THE UNIVERSITY OF WINNIPEG

Photogrammetry

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On behalf of the Canadian Photogrammetry group

WCTE Collaboration Meeting
Jun. 22, 2022

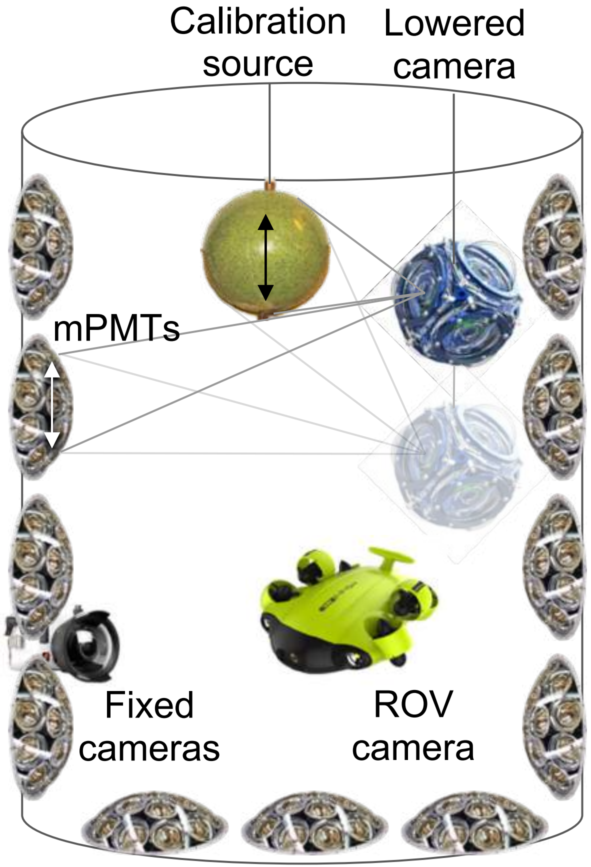
Outline

- Photogrammetry in WCTE overview
- Camera calibration studies (UBC Pool and TRIUMF group)
- Drone testing and locating (UBC Pool and TRIUMF group)
- Camera and lighting placement in WCTE
- R&D towards the camera housing and readout
- Camera position adjustment relative to dome

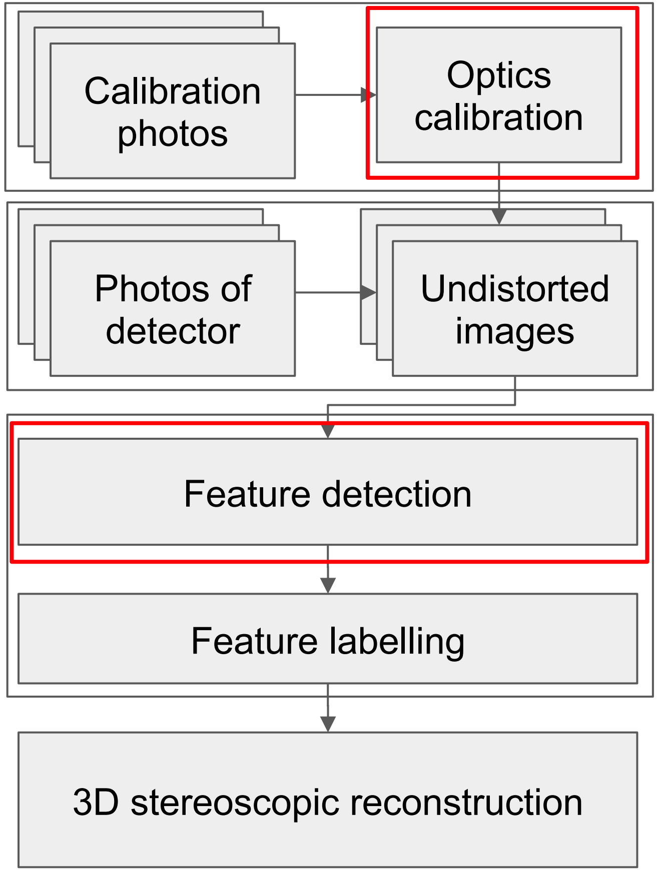
Photogrammetry

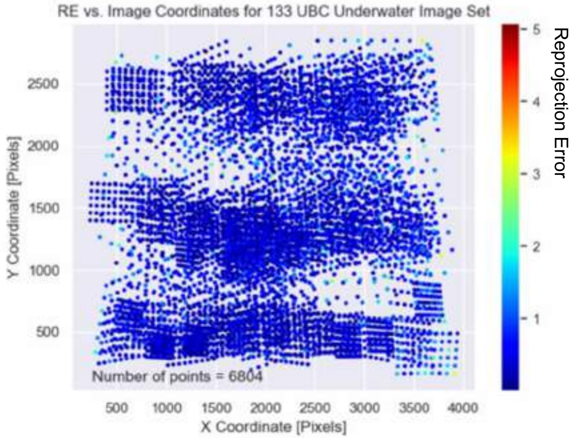
- Detector geometry and source position measurements using stereoscopic reconstruction with photographs

- Mitigate uncertainties due to:
    - Construction tolerances / imperfections
    - Stretching / twisting of support structure due to PMT buoyancy
    - Source deployment positioning

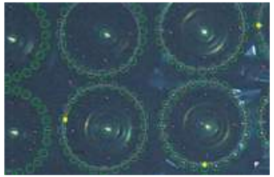


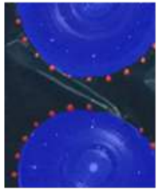
Photogrammetry Systematics





- Estimate/constrain uncertainties in:
  - Intrinsic camera parameters and the parameterization itself
    - Determine any depth dependence in pressure vessel at NV Mechanics Design Burnaby
  - Feature detection algorithms: image processing parameters, ML training sets/augmentations/hyperparameters





- Propagate uncertainties through analysis to determine effect on:
  - Simulations, long-range known pool measurements, SK data

Camera calibration studies motivation

- Simulations already done (N. Prouse) to determine effect of changing camera parameters
  - How well positions can be reconstructed depends on number of pixels reprojection error achieved
- Need to determine uncertainties in camera parameters as a function of location in the image
- Study this underwater using calibration patterns

Simulating camera miscalibration

Mean reprojection errors of the fit

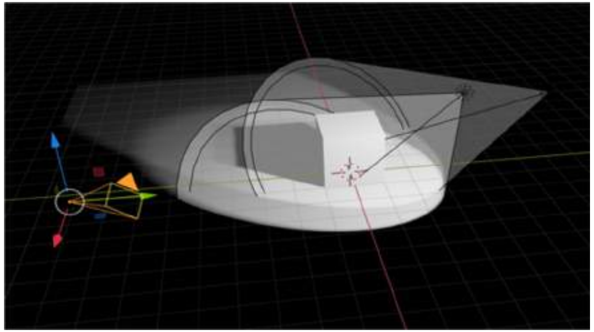
Random error	1 px	3 px	5 px	10 px
Actual parameters	0.86 px	2.59 px	4.28 px	8.47 px
+1% to focal length	5.34 px	6.04 px	7.04 px	10.44 px
+1% to principal point	8.80 px	9.08 px	9.74 px	12.40 px
+5% to radial distortion	4.80 px	5.53 px	6.63 px	10.16 px

Study by Nick Prouse

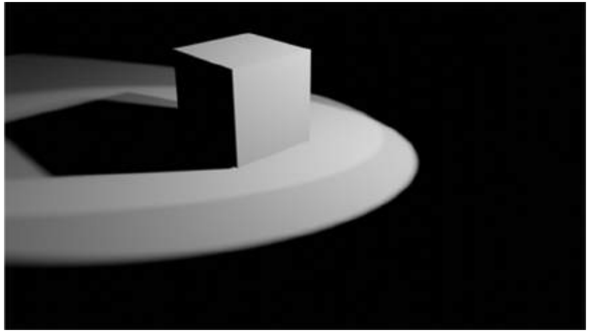
Improving WCTE Photogrammetry Simulation Using Blender*

- Current model just treats light as points.
  - Light perpendicular to mPMT dome -- given angular distribution of light -- are they visible at cameras?
- **Blender** for rendering an image of the light seen at camera
- Blender Advantages / Features:
  - includes directional light objects and camera models
  - Can include camera intrinsics
  - Light intensity specified in physical units (Watts, FOV, etc)
  - Python library - LED and camera geometry data copied directly from the existing jupyter notebook
  - Can include refraction effects, reflections, surfaces, etc.)

