Deep Learning for Space Applications

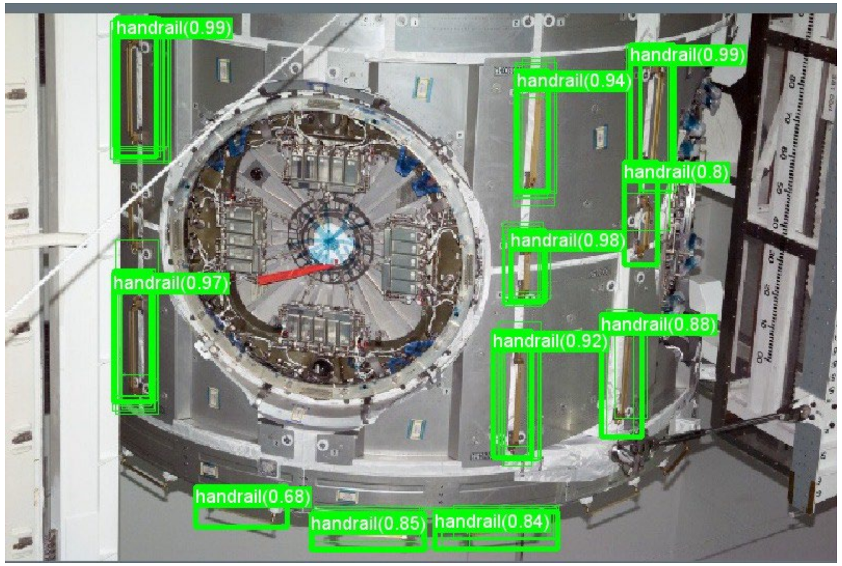
Lui Wang

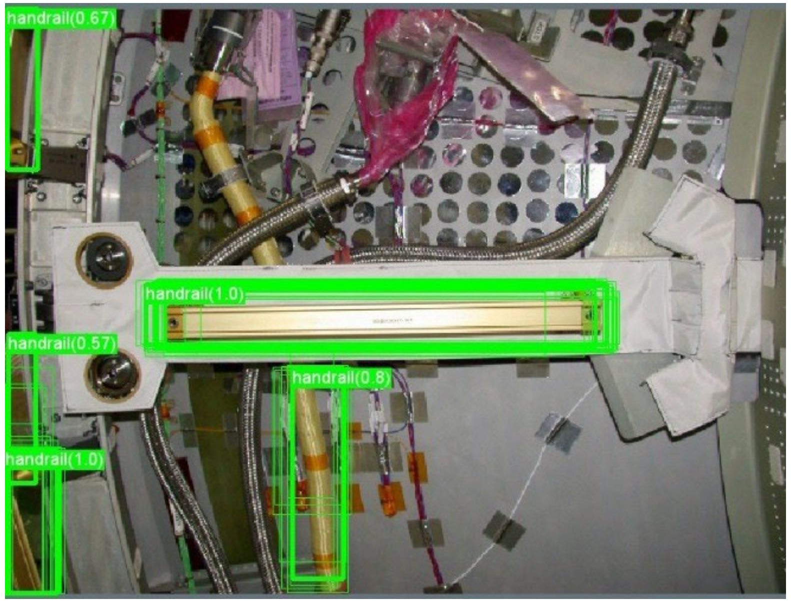
Spacecraft Software Engineering (ER6)
Software Robotics Simulation Division
NASA / JSC

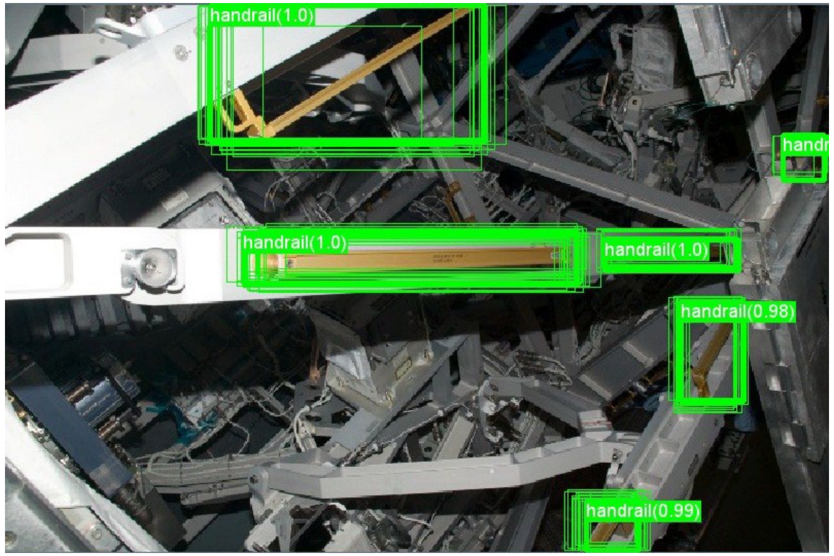
ISS Handrails Machine Vision Recognition - 2017

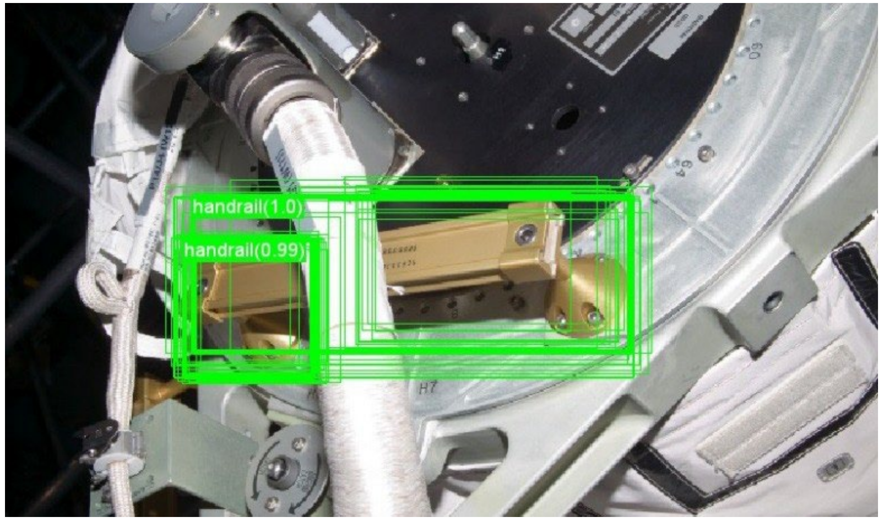
- Goal: assist JSC imagery team by automating manual and laborious process of identifying Object of Interest
  - Identify and tag Handrail on external ISS imagery
- Techniques:
  - Manual labeling of imagery
  - Faster R-CNN algorithm
  - Used Particle Swarm Optimization to optimize key hyperparameters of R-CNN
- Lessons Learned:
  - Manual labeling is tedious and error prone
  - Insufficient number of images with different views, lighting, …
  - Overall worked relatively well, with good success in complex pictures

