NRI: 3-D Maneuverable Feedback-Controlled Micro Swimming Drone for Biomedical Applications
(ECCS-1627815)

PI: Sung Kwon Cho: Build 3-D Swimming Drone

Dept. of Mechanical Engineering/Materials Science

Co-PI: Nitin Sharma: Feedback Control of Motion

Dept. of Mechanical Engineering/Materials Sciences

Co-PI: Kang Kim: Ultrasound imaging

Dept. of Medicine
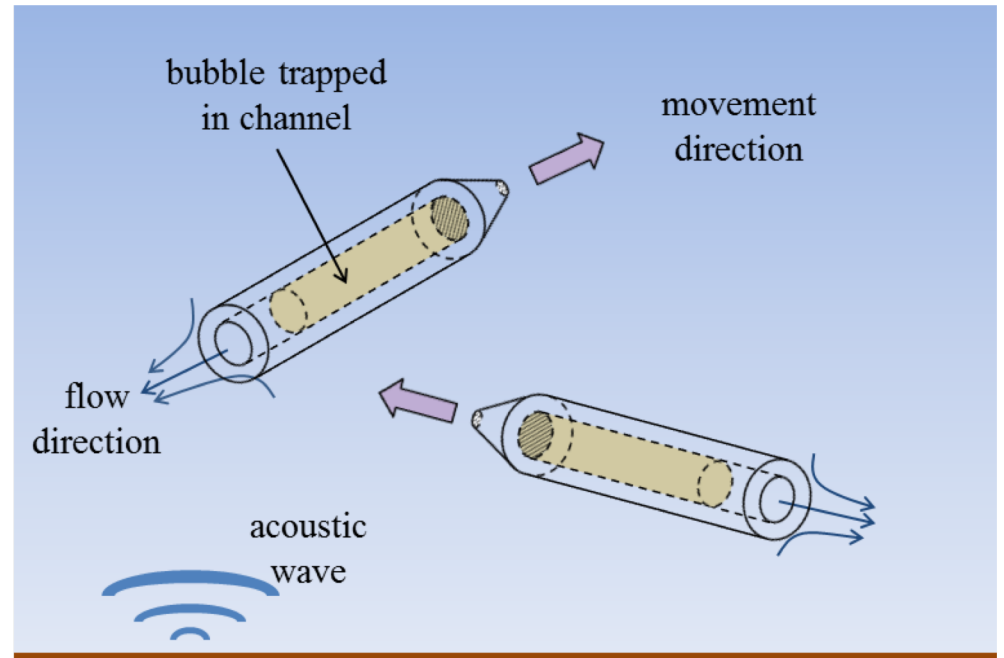
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Motivation: μSwimmer

"Fantastic Voyage" (1966)

