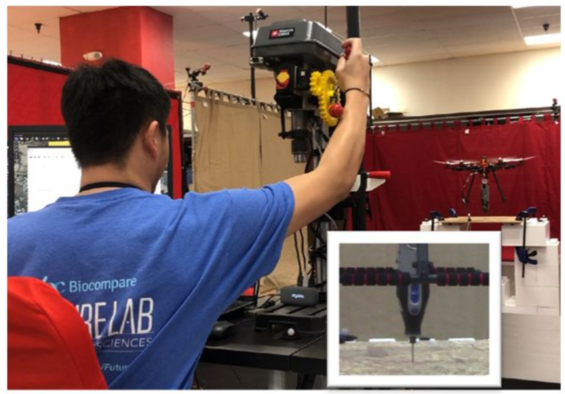
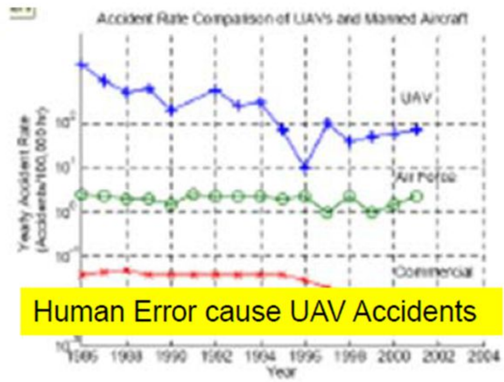
Human Collaborative Haptic-based Mobile-Manipulating UAVs



Drones and Autonomous Systems Lab(DASL)

DONGBIN KIM - University of Nevada, Las Vegas
Dr. Paul Y. Oh - University of Nevada, Las Vegas

Gaps that “bugged” me… **Revisited**



INSPIRE
UNIVERSITY TRANSPORTATION CENTER
LED BY MISSOURI S&T

2016 – 2020

Issue/Task	DRC Lesson learned
Dexterous Manipulation	Mechanical design and sensors
Bridge repair (epoxying)	Wall-cutting task: motion planning
Bridge cleaning (hosing)	(Jet Stream) **Reaction forces/torques**
Human role	Expert-systems: need **haptics**
User Interface	Augmented Reality; **Avatars**

Thank you Prof. Genda Chen!

DASL
Drones and Autonomous Systems Lab @ UNLV

Bridge Inspection/Maintenance

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

Bridge Inspection/Maintenance


Drilling


Riveting



Experience : *Bridge conditions – Sense of Touch (Haptics), Sound, Weather* → ***Dataset***

Many years
Dataset

→ Expert Worker

Missouri Department of Transportation

Code: R01109 **Title: Bridge Maintenance Supervisor**

Exemption Status: Non-Exempt **Grade: 14**

Seven years of experience in bridge maintenance, special maintenance, or bridge inspection.


MM-UAV

DASL
Drones and Autonomous Systems Lab @ UNLV

MM-UAV Challenge

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

"Past MM-UAV Vision : *Fully Autonomous*"

(Hose insertion, 2013)

(Visual Servoing, 2015)

(Pick-and-place, 2018)

(Contact Inspection, 2018)

(Contact Inspection, 2018)

"Blake Hament's Contribution in HSI"

HSI Contributions

1. Field Testing of Hyperspectral Imaging (HSI) for Structural Health Monitoring (SHM)
   a. Identified important variables for normalizing spectral data across field sites
   b. Demonstrated need for more sophisticated modeling of concrete reflectance and concrete health

Too Broad
Too many things to Consider for MM-UAV in Bridge Inspection/Maintenance

A. Ollero, A. Franchi, et. al, "The AEROARMS Project – Aerial Robots with Advanced Manipulation Capabilities for Inspection and Maintenance," IEEE Robotics and Automation Magazine, Dec 2013

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

T. Danko, P. Y. Oh, "A Parallel manipulator for mobile manipulating UAVs," IEEE International Conference on Technologies for Practical Robot Applications (TePRA), Oct 2015

D. Kim, P. Y. Oh, "Toward Lab Automation Drones for Micro-plate Delivery in High Throughput Systems," IEEE International Conference on Unmanned Aircraft Systems (ICUAS), Dallas, TX, USA, Aug 2018

DASL
Drones and Autonomous Systems Lab @ UNLV

New MM-UAV Concept

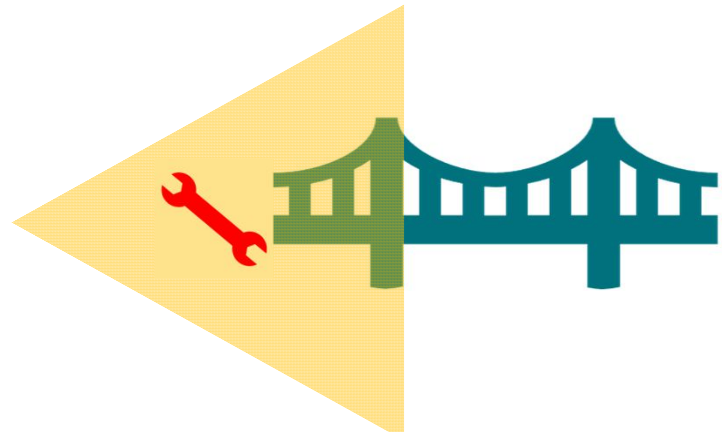
Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

Expert Workers

- Skilled
- Experienced
- Knowledgeable

MM-UAV

- Accessibility
- Haptic feedback
- Tele-operated manipulation



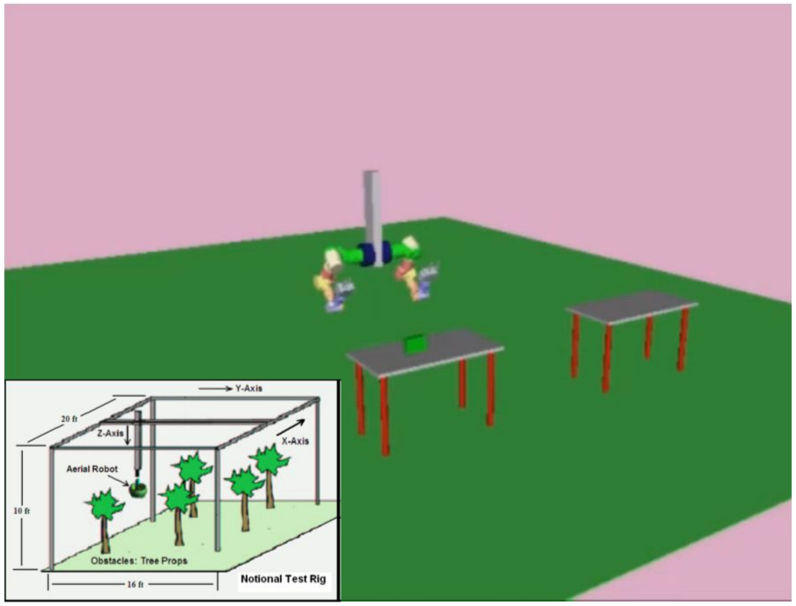
Bridge Inspection/Maintenance

"Human Collaborative Haptic-based MM-UAV"