Success in complex images





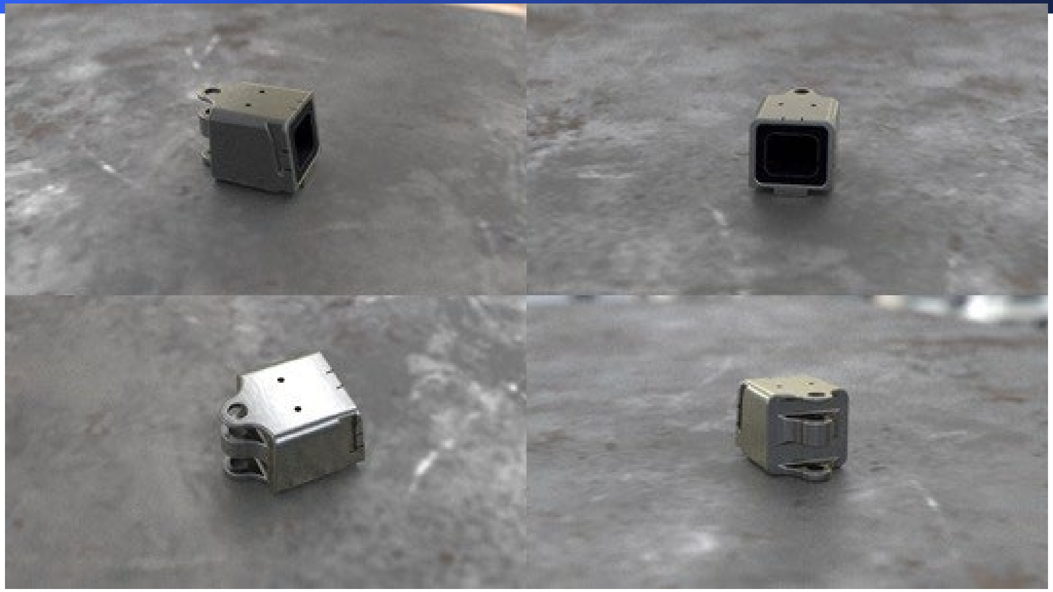


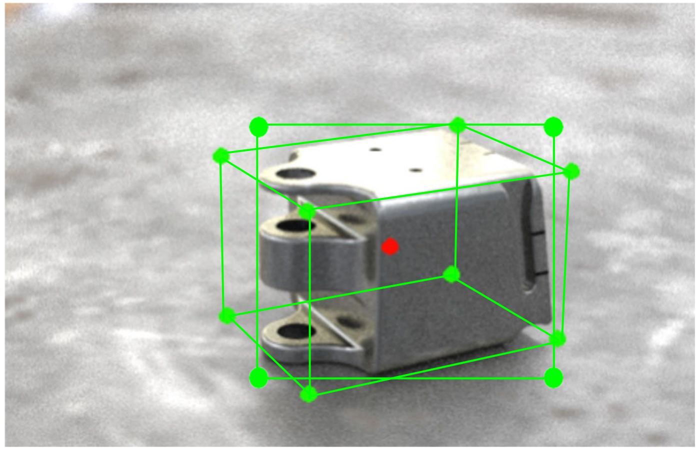


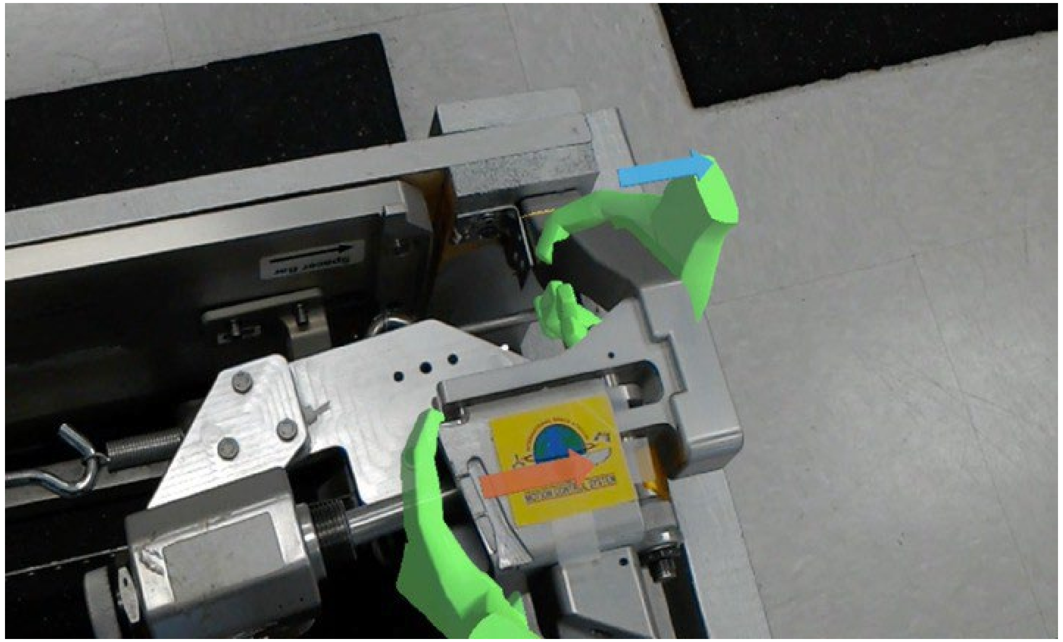
ISS Treadmill Component

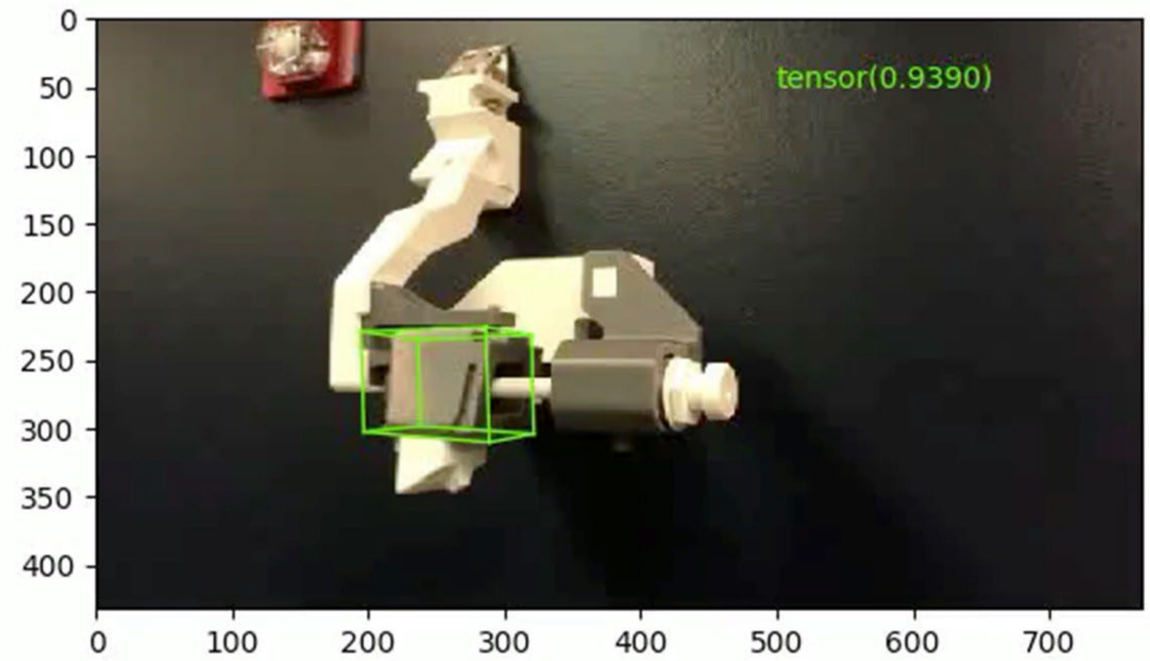
- Goal: Recognize Treadmill snubber cup object and its orientation for AR based maintenance procedure
  - 6DOF Object Pose Estimation
- Techniques:
  - Synthetic image generation and labeling
    - 100k synthetic images rendered using Unreal engine
    - 3D Bounding boxes automatically generated
    - Vary parameters (background, clutter, distortion, lighting, etc)
  - SingleShotPose algorithm developed by Microsoft
  - 3D printed model for testing
- Lessons Learned:
  - Synthetic photorealistic images can provide very large annotated dataset
  - Large range of views angle, lighting, other objects, …
  - Trained model worked very well but cannot be deployed on AR device

Object Pose Estimation









EVA Gloves

- Goal: Post-EVA Glove Analysis Process
  - Classify glove after EVA to assess its state: can it be reused, does it need to be repaired, should it be discarded.

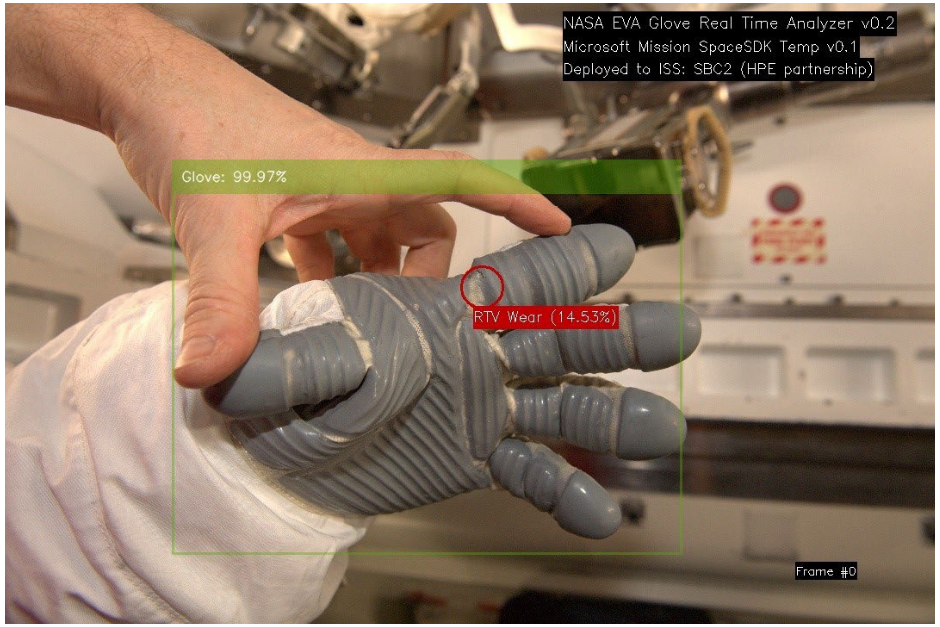
- Techniques:
  - Manual labeling
    - 100 images classified in three bins: Good, Bad, Repairable
  - Microsoft customvision.ai service
- Lessons Learned:
  - Trained model deployed on board computer, worked very well
  - Shorten the workflow, reduce the need to upload the pictures to MCC

Deep Machine Learning


Damaged Glove


On Board Picture taking of glove


On Board DML damage identification



EVA Tools

- Goal: Ensure that all EVA tools required are being attached to EVA crew
