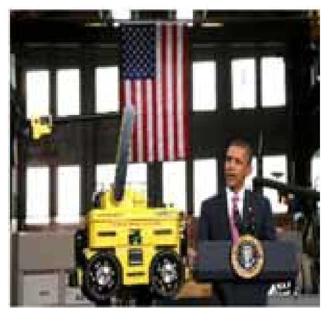
Raven-II Update: Deployment and Research

IROS 2017 Workshop:
Shared Platforms for Medical Robotics Research **24-Sept-2017, Vancouver BC**

Blake Hannaford

UNIVERSITY OF WASHINGTON
ELECTRICAL ENGINEERING

http://brl.ee.washington.edu



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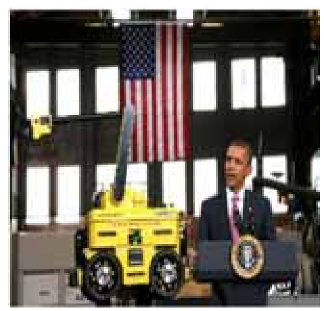


* Blake Hannaford is a co-founder of Applied Dexterity

Thanks!

- ***Jacob Rosen, Ph.D.***
- Mika Sinanan, MD/PhD
- Rick Satava, MD
- Thomas Lendvay, Ph.D.
- Howard Chizeck, ScD.
- Tim Broderick, MD
- Kristin Moe, MD
- Randal Bly, MD
- *Dozens of students!*

Thanks!

)

students!

