RiBBIT

River **B**athymetry **B**ased **I**ntegrated **T**echnology

Spring Final Review

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Project Overview

Mission Motivation

Problem

Rivers are a critical resource to monitor due to contributions to agriculture, urban development, hazard monitoring, and environmental monitoring.

There is a lack of updated and accurate global data for river discharge, especially in hard to access rivers.

A hard to access river is one which presents a physical risk for humans to access on foot.

Existing Solutions

Earth Orbiting Satellites

Boat tagline system with acoustic instrument and velocity tracker

Helicopters towing radar systems

ASTRALite EDGE

Market Gaps

Data Resolution

Safety

Low-Cost

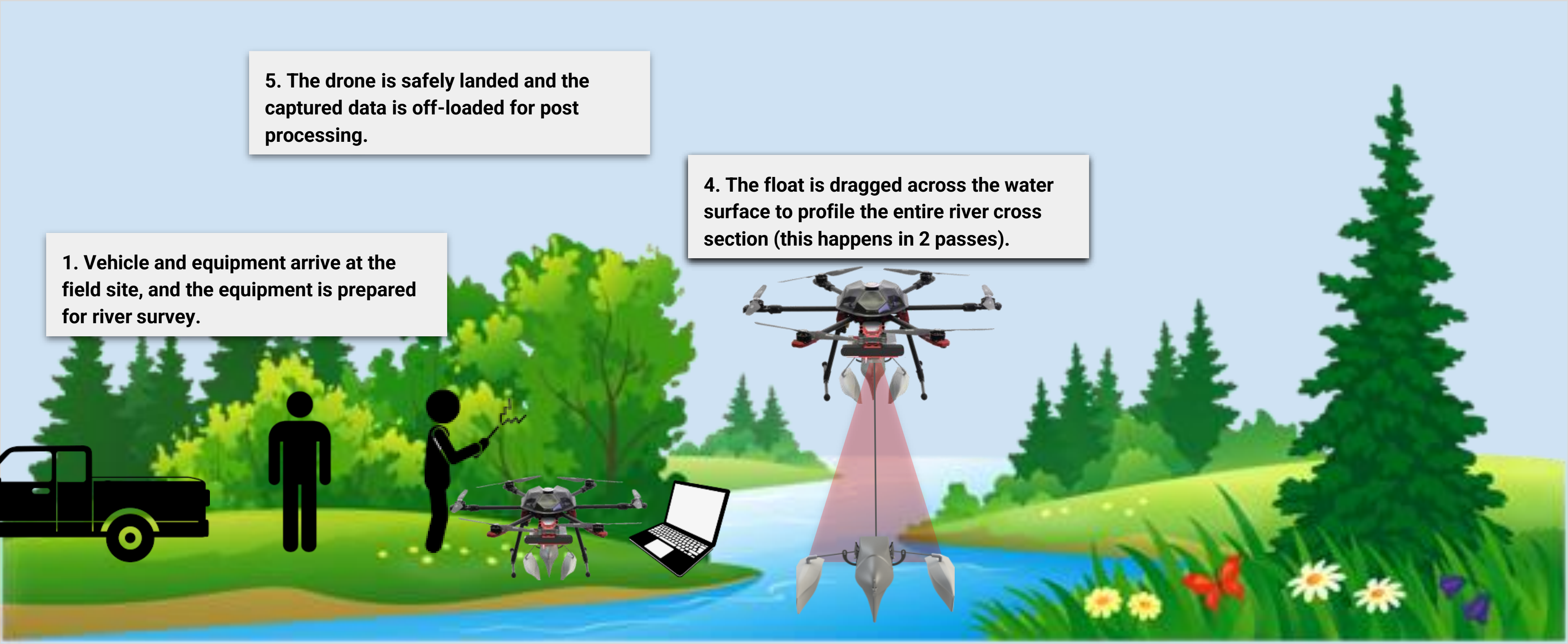
Ease of use

Quick set-up and data collection

Mission Statement

"The long term goal of this project is to design, manufacture, and test a drone-mounted sensor system to gather river depth profile and velocity data in hard-to-access areas for the purpose of monitoring river discharge."

CONOPS



5. The drone is safely landed and the captured data is off-loaded for post processing.

4. The float is dragged across the water surface to profile the entire river cross section (this happens in 2 passes).

1. Vehicle and equipment arrive at the field site, and the equipment is prepared for river survey.

Levels of Success

	Level 1
Drone Command & Control	Drone is capable of being flown manually the entire course of the flight
Drone Performance	Drone is capable of carrying payload. Drone is capable of flight time of at least 12 minutes carrying payload

Levels of Success

	Level 1	Level 2	Level 3
Depth Sensing	Instrument system can measure river depths of 0.5m-3m in ideal conditions to an accuracy of <1% of the total depth	Instrument system can measure river depths of 0.5m-3m in ideal conditions to an accuracy of <0.75% of the total depth. Instrument can measure river depths to 3-5m in ideal conditions with an accuracy of <1% of the total depth.	Instrument system can measure river depths to 0.5m-3m in ideal conditions to an accuracy of <0.5% of the total depth. Instrument can measure river depths to >5m in ideal conditions with an accuracy of <1% of the total depth.

Levels of Success

	Level 1	Level 2
Velocity Measurements	Instrument system can sufficiently capture surface velocities between 0m/s-4m/s.	
Velocity Post Processing	The river is modeled as a flat plane.	The river is modeled as a 3D surface.

Levels of Success

	Level 1	Level 2
Positional Measurements	The instrument system can know its relative horizontal position to an accuracy of +/-3 cm and its vertical position to an accuracy of +/-4 cm using RTK or PPK. The instrument system will know its angular position to an accuracy of +\- 1 degree	Inclusion of ground control points or use of advanced base station localization techniques such as truthing to survey landmarks. Perform SLAM algorithm to integration receivers and IMU.

Functional Requirements

ID	Functional Requirement
FR1	RiBBIT shall be an unmanned aerial vehicle (UAV) system.
FR2	RiBBIT shall be capable of operating in rivers with velocity between 0-4m/s and depths between 0.5-3m.
FR3	RiBBIT shall include an instrument suite payload that is compatible with the Tarot 680.
FR4	The instrument suite shall be capable of measuring the bathymetric profile of a river cross section from one bank to the other, perpendicular to the current.
FR5	The instrument suite shall be capable of measuring the surface velocity of a river cross section
FR6	RiBBIT shall be able to power and command all instruments and sensors.
FR7	The collected data shall be post-processed to calculate river discharge.
FR8	The UAV shall comply with all FAA and safety requirements

Design

Final Design

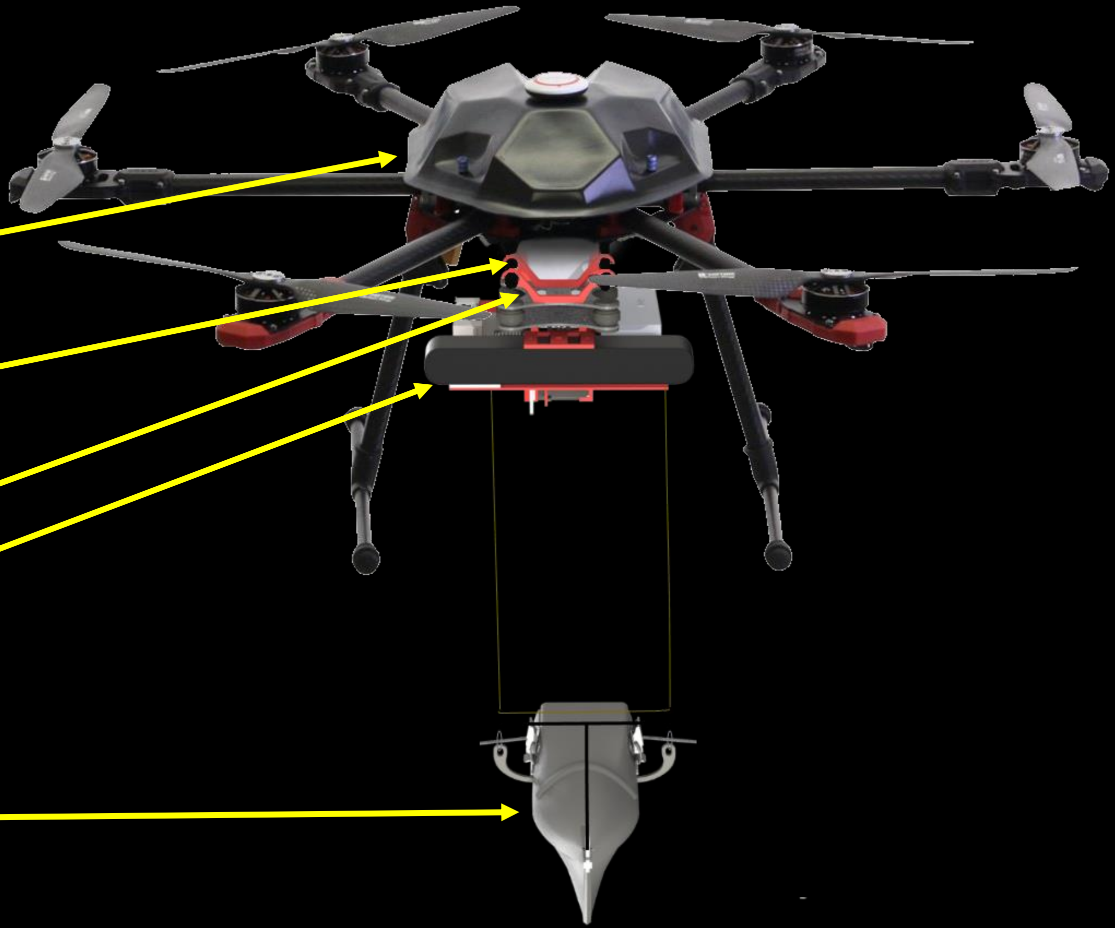
Tarot 680 Pro Hexacopter

3D printed drone mount (includes motor housing and electronics mounts)

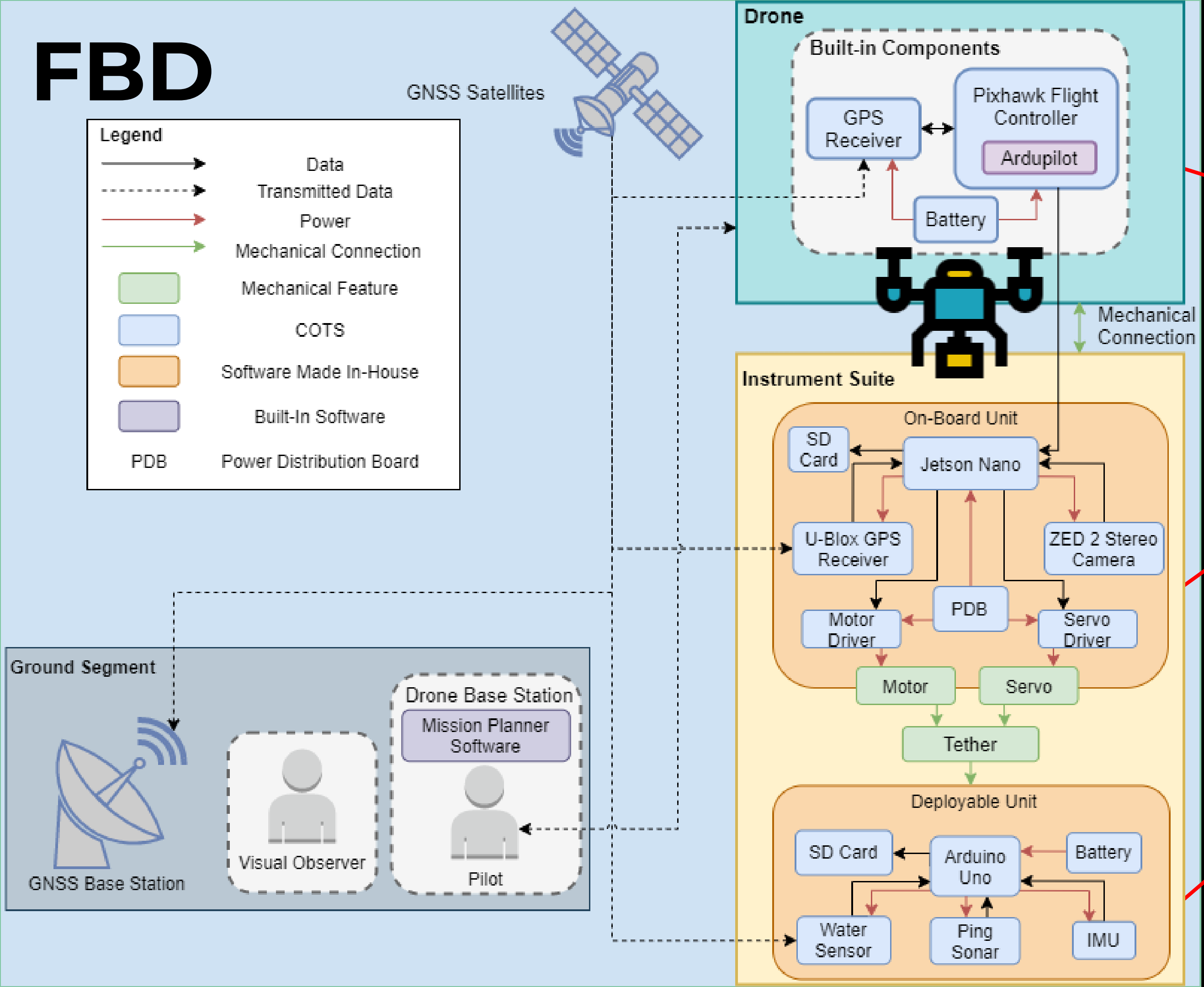
3D printed camera mount

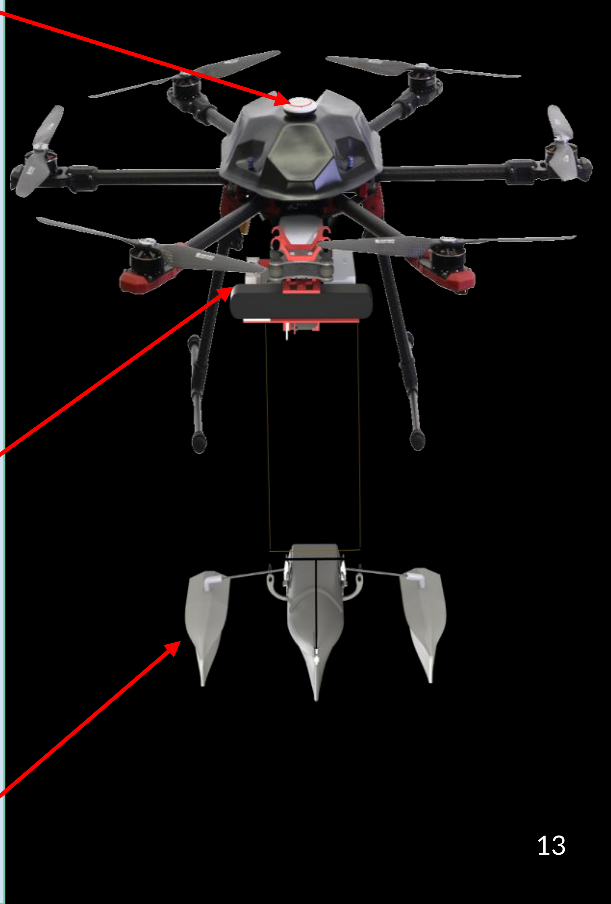
Stereo Camera

3D printed waterproof sonar float (houses sonar device, IMU, water sensor, battery, Arduino)



FBD


GNSS Satellites
Legend
Data
Transmitted Data
Power
Mechanical Connection
Mechanical Feature
COTS
Software Made In-House
Built-In Software
PDB
Power Distribution Board
Drone
Built-in Components
GPS Receiver
Pixhawk Flight Controller
Ardupilot
Battery
Mechanical Connection
Instrument Suite
On-Board Unit
SD Card
Jetson Nano
U-Blox GPS Receiver
ZED 2 Stereo Camera
PDB
Motor Driver
Servo Driver
Motor
Servo
Tether
Deployable Unit
SD Card
Arduino Uno
Battery
Water Sensor
Ping Sonar
IMU
Ground Segment
GNSS Base Station
Visual Observer
Drone Base Station
Mission Planner Software
Pilot

