Unmanned Partially Autonomous Boat for Profiling and Sampling the Berkeley Pit

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ABSTRACT: The Berkeley Pit in Butte, Montana is part of the largest US Environmental Protection Agency (EPA) Superfund site in the nation. The Berkeley Pit was an open pit copper mine that operated from 1955 to 1982. Since its abandonment, the pit has been filling with metal laden, low pH water; it currently contains over 46 billion gallons (174 billion liters) of water and is over 850 feet (260 meters) deep. Semi-annual sampling and profiling of the pit is required by the EPA and Montana Department of Environmental Quality (DEQ) under the terms of the 2002 Consent Decree. Due to safety concerns, manual profiling and sampling of the Berkeley Pit ceased in 2013; this change in procedure has required the development of a remotely operated boat capable of profiling and sampling the water from 3 feet to 600 feet in depth. This paper describes the development of a boat capable of performing these tasks with much less risk to human life and some preliminary data.

INTRODUCTION

From 1955 to 1982, the Berkeley Pit was an active mining site that produced large volumes of copper and other minerals. During that time, pumps located deep underground were used to keep water from flooding the Berkeley Pit and adjacent underground mine workings (Gammons and Duaime, 2006; Duaime et al., 2016). When mining operations ceased in 1982, the pumping of water also ceased and allowed the Berkeley Pit to fill with water. Over the past 36 years the pit has continued to fill and currently it holds 47 billion gallons (180 billion liters) of water. The reaction of water and oxygen with sulfide minerals in walls of the pit and adjacent tailings deposits caused the water have a low pH and high metal concentrations.

The EPA and DEQ have required semi-annual profiling and sampling of the Berkeley Pit as part of monitoring for the Butte Mine Flooding Operable Unit of the Silver Bow Creek Superfund Site. Until 2013, this work was performed manually with a field crew using a boat to collect samples and data. In 1998 a significant slope failure occurred on the south east rim that caused 50 ft (15 m) waves. More recently (2012-2013), a number of smaller failures occurred causing safety concerns of capsizing the boat with dangers of the waves pushing the occupants into the pit walls, drowning, and hypothermia. Due to these risks sampling and profiling operations temporarily ceased in 2013. In 2015, Montana Resources funded Montana Tech to develop a remotely operated boat to profile and sample the Berkeley Pit.

MATERIALS AND METHODS

The task of the pit boat was initially divided into the following subsystems; physical build, locomotion, communication, profiling and sampling. Each of these tasks have their inherent difficulties.

The physical build was developed around an existing 12 ft (3.7 m) fiberglass drift boat as Figure 1. This boat was used due to its availability, its ability to withstand the acidic and corrosive nature of the Berkeley Pit water and its ability to securely hold all necessary

Figure 1. Drift boat prior to installation of instrumentation.

equipment. The boat was outfitted with a wooden platform to hold sampling and profiling equipment as well as a mounting rail for the drive system.

Locomotion was designed around a pair of 50-pound Minn Kota electric trolling motors. The motors were mounted on a rail on either side of the boat with a fixed forward angle. Each motor was designed to be controlled independently in a skid-steer configuration. A Sabre-Tooth Dual motor controller was used to drive the two motors.

Initially, communications were to be performed over three different bands; 433 MHz was to be used for digital manual control of propellers and autopilot, 915 MHz was to be used for telemetry feedback, and 2.4 GHz for control of the profiling and sampling equipment. During trials and testing the 915 MHz band was eliminated because telemetry could be provided through the 2.4 GHz band.

A Taranis hobby radio control was used with a Scherrer RF 433 MHz range extender for the radio communications. In order to minimize the interference patterns of the single source radio communications over water, a dual antenna transmitter was built to disrupt the interference pattern. This setup allows for radio connectivity over several miles over the water.

For the 2.4 GHz band, a pair of Ubuiquity WIFI radios were used with a high gain sector antenna for the base station and a high gain dipole antenna for the boat. This setup allows for high bandwidth connection up to three miles over the water. This channel supplied the video and audio feedback, as well as, the control of all of the sampling and profiling equipment. Three cameras were mounted on the boat that utilized the wifi communication path, two were standard IP network cameras controlled on a pan tilt gimble, and the third camera was a Raspberry Pi computer and computer. The Pi camera was programmed to have very low latency to facilitate ease in navigating the boat manually.

