

# Checkpoint Presentation

Co-robotic Ultrasound Imaging System

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# 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



6 DOF Robotiq FT-150  
force/torque sensor

Handheld US device

Ultrasonix US  
linear array probe

1 DOF Honeywell  
Model 31 load cell

6-axes robots arm  
(Universal Robots, UR5)



# Deliverables

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## **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

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## 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)

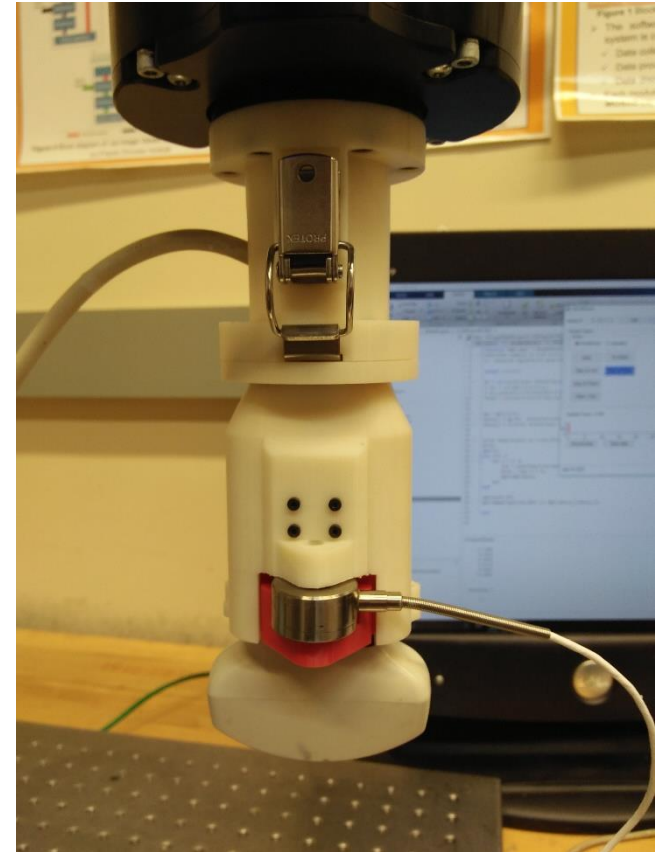
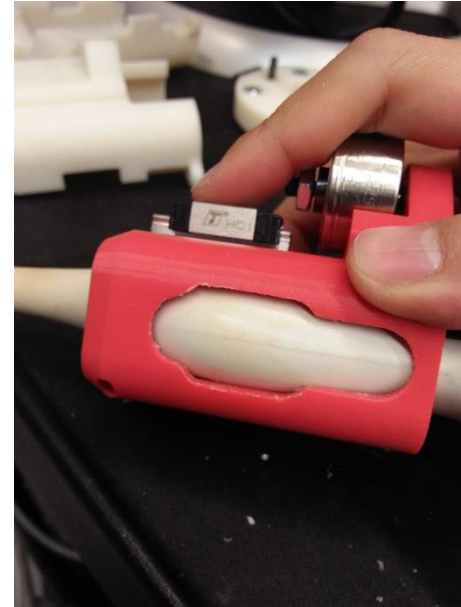
- ~~1. Perform US calibration for the new attachment~~
- ~~2. System validation using a phantom ( probably a general US phantom or a female uterus phantom)~~
3. Extended synthetic tracked aperture (SA) from 2D to 3D and perform out-of-plane scanning
4. Experiment with the extended SA using a phantom