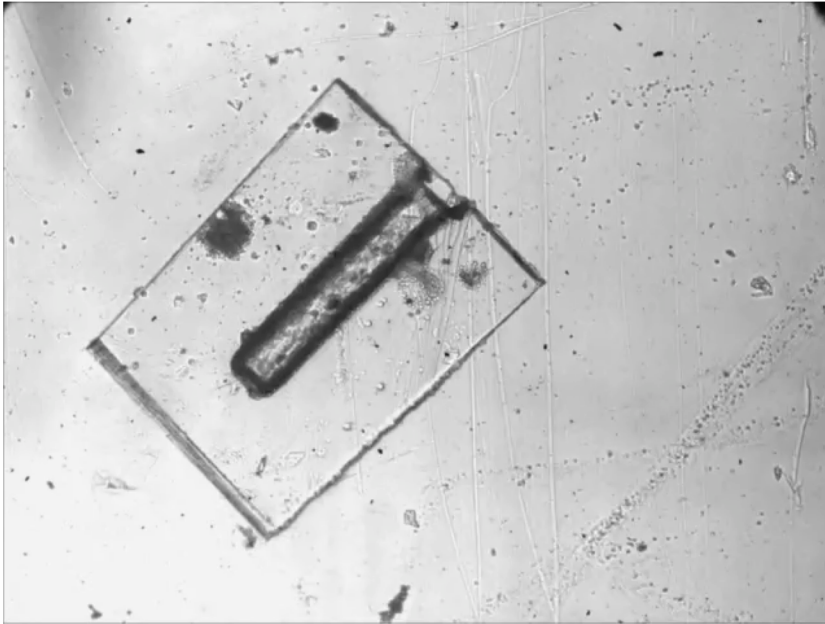**Possible Applications:**

Drug delivery, Bio-sensing, Bio-surgery, …

Propulsion Engine
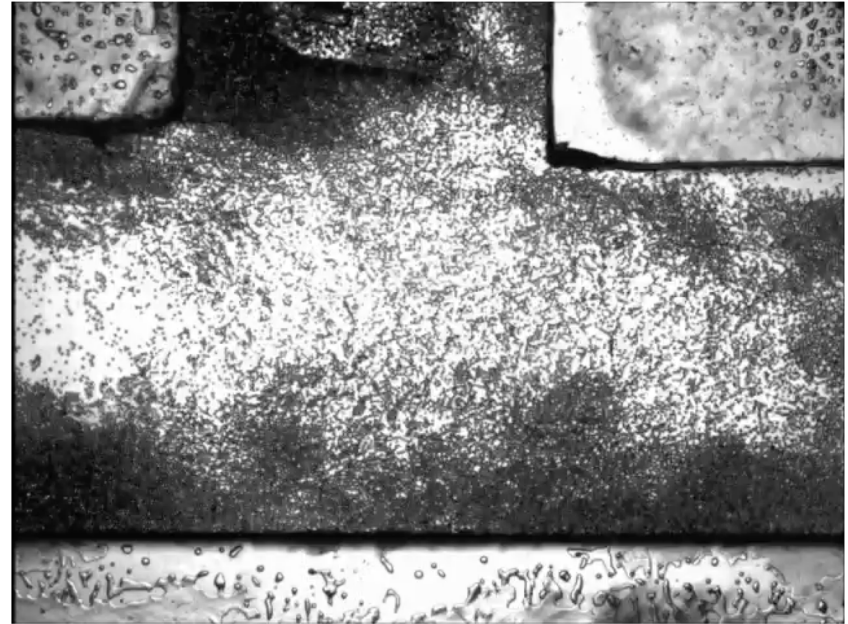
1-D/2-D Propulsion

1-D Propulsion

2-D Propulsion/Steering

