US data
2. Apply one or more of imaging protocol on in vivo subjects
3. Replace the 1-DOF load cell with a multi-axis force sensor for higher dexterity
4. ~~Upgrade the current mechanical design of the US probe holder~~

New ultrasound attachment – Convex probe



New ultrasound attachment – 3-axis load cell



2D STRATUS algorithm

- Zhang, H. K., Cheng, A., Bottenus, N., Guo, X., Trahey, G. E., & Boctor, E. M. (2016). Synthetic tracked aperture ultrasound imaging: design, simulation, and experimental evaluation. *Journal of Medical Imaging,3*(2), 027001. doi:10.1117/1.jmi.3.2.027001

$$M = X^{-1} B_i^{-1} B_j X$$
$$B_j = B_i X M X^{-1}$$

where B_i and B_j correspond to two poses of the tracked marker. To introduce the motion M, the new probe pose is determined

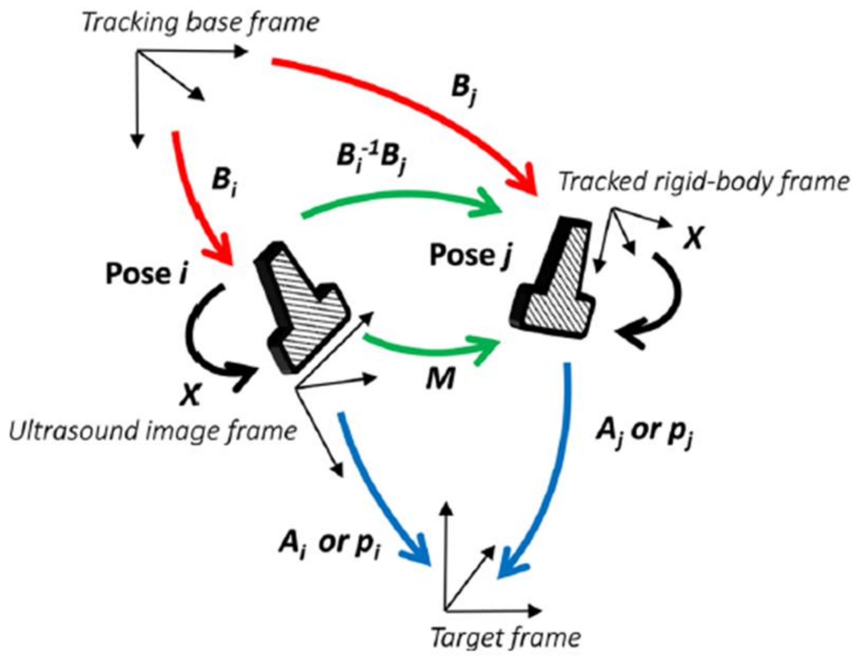
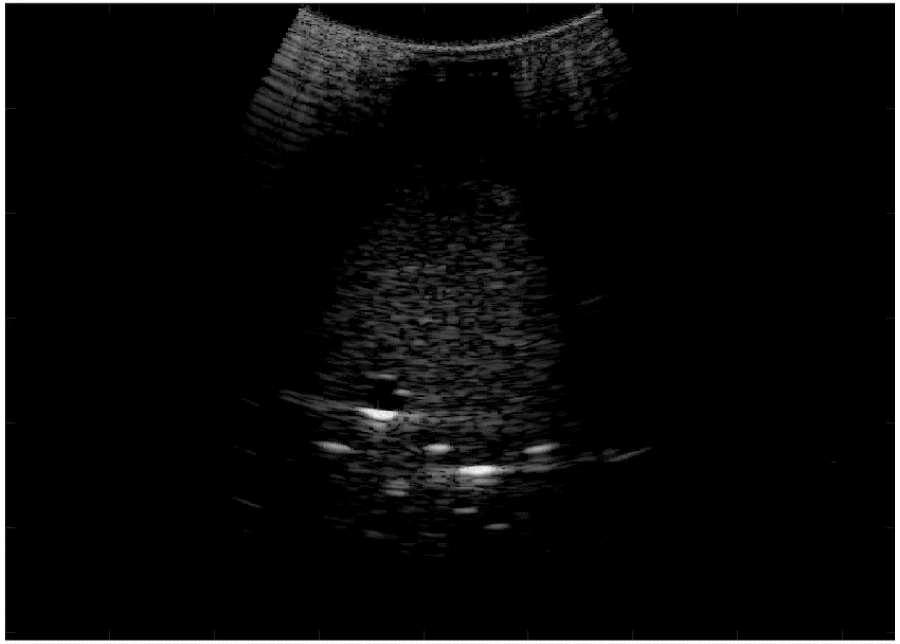
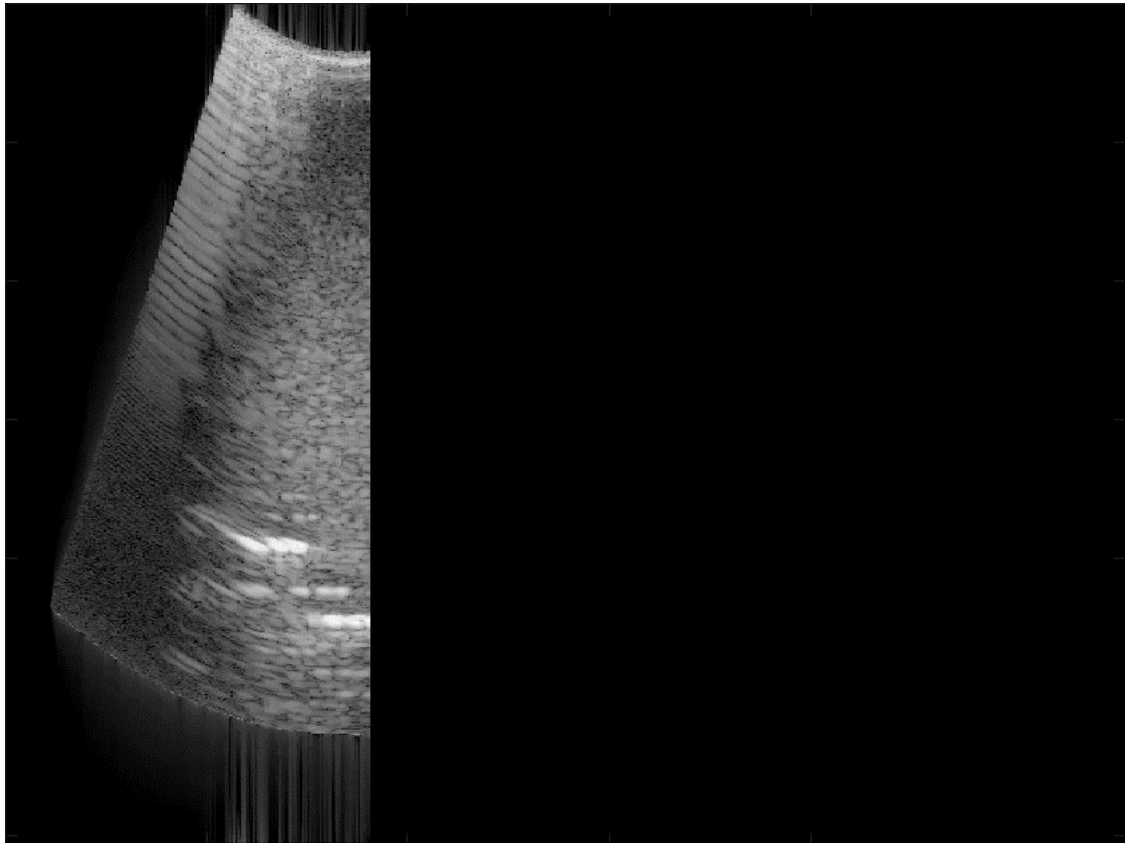