  - ISS based EVA tool configuration is laborious process that is rife with potential error and corrections needed prior to an EVA.
    - Detailed spreadsheet with Tools, quantities, locations, request for serial numbers; all needing to be recorded by the crew and then downlinked in stages.
    - This tool gather and buildup takes 10 hours per EVA*.
    - There is tool stow time as well. Having a system that could track tools, grab s/n when needed, track stowage locations by “watching” and then feeding that into stowage database
    - Process has grown to include images from the crew to be downlinked to help confirm the final tool configuration prior to EVA.
- Techniques:
  - Synthetic image generation and labeling
    - 1000 synthetic images rendered using Nvidia Omniverse Replicator
    - 3D Bounding boxes automatically generated
    - Vary parameters (background, clutter, distortion, lighting, etc…)
  - Qubvel instance segmentation model algorithm
- Lessons Learned:
  - Synthetic photorealistic images provide very large annotated dataset
  - Large range of views angle, lighting, other objects, …
  - Trained model worked very well

Procedure version

66-0132 – US EVA P1 SASA R&R - TOOL CONFIG SUMMARY

EV 1

- ☐ ☐ MWS
  - ☐ ☐ BRT (L)
    - ☐ ☐ RET (sm-sm)
    - ☐ ☐ Short Wire Tie (2)
    - ☐ ☐ Long Wire Tie (2)
  - ☐ ☐ T-Bar
    - ☐ ☐ Dual Tether Points (2)
    - ☐ ☐ RET (Lg-sm) (for SASA RFG HRs)
    - ☐ ☐ RET (PIP Pin)
    - ☐ ☐ Adj Equip Tether (2)
    - ☐ ☐ Small EVA Trash Bag
    - ☐ ☐ EVA Camera + L-Bracket
  - ☐ ☐ Swing Arm (R)
    - ☐ ☐ RET (sm-sm)
      - ☐ ☐ PGT [CAL, MTL 30.5]
        - ☐ ☐ PGT Battery
        - ☐ ☐ 7/16"x6" Wobble Socket