Blender demo:

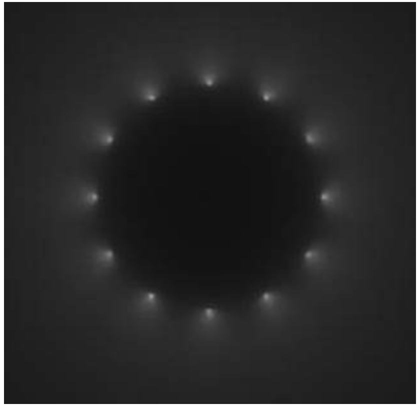


Specifying two light sources, a cube, and a camera



Output - rendered image from camera's perspective

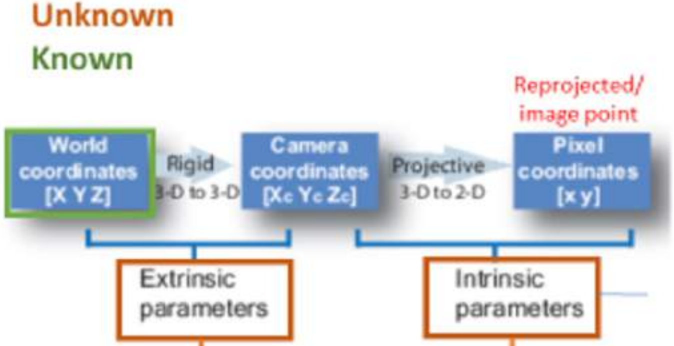
Eg. Looking directly at mPMT
Light sources radially out of dome



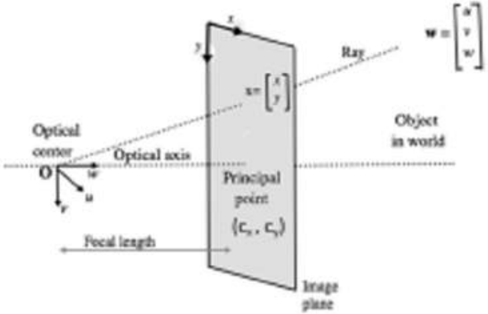
Blender - open-source 3D computer graphics software toolset

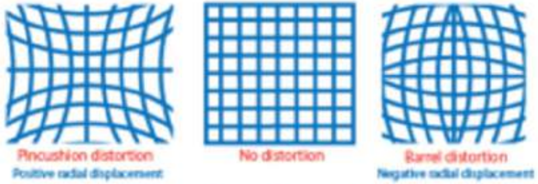
Michael S.

Underwater Camera Calibration



Camera model (intrinsic parameters and lens distortion) can be constrained using chessboard pattern with features of known size.





$$x_{distorted} = x(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$$

$$y_{distorted} = y(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$$

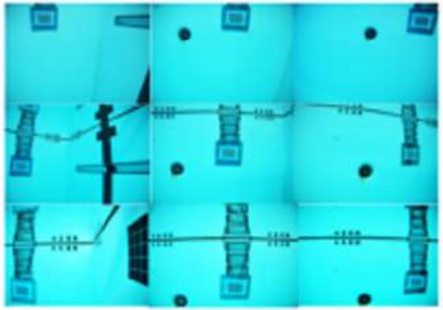
Lens distortion model used to correct for radial distortion.

$$w\,[x\ y\ 1] = [X\ Y\ Z\ 1]\,P$$

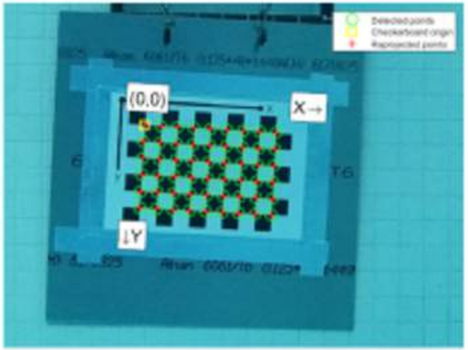
Scale factor · Image points · World points

$$P = \begin{bmatrix} R \\ t \end{bmatrix} K \qquad K = \begin{bmatrix} f_x & 0 & 0 \\ s & f_y & 0 \\ c_x & c_y & 1 \end{bmatrix}$$

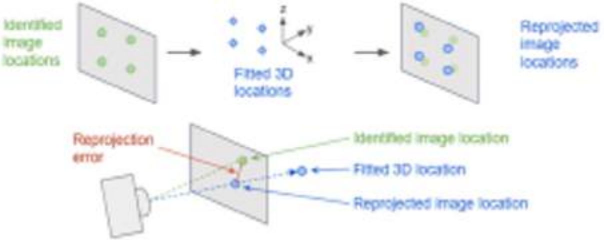
Camera matrix · Extrinsics: Rotation and translation · Intrinsic matrix



Calibration pattern imaged with Fifish V6 drone in different parts of the FOV.

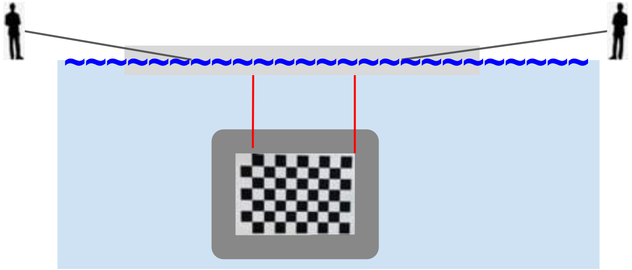


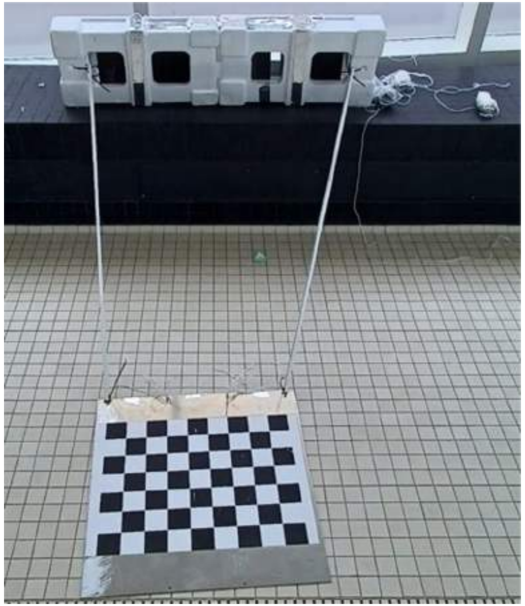
Chessboard pattern with detected and reprojected square corners.



Calibration pattern board control

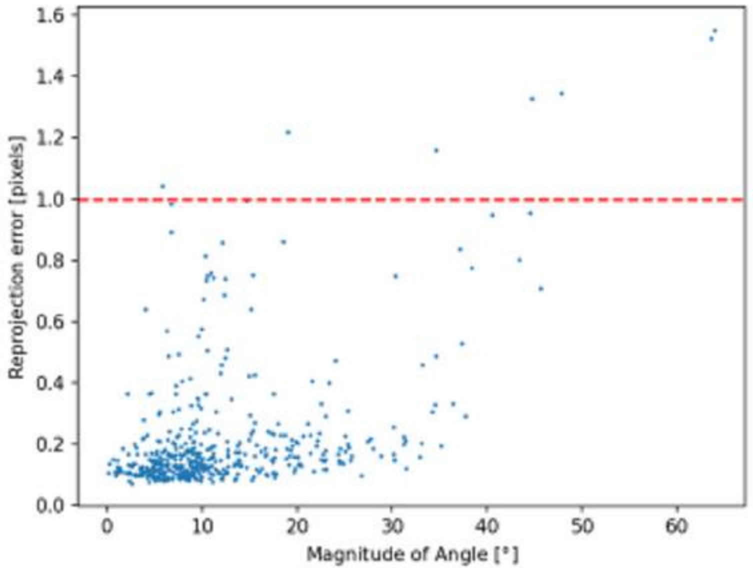
- Developed system for calibration pattern board control
- Board attached to floatie via rigid adjustable rods
- Floatie's position controlled by two ropes
- Working on reducing drag





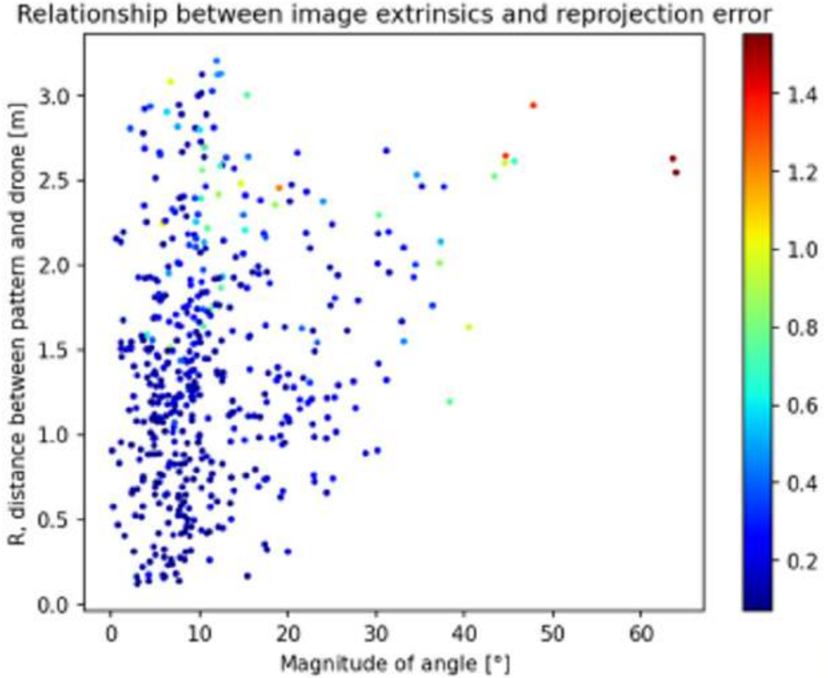
Super-K Underwater Drone Calibration

- Higher order description of distortions
- Systematic image acquisition procedure
- Large image sets
- Improved reprojection errors