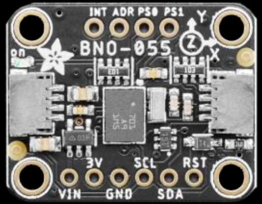


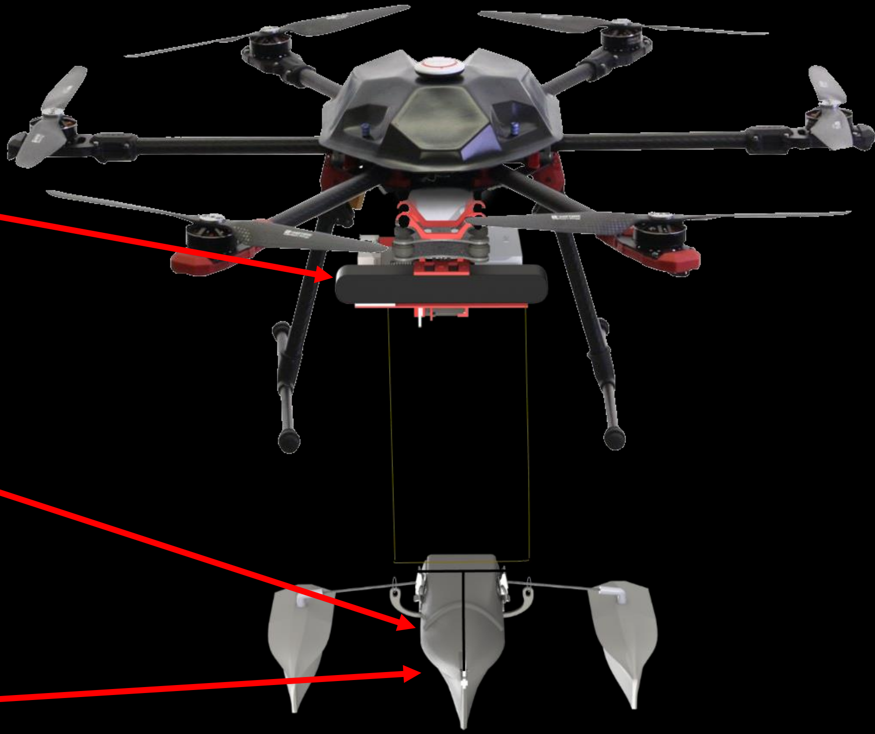
Science Instruments

Zed 2 Stereo Camera
Velocity Data

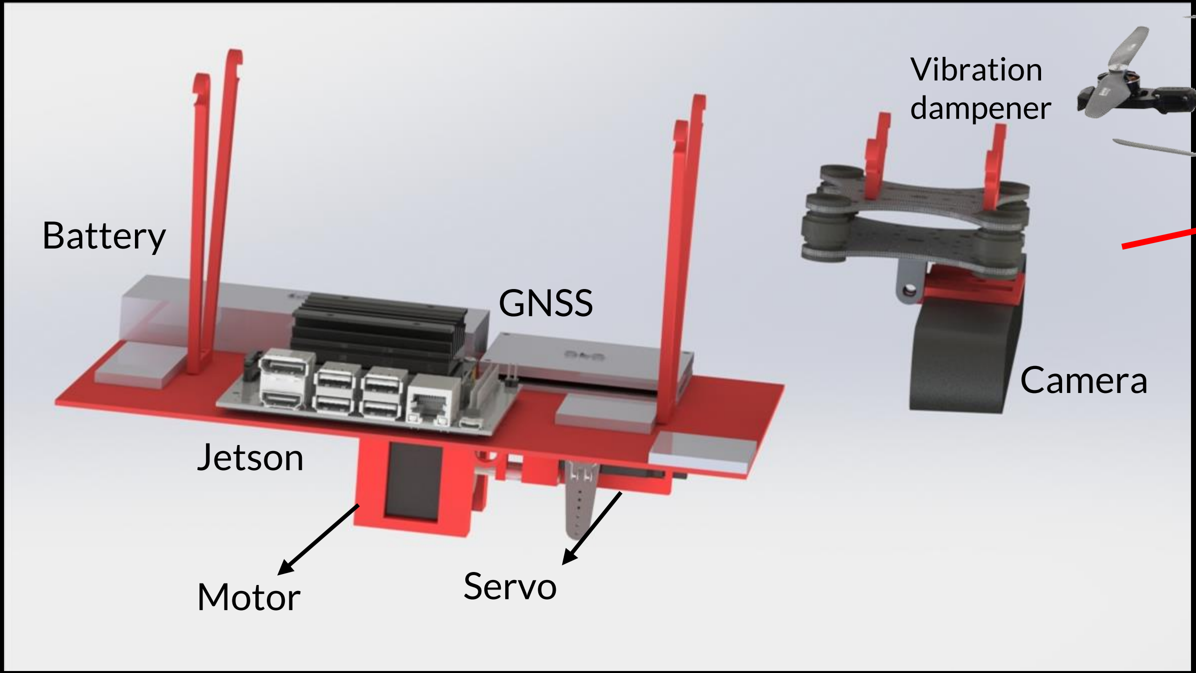
Ping Sonar Echosounder
Depth Data

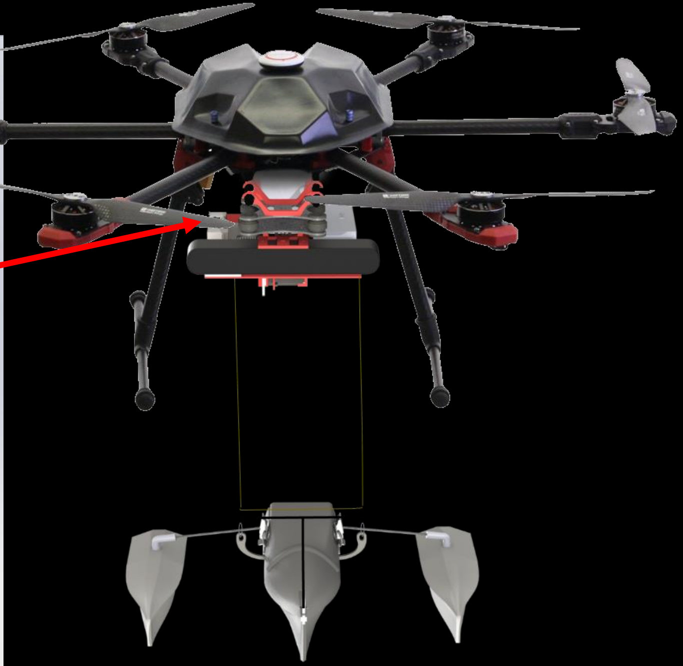
BNO055 IMU



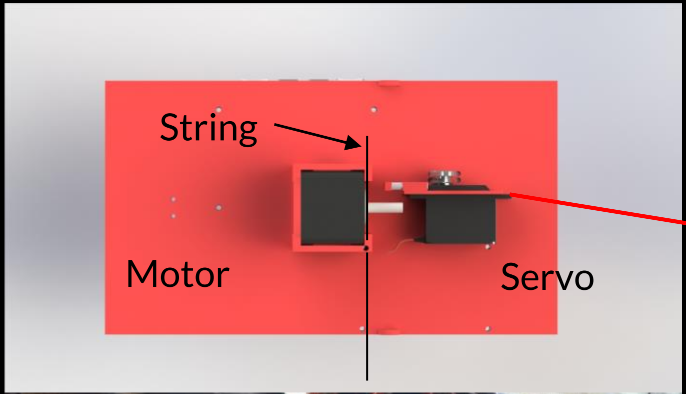


Drone Mount


Vibration
dampener
Battery
GNSS
Camera
Jetson
Motor
Servo

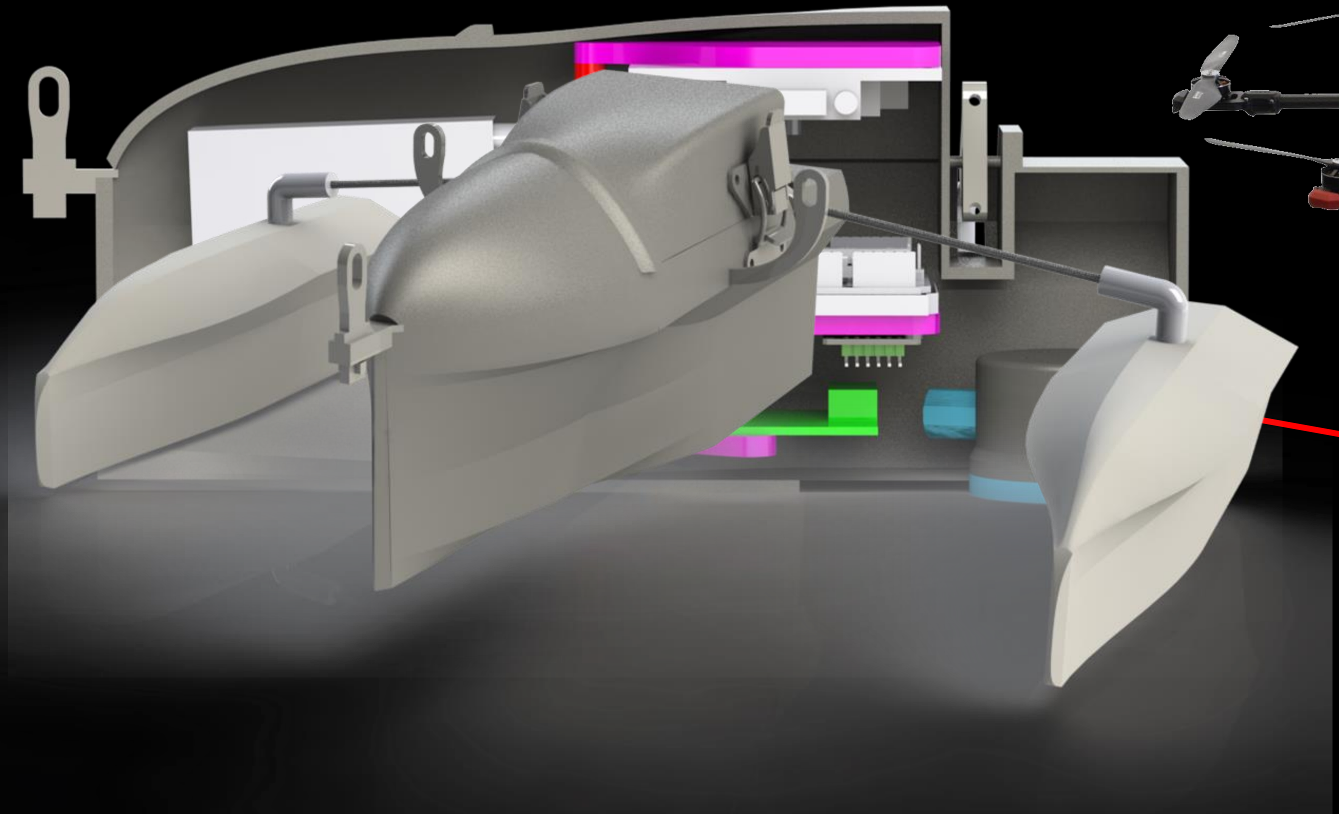


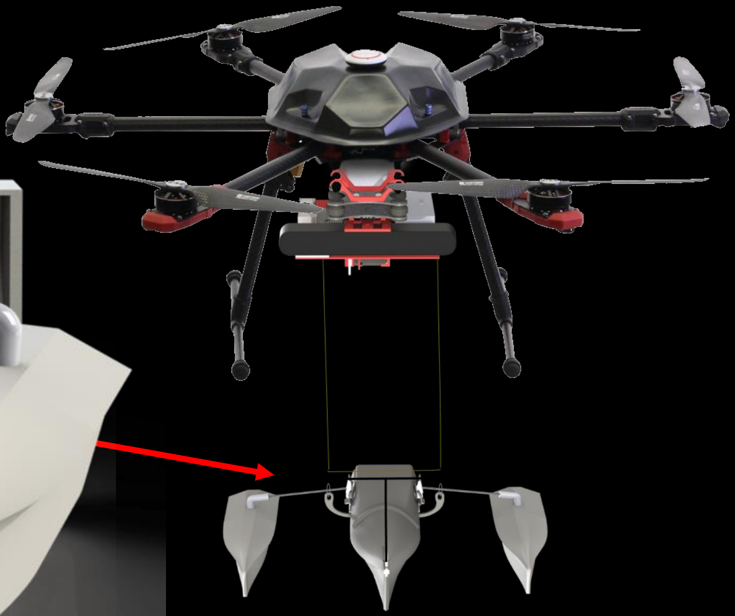
Deployment Mechanism



Sonar Float Design

Total weight: 955 grams





Sonar Float Model

Removed pontoons due to weight limitations and added polyethylene foam to stabilize the float.

- Float battery, electronics and Sonar fit well
- Added silicon to ensure waterproof seal

Full Integrated System

Weight Breakdown

Drone (not including battery)	1,808 g
Drone Battery	1,366 g
Drone Mount (including electronics)	880 g
Float	674 g
Total Weight:	4,728 g
Drone payload capacity:	2,000 g
Payload Weight	1,504 g

Test Overview & Results

Test Overview

- Structural
  - Float Structure Test
  - Waterproof Test
- Flight Software
  - Jetson Nano Flight Software Test
  - Arduino Uno Flight Software Test
  - Pixhawk-Jetson Communication Test
- Avionics
  - UAV Flight & Control Test
  - Deployment Mechanism Test
  - Power System Test
- Science Instruments
  - Sonar Test
  - IMU Test
  - Stereo Camera Test
  - GNSS Base Station & Receiver Test
- Data Post Processing Software
  - Depth Profile Correction Test
  - Stereo Camera Image Verification Test
  - SLAM Test
  - Velocity Post-Processing Testing (RIVeR Software)
  - Uncertainty Quantification Program

Day In the Life Test

Sonar Testing: Overview

Design Requirements:

DR4.1.2 - The SONAR instrument shall be capable to measure depths to an accuracy of <1% of the total depth.

DR4.6.2 - The IMU shall measure the angular displacement between the SONAR pointing ray within ± 1 degree accuracy.

DR6.2.1 - The micro-controller shall be responsible for storing the data locally to an SD card.

DR7.2.1 - The depth profile shall be post-processed to correct for the angular displacements of the float.

Test Purpose: Verify the corrected depth measurements from SONAR and IMU are within accuracy requirements and that data is written to and stored on the onboard SD card.

Test Validation: Compare corrected distance measurements with known distance

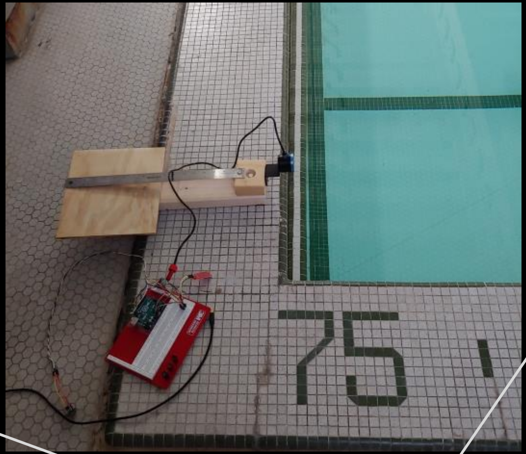
Test Criteria: Corrected depth measurements shall be accurate to <1% of the true depth

Sonar and IMU Test

Testing took place at Clare Small pool in the CU Rec center

IMU/Sonar test Rig

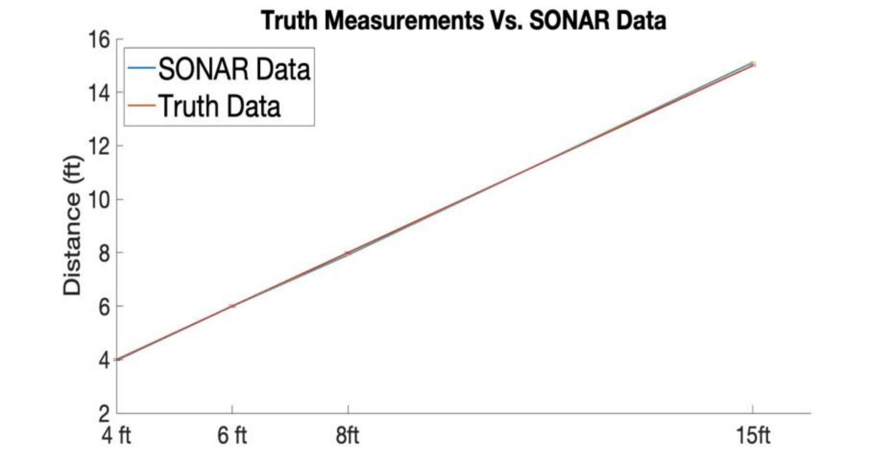
Rig set-up

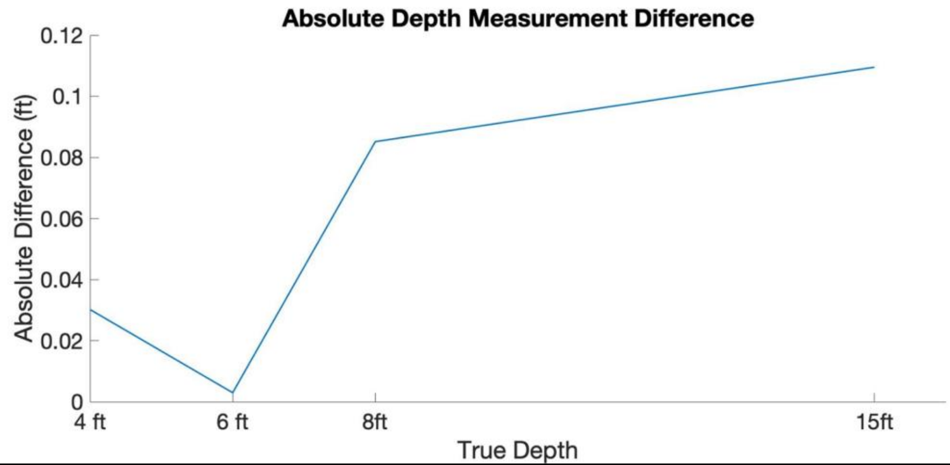


Sonar depth data collection

IMU was place on top of wooden block (not pictured)

Sonar Testing: Results



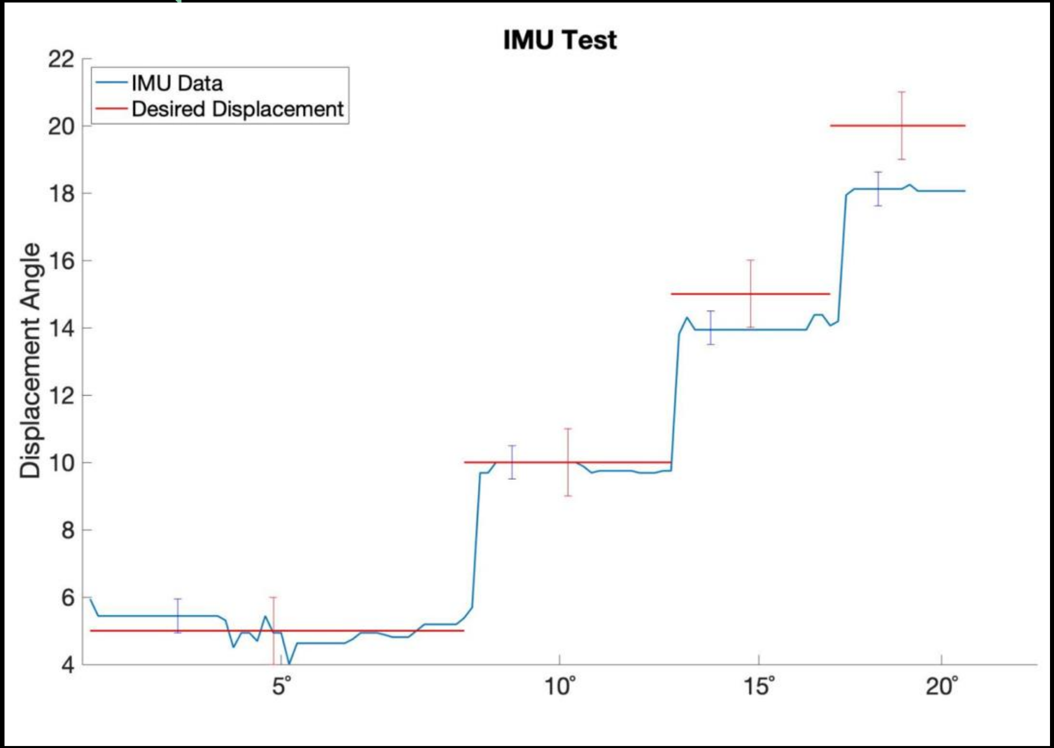


Method: Truth data taken using tape measure
Measurement Range: 4, 6, 8, 15 feet
Average Error: 0.65% of total depth?
Accuracy: All measurements within 1% of truth value given ±0.25 in uncertainty   Satisfies DR4.1.2