Profiling was performed using a Hydrolab MS5 Data Sonde. A 200 meter reel and serial cable were used to communicate back to the boat. The reel was mechanized to automatically reel the 200 meter cable up and down (Figure 2). To automate the reel, a magnetic click counter was installed as well as a bump-stop to detect when the reel had rewound completely. The data were recorded at the boat via the on-board computer and then transmitted to the shore base-station for real-time analysis. The data collected included depth, temperature, pH, specific conductance (SC), dissolved oxygen (DO), and turbidity.

FIGURE 2. The mechanized data sonde reel.

The most complicated mechanism of the boat was the sample collection mechanism. This portion was broken into three different sub-mechanisms. A peristaltic pump was used to prime and purge the 750 ft (230 m) of vinyl tubing. Priming was necessary to remove all air bubbles from the tubing before purging. The second mechanism was a modified hose reel. The original reel was provided by Summit Mfg. and was motorized, but was modified to have a linear stage to raster the hose evenly on the reel (Figure 3). The reel was also fitted with a mechanized outrigger that holds the hose below the prop level of the trolling motors to ensure the hose would stay below the level of the propellers and could not be wrapped around one of the propellers. The outrigger was designed to be remotely

FIGURE 3. The mechanized hose reel.

raised and lowered. Additionally, a brake was installed to hold the reel from unraveling due to the weight of the hose below the water. The end of the hose was also weighted to ensure a relatively vertical hanging angle of the hose.

The third mechanism was the sampler. This project started with an ISCO 3700 automated sampler. This sampler has the capability of filling 24 one-liter bottles in its carousel. The electromechanical systems were modified to be remotely controlled to fill each individual bottle.

Each mechanism in the boat was controlled independently with a custom printed circuit board (PCB; Figure 4) and custom software was created to control each mechanisms.

These PCBs were controlled directly with a Raspberry Pi computer. The Raspberry Pi acted as a server that could be accessed remotely to control each of the functions described above.

Each subsystem was constructed and tested. These systems were assembled onto the completed platform (Figure 5).

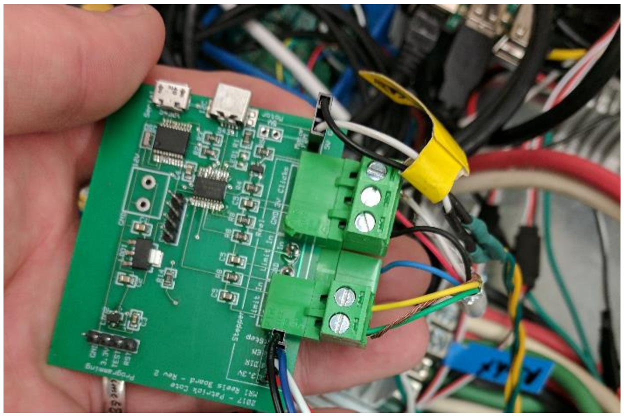

FIGURE 4. Example of a custom printed circuit board.

FIGURE 5. The completed boat showing all subsystems.

FUTURE CHANGES AND PLANS

One addition requested by Montana Resources was to add a propane cannon. During migration of waterfowl, the Berkeley Pit can attract waterfowl as a safe harbor. Unfortunately however, the toxic nature of the pit water can be harmful or fatal to waterfowl. Montana Resources has employed a number of hazing methods to deter birds from landing and/or staying on the pit water. The propane cannon on the boat is another bird hazing method. In addition to the propane cannon, a LED light bar is being added that can shine bright lights at the birds in hopes of deterring them from staying on the Berkeley Pit.

One of the dangers associated with launching the boat is that currently someone is required to board the boat during launching to lower the propellers and the data sonde into the water. A system to automatically raise and lower the propellers and the data sonde is being implemented. This will allow for the boat and trailer to be the only things to touch the water during launch and also reduce danger of someone falling into the water during launch and recovery.

A significant change will be to find a way to purge and prime the hose faster. Priming is necessary to remove all air bubbles from the hose. Because priming is done with a positive pressure against the long length of the hose, it takes between five and seven minutes. Purging between samples takes 20 minutes for one hose length. This is due to the fact that in negative pressure against the long length of the hose, the flow is limited by the resistance of the long length of hose. There are currently projects exploring ways to improve the speed of these two processes.

Also requested by Montana Resources is a way to collect large samples of 4 gallons or more.