Drones and Autonomous Systems Lab @ UNLV

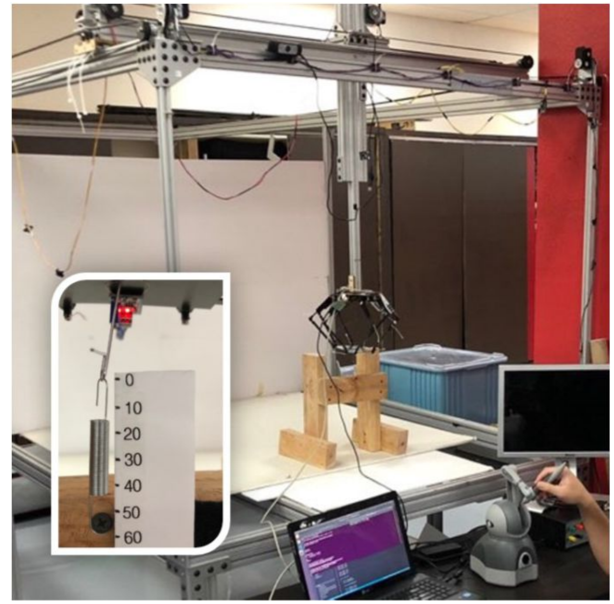
Test-and-Evaluation (T&E) platform

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



System Integrated Sensor Test Rig (SISTR)

Motivation



T&E platform

- **D. Kim,** P. Y. Oh, “Testing-and-Evaluation Platform for Haptic-based Aerial Manipulation with Drones,” IEEE American Control Conference (ACC), Denver, CO, USA, 2020
- Safe/Repeatable flight practice environment to MM-UAV for haptic manipulation

Drones and Autonomous Systems Lab @ UNLV

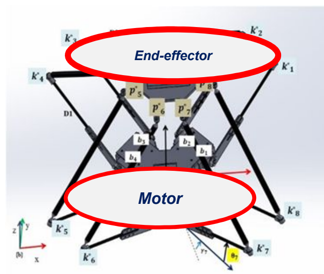
T&E Platform Build and Test

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

1. Mechanical Design

Serial Manipulator

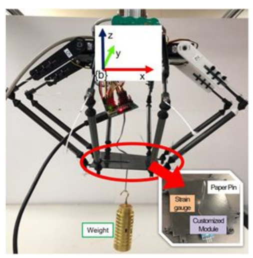
VS



Parallel Manipulator

2.Sensor Design

Haptic Feedback : Spring Force



Sensor Calibration

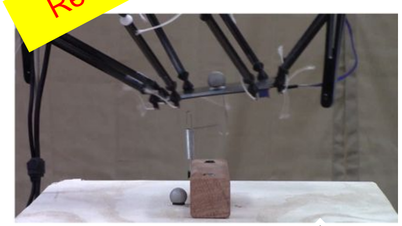
3. Proof-of-Concept MM-UAV

4. T&E Platform and User Interface

Results Similarity : 90%

5. Test Flight for verification-and-validation

Tele-Operating Station



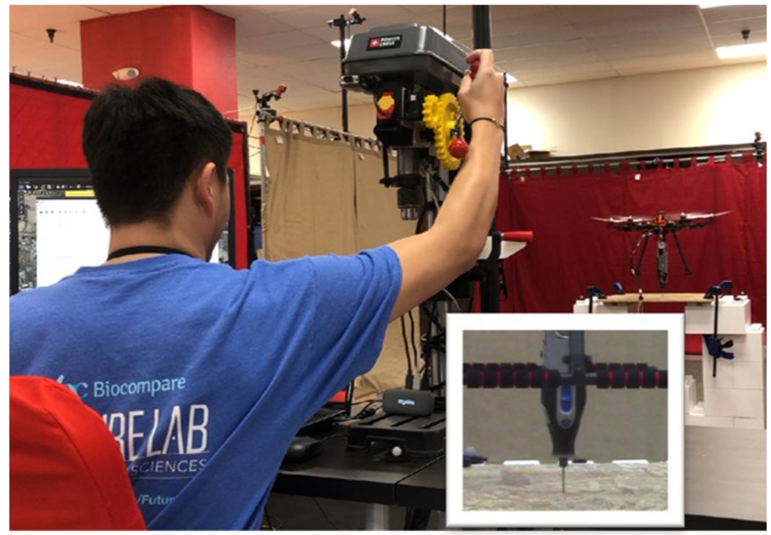
Manipulation Zoom-in

Drones and Autonomous Systems Lab @ UNLV

Drill Task Case Study

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

Drill Tasks in Bridge
Inspection/Maintenance



Haptic Drill Press Platform

- Familiar User Interface
- Analytic benefit (Dataset)

D. Kim, P. Y. Oh, “Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback,” IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

Drones and Autonomous Systems Lab @ UNLV

Drill selection for MM-UAV Arm

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

(a) DeWALT cordless hammer drill

(b) DeWALT cordless drill

(c) DREMEL cordless rotary tool

Properties	(a)	(b)	(c)
Weight	1.62 kg	1.98 kg	0.72 kg
Operation	Power grasp	Power grasp	On-and-off

(Drill Properties)

- **Drill Selection for MM-UAV Arm**

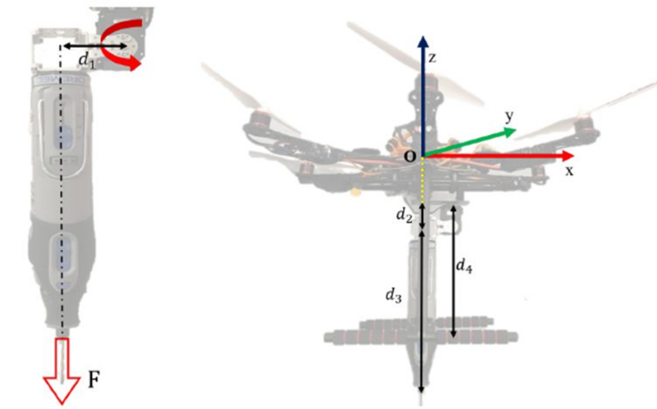
- MM-UAV Payload : 3.6 kg
- DREMEL cordless rotary tool is selected
- On-and-Off operation
- Drill speed : 5,000 to 30,000 RPM
- Selected Materials *: Acrylic Sheet, Plywood, Metal Sheet, PVC pipe, Drywall, Concrete, Red Clay Brick*

D. Kim, P. Y. Oh, “Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback,” IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

Drones and Autonomous Systems Lab @ UNLV

Proof-of-concept MM-UAV

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



(a) 1 DoF cordless drill manipulator design

(b) Aerial Manipulator Design

(Drill limb properties)

Symbol	Value	Description
d_1	0.05 m	Length between dynamixel joint and rotary drill
d_2	0.045 m	Length between drone belly to rotary drill)
d_3	0.29 m	Rotary drill length with a drill bit
d_4	0.21 m	Height of drone's workspace
M_{arm}	0.79 kg	Total mass of 1 DoF drill limb
M_{total}	2.79 kg	Total mass of Aerial Drill Press