## 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



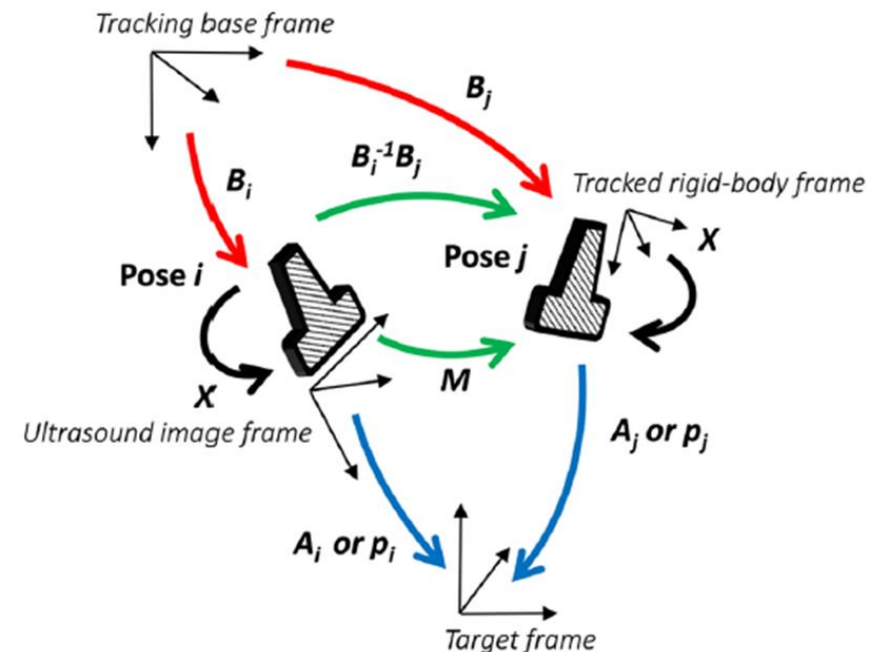


# 2D STRATUS algorithm

- › 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

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

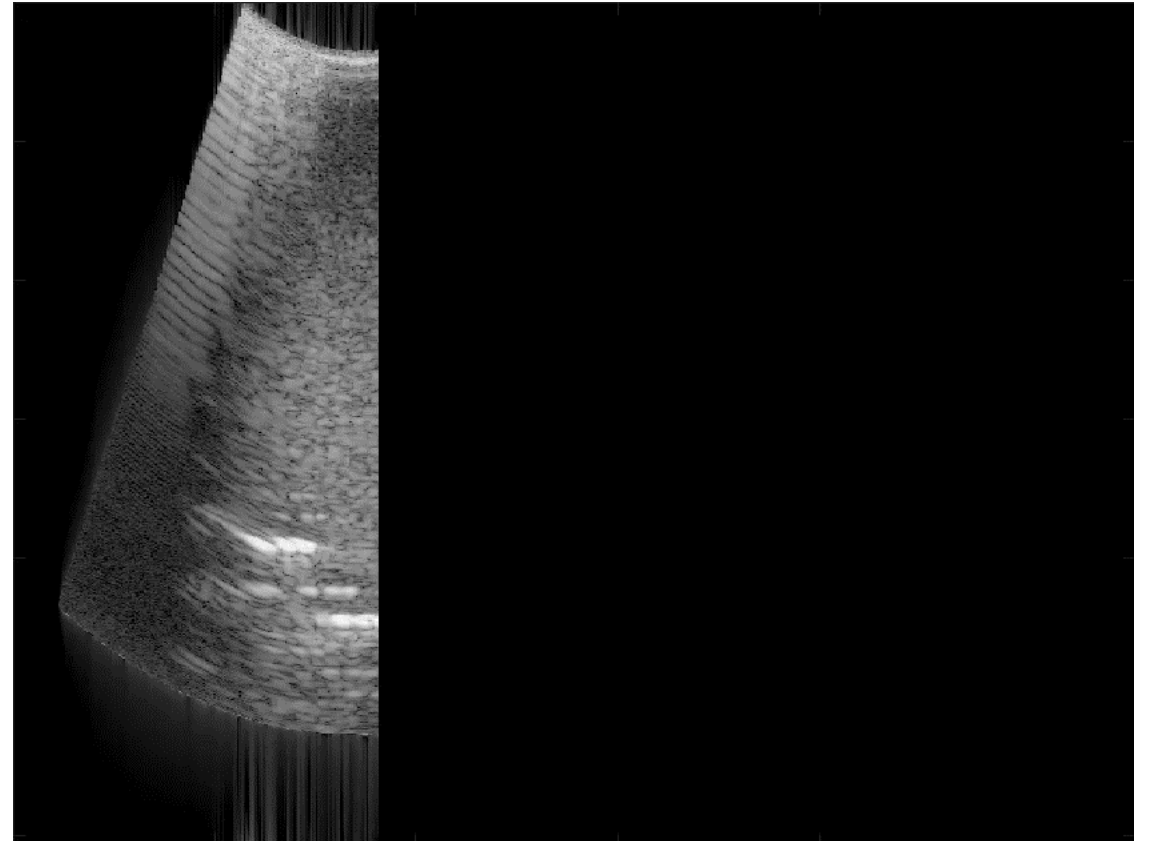
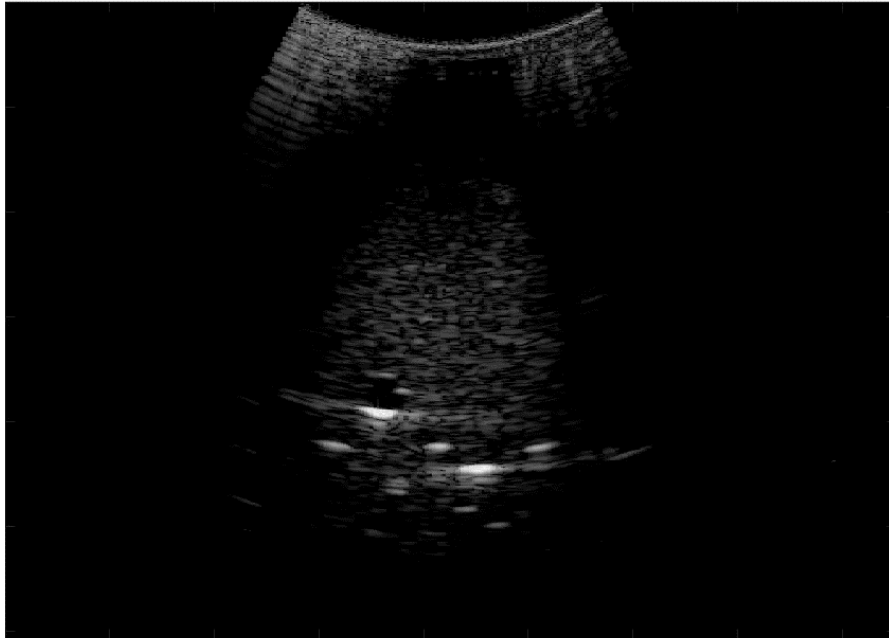
where  $B_i$  and  $B_j$  correspond to two poses of the tracked marker. To introduce the motion  $M$ , the new probe pose is determined