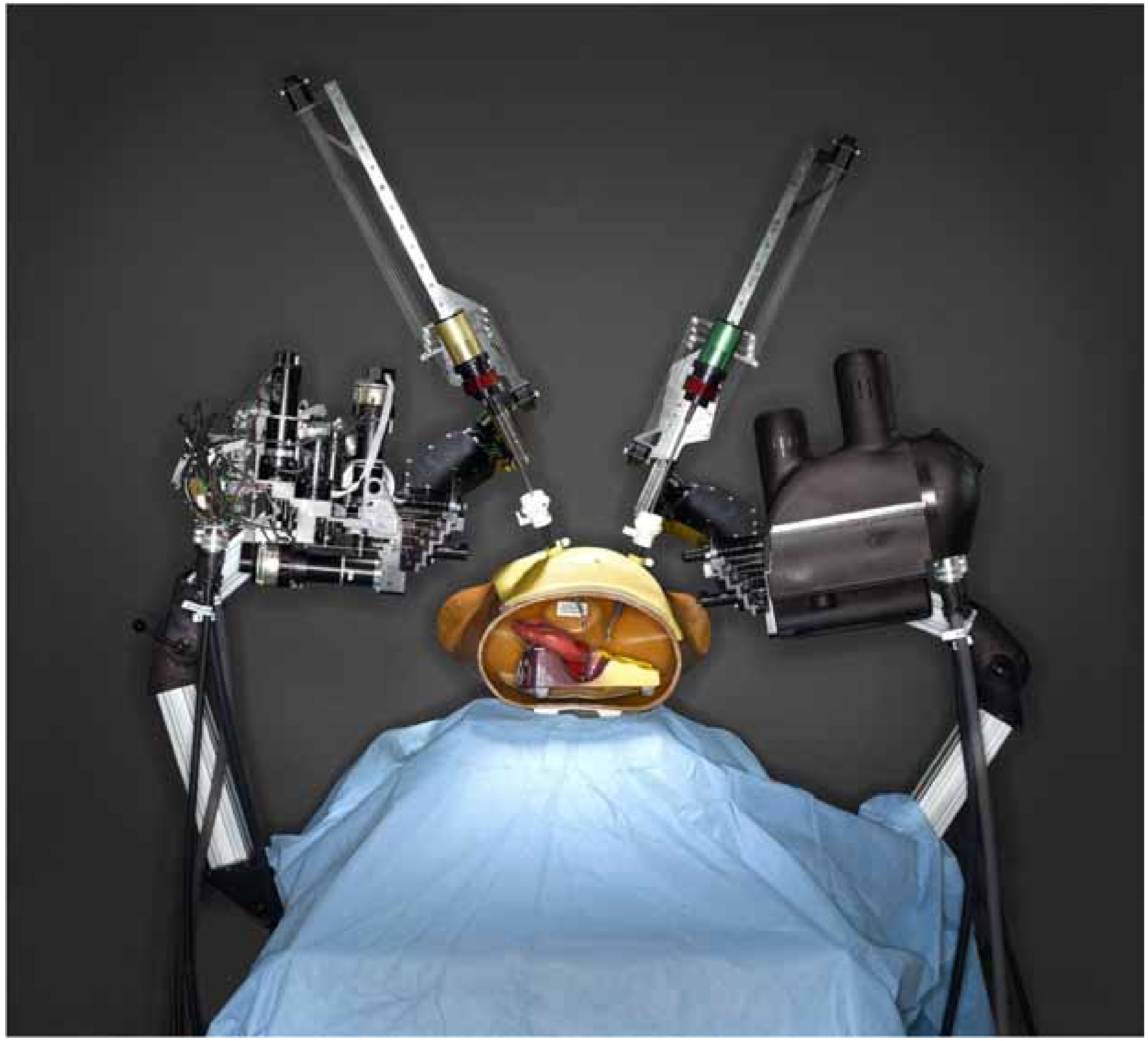
Raven Commercialization

Open source software:
`https://github.com/uw-biorobotics/raven2`

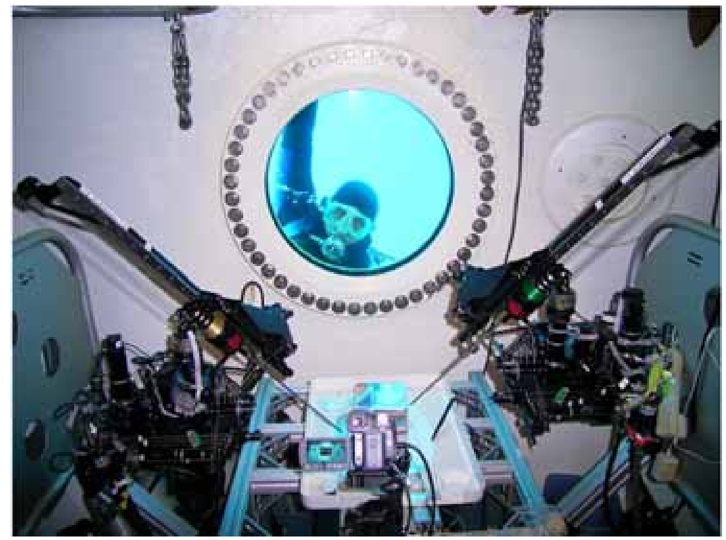
Raven : Goals (2002)

- Portable and robust surgical telerobot research platform
- Minimize mechanism size
- Maximize **Vw/Vm** (workspace/total volume)
- Enable field use
- Support open software development
- Support Interoperable Teleoperation

Raven-I



HapSmrt (2006) and Nemo (2007)



Field Demonstrations:

Demonstrate Field operation of a surgical robot: Generator Power, Radio Internet Links, Desert /Underwater Conditions.

Raven-II (2011)

Support from NSF-Computational Research Infrastructure

- Build a platform for surgical robotics research teams around the US.
- Advance the Raven-I design
- Support commercial instruments
- Open-source the software and create a software community

	University of Washington	**Prof. Blake Hannaford**	
	U.C. Santa Cruz	**Prof. Jacob Rosen**	
2012	Harvard	Prof. Rob Howe	Beating Heart Surgery
	Hopkins	Prof. Greg Hager	Human-Machine Cooperation
	Nebraska	Prof. Shane Farritor	Deployable surgical robots
	UCLA	Prof. Warren Grundfest	Tactile feedback to surgeon
	U.C. Berkeley	Prof. Ken Goldberg & Pieter Abbeel	Machine Learning of surgical autonomy
2013	Stanford University	Prof. Allison Okamura	NRI Large Project
	Montpellier University (Fr)	Prof. Philipe Poignet	LIRMM
	U. of Central Florida	Prof. Zihua Xu	
	U. of Western Ontario (Canada)	Prof. Rajni Patel	(four-arm system)

Raven-II Sites

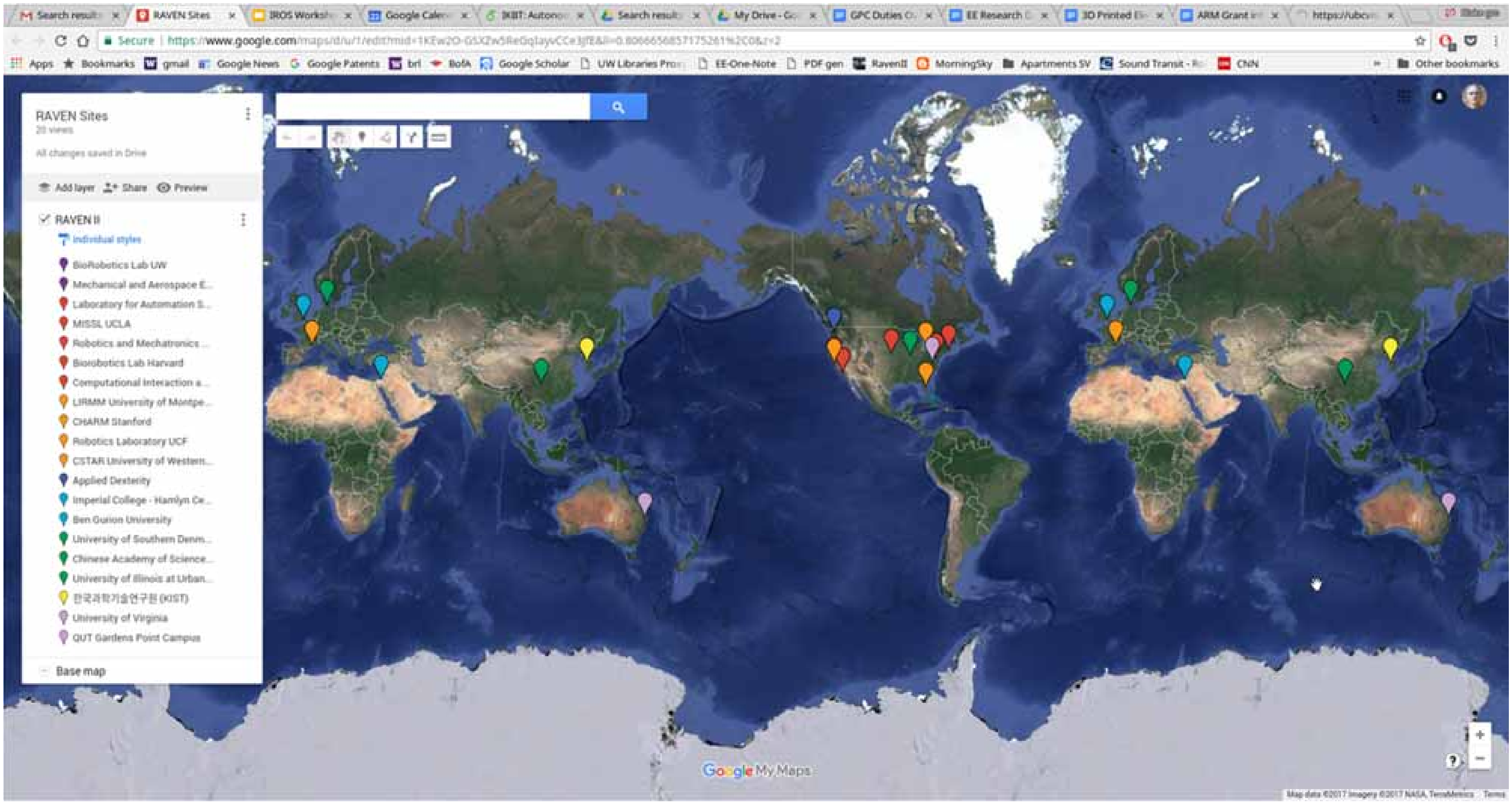
★ NSF CRI Sites (installed 2012)