- **Proof-of-concept MM-UAV design**

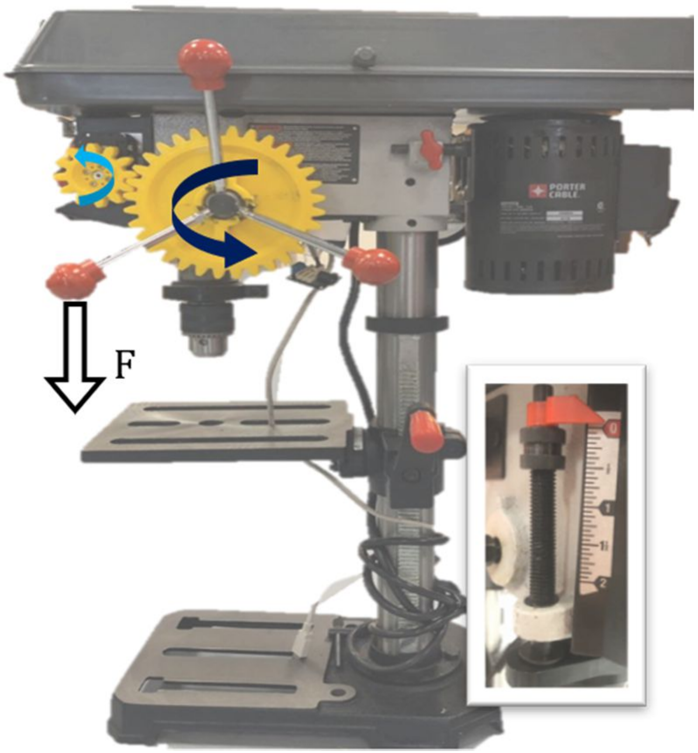
- Q550 Hexacopter
- Pixhawk 4
- Payload : 3.6 kg
- 11.1V 3S 2.2mAh Li-Po battery
- Drill Arm : Dynamixel MX-28 with steel joint
- DREMEL rotary tool to the steel joint.
- The force is sensed by MX-28 when drill bit touches the material surface

D. Kim, P. Y. Oh, "Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback," IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

Drones and Autonomous Systems Lab @ UNLV

Customized haptic drill press

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



(Customized Haptic Drill Press)

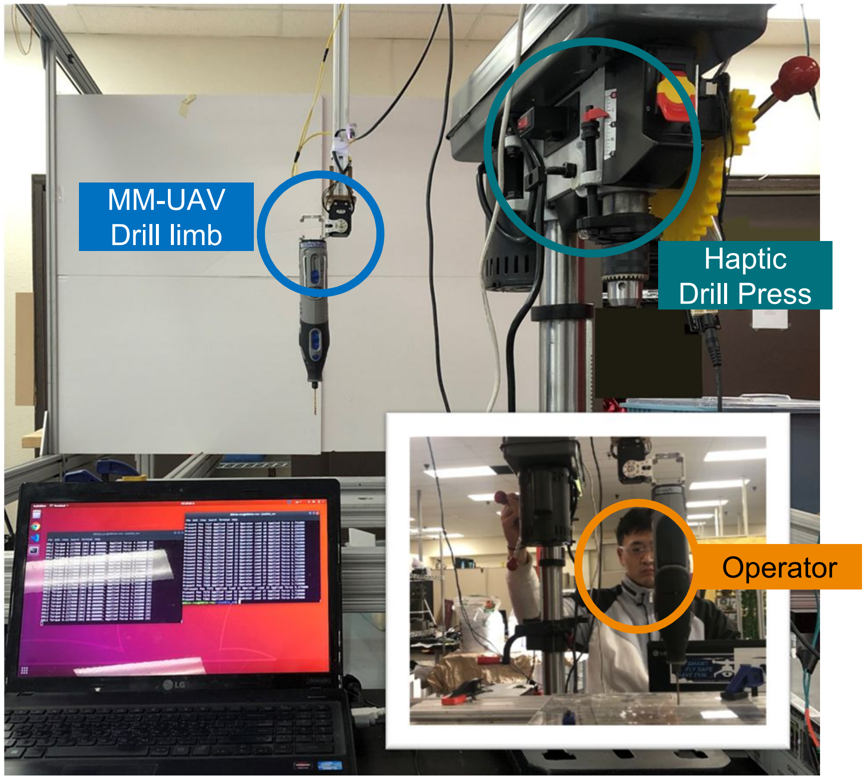
- **Customized Haptic Drill Press**

- Motivation 1 : Expensive commercial haptic device (3DSystem Haptic : $ 20k)
- Motivation 2 : Worker's motion in an actual drill press task
- Porter Cable drill-press
- Dynamixel MX-28 to render force.
- Gears between MX-28 and the rotary handle
- Sensed force is rendered to the operator through the handle
- Sensitivity (α) : Amplify/reduce force rendering -> *operator sense better!*

D. Kim, P. Y. Oh, "Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback," IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

Test in T&E Platform - Build

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



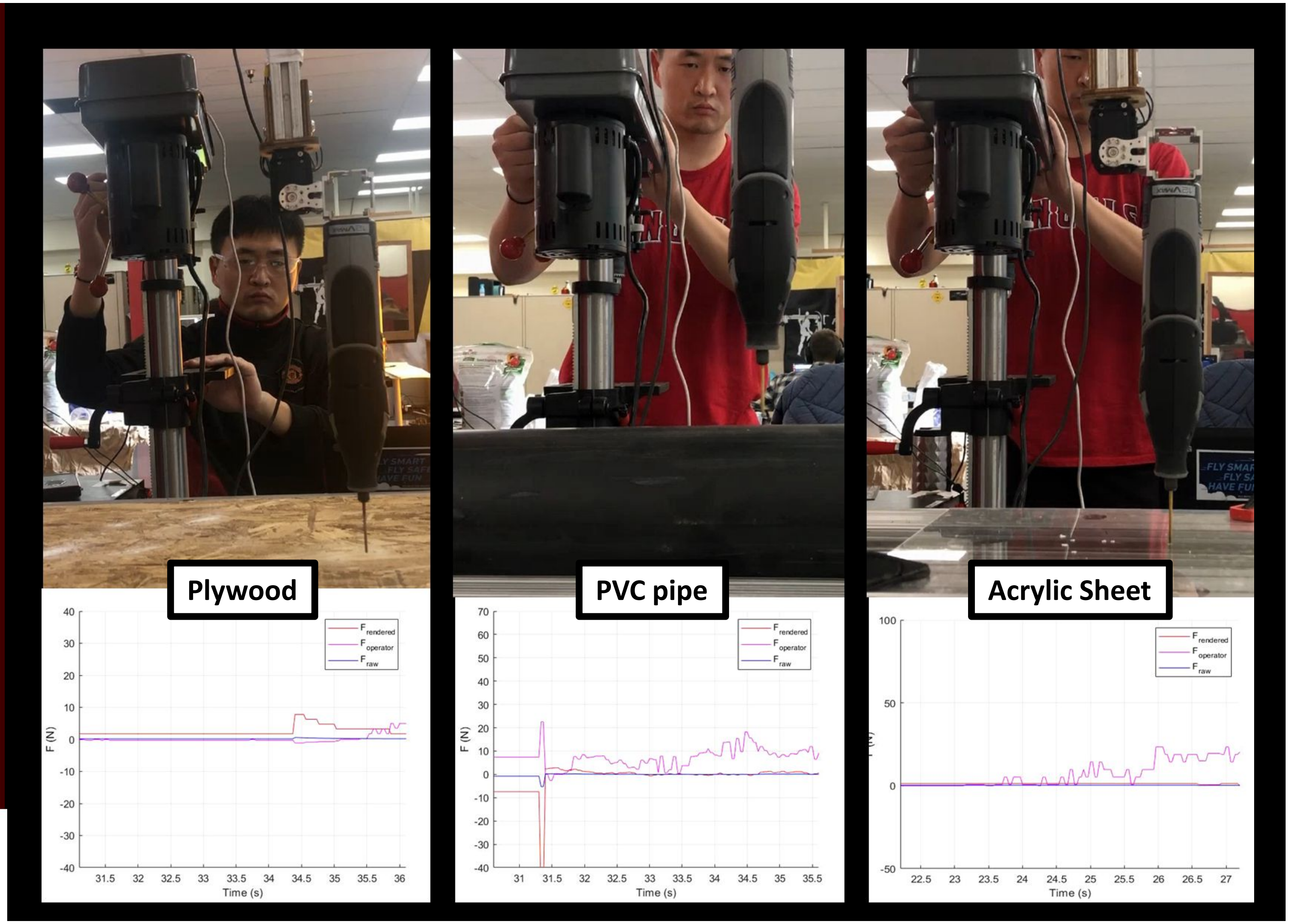
- **T&E Platform for the proof-of-concept**

