Environmental Sampling Drone

Final Design Report

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Special Thanks

We, the design team, consider ourselves to be incredibly lucky to have had the opportunity to work with and develop such an under researched system. Had we been solely responsible for the purchase of all the necessary parts and solutions required for full fabrication of the drone and sampler, we would have surely failed.

We wish to extend our deepest gratitude to several organizations and people. Dr. Robert Erikson and Dr. Kevin Kilty, despite their incredibly busy schedules, took the time to guide us through the problem-solving process. They advised us on the best course of action to take when obstacles presented themselves. Their engineering expertise and willingness to oversee our project kept milestone goals realistic and attainable, and it is for this we offer our greatest thanks.

The Trihydro Corporation proposed the idea of water sampling with a drone and generously donated nearly $8000.00 worth of equipment to aid in our endeavor to fabricate a creative solution. This project would not have been possible without the drone parts they were willing to part with. We extend our deepest gratitude to the Trihydro Corporation for their generosity.

Dan Mummert, the Drone Specialist for the Trihydro Corporation, kept in frequent contact with us and shared his knowledge so that rebuilding the drone went smoothly. The drone's ability to fly is credited to him, and we are very grateful to have had him as a resource.

Finally, we would like to thank the Wyoming Nasa Space Grant Consortium. We used nearly $1200.00 worth of their funding to create the sampling system and to purchase miscellaneous parts needed for full system functionality.

Introduction and Motivation

Figure 1: Mining Pit of Interest Located in Montana

Mining produces harmful contaminates that can make their way into the surrounding environment. The level of contamination by any means of production are regulated and it is required that environmental pollution be kept to acceptable levels. Sampling the water within pits allows for a close analysis of contaminants and offers insight into the nature of needed remediation actions. An example of a mining pit can be viewed in **Figure 1**. Traditionally the water at the bottom of the pits are collected by individuals who must traverse its steep slopes. This poses unsafe conditions and could possibly result in injury or death. The Montana Department of Environment Quality proposed the use of a drone to perform water sampling in mining pits. This method eliminates the need for unsafe sampling practices. It is a safer and more robust method for performing the task. However, the technology needed is underdeveloped. There have been very few attempts made at fabricating a drone system that is capable of collecting quality water samples at the surface of bodies of water in pits, much less at depth.

The Trihydro Corporation based out of Laramie, WY heavily focuses on environmental remediation work for many of their clients. They use drones to perform surveying, photography and environmental reconnaissance. The company made an attempt to win a bid with the MDEQ to sample mining pits using a drone but were not successful. The design team has a personal relationship with the corporation and this project was suggested by an individual under their employment as a result of their experience with the bid. The Trihydro Corporation donated most of the equipment needed to develop the project. This included most of the drone, saving the design team thousands of dollars. However, the drone donated had experienced a crash due to a battery malfunction. Some parts were damaged beyond use, so they needed to be replaced or fabricated from scratch.

Prior Art

The Trihydro Corporation lost the bid with the MDEQ to a company called Hatch. This is the only known company that performs water sampling with a drone. The design they patented can be viewed in **Appendix A**. Based on their design it can be stated with reasonable certainty that they experimented with design aspects that were also considered for this project. They decided on an in-house Van Dorn sampler design. The benefits of a Van Dorn sampler were weighed heavily for this project, and most likely would have been the sampler of choice had it been within budget. Hatch's design, however, lacks the ability to take two simultaneous samples at once.

A group from the University of Nebraska fabricated a water sampling drone. This drone however only took surface samples and were 100mL in size [1]. Hatch and the University of Nebraska offer the only other two designs for a water sampling drone that could be found through extensive research. Our design was slightly influenced by these systems, but they lacked in areas where we could improve.

Design Objective

The finished sampling drone will be able to travel to a body of water and collect two water samples. One sample will be a surface sample, and the other a subsurface sample from a depth between 3 and 15 meters. The drone will then bring the samples back to a point where the samples can be secured. The drone will not be automated but piloted remotely by a qualified individual. The minimum sample size allowed by the MDEQ is 500 ml, but both of our samplers will be 1L. It is worth mentioning that any further work beyond sampling is not within the scope of this project. The overall goal is to successfully collect the needed samples from a possibly contaminated body of water. Analysis of the water post sampling will not be a consideration. The form provided by the MDEQ with a detailed list of objectives can be viewed in **Appendix B.**

Budget

We were allotted a total of $1250.00 from the Wyoming Nasa Space Grant Consortium (WNSGC). This money was used over the course of the last two semesters to purchase parts for the sampling system, small parts for the drone and other required miscellaneous items. Each item purchased with the WNSG money, the quantity and cost can be viewed in **Table 1**.

