INSPIRE: Mobile-manipulating UAVs for Sensor Installation, Bridge Inspection and Maintenance

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Missouri Science and Technology (MS&T) Annual Meeting

Rolla, MO, August 14, 2018

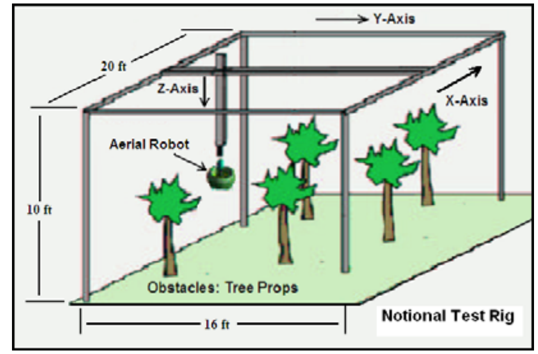
History: Continuum of Research

2000 – 2011: UAVs

- NASA JPL: Perch-and-Stare
- NSF CAREER: **Fly indoors**
- DARPA OAV – Army FCS
- Caves (**Hovering Airplane**)
- UAV-UGV Coordination (**Transport)**
- Pilot Training (**Chase View**)

Sept. 11, 2001

Hurricane Katrina



2007 – 2012: UAVs & Humanoids

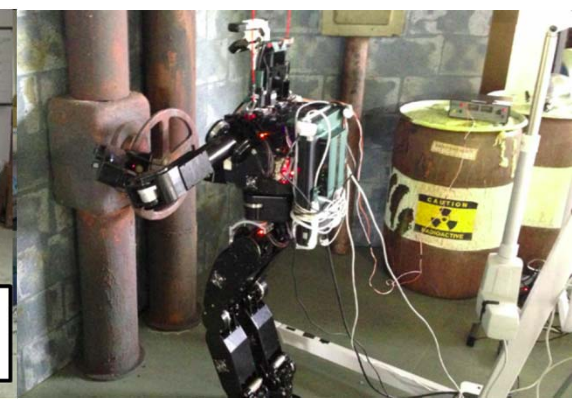
- Boeing - Globalization
- NSF PIRE (**Humanoids** International)
- NSF MRI (7 Hubos to US schools)
- NSF CRI: **UAVs with Limbs** (MM-UAV)

Boeing Welliver

2008 – 2014: Manipulation

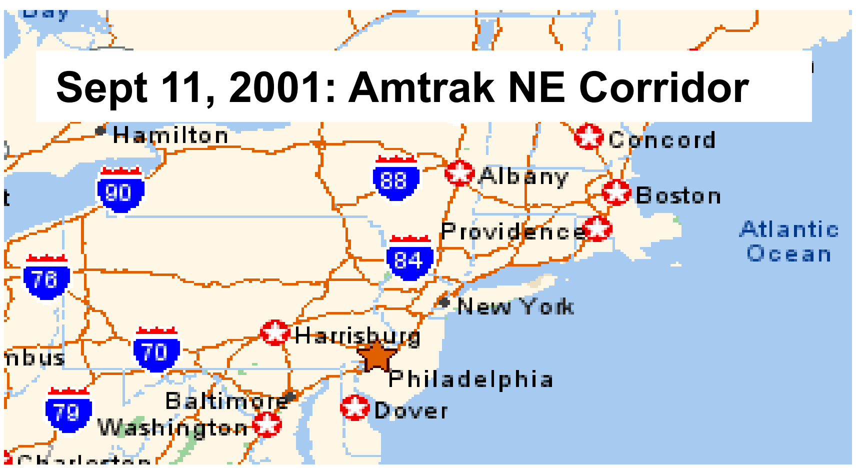
- UAVs and Manipulation (peg-in-hole)
- **DARPA Robotics Challenge**
- **UAVs and valve-turning**


B. Kobe (EE), RJ Gross (ME)
First trip outside US (PA)



Hi-DOF General Purpose Robots: Systems for Tomorrow's "Material-Handling" Needs

Disasters as "Why" … Shaped my "What" and "How"

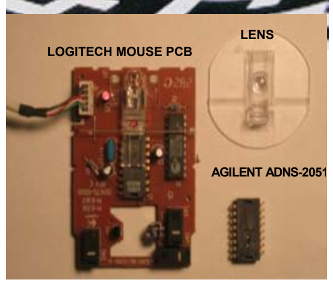


U.S. Army Telemedicine and Advanced Technology Center

ATA American Telemedicine Association

Near-Earth UAVs

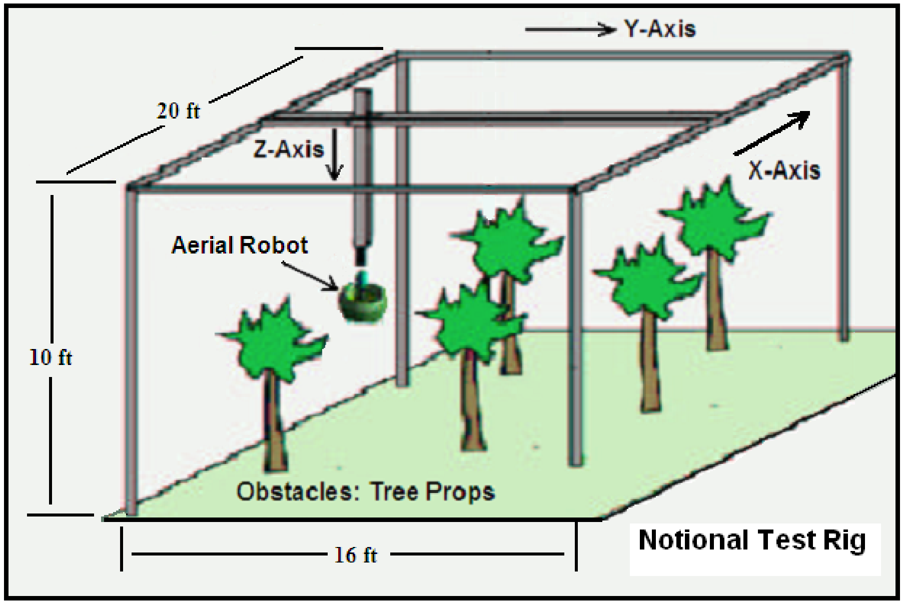
- Degraded Comms
- Poor GPS
- Obstacles
- Dynamic