Raven-II Sites

Raven-II Sites

BioRobotics Lab

Jan 2018 map



BioRobotics Lab

Research Case Study 1:

Cable Friction Losses

Cable Driven Mechanisms


Photo Credit: CMU Biorobotics Lab


Photo Credit: Bionics Lab UCLA

Photo Credit: Intuitive Inc.

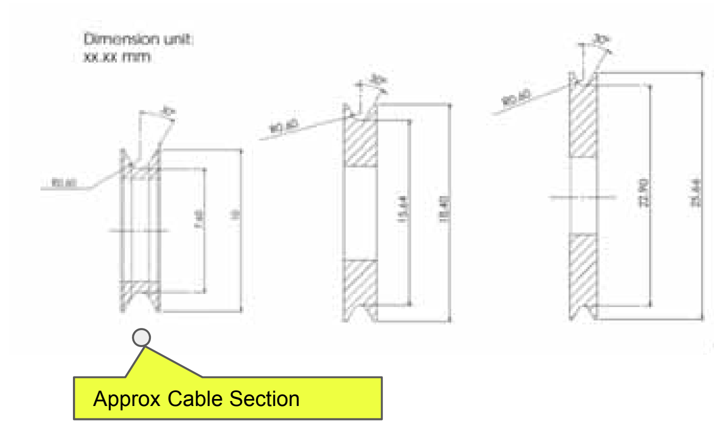

Photo Credit: Fraunhofer IPA


Photo Credit: Force Dimension


Photo Credit: Delft Haptics lab

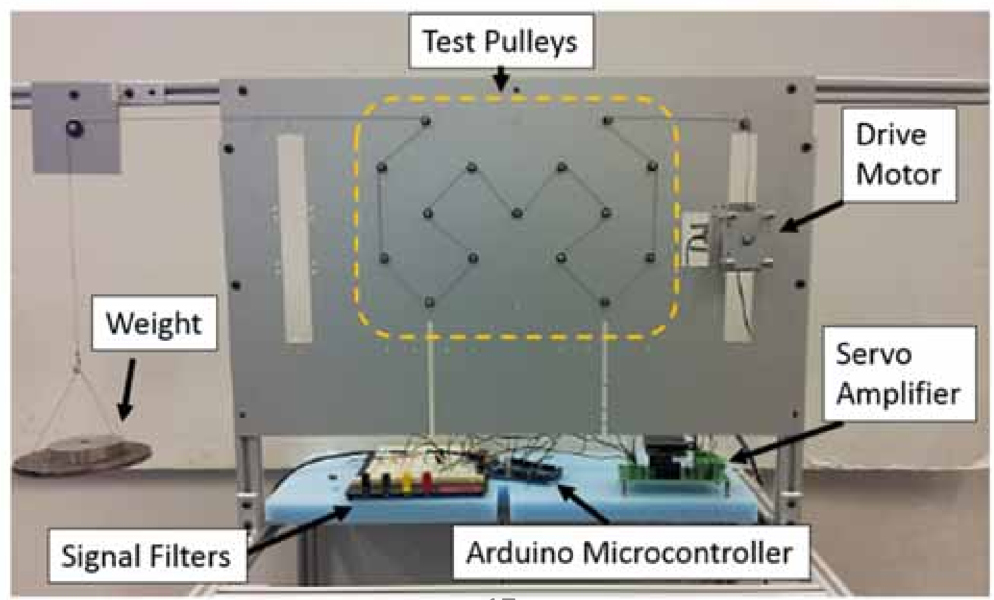
Cable Drive Parameters

- Pulleys:
  - Diam. 7.6, 15.6, 22.9mm
  - 6061 Al, hard anodized finish,
  - ball bearing
  - rec: 25x0.61 = 15.25
- Cable:
  - 304 stainless steel,
  - 7 strand x 19 wire construction,
  - 0.61 mm diameter.
- Variables:
  - Tension preload
  - Velocity
  - Wrap angle
  - # pulleys