- Drill arm is attached
- Drill speed is set to 30,000RPM
- The haptic drill press handle controls the drill arm in z-axis
- Test Material : *Acrylic Sheet, Plywood, Metal Sheet, PVC pipe, Drywall*
- Drill arm weight is offset to render sensed force
- The operator feels rendered force.
- **α** is tuned differently with materials
- Each task is repeated *5 times*

D. Kim, P. Y. Oh, "Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback," IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

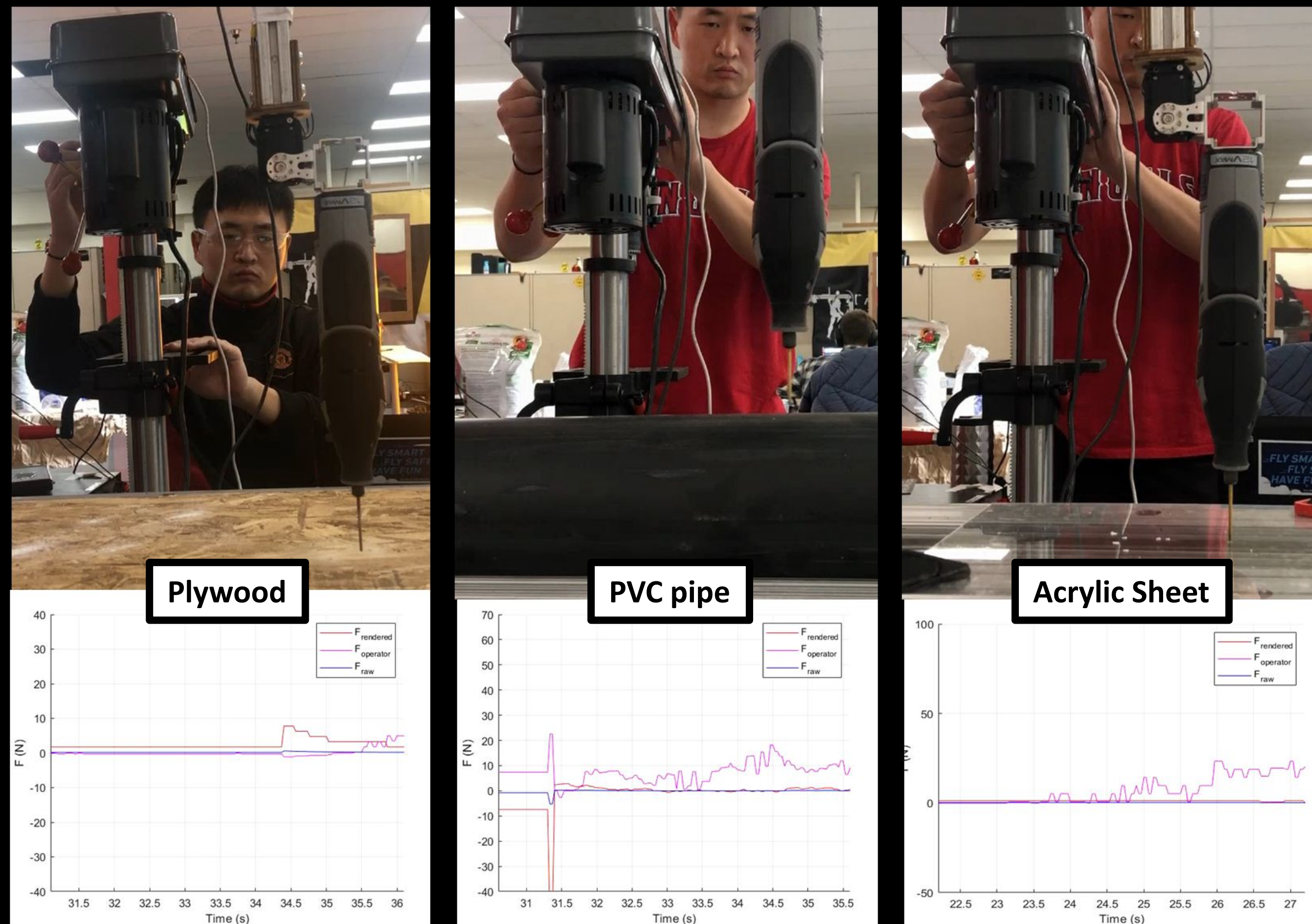
Drones and Autonomous Systems Lab @ UNLV