Table 1. WNSGC Budget Breakdown

Parts Needed	QTY	Price
3D Printed Parts	1	$ 30.00
DJI CAN-Bus Cable	1	$ 5.00
Folding gps kit	1	$ 12.00
Leg	2	$ 29.98
Arms CW	4	$ 258.00
Arms CCQ\W	4	$ 258.00
Data Link	1	$ 125.00
Weighted Bailer	2	$ 163.77
GPS	1	$ 99.00
Servo Motor	1	$ 8.07
Various Cables	Varied	$ 50.46
Charging Cable	1	$ 23.98
Arduino Uno	1	NA
Miscellaneous	Varied	$ 60.00
Total Price	$1,123.26	

Alongside the money received from the WNSGC, the Trihydro Corporation donated a large amount of drone parts that were worth thousands of dollars. This included the frame, remotes, electronic components among other things. The full list of items as well as the amount and cost can be viewed in **Table 2**.

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Table 2. Donated Parts

Item Name	Qty	Price	Total Price
Video Converter CVB/S to VGA	1	$ 15.00	$ 15.00
AV to HDMI Converter	1	$ 7.00	$ 7.00
XH Adapter	1	$ 11.00	$ 11.00
DJI GPS-Compass Pro Plus	1	$ 89.00	$ 89.00
Lumenier Mini FPV Cam	2	$ 25.00	$ 50.00
s1000 Propeller	6	$ 4.00	$ 24.00
HiTec 2x400w/20a Charger	1	$145.00	$ 145.00
hitec 100-240W Charger	1	$225.00	$ 225.00
14SG Futaba Controller	2	$600.00	$1,200.00
Black Pear 7"Hd FPV Screen	2	$145.00	$ 290.00
AVL58 Video Downlink Antenna	6	$ 12.50	$ 75.00
3300 mAh Battery	1	$ 34.00	$ 34.00
3000 mAh Battery	1	$ 30.00	$ 30.00
A2 Flight Controller Unit	1	$ 90.00	$ 90.00
AVL58 5.8G Video Link Transmitter	2	$ 45.00	$ 90.00
Zenmuse 5dD-HD GCU	2	$200.00	$ 400.00
Zenmuse 5D-HD (Gimbal)	1	$550.00	$ 550.00
2.4 Data Link (LK24-BT)	1	$ 74.00	$ 74.00
A2 Flight Controller IMU	1	$250.00	$ 250.00
iOSD on Screen Display Mark 2	1	$ 89.00	$ 89.00
A2 PMU	1	$ 30.00	$ 30.00
30C 21000mAh 6s1P 22.2V	10	$250.00	$2,500.00
R7008SB Reciever	1	$165.00	$ 165.00
Drone S1000 Hub	1	$239.00	$ 239.00
Carbon Fiber Legs part 53	1	$ 80.00	$ 80.00
Pelican Case	1	$846.00	$ 846.00
Total Price			$7,598.00

Functionality

The sampling system is composed of the drone, buoy, and samplers. The sampling system will be attached to the drone via a flexible steel cable. A quick release mechanism serves as the point of attachment of the steel cable to the drone. The primary purpose of the buoy is to serve as a datum for the surface sampling device. The subsurface sampler is fixed to the end of the steel cable while the surface sampler has mounted eye hooks which the cable is routed through. The buoy is attached to the top of the surface sampler. This setup permits the depth sampler to descend to depth while the surface sampler slides along the cable, remaining at the surface of the water due to the buoyancy of the attached buoy. The depth reached by the subsurface sampler is controlled by a stopper on the steel cable which catches on the surface sampler and prevents the depth sample from descending further. A flag is used as a visual indicator to ensure the stopper contacts the buoy. After the depth sampler has descended to depth the drone begins to lift both the samples out of the water. The samplers must seal adequately, and the water samples are pulled from the body of water and transported back to land where they can safely be retrieved.

The release mechanism that connects the sampling system to the drone must be reliably and remotely activated in order to disconnect the drone from the sampling system at any time. It must have the required strength to support and disconnect the fully weighted payload. All functionalities working together make it possible for our sampling system to meet the outlined design objectives.