Optic Flow Sensor

Courtesy: Geof Barrows, Centeye

Notional Concept

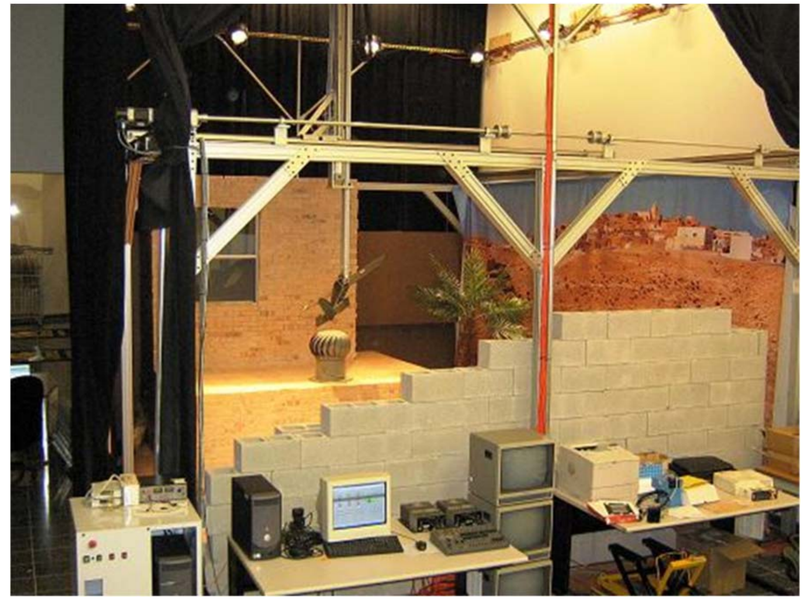


- Gantry + PTR (6-DOF)
- Mockup air vehicle
- Real sensors, time, obstacles
- Hi-fidelity aircraft model

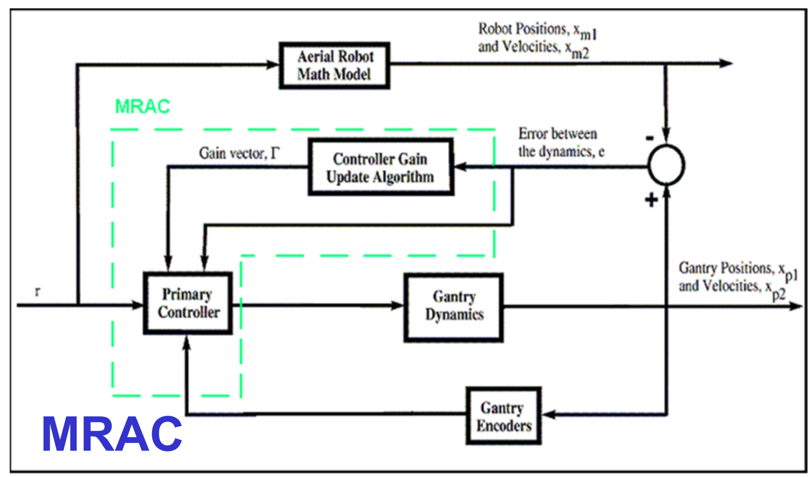
HITL: Test rig moves the aerial robot by mimicking the math model

Realization

CAREER
IIS- 0347430

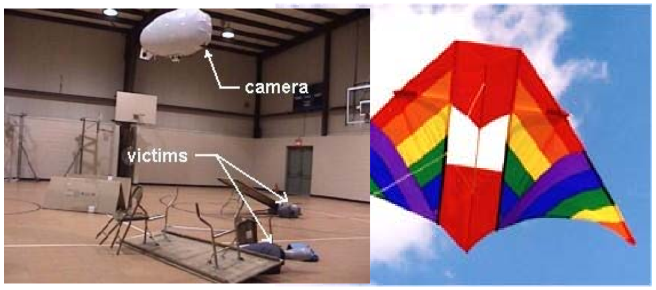


Volume: 25 x 25 x 15 cubic feet



"A Hardware-in-the-Loop Test Rig for Designing Near-Earth Aerial Robotics,"
V. Narli, P.Y. Oh, IEEE ICRA, Orlando FL, pp. 2509 - 2514, May 2006.

New Tools Enable Designing Analytically (2002-2008)



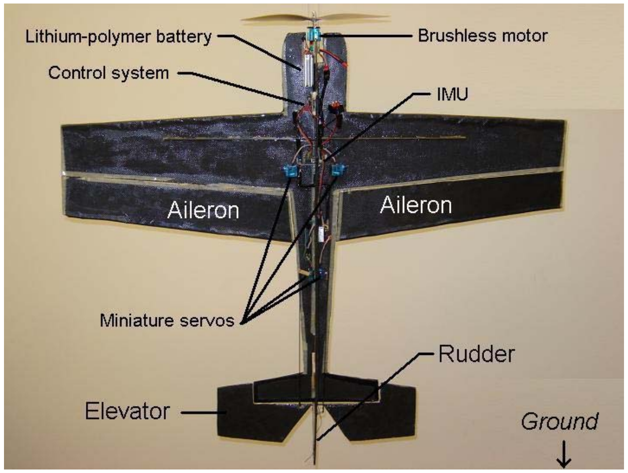
- Search & Rescue Blimp
- 3D Reconstruction Kite