Error Sources:

- Small angular displacements (~1˚)
- Truth measurement error from tape measure(0.25in)

IMU Testing: Results



Method: Data taken using test ri

Measurement Range: 5˚, 10˚, 15˚, 20˚

Average Error: **4.7%**

Accuracy: ± 1 degree accuracy requirement met for all but 20˚ displacement test

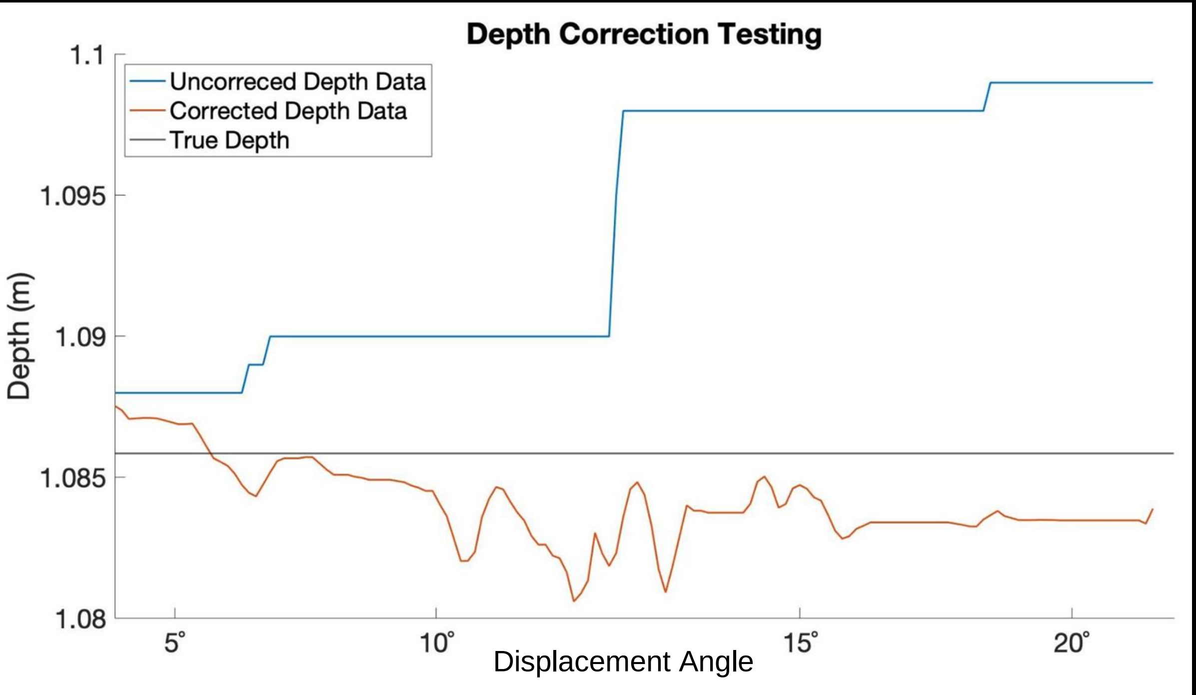
- Last data point 0.8˚ out of req range

Satisfies DR4.1.2

Error Sources:

- Test stand construction
- Human error while testing
- IMU initiation offsets

Depth Correction Testing

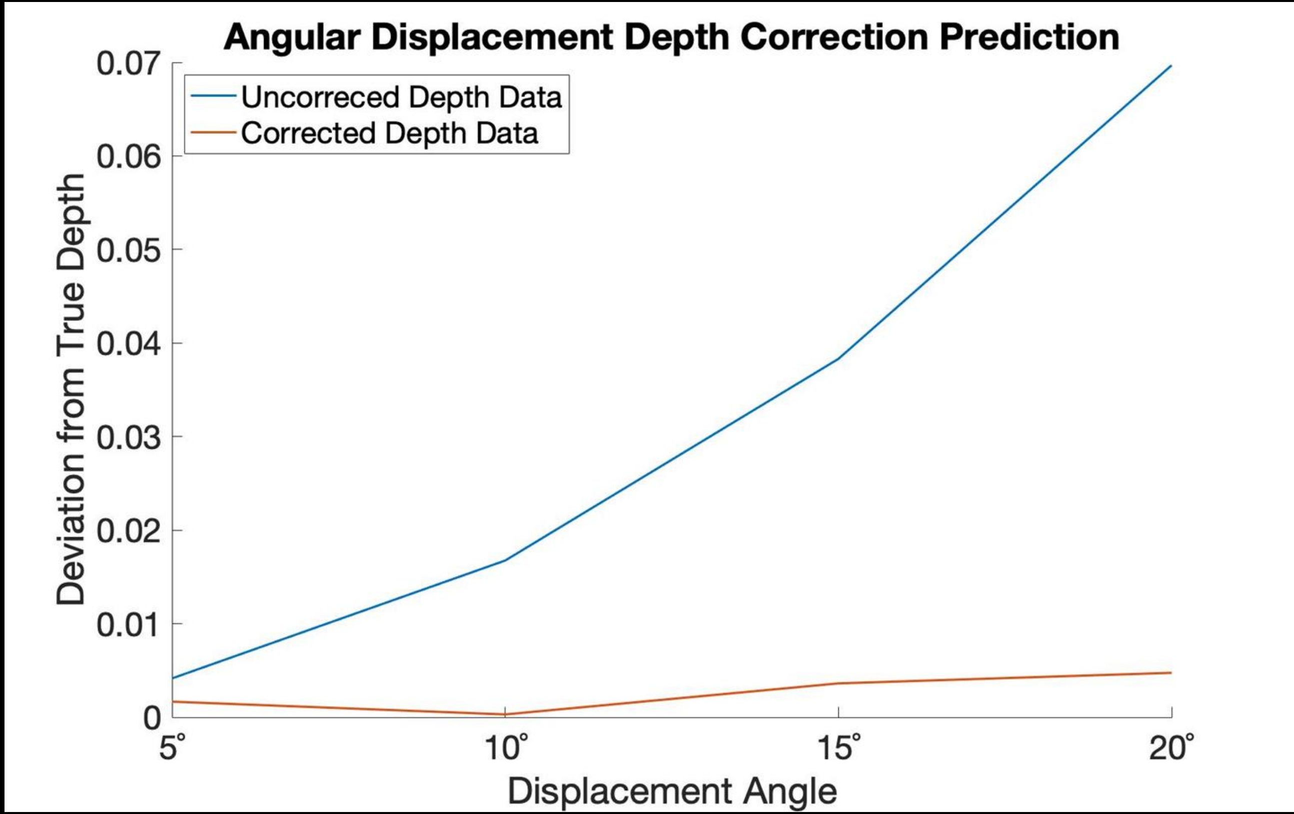


Method: Depth held constant, changed angular displacement
Measurement Range: 5°, 10°, 15°, 20°

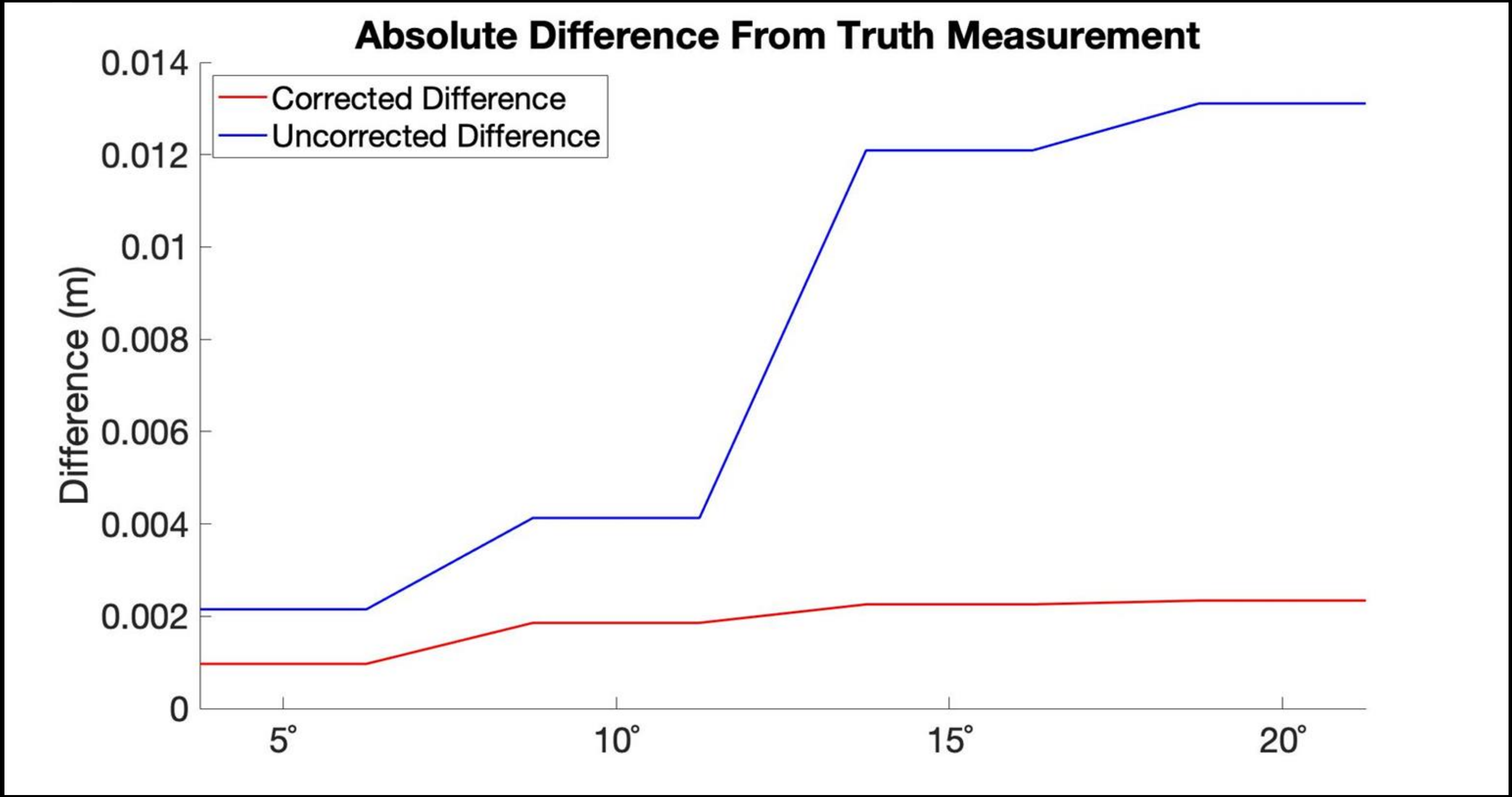
Key Impacts:

- Flattening of depth curve
- Reduction of absolute displacement error
- Larger angular displacement results in constant bias rather than increased error

Angular Displacement Depth Correction Model



Difference Between Corrected and Raw



Day in the Life Test Overview

Design Requirements: FR1-FR8

Test Purpose: Demonstrate “day in the life” functionality, supplying final river discharge and supplementary data from instrument suite.

Test Status: Component commanding & data collection tests completed, full UAV system test postponed due to crash

Test Validation: Test validates drone communication, deployment mechanism functionality, power supply, microcontroller functionality, data collection and post-processing.

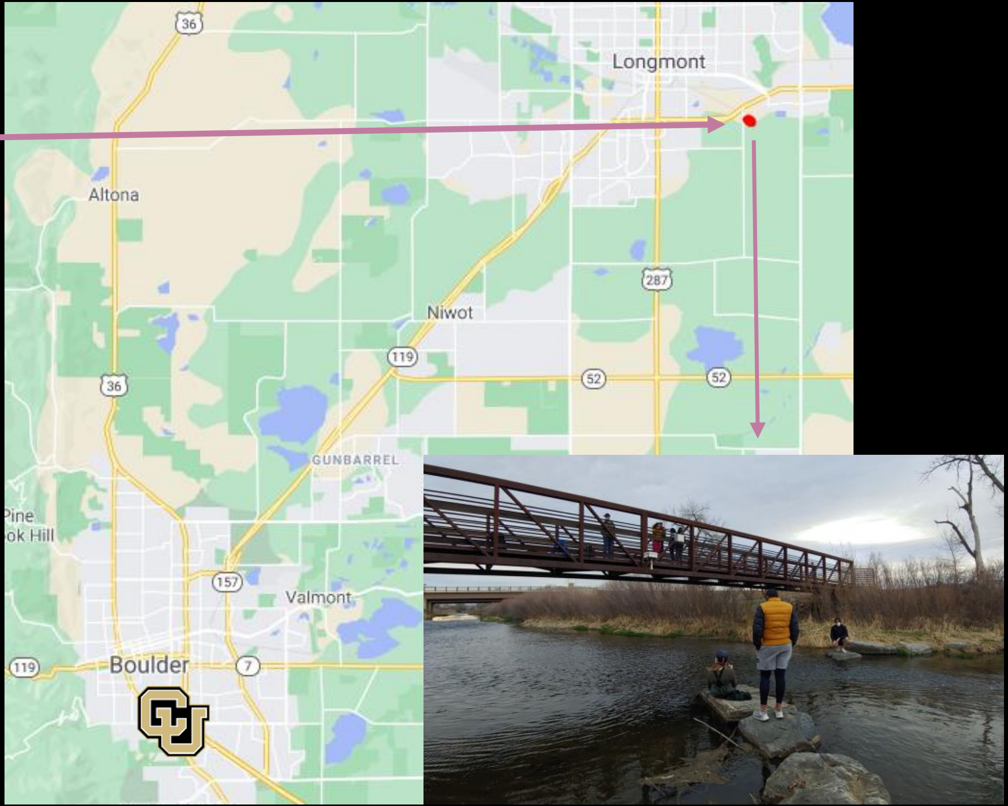
Test Criteria: Full system functionality and requirements are verified. Data is successfully off-loaded and post processed and compared to truth data.

Test Science Instruments & Data Post Processing

Test Location: St. Vrain River, Longmont, Colorado
Collected on 4/11/2021 at ~5pm

Tests Completed: SONAR and stereo camera command & data collection component testing

Tests Remaining: Integrated UAV system test



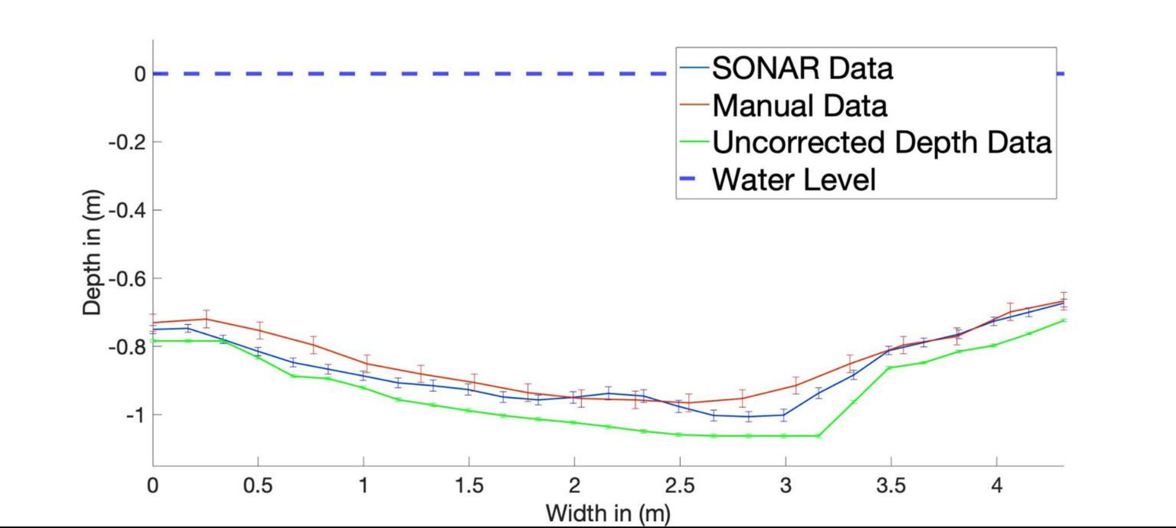
River Depth Profile: Manual Measurement

- **Recorded Measurements:** 0-170 inches in 10 inch increments
- **Uncertainty:** +/- 1 inch for each station measurement

River Depth Profile: SONAR Float Measurement

- **Recorded Measurements:** 0-170 inches in 10 inch increments
- **Uncertainty:** Varies on station IMU angle, with 5˚ systematic error due to initiation angle uncertainty