Design Considerations

The final design is a product of consideration of existing designs/components and novel approaches developed by the design team.

Choosing a Sampler

One of the challenges in the design objectives specified by MDEQ was collecting both a surface and a depth sample at the same location in a single flight. Hatch developed an autonomous sampling system utilizing a single Van Dorn sampling bottle. This design lacks the capability to collect both a surface and a subsurface sample simultaneously. Attempting to utilize a system with two Van Dorn bottles presents highly increased difficulties and expenditures associated with making sure both devices are consistently activated at the proper depth. Also, the increased weight due to two Van Dorn samplers would reduce sampling range. The final design using modified self-sealing bailers enables a team to collect a surface and depth sample at the same time, and the reduced weight extends sampling range. Using bailers also greatly reduces the cost of system fabrication. Minimal water column disturbance is also a priority. While further testing is needed to verify the depth sample bailer efficacy of preventing sample contamination, visible sediment in the depth sample during

***Figure 2**. Vandorn Sampler (Above), and Bailer Sampler (Below)*

field tests suggests the depth bailer accurately collects samples from depth with little or no contamination.

Data Sonde Probe

In the original bid form, the MDEQ asked that a Data-Sonde probe be used to decide on the depth at which the water would be sampled, a Data-Sonde would be sent to test the pH, conductivity and temperature at different depths. The gathered data would be used to identify whether the lake is stratified within the depth interval sampled. The sub-surface sample would then be collected from a depth at which the lake chemistry may be different than at surface. It was decided among the design group to proceed without the use of the Data Sonde probe, as it is prohibitively expensive.

Alternative Detachable Sampling Package Design

Another design that was considered involved dropping off a buoy and sampling package on the water surface and retrieving it later after the samples had been collected. This approach would extend the capabilities of the sampling system. With this system the drone would not have to carry the full load of the buoys and samples to and from the sample location on a single battery charge. The drone could drop off the sampling package on the water and return to shore and recharge while the sampling package collects samples and runs tests. This would extend the sampling range of the drone. Additionally, the sampling package could have more sophisticated functionality built in, making Van Dorns a more realistic option and aiding in real time sample analysis. This equipment adds weight but could be utilized if payload weight is of less concern.

However, it was decided these benefits were not worth the technical difficulties associated with recapturing the sampling package and the dangers this process would pose to the drone.

Release Mechanism

Another design consideration is the installation of a release mechanism in case the sampling system comes in contact with vegetation and other snag points under the water. It is important to know water depth information before sampling to ensure the depth sample bottle doesn't approach the bottom of the water body. The remotely controlled release mechanism must reliably detach the sampling system from the drone to allow the drone to return to dry land if the sample bottles or buoy become snagged. Additionally, the release mechanism will aid in retrieval of the bailers after samples have been transported back to dry land. Commercially available drone release mechanisms are more expensive than is justified by the components. The team decided that the best option for the release mechanism was a quality servo motor (DSSERVO DS321MG) integrated with a Tarot TL2961-02 payload release frame, and an Arduino microprocessor to receive a signal from the drone and control the servo.

Other Considerations

Other considerations such as what kind of drone to use were discussed as well. A detailed list of considerations, associated constraints and final decisions made can be seen in **Table 1**.

Table 1. Design Considerations

Item	Considerations	Other Constraints	Possible Solutions	Final Decision
Water Sampler	Must allow for simultaneous depth and surface sampling	Weight, Sample quality, Cost, System complexity	Double Bailer and Van Dorn	Double Bailer
Release Mechanism	Must be activated remotely and be extremely reliable	Cost, weight capacity, response time	Commercial mechanisms, Tarot Release Frame with Integrated Servo/Arduino	Tarot Release Frame with Servo/Arduino
Buoy	Must be able to float one bailer	Size, Cost, Weight	Sheath Bouy, Conical Buoy, Foam or plastic buoy, Rubber Ducks	Rubber Ducks
Drone	Must be able to lift 2L of water and have suitable flight time	Cost, Size	Heavy, Powerful Drone Lightweight, less powerful drone	DJI S1000+
Sampling System	Must successfully be able to retrieve and deliver samples as specified	Technical obstacles, Cost	Drop off sampler and retrieve later or maintain drone connection throughout sampling process.	Maintain drone connection to sampling system throughout process

Schedule

Figure 2: *Gantt Chart*

In an effort to better organize our approach to the fabrication of the drone system, a Gantt chart, seen in **Figure 4**, was created. It was decided that larger windows were needed with some tasks as a result of shipping logistics. Most milestones were met on time with the exception of flying the drone. This was done a week before URD as a result of several obstacles including shipping, battery malfunction, gps connection and software cooperation.