RESULTS AND DISCUSSION

All of the subsystems of the boat were tested on local lakes prior to launching the boat in the Berkeley Pit. First Berkeley Pit launch occurred in April 2017. During this trip the hose wrapped around the left prop causing the boat to become disabled. The boat drifted close to shore where it was able to be recovered using a fishing rod. The launch was repeated in May of 2017 with a similar result. The change that was necessitated after these incidents was the construction of the outrigger on the hose and the brake on the hose reel. These two additions allowed for the hose to not unspool independently and also kept the hose below the level of the prop.

Between May and November 2017 the boat has been successfully launched and recovered six times. Two successful profiling and samplings events occurred during this time period. The autopilot system was successful in navigating to previously sampled locations for repeated samples. During this time the number of people needed to launch and recover the boat has also reduced. Initially, four people were needed in concert to launch and recover the boat. This could be reduced to one, but for safety concerns, two people are required.

Water samples collected during development of the drone boat will be evaluated as part of the ongoing monitoring effort. Water chemistry profile data provide an example of the information that can be gained through a remote sample/profile system. Figure 6 presents profiles (parameter vs depth) for two exhibitions of the drone boat. The data that have been collected show significant differences Berkeley Pit chemistry during 2017 (Figure 6). The upper 50 to 100 feet of the pit is mixed by wind action, but below 100 feet the water column is stagnant for most of the year. If the pit lake were stagnant all year, one would expect that these parameters would not change significantly from May to November. However, temperature, pH, dissolved oxygen (DO), and turbidity all show significant changes (beyond calibration error) that extend throughout the profile. These data indicate that the Berkeley Pit experienced a turn-over event sometime between May and November 2017. This is an important observation for understanding the chemical evolution of the Berkeley Pit.

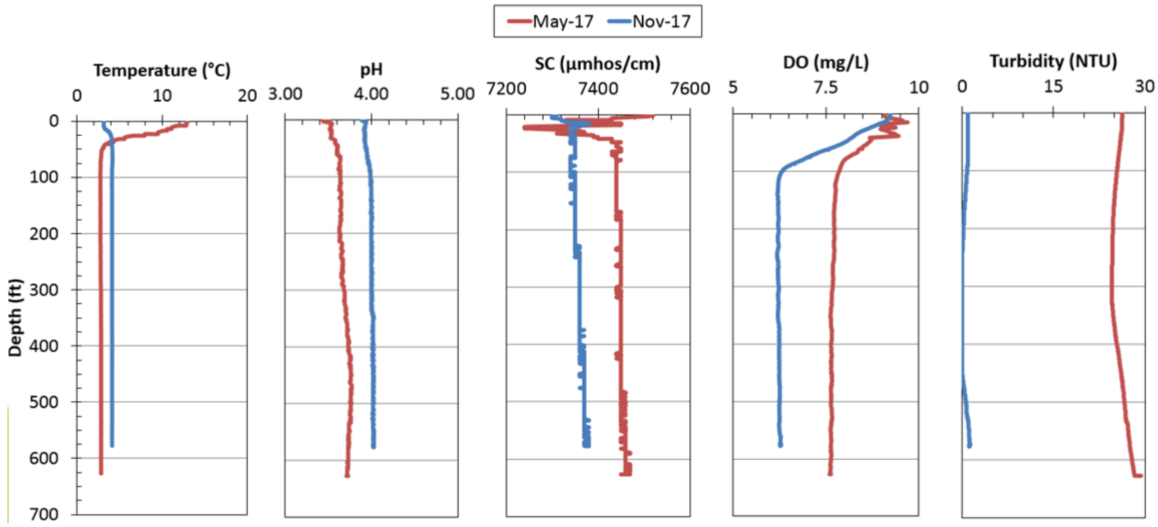

FIGURE 6. Data collected in May and October 2017 for comparison of chemical changes in the Berkeley Pit

CONCLUSIONS

The collection of these profile data and companying water samples demonstrates that the drone boat design works and is capable of collecting the data necessary to monitor the pit chemistry. The boat is versatile in that it can be used to collect large mass samples, it is able to stay on the water for extended periods of time, and can be recovered after a systems failure. In addition to sampling equipment, the boat is easily retrofitted with heavier equipment such as propane cannons and lights/lasers for bird hazing purposes.

Future uses of all unmanned vehicles in mining and remediation are of significant worth. Essentially these vehicles are robots. The primary use for robots include the three D's of Dull, Dirty, and Dangerous. Remediation work can include one or more of these reasons. It is anticipated that the use for robots in the future, but especially in remediation will be a growing field. The Berkeley Pit will need continued monitoring efforts using robotics including this boat and possibly other boats for future uses, and a variety of UAVs.

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