7x19


(7x7 cable)



Results: Friction vs velocity

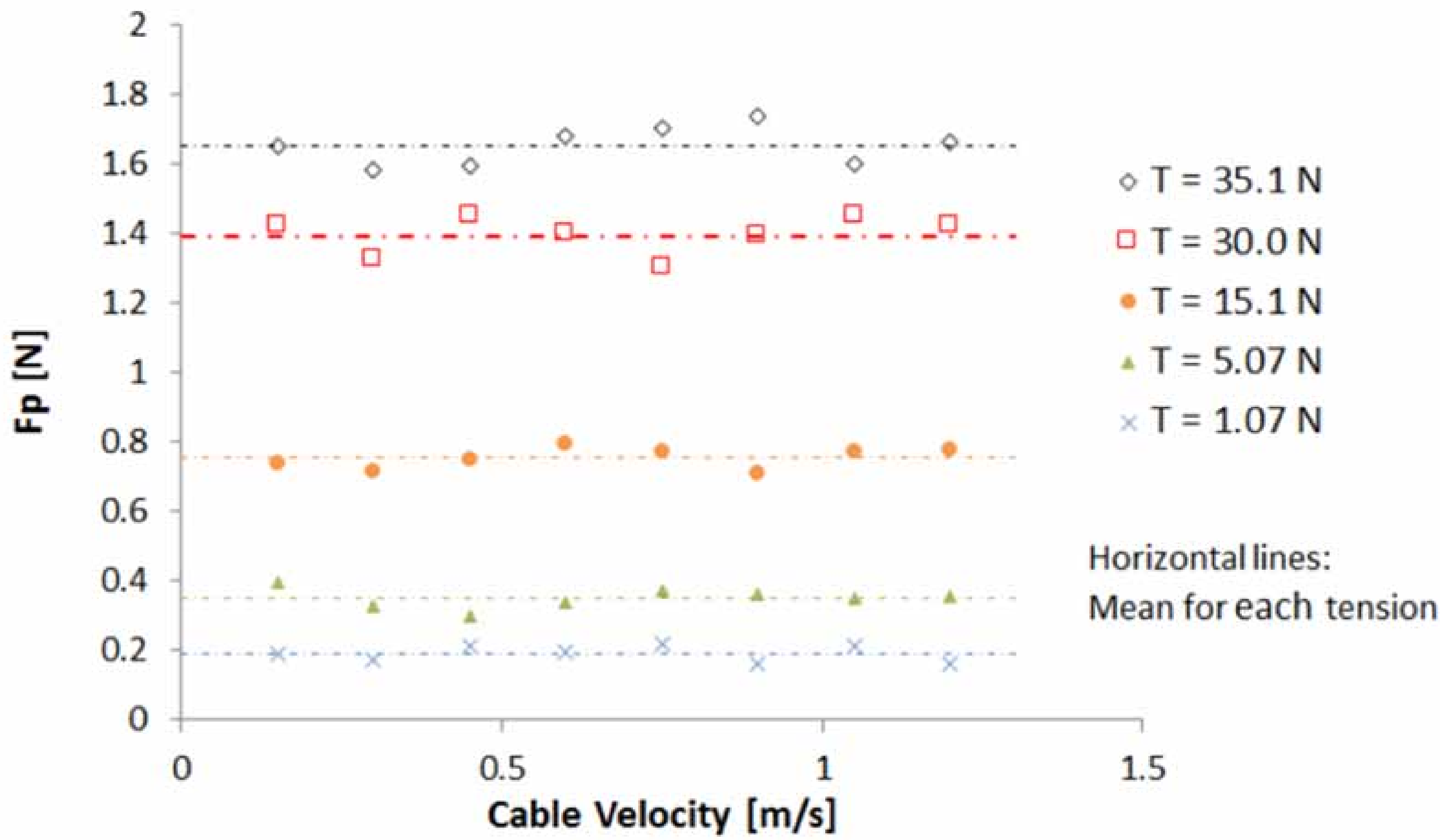
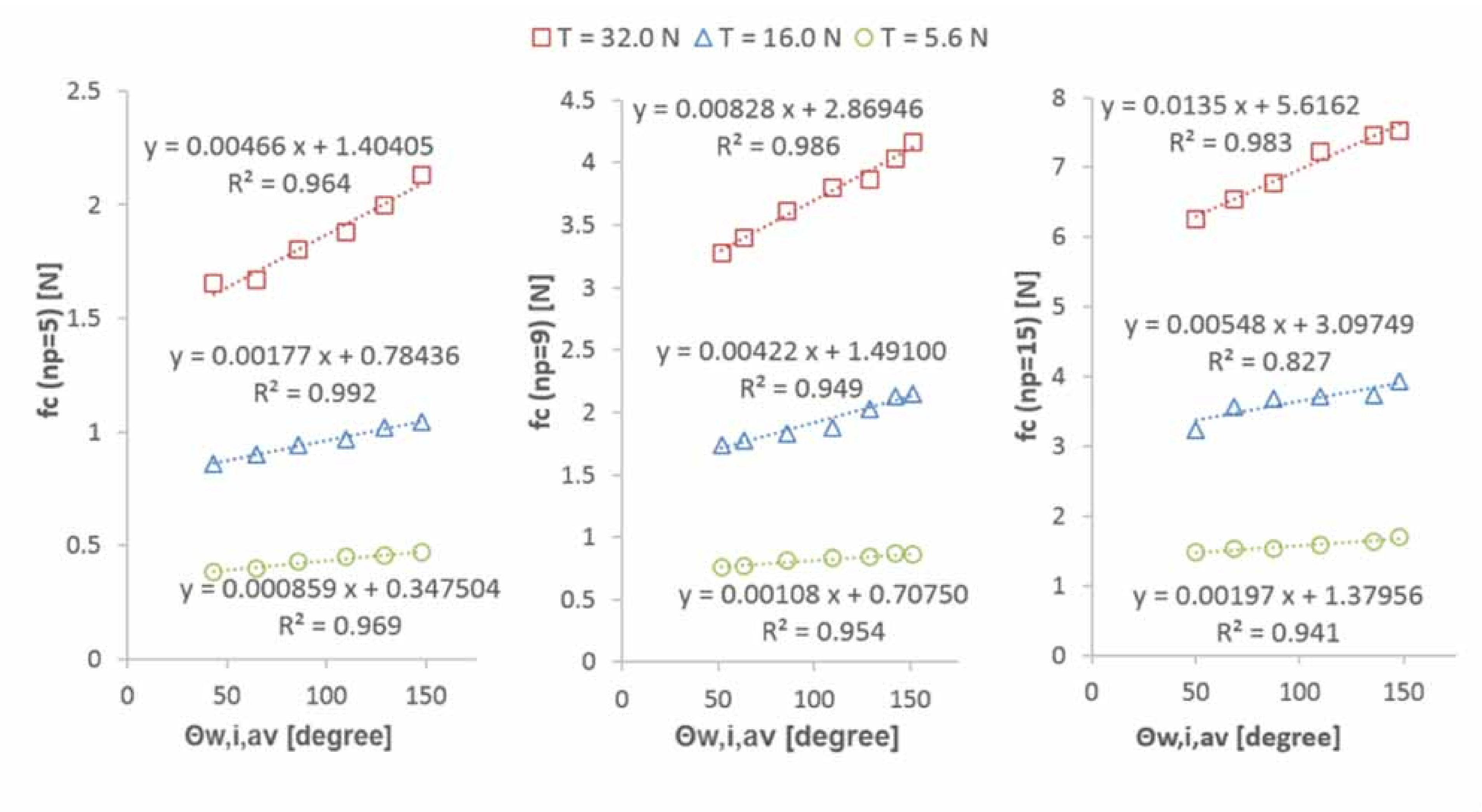