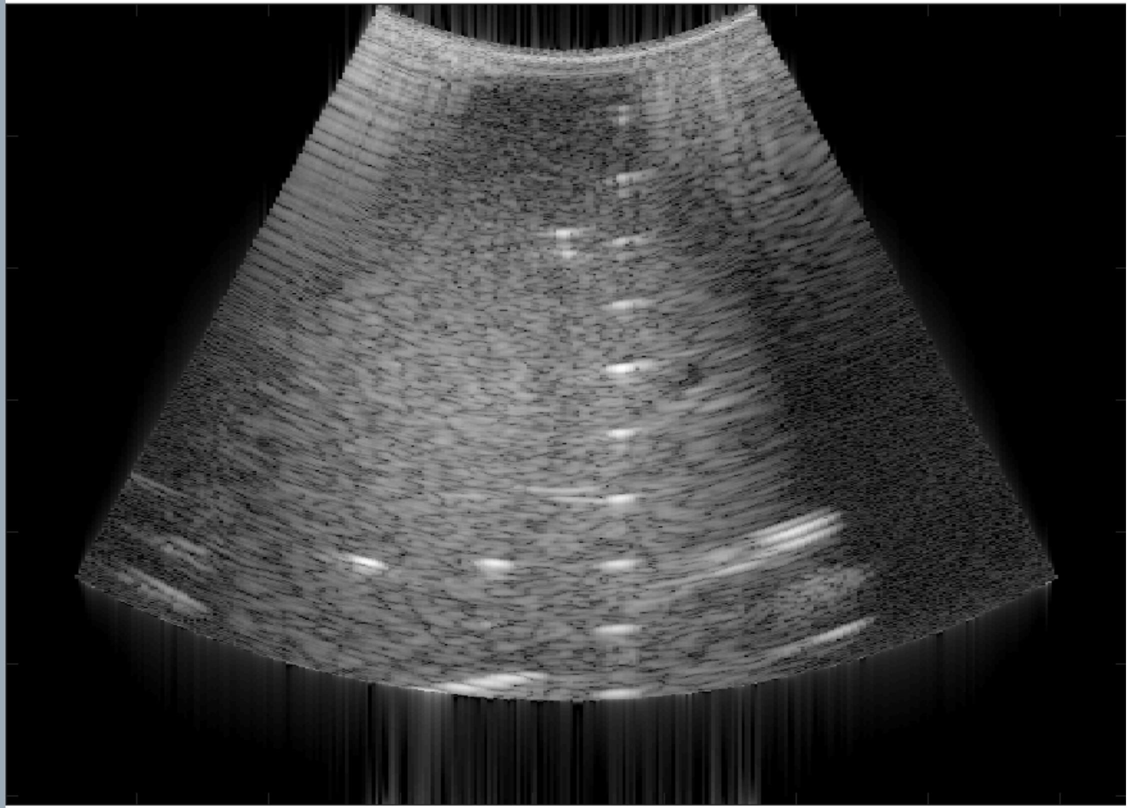
Fig. 2 The coordinate systems involved in synthetic tracked aperture ultrasound (STRATUS) imaging.

