A Multipurpose Unmanned Aerial Vehicle (UAV) for Water Sampling and Mapping a Flooded Mine Pit

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Berkeley Pit

- Located in beautiful Butte Montana
- Former open pit copper mine, now filled with water
- Pit is approximately 1 mile long by ½ mile wide and 800 ft deep
- Contains approximately 50 billion gallons of water
- Water is acidic (~3-4 pH) and has high metals concentrations
- The site is currently on the National Priority List of EPA Superfund Sites
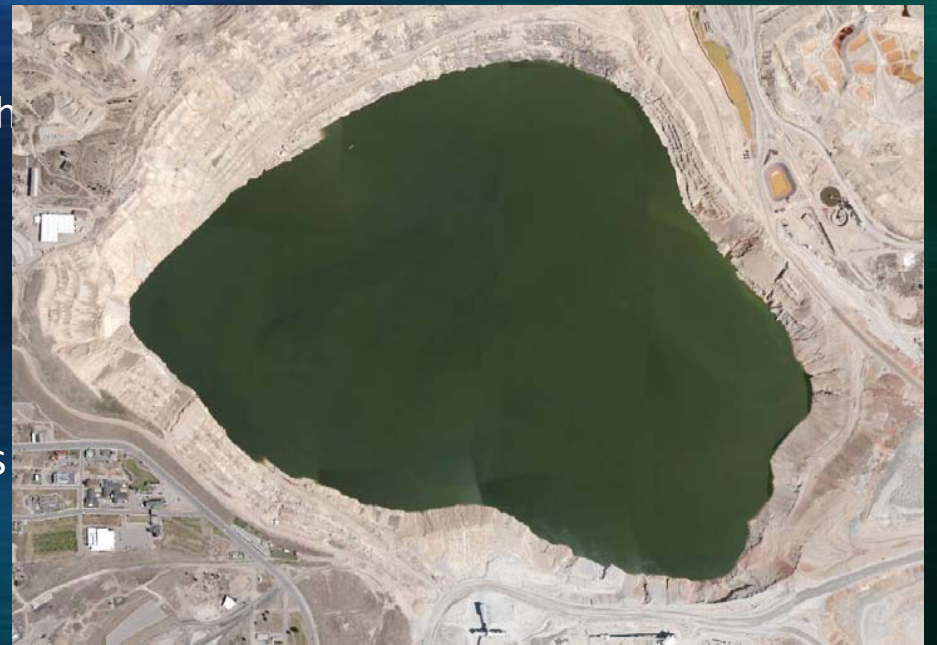
UAV Usage at Berkeley Pit

- UAV's provide an excellent platform for performing small scale aerial imagery data collects
- Variety of commercially available and custom UAV platforms for performing these tasks

  - Team utilizes mapping technologies at various former mining sites for:
    - Monitoring surface spectral reflectance of water
    - Multispectral mapping for vegetation health analysis
    - Mapping surface water thermal anomalies
    - Monitor movement of debris on water surface
    - Mapping of Pit walls for stability analysis/comparison
    - Aggregate pile volume estimation

  - Other uses
    - Collect water samples at various depths at any location in pit
    - Echosounding – depth to bottom sensors
    - Other aqueous monitoring and sensor units

DJI M600 Pro

- Team originally performed mapping of surface water and pit wall topography with DJI Matrice 100
- Team is currently using a modified DJI Matrice 600 Pro
- Reason M600 Pro Chosen
  - Inexpensive
  - Multiple Redundancies
  - High Payload
  - Large user community
  - Built in safety features
  - Parts readily available
  - Easy to fly
  - Large number of flight plan apps available

# M600 Pro Modifications for Mapping

- Originally used DJI X3 RGB camera mounted on M100 for mapping
- M100 provided excellent results, but we required higher resolution
- Upgraded to custom M600 Pro kit
  - Sony A7R 1 camera
  - Sony Sonnar T35 mm f/2.8 ZA lens
  - DJI Z15-A7 Gimbal
  - Onboard microcomputer for triggering camera
  - Microcomputer triggered by MapPilot iOS application

Drawbacks of M600 Pro Kit

- More expensive than M100
- Requires 6 batteries to get similar flight time using 2 batteries on M100
- Larger craft, requires 2 persons to handle travel case
- Sony A7R does not have onboard GPS – Images must be post geotagged to get location – takes long time if time not synced
- Stuck in DJI ecosystem – not much room for customization