Fig. 4. Cable-pulley friction against cable velocity for a setup with 9 medium pulleys and $\theta_{w,i,av} = 85°$ at five different tensions.

Results: Coulomb friction, small pulley



$$
\begin{aligned}
F_p &= f_c[T, n_p, \theta_{w,i,av}]sign(\dot{x}) \\
&= n_p((c_1 + c_3(\theta_{w,i,av} - 85^\circ))T + c_2)sign(\dot{x})
\end{aligned}
$$

Hannaford, Blake *Measurement of the Cable-Pulley Coulomb and Viscous Friction for a Cable-Driven Surgical Robotic System.* IROS 2015.

Pulley size	Radius $[mm]$	c_1 $[unitless]$	c_2 $[N]$	c_3 $[1/degree]$
Small	3.80	0.0128	0.0261	2.79×10^{-5}
Medium	7.82	0.00416	0.0165	1.02×10^{-5}
Large	11.45	0.00239	0.0129	0.737×10^{-5}

IEEE IROS Hamburg 2015

Case Study 2:

Doing Something About it (in software)

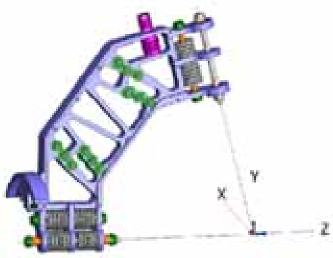
Challenges

- Stiffness
  - Lower stiffness compared to rigid transmission
- Control
  - Added nonlinearity due to elasticity of cables
  - Lower stiffness may cause undesirable vibrations
- Accuracy
  - Relative position error between motor and link due to lower stiffness

[Kosari et al., 2013] [Pradeep et al., 2014] [Zhuang et al., 1995] [Kehoe et al., 2014]

Raven Hardware and Kinematics

CAD models



$$I_{l_1}=\begin{bmatrix}17.376 & 0.291 & -0.374\\ 0.291 & 11.000 & -5.483\\ -0.374 & -5.483 & 6.499\end{bmatrix}\times 10^{-3}\,[kg\cdot m^2]$$

$$I_{l_2}=\begin{bmatrix}81.579 & 0.773 & 0.762\\ 0.773 & 44.329 & 37.973\\ 0.762 & 37.973 & 37.686\end{bmatrix}\times 10^{-3}\,[kg\cdot m^2]$$

$$I_{l_3}=\begin{bmatrix}2.908 & -0.001 & -0.066\\ -0.001 & 3.009 & -0.009\\ -0.066 & -0.009 & 0.355\end{bmatrix}\times 10^{-3}\,[kg\cdot m^2]$$