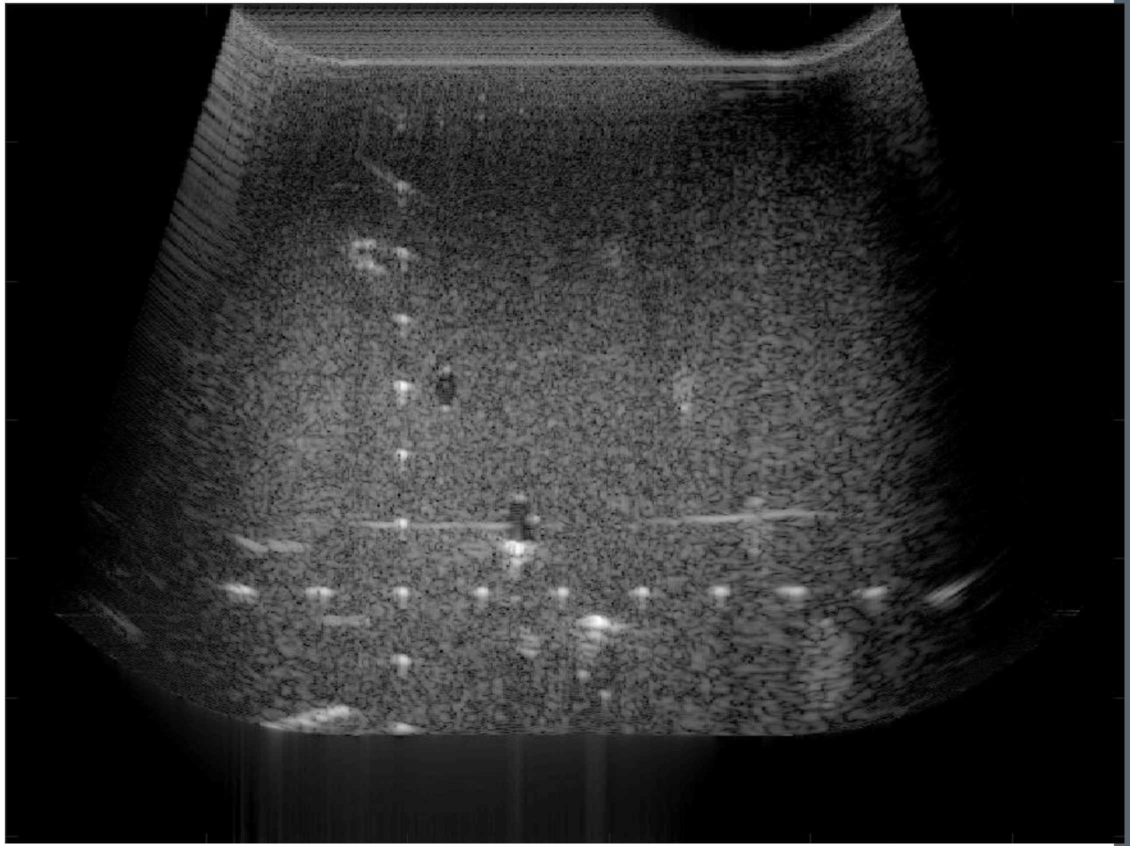
2D STRATUS algorithm





2D STRATUS algorithm





Virtual Fixtures

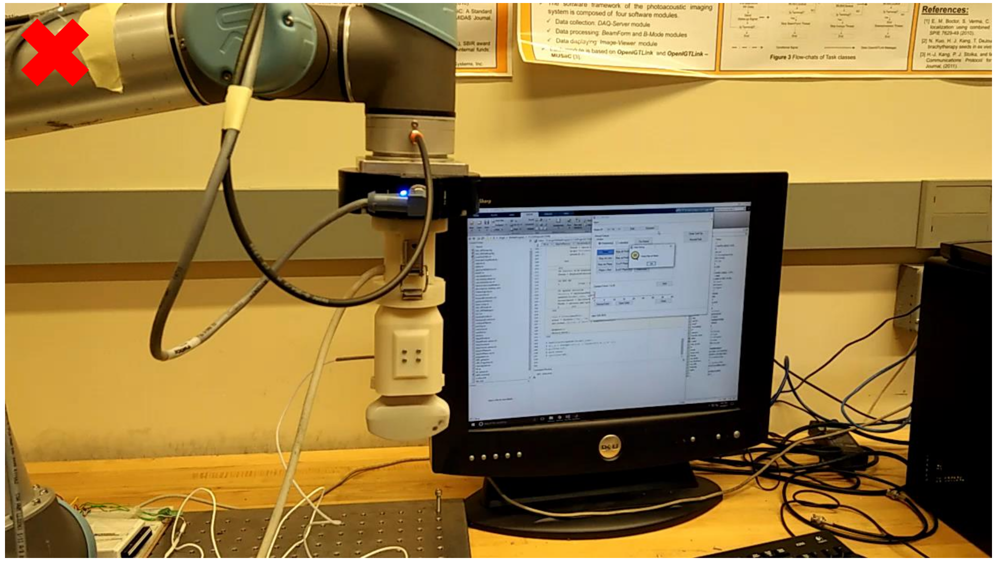
- Li, M., Kapoor, A., & Taylor, R. (2005). A constrained optimization approach to virtual fixtures. 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems. doi:10.1109/iros.2005.1545420

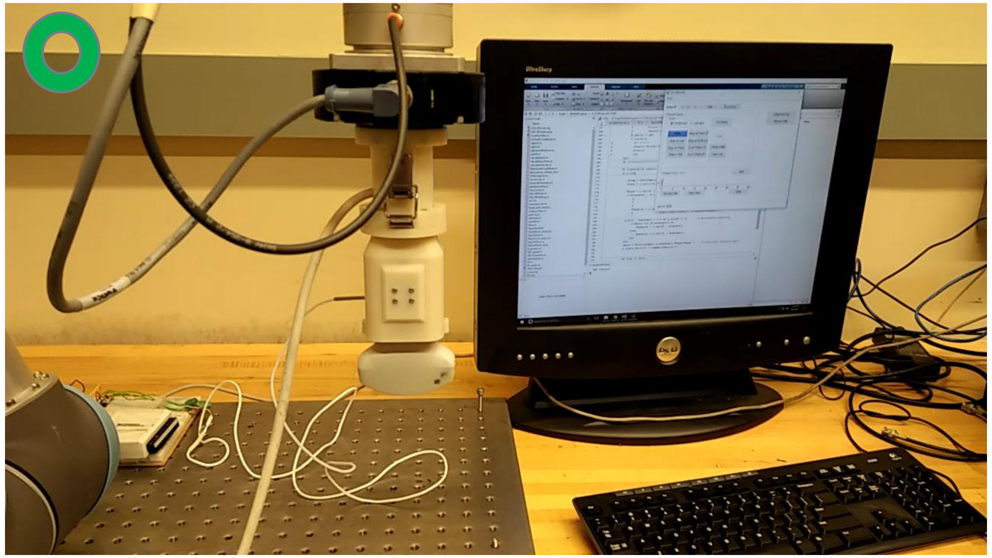
$$\begin{aligned} &\arg\min_{\Delta\vec{q}/\Delta t} \|W(\Delta\vec{x}/\Delta t - \Delta\vec{x}_d/\Delta t)\|, \\ &s.t. \quad H\Delta\vec{x}/\Delta t \geq \vec{h}, \\ &\Delta\vec{x}/\Delta t = J\Delta\vec{q}/\Delta t \end{aligned}$$

- Defined constraint matrix H and h; solve joint speed with Matlab function "lsqin"