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



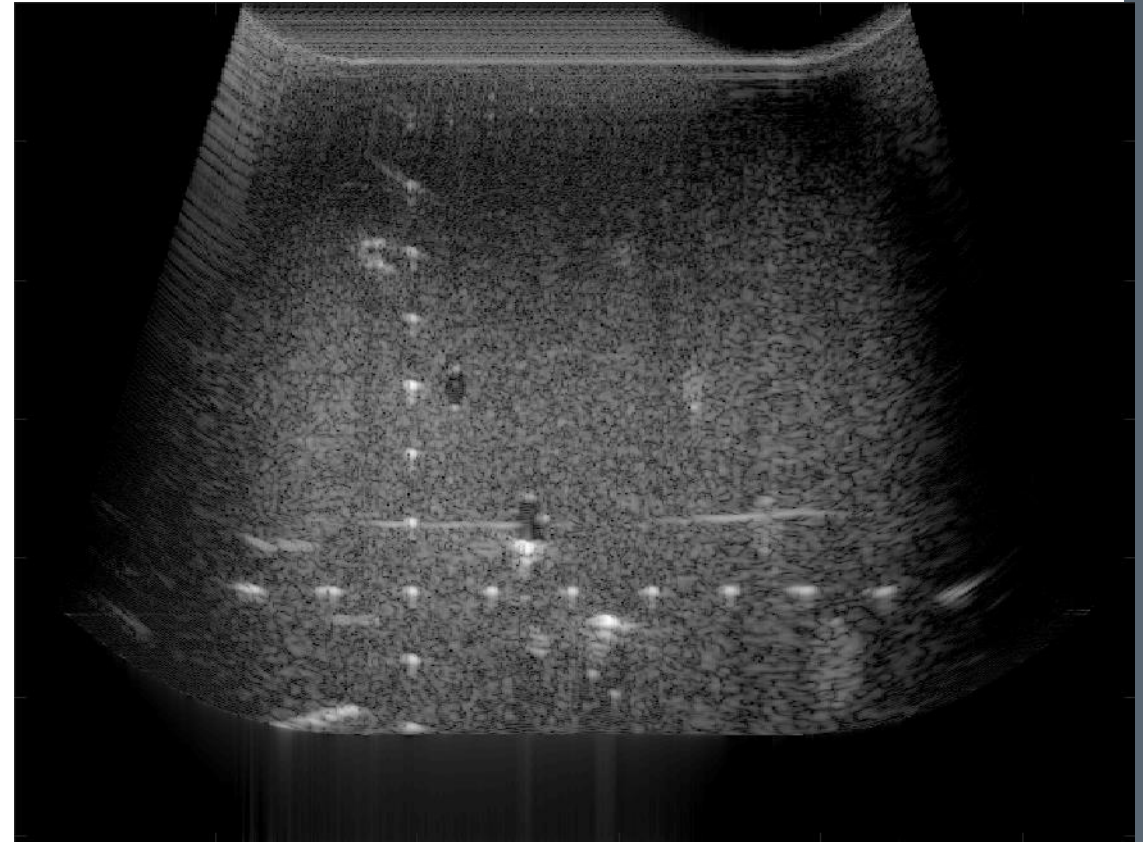
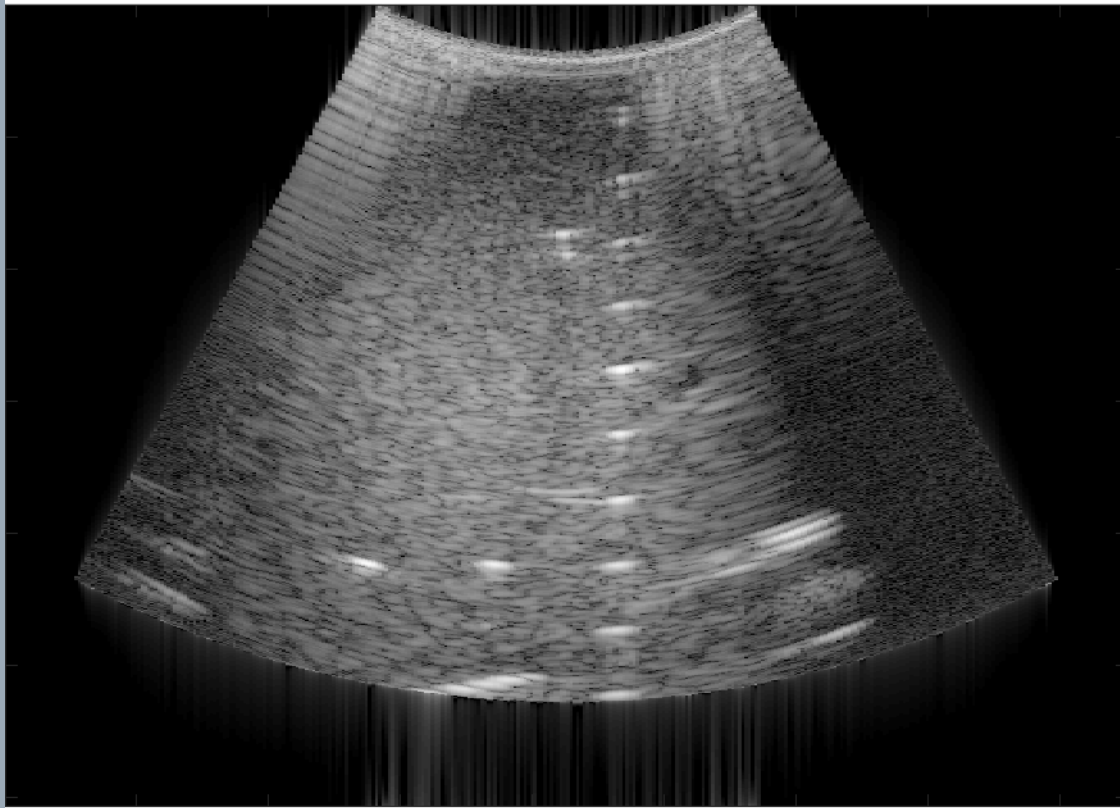
# 2D STRATUS algorithm