Cable Coupling

The motion of one actuator may cause joint motion in another link

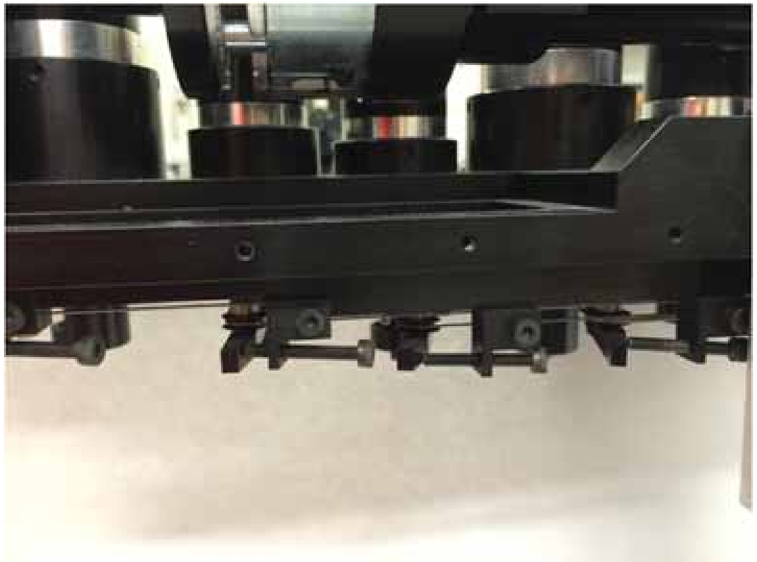
$$\begin{bmatrix}q_{m_1}\\ q_{m_2}\\ q_{m_3}\end{bmatrix}=\begin{bmatrix}t_{r_1} & 0 & 0\\ C_{01}t_{r_2} & t_{r_2} & 0\\ C_{02}t_{r_3} & C_{12}t_{r_3} & t_{r_3}\end{bmatrix}\begin{bmatrix}q_1\\ q_2\\ q_3\end{bmatrix}$$

Experiments

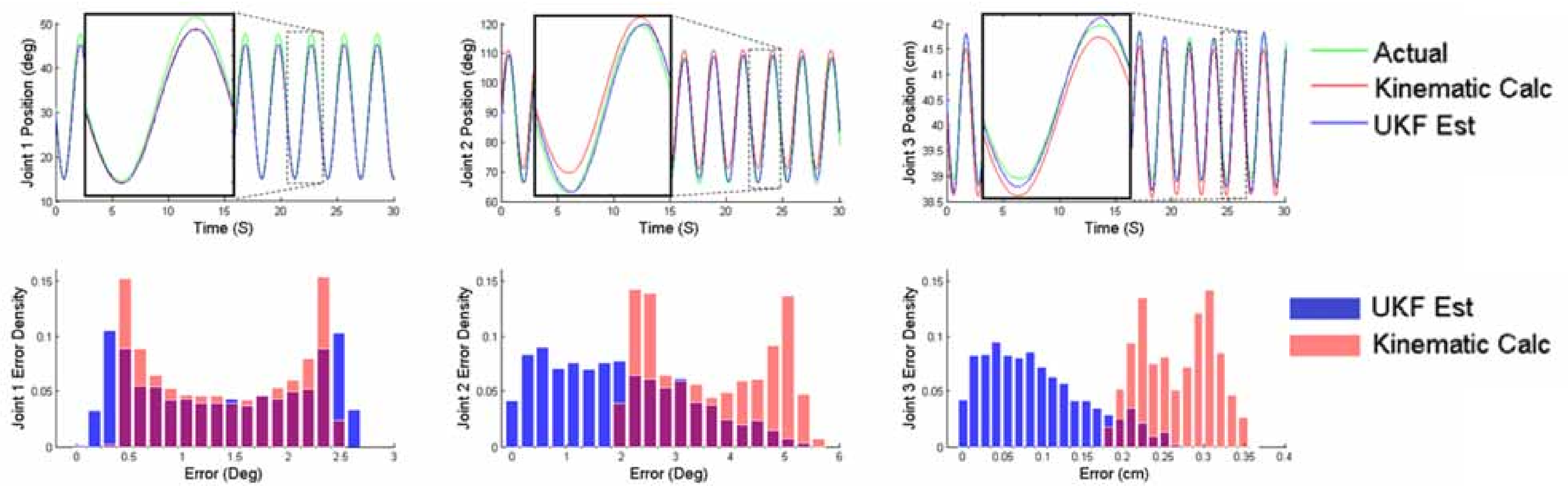
A: High Tension Performance
- Set cable tension to "High" value
- Apply sinusoidal trajectory

B: Low Tension Performance
- Set cable tension to "Low" value
- Apply sinusoidal trajectory

C: Adding Mass to system
- Set cable tension to High value
- Attach an object to end-effector