- Indoor flying
- Perch & Stare

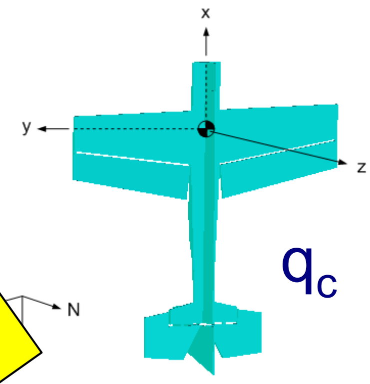
- Autonomous Landing
- Collision Avoidance

- Hovering Airplane
- UGV-UAV coordination

Solution: Quaternions Enable Cruise-to-Hover and Navigation



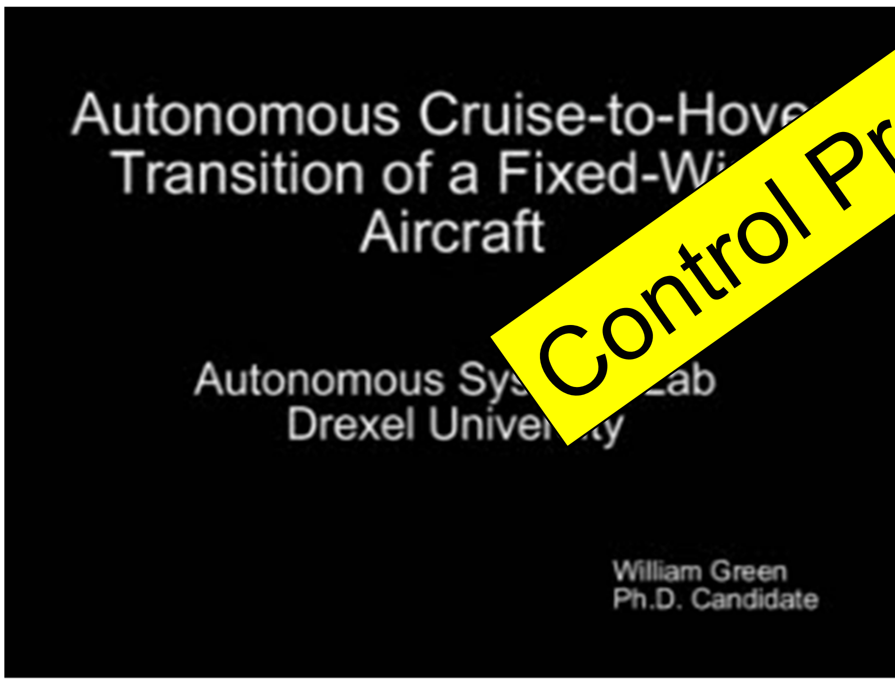
- High endurance
- High Maneuverability ("Dash")
- Hovering Capability

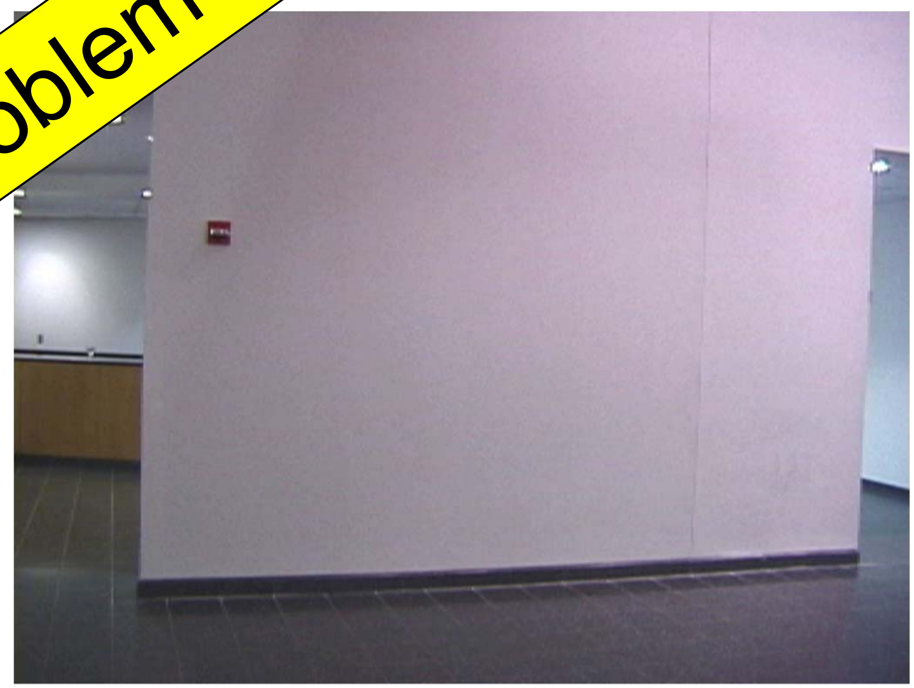


Error
Quaterni

$$e = q_m^{-1} \otimes q_c$$

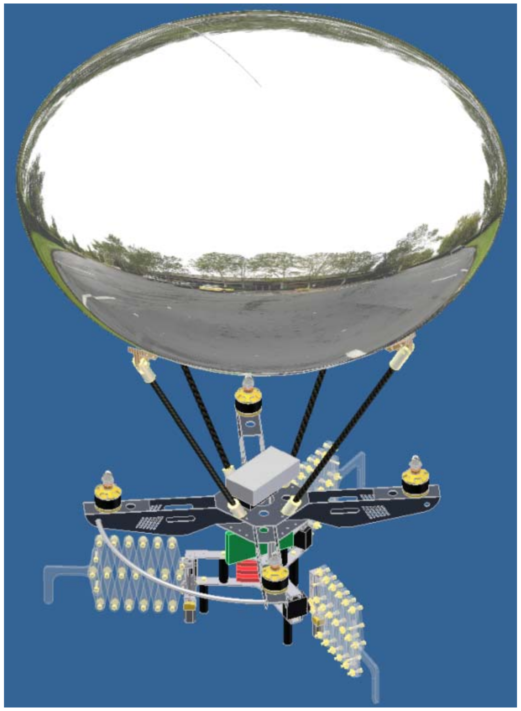
Control Problem Solved





Green, W.E., Oh, P.Y., "A Hybrid MAV for Ingress and Egress of Urban Environments", *IEEE Transactions on Robotics*, May 2009

How to Open Doors? Aerial Manipulation?