# 2D STRATUS algorithm



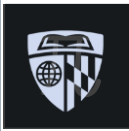


# Virtual Fixtures

- › 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

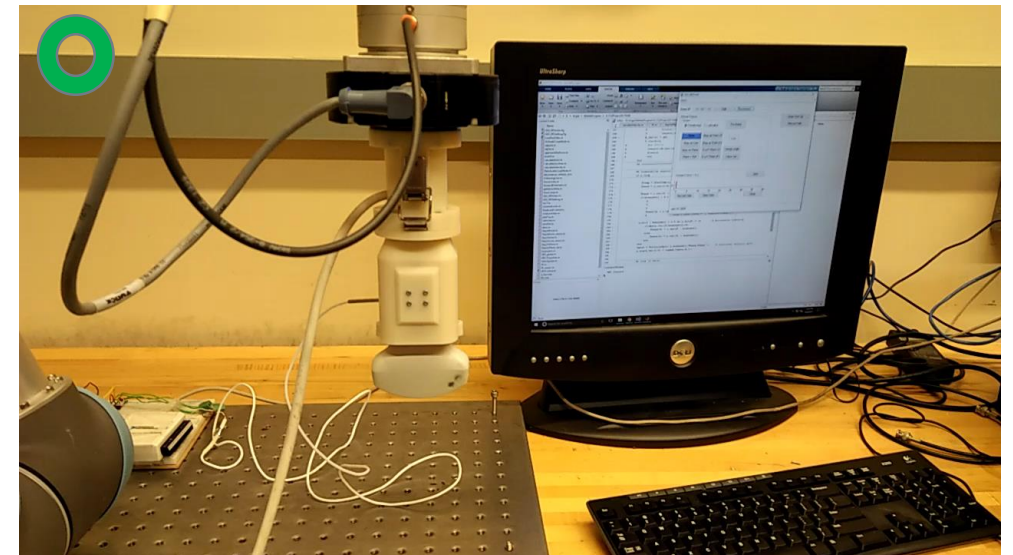
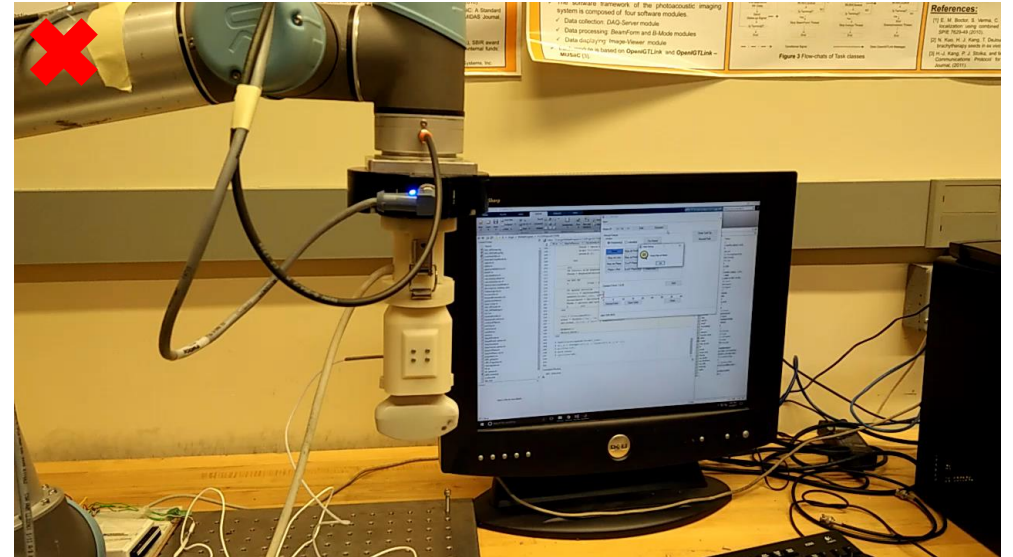
$$\begin{aligned} \arg \min_{\Delta \vec{q}/\Delta t} & \|W(\Delta \vec{x}/\Delta t - \Delta \vec{x}_d/\Delta t)\|, \\ \text{s.t.} & \quad H \Delta \vec{x}/\Delta t \geq \vec{h}, \\ & \quad \Delta \vec{x}/\Delta t = J \Delta \vec{q}/\Delta t \end{aligned}$$