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3-D Propulsion: Design/Fab
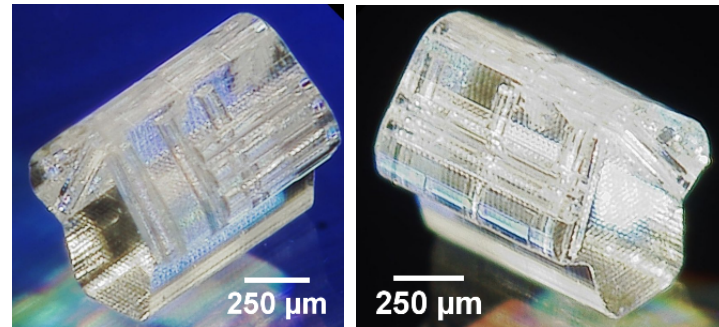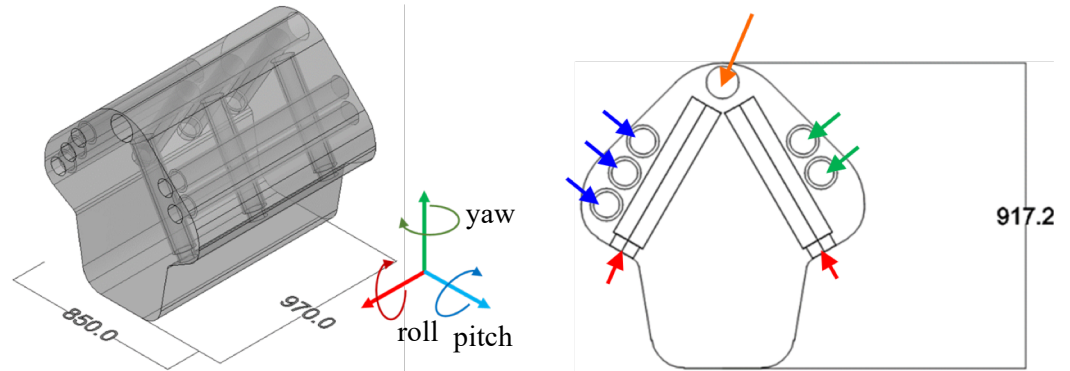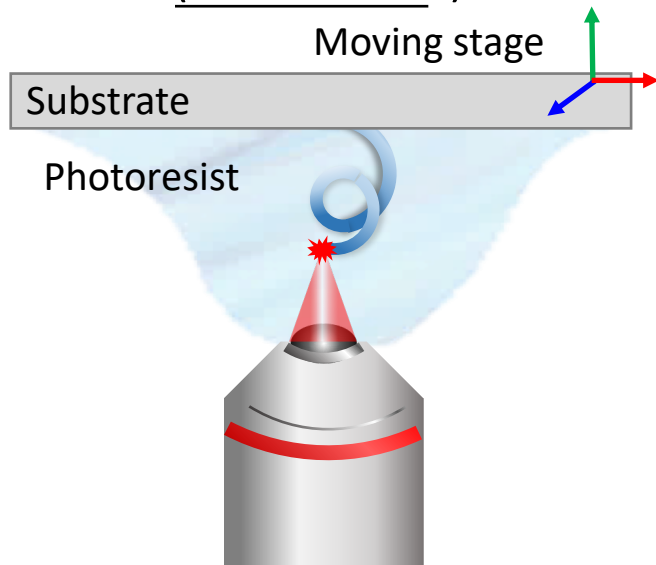
3-D 2-photon laser printing (Nanoscribe®)