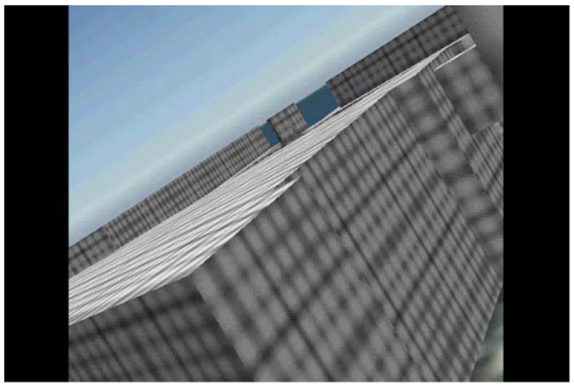


- Buoyancy Envelope
- Quad 500 g payload
- 2 operators
- 3 scissor arms
- Linear actuator
- Roll and Extend

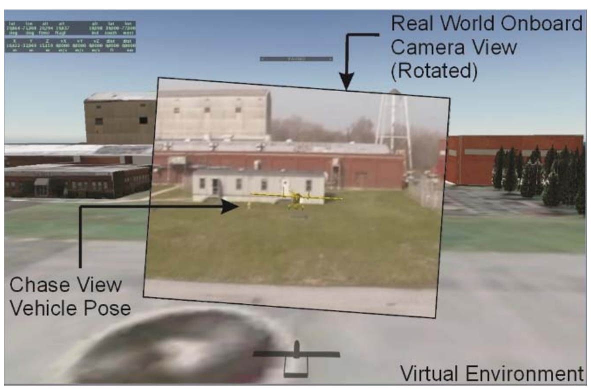
- Payload not key issue
- Perfect LOS and Comms
- 2 operator coordination issue

Korpela, C.M., Danko, T.W., Oh, P.Y., "**Designing a System for Mobile Manipulation from an Unmanned Aerial Vehicle**" IEEE TEPRA, Woburn, MA 2011

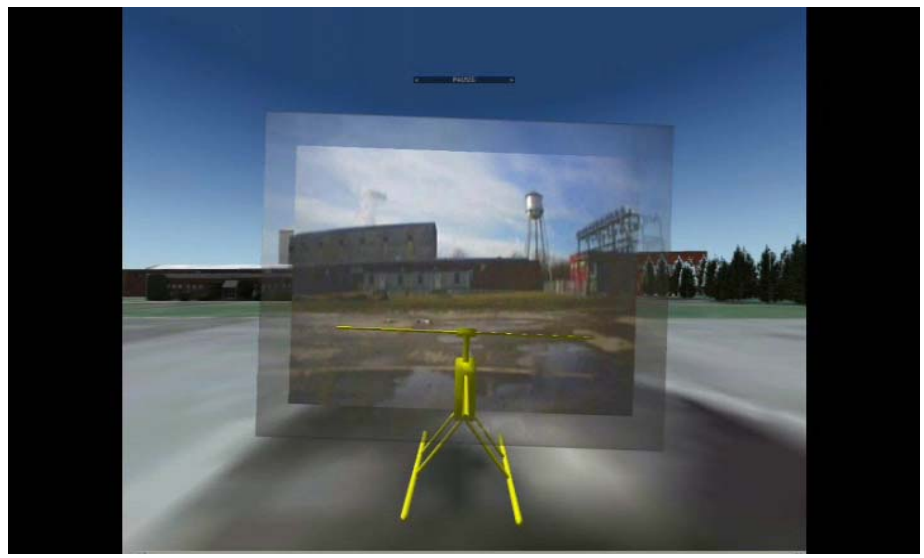
Improved Field-of-View: Shared Fate Approach?



Internal View

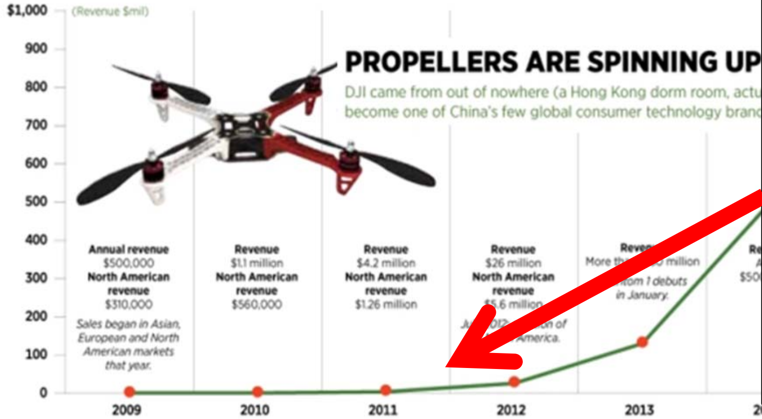


Chase View



Hing, J,. Sevcik, K., Oh, P.Y., "Improving unmanned aerial vehicle pilot training and operation for flying in cluttered environments", IEEE IROS 2009