Sonar Depth Profile: Comparison to Truth



	Corrected	Uncorrected
% Mean Depth Error	3.5%	10.4%

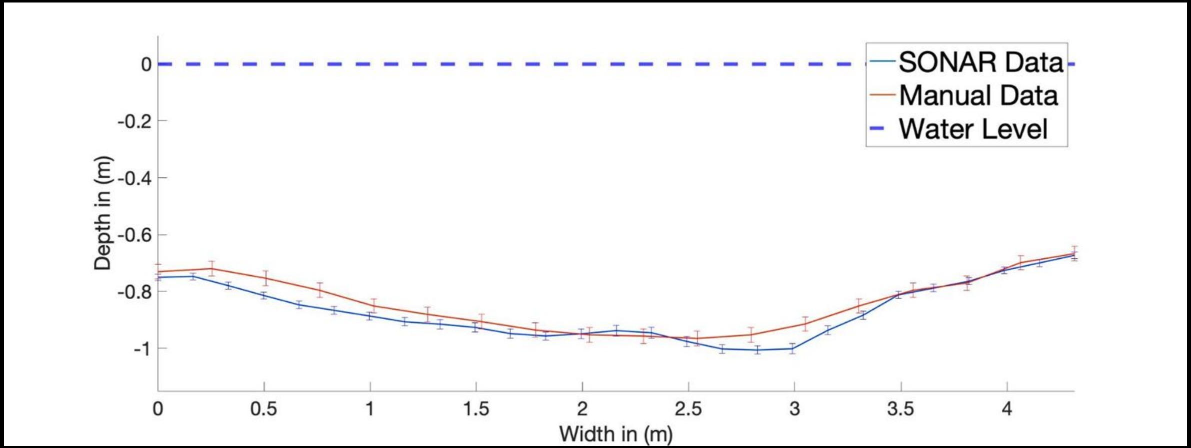
SOS correction applied to account for water temperature

Truth Error: ±0.0254 m error bar

SONAR Error: 0.7% error added to SONAR measurements to account for IMU initialization uncertainty

SONAR depth corrected using IMU angular displacement data

Sonar Depth Profile: Comparison to Truth



	Cross Sectional Area	Uncertainty
Truth Data	3.7 m^2	±0.1 m^2
Corrected Sonar Data	3.77 m^2	±0.06 m^2

Percent Difference:
3.1% cross section area error compared to truth data

Depth Testing Summary

SONAR Pool Test:

- Met requirement with 0.63% error

IMU Test:

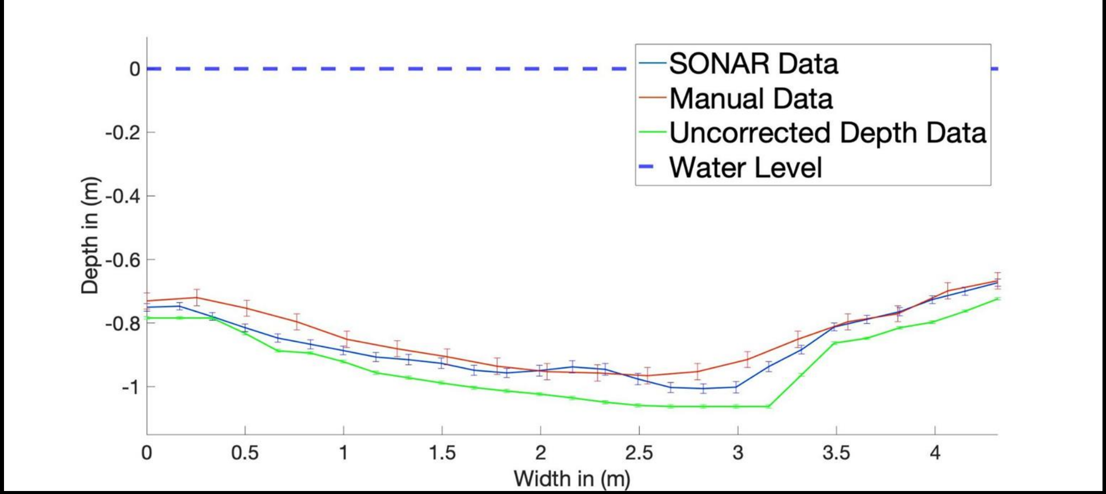
- Pointing ray accuracy requirement met for all but one angle tested
- Sufficient accuracy for application

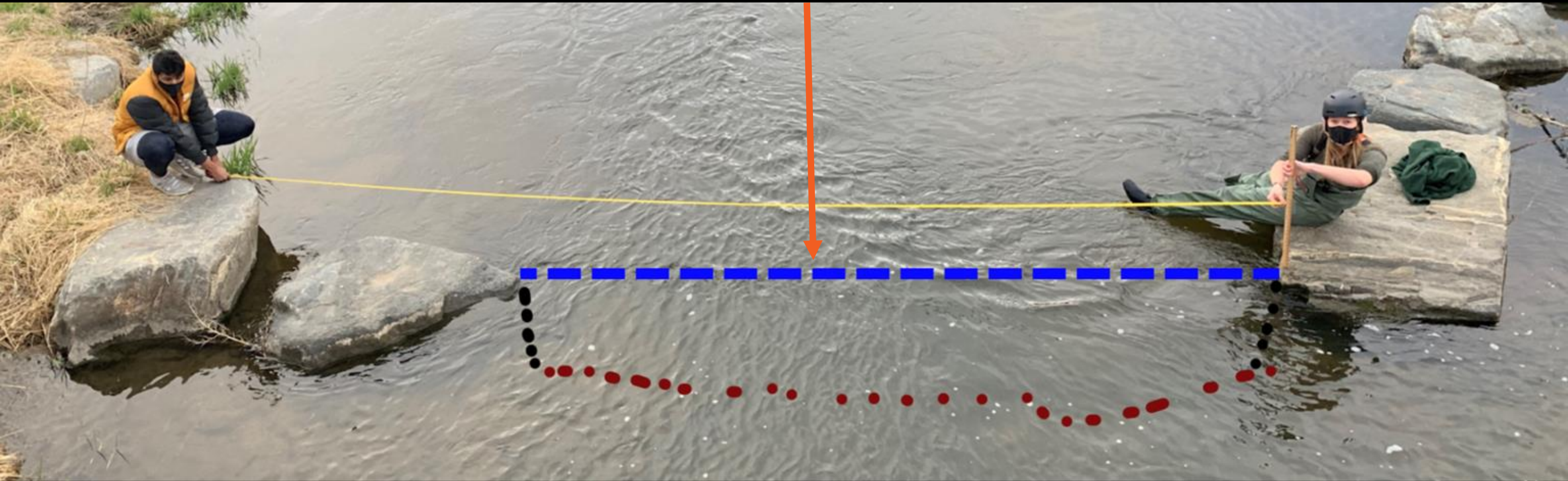
Angular Correction Pool Test:

- Effectively cut down on depth error
- Mean depth accuracy of 0.25%
- Met requirement of being within 1%

DITL River Depth Test:

- Mean depth error of 3.5% (down from 10.4%)
- Outside of requirement range
- Likely due to environmental factors and error in truth data collection


SONAR Data
Manual Data
Uncorrected Depth Data
Water Level
Depth in (m)
Width in (m)
0
-0.2
-0.4
-0.6
-0.8
-1
0.5
1
1.5
2
2.5
3
3.5
4



Velocity Post-Processing Testing and Validation

Design Requirements:

DR7.1 - The stereo camera shall be able to capture surface velocities between 0-4m/s.

DR7.1.1 - The stereo camera data shall have particle density between 1-8%

DR7.1.2 - The stereo camera data shall have particle diameter between 1-4 pixels.

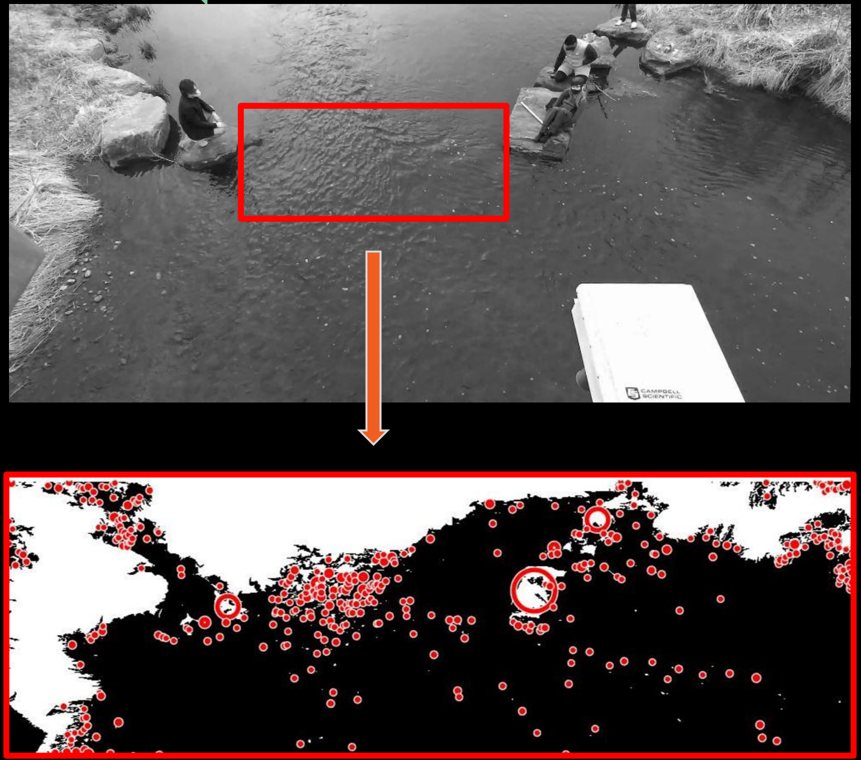
Test Purpose: Ensure meaningful surface velocity calculations can be computed via collected stereo camera river video and 3D depth data.

Test Status: Test of data run-through in RIVeR software application complete.

Test Validation: Collected images will be run through image quality verification software to ensure images meet optimal conditions as defined by PIVlab, this will ensure accurate velocity results

Test Criteria: Stereo camera images have particle density between 1-8% and particle diameter between 1-4 pixels.

Image Quality Verification



Method: Run river image through *ImageAnalysis_Main.m* which runs *findDensity.m* and *findParticleSize.m* functions to validate image quality is within desired conditions

Particle Density: 2.89%

Satisfies DR7.1.1

Average Particle Diameter: 1.11 pixels

Satisfies DR7.1.2

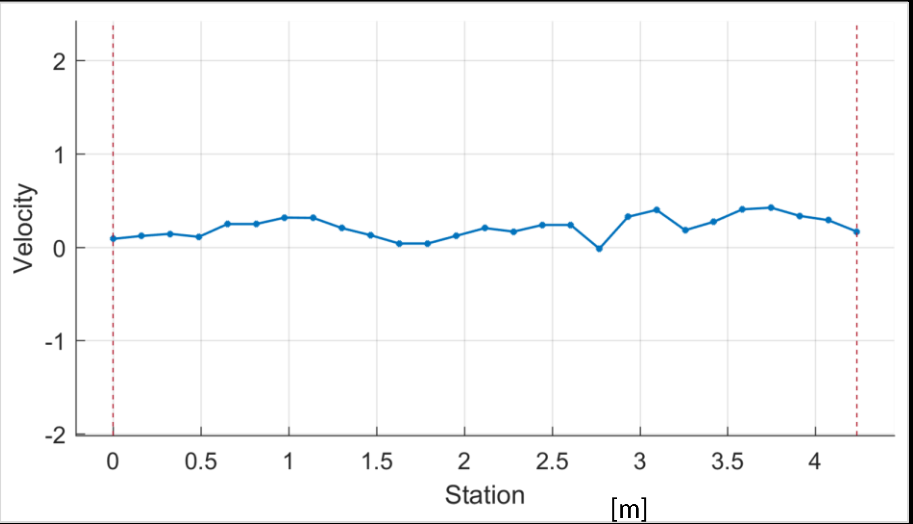
Accuracy: If the density of particles is between 1%-8% and the particle diameter is between 1-4 pixels, the RMS error will be less than 0.1 pixels. Assuming 10m distance to camera, this correlates to a worst case 0.0299 [m/s] error*

*Further elaboration in backup slides

Satisfies DR7.1

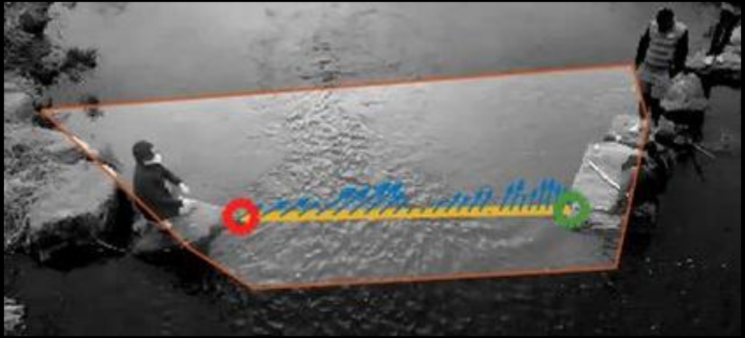
Velocity Data

Velocity Measurements in [m/s]



Mean Velocity at Cross-Section*:
0.21 ± 0.03 [m/s]

Gage Measured Mean Velocity: 0.34 [m/s]



*LoggerPro used to confirm surface velocity range

Discharge Calculations

System Measured River Discharge:
0.8 ± 0.1 [m^3/s]*

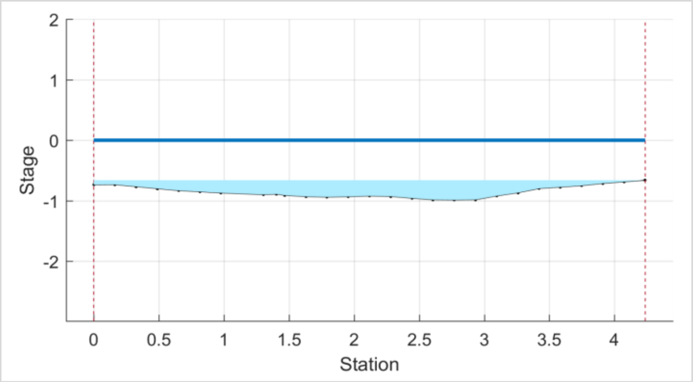
River Discharge Provided by Colorado Department of Natural Resources:
0.85 ± 0.07 [m^3/s]

Percent Difference: 9.4%

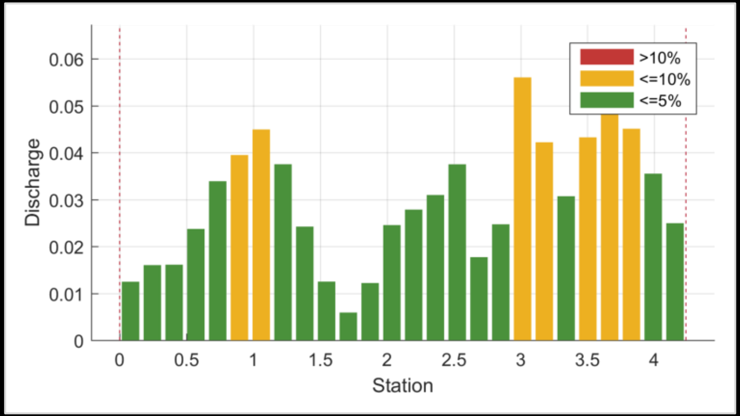
Existing system takes mean velocity & multiplies by the cross-sectional area (function of gage height)

*Note: the error comes from the average surface velocity multiplied by the cross sectional area. The actual uncertainty is likely much smaller due to the models used in the RiVER

River Depth in [m]



River Discharge in [m^3/s]



Day in the Life Data Validation

Depth Data Validation:

Primary Post-processing Software: Depth Correction Program (in-house)

- Compare with truth data. Verify collected sonar depth measurements are within 1% relative error of the measured truth depth at each station

Velocity Data Validation:

Primary Post-processing Software: RiVER (open source, credit: USGS)

- Compare with truth data. Verify collected surface velocity measurements are within 20% relative error of the truth surface velocity at each station

SLAM:

Primary Post-processing Software: SLAM (open source, credit: Georgia Tech)

- Output the mission trajectory with uncertainty bounds.

Final River Discharge Uncertainty Quantification:

Primary Post-processing Software: Uncertainty Quantification Program (in-house)

- Output the total uncertainty bounds of the computed discharge at field site

Did We Meet Functional Requirements?

ID	Functional Requirement	
FR1	RiBBIT shall be an unmanned aerial vehicle (UAV) system.	
FR2	RiBBIT shall be capable of operating in rivers with velocity between 0-4m/s and depths between 0.5-3m.	
FR3	RiBBIT shall include an instrument suite payload that is compatible with the Tarot 680.	
FR4	The instrument suite shall be capable of measuring the bathymetric profile of a river cross section from one bank to the other, perpendicular to the current.	
FR5	The instrument suite shall be capable of measuring the surface velocity of a river cross section	
FR6	RiBBIT shall be able to power and command all instruments and sensors.	
FR7	The collected data shall be post-processed to calculate river discharge.	
FR8	The UAV shall comply with all FAA and safety requirements	

Systems

Trade Studies

UAV
- -Tarot X6
- -DJI S900
- -SwellPro
- -Tarot 650
- -Tarot 680

Bathymetric Technique
- -LiDAR
- -Acoustic Doppler Current Profiler
- -BlueRobotics Ping Sonar

Velocimetry Technique
- -Optical Camera
- -Thermal Camera
- -Stereo Camera (ZED 2)

Deployment Mechanism
- -Hanging Cable System
- -Rigid Sonar Deployment System
- -Cable Rappelling System with motor & servo

On-Board Computer
- -Arduino Mega
- -Raspberry Pi 4
- -Odroid XU4
- -Jetson Nano

Deployable Unit Computer
- -Arduino Fio with XBee
- -Arduino Uno

Positional Determination
- -Custom Sensor Fusion
- -Emlid RS2 + U-blox Receivers

All components were downselected to meet cost, data quality, power and capability requirements

Flowed Down Requirements from Functional Objectives

FR4			**The instrument suite shall be capable of measuring the bathymetric profile of a river cross section from one bank to the other, perpendicular to the current.**
	DR4.1		The instrument suite shall use SONAR to capture depth measurements.
		DR4.1.1	The SONAR instrument shall be capable of sensing depths from 0.5 meters to 3 meters in ideal conditions.
		DR4.1.2	The SONAR instrument shall be capable to measure depths to an accuracy of <1% of the total depth in ideal conditions.
		DR4.1.3	The SONAR instrument shall be capable of measuring depths in water temperatures between 0 and 20 degrees Celsius.