R D-ring
- ☐ ☐ D-ring Extender
  - ☐ ☐ Waist Tether

L D-ring
- ☐ ☐ D-ring Extender
  - ☐ ☐ 85-ft Safety Tether, **RED** hook to D-ring Extender, **YELLOW** hook to **GREEN** Reel
  - ☐ ☐ 85-ft Safety Tether, **GREEN** hook to **RED** Reel, **ANCHOR** hook to **MWS**

> NOTE: Prior to use, inspect the following hardware:
> - ☐ RET cords for fraying; ref 1.6.107 EVA RET INSPECTION, ISS EVA Task Checklist
> - ☐ Load Alleviating Straps and D-ring Extenders; ref 1.6.101 CREW TETHER INSPECTIONS, ISS EVA Task Checklist
>   1. MMOD/general damage
>   2. Discoloration
>   3. Tack Stitching
>   4. Red Band
> - ☐ Small EVA Trash Bag:
>   1. Bristle Deformation/ Damage, after having stowed tools in the Trash Bag
>   2. Verify trash bag empty (of previous trash) and zipper closed
> - ☐ Verify Swing Arm Stiffness

EV 2

- ☐ ☐ MWS
  - ☐ ☐ BRT (L)
    - ☐ ☐ RET (sm-sm)
    - ☐ ☐ Short Wire Tie (2)
    - ☐ ☐ Long Wire Tie (2)
  - ☐ ☐ T-Bar
    - ☐ ☐ Dual Tether Points (2)
    - ☐ ☐ RET (sm-sm)
    - ☐ ☐ RET (PIP Pin)
    - ☐ ☐ Adj Equip Tether
    - ☐ ☐ EVA Camera + L-Bracket
      - ☐ ☐ RET (sm-sm)
  - ☐ ☐ Swing Arm (R)
    - ☐ ☐ Adj Equip Tether
      - ☐ ☐ Small EVA Trash Bag
    - ☐ ☐ RET (sm-sm)
      - ☐ ☐ PGT [CAL, MTL 30.5]
        - ☐ ☐ PGT Battery
        - ☐ ☐ 7/16"x6" Wobble Socket

R D-ring
- ☐ ☐ D-ring Extender
  - ☐ ☐ Waist Tether
  - ☐ ☐ 85-ft Safety Tether, **RED** hook to D-ring Extender, **YELLOW** hook to **GREEN** Reel
    - ☐ ☐ 85-ft Safety Tether, **GREEN** hook to **RED** Reel, **ANCHOR** hook to **MWS**

L D-ring
- ☐ ☐ D-ring Extender

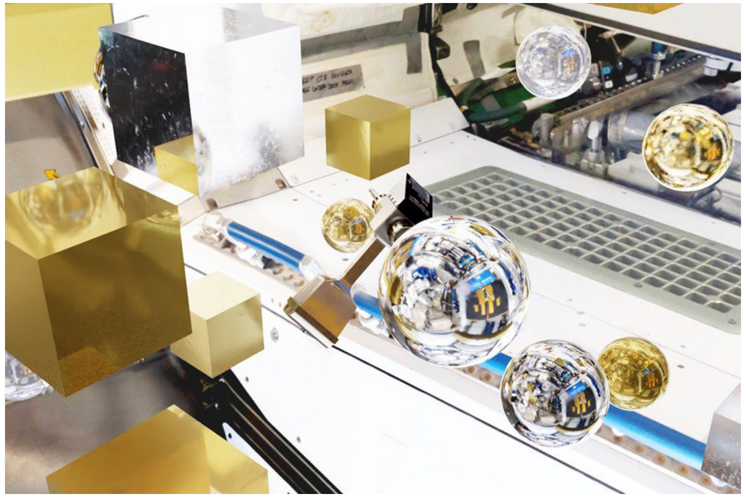
AIRLOCK

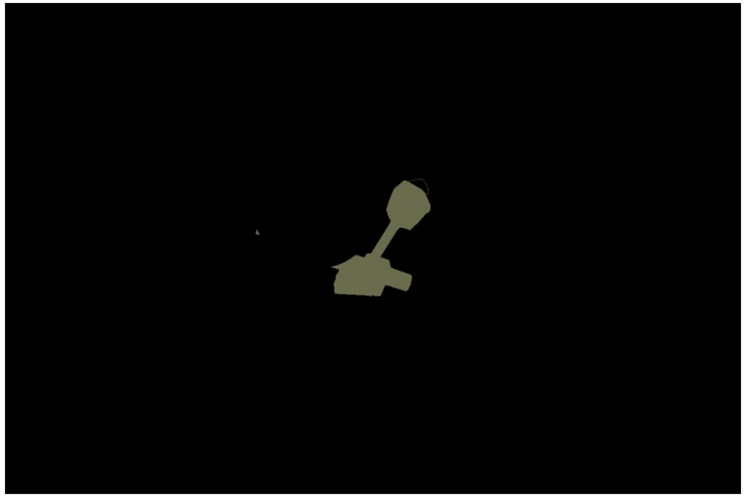
Airlock Internal D-ring
- ☐ ☐ D-ring Extender
  - ☐ ☐ Waist Tether

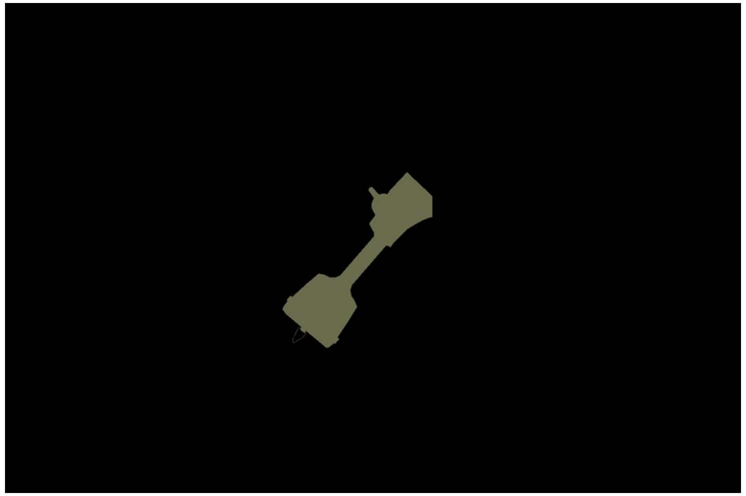
Tether Counts: used (available)	
RETs (sm-sm) = 10 (25)	Adj Equip Tethers = 8 (24)
RETs (PIP pin) = 2 (5)	Adj Equip Tethers (Lg-sm) = 3 (6)
RETs (Lg-sm) = 8 (10)	Fish Stringers = 2 (5)