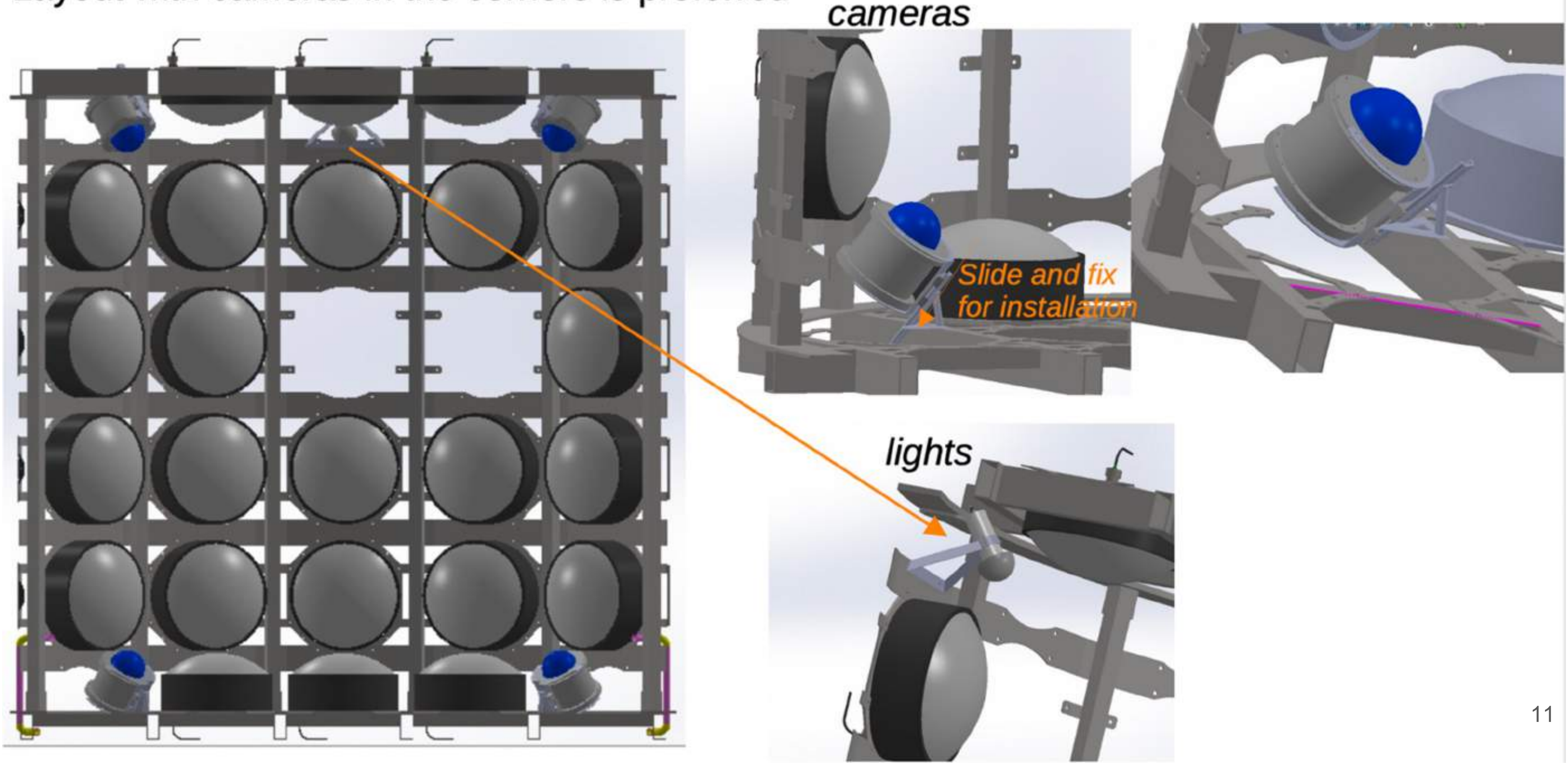
Reprojection error per image as a function of angle between pattern and camera..
Mean error = 0.21 pixels. Improved from previous mean error of 0.51 pixels.

- Optimal camera positioning relative to calibration pattern to minimize reprojection error and build accurate models.



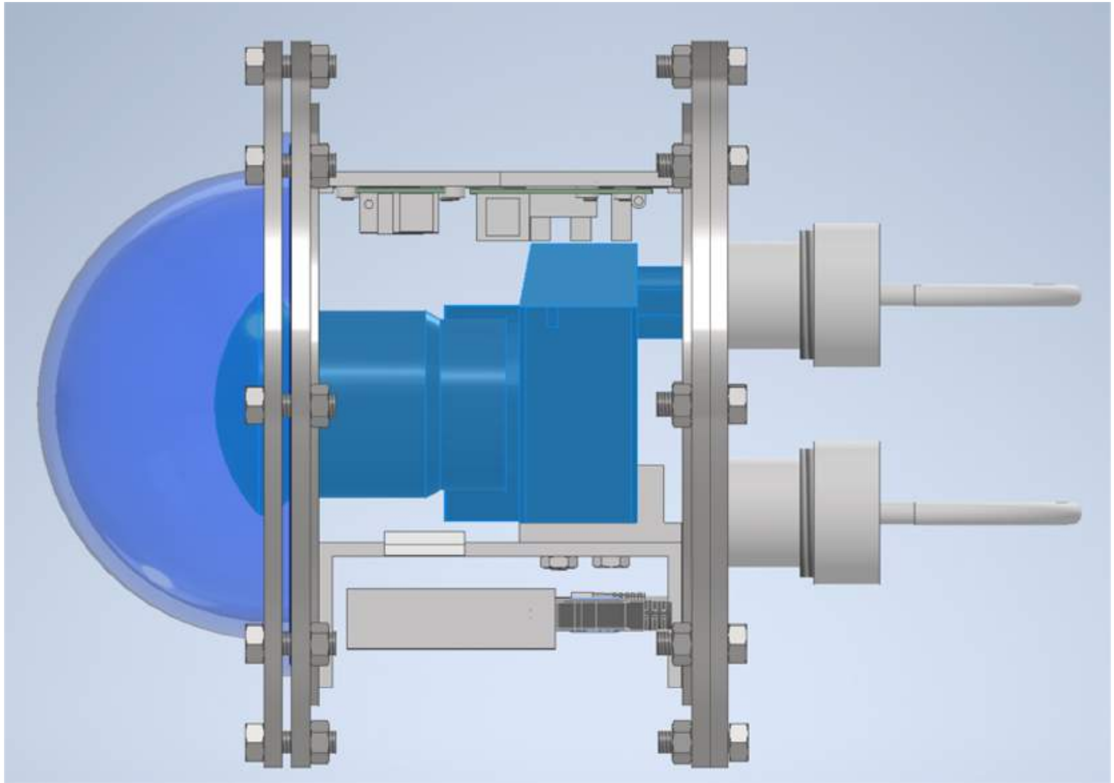
WCTE Mechanical Design

Layout with cameras in the corners is preferred



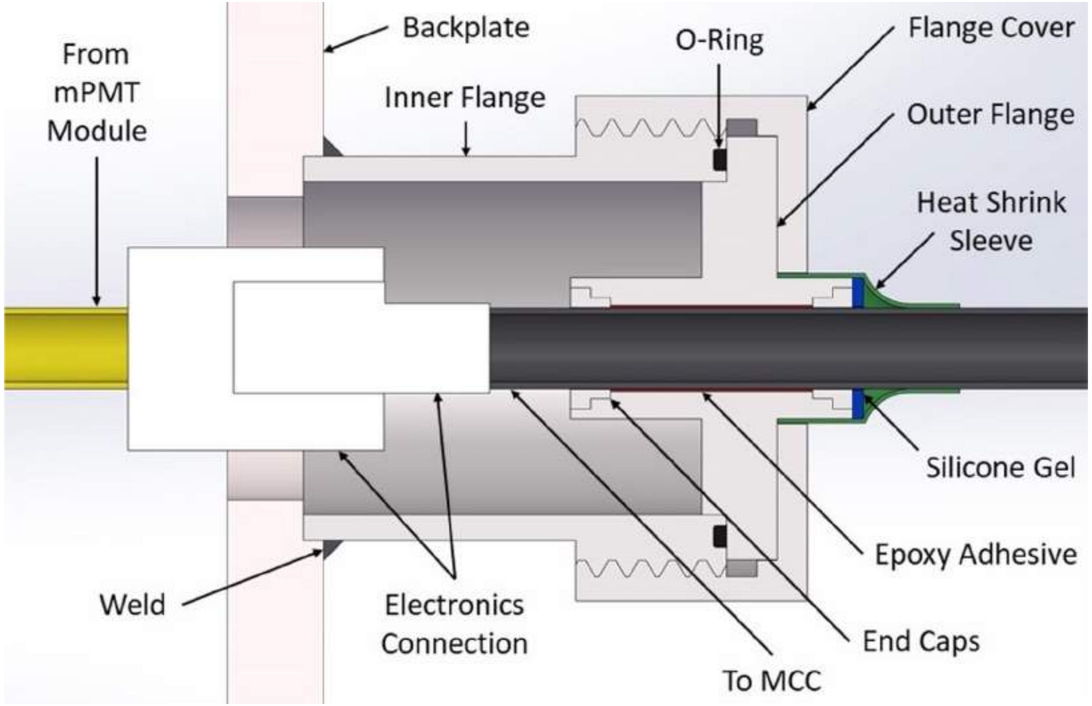
Camera housing prototype

- Camera and lens selected based on need for high resolution, and each covering wide field of view
    - Sony A7R IV (64 MP)
    - Rokinon/Samyang 12mm fisheye
- Camera housing made of stainless steel
- Two feedthroughs in current design
    - One for HDMI, One for USB/Control