The Proof-of-concept In T&E Platform

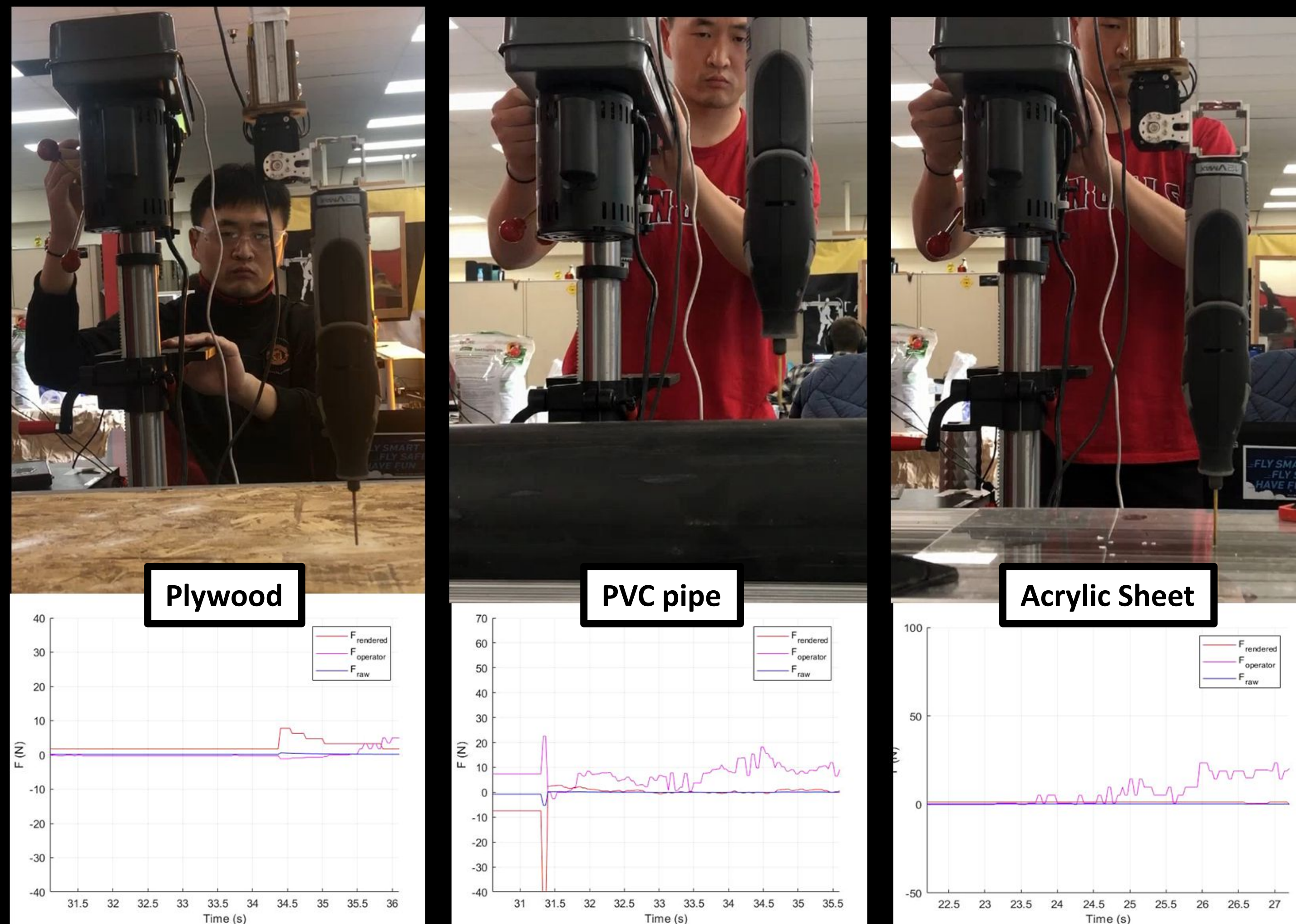


Drones and Autonomous Systems Lab @ UNLV

The Proof-of-concept In T&E Platform



The Proof-of-concept In T&E Platform



Drones and Autonomous Systems Lab @ UNLV

The Proof-of-concept In T&E Platform (Failed)

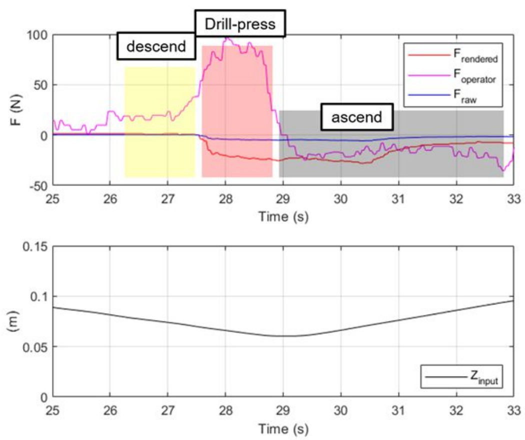
Drywall – Reaction force is too small to sense
Metal – Skating, Require more press force than the limit

These materials are not selected for next step

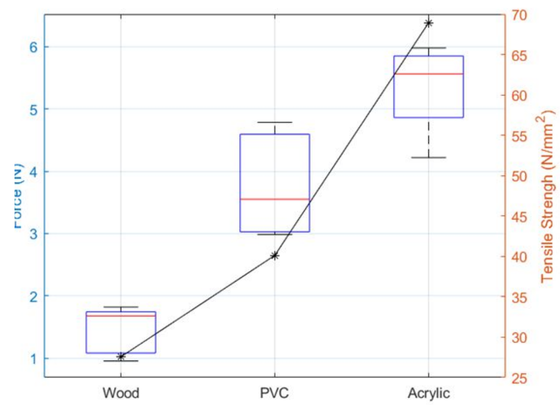
Drones and Autonomous Systems Lab @ UNLV

Test in T&E Platform - Results

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



(From top to bottom, force measurement, Drill press Input)



(Tensile Strength vs Sensed raw Force)

Materials 0	F_{raw} Mean (N)	F_{raw} Standard Deviation (N)	Sensitivity (α)	Tensile Strength (N/mm^2)
Plywood	-1.4598	0.3907	15	27.57
PVC	-3.7786	0.8374	10	40.13
Acrylic	-5.3287	0.7075	5	68.94

(Result Summary)

- **Test Results**

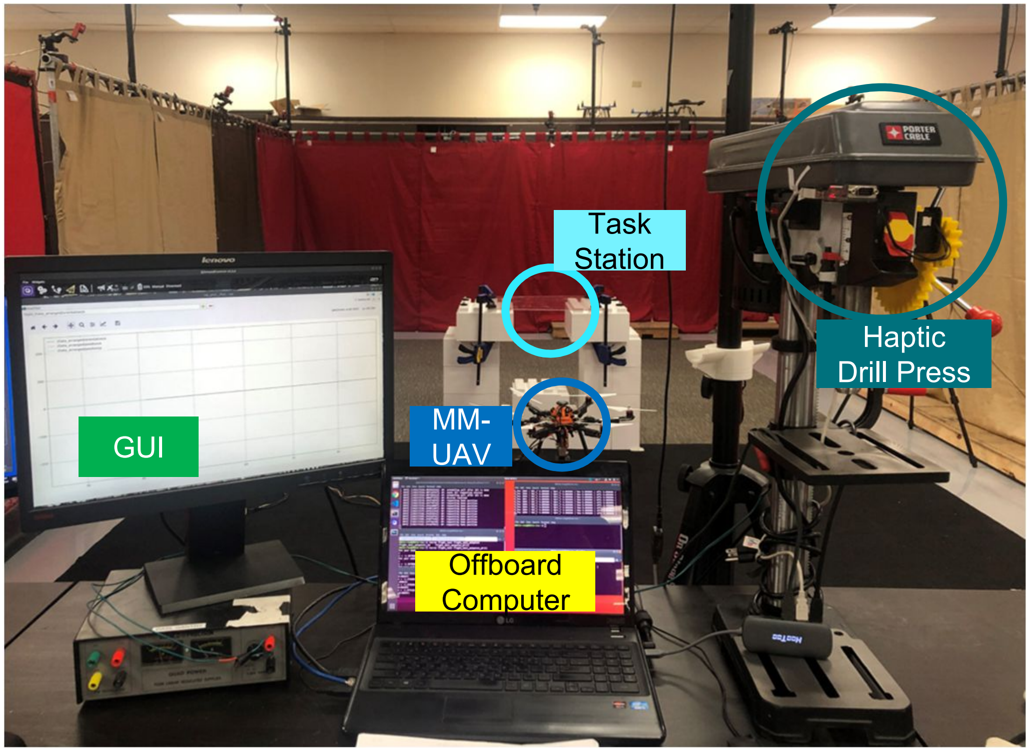
- Selected materials : *Plywood, Acrylic Sheet, PVC pipe*
- Sensed torque is amplified to render by **α**
- Materials tensile strength is proportional to the sensed raw force
- **α** is inverse-proportional to the tensile strength
- The offset changes when drill is pulled off from the materials