- ☐ ☐ RET (Lg-sm)
  - ☐ ☐ **Crewlock Bag #1 (EV1)**
    - ☐ ☐ RET (sm-sm) *(exterior)*
    - ☐ ☐ Adj Equip Tether (Lg-sm) *(exterior)*
      - ☐ ☐ Int RET
        - ☐ ☐ Socket Caddy
          - ☐ ☐ ERAD
            - ☐ ☐ 7/16" x 2" Rigid Socket
      - ☐ ☐ Int RET
        - ☐ ☐ Pry Bar
      - ☐ ☐ Int RET
        - ☐ ☐ LDTDT + Long Wire Tie
      - ☐ ☐ Int RET
        - ☐ ☐ Adj Equip Tether (sm-sm)
          - ☐ ☐ EVA GoPro (to int bag D-ring)
      - ☐ ☐ LDTDT + Long Wire Tie (internal bag d-ring)
      - ☐ ☐ RET (sm-sm) (to internal bag d-ring)
        - ☐ ☐ EVA Ratchet w/Palm Wheel
      - ☐ ☐ Waist Tether (to internal D-ring)
- ☐ ☐ RET (Lg-sm)
  - ☐ ☐ **Medium ORU Bag (EV2)**
    - ☐ ☐ RET (Lg-sm) (exterior for temp stow)
    - ☐ ☐ Adj Equip Tether (Lg-sm) (exterior for temp stow)
    - ☐ ☐ RET (Lg-sm)
      - ☐ ☐ MUT-BS-MUT
    - ☐ ☐ Adj Equip Tether (shirt/scarf MLI at bottom of bag)
    - ☐ ☐ RET (Lg-sm) (attached to AET D-ring)
      - ☐ ☐ Adj Equip Tether (sm-sm) (for shirt/scarf MLI)
        - ☐ ☐ Scarf MLI
        - ☐ ☐ Shirt MLI
    - ☐ ☐ **Crewlock Bag #2 (EV2)** (ext tether to ORU bag)
      - ☐ ☐ RET (Lg-sm) *(exterior C/L Bag for temp stow)*
        - ☐ ☐ Int RET
          - ☐ ☐ Socket Caddy
            - ☐ ☐ 7/16" x 6" Wobble Socket
            - ☐ ☐ ERAD
              - ☐ ☐ 7/16" x 2" Rigid Socket
        - ☐ ☐ Int RET
          - ☐ ☐ LDTDT + Long Wire Tie
        - ☐ ☐ Int RET
          - ☐ ☐ Cap Keeper (for Spare SASA Caps (3))
        - ☐ ☐ Int RET
        - ☐ ☐ RET (sm-sm) (to internal bag d-ring)
          - ☐ ☐ EVA Ratchet w/Palm Wheel
        - ☐ ☐ RET (Lg-sm) (for SASA Clamshell MLI)
        - ☐ ☐ Adj Equip Tether (Lg-sm) (SASA MLI tent)
        - ☐ ☐ Adj Equip Tether (sm-sm) (int bag d-ring)
          - ☐ ☐ EVA Go-Pro