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



# Current problem for VF

- › Body velocity  $\rightarrow$  Spatial velocity  $\rightarrow$  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  $\rightarrow$  Spatial velocity  $\rightarrow$  Joint speed  $\rightarrow$  Spatial velocity  $\rightarrow$  Body  $V \rightarrow$  joint speed





# Virtual Fixtures

The screenshot displays a software interface for virtual fixtures. The main window is titled "GUI.URSimain" and contains several panels:

- Code Editor:** Shows a script with MATLAB-like syntax for robot control and data logging.
- Control Panel:** Includes fields for "Robot IP" (192.168.1.142) and "Ultrasound IP" (192.168.1.146), along with buttons for "Edit", "Disconnect", and "Connect to US".
- Virtual Fixture Section:** Features a "Virtual Fixture" dropdown menu with options: "None", "Stay on Line", "Stay on Plane", "Plane + Rot", "Elevation(y)", "lateral(x)", "Stay at Point (T)", "Stay at Point (F)", "S a P Plane (F)", "S a P Plane (T)", "Fix Robot", "Change Length", and "Follow Line".
- Contact Force:** A section with "Contact Force = 0.01" and a "Zero" button.
- Data Logging:** A graph showing a red bar at the start of a 40-second scale, with buttons for "Record Data", "Save Data", and "Clear". The rate is displayed as "rate=31.9576".
- Data Table:** A table on the right side of the interface with columns for "Value" and various data points.

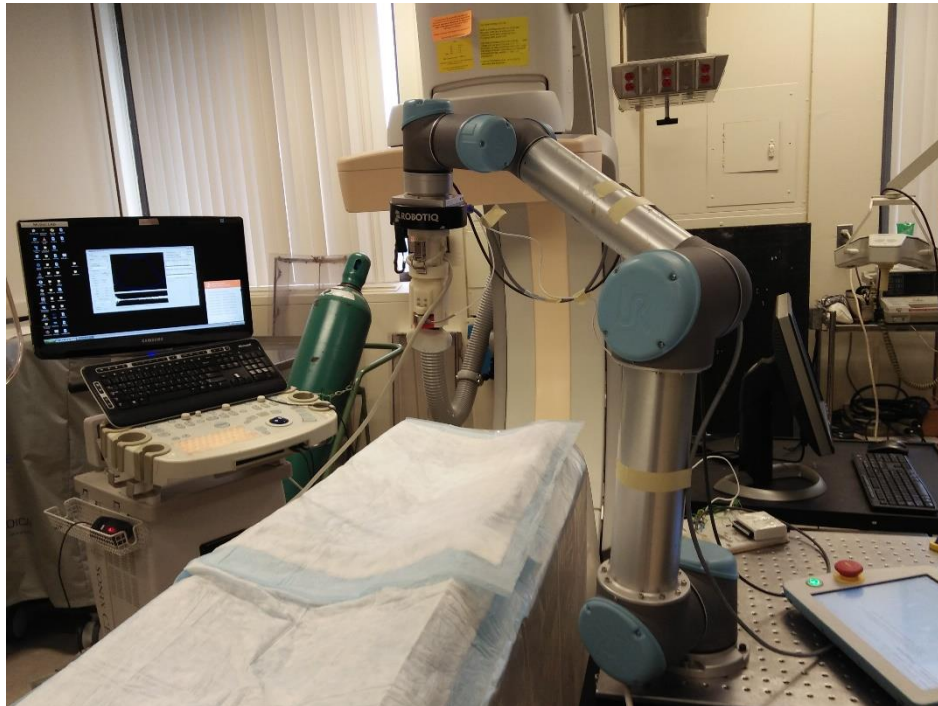
```
load('UR5Control.m', 'VF.m')
hold on
% futek
global session;
session = daq.createSession('ni');
session.Rate = 10000;
session.DurationInSeconds = .1;
ch = addAnalogInputChannel(session);
ch.Range = [-10 10];
ch.InputType = 'SingleEnded';
loadvoltage = mean(atariForegro);
pause(0.1);
p.zero = loadvoltage(1)*p.slope;
twist_lock = zeros(4,1);
quiet = GUI.URSimain();
global n;
n = 0;
t_start = timer('TimerFcn', @TIM...
    'FixedSpacing', 'Period', 10);
loop_1 = 0;
global F_contact;
F_contact = [];
while true
    loop_1 = loop_1 + 1;
    rateTime = t;
    time = t;
end
```

