# MBARI VR Camera Proposal

In partnership with:

VRTUL Sexton
CUSTOM UNDERWATER PRODUCTS

(Preliminary Design Example)

**PREPARED FOR**

MBARI, Ben Erwin, Eric Martin, Steve Haddock, and Kakani Katija

**PREPARED BY**

Casey Sapp (VRTUL), Jeremy Childress (The Sexton Corporation)

March 21st, 2019

Dear Ben, Eric, Steve, Kakani, and the MBARI team

Re: 180 3D Video Underwater Camera System w/ Point Clouds

Please find enclosed our detailed proposal for your kind consideration.

VRTUL and The Sexton Corporation have led the AR/VR industry for a combined total of 10 years developing the highest grade 180, 360, and multi-lens underwater camera systems in the world. Our world class technical and content development experience has led us to develop high-end, custom underwater housings and lead productions seen by millions worldwide with Good Morning America, Discovery, National Geographic, BBC, Red Bull, and many other top brands. We also blend that background with deep custom machine vision camera system experience for scientists and research institutions like MBARI.

We are aware this project has unique depth and control requirements. Our reputation is built on execution and exceeding client expectations. We plan to deliver an innovative proposal and follow through with it to an outstanding delivery which is both on time and within budget.

We also pride ourselves on our client-care including our guarantees, staff-training and offsite support. In all project facets VRTUL and The Sexton Corporation will continue to strive for best in class communication and teamwork with all parties involved.

Yours Truly,

Casey Sapp & Jeremy Childress

Casey Sapp 

# EXECUTIVE SUMMARY

The purpose of this project is to develop a fully integrated custom underwater 180 3D camera system which provides best in class imagery and metrology capabilities on the ROV Doc Ricketts. While the details of the optical and engineering design are becoming finalized, the requirements for a successful delivery are clearly understood by all parties. The timeline for this project is expected to be about 4 - 6 months from the design phase through final testing and then handoff to MBARI staff.

**Signed as accepted by client:**

| | |
|---|---|
| Basilio Martinez, Chief Financial Officer | March 26, 2019 |

## 1. Project Overview

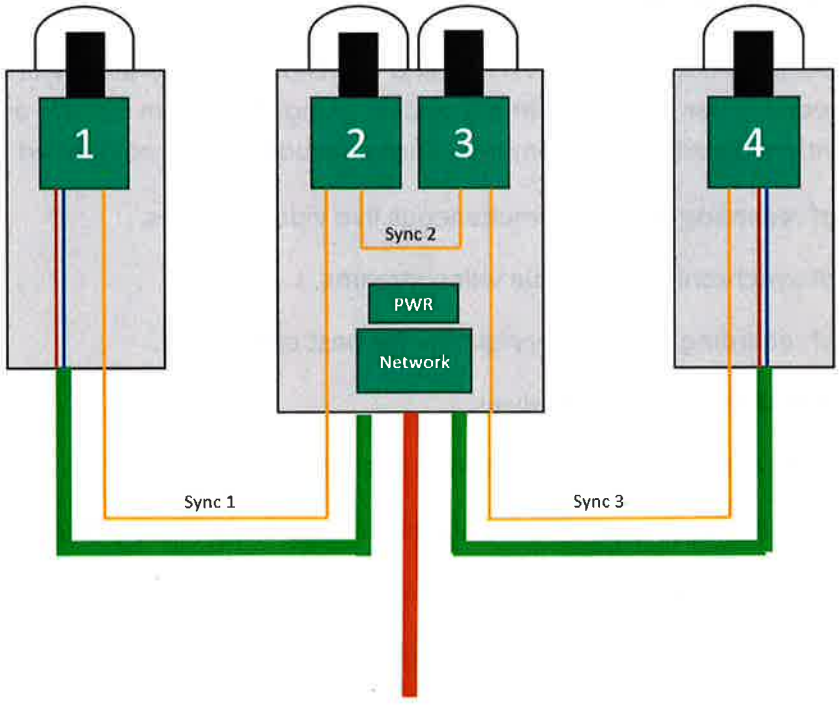
In 4 months from design through testing, VRTUL and The Sexton Corporation will develop a fully functional, best in class underwater "near 180" 3D camera system using the Z-Cam E2. We are experts at developing creative solutions within identified requirements. Those include but are not limited to:

- Be capable of recording multiple simultaneous live video streams.
- Be capable of synchronizing multiple video streams.
- Be capable of recording in necessary quality for best experience.
- Recorded video allows for data analysis.
- Be capable of recording simultaneously with live-feed.
- Be capable of providing live panoramic 3D feeds to a Virtual Reality headset.
- Be capable of filming content in the region illuminated by the ROV.
- Have cameras optically spaced to allow for near human inter-ocular scaling.
- Withstand pressures consistent with all ROV Doc Ricketts operations.
- Integrate with standard ROV electro-optical interfaces.

- Be capable of time synchronization to ancillary data sources.
- Be capable of capturing sparse point clouds to output textured mesh and dense representations

These functional requirements have been provided by MBARI in their document, ROVVR SOW for VRTUL/SEXTON (see attached) which contains further explanation of the work breakdown structure and goals of the final system. Beyond the implementation of the camera system, we are seeking to train and complete a full handoff of the system to MBARI staff.

These basic diagrams represent a first pass design that we propose take place as part of a research and development effort prior to final system manufacturing. Based on the accuracy diagnostics to create multi-view stereo and sparse point clouds the configurations of the individual housings will change. Those assumptions will be tested in our initial pool exercises with experimental aluminum housings.


Connection to ROV
- 12VDC
- GigE Network

## 2. Why Is This VR Camera System Special?

Jeremy and I have been pushing the boundary of multi-lens camera systems for a long time. In each design we finish and take to market we learn more of what users want and how we can stay on the cutting edge of this field of research. Trying to do as much as we are in a compact, deep water tested form factor is the sum of all of our past experience. This VR camera system will be special for its:

1) Dynamic range, low-light capability, and dual native ISO
2) Real-time ROV navigation capabilities
3) Combined cinematic and scientific use cases
4) Global onboard controls
5) Synchronization and global shutter
6) Efficient data management and post workflow
7) No one else has built a deep water underwater housing for the Z Cam E2 cameras, let alone a full stereo enclosure. It will be a natural extension of the products we have already developed.
8) Sparse point cloud development to output textured meshes, combined in a capture system primarily designed for cinematic immersive capture

## 3. Research Activities

VRTUL, The Sexton Corporation, and MBARI are partnered in creating a solution which has never been built before. We are striving to finish a solution which offers beautiful imagery in an unsurpassed, sturdy, compact form factor with metrology capabilities for measurement and volume extraction. In order to accomplish this goal, there are a host of tests and experimentation needed in order to finish the design and achieve all the goals we have set out. We have great confidence in succeeding based on numerous other successful custom housing jobs, however there is still much work to be done.

The greatest obstacle of all that we foresee is being able to do ample testing and configuration experiments in order to get the most accurate measurements for scientific use cases. Additionally, there is a delicate balance between image quality, imager size, frame rate, ability for cameras to sync, and the packaging constraints on the Rickett's which we need to work within. There are large cameras, such as RED, that have all of these characteristics but would be impractical to enclose in an underwater enclosure. There are integrated solutions with small footprints and small sensors, like Blackmagic, which will lack the dynamic range and image quality that we would like to provide. The Z-Cam E2 is the best and newest camera able to check those boxes, but there is little work which has been done to do scientific research with it.

For live streaming, we know that we can use Voysys, TouchDesigner, Stereostich, or Prosense stitcher for OBS Studio to provide real-time dewarping of fisheye lenses (intrinsic characteristics) and projection for low-latency stereo 180 viewing of multiple video streams. Because a number of these options have expensive subscriptions we believe they won't be the most long-term cost effective solution for a simple two

camera system (no panorama generation). We are currently exploring custom designed pipelines that would have a lower cost of ownership.

For post-processed 3D reconstruction of objects encountered by the ROV we plan on developing a toolkit that uses the following:

- OpenCV for lens and stereo calibration
- OpenMVG (Multiple View Geometry) – solve for precise camera locations and orientations
- VisualSFM (Structure from motion) – alternative to OpenMVG
- OpenMVS (Multiview Stereo) – input camera poses and sparse point cloud; output textured mesh and dense representation.
- Procedure to calibrate the camera will require a checkerboard pattern attached to a flat substrate. The size of the cells will be dependent on the distance we are designing the system for.