D. Kim, P. Y. Oh, “Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback,” IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

Drones and Autonomous Systems Lab @ UNLV

Flight Trials – Test Environment set-up

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

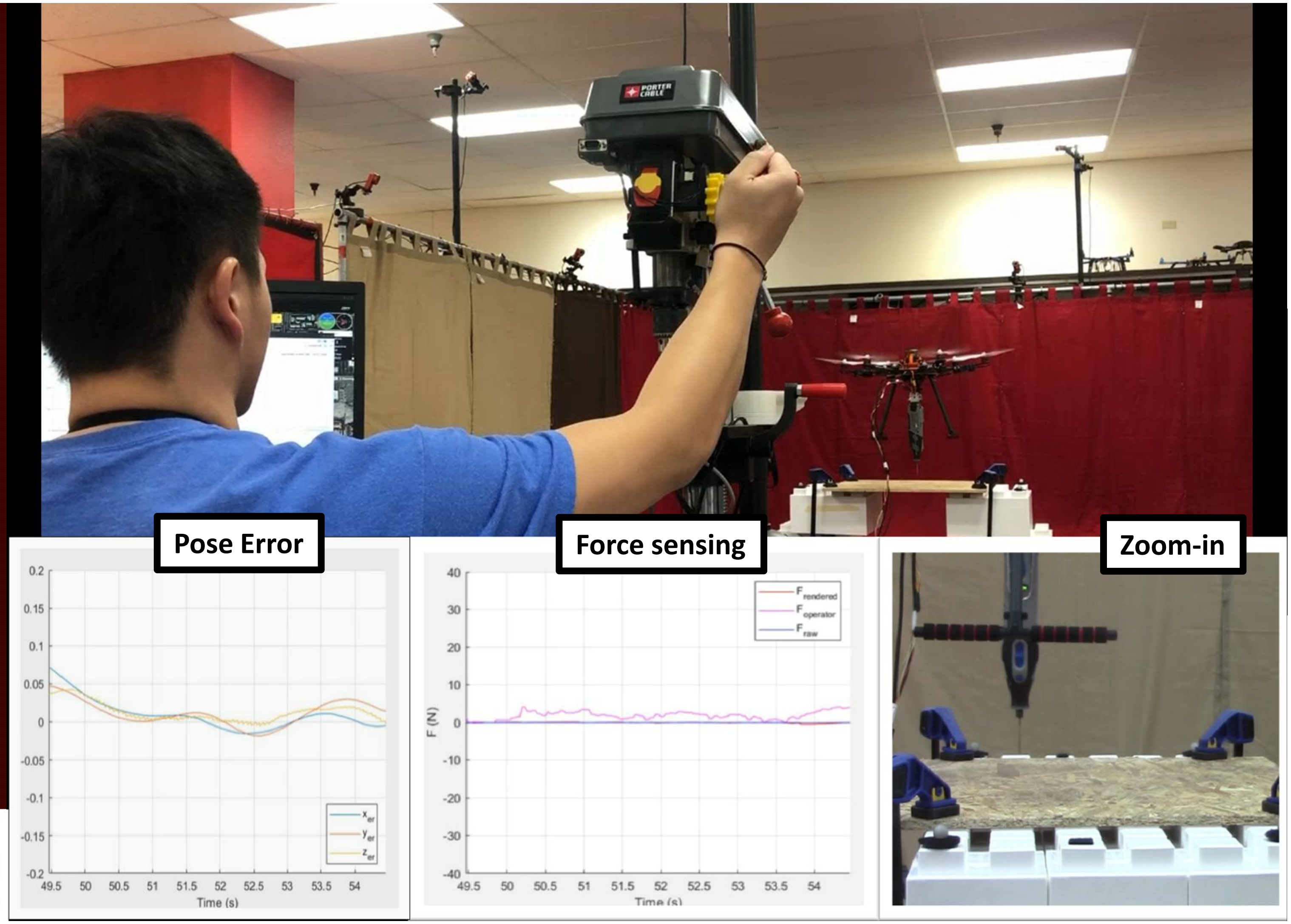


- **Flight Trials**

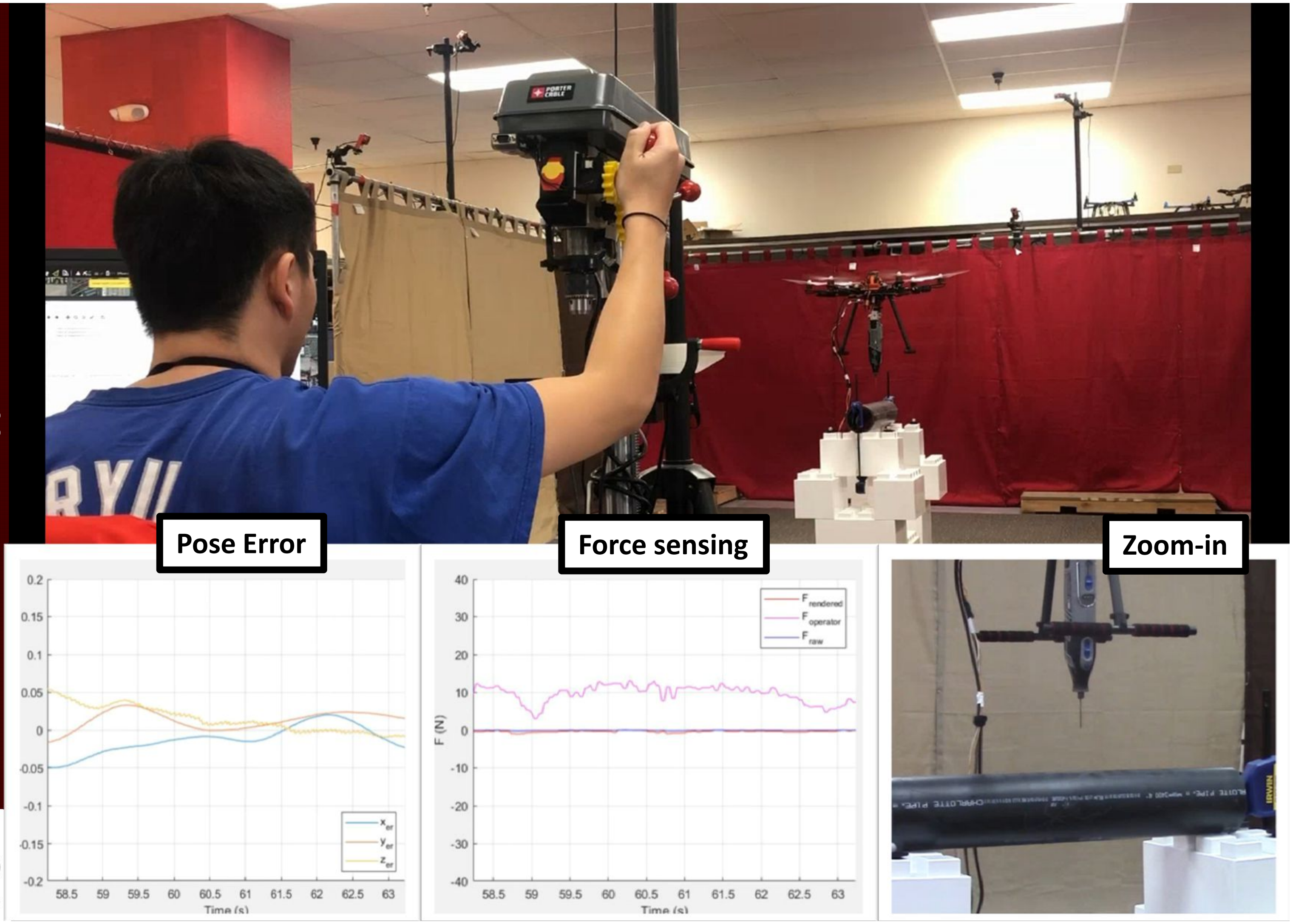
- Validation-and-Verification MM-UAV flight.
- Task station, MM-UAV in the motion capture arena.
- Drill speed is set to 30,000 RPM
- MM-UAV is deployed above the task station
- The operator uses the haptic drill press handle to ascend MM-UAV fpr drill tasks on the materials
- **α** is tuned differently with materials
- Each task is repeated 5 times