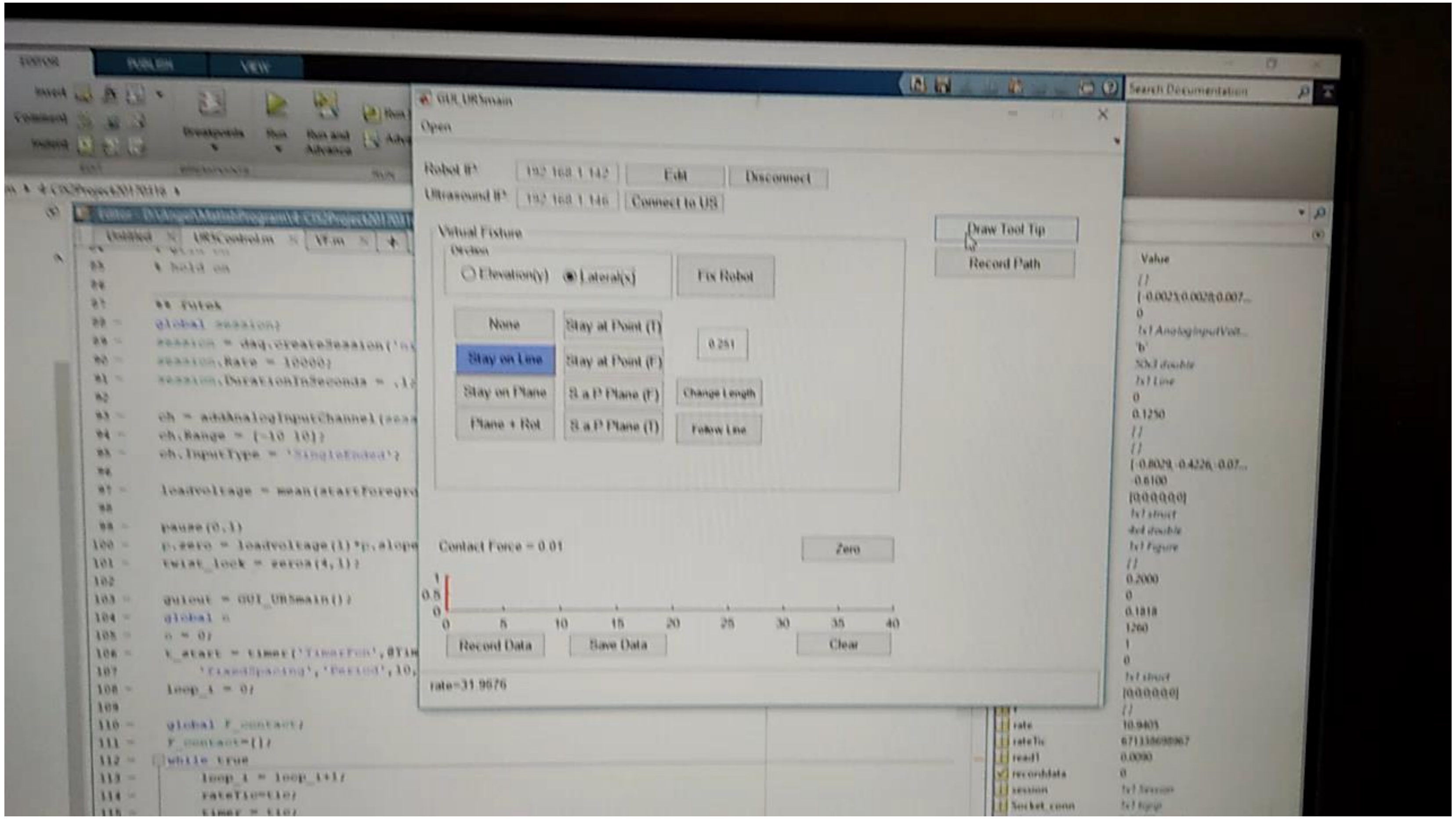
Current problem for VF

- Body velocity → Spatial velocity → Joint speed
- Apply constrain function to minimizing problem
- VF function returns undesired movement.
- Possible causes: Kinematics errors (Adjoint & Jacobian); linqin errors;
- Current solution: feedback control loop
- Body velocity → Spatial velocity → Joint speed → Spatial velocity → Body V → joint speed