Breakdown of Work Performed

The tasks necessary for completion of the system were identified and separated into tasks. Each task was given to a member of the design team of several members of the design team. The detailed work breakdown can be viewed in **Figure 5**.

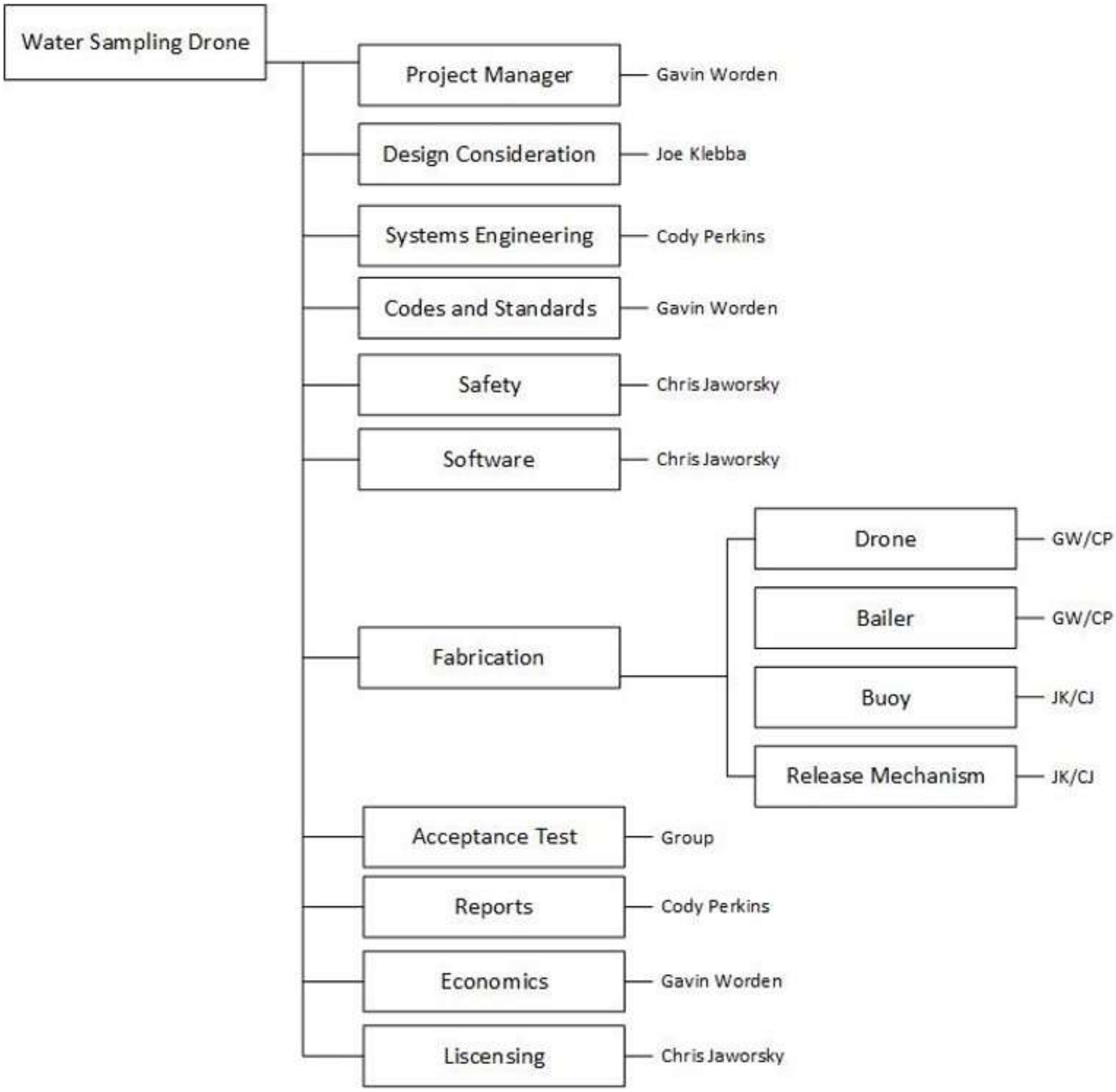


Figure 3: *Work Breakdown*

Assembly of System

Drone

The drone was donated to the group by the Trihydro Corporation. The drone had been crashed and was missing most of the parts for the drone to fly. The drone had to be completely rebuilt.