We understand from our research and discussions with computer vision specialists that the more camera angles we have, the more detailed our resulting 3D reconstructions will be. We aim to do in-air testing with 2,3 and 4 cameras and in-water testing with 2,3, and 4 cameras using the Aluminum enclosures. We will also develop a modular frame system to allow moving the cameras around into different fixed positions to see how that affects the quality of our output mesh.

## 4. System Features

There are a host of technical obstacles to overcome, many of which have already been discussed in detail between MBARI, VRTUL, and Sexton. Some of them up for most consideration are:

1) Ensuring the ROV can handle the weight and power requirements of the camera
2) Heat mitigation and extended recording times
3) Developing a data and post-production workflow easily understood by MBARI media staff
4) Real-time preview
5) Accurate 3D measurements and metrology calibrations
6) Automated 3D data processing
7) Real-time ROV navigation Mixed Reality components.

## 5. Budgetary Risks

Our biggest individual risk is such that we need to buy a large number of parts and material after the first payment, in which we will then be stretched until the following agreed upon milestone for a second installment. However, we do believe with a contract agreement, that we will be able to stay within the budget and through each deliverable the client will have assurity everyone is on track with the end goal.

The second situation of note is developing formal training documentation. It is important to note that since we are doing such groundbreaking work, each time the camera goes out on an expedition or in the water the

team will have something to learn. Because there will be constant modifications and improvements over time, there shouldn't be any expectation of an "official instruction manual" to go along with the camera. We will manage a working document of the most popular Q&A asked by MBARI staff and all contributors which will be available to the team. The handoff of the camera will happen through apprenticeship and mentorship. Basic wiring schematics, dimensional drawings, and assembly documentation will be provided.

The budget does not account for expenses to and from Monterey for testing and handoff. Other notable exceptions not included in the budget are computer hardware, a commercial livestreaming (ROV navigation) license, or extensive custom development utilizing OpenCV/OpenMVS/OpenMVG. We will try and use the free version for Voysys in our initial testing, and build some basic proof of concepts should we decide the custom route is more desirable.

# 6. Phases & Key Deliverables

Based on 4 month projected development schedule

| Phases | Activities | Key Deliverables |
|---|---|---|
| **Payment Milestone #1** | | |
| | Client Signoff | 60% Installment |
| **1 - Analysis** | | |
| 1.1 | Analysis and design stage: create system mockup | Present images to MBARI and incorporate all feedback for first round of optical and data tests |
| **2 - Aluminum Housing Development & Data Analysis** | | |
| 2.1 | Order materials and build housing | Present images to MBARI |
| 2.2 | In-water optical, electrical, mechanical testing | Present images to MBARI with samples images of:<br>- Underwater focus<br>- Buoyancy<br>- Waterproof<br>- Camera and cable setup |
| 2.3 | Do multiple data analysis passes (3D reconstruction, stereo, resolution) | Provide a report outlying with recommendations of:<br>- Resolution & Bit Rates<br>- 3D data accuracy of 2, 3, and 4 camera configurations<br>- Video stream latency<br>- Video with stereo calibration of the stereo pairs |
| 2.4 | UI / UX testing and review | Provide a report outlying recommendations of:<br>- Specs and CPU setup needed on the ship to support the camera<br>- Screenshots of Z-Cam native app and VRTUL app |

| | | |
|---|---|---|
| 2.5 | ROV Live Navigation | - Present software integration recommendations and workflow diagram<br>- Show proof of concept livestream to VR headset in a pool dive using Voysys (need a VR headset from MBARI which they plan to employ) |
| **3 - Titanium Housing Development, Testing, & Data Analysis** | | |
| 3.1 | Order materials and build Titanium Housing | Present images to MBARI |
| 3.2 | Pressure test (Location TBD; MBARI preferred) | Present certificate to MBARI |
| 3.3 | In-water optical, electrical, mechanical testing | Present images to MBARI with samples images of:<br>- Underwater focus<br>- Buoyancy<br>- Waterproof<br>- Camera and cable setup |
| **Payment Milestone #2** | | |
| | Client Signoff | 20% Installment |
| **4 - On-Site Testing & Training** | | |
| 4.1 | MBARI integration and on-site testing | Face to Face Client Meeting |
| 4.2 | Staff training with live environment tests | - Face to Face Client meeting |
| **5 - Payment Milestone #4** | | |
| 5.1 | Full Handoff to MBARI | 20% Installment (At time of full client handoff, and release of system for use on ROV.) |

# 7. Pricing Breakdown

We strive to deliver excellent product with fair and reasonable estimation of man hours and materials needed. We are seeking a 60% - 20% - 20% payment schedule so the project doesn't run into cash flow issues.