Moving stage

Substrate

Photoresist

Microscope Objective

yaw

roll   pitch
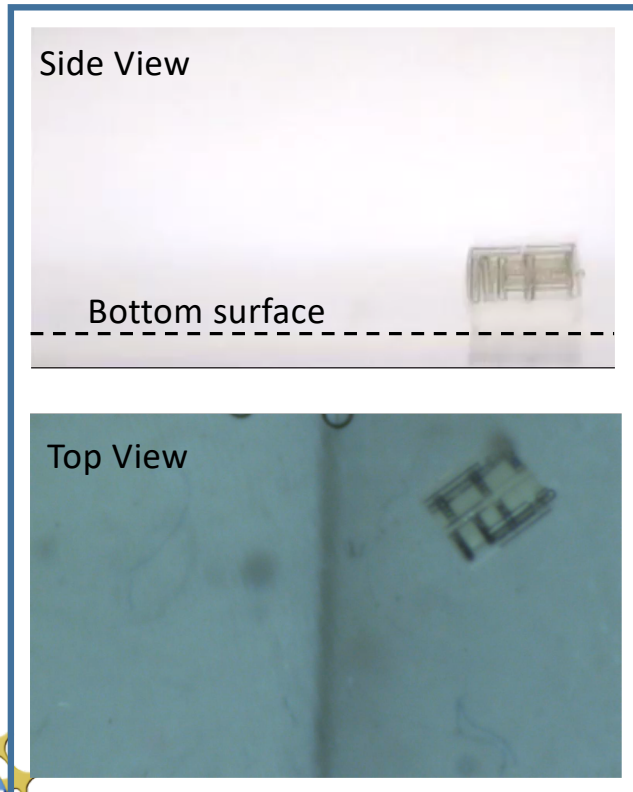
850.0   970.0

917.2

250 µm   250 µm

Image of 3D digital microscope (HiROX, USA)

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3-D Propulsion: Testing

Takeoff and Move Forward

Side View

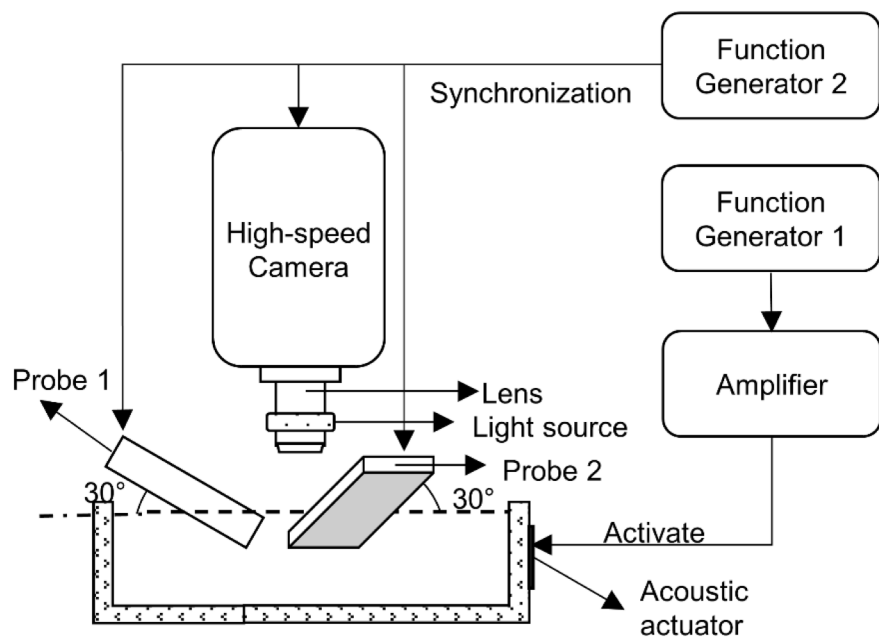Bottom surface

Top View

Yawing

Top View

Side View

(Two video were simultaneously taken)