Main Systems Engineering Issue

- Over optimistic schedule
  - Drone crashes
  - Requiring replacement parts
  - Frequent 3D printing failures
  - Quarantine due to COVID
  - Weather

Predicted Systems Engineering Risks

Identified Risks	Comments	Mitigation?
Stereo Camera Data inadequate for measuring velocity	Multiple tests conducted with camera, proving the accuracy of the software.	Easy
Sonar Collection Errors	Testing and angular correction proved sonar collection is consistent.	Easy
Environmental Hazards	Winds and drone piloting was sometimes difficult to control. Emergency release mechanism works, but time delay is significant.	Moderate
Float Deployment Mechanism Failure	Motor issues, did not account for added friction in system or significant swinging during flight. Resulted in last minute design changes	Difficult
Test Schedule Slip	The biggest challenge.	Difficult

Key Lessons Learned

- Integration takes much longer than expected
- Sufficient margins are critical and necessary
- Early and active communication is key
- Smaller, specific milestones are easier to meet rather than generalized large scale goals

Management

Project Management Lessons Learned

Approach:

- JIRA task tracking for responsibility delegation & planning
- Biweekly meetings for subsystem updates & working through blockers
- Early first semester meetings with project customers for design advice and desired data products

Difficulties:

- Planning margin with lots of uncertainty
- Keeping up with & unchaotically organizing task tracking applications, stopped using it second semester
- Needed better method of tracking problems that arose across subsystems
- Schedule slips
- COVID restrictions & setbacks

Future Improvements

If time wasn't out...

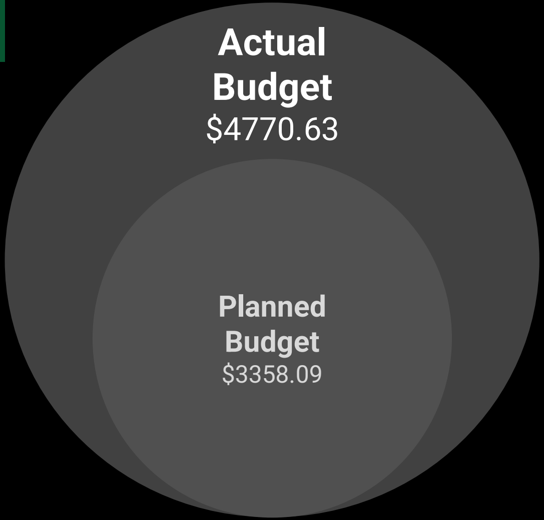
- Continued testing of UAV system with commanding to deploy float & collect data
  - Vary environment & river conditions
  - More stepper motor testing with varied rope orientations & test alternative winches
- Iterate design to improve UAV flight stability
  - Design float rope holding to reduce float spin when flying
- More iterations of boat design, fiberglass mold
- Add molds to the on-board plate to fit the float into when undeployed
- More responsive emergency release mechanism (shorter time lag)
- Simultaneous integration of AprilTags, GNSS, and IMU positioning

If money wasn't limited...

- Purchase mounted lidar system for water depth measurements, thus not requiring a deployable unit
- Purchase larger carrying capacity drone with improved flight features for more reliable system
- Rent ADCP system to compare velocity and discharge data to

Budget

January	UAV, Storage, Ping Echosounder, ZED Stereo Camera, Arduino, Pilot License, Jetson Nano, Lipo batteries, charger, SD Card, Mounting Kit, PLA filament, Arduino UNO, Pilot License
February	Batteries, electrical components, 3D printing materials and fees, FAA UAV registration, Breadboard, Protoboard
March	Replacement motor, driver, Servo motor, Pilot License, stepper motor, Arduino ZERO, Arm Mounting Kit, Carbon rods
April	Replacement Blades, Measurement tools, Carbon FIber pipes, Storage box, Batteries



Industry Cost:

32 Weeks x 13 Hours per Person x 10 People x $31.25 per hour = **$130,000**

Group Tuition Paid = $~200,000

Questions?

Backup Slides

Backup Slides Table of Contents

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- Stereo Camera Image Verification Program
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- Requirements
- Levels of Success
- Budget Breakdown

Testing Schedule

Round 1 - Complete by Early March

Component Testing

- Zed 2 Camera
- Ping Sonar
- UAV + Pixhawk Controller
- Deployment Mechanism/Motor
- Float & Electronics Box

On-Board Unit Interface Testing

- Zed Camera + Jetson
- U-blox receiver + Jetson
- Remote Controller + Pixhawk + Jetson
- Data Initiation & Collection Programs

Deployable Unit Interface Testing

- Ping + Arduino
- IMU + Arduino
- U-blox receiver + Arduino
- Data Initiation & Collection Programs

Round 2 - Complete by Mid-April

On-Board Unit Integration

- On-Board Electronics Integration
- On-Board Electronics Fastening to payload housing
- Complete Data Initiation & Collection Programs

Deployable Unit Integration

- Pre-stacked electronics integration
- Stacked electronics integration
- Float + Electronics Box Integration
- Complete Data Initiation & Collection Programs

UAV Integration

Post-Processing Software

Sonar Testing: Equipment and Facilities

Test Facilities:

- CU Clare Pool

Equipment:

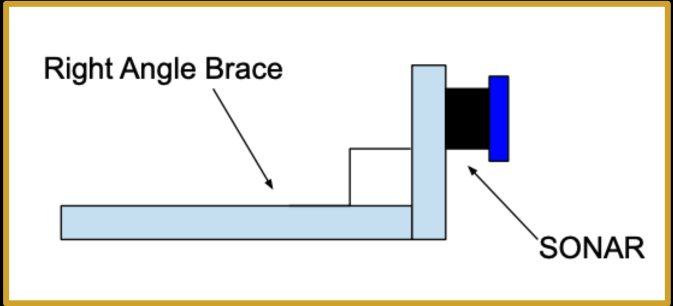
- Ping Sonar
- Right Angle Brace
- IMU
- Water Sensor
- Arduino UNO
- SD Card Reader with SD Card

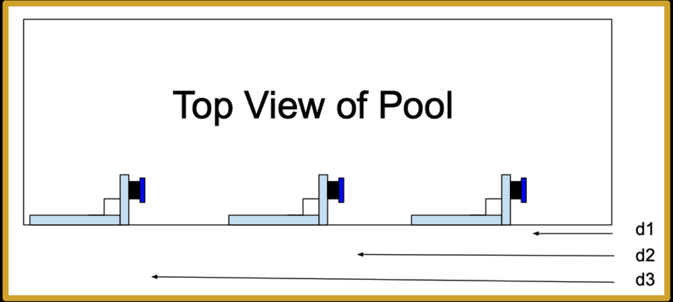
Outcome: Success

Sonar Depth Testing: Test Procedure Review

Distances to Test	4 ft	6 ft	8 ft	15 ft

1. Fully Charge Battery
2. Connect Power to Arduino
3. Measure Truth Distance (Not using SONAR)
4. Place SONAR Into Water Parallel to the Side Wall
5. Initiate Data Collection
6. Remove Test Assembly from Water
7. Off-Load Data and Compute Depth
8. Compute Percent Error between Measurement and Truth
9. Repeat with Varied Distances





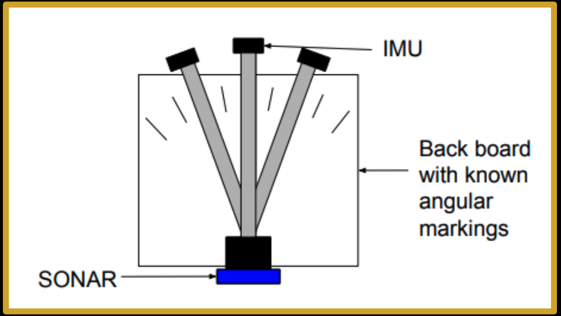
Outcome: Success

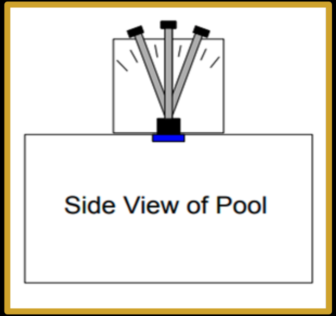
Sonar Angular Displacement Testing: Test Procedure Review

Angles to Test	±5º	±10º	±15º	±20º

Fully Charge Battery → Connect Power to Arduino → Place Testing Assembly at the Side of the Pool → Measure Truth Depth (not using SONAR) → Initiate Data Collection

→ Tilt the Components by a Known Angle → Remove Test Assembly from Water → Off-Load Data and Compute Depth → Compute Percent Error between Measurement and Truth





Outcome: Success

Velocity Post-Processing Testing and Validation

Design Requirements:

DR5.1.2 - The stereo camera shall be able to capture surface velocities between 0-4m/s.

DR6.1.1 - The main computer shall store the data collected by the stereo camera locally to an SD card.

DR7.1 - The stereo camera shall be post-processed to calculate to river surface velocity.

DR7.1.1- The computed surface velocity shall be within 20% of the true surface velocity.

Test Purpose: Ensure meaningful surface velocity calculations can be computed via collected stereo camera river video and 3D depth data

Test Status: Test of data run-through in RIVeR software application complete.

Test Validation: Collected images will be run through image quality verification software to ensure images meet optimal conditions as defined by PIVlab, this will ensure accurate velocity results

Test Criteria: Computed surface velocity will have less than 20% error.

Velocity Post-Processing Testing and Validation

Test Facilities:

- East Boulder Rec Center Lazy River

Equipment:

- Stereo Camera
- Jetson Nano
- Power Source
- Measuring Tape
- Ping-Pong Balls
- iPhone Camera
- Logger Pro Software
- Ladder

Velocity Post-Processing Testing Procedure

Truth Data Collection

Line up row of ping-pong balls in lazy river → Set up iPhone camera directly overhead pointing down → Raise ping pong ball holding gate → Compute truth particle velocity with Logger Pro

Credit: Boulder Creek rubber duck race

Stereo Camera Data Collection

Fully Charge Battery → Connect Stereo Camera, Jetson Nano, and Power Source → Initiate Camera Data Collection → Hold Components 3m from water's surface facing directly down → Offload data & run through post-processing software → Compare system collected data to truth data

Velocimetry Error Uncertainty Quantification

DESIGN REQUIREMENT 7.1:

The stereo camera data shall be post-processed to calculate river surface velocity.

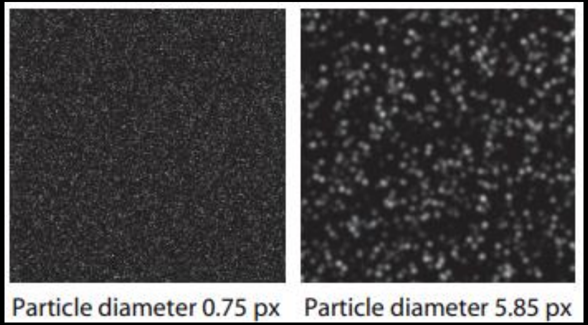
The surface velocity of the river is calculated using a Particle Image Velocimetry (PIV) tool developed in MATLAB.

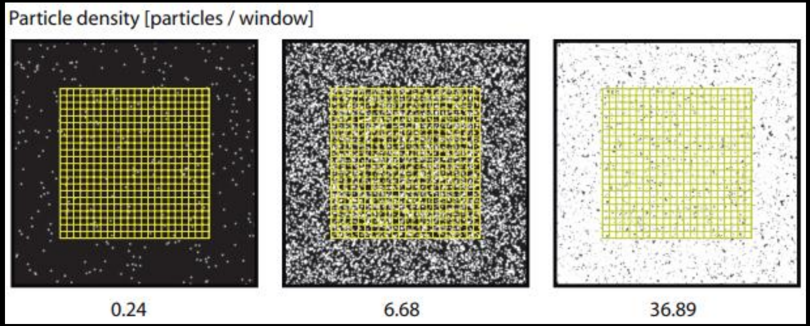
Using this software we can achieve a bias error of less than 0.005 pixels and and random error of less than 0.02 pixels.[1,2]

Velocimetry Error Uncertainty Quantification

To get these results, we must prove that our images fall under the optimal conditions as defined by the PIVlab analysis[1,2]:

- Particle Image Diameter (1-4 pixels)
- Particle Density (1-8%)
- Sensor Noise
- Particle Pair Loss
- Motion Blur





Velocimetry Error from PIVLab Explanation

Velocity is calculated by comparing the same particle from one frame to the next.

The distance that the particle traveled between frames can be calculated using the pixel difference and then relating it to distance.

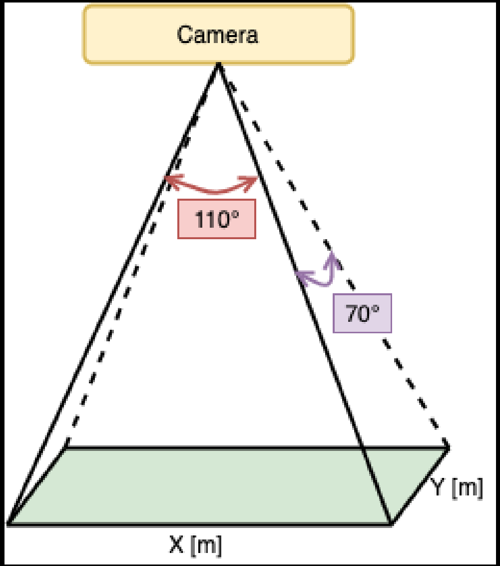
If we consider the worst case scenario (bias error = 0.005, random error = 0.02 pixels) in both frames, we would have a total particle displacement error, ε_{total}=2*[bias+random errors] = 0.05).

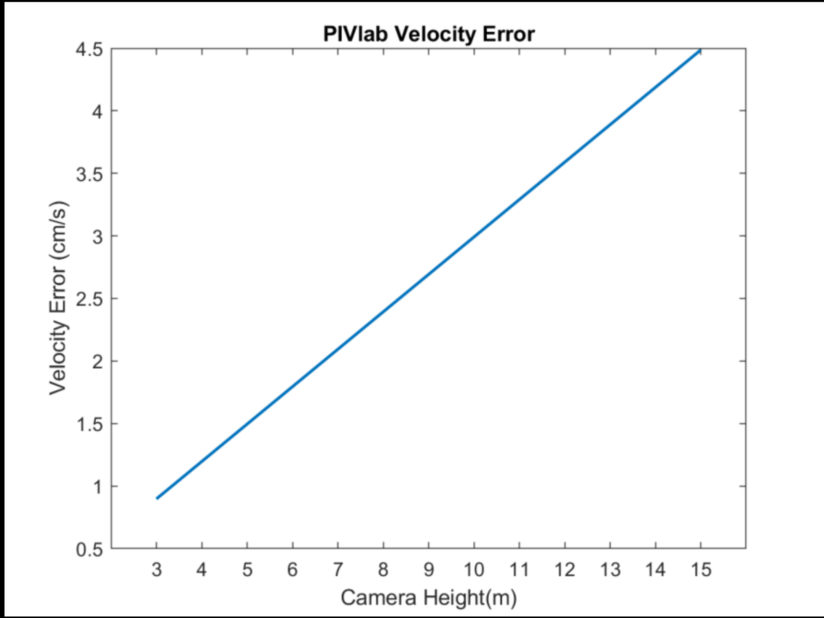
The maximum distance that the particle can travel (per pixel) is the distance represented by the diagonal length of the pixel, *d*.

The Δt between frames is 1/30 sec. We can then calculate the velocity error using the maximum particle displacement error by:

$$\varepsilon_{velocity}\,[m/s] = (\varepsilon_{total}\,[pixel] \times d\,[m/pixel]) / \Delta t[s]$$

Velocimetry Error from PIVlab





Camera Resolution: 1920 x 1080p

Bias Error < 0.005 pixels*

30 Frames per Second

Random Error < 0.02 pixels*

** assuming optimal conditions, additional information in backup slides*

Velocity Error Data

Height Above River [m]	X [m]	Y [m]	X Resolution [m/pixel]	Y Resolution [m/pixel]	Diagonal Distance [m/pixel]	Worst Case Error* [m/s]	Worst Case Error* [cm/s]
3	6.54	5.31	0.0034	0.0049	0.0060	0.0090	0.8973
5	10.91	8.85	0.0057	0.0082	0.0100	0.0150	1.4954
10	21.81	17.70	0.0114	0.0164	0.0199	0.0299	2.9909
15	32.72	26.54	0.0170	0.0246	0.0299	0.0449	4.4863

Day in the Life: Equipment and Facilities

Test Facilities:

- Colorado Blue River Confluence

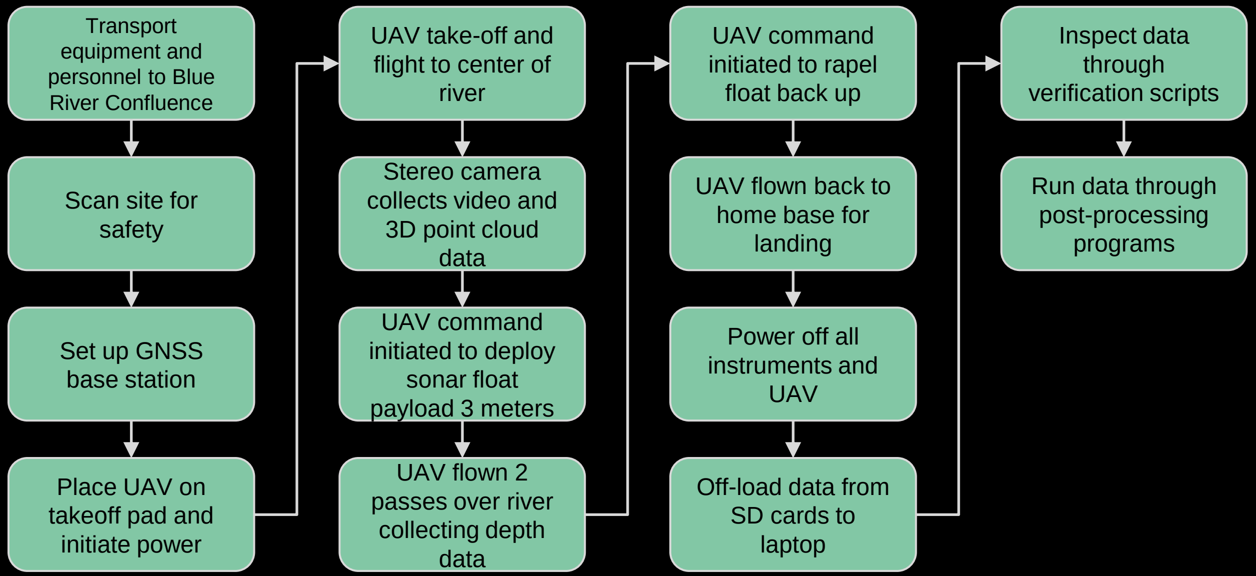
Equipment:

- UAV
- On-Board and Deployable Instrument Suite
- GNSS Base Station
- Extra charged battery
- Laptop for off-loading and inspecting data
- Measuring tape & meter stick
- Ping pong balls
- Net
- Waders (for wading into the water)

Outcome: Mixed

Day in the Life Test Procedure

Test Procedure:



Data Collected: Stereo camera river surface video, river 3D point cloud, sonar depth measurements, on-board and deployed unit GNSS coordinates

Day in the Life Truth Data Collection Procedure

True Velocity Data Collection

Set up net in river to catch ping-pong balls down river → Line up row of ping-pong balls behind holding gate in river → Set up iPhone camera directly overhead pointing down → Raise ping pong ball holding gate → Capture video of ping pong balls → Compute truth particle velocity with Logger Pro

True Depth Data Collection

Wade into river at desired cross-section → Lay measuring tape across river cross-section → With meter stick, measure depth at 10-15 stations, recording distance from bank

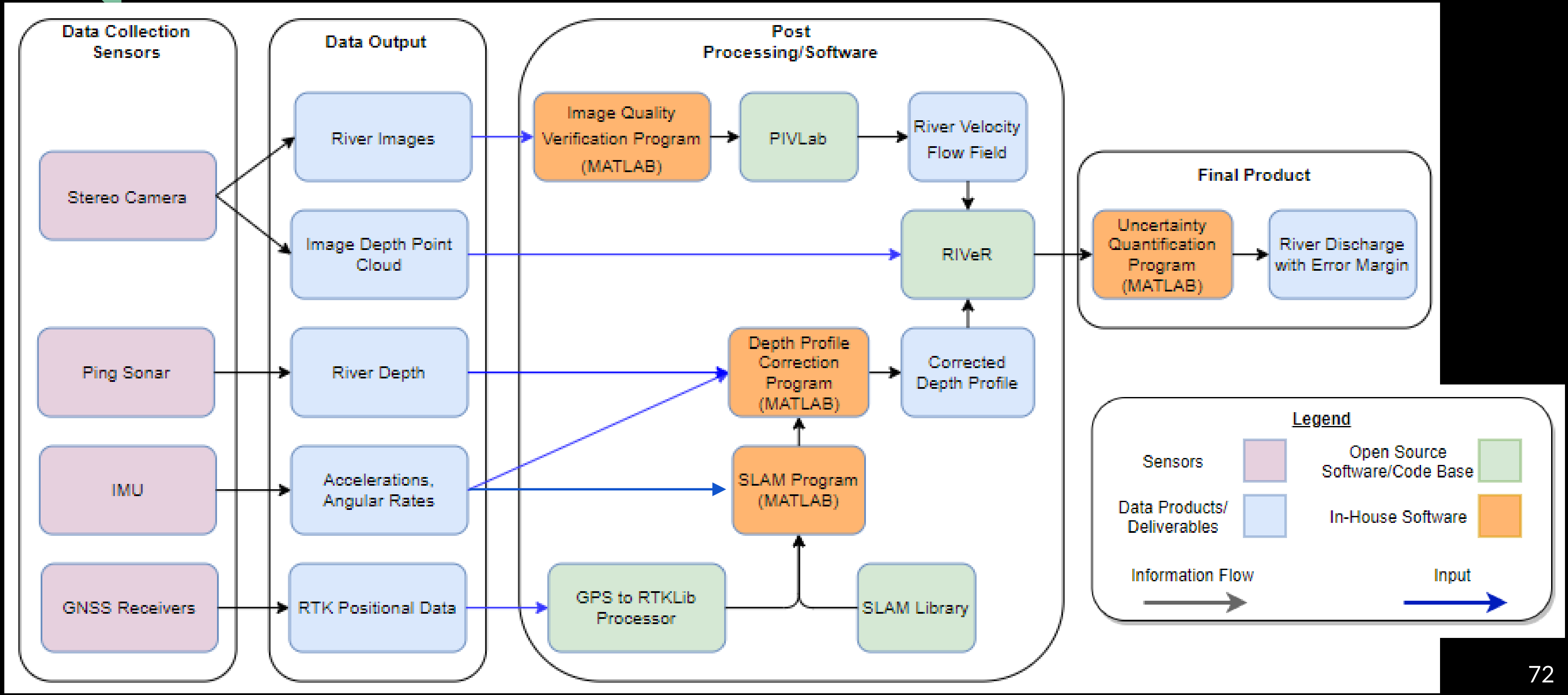
Credit: USGS

Colorado Division of Natural Resources Discharge Calculation Method.

Talked to state hydrologist to get details on collection method.

- Mean Velocity method involves taking velocity measurements at 25 locations across river at 2/10th, 8/10th and if river is deep enough, 6/10ths of the total depth.
- They then take these measurements to create a mean velocity for the river for that gauge (water level) height.
- They then use the mean velocity and river cross sectional area to calculate the discharge for a given gauge height.
- This is done when river is at multiple gauge heights, allowing a rating table to be developed relating river gauge to discharge.
- This allows them to only need to measure gauge height (via a radar device at the location) to calculate discharge.
- Link to measurement location: https://dwr.state.co.us/Tools/Stations/SVCLOPCO?params=DISCHRG,GAGE_HT

Post-Processing Software Overview



Float Structure Test

Outcome: Success

Design Requirements: The Float shall be designed such that the...

DR 4.2.1 … bottom 2.5 cm of the SONAR instrument is submerged under water.

DR 4.2.3 … amount of time the float is angularly displaced by +/- 20 degrees is minimized.

Test Purpose: Gain insight into float stability and buoyancy characteristics with simulated weights in float.

Test Status: Waterline and center of buoyancy: March 1st-3rd. Stability: March 4th

Test Validation: A ruler will be placed in background to enable a relative sense of displacement and pivot location.
The expected center of buoyancy and waterline will be calculated using the Solidworks model.

Test Criteria: The float does not *per se* excessively wobble after disturbance and is not easily submerged. When in a current it exhibits weathervane stability.

Float Structure Test

Test Facilities:

- Bathtub
- Boulder Creek

Equipment:

- Ruler
- Phone Camera
- String
- Weights

Float Structure Test Procedure

Test Procedure for waterline and calm water stability

1. Calculate expected waterline and Center of Buoyancy in Solidworks
2. Fill bathtub
3. Place float with simulated weights and pontoons in bathtub
4. Measure Waterline

Data collected:
Waterline

5. Tape ruler behind float
6. Place camera as close to in front of float as possible
7. Disturb float from sides and record response

Data collected:
Calm water stability

Test Procedure for weathervane stability

1. Attach float to strings in same manner as will be attached to drone
2. Take float to bridge over Boulder Creek
3. Lower float into water and move across creek

Data collected:
Weathervane stability

Outcome: Mixed success

Waterproof Test

Design Requirements:

DR 4.2.2 The float shall be designed such that the electronic components are located inside of a waterproof housing.

Test Purpose: Ensure that polyurethane coating is waterproof and electronics lid make a waterproof seal. Both when fully submerged and when experiencing disturbances. Ensure remains waterproof through conditions far worse than anticipated.

Test Status: In progress - polyurethane has been applied and passed a 30 min partial submersion test. Full submersion lid seal testing planned for Match 4th-8th.

Test Validation: A paper towel will be placed inside of hull while undergoing testing.

Test Criteria: Submersion testing will be done at least 5 times and then twice a day until the electronics need to be placed inside the box. If the paper towel is completely dry each and every time the test will be considered successful.

Waterproof Test and procedure

Outcome: Mixed success

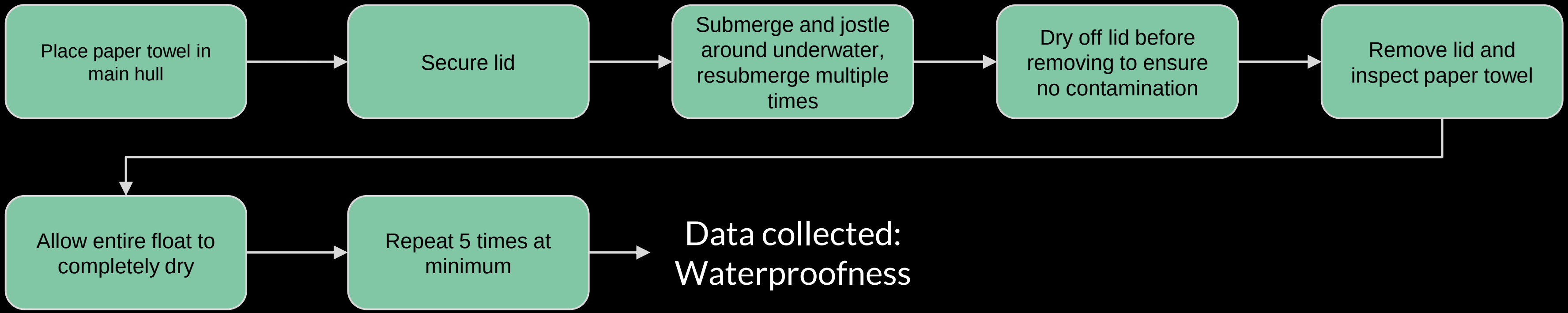
Test Facilities:

- Team members house

Equipment:

- Bucket big enough to fully submerge hull
- Paper towel

Test Procedure for waterproof test



Waterproof Test Outcome: Mixed success

Float is waterproof but when fully submerged, water pressure causes small leaks.

- A submersion test was probably too ambitious.
- There is no design requirement that requires the float to be a fully submersible vehicle (although that would be nice).
- When water is continuously poured over the float there are no leaks.
- This meets our design requirement and therefore this outcome is acceptable.

Outcome: Success

Jetson Nano Flight Software Test

Design Requirements:

DR6.1.1 The main computer shall be responsible for storing the data collected by the on-board instruments locally to an SD card.

DR6.1.2 The SD card shall be capable of storing the necessary data volume.

Test Purpose: Verify that the Jetson Nano can initiate on-board data collection and save the data correctly to the micro-SD card.

Test Status: Completed, Successful

Test Validation: The Jetson Nano will initiate data collection on the ZED stereo camera and U-Blox receiver. The instruments will collect data for an amount of time. The collected data will be saved to a micro-SD card on the Jetson Nano. After collecting data for a specified amount of time, the Jetson will stop data collection.

Test Criteria: Data collection must be initiated by the Jetson Nano computer on board the drone. All of the collected data must be saved in the correct format.

Jetson Nano Flight Software Test

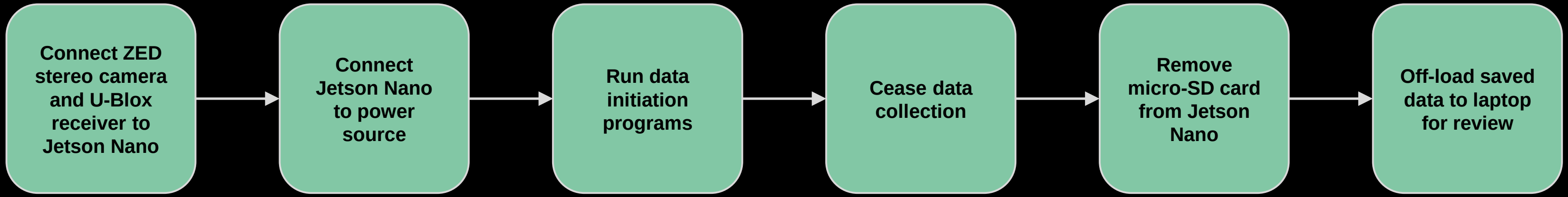
Test Facilities:

- N/A

Equipment:

- Jetson Nano
- ZED stereo camera
- U-Blox GNSS receiver
- micro-SD card

Test Procedure:



Outcome: Success

On-Board Initiation Programs

Language: Python

Critical Tasks:

1. Respond to commands from Pixhawk controller
2. Initiate ZED camera data collection program
3. Initiate deployment system functions
4. Activate emergency release if necessary

Status: Successful, however, function of emergency release mechanism is not ideal

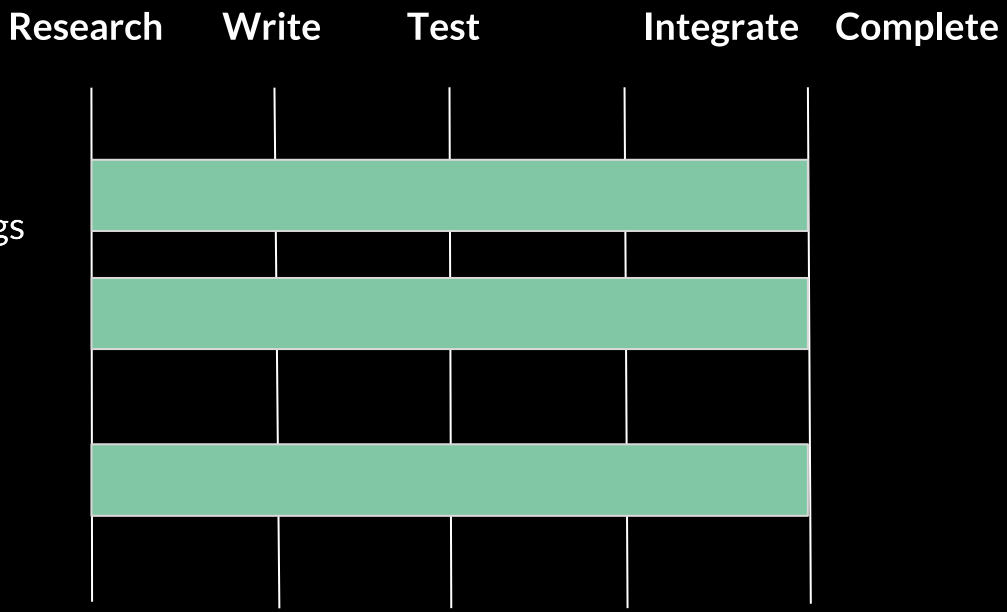
Outcome: Success

Stereo Camera Data Collection Program

Language: Python

Critical Tasks:

1. Set recording parameters and camera settings
2. Record video data
3. Save recorded video to output file on Jetson Nano in SVO format



Status: Successful

Outcome: Success

Arduino Uno Flight Software Test

Design Requirements:

DR6.1.1 The main computer shall be responsible for storing the data collected by the on-board instruments locally to an SD card.

DR6.2.1 The micro-controller shall be responsible for storing the data collect by the deployed instruments locally to an SD card.

Test Purpose: Validate that Data Collection from IMU and SONAR is initiated and Data is Stored Successfully and in the Correct Format to the Onboard SD Card

Test Status: Complete with the exception of U-Blox integration

Test Validation: The water sensor will be placed in contact with water triggering data collection. Following this the IMU and SONAR will be moved around while data is being collected. Finally, the water sensor will be taken out of the water, stopping data collection, and the SD card will be connected to a computer to inspect the data.

Test Criteria: **Data collection must be triggered and stopped by the Water sensor and the collected data must be stored in the correct format on the SD Card.**

Arduino Uno Flight Software Test

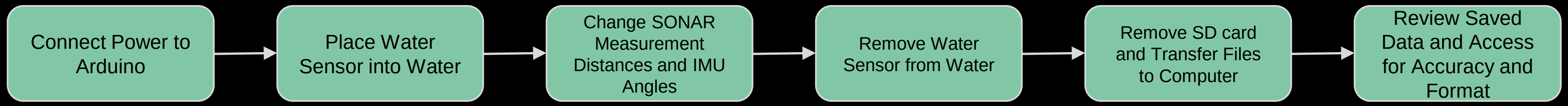
Test Facilities:

- N/A

Equipment:

- Computer running Arduino IDE
- Arduino
- SONAR
- IMU
- SD Card Reader with SD Card
- Water Sensor
- Bowl of Water

Arduino Uno Flight Software Test Procedure

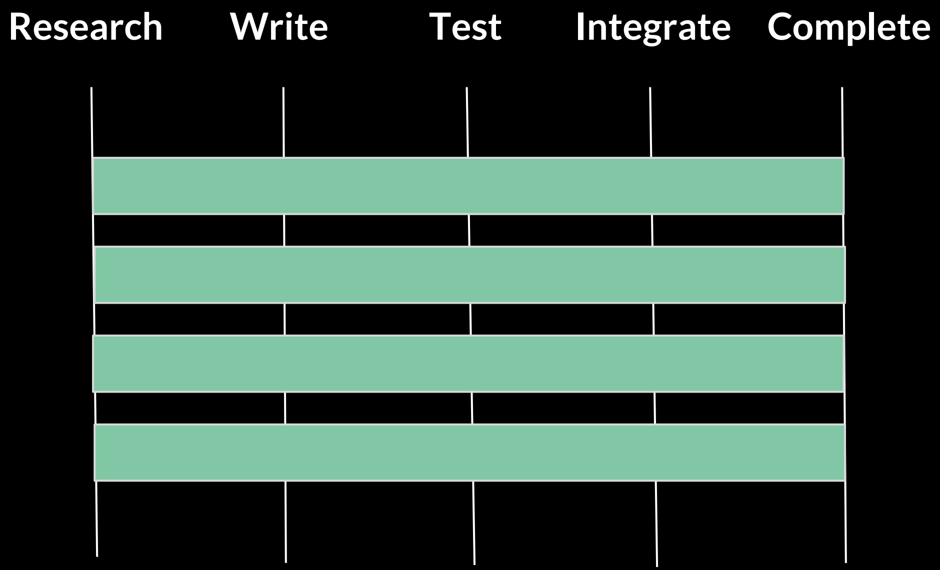


Deployable Float Initiation Programs

Language: c/c++ (Arduino)

Critical Tasks:

1. SONAR sensor initiation/ data collection
2. IMU sensor initiation/ data collection
3. SD card data logging (from sensors above)
4. Data collection trigger



Status: Successful and fully functioning

Outcome: Success

Pixhawk-Jetson Communication Test

Design Requirements:

DR6.1 There shall be a main computer with the drone-fixed instrument suite to command and direct power to all drone-fixed instruments and mechanisms.