D. Kim, P. Y. Oh, “Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback,” IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

The Proof-of-concept Flight Trials (Plywood)



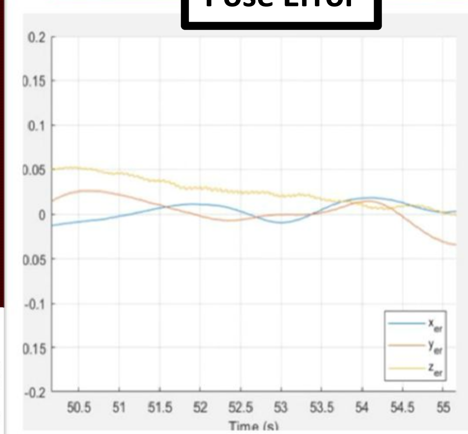
The Proof-of-concept Flight Trials (PVC Pipe)



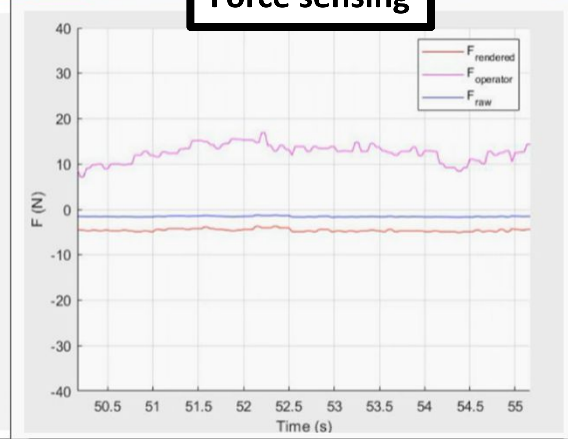
Drones and Autonomous Systems Lab @ UNLV

The Proof-of-concept Flight Trials (Acrylic Sheet)

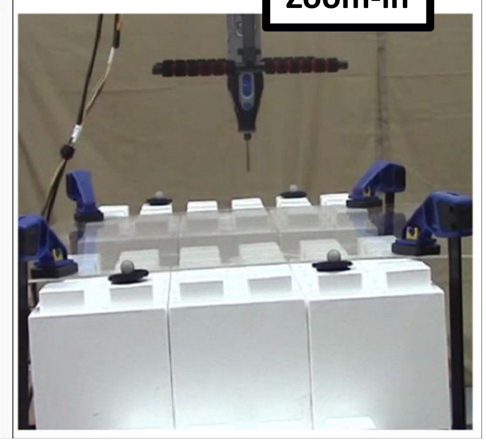
Pose Error



Force sensing



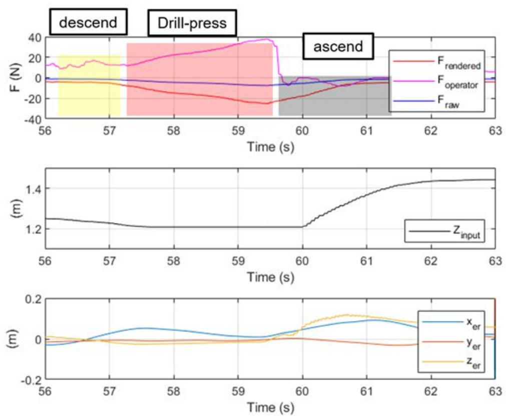
Zoom-in



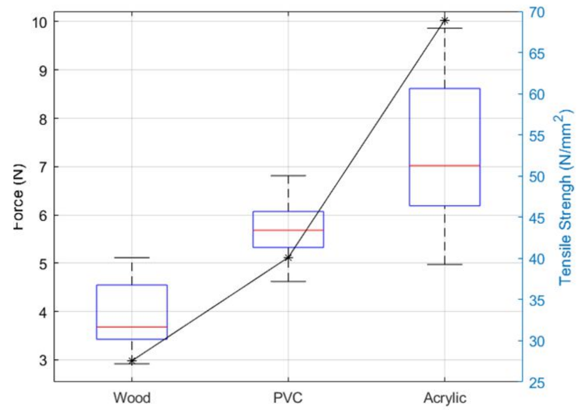
Drones and Autonomous Systems Lab @ UNLV

Flight Trials – Result

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



(From top to bottom, force measurement, Drill press Input, MM-UAV position error)



(Tensile Strength vs Sensed raw Force)

Materials	F_{raw} Mean (N)	F_{raw} Standard Deviation (N)	Sensitivity (α)	Tensile Strength (N/mm^2)
Plywood	-3.9340	0.8351	6	27.57
PVC	-5.6999	0.7796	4	40.13
Acrylic	-7.3302	1.8283	3	68.94

(Result Summary)

- **Test Results**

- Selected materials : Plywood, Acrylic Sheet, PVC pipe
- α is reduced to a half of the one from the test in T&E platform
- Flight fluctuation : the force measurement increase
- The results is similar to the ones from the test in T&E platform

D. Kim, P. Y. Oh, "Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback," IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

Drones and Autonomous Systems Lab @ UNLV

Conclusion

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

Contribution

- Customized haptic drill press
- Sensitivity (**α**) to amplify/reduce sensed force to help the operator's sensitivity
- Human-drone collaborated aerial manipulation perform drill tasks on materials

Conclusion

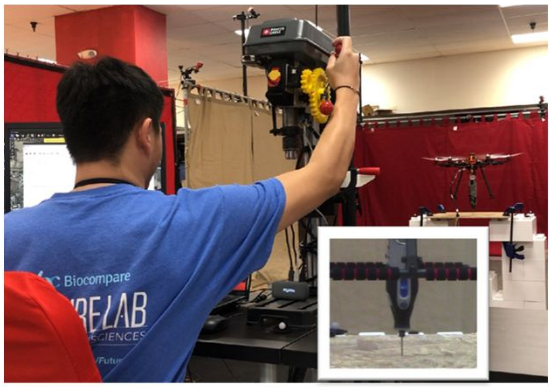
- Flight trial results show similar pattern to the ones from the test in T&E Validation-and-verification flight shows T&E platform's efficacy
- Drill press : **α** is reduced to a half of the one fro m the test in T&E platform
- The material tensile strength: proportional to the sensed raw force from drill task

D. Kim, P. Y. Oh, "Testing-and-Evaluation Platform for Haptic-based Aerial Manipulation with Drones," IEEE American Control Conference (ACC), Denver, CO, USA, 2020. (Accepted)

D. Kim, P. Y. Oh, "Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback," IEEE International Conference on Intelligent Robots and Systems, 2020. (Submitted)

New User Interface

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



To the
real world!