Hockey Stick Graph – The Outcome-Based Economy

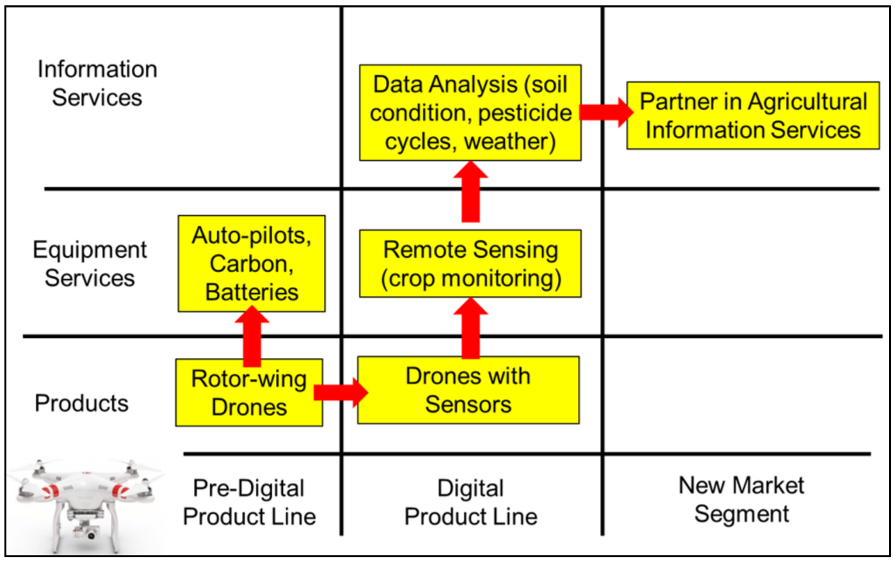


UAV Academics Timeline

- 2002: Collision Avoidance focus
- 2003: LIPO Batteries
- 2004: Carbon Fiber
- 2005: Brushless DC motors
- 2007: Cameras, GPS, IMU
- 2008: Lower-cost LIDAR

Great for 3Ps:

- Proposals
- Publish
- PhDs



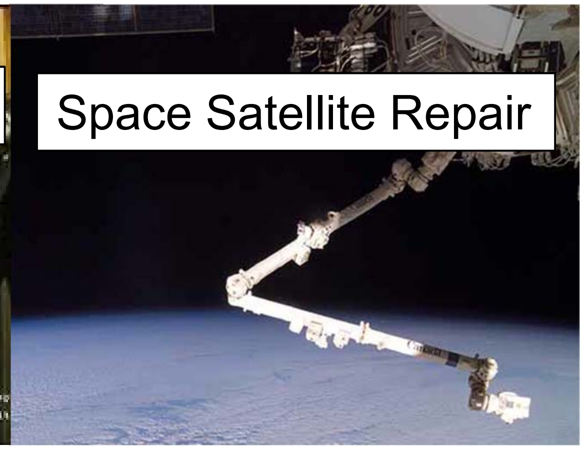
Outcome-Based Economy (workforce development and capacity building)

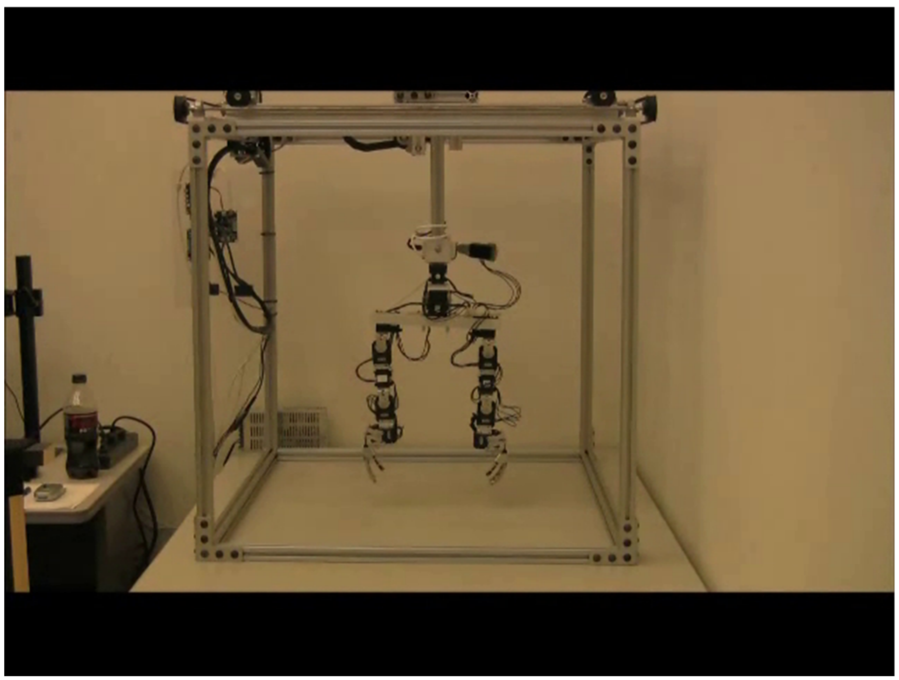
- Pay-per-outcome
- New connected **ecosystem**
- **Platform** Enabled Marketplace