Value
[]
[-0.0025, 0.0020, 0.007...
0
1x1 AnalogInputVolt...
b'
50x3 double
1x1 Line
0
0.1250
[]
[]
[-0.8029, -0.4226, -0.07...
-0.6100
[0 0 0 0 0]
1x1 struct
4x4 double
1x1 Figure
[]
0.2000
0
0.1818
1260
1
0
1x1 struct
[0 0 0 0 0]
[]
rate
rateTime
read
recorddata
session
socket_comm



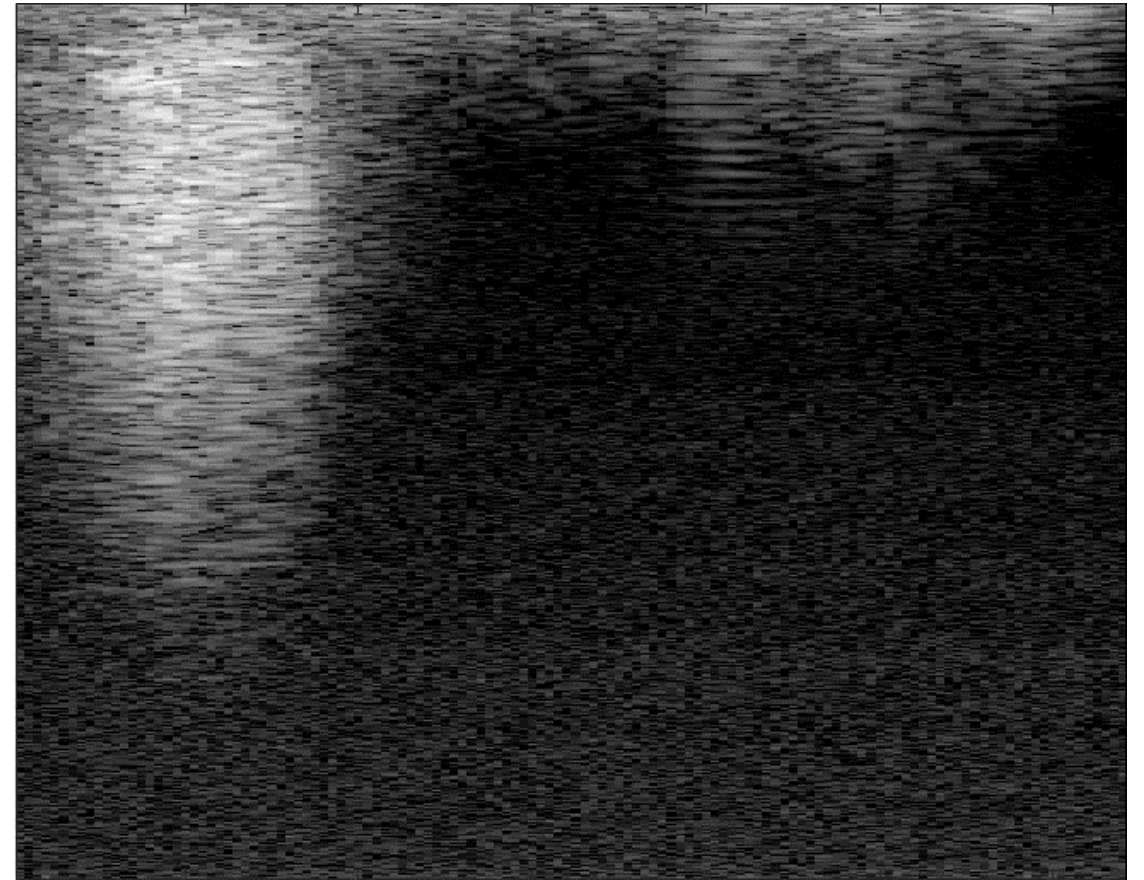
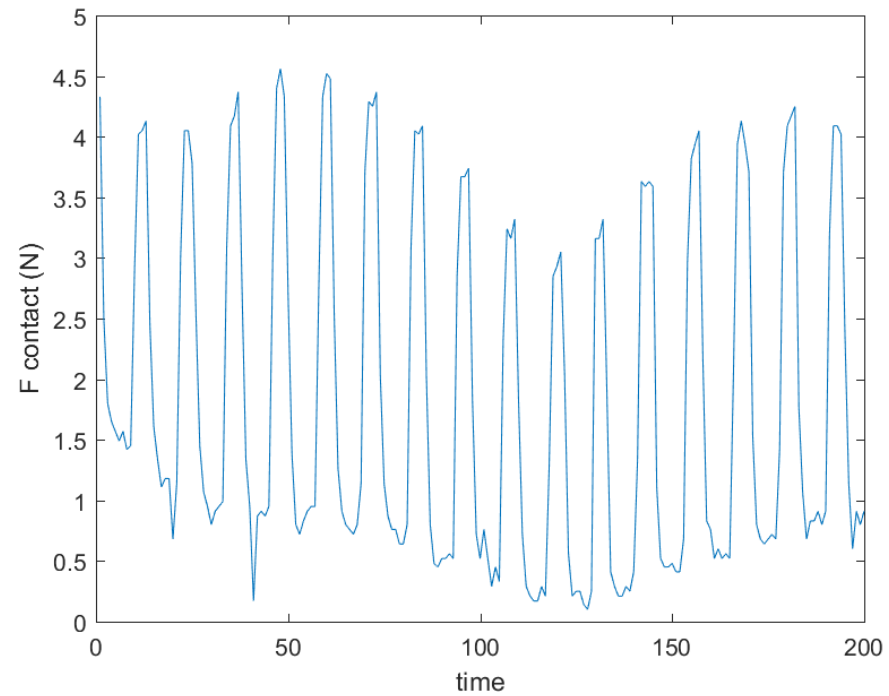
# Animal Experiment