BIG PICTURE (2003)

Near-Earth UAVs

- Degraded Comms
- Poor GPS
- Obstacles
- Dynamic

+ Beyond line-of-sight
+ Accidents
+ Collisions

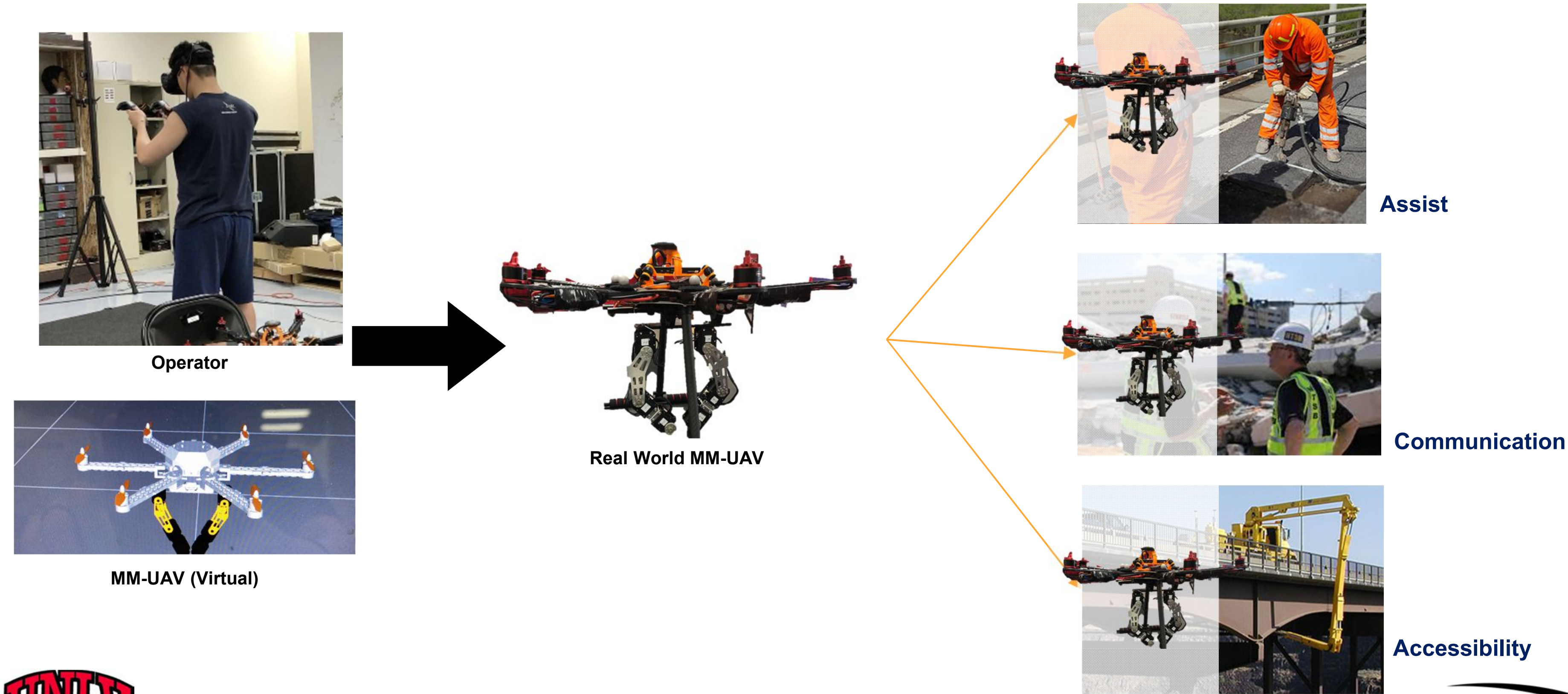
Immersive Technology
VR, AR

“Drone Avatar”

Drones and Autonomous Systems Lab @ UNLV

Drone Avatar Vision

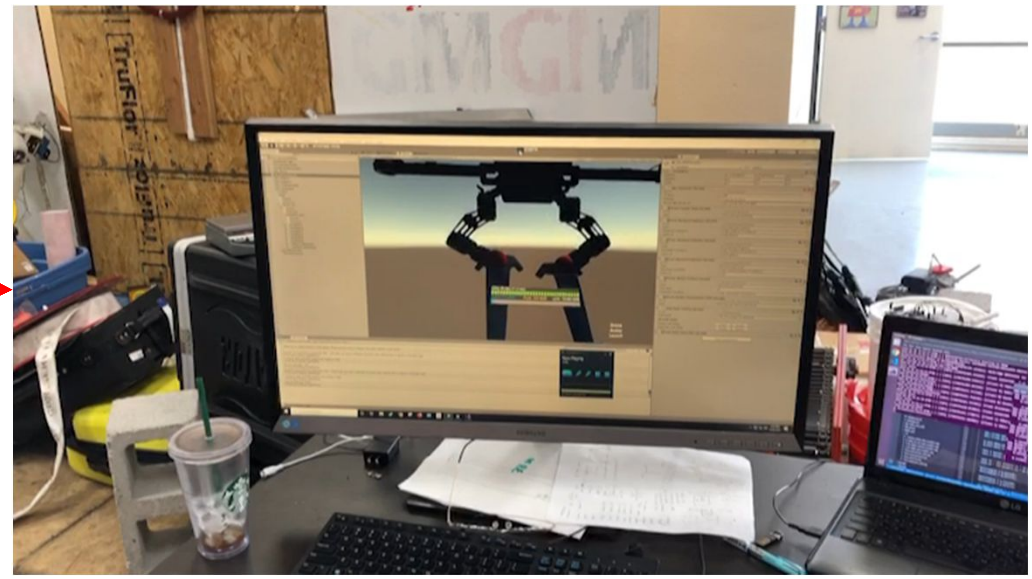
Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



DASL
Drones and Autonomous Systems Lab @ UNLV

Drone Avatar – Current Progress

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV



User and MM-UAV Sync in Virtual World

Drone Avatar – Current Progress

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

User and MM-UAV Sync in Virtual/Real World

Drones and Autonomous Systems Lab @ UNLV

Drone Avatar Next Step

Author :Dongbin Kim, Dr. Paul Oh.
E-mail : dongbin.kim@unlv.edu
Drones and Autonomous Systems Lab, UNLV

Next step
(Target 09/2020)
- Drone Avatars provides 3D Vision Feedback
- Communication system
- Haptic feedback to the operator
- Flight Test (Human Interaction)

Drones and Autonomous Systems Lab @ UNLV

“Thank you, Dr. Genda Chen, Team INSPIRE, and US Department of Transportation!”