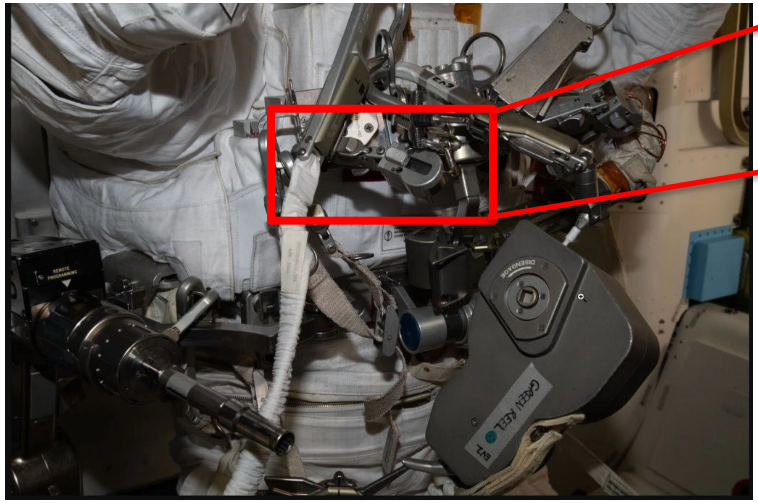
Training Masks

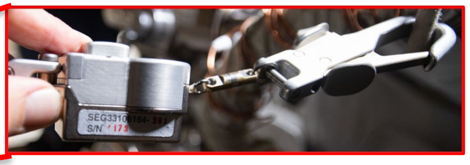




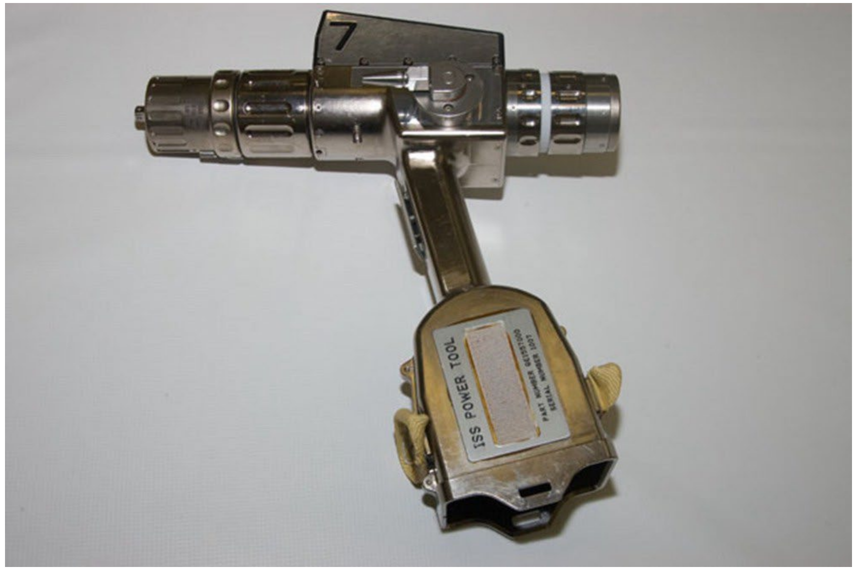


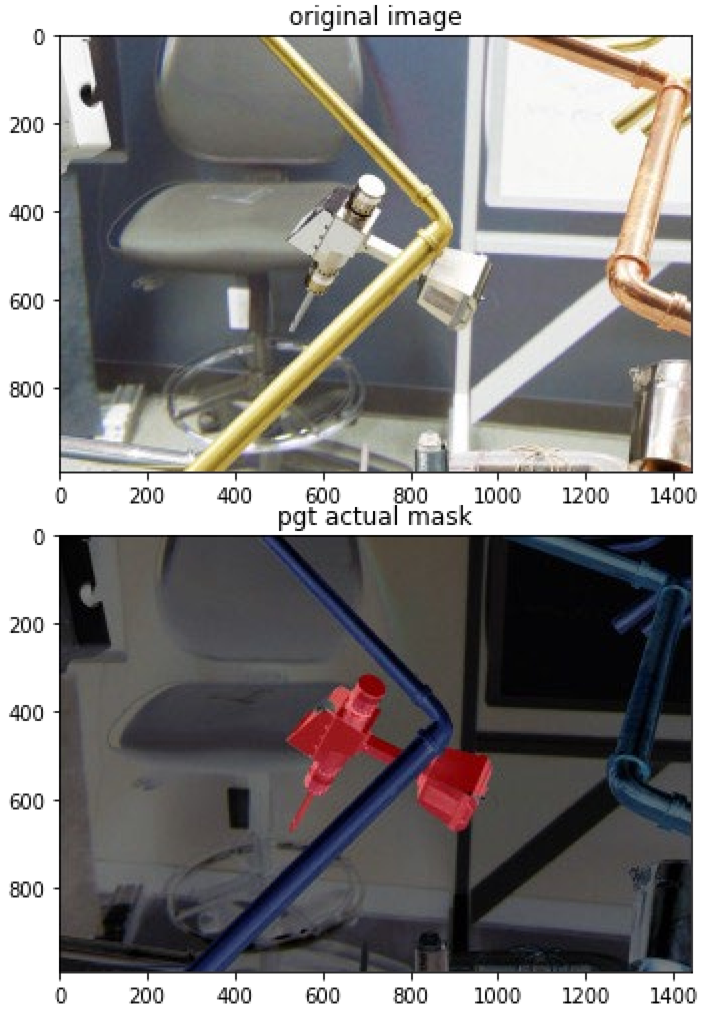
Actual Images of EVA Tools





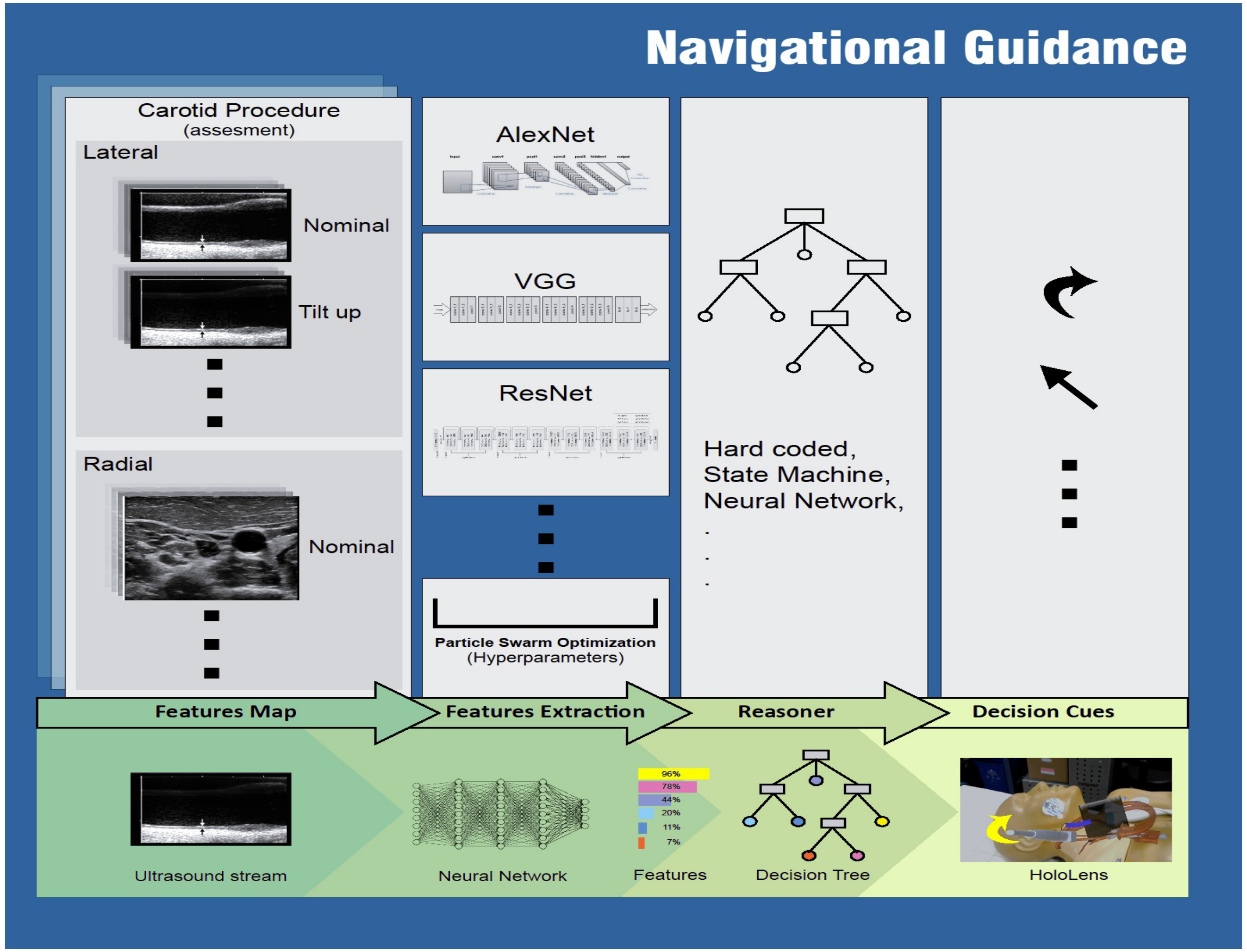
- Synthetic images generation for training [EVA tools]