Experiment A: High Cable Tension



Results

Average position errors and improvement of all the experiments

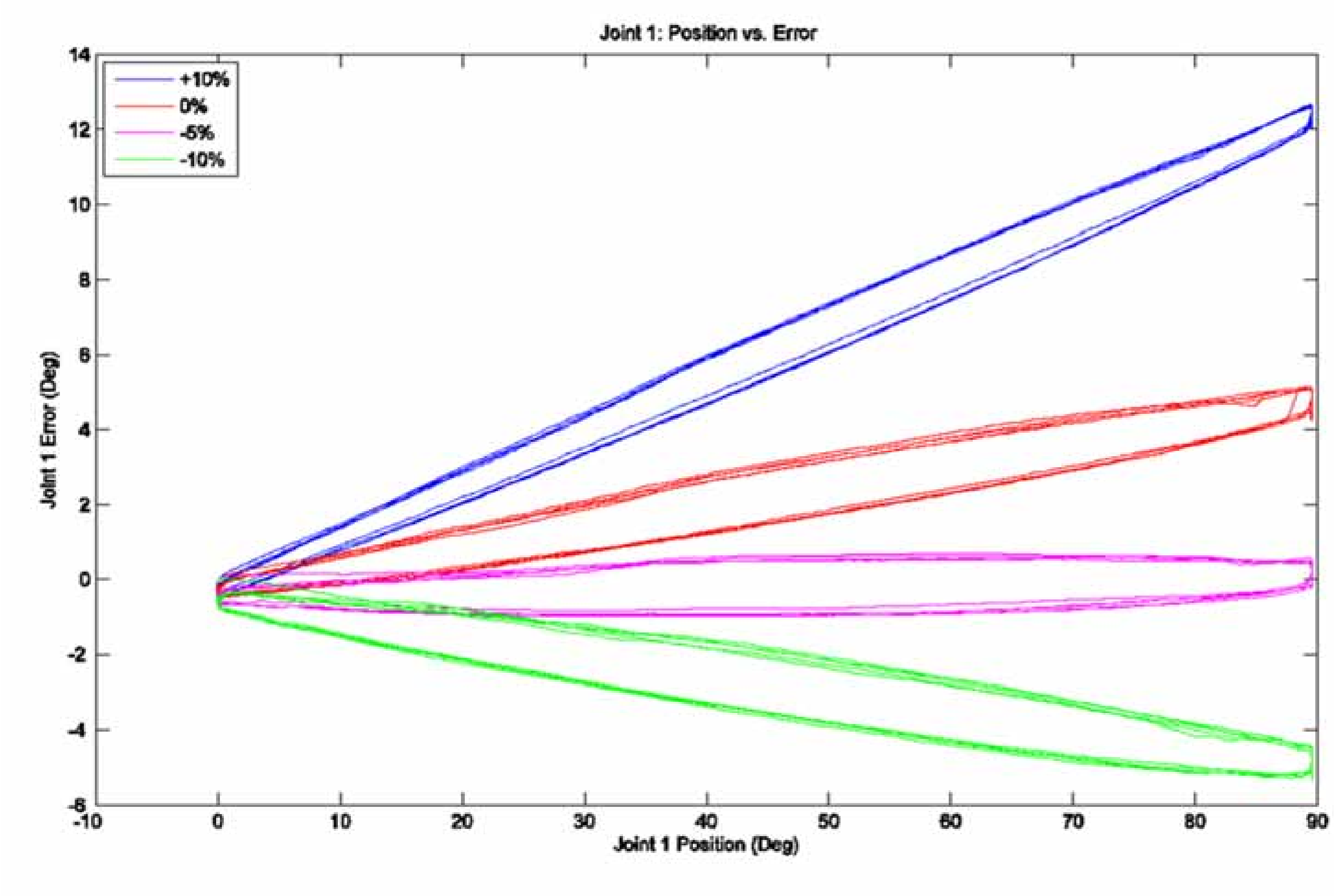
Joint (Unit)	Avg. UKF MAE	Avg. Non UKF MAE	% Improvement
1 (Deg)	1.2946	1.3134	1.434
2 (Deg)	1.6685	2.6383	36.76
3 (cm)	0.0928	0.2507	62.99

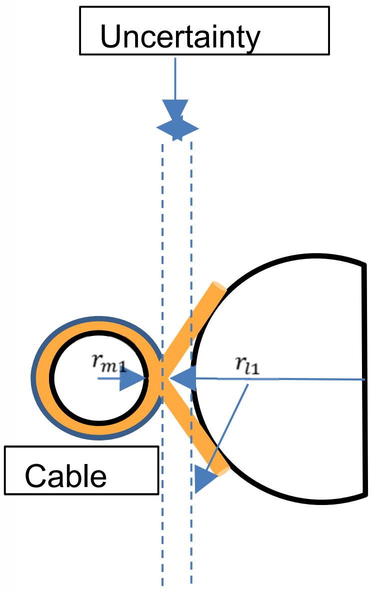
$$\%Improvement = 100 \times (Kinematic_{est} - UKF_{est})/Kinematic_{est}$$

"Improving Position Precision of a Servo-Controlled Elastic Cable Driven Surgical Robot using Unscented Kalman Filter," in Intelligent Robots and Systems (IROS), 2015 IEEE International Conference on, IEEE, 2015.