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Ultrasound Imaging: 2-D Setup

(a)

(b)

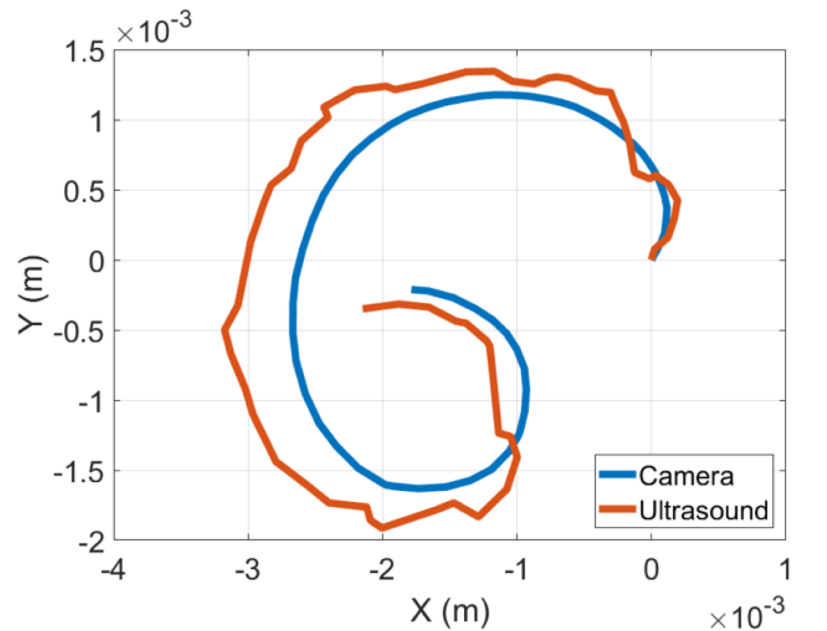# Ultrasound Imaging: 2-D Results

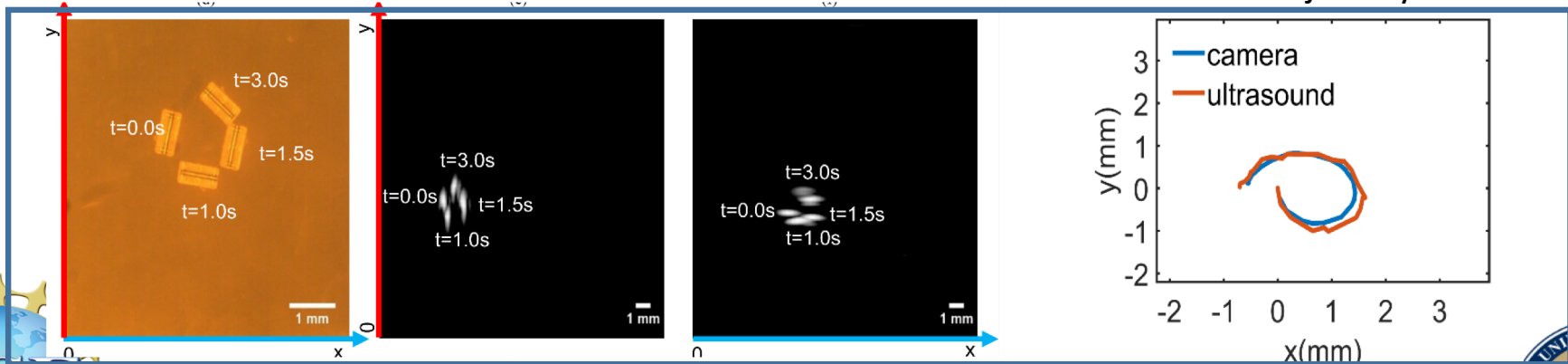# Ultrasound Imaging: 2-D Results
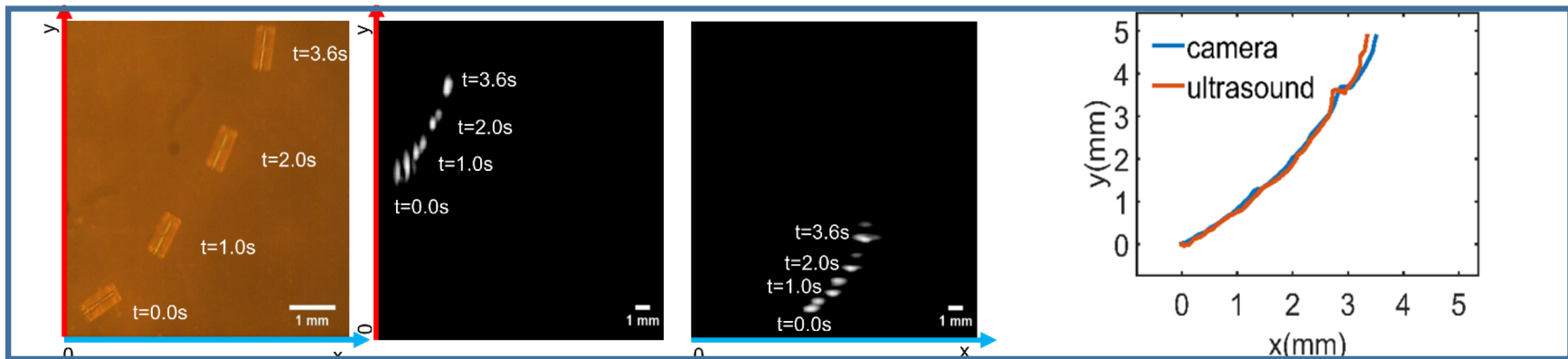
camera   US Probe 1   US Probe 2   2-D Trajectory