There are 4 main areas in which all the costs and man hours will occur.

1) **Engineering & Design**
    a) Mechanical (materials, structural) - Aluminum & Titanium
    b) Electrical (sensors, communications bus)
    c) Optical (lenses, dome ports)
    d) Camera head enclosure
    e) Controls and Electronics (inside sub)
2) **Manufacturing - Machining, Parts, and Spares**
    a) Machining - Aluminum & Titanium
    b) Cameras

c) Custom Lenses and Mounts
d) Connectors
e) 3D Printed Rigid Frame for Testing

3) **Control Systems Development**
   a) UI/UX Global Camera Controls
   b) Finestitching & LUT Templates
   c) Live preview on ROV
4) **Testing, Training, Consulting**
   a) Trainings, Visits, and/or handoffs with MBARI
   b) Consultation on LUTs, production, post-production, and all facets of pipeline
5) ***Go-Live**
   a) Expenses for any travel expenses to Monterey is not included
   b) Formal instruction manuals are not included; only working docs made available online

**Total cost of project: $80,000**

| Summary of Estimated Costs | | |
|---|---|---|
| 1 | Engineering & Design | $4,500 |
| 2 | Internal Components, Cameras, Connectors, and Cables | $25,000 |
| 3 | Experimental Aluminum housing tests, final Titanium housing, custom domes, stereo calibrations, basic metrology data processing, custom app development for global controls, UI/UX | $40,000 |
| 4 | Testing/Pool Time, Training, Contingency, & Legal | $10,500 |
| 5 | **Grand Total:** | **$80,000** |

# 8. Z-Cam E2 and Lens

Specs (copy and pasted from the web for the Rolling Shutter version; the Global Shutter specs have not been posted publicly):

**4K CINEMATIC CAMERA**

***Specifications:***

- One-piece compact 4K resolution MFT camera
- 4K @ 120fps, 10-bit colour
- 4/3" WDR CMOS Sensor sensor
- Timelapse mode available
- 13 stops dynamic range (16 with WDR enabled)
- Gigabit Ethernet for data, control & live stream
- Full camera setting control & live preview via iOS App
- Multi-cam synchronization
- Open API & SDK
- External Power or Battery
- Dimensions 90 x 100 x 90mm, Weight 757 g.
- Comprehensive range of lenses available

**The ZCAM E2 Cinematic camera is a 4K UHD (ultra-high definition) micro four-thirds (MFT) camera with an interchangeable lens system.**

The E2 camera easily captures cinema quality 4K 4096x2160 video utilising 13 stops of WDR at up to 120 fps with H.265 compression. The camera is feature rich and utilises an open source API and SDK. The E2 can be controlled in several ways including an IOS App which includes live preview and all camera setting controls. Recording is achieved on camera via a CFAST card or externally via USB 3.0.

Its micro four-thirds lens mount accomodates a wide range of auto-focus (AF) and manual-focus (MF) lenses from brands such as Olympus, Panasonic, Lumix, Leica and Sigma. All help the E2 capture some of the highest quality images possible in it's market group.