3D Model of Camera housing (walls not shown)

Feedthrough same as mPMT



Assembly and use of consumables will be done at Uwinnipeg after SS parts machined and welded

Component	Material	Quantity
Inner Flange	SS 304	1
Outer Flange	SS 304	1
Flange Cover	SS 304	1
End Cap	SS 304	2
O-Ring (ø34.65 x 1.78)	Viton	1

Consumable	Material	Quantity
Adhesive (Araldite)	Epoxy	---
Gel (Anabond RTV)	Silicone	---
Heat Shrink Sleeve	Polyolefin	1

Consumable	Material	Quantity
Restrictor Plate	Plastic	1
Support Block	Foam	1
Plastic Cap	Plastic	1

Cat6 cable for testing

- PE outer jacket
- HDPE inner insulation and water blocking tape
- Mylar sheet shielding
- Measured out two 300’ cables for initial tests

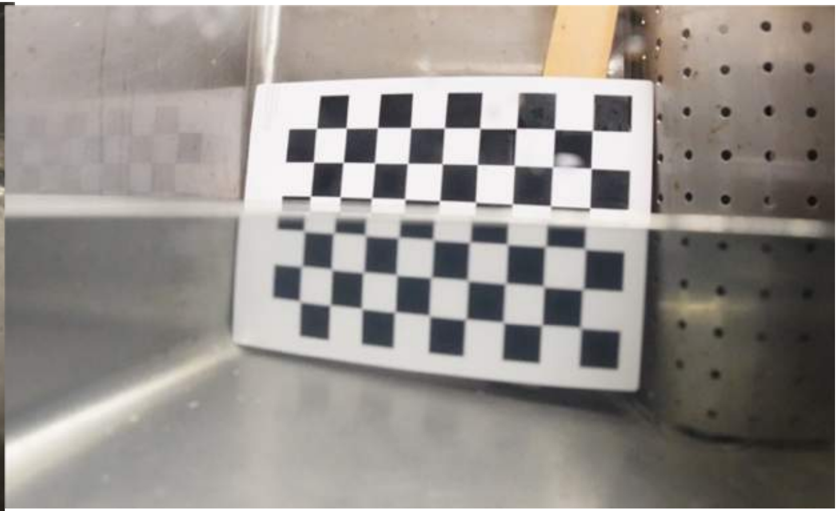
Machined parts for backplate with feedthrough

- Parts arrived, and feedthroughs assembled
- Previous iteration with Dive and See cable – one cable died and both (nickel coating) have galvanic action with steel

- New cable: HDMI connection works with 300’ cable
- USB only works with shorter cable 250’
- No problem for WCTE or IWCD, further work needed for Hyper-K

Feedthrough and housing is water-tight

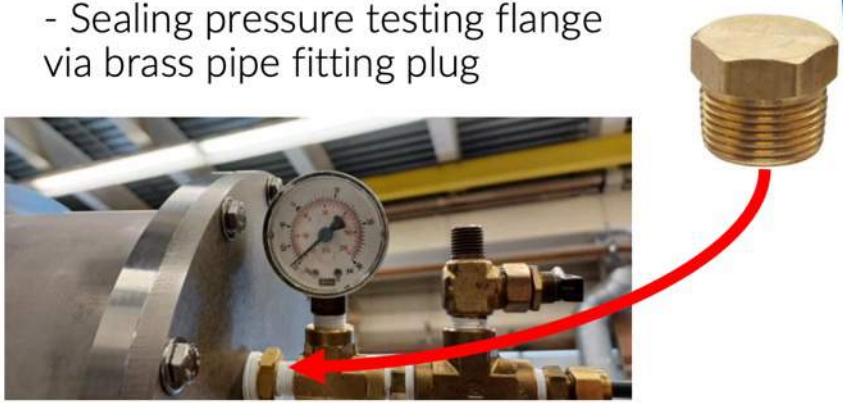
Test in sink had no leaks

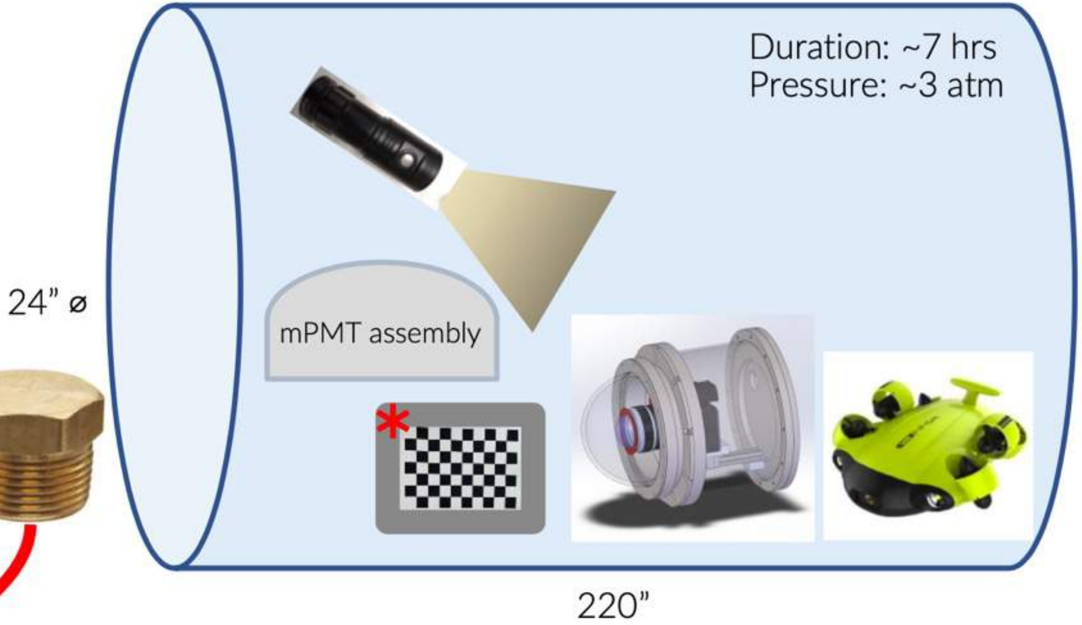


- Small sink – pattern not far enough back to focus
- Camera not quite aligned with dome – some work on mounting bracket needed

Pressure Testing

- Pressure testing equipment under WCTE conditions in a chamber in Burnaby
- Camera housing with A6000 prep:
    - Electronics for pressure sensing and saving images (Jason)
    - Electronics mounting (Michael)
    - Sealing pressure testing flange via brass pipe fitting plug