Test Purpose: To make sure the Jetson can act on commands received by the Pixhawk

Test Status: Not Complete

Test Validation: HITL simulation with Pixhawk

Test Criteria: Jetson must be able to execute code once a command is sent through a HITL simulation

Equipment: Laptop, Pixhawk, Jetson Nano, cables/wires

Pixhawk-Jetson Communication Test Procedure

1) Pixhawk is connected to Laptop using USB, Jetson is connected to Pixhawk using UART

1) HITL simulation is run using jMAVsim and Qgroundcontrol, MAVproxy is run on the Jetson to connect to the Pixhawk

1) Flight plan with Start camera command and do Winch command uploaded to Pixhawk using Qgroundcontrol

1) Jetson prints out message received

Outcome: Mixed, need more testing

UAV Flight & Control Test

Design Requirements:

DR1.1 - The system shall have a minimum operational flight time of 12 minutes.

DR1.2 - The flight vehicle shall have a minimum carrying capacity of 2 kg.

Test Purpose: To confirm the capabilities of the drone without the payload

Test Status: Incomplete

Test Criteria: Drone will be capable of performing an autonomous flight

Test Facilities: Boulder Model airport, CU South Campus

Equipment: Drone, controller

UAV Flight & Control Test Procedure

1) Preflight checks
2) Take off
3) In stabilize mode perform flight maneuvers and use landing button to land
4) Take off in stabilize mode and land using RTL mode
5) Switch to autonomous mode and fly a short mission with a landing sequence
6) Using autonomous mode fly the same mission but interrupt it with RTL mode

Drone Instability

- Drone experienced instability after adding payload and moving battery on top of the drone
- Moved battery back below the drone as well as extending the plate's connectors
- Still experienced instability
- Identified the cause to be a trim error and fixed it by recalibrating the accelerometer

Outcome: Mixed, need more testing

Deployment Mechanism Test

Design Requirements:

DR4.3 There shall be a mechanism which lowers the float to the water surface

DR4.3.4 The mass lowered by the mechanism shall not exceed 1kg

Test Purpose: Demonstrate ability to carry a simulated payload as well as test the behavior of the stepper motor at various voltages

Test Status: Complete

Test Results: Stepper motor gets hot at 12V. 8V was sufficient to lift a 1kg payload

Test Validation: The voltage and current were verified using a multimeter

Test Criteria: Stepper motor must be able to lift a 1kg payload

Equipment: Stepper motor, motor driver, Jetson nano, power supply

Deployment Mechanism Test Procedure

1) Jetson nano is connected to a monitor and powered using a USB-C cable
2) Stepper motor is connected to a motor driver which connects to the GPIO pins of the Jetson nano
3) Portable power supply generates the voltage needed to the stepper motor
4) Short python script controls runs the stepper motor at a controlled speed
5) The current and voltage supplied to the stepper motor is validated using a multimeter
6) A 1kg payload is attached to the stepper motor to simulate lifting the float
7) Test is run at various voltages (8V-12V)

Deployment Mechanism Testing

Test Results: Stepper motor successfully deploys the payload but struggles to lift it back up

Issues: Getting hot - Unable to lift float during flight

Potential Causes: Spool size - Attachment points - Drone Vibration - Friction

Suggested Improvements: Alternative winch techniques - Stronger stepper motors - Different rope orientation/attachment points

Deployment Mechanism Testing

Test Results: Stepper motor successfully deploys the payload but struggles to lift it back up

Issues: Getting hot - Unable to lift float during flight

Potential Causes: Spool size - Attachment points - Drone Vibration - Friction

Suggested Improvements:

- Drone winch (5kg payload - 24V)
- 12V > Stepper motor
- Increase and spread attachment points
- Use a slightly more rigid rope to minimize twisting in the float

Deployment Mechanism Test

- 8V supplied to stepper motor
- 1kg payload

Outcome: Mixed Success

Emergency Release Mechanism Testing

Test Results: Emergency release mechanism works successfully using the transmitter

Issues: Delay in performing the command

Potential Causes: The way it is scripted in python

Suggested Improvements: Rewrite the python script so that it prioritizes the emergency release command

Outcome: Success

Power System Test

Design Requirements:

DR6.1 There shall be a main computer with the drone-fixed instrument suite to command and direct power to all drone-fixed instruments and mechanisms.

DR6.3 Both the on-board and deployed sensor units shall include batteries to provide enough power for 30 minutes of operation at maximum power consumption.

Test Purpose: To verify that power distribution units (PDU) supply proper voltage and current to proper components and the batteries operate at max voltage/current operation for 30 minutes.

Test Status: Power distribution unit in prototyping stage

Test Validation: Run PDUs on system at max operating power for 30 minutes

Test Criteria: The PDUs must provide constant power with no power failure

Power System Test

Test Facilities:

- The testing will take place in the PILOT lab

Equipment:

- The test will utilize a digital multimeter and a DC power supply
- The test will utilize all related system electronics

Power System Test Procedure

1) Check the output voltage of the PDU using a digital multimeter to ensure there is consistent 5V & 8V output (different voltages determined per component)
2) Check the current coming out of the PDU to ensure the board has the capacity to output maximum current
3) Check that each PDU provides constant power to all necessary components for 30 minutes

Outcome: Success

Deployed Float Data Collection Testing

Test Purpose: Demonstrate initiation with water contact and proper data collection and storage

Test Equipment: SONAR, IMU, Water Sensor SD card reader, arduino UNO

Test Facilities: N/A

Test Status: Complete (SONAR in air) (2/24/2020)

Test Criteria: Data collection from SONAR and IMU must start and stop based on water detection with data being saved to the onboard SD card

Results: All sensors and systems functioned as expected and produced valid data

Outcome: Success

IMU Test

Design Requirements:

DR4.6.2 - The IMU shall measure the angular displacement between the SONAR pointing ray within ± 1 degree accuracy.

Test Purpose: Test Functionality and Accuracy of IMU

Test Status: Hardware and Software are Complete and Functional. Constructing Test Stand

Test Validation: Compare IMU Readings to Known Measurements

Test Criteria: IMU angular displacement measurements shall be accurate to within ±1°

IMU Test

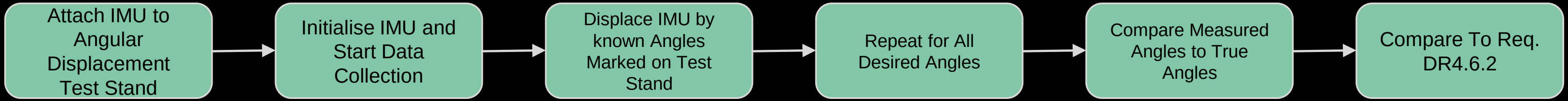
Test Facilities:

- No specific Facilities needed

Equipment:

- IMU
- Arduino
- SD card reader with SD card
- Computer to review Data
- Angular Displacement Test Stand (see slide 19)

IMU Test Procedure



Outcome: Success

Stereo Camera Test

Design Requirements:

DR5.1 The drone-fixed instrument suite shall use a stereo camera to measure river surface velocities.

DR5.1.2 The camera shall be able to sufficiently capture river velocity data between 0-4m/s.

Test Purpose: **Test functionality and image quality of ZED stereo camera.**

Test Status: **In progress**

Test Validation: **Use image processing scripts to verify quality of stereo camera images.**

Test Criteria: **Images meet particle size and density requirements set for use of PIVlab. User can change camera settings, capture video, and capture a 3D depth point cloud. Images are sufficient for measuring velocities within 0-4 m/s.**

Stereo Camera Test

Test Facilities:

- N/A

Equipment:

- ZED stereo camera
- Jetson Nano or other computer with Nvidia GPU
- ZED SDK software

Stereo Camera Test Procedure

Camera Controls Test:

1. Connect ZED stereo camera to power source
2. Run program to change camera settings
3. Review output statements to verify that camera settings were adjusted correctly

Image Capture Test:

1. Connect ZED stereo camera to power source
2. Run program to capture images
3. Run saved images through Matlab image processing programs
4. Compare particle size and density results to the allowable values

Depth Point Cloud Capture Test:

1. Connect ZED stereo camera to power source
2. Run program to capture depth point cloud
3. Verify that depth point cloud data can be used with RiVER software for post-processing

Outcome: Success

GNSS Base Station & Receiver Test

Design Requirements:

DR4.7 - The deployable float shall include a GNSS receiver

DR5.2 - The drone-fixed instrument suite shall include a GNSS receiver

DR7.4 - The GNSS data shall enable post-processed positioning with horizontal accuracy of +/- 4 cm and vertical accuracy of +/- 5 cm in ideal conditions.

Test Purpose: Validate GNSS functionality and accuracy

Test Status: Complete for u-blox receivers, waiting on base station

Test Validation: Run data collection outdoors with base station and both u-blox receivers

Test Criteria: Successful data collection and accurate results within horizontal position accuracy within 4 cm and vertical position accuracy within 5 cm.

GNSS Base Station & Receiver Test

Test Facilities:

- Outdoor space with ground truth markings, such as a track

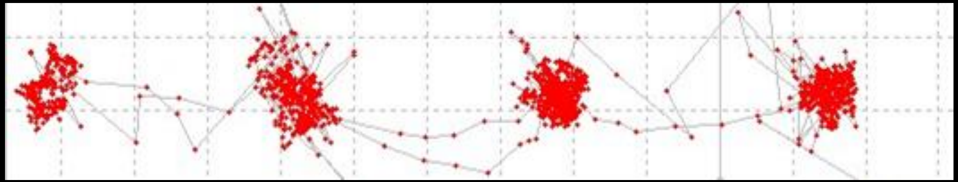
Equipment:

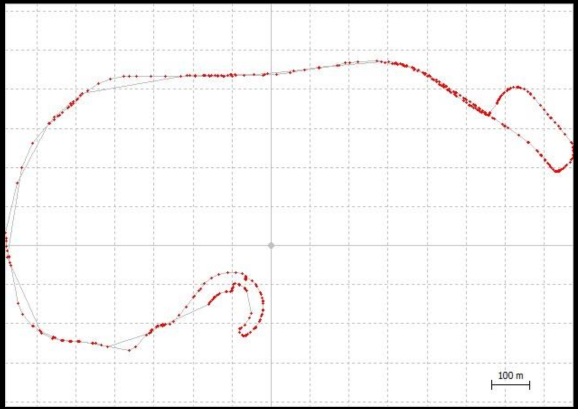
- Two u-blox receivers
- Jetson Nano
- Arduino Uno
- Portable usb-c power supply
- Emlid base station

GNSS Base Station & Receiver Test Procedure

- Set up and power on u-blox receivers, Jetson Nano, Arduino Uno, and Emlid base station at suitable location.
- Connect to base station from mobile device via ReachView3 app to initialize data collection.
- With one person holding each u-blox receiver, walk between quantitatively marked ground locations and record trajectory.
- Verify u-blox results onsite with a laptop.

GNSS Testing: Results





Method: Truth locations at constant intervals
Average Error: 15cm
Accuracy: The GNSS data shall enable post-processed positioning with horizontal accuracy of +/- 4 cm and vertical accuracy of +/- 5 cm in ideal conditions.

Does not satisfy DR7.4

Error Sources:

- Signal reflections
- Equipment quality (especially receiver)

Outcome: Success

Depth Profile Correction Program Test

Design Requirement:

DR4.6.2 - The IMU shall measure the angular displacement between the SONAR pointing ray within ± 1 degree accuracy.

DR7.2.1- The depth profile shall be post-processed to correct for the angular displacements of the float.

Test Purpose: Show that our corrected depth accuracy complies with DR4.1.2

Test Status: **All required electronics are functional, waiting for approval from Rec Center**

Test Validation: **Comparing corrected measurement to physical Truth values**

Test Criteria: **The measured depth should be accurate to <1% of Truth value (within ±20°)**

Depth Profile Correction Program Test

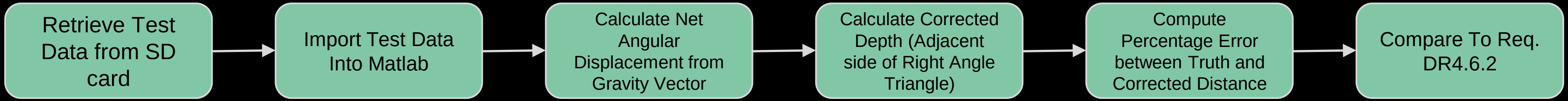
Test Facilities:

- Pool with Minimum Depth of 0.5 Meters

Equipment:

- SONAR
- IMU
- Arduino
- SD card reader with SD card
- Computer running Matlab
- Angular Displacement Test Stand (see slide 19)

Depth Profile Correction Program Test Procedure



Outcome: Success

Stereo Camera Image Verification Program Test

Design Requirements:

DR7.1 The stereo camera data shall be post-processed to calculate river surface velocity.

DR7.1.1 The computed surface velocity shall be within 20% of the true surface velocity.

Test Purpose: **Verify that image processing programs provide reliable particle size and particle density values for various images.**

Test Status: **In progress**

Test Validation: **Look at a variety of test results to get an expected particle size and density for different river conditions**

Test Criteria: **Image processing programs should give consistent particle size and density values for various river conditions**

Stereo Camera Image Verification Program Test

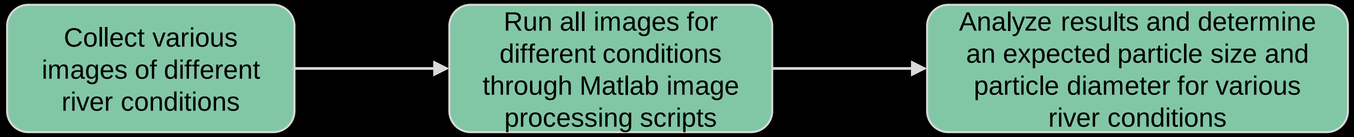
Test Facilities:

- Outdoor river

Equipment:

- Matlab
- IPhone camera

Test Procedure:



SLAM Test

Design Requirements:

DR7.5 - Positional data post-processing requirement.

DR7.4 - The GNSS data shall enable post-processed positioning with horizontal accuracy of +/- 4 cm and vertical accuracy of +/- 5 cm in ideal conditions.

Test Purpose: Validate our capacity to obtain an accurate mission trajectory.

Test Status: Preliminary code structure has been implemented.

Test Validation: Processing GNSS and IMU data from a path of known relative distances.

Test Criteria: Horizontal position accuracy within 4 cm and vertical position accuracy within 5 cm.

SLAM Test

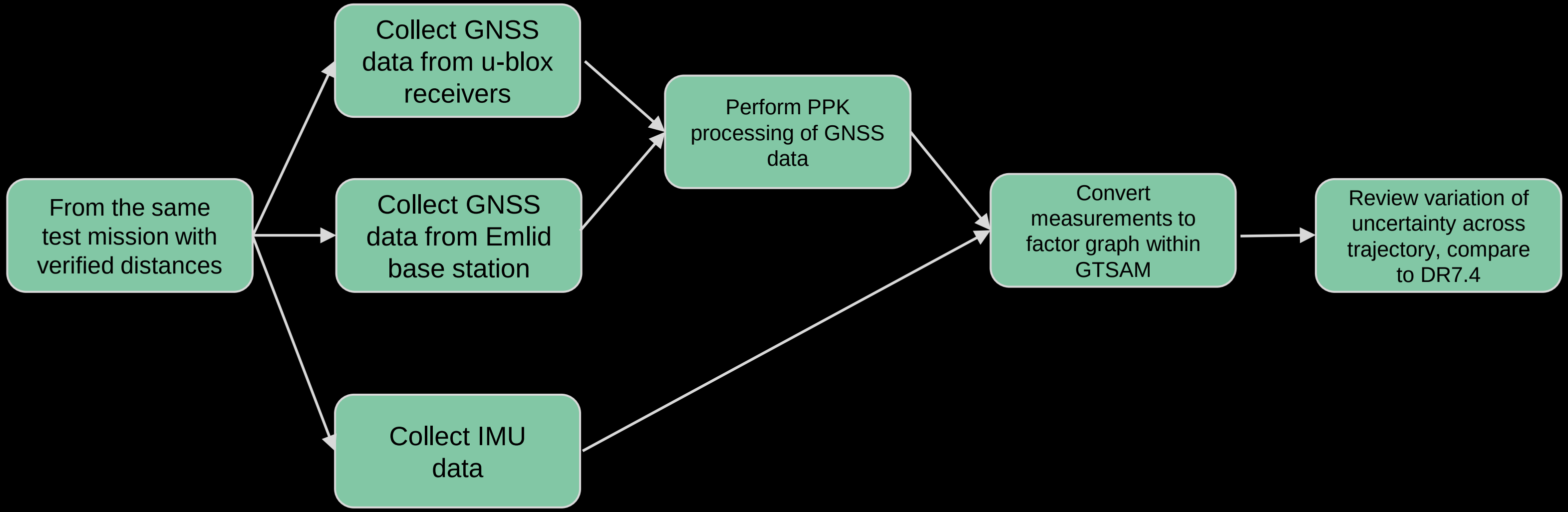
Test Facilities:

- N/A

Equipment:

- Emlid base station
- Jetson Nano
- U-blox receivers
- Arduino Uno
- IMU
- Power supply
- Computer

SLAM Test Procedure



Uncertainty Quantification Program Test

Design Requirements:

DR7.5 - The computed discharge data shall be delivered with the associated error uncertainty bounds.

Test Purpose: Ensure system calculated river discharge with error bounds encompass the collected truth river discharge measurement.