**SeeSense are able to provide full technical assistance and back up for this camera. Please contact SeeSense for further details and for our recommended lens options.**

This camera has many suitable applications and uses:

- Micro Cinematic Camera
- Film & Broadcast
- Pre-visualisation
- Natural History
- Supplementary Camera
- Filming in tight spaces / extreme angles
- POV Camera
- Bullet time array & Timelapse Imaging
- Motion Capture
- 360 & 180 Degree VR

## Specification - Features

| | |
|---|---|
| Image Sensor | 4/3"WDR Sony CMOS sensor 17.3 x 13mm |
| Output Pixels | Horizontal: 4096, Vertical: 2160 |
| Effective Pixels | 10.28MP |
| Sync / Freq | 4K @ 120 fps ~ 1080p @ 240 fps |
| Dynamic Range | 13 stops (ZLog) / 16 with WDR enabled |
| Microphone | Built in Stereo Microphone |
| ISO | Auto, Manual 160~25600 (80~12800*. Native ISO: 80* / 160 / 800 (* with WDR active) |
| Shutter Modes | Auto / Manual – Off (up to 1/8000s) OR Shutter Angle Auto, Manual (11.25°~360°) |
| White Balance | AWB (Automatic White Balance), Preset, OR Manual (2300K ~ 7500K) |
| Focus Mode | Manual, Auto or Continuous Active (CAF) |
| Image | Brightness / Contrast / Saturation / Sharpness |
| LUT | Rec.709 / ZLog / Flat |
| Audio | Audio In / Audio Out Level |
| Time Code | Current Time / Manual Input |
| Multi-cam Sync | Via sync cable **(not included)** |
| Remote Control | Z Camera App (iOS) for live preview and control via WiFi or USB cable |

## Connectivity

| | |
|---|---|
| HDMI | HDMI 2.0 TypeA (video output to C4K @ 60fps) |
| USB | USB-C, 3.0 (data transfer / storage) |
| I/O | 10-pin LEMO port for synchronization * |
| COM | DB-9 connector, supports RS-232 |
| Remote Control | 2.5mm jack socket (Sony LANC compatible) |
| Audio-In | 3.5mm stereo jack for active mic only, or 5-pin LEMO port for dual channel XLR mic |
| Audio-Out | 3.5mm stereo jack |
| Wi-Fi | 802.11n 2.4G with external antenna port |
| Ethernet | Gigabit Ethernet port for settings & live streaming |
| DC Power Port | 12 V DC 5 Amps with 4-pin LEMO and PSU Hot swap is supported |

## Storage

| | |
|---|---|
| Media | CFAST 2.0 (slot beneath the camera) |
| File System | exFAT |
| External | To external drive via USB-C |

## Recording

| | |
|---|---|
| Video System | NTSC / PAL / CINEMA |
| Video Format | 4096 x 2160 / 59.94, 50, 29.97, 25, 24, 23.98 fps<br>3840 x 2160 / 59.94, 50, 29.97, 25, 24, 23.98 fps<br>3696 x 2772 / 59.94, 50, 29.97, 25, 24, 23.98 fps<br>1920 x 1080 / 59.94, 50, 29.97, 25, 24 fps |
| Max Variable | 120 fps for 4096 x 2160 & 3840 x 2160<br>59.94 for 3696 x 2772, 240 fps for 1920 x 1080 |
| Max Bit Rate | 230 Mbps for 4096 x 2160, 3840 x 2160 & 3696 x 2772, & 200 Mbps for 1920 x 1080 |
| Colour Bit Depth | 10 bit (H.265) / 8 bit (H.264) |
| Video Encoder | ProRes 4:2:2 HQ, ProRes 4:2:2, ProRes 4:2:2 LT / H.264 High Profile / H.265 main 10 profile |
| Audio Format | 24-bit 48 kHz |
| Audio Encoder | AAC / PCM (for MOV only) |
| File Format | MOV / MP4 |
| Record Mode | Video / Time Lapse Video |

## Specification - Physical

| | |
|---|---|
| Battery | Sony NP-F series **(Battery NOT Included)** |
| Body Material | Aluminium Alloy |
| Lens Mount | Active Micro Four-Thirds (MFT) |
| Dimensions | 98.2 x 99.2 x 89.1mm (WxHxD) 1080 |
| Weight | 757 grammes (excludes lens) |
| Camera Mount | Multiple 1/4-20 UNC Standard tripod mounts around the camera body |
| Operating Temperature | 0°C ~ + 40°C |
| Storage Temperature | -20°C ~ + 60°C |

## What's In The Box?

**ZCAM E2 camera, LEMO Power Cable with D-TAP Plug, & Connector, AC/DC Power Supply with UK, EU & US plugs, Quick User Guide, & Warranty Card**

## Optional Accessories

- Sony NP-F series battery
- Z Camera App (iOS)
- LUTs & Colour Correction Plug In
- Open API & SDK
- Video Concatenator, Video Transcoder

## Lenses

- The E2 supports a selection of Leica, Lumix, Olympus, Panasonic & Sigma, etc MFT lenses.