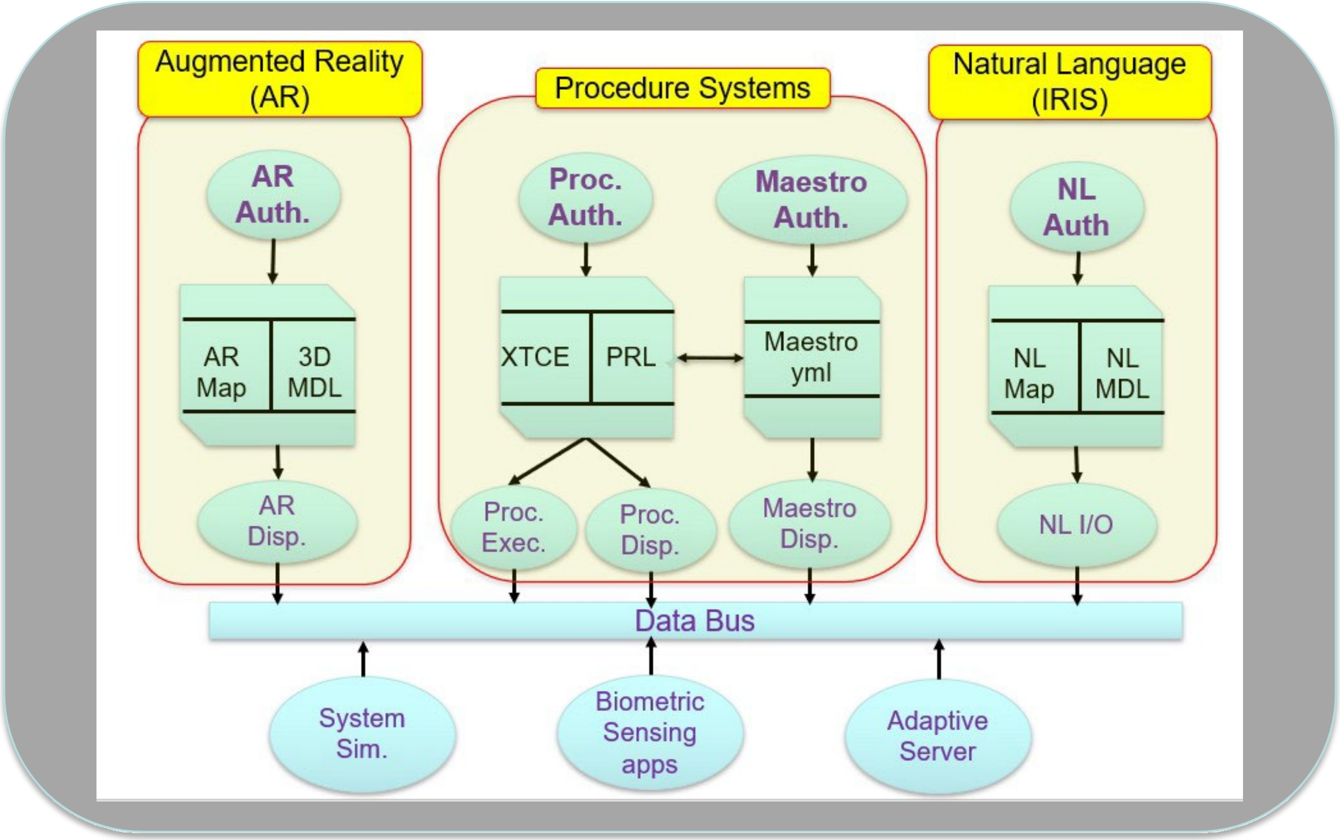
Medical Procedure Guidance

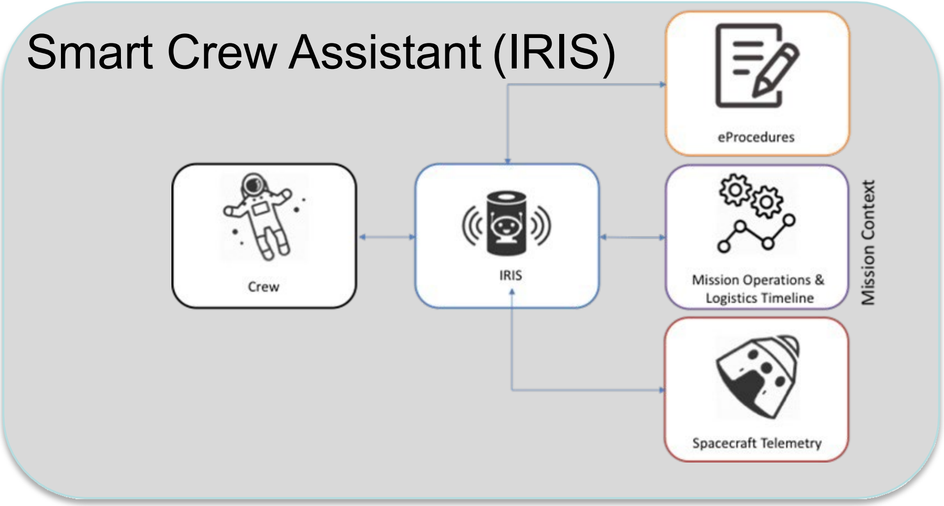
- Goal: Provide a suite of integrated tools to enable crew member medical autonomy during NASA's Deep Space Missions where ZERO remote communications are possible
  - DML provides target-specific closed loop guidance to ensure correct, clinically acceptable ultrasound study is conducted
  - Guides operator on how and where to operate US probe
  - Gives corrective guidance if location or image is sub-optimal
- Techniques:
  - Ultrasound images labeled manually
- Lessons Learned:
  - Trained model worked very well