Same Issues: Falling…

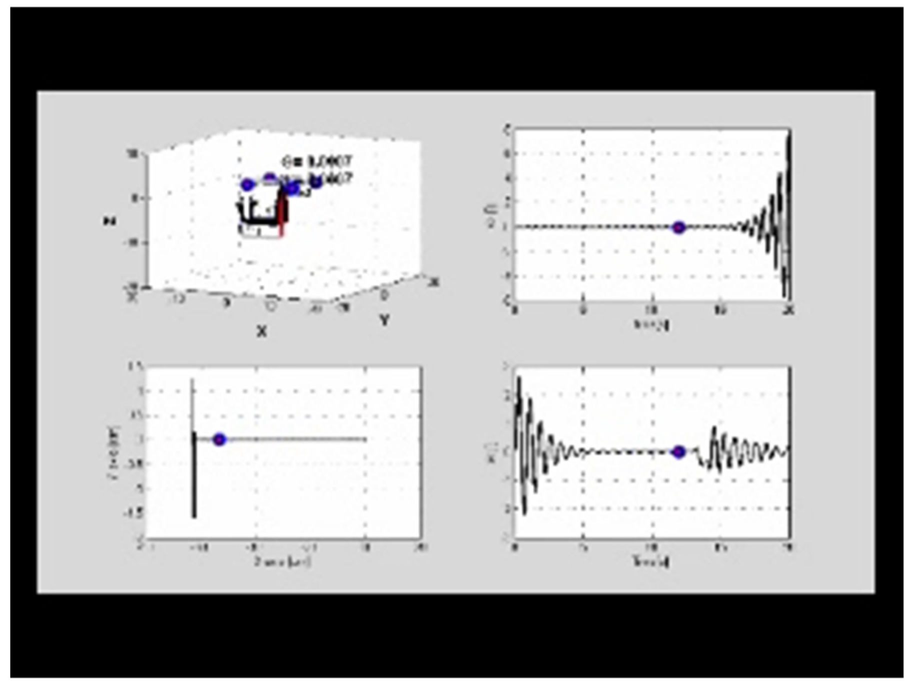

Manipulation Destabilizes

Mobile Manipulating UAVs (MM-UAVs) Concept



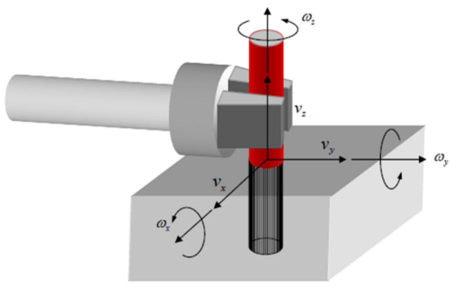


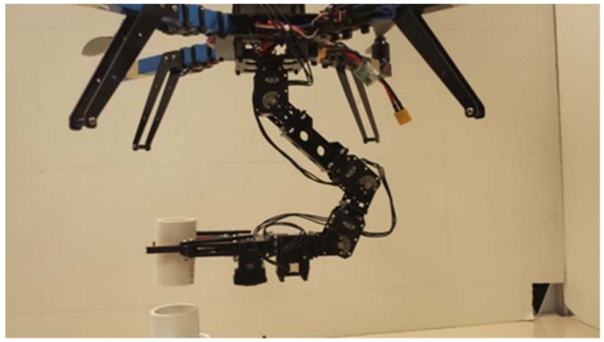
Vehicle-Manipulator Momentum Conservation



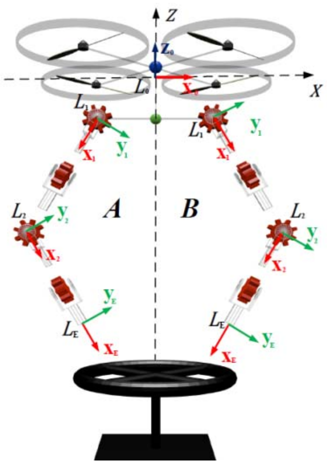
Coupling Momentum and Reaction Null-Space

MM-UAV: Mobile-Manipulating UAVs – Sample Demos and Publications

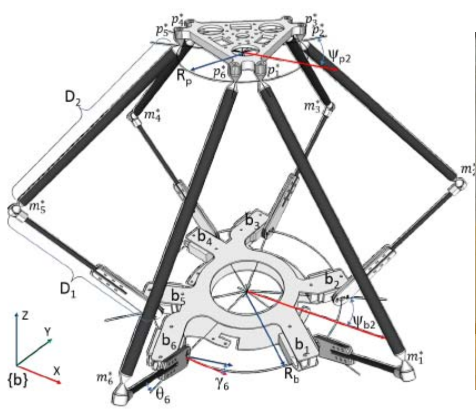




Korpela, C., Orsag, M., Miles, C.D., Oh, P.Y., "Dynamic Stability of an Unmanned Aerial Vehicle," IEEE International Conference on Robotics and Automation (ICRA), Karlsruhe, Germany, May 2013



Orsag, M., Korpela, C., **Bogdan, S**., Oh, P.Y., "Valve turning using a Dual-Arm Aerial Manipulator," International Conference on Unmanned Aerial Systems (ICUAS), Orlando, FL, May 2014



Danko, T., Oh, P.Y., "Design and Control of a Hyper-Redundant Manipulator for Mobile Manipulating Unmanned Aerial Vehicles," Journal of Intelligent and Robotics Systems (JINT), Springer-Verlag, Oct 2013

Mobile-Manipulation UAVs: Insertion, Valve-Turning, and Visual-Servoing

INSPIRE
UNIVERSITY TRANSPORTATION CENTER
LED BY MISSOURI S&T

Year 0-1
May 2016 – Nov 2017

Center Mission: To revolutionize bridge inspection and preservation methodologies and tools as well as workforce development strategies by developing advanced technologies (e.g. sensors, nondestructive evaluation, unmanned aerial vehicles, and robotics) and integrating them into practice in order to cost-effectively manage our nation's aging transportation infrastructure.

Approaches (2016 Proposal)

1. UAV uses can of **compressed air** for bridge-cleaning
2. Two UAVs (potentially 1 blimp and 1 rotorcraft) airlift, position, and **operate hoses** from ground

Year 1 Scope of Work (2016 Proposal)

1. Hyper-redundant **serpentine-like limbs** for dexterous manipulation
2. **Multi-UAVs** for coordinated and cooperative missions

Feb 2017 (Project Start)

MM-UAV needs strong arm and hand!

Dr. Paul Oh

From 11/27/17 Progress Report
10-months effort and outcome

PROJECT: Mobile-manipulating UAVs for Sensor Installation, Bridge Inspection and Maintenance

ACCOMPLISHMENTS:

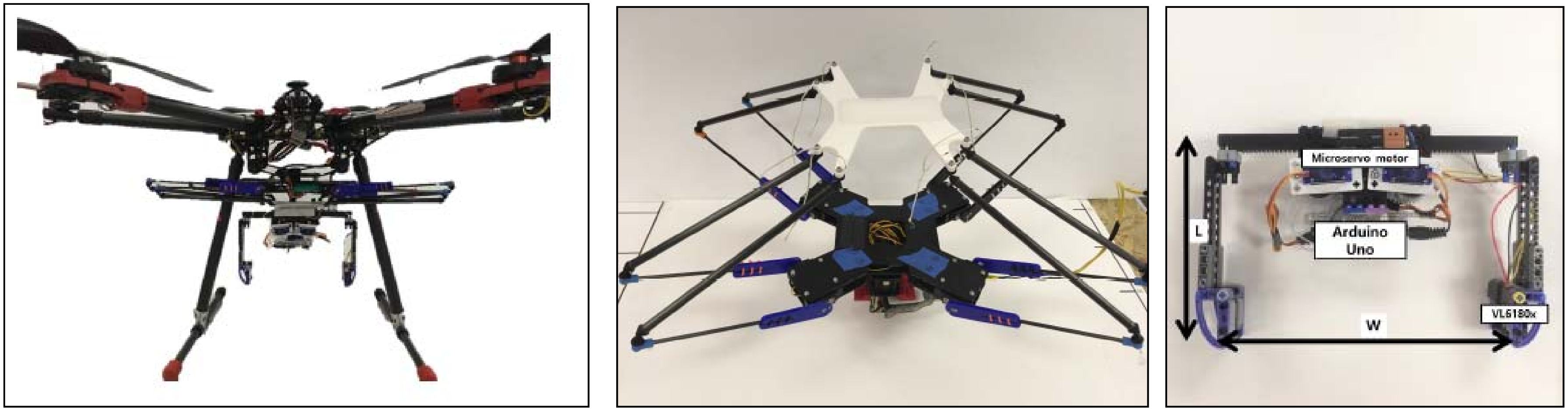
- Theory: impedance-based arm control design ✓
- Design: parallel-based mechanism arm and gripper ✓
- Experiments: pick-and-place and hose-carrying ✓

PLANNED ACTIVITIES:

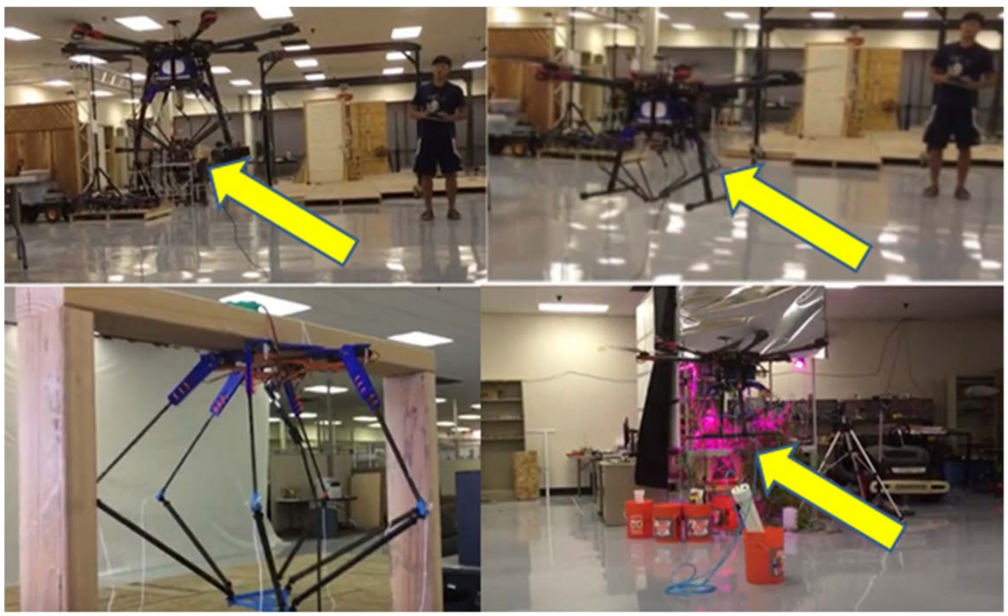
- Design: 4-bar linkage gripper with infrared sensors
- Testing-and-evaluation of gripper and sensor
- Verification-and-validation of gripper and sensor

PRODUCTS:

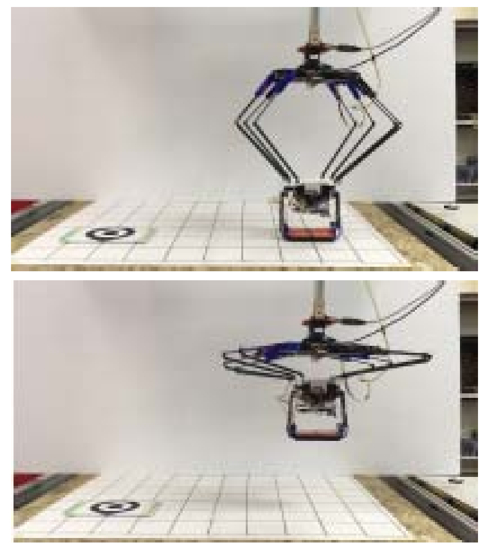
- Hament, B., Oh, P.Y., "Unmanned Aerial and Ground Vehicle (UAV-UGV) System Prototype", *IEEE International Conference on Consumer Electronics*, Las Vegas, Jan. 2018.



Parallel-based arm (middle) and gripper (right) in stowed position on rotorcraft (left)



Arrows show gripper carrying (water) hose



Gripper pick-and-place test: approaching object (top) and lifting from table (bottom)

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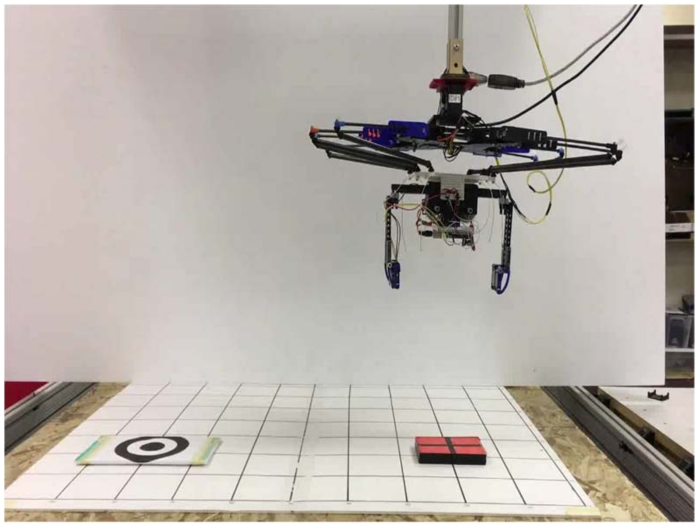
Year 1.5
Dec 2017 – Nov 2018