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



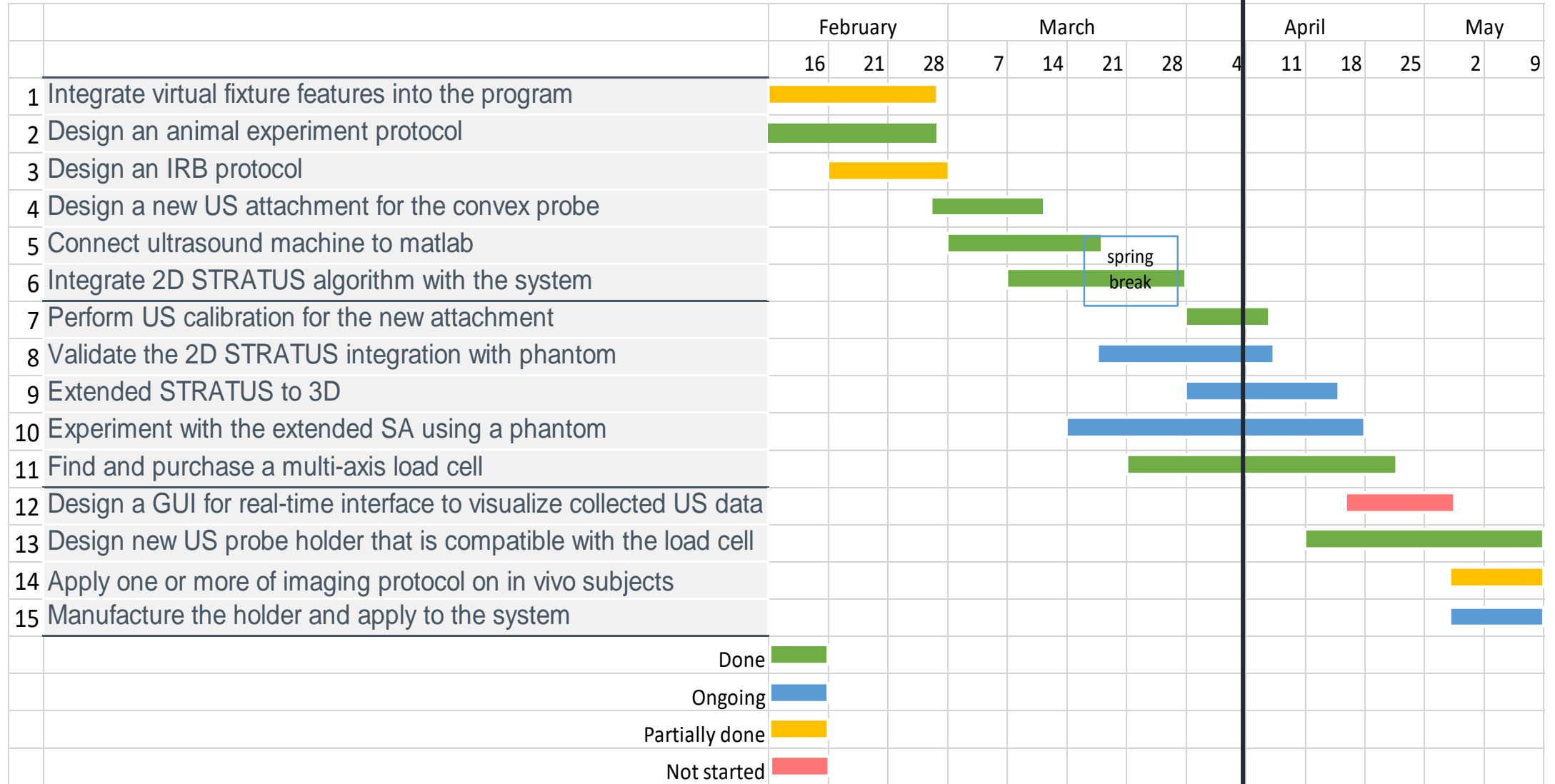


# Animal Experiment



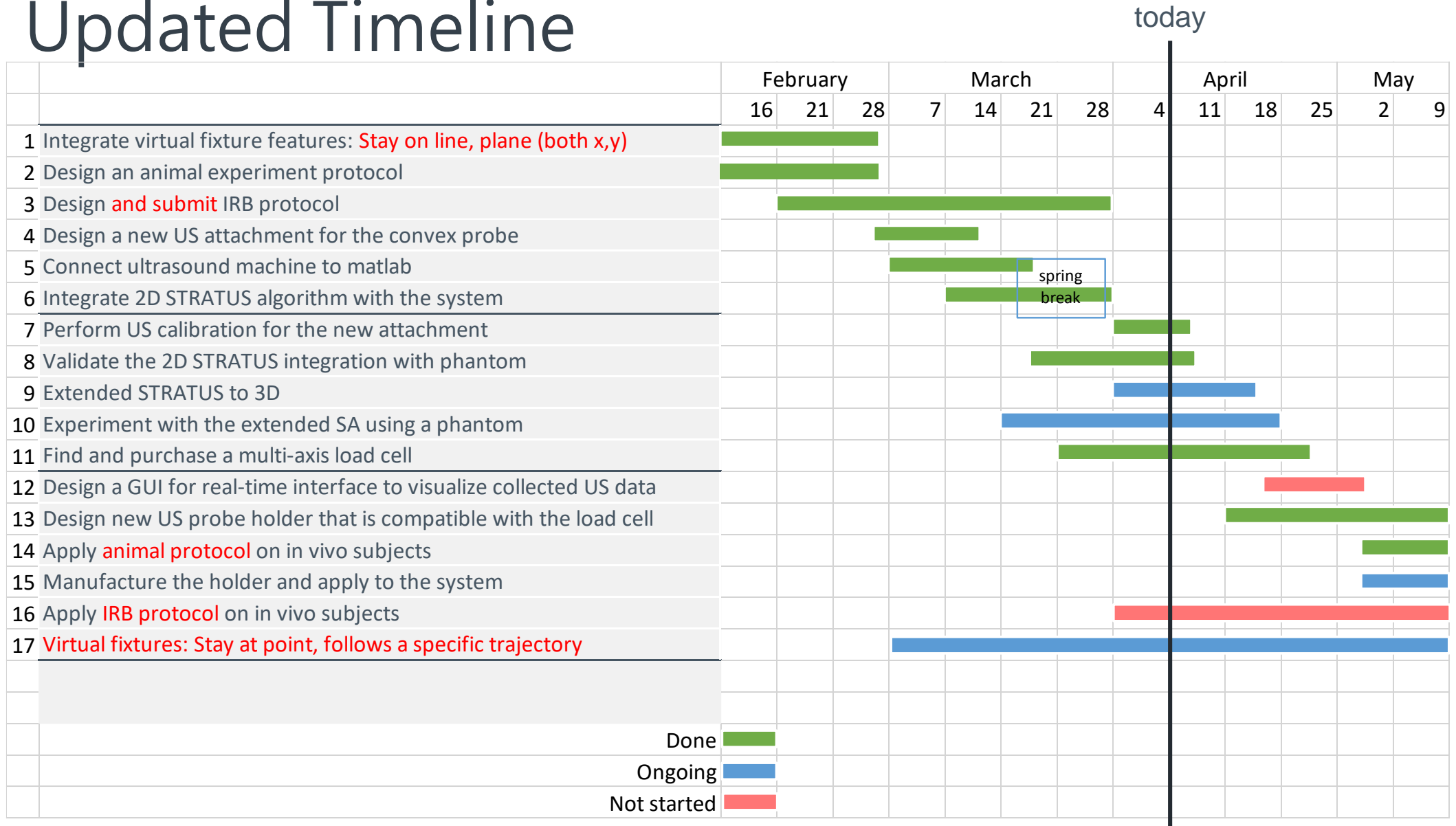


# Timeline





# Updated Timeline

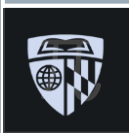






# Reading list

- › 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?