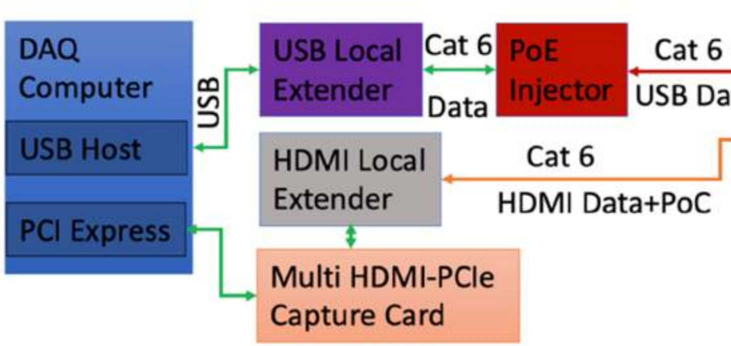


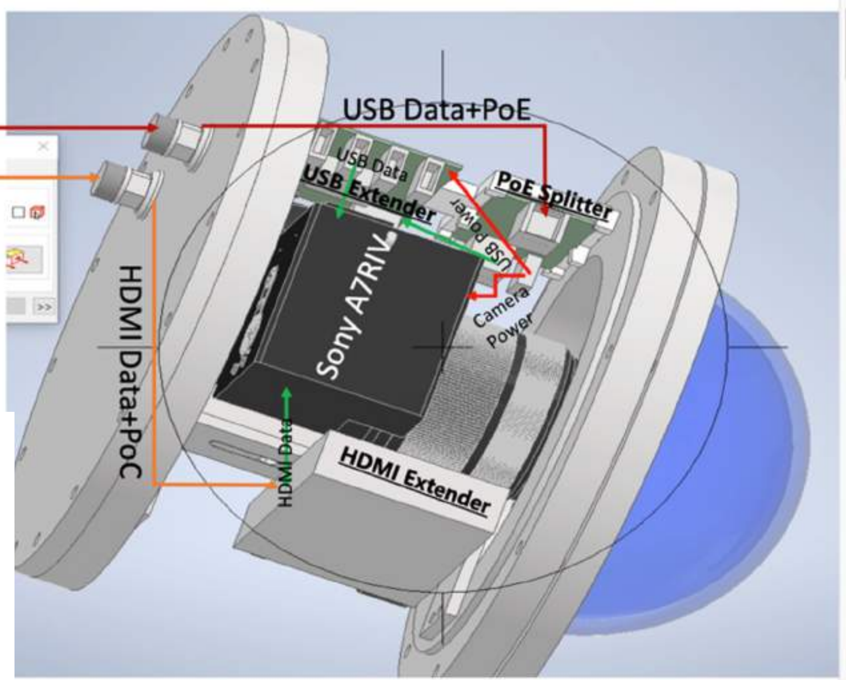


* (alternatively a focus chart)

    - 3D-printing mounting platform for A6000 (currently only A7R-IV)
- LED lighting for imaging
    - Use lights from previous pool tests done by ubc capstone group

Camera electronics / readout



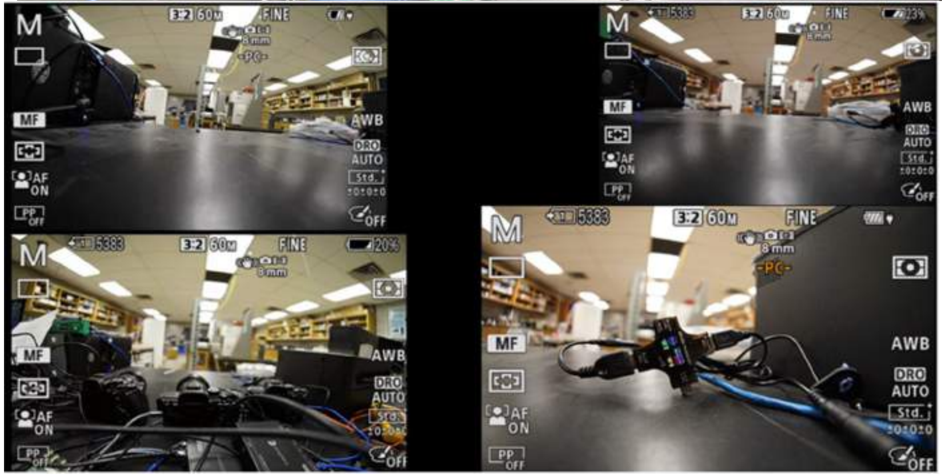


S.Ahmed UWinnipeg MRS

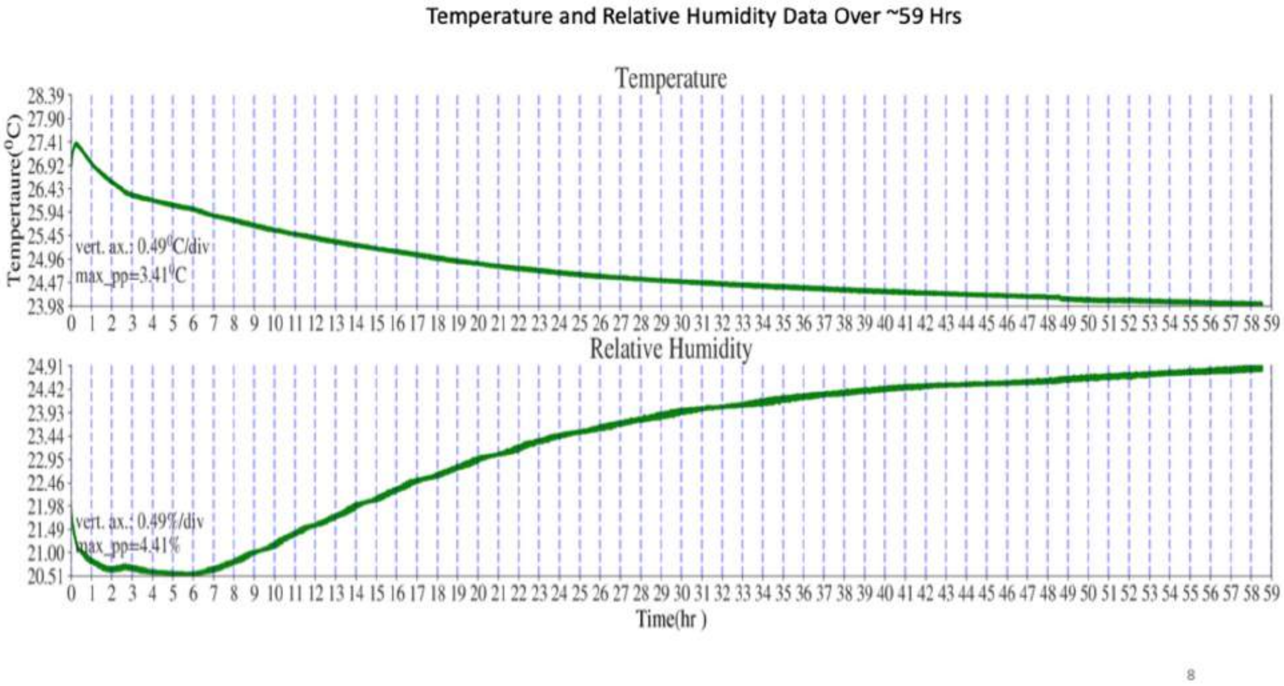
- Separate paths for video and control
- HDMI for live-streaming video
- USB for control and image capture
- Multiple camera views using HDMI-PCIe capture cards
- Power over ethernet to power all electronics including camera

Testing status

- Started testing with 300’ (90 m) cables that we built
- HDMI signal is working fine with 75 m cable
- USB connection only working with shorter 250’ (75 m) cable
- Tests with HDMI capture card work fine with no delay
- Working on rack to mount electronics
- Working on custom DAQ pages to make control of multiple cameras easier to use
- Work still needed for solution with up to 120 m needed for Hyper-K



Temperature and Humidity in camera housing



- Temperature and humidity relatively stable inside housing
- No signs of leaking
- Temperature drops inside housing when in water

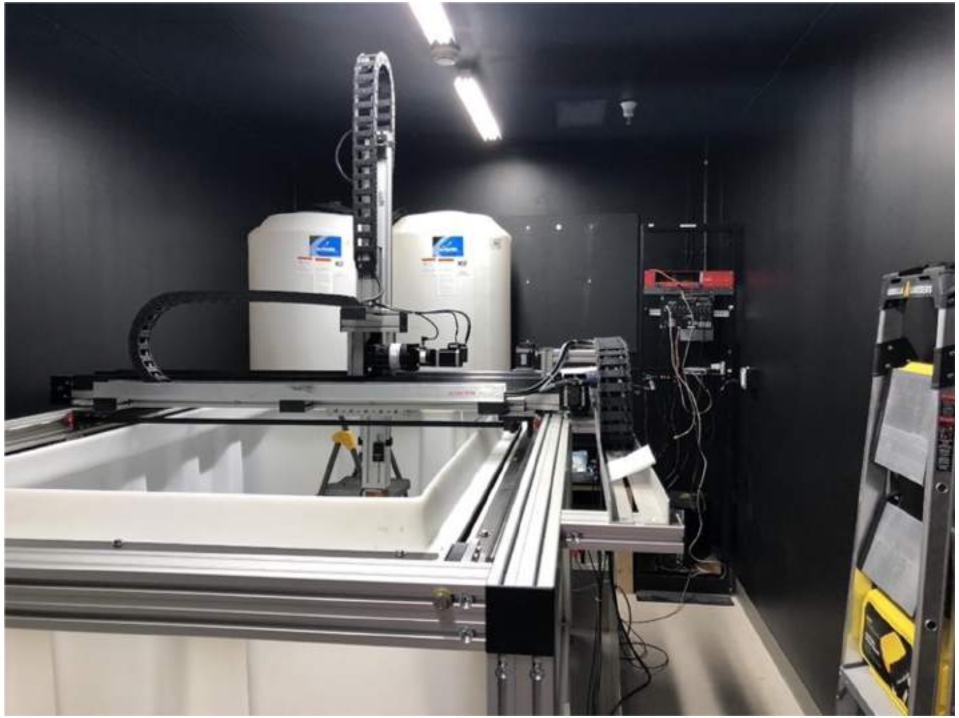
Light mitigation

- Every piece of electronics in camera housing has LEDs on it
- Need to remove those!
- Also darken camera lights!
  - Set in software not to use AF illumination light
  - LED in memory bay indicating ”disk use” to tape over