To begin, the arms had to be ordered and attached. Unfortunately, the model of drone was unknown to the group and the wrong arms were ordered. The only difference between the two models is the power distribution to the individual arms. The arms that we bought were coaxial when we needed a split cable. The problem was solved by cutting into the coaxial cable and splitting it manually. On top of that the drone was no longer in production so parts are extremely far and few between. Because there was no other option, we had to make the arms work this way.

The next thing that needed to be fixed was the landing gear. The carbon fiber legs needed to be ordered. The only part that was missing in the landing gear was the legs. These were attached without a problem. After all the necessary parts where ordered and attached it was just a matter of following the instruction manual to wire up all the motor and power management units. The wiring diagram is located in **Appendix E.** One troubleshooting problem we had was when the new GPS was installed it needed to be recalibrated. To do this the drone must be rotated in certain directions in accordance with a LED light on the drone. Not known to us, the green led had burnt out, this made calibrating difficult because we did not originally know this.

The original design had two cameras on the drone itself to allow for easier navigation for the pilot. This was later taken out because we didn’t have enough batteries to power the command station monitors. This would be a good component to have as it makes the drone safer.

Release Mechanism

***Figure 4**: Release Mechanism*

Due to the unjustified expense of commercial products and the need to retrofit a solution to the discontinued DJI S1000+ the team elected to fabricate a custom release mechanism for the sampling system. The mechanical portion of the release mechanism consisted of a Tarot QWinOut TL2961-02 payload release frame integrated with an DSSERVO DS3218MG servo. The servo actuates a sliding pin on the payload release frame that one end of the sampling system's attachment cable is looped around. When the sliding pin is pulled back by the servo the sampling system becomes completely detached from the drone. The rated strength of both the Tarot payload release frame and the servo exceed the sampling system's requirements. The Tarot frame is rated for 10kg and the DS3218MG servo's torque is rated as 20kg*cm. The most revealing assessment of the suitability of the components was a test in which the sliding pin was readily actuated with full load on the release mechanism and no deformation or damage to any components occurred.

Another obstacle in the design of the release mechanism was signal transmission and servo control. Because the servo must be reliably remotely controlled the best option is to communicate with the servo through the drone's built in communication channel. The team mapped a port on the drone meant to control the camera gimbal mount to a toggle switch on the drone remote. Flipping this toggle switch produces a change in signal frequency out of the port. An Arduino microcontroller onboard the drone was used to monitor the port for a change in signal frequency and control the servo motor in the required way when the change in signal occurs. The Arduino code used to achieve this functionality as well as a plot of the change in signal can be found in **Appendix F.**

The release mechanism was attached to the underside rails of the drone using a simple custom mounting plate. This plate provided housing for the release mechanism and related components. Additionally, the plate's mounting position was adjustable, allowing for center of mass balancing of the drone.

Water Sampler

For the water sampling portion of the project it was crucial that the sampling system could successfully collect two samples, and that the samples were representative of the depths at which they sampled. It was decided that a bailer would be the best option for this application. The bailer uses a check valve that allows water to flow through when it is lowered into the water but will not allow the water to flow back out when the bailer is pulled up from depth. The design file is in **Appendix D.** This was the best option because it was inexpensive and does not require a triggering mechanism to trap the water inside.

Figure 5*: Full Assembly*

In this design it was important that we could get a sample at depth and a sample at the surface. To acquire a sample at the surface a buoy was attached to the surface sampler to allow it to float at the surface. The surface sampler also had two eye bolts attached to it to allow a cord to run through it. The design file for the bailer attachment is in **Appendix D**. This allowed the surface sampler to move any distance apart from the depth sampler. There was a cord attached to the drone's release mechanism that would go through the surface sample and then attach to the depth sample. With a set point using a marker on the cord we could get a specific depth tested from the surface sample.

Testing

For the testing of the design there were four tests performed. Each test will be talked about below.