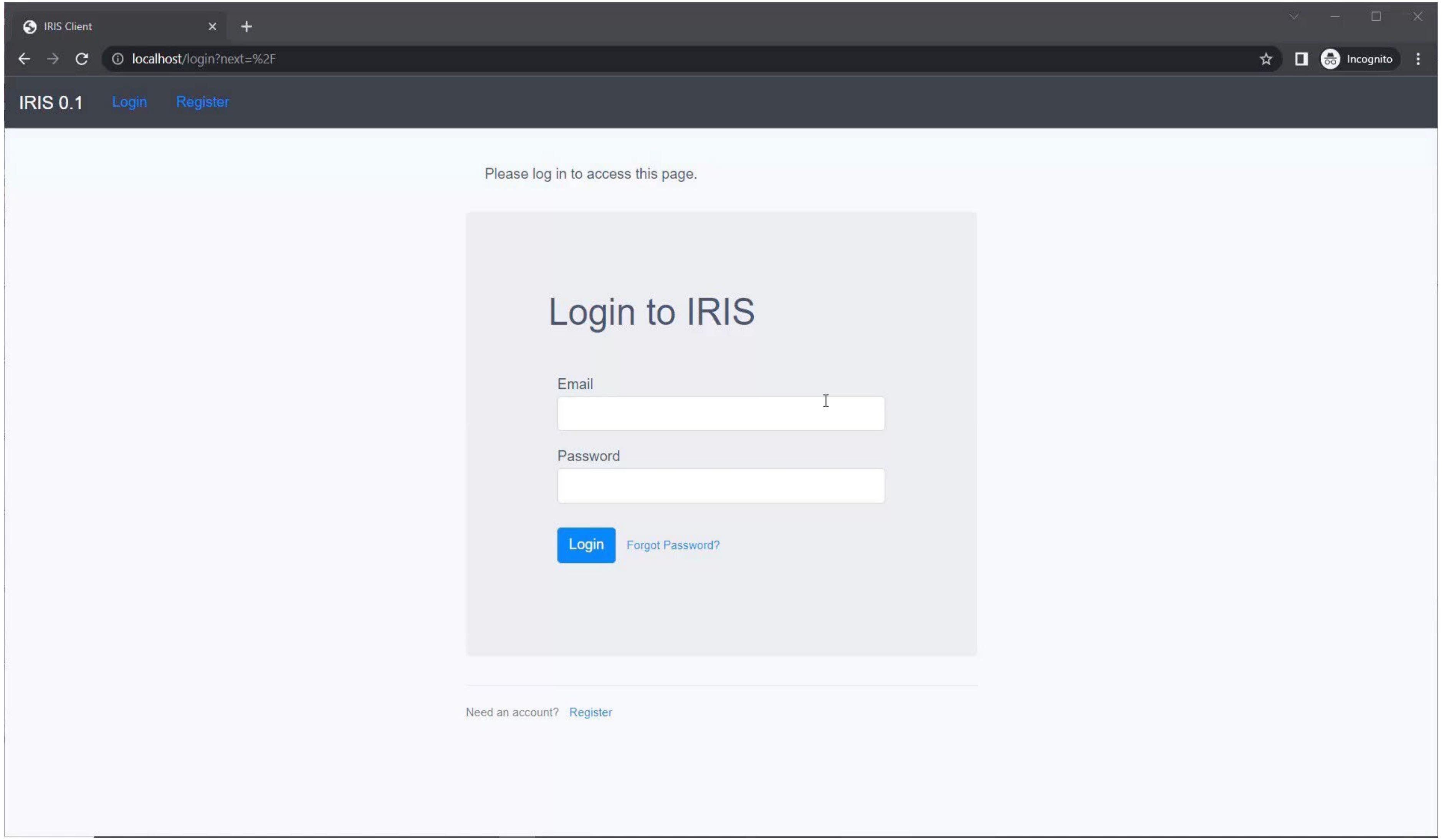
Smart Crew Assistant - Voice

Dialog Based Smart Crew Assistant for EVA that provide support when/where/as needed, understanding Crew protocol, having access and knowledge about the crew timeline and procedures, enabling the crew to get just-in-time training refresher.

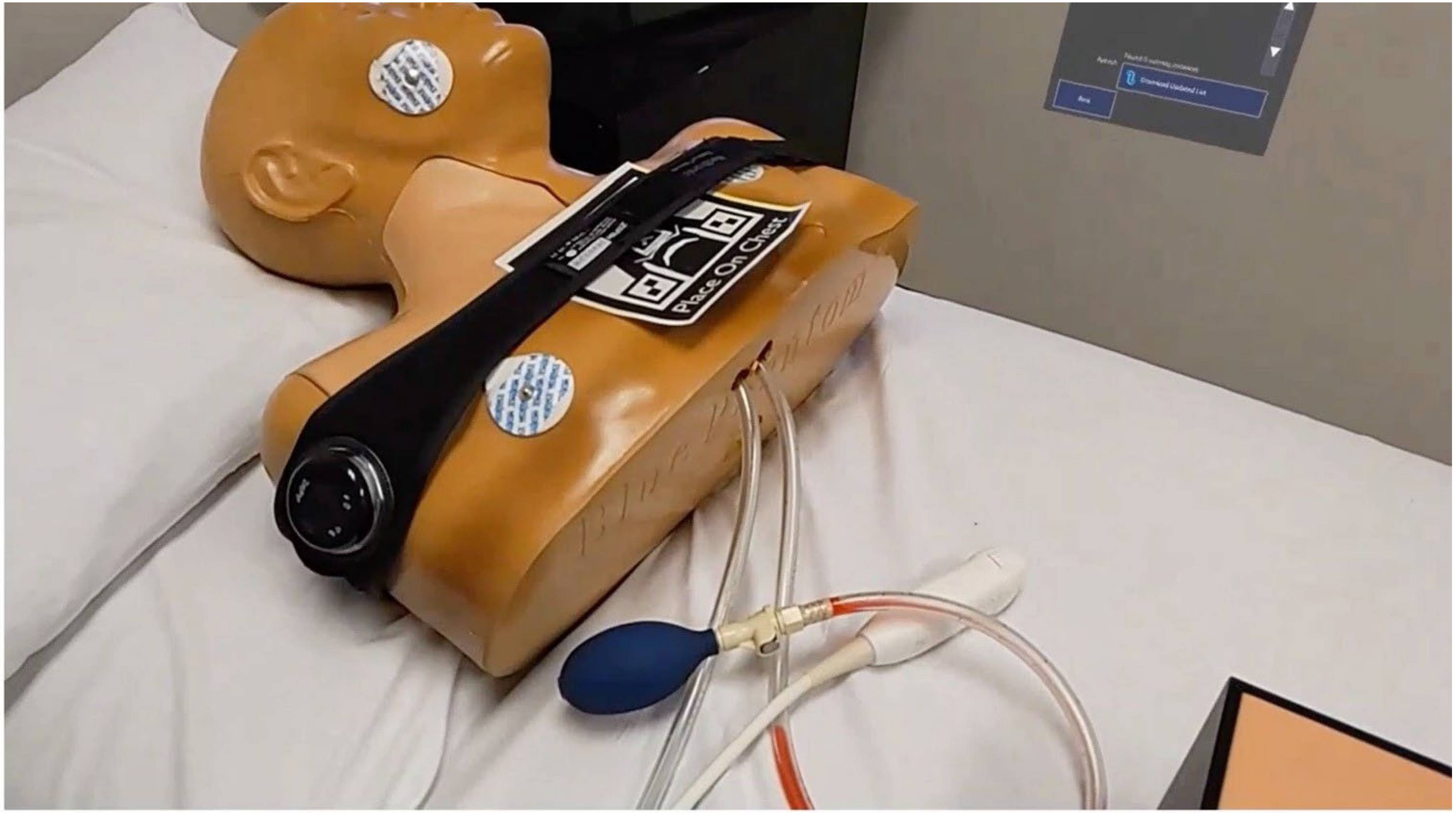




IRIS Workbench



IMCA



IRIS for IMCA (Collaboration w/ Tietronix SBIR)

Cognitive State Monitoring for NASA/DARPA/USAF

- Pilot Training Next (PTN) utilizes real time cognitive state sensing to optimize individual pilot training on VR trainer
- Machine Learning (ML) techniques to determine workload/cognitive states for replay and real-time functions
- Sensors:
  - Muse 2 (EEG, PPG), Pulse oximetry, breathing, accelerometer, Empatica E4, EDA (GSR), temp, PPV, accelerometer, Polar H10, ECG, (HRV)