S.Ahmed UWinnipeg MRS

Next steps in camera testing

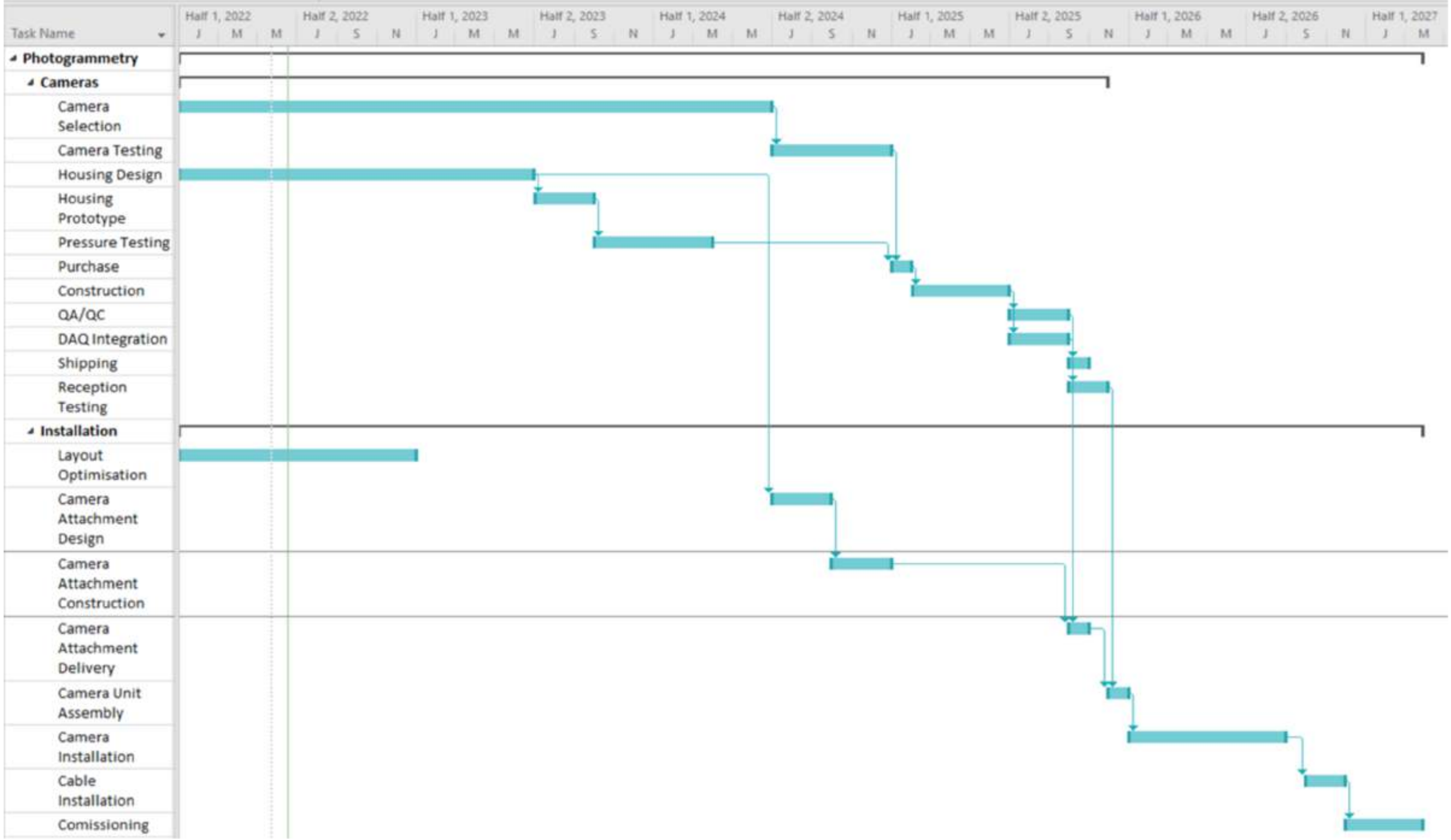
- Setting up new lab space in Winnipeg to test underwater components
- Gantry to move camera calibration targets
- Large water tank to do photogrammetry studies over longer periods of time
- Also to be used for mPMT testing and calibrations



WCTE Photogrammetry timeline

- Highlights
  - First prototype testing over Summer 2022
  - Redesign of housing Fall 2022 based on what we learn
  - Final version produced in Jan-Mar 2023
  - Final testing of versions to send to WCTE in Mar-Jun 2023
  - Ship to CERN July 2023
  - Assemble and install Fall 2023

HK Photogrammetry timeline

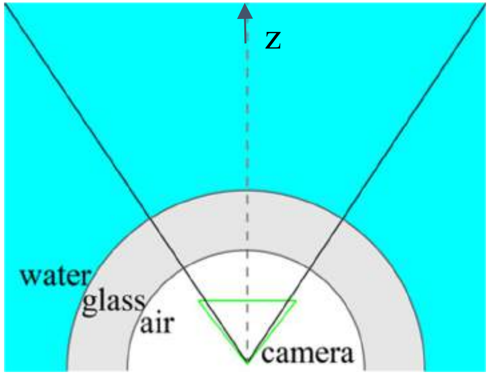


Conclusion

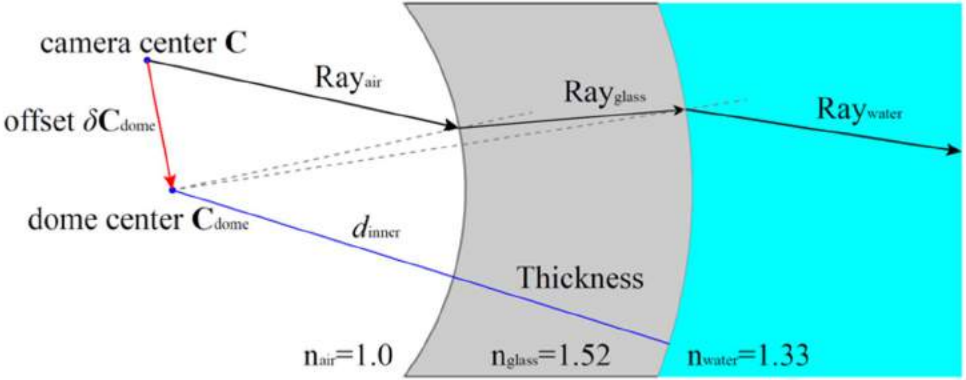
- Photogrammetry will allow precise location of mPMT modules in the detectors
- Prototype camera housings are beginning to be tested now
- Will get a chance to use them in WCTE first before installation in Hyper-K
- Further validation with high pressures needed for Hyper-K

Adjustment and Calibration of Camera and Dome inside Housing

- Reducing misalignment in the **camera nodal point** relative to **dome centre of curvature**
- There are no **refraction** effects when the dome centre is aligned with the nodal point
- **Alignment along forward/backward direction** is the hardest (others are already done by design)
    - Difficult to determine nodal point
    - Difficult to determine dome centre (dome not necessarily a perfect semi-sphere, difficulty measuring with certain flange designs, etc.)



No refraction when camera at the dome centre



Refraction caused by misaligned dome / lens
source

From paper: Adjustment and Calibration of Dome Port Camera Systems for Underwater Vision.

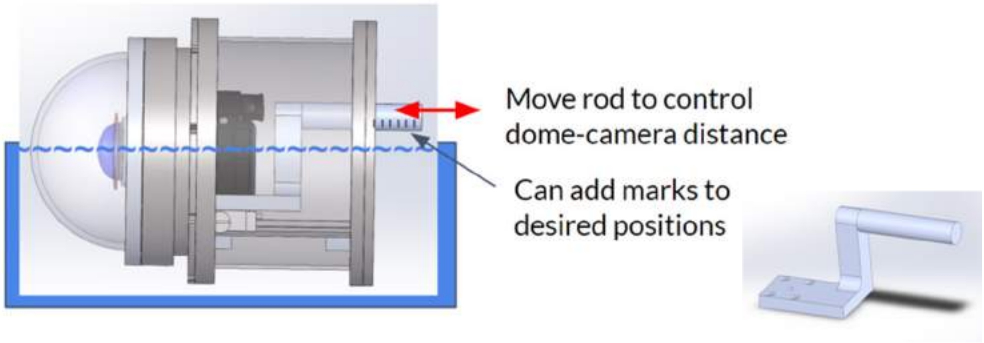
Michael S.

Adjustment and Calibration of Camera and Dome inside Housing

1. Mechanical Adjustment

- Dome positioned **halfway underwater** and **parallel to water surface**
- If the camera is centered perfectly, lines crossing the underwater and above water parts of the checkerboard pattern be continuous

Fig. 3. Simulated Chessboard images with parts above and below the water line. The lens is misaligned forward (left), aligned (center), misaligned backwards (right).