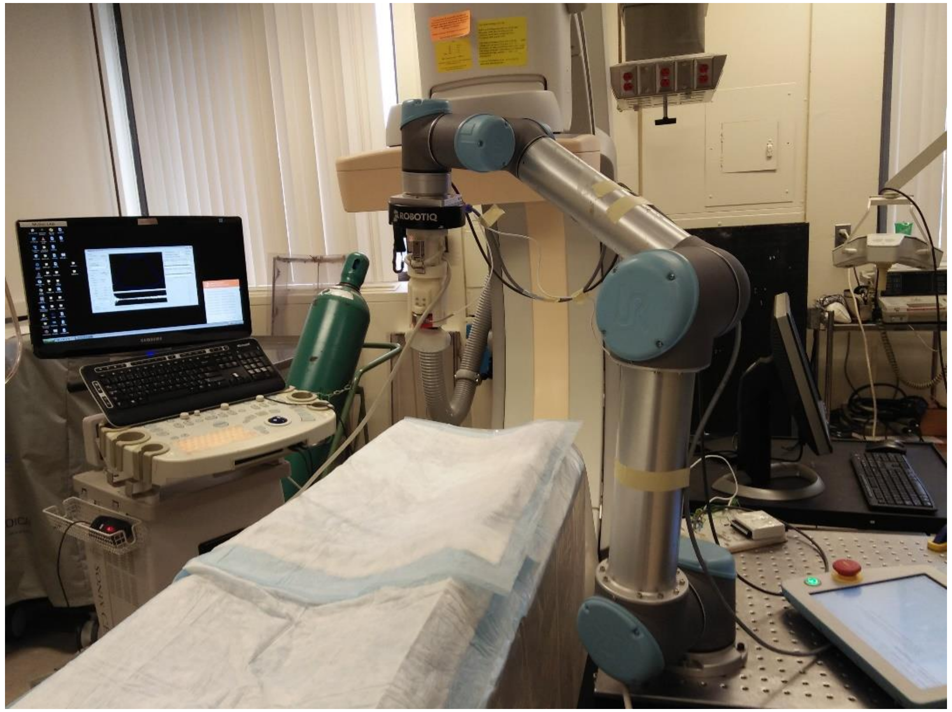


Virtual Fixtures

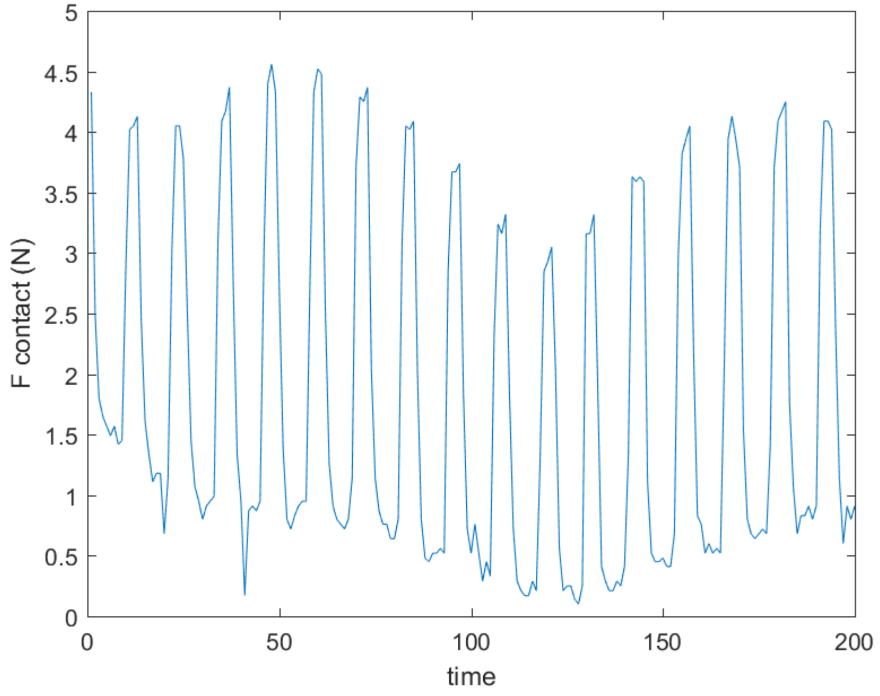


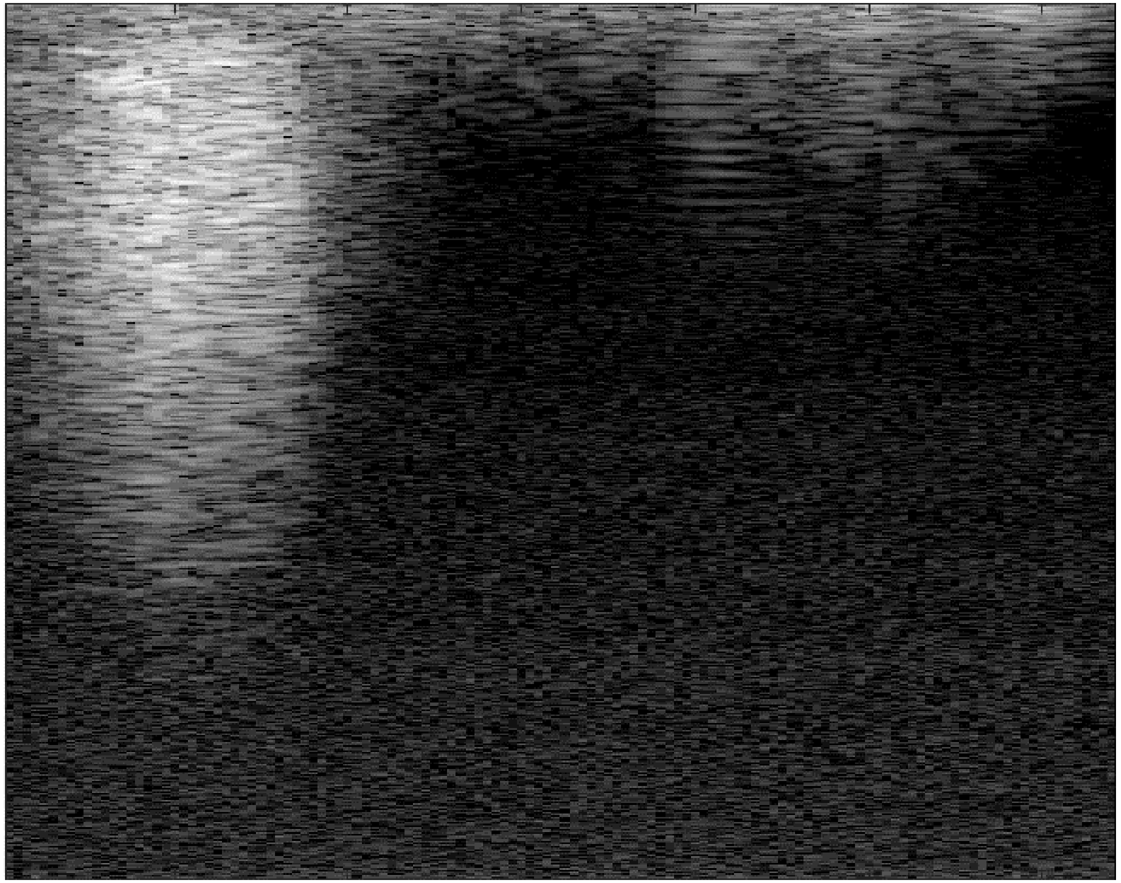
Animal Experiment

- Abdominal imaging
  - Stay on x axis
  - Stay on y axis
  - Autonomous / cooperative