**Please contact SeeSense for details and advice**

Rev: 1.012.0119 E&OE

Applicable camera (model)

1 | 2/3 | 1/2 | 1/3 | 1/4

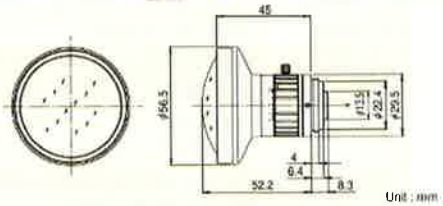
**For Security**
**Fish-Eye**

# FE185C086HA-1

FIXED Fixed Focal | Fish-Eye 185° Fish-Eye | 5 Mega For Megapixel Camera | MANUAL Manual Iris | CS-mount C Mount | METAL Metal Mount

*Photograph is a similar model.

- High-resolution design, providing support for up to 5 megapixel camera resolution.
- Super wide angle of 185 degrees that eliminates dead angles and enables effective, wide-area surveillance.
- Designed with the f-theta system, most suited for uniform displaying of images. Allows high-quality image display, partial enlargement, and conversion to ordinary-looking images to be performed easily with imaging software.




Unit : mm

| | | |
|---|---|---|
| Focal Length (mm) | | 2.7 |
| Iris Range | | F1.8 ~ F16 |
| Operation | Focus | Fixed |
| | Iris | Manual |
| Angle Of View (H×V) | 1" | 185° × 185° (φ8.6mm) |
| | 2/3" | 185° × 140°35' |
| | 1/2" | 136°18' × 102°19' |
| Focusing Range (From Front Of The Lens) (m) | | ∞ ~ 0.2 |
| Back Focal Distance (in air) (mm) | | 9.75 |
| Exit Pupil Position (From Image Plane) (mm) | | −49 |
| Filter Thread (mm) | | — |
| Mount | | C |
| Mass (g) | | 160 |
| Remarks | | ·With Metal Mount<br>·With Locking Knob for Iris |

[Fish-Eye Lens Image]

1"

2/3"

1/2"