Scope of Work

Effort since Dec 2017 to Present

1. Sensorized 4-bar linkage gripper ✓
2. Test-and-evaluate fluid-handing (air and liquid) ✓



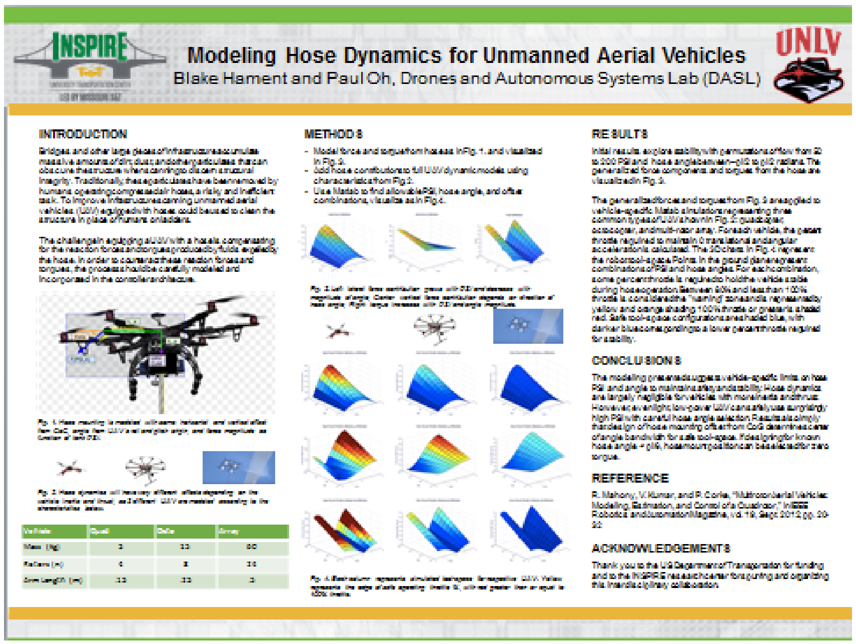
4-bar Linkage Proof-of-concept (979 gram)

- Test drone (DJI F450) 8.3 Kg payload
- Arm Mass Objective: under 1 Kg

Fire-fighting Drone (Social Media)
https://www.youtube.com/watch?v=Bm2BVTTir4c

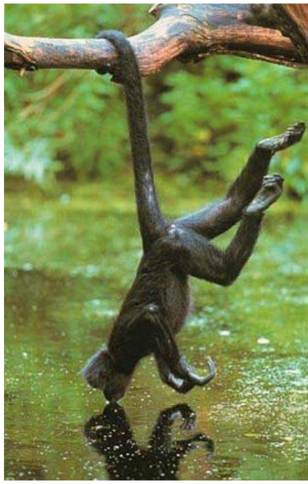
- Stable flight despite strong jetting
- Literature domain absent
- Company personnel not from robotics society

Modeling and Analyzing Hose Dynamics

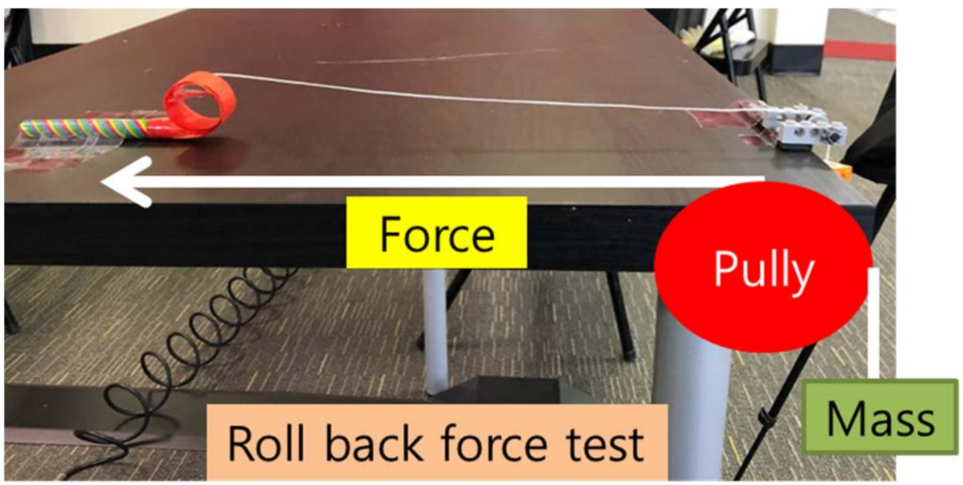


- Tests: 50 to 200 PSI compressed air
- Tests: Quad, Octo, and Array UAV
- Large Moment of Inertia = stability
- Large Thrust = stability
- Hose mounting location = stability

Hyper-redundant Serpentine Manipulators



Bridge-maintenance: perching * ballistic actions * nailing * debris-collection



Bio-inspired “soft” manipulator: party whistle

Summary

UAV Continuum of Research

- Control and Navigation Needs: well-understood
- Field-of-view: tools (e.g. chase view) available but perhaps not needed
- Aerial Manipulation needs: potential (and limitations) generally understood

INSPIRE: Aerial Manipulation for Bridge Applications

- 2016 Proposal: Parallel Mechanism Arm ✓
- 2017 Activity: Arm design; 4-bar linkage hand; underlying control theory ✓
- 2018 Activity: Air jet handling; Hyper-redundant bio-inspired manipulator

Discovery-led Research Direction (Potential Future Work)

- Optimal hose mount design (based on location, thrust and moment of inertia)
- Epoxy applicator using bio-inspired “frog tongue”

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INSPIRE Transportation Center thru UDDOT/OST-R grant #69A3551747126

Special Thanks: Prof. Genda Chen and Amy Gillman!