Test Status: In-progress, final testing will be with full day in the life test

Test Validation: Truth river discharge calculation will lie in error bounds of system-calculated river discharge

Uncertainty Quantification Program Test

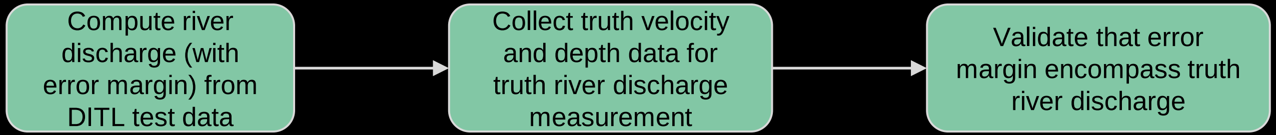
Test Facilities:

- Blue River Confluence

Equipment:

- Computer
- Full UAV + instrument suite
- GNSS base station & receivers

Uncertainty Quantification Program Test Procedure



Budget

UAV	$1,492.11
PLA & Arduino	$152.14
UAV License	$75
Ping Sonar	$310.50
Jetson Nano & SD Card	$102.24
Lipo Batteries	$462.54
U-Blox	$409.99
Stereo Camera	$489
Battery Charger	$81.63
fuse cartridge	$24.84
Breadboard & Screws	$40.35
3D Printing	$12.50
Vector Board	$29.92
Voltage Regulator	$13.04
SD Shield	$5.43
Adapter	$11.93
Water Sensor & Rods	$39.60
FAA Registration	$5
Jetson Developer Kit	$54.41
IMU Fusion Breakout	$25.89

Hand-held LSPIV Guidelines – On Site Checklist

Video and Site Requirements

Video

- ☐ Video resolution is at least 640 x 480 pixels (most smart phone cameras)
- ☐ Minimum of 15 frames per second
- ☐ No wide angle lens or other distortion
- ☐ Video duration at least 60 to 90 seconds
- ☐ Camera platform is as stable as possible by mounting on a tripod or bracing against a fixed object

Site

- ☐ Surface flow disturbance patters are uniform with time
- ☐ No effects of pier wake or other flow disturbances. If near a structure, shoot video looking upstream.
- ☐ Ideally, river has a stable bottom not subject to erosion

Field of View Requirements

Visible items

- ☐ Entire width of channel at measurement cross-section
- ☐ Fixed locations on both sides of the channel (e.g. banks, trees, structures)
- ☐ Minimum of 4 control points

Camera angle

- ☐ High angle is best (closest to 90°), therefore try to look down on the water as opposed to looking across it
- ☐ If standing on the bank, ensure angle is higher than 15°
- ☐ If standing on a bridge, ensure all visible items are in the field of view

Lighting

- ☐ Avoid shadows and reflections
- ☐ Avoid sparkling patterns on water surface

Control Points and Measurements

Control Points

- ☐ Minimum of 4 fixed control points, positioned as to maximize size of velocity field in camera field of view
- ☐ At least 2 on each bank, but can add more to enlarge visible velocity field
- ☐ Located at or as close as possible to the water surface
- ☐ Distance between points is known or can be measured

Note: do not need to form a perfect square

Examples: rocks, trees, stakes, pylons

Additional Measurements

- ☐ Distances between control points, including diagonals
- ☐ One cross-section bathymetry
- ☐ Fill in LSPIV Data Submission Form

Video from bank: Field of view includes all visible items, very well defined control points

Video from bridge: Field of view includes both banks, control points not well defined

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Discharge Calculations from: Engel, F. “Surface Velocity Workgroup: How to Articles.” Office of Surface Water, USGS, 2020.

How to translate Surface-water Velocities into a Mean-vertical or mean-channel Velocity

Regardless of the method (LSPIV or velocity radars) used to measure surface-water velocities, computing a discharge requires:

- Mean-channel velocity
- Cross-sectional area

This post offers methods for translating surface-water velocities into a mean-vertical (u_{vertical}) or mean-channel (u_{avg}) velocity either directly (USGS Surface-water Method, Probability Concept) or indirectly (Index Velocity Rating). Future posts will address steps for (1) assessing the quality of surface-waters scatterers, (2) correcting for wind drift, which can bias measurements and alter surface-water velocities, (3) schemes for filtering instantaneous velocity measurements, (4) computing area, and (5) computing real-time discharge.

It is important that when reporting u_{avg}, the method should account for the velocity distribution that exists at the transect or cross-section-of-interest. For example, if the maximum velocity occurs at the water surface, a logarithmic or or power law can be assumed; however, if the maximum velocity occurs below the water surface, a non-standard velocity distribution equation (e.g., Chiu velocity equation) should be used.

Discharge calculations from [6]

Direct Measurement:

USGS Surface-water Method for estimating the mean-vertical velocity

If surface-water velocities (u_D) are measured directly (LSPIV or velocity radars) and at multiple stations (25-30) from the left edge of water (LEW) to the right edge of water (REW), $u_{vertical}$ at a station can be computed using equation 1:

- $u_{vertical} = u_D$ *x coefficient (typically ranging from .84 to .90)* *Eq. 1*

This assumes the vertical-velocity profile can be characterized by a logarithmic or 1/6th or 1/7th power law (Mueller, 2013). Rantz et al. (1982) and Turnipseed and Sauer (2010) recommend a coefficient is necessary to convert a surface-water velocity to a $u_{vertical}$; however, these coef-ficients are generally difficult to determine reliably because they may vary with stage, depth, and position in the measur-ing cross section. Experience has shown that the coefficients generally range from about 0.84 to about 0.90, depending on the shape of the vertical-velocity curve and the proximity of the vertical to channel walls, where secondary currents may develop causing the maximum velocity to occur below the water surface. During these conditions, the coefficient can exceed unity (1.0). Larger coefficients are generally associated with smooth streambeds and normally shaped vertical-velocity curves; whereas, smaller coefficients are associated with irregular streambeds and irregular vertical-velocity curves.

In many instances, the velocity distribution is non-standard or the maximum velocity occurs below the water surface. In these cases, an alternative velocity distribution equation is needed to translate a surface-water velocity into a u_{avg} (Chiu, 1989; Chiu and Tung, 2002; Fulton and Ostrowski, 2008) or $u_{vertical}$ (Guo and Julien, 2008; Jarrett, 1991; Kundu and Ghoshal, 2012; Wiberg and Smith, 1991; Yang et al., 2006).

Discharge calculations from: Engel, F. "Surface Velocity Workgroup: How to Articles." Office of Surface Water, USGS, 2020.

Probability Concept Method for estimating the mean-channel velocity

The Probability Concept was pioneered Chiu (1989) and offers an efficient platform for computing u_{avg} at a cross-section-of-interest. Two parameters, and the maximum-instream velocity (u_{max}), are needed to compute u_{avg} The variable is derived by measuring point velocities along a very important and single vertical as a function of depth beginning at the channel bottom and concluding at the water surface or by collecting pairs of u_{avg} and u_{max} for a variety of flow conditions. The vertical is called the "y-axis" and all data collection efforts should focus on that station, which is that vertical that contains the maximum information content (minimum velocity, maximum velocity, and depth) to derive the parameters u_{max} , h/D used to compute u_{avg} (equations 2 and 3). Research suggests (Chiu et al., 2001; Fulton and Ostrowski, 2008; Fulton et al., in preparation) the location or stationing of the y-axis is generally stable for a given transect and does not vary with changing hydraulic conditions including variations in stage, velocity, flow, flow, channel geometry, bed form and material, slope, or alignment; however, field verification of these parameters must be conducted periodically and a stage-area rating must be maintained. The y-axis rarely coincides with the thalweg in open or engineered channels. Computing is accomplished through a Python or R-script (**will provide link**); u_{max} can be computed or measured directly using LSPIV or velocity radars.

- $u_D = u_{max}/M \times \ln[1+ (e^M-1) \times 1/(1-h/D) \times \exp(1- 1/(1- h/D))]$ *Eq. 2*

- $= u_{avg} / u_{max}$ *Eq. 3*

*Where = function of M (2 to 5.6) and generally ranges from **.58 to .82** and*

u_{max} *= maximum in-stream velocity*

u_{avg} *= mean-channel velocity*

M = entropy parameter and is related to $= e^M / (e^M-1) - 1/M$

u_D *= surface-water velocity*

h/D = location of u_{max} *below the water surface at the y-axis/water depth at the y-axis*

Indirect Measurement:

Index Velocity Rating for estimating the mean-channel velocity

The protocol for establishing index velocity ratings are described by Levesque and Oberg (2012) where an index such as u_D can be paired to a measured discharge for a variety of flow conditions.

Discharge calculations from: Engel, F. "Surface Velocity Workgroup: How to Articles." Office of Surface Water, USGS, 2020.

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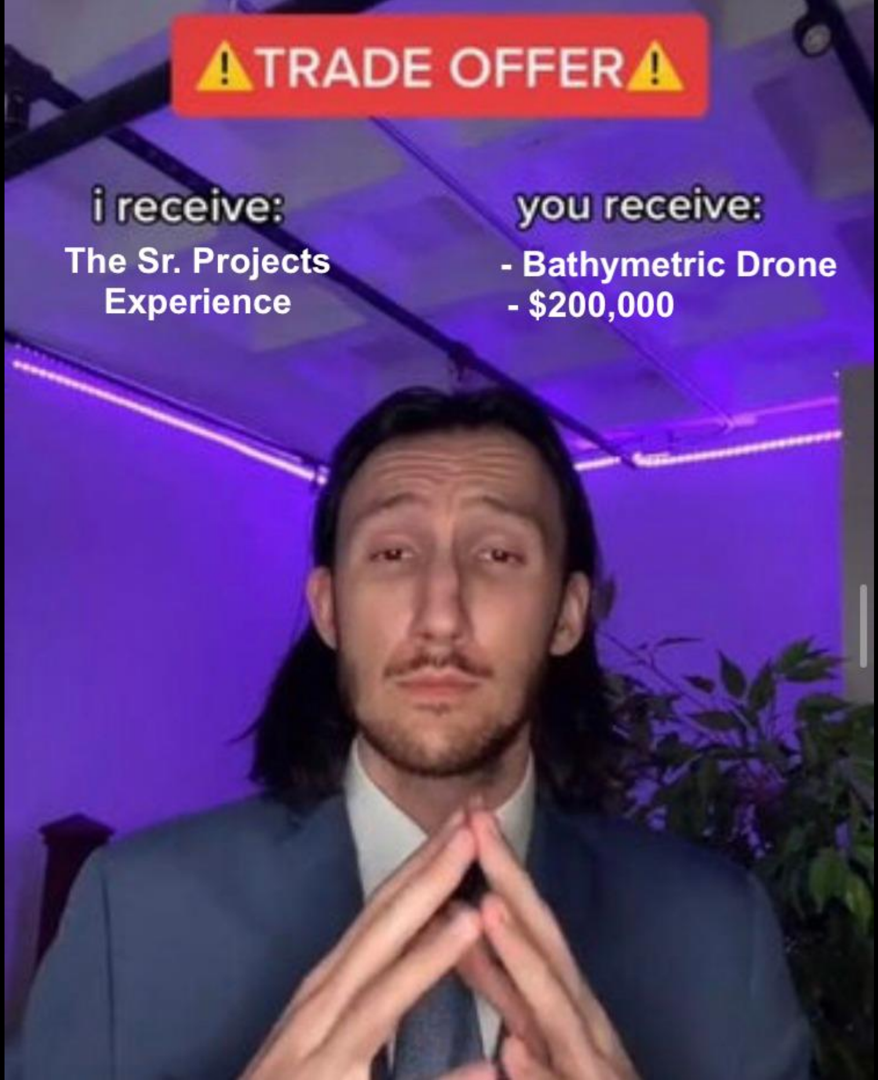
Float Weight Budget

Part	Weight [g]
Arduino Uno	25
1000mAh Battery	98
SD Shield	5
Wiring	15
Ping Sonar	135
IMU	3
U-Blox	35
Hull	219
Pontoons	364
TOTAL	**894**

FR1			**RiBBIT shall be an unmanned aerial vehicle (UAV) system.**
	DR1.1		The system shall have a minimum operational flight time of 12 minutes.
	DR1.2		The flight vehicle shall have a minimum carrying capacity of 2 kg.
	DR1.3		The surveyor shall choose river cross sections with open sky and minimal tree obstruction.
FR2			**RiBBIT shall be capable of operating in *customer specified* river conditions.**
FR3			**RiBBIT shall include an instrument suite payload that is compatible with the Tarot 680.**
	DR3.1		The payload shall be have a maximum total weight of 2 kg.
	DR3.2		The instruments shall be composed of commercial off the shelf components.
	DR3.3		The payload shall be designed such that it minimizes the external applied moments on the drone.
	DR3.4		The payload shall be mounted such that it minimizes the external applied moments on the drone.
	DR3.5		The drone-fixed payload shall be capable of operating in ambient temperatures between -10 and 50 degrees Celsius.
FR4			**The instrument suite shall be capable of measuring the bathymetric profile of a river cross section from one bank to the other, perpendicular to the current.**
	DR4.1		The instrument suite shall use SONAR to capture depth measurements.
		DR4.1.1	The SONAR instrument shall be capable of sensing depths from 0.5 meters to 3 meters in ideal conditions.
		DR4.1.2	The SONAR instrument shall be capable to measure depths to an accuracy of <1% of the total depth in ideal conditions.
		DR4.1.3	The SONAR instrument shall be capable of measuring depths in water temperatures between 0 and 20 degrees Celsius.
	DR4.2		The SONAR instrument shall be located on a deployable float.
		DR4.2.1	The float shall be designed such that the bottom 2.5 cm of the SONAR instrument is submerged under water.
		DR4.2.2	The float shall be designed such that the electronic components are located inside of a waterproof housing.
		DR4.2.3	The float shall be designed such that the amount of time the float is angularly displaced by +/- 20 degrees is minimized.
	DR4.3		There shall be a mechanism which lowers the float to the water surface.
		DR4.3.1	The mechanism shall be triggered to lower and raise the float via the drone pilot controller.
		DR4.3.2	The mechanism shall lower the float to the water surface in a controlled manner such that the drone is minimally perturbed.
		DR4.3.3	The mechanism shall include a failsafe option to release the payload if the translated forces and moments to the drone exceed its flying ability.
		DR4.3.4	The mass lowered by the mechanism shall not exceed 1 kg.
	DR4.4		The float shall be attached to the drone through a non-rigid material.
	DR4.5		The UAV shall fly at a minimum of 3 meters above the river surface while collecting depth measurements.
	DR4.6		The deployable float shall include an IMU.
		DR4.6.2	The IMU shall be capable of measuring the angular displacement between the gravity vector and the SONAR pointing ray with +/- 1 degree accuracy.
	DR4.7		The deployable float shall include a GNSS receiver.
	DR4.8		The total deployed weight shall not exceed the 1.6 kg torque capacity of the motor.
FR5			**The instrument suite shall be capable of measuring the surface velocity of a river cross section**
	DR5.1		The drone-fixed instrument suite shall use a stereo camera to measure river surface velocities.
		DR5.1.1	The camera shall be fixed to the instrument suite that is mounted to the drone.
		DR5.1.2	The camera shall be able to sufficiently capture river velocity data between 0-4m/s.
	DR5.2		The drone-fixed instrument suite shall include a GNSS receiver.
FR6			**RiBBIT shall be able to power and command all instruments and sensors.**
	DR6.1		There shall be a main computer with the drone-fixed instrument suite to command and direct power to all drone-fixed instruments and mechanisms.
		DR6.1.1	The main computer shall be responsible for storing the data collected by the on-board instruments locally to an SD card.
	DR6.2		There shall be a microcontroller on the deployed sensor unit which commands and directs power to all deployed instruments.
		DR6.2.1	The micro-controller shall be responsible for storing the data collect by the deployed instruments locally to an SD card.
	DR6.3		Both the on-board and deployed sensor units shall include batteries to provide enough power for 30 minutes of operation at maximum power consumption.
FR7			**The collected data shall be post-processed to calculate river discharge.**
	DR7.1		The stereo camera data shall be post-processed to calculate river surface velocity.
		DR7.1.1	The computed surface velocity shall be within 20% of the true surface velocity.
	DR7.2		The SONAR data shall be post-processed to model the river cross section.
		DR7.2.1	The depth profile shall be post-processes to correct for the angular displacements of the float.
	DR7.3		The river discharge shall be calculated by the product of the surface velocity multiplied by the area of the river cross section.
	DR7.4		The GNSS data shall enable post-processed positioning with horizontal accuracy of +/- 4 cm and vertical accuracy of +/- 5 cm in ideal conditions.
	DR7.5		The computed discharge data shall be delivered with the associated error uncertainty bounds.

Requirements cont.

FR8			**The UAV shall comply with all FAA and safety requirements**
	DR8.1		The flight vehicle shall be operated under all FAA safety regulations
		DR8.1.1	The UAV shall be registered if it weighs more than 0.55 lbs (250 grams).
		DR8.1.2	Unmanned aircraft must weigh less than 55 lbs (25 kg).
		DR8.1.3	UAV shall be flown below 400 feet above ground level at all times.
		DR8.1.4	UAV shall be flown in line of sight.
		DR8.1.5	UAV shall not be flown within 5 mile radius from any active airport/airfield.
		DR8.1.6	UAV shall be flown in daylight-only operations, or civil-twilight with appropriate anti-collision lighting.
		DR8.1.7	The smartphone app B4UFLY shall be referenced before flight to determine airspace restrictions.
	DR8.2		The UAV shall be operated by a person with proper FAA and/or municipal permissions
		DR8.2.1	A person operating a small UAS must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate (remote pilot in command)
	DR8.3		The UAV shall not be operated in any way that may cause harm to any person or property
		DR8.3.1	UAV shall have a safety control in case of emergency to return to pilot.
		DR8.3.2	UAV shall not be flown near or over sensitive infrastructure or property.
		DR8.3.3	All personnel shall remain clear of the UAV and not interfere with it's flight.
	DR8.4		There shall be visual observer to monitor the environment that the drone is flying in.


⚠TRADE OFFER⚠
i receive:
The Sr. Projects Experience
you receive:
- Bathymetric Drone
- $200,000