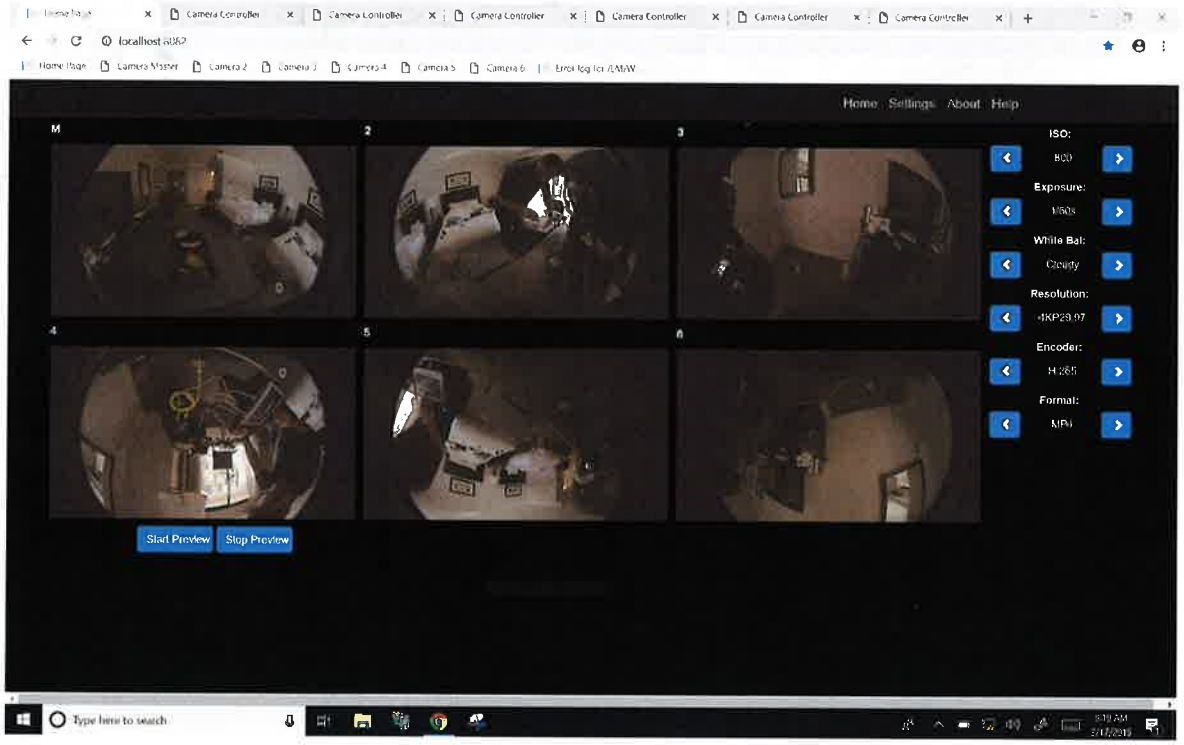
# 9. Project Inventory

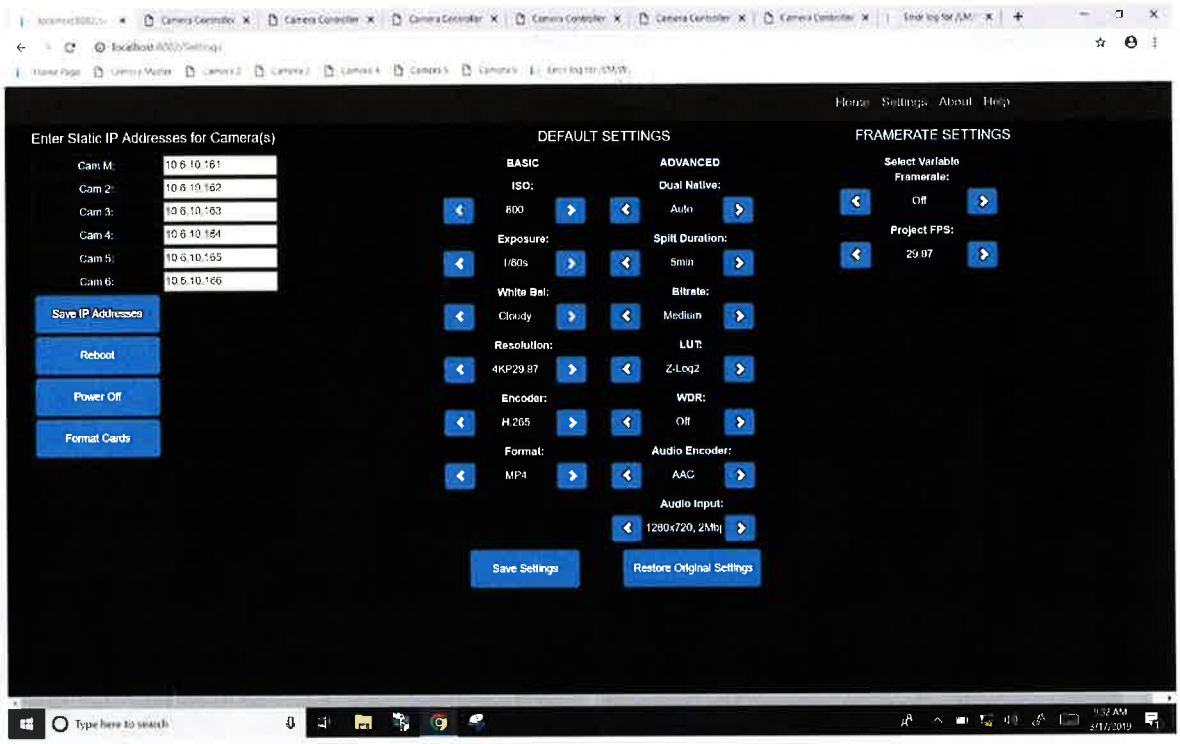
| | | |
|---|---|---|
| **Camera System** | **Description** | |
| Underwater Housing | 1x stereo titanium housing for Z-Cam E2 | 1 |
| Underwater Housing | 2x individual titanium housings for Z-Cam E2 | 2 |
| Z-Cam E2 | 4x "E2G" Global Shutter 4k @ 30fps cameras | 4 |
| Lenses | Fujinon Fisheye Lenses | 4 |

| | | |
|---|---|---|
| Network Switch | Netgear GS105 | 1 |
| Subconn Connectors | 4 - 6 (TBD) | 4 - 6 |
| Pelican Case | to hold and travel with enclosures | 1 |
| CFast Cards | 128 GB | 4 |
| 3D Printed Frame | Rigid frame for testing | 1 |