For the first test the drone was tested by itself. After putting the drone together, the design team went out to an open field to test the drone's ability to fly. This was the first time the drone had flown since Trihydro crashed it before giving it to us. To ensure as much safety as possible we tethered the drone to the ground just in case of a malfunction in the communication. The motors were tested using the DJI software to guarantee that the modifications that were made to the power distribution of the wings. The pilot then took off to test all maneuvers of the drone. All the maneuvers passed and was deemed a very successful flight.

For the second test the design team tested the operation of the drone attached to the sampling system. This test was to confirm the operation of the release mechanism as well as to see if the drone could support the samplers. The release mechanism operated as planned and the drone flew well with the samplers.

For test three the design team decided it was time to test the full operation over water and retrieve a sample. This test was a failure but provided us with design changes that led to our final design. When the drone lowered the samplers into the water the samplers did not sink right away because of the way the drone lowered them into the water. The samplers were swinging when they were lowered into the water and that caused them to lay on their sides. The water slowly entered the sampler and slowed the sinking time. This was a major problem because they would not retrieve a good sample at depth. When the drone retrieved the samplers out of the water, the water discharged out of the bottom of the samplers through the check valve. The design team was unsure why this happened but most likely there was something keeping the check valves open. When the drone coming back to land it suffered a glitch which caused the home position of the drone to reset. The new point was set three feet from the lakes edge. This problem was never resolved.

For the fourth and final test the design team made some improvements to the bailers and made sure the pilot was comfortable with flying the drone without relying on the GPS. A QR code has been added to **Appendix C** which is a link to the video of the final flight. Before the final test the design team added weights to the bottom of the bailers to allow them to sink at a faster rate. The samplers still suffered from tipping over and lying flat. Though the added weight significantly helped the sinking rate. When the drone lifted the samplers out of the water there were two full samples including sediment at the bottom of the depth sampler signifying the design team achieved a sample at depth. The buoy also stayed at the surface as the drone was lowering, meaning the buoy and bailer attachment system worked well and the surface sample was taken successfully. The drone then flew safely back to its home position and the design team successfully acquired the two samples the design scope was looking for.

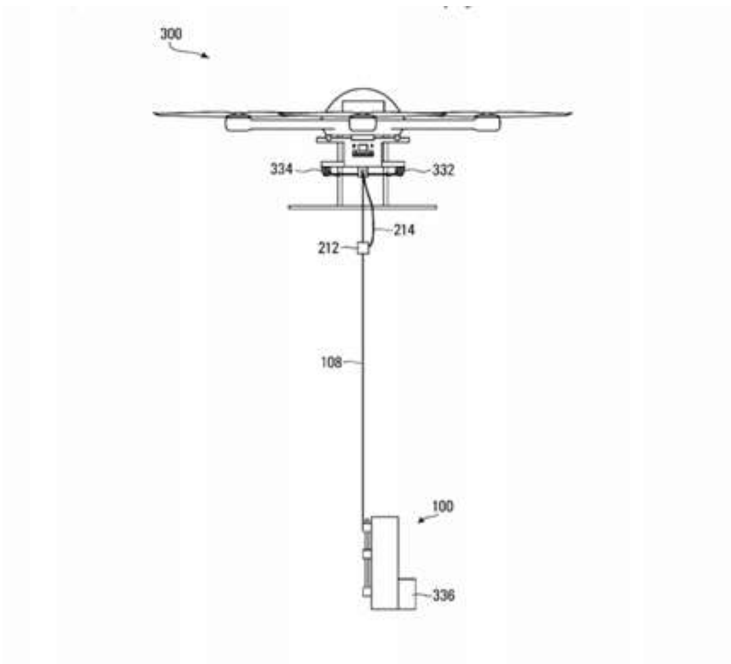
References

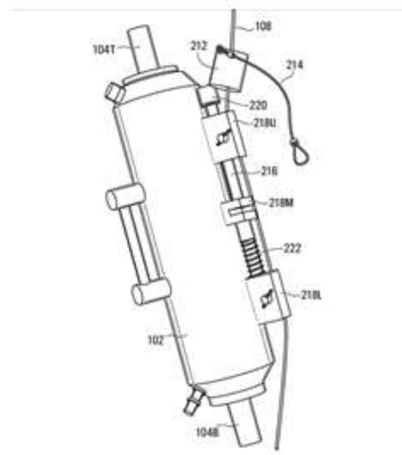
1. "Autonomous Aerial Water Sampling", https://cse.unl.edu/~carrick/papers/OreBED2015.pdf

2. "DJI - The World Leader in Camera Drones/Quadcopters for Aerial Photography." *DJI Official*, www.dji.com/spreading-wings-s1000/spec.