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State Dependent Coefficient Observer

$$\overline{A}(q)q = \rho_1 A_1(q)q + \ldots + \rho_5 A_5(q)q$$

$$\sum_{i=1}^{5} \rho_i = 1$$

$$f(q, \tau_0) = \overline{A}(q)q + B\tau_0$$

System Input

Swimmer Dynamics

A_1 •••• A_5

Algebraic Riccati Equation

Propagated error

Filter Gain

K

Measurements and measurements model

$f(\hat{q}, \tau_0) + K(Z - h)$

Full State Estimation

$\hat{q}$

A. Dani, S. Chung, S. Hutchinson IEEE TAC 2015
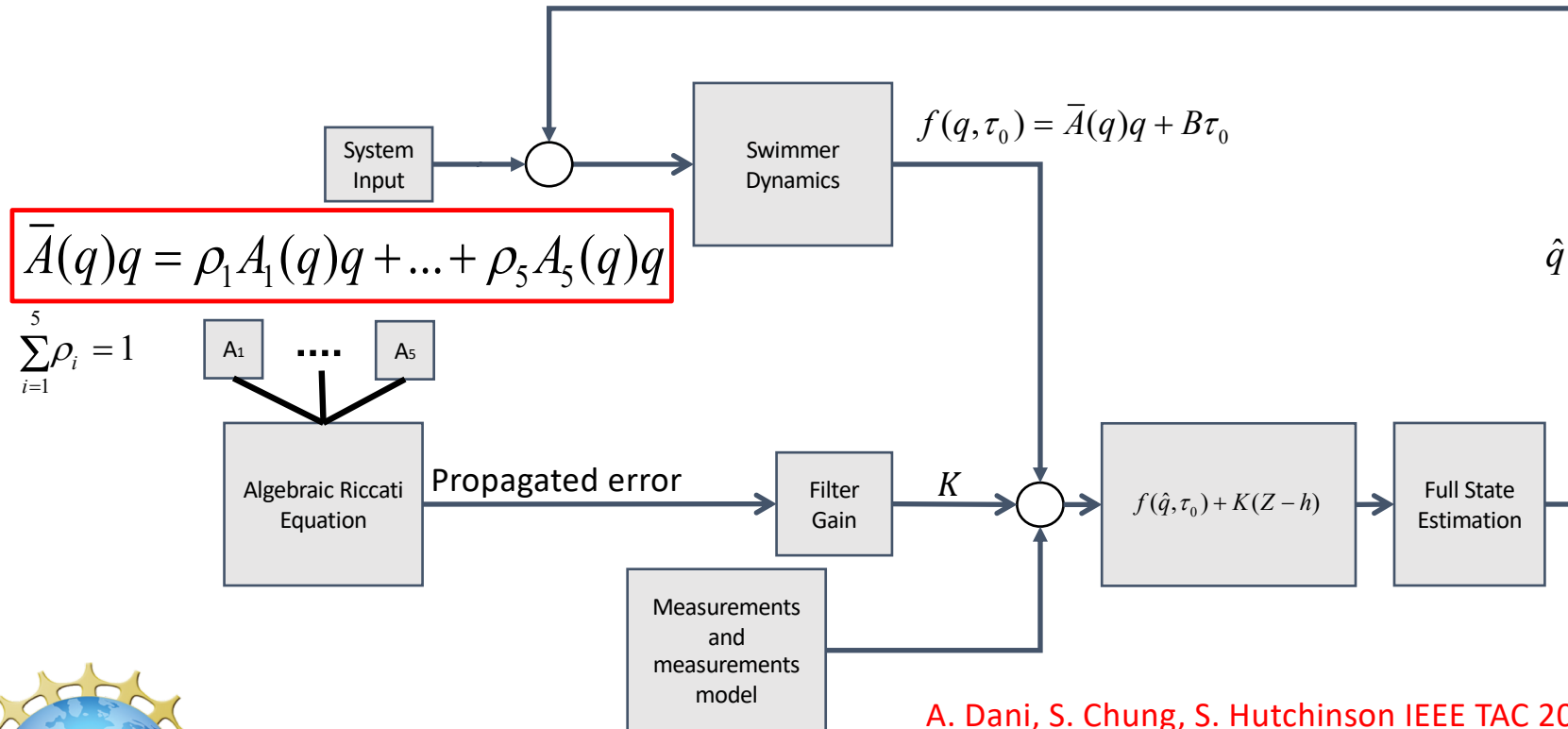
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State Estimation Results
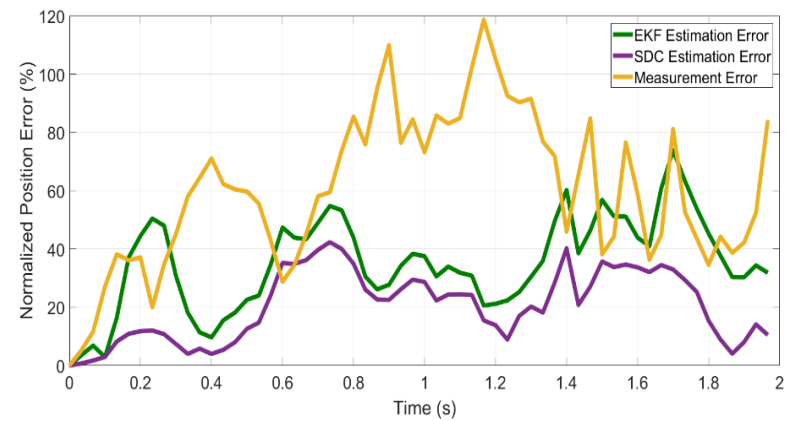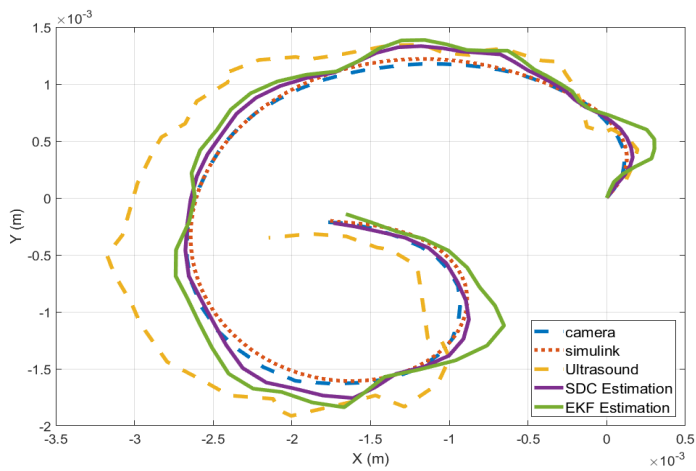
- ❏ 22% reduction in normalized position error due to the SDC observer compared to EFK

Xiao et al. ICRA 2019 (under review)

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Summary

1. **3-D Swimming Drone: Design/Fab**

   - 3-D printed prototype (< 1 mm^3)
   - Controllable takeoff, forward motion, and yaw

2. **US Imaging and State Estimation**

   - Two orthogonal US probes
   - Reconstructed 2-D trajectory from US data using an observer

3. **Feedback Control**

   - Currently implementing observer-based controller

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