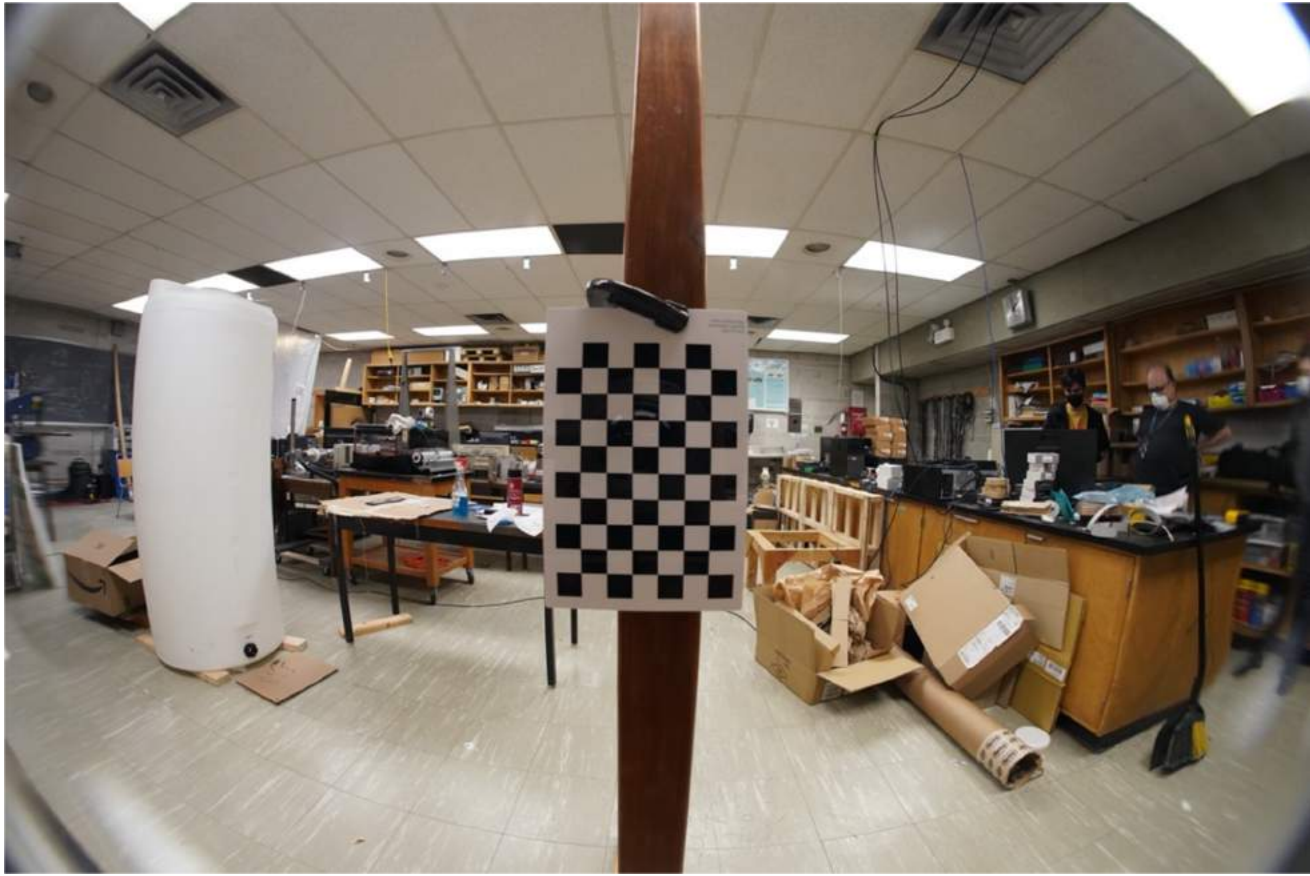
2. Calibrating for remaining misalignment

- A calibration is carried out **in air** using the standard pinhole camera model
- With the camera aligned via the **mechanical adjustment method**, photographs of a checkerboard pattern are taken **in air** and **in water** with the same calibration pattern positions.
- Any mismatches between in-air and in-water images (calibration pattern corner positions) are attributed to **refraction** effects, i.e. dome-lens misalignment.
- The 3D offset can be estimated by choosing an offset that **minimizes the 2D coordinate difference between in-air and in-water images** (working on understanding the details of this calculation).
- More details in paper: Adjustment and Calibration of Dome Port Camera Systems for Underwater Vision

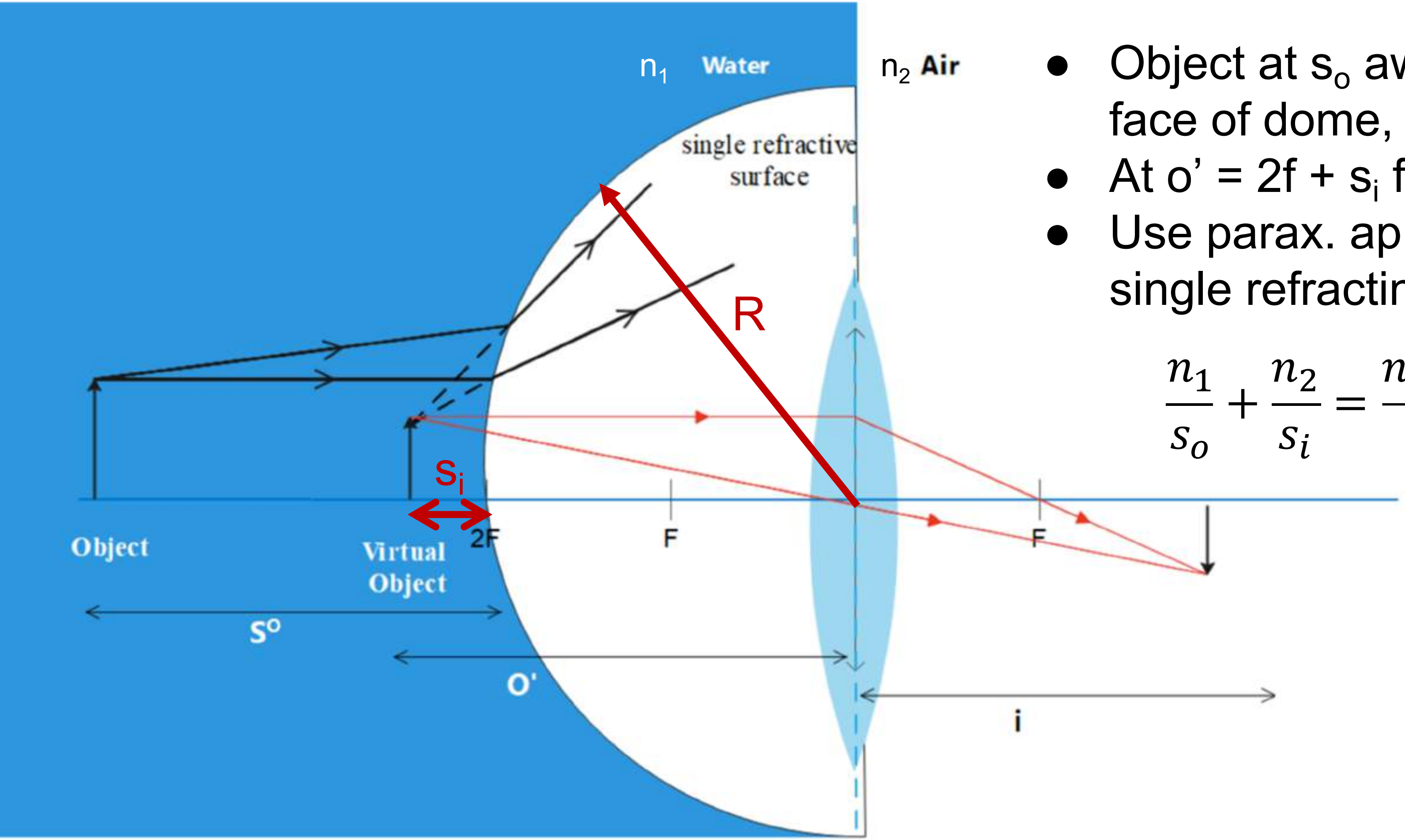
Michael S.