Appendices

Appendix A – Hatch Patent





Appendix B – MDEQ Objective Guideline

Pit Lake Water Sample
Unmanned Aerial Vehicle (UAV)
Montana Tunnels Mining, Inc.
August 30, 2018

The Montana Department of Environmental Quality (DEQ) is interested in obtaining a proposed bid to sample pit lake water from an open pit mine just west of Jefferson City, Montana. Jefferson City is located approximately 18 miles south of Helena.

Site Location: Montana Tunnels Mining, Inc.
46.373234, -112.132189

Depth of Lake: > 60 meters

Sampling: Up to 1 day of sampling with a total volume (all samples combined) of 3500 mL

Samples are to be collected from two locations within the pit lake (one at the water surface and one from depth). DEQ would like to obtain 1750 mL (1/2 gallon) samples from each location.

Minimum Volume Per Sample: 500 mL

DEQ would prefer that each 1750 mL sample be obtained during one flight. If this exceeds the weight limitations of your UAV, please indicate what maximum sample size can be obtained per flight. Minimum acceptable volume per flight would be 500 mL, which would necessitate at least three flights per sampling location. DEQ would consider reducing the required sample volume per location to 1250 mL if necessary.

Sample Collection Container: Provided by UAV contractor. DEQ recommends that a "Van Dorn" bottle or similar device would be used to obtain the sample.

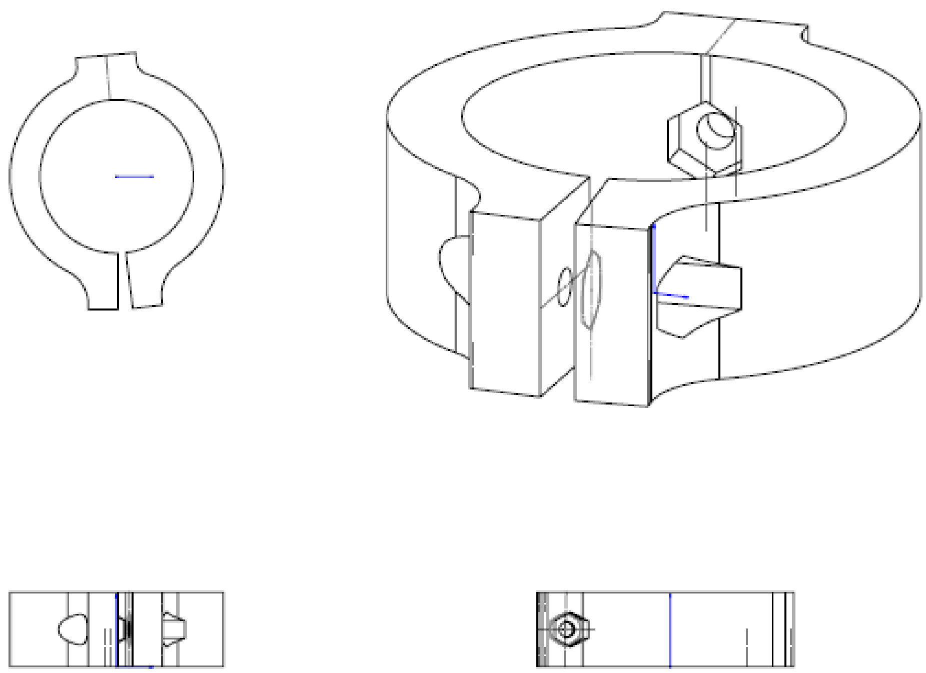
Sample Depth: Two distinct sampling depths

1) Surface Samples (½ of total samples) – upper meter
2) Beneath Surface Samples (½ of total samples) – likely between 3 and 15 meters depth.