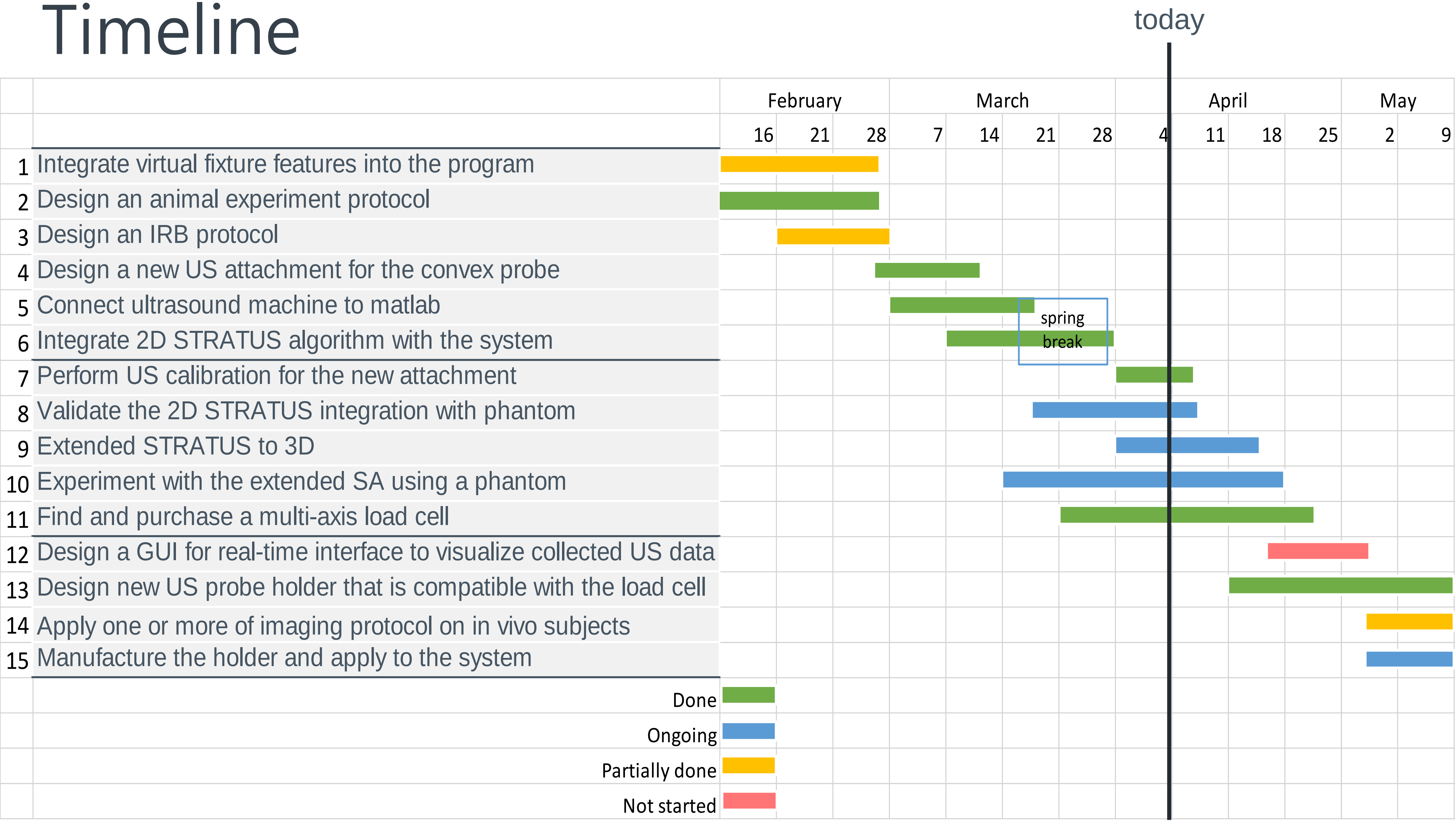


Animal Experiment

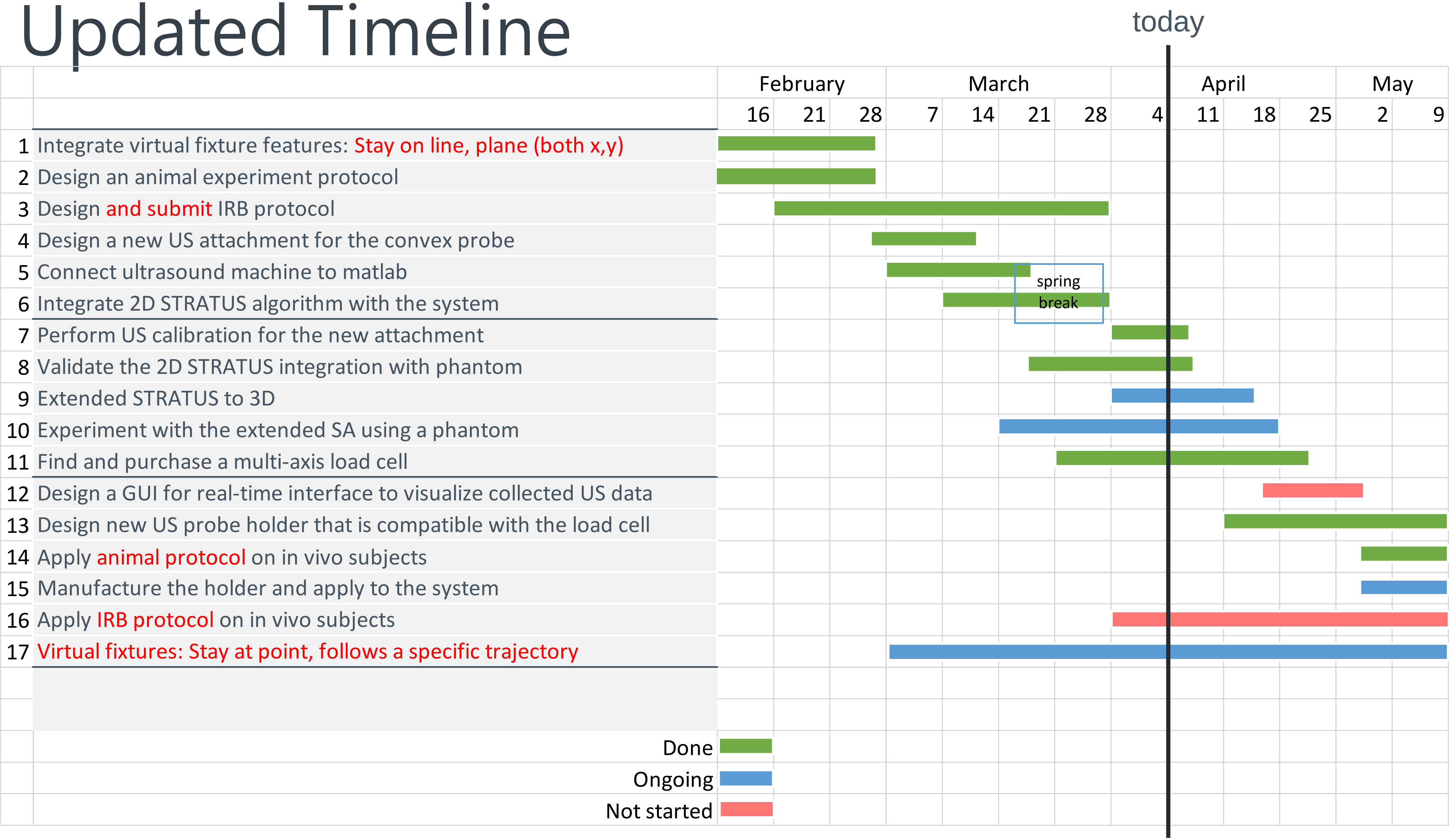




Timeline


today
February
March
April
May
16
21
28
7
14
21
28
4
11
18
25
2
9
1 Integrate virtual fixture features into the program
2 Design an animal experiment protocol
3 Design an IRB protocol
4 Design a new US attachment for the convex probe
5 Connect ultrasound machine to matlab
6 Integrate 2D STRATUS algorithm with the system
7 Perform US calibration for the new attachment
8 Validate the 2D STRATUS integration with phantom
9 Extended STRATUS to 3D
10 Experiment with the extended SA using a phantom
11 Find and purchase a multi-axis load cell
12 Design a GUI for real-time interface to visualize collected US data
13 Design new US probe holder that is compatible with the load cell
14 Apply one or more of imaging protocol on in vivo subjects
15 Manufacture the holder and apply to the system
spring
break
Done
Ongoing
Partially done
Not started

Updated Timeline



Reading list

- Zhang HK, et al. (2016) Synthetic tracked aperture ultrasound imaging: design, simulation, and experimental evaluation. Journal of Medical Imaging 3:027001. doi: 10.1117/1.jmi.3.2.027001
- Zhang HK, et al. (2016) Co-robotic synthetic tracked aperture ultrasound imaging with cross-correlation based dynamic error compensation and virtual fixture control. 2016 IEEE International Ultrasonics Symposium (IUS). doi: 10.1109/ultsym.2016.7728522
- Li M, et al. (2005) A constrained optimization approach to virtual fixtures. 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems. doi: 10.1109/iros.2005.1545420
- Gilbertson MW, Anthony BW (2013) An ergonomic, instrumented ultrasound probe for 6-axis force/torque measurement. 2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). doi: 10.1109/embc.2013.6609457

Question/Comment?