# 9. Control Software Screenshots

Custom VRTUL/Sexton Windows app (sample screenshots)






Desktop Version (2018 spec sheet)

# Z CAM™ WonderLive

Z CAM™ WonderLive is a feature within Z CAM™ Controller that performs live stitching of video stream from Z CAM™ S1 & Z CAM™ S1 Pro through the Ethernet port, and output to RTMP.

Z CAM™ WonderLive requires a valid software license associated with a designated Z CAM™ S1 or Z CAM™ S1 Pro to use and nontransferable. Note that Z CAM™ WonderLive only works on Z CAM™ S1 with firmware version 0.65 or above.

**System Requirements**

OS : Windows 10 64-bit
CPU : i7 is recommended
GPU : AMD WX7100, Nvidia GTX 1070/1080 are recommended
Memory : 8GB or above
Network Adapter : Two network adapters are recommended. One directly connected to Z CAM™ S1 and the other one to Internet for streaming.

**Supported Features**

- Up to 4K output resolution equirectangular image
- Save live stitched video file
- Preview live stitched video
- Facebook 360 Live integrated
- Weibo Live integrated
- RTMP live streaming output

**Quick User Guide**

1. Open Z CAM™ Controller, select network mode to Direct, connect Z CAM™ S1 to PC directly through the Ethernet port.
2. Connect power to Z CAM™ S1 and it will be turned on automatically.
3. PC should be connected to Internet in order to perform RTMP live streaming.
4. On Z CAM™ Controller, click the tab Tools and select Z CAM™ WonderLive, four IP addresses will be detected and shown.
5. Select the below options accordingly:

Stitch template
- Auto adaptation : Configuration file will be generated automatically.
- PTGui file : Browse to select your own PTGui file deemed fit.

Encode
- Select resolution, bit rate and IDR interval according to network conditions.

RTMP
- Facebook Live : Facebook 360 Live integrated, click to select.
- URL : Manual input URL to stream.

Output
- Preview : Select this output option to enable live preview in equirectangular format.
- SDI : Blackmagic Design DeckLink Studio 4K card has been functionally tested and verified. Note that if SDI is selected, all other output options would then be prohibited.
- Stitched file : Save stitched video (with audio track) to a file.
- Source file : Save original video/audio streams to four respective files.

Note that RTMP Preview, Saving stitched video could work simultaneously depending on system performance.

# 10. Past Production Experience


**Good Morning America**
ABC

**Into the Now – RSA**
MICHAEL MÜLLER


**ORCA 360**
SEAWORLD

**Google Expeditions – NEKTON**
GOOGLE

**The Daily 360**
NEW YORK TIMES

**Embrace the Future**
IMMEREX


**Le Musk**
A.R. RAHMAN

**Huberman Lab**
STANFORD UNIVERSITY

## 11. Some of Our Other 360 Camera Work









# 11. Q & A - Misc info in providing full view of specs

**Q: What are the power requirements of the cameras?**

A: Each camera when its recording is 24 watts which is 12 volts at 2 amps

**Q: What is the estimated GB/hour data consumption of the cameras?**

A: It will depend on the settings of the camera such as H.264 vs. ProRes. Those tests can be done in detail during the pool exercises.

**Q: How will we get data off of the cameras?**

A: We are recommending a USB-C offload through opening up a port. The easiest solution which won't require opening up a housing would be over ethernet, but the time to offload would be longer.

**Q: What are video formats and max bit rates of the E2G?**

A: Those specs currently aren't available and will need to be tested once we have a camera in hand.

**Q: Will the camera include audio?**

A: They have audio input, but it will obviously be muffled in the housing.