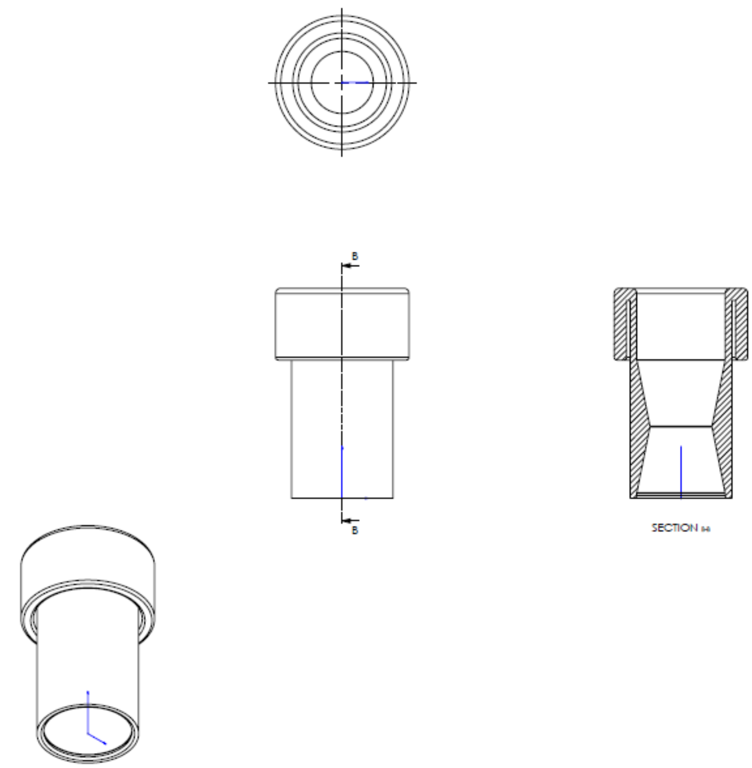
Appendix C – QR Code

Appendix D – Designed Components

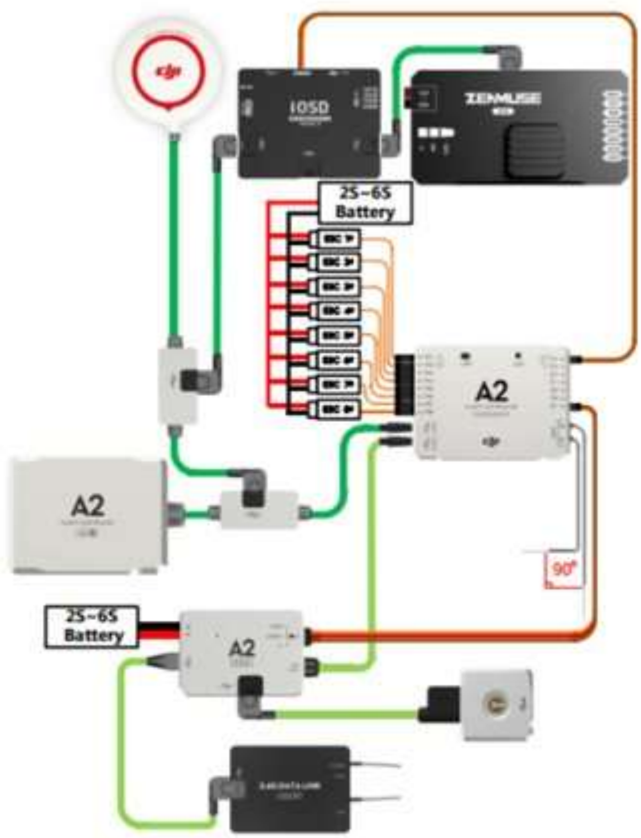
Bailer Attachment



Double Check Valve



Appendix E - Wiring Diagram



Appendix F - Arduino Code

```
#include <Servo.h>

Servo myservo;  // create servo object to control a servo
// twelve servo objects can be created on most boards

int pos = 0;    // variable to store the servo position
long val = 0;
long val2 = 0;

void setup() {
  myservo.attach(9);  // attaches the servo on pin 9 to the servo object
  pinMode(A0,INPUT);

Serial.begin(9600);
}

void loop() {

val = analogRead(A0);
val = map(val,0,1023,0,5);
val2 = pulseIn(A0,HIGH);
 if (val2<1250){
    pos = 135; // goes from 0 degrees to 180 degrees
    // in steps of 1 degree
    myservo.write(pos);              // tell servo to go to position in variable 'pos'
  }
else {
    pos = 95; // goes from 180 degrees to 0 degrees
    myservo.write(pos);              // tell servo to go to position in variable 'pos'
  }
Serial.println(val2);
}
```