Mohammad Haghighipanah, Yangming Li, Muneaki Miyasaka, and Blake Hannaford

Kinematic Uncertainty





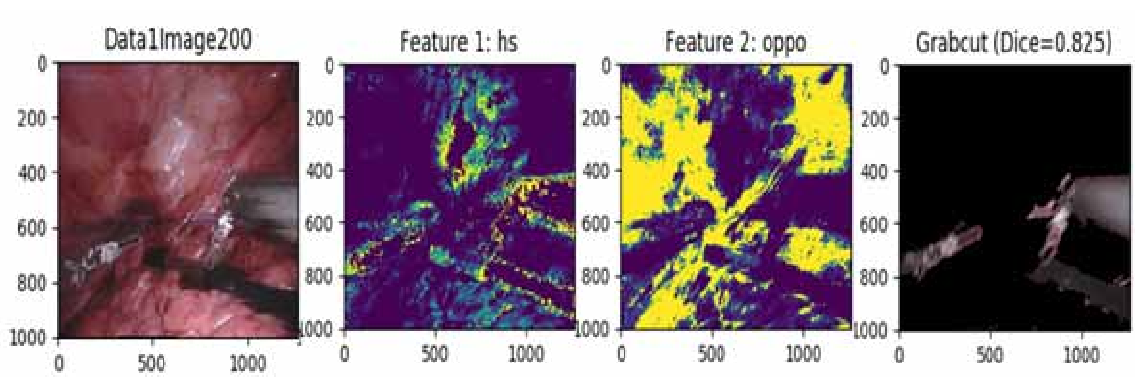
Case Study 3:

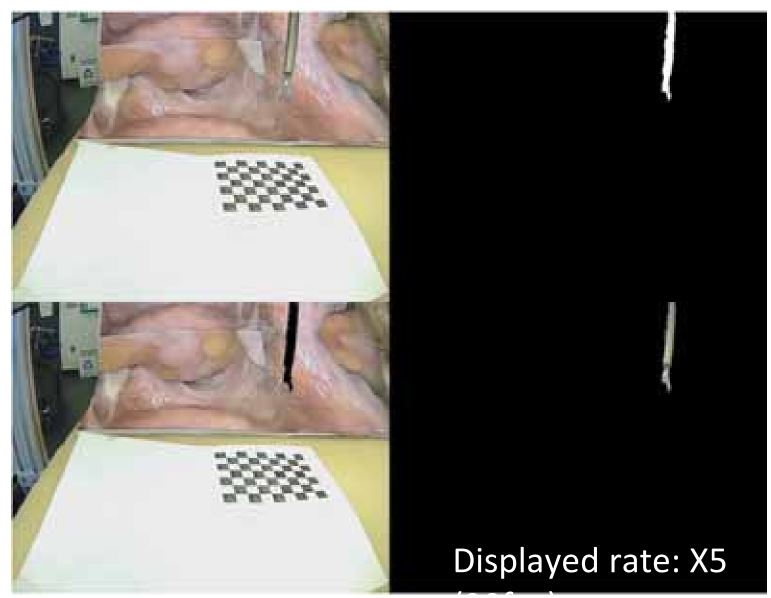
Surgical Instrument Segmentation with Kinematics Prior

Surgical Instrument Segmentation
BRL Team: Yun Hsuan Su, Nive Kalavkonda

- **Method:**
  - Autonomous classification for image **blurriness**.
  - Segmentation strategies or parameters dependent on level of blur.
  - Color filter in **opponent color space** with border constraints.
  - Consider other features – shape, disparity discontinuity applied to the color filtering mask with weighting values.
  - Segmentation decision by **Grabcut with mask** with OpenCV.
- **ISI Instrument Segmentation Challenge Result:**
  - The only team NOT using machine learning methods.
  - Rank 8th out of the 28 downloads. (still improving our algorithm)

- **Implementation on Raven:**
  - Robot Kinematics: tool tip position generates prior (rostopic: ravenstate)
  - Average **Dice Coefficient**: **0.75**
    Processing rate: ~ **6fps** (no GPU)
  - Video pipeline with tool segmentation:
    further applications on Raven.





Recent Raven - Related Results from UW BRL

Miyasaka, Muneaki, Joseph Matheson, Andrew Lewis, and Blake Hannaford. "Measurement of the cable-pulley coulomb and viscous friction for a cable-driven surgical robotic system." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 804-810. IEEE, 2015.

Haghighipanah, Mohammad, Yangming Li, Muneaki Miyasaka, and Blake Hannaford. "Improving position precision of a servo-controlled elastic cable driven surgical robot using unscented kalman filter." In Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, pp. 2030-2036. IEEE, 2015.

Miyasaka, Muneaki, Mohammad Haghighipanah, Yangming Li, and Blake Hannaford. "Hysteresis model of longitudinally loaded cable for cable driven robots and identification of the parameters." In Robotics and Automation (ICRA), 2016 IEEE International Conference on, pp. 4051-4057. IEEE, 2016.

Li, Yangming, Muneaki Miyasaka, Mohammad Haghighipanah, Lei Cheng, and Blake Hannaford. "Dynamic modeling of cable driven elongated surgical instruments for sensorless grip force estimation." In Robotics and Automation (ICRA), 2016 IEEE International Conference on, pp. 4128-4134. IEEE, 2016.

Haghighipanah, Mohammad, Muneaki Miyasaka, Yangming Li, and Blake Hannaford. "Unscented kalman filter and 3d vision to improve cable driven surgical robot joint angle estimation." In Robotics and Automation (ICRA), 2016 IEEE International Conference on, pp. 4135-4142. IEEE, 2016.

Haghighipanah, Mohammad, Muneaki Miyasaka, and Blake Hannaford. "Utilizing Elasticity of Cable-Driven Surgical Robot to Estimate Cable Tension and External Force." IEEE Robotics and Automation Letters 2, no. 3 (2017): 1593-1600.

Raven-II Community Publications