Dome

- View out of the acrylic EZTops dome
- Very wide field of view
- Tests underway to study whether quality of dome is sufficient
    - Rayotek and Nautilus glass domes at TRIUMF being tested



Focus underwater with lens at center of dome

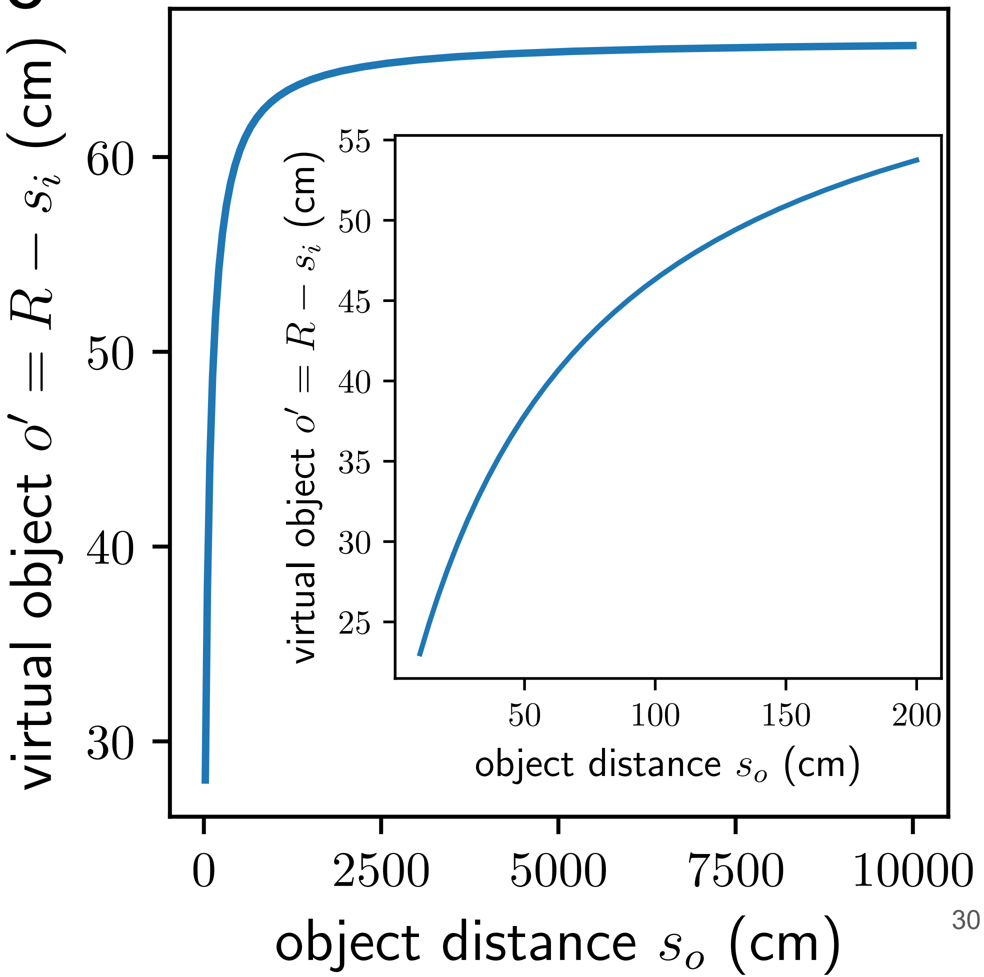


- Object at s_o away from face of dome, appears
- At o' = 2f + s_i from lens
- Use parax. approx for single refracting surface:

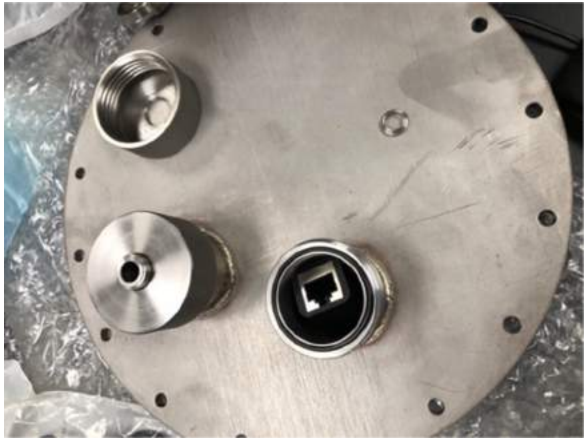
$$\frac{n_1}{s_o} + \frac{n_2}{s_i} = \frac{n_2 - n_1}{R}$$

Underwater focus in dome

- For a 12 mm lens at f/4 the depth of field is maximum when focus set to hyperfocal length of 1.21 m
- In water want to focus on virtual objects between 27 cm and 66.6 cm
- Equivalent to real objects 20 cm to infinitely far away
- Can be achieved by setting focus to 40 cm



Socket connector (inside cable)

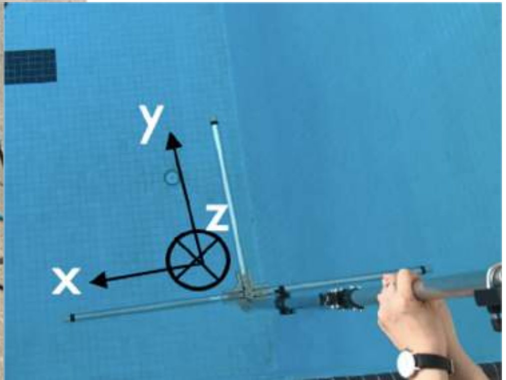


- RJ45 Jacks are quite large
- This solution doesn’t really work well b/c of space constraints
- Back of camera is in the way
- Looking into using short male/male patch cable inside
- And use jack on feedthrough
- That way feedthrough can sit mostly in the connector port

ROV Hardware

- New FIFISH Pro v6 Plus Drone
  - Doppler Velocity Logger (DVL) and acoustic based Underwater GPS system accessories for more precise drone positioning

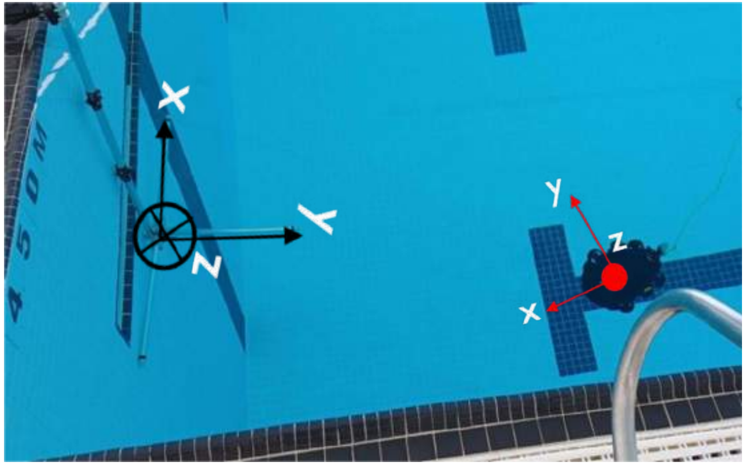
Left:
- Locator device attached to backside of ROV
- Pelican box topside control unit
- Antenna with 4 acoustic receivers and the orientation of the antenna reference frame



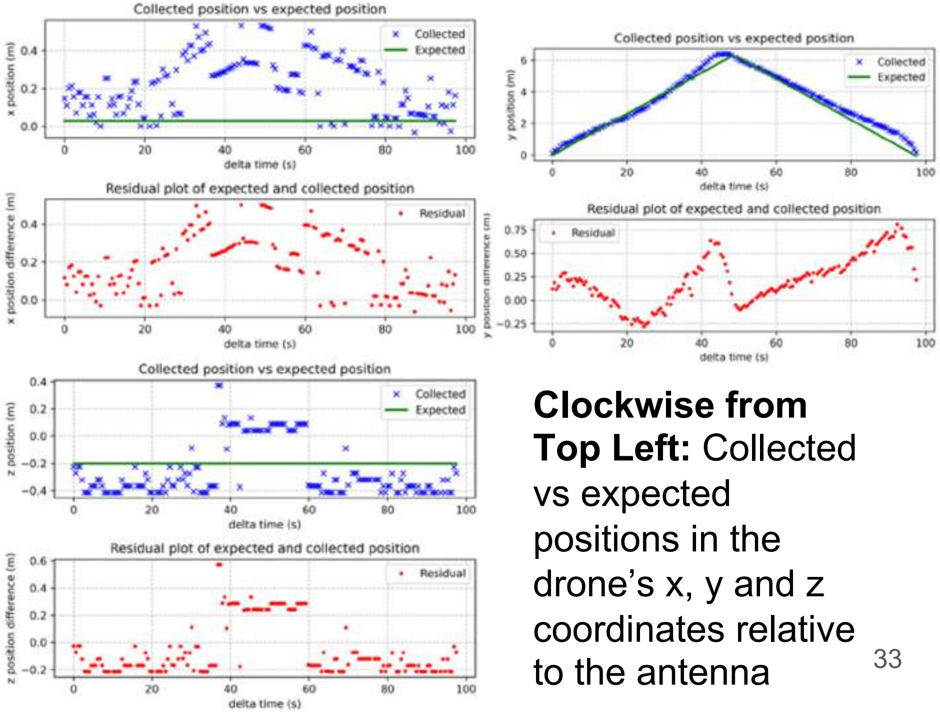
Above: ROV with the Doppler Velocity Log attached. DVL velocity of the drone relative to seafloor and maintains drone position (station-keeping)

Drone Positioning

- Advertised to have an error margin of < 0.2% in its horizontal range (100 m or 300 m range)
- Used built-in drone feature to lock drone's position in two directions and moved along third
  - Deviation from expected and measured positions relative to antenna was at most 0.75 m
    - Initial measurements did not account for drone rotation about its own axis



Above: Setup for positioning test. Drone is distance locked from wall in x-direction and altitude locked with floor in z-direction, then moved along the positive y-direction



Clockwise from Top Left: Collected vs expected positions in the drone's x, y and z coordinates relative to the antenna