- Team is investigating other custom UAV systems with longer flight times and different flight controllers
- This will allow for longer flight times, larger payloads, and easer integration with other sensors such as other RGB cameras, thermal infrared sensors, multispectral sensors, and Lidar

Image Collection

- Missions are planed on iOS or Android mobile device using one of commercially available mission planning apps
- Available mission types include rectangles, polygons, and linear features
- Topography and ground elevation information can be imported so UAV maintains constant altitude above ground surface
- Images can be triggered using waypoints, elapsed time, or distance travelled
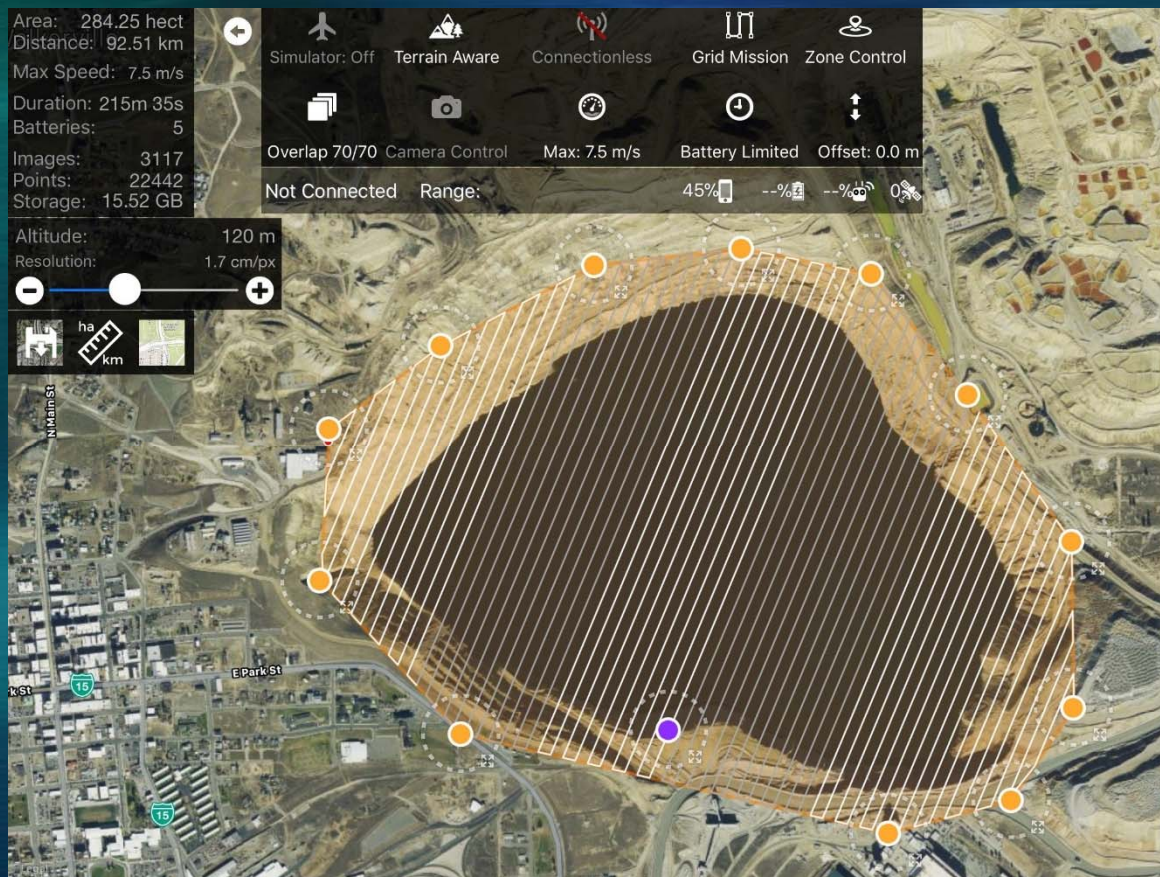
Ground Control Points

- GCPs are used to increase the accuracy of UAV derived data products
- M600 Pro uses a combination of barometer and GPS to calculate altitude
- M600 Pro GPS has an accuracy of ± 3-5 meters

- High precision RTK GNSS units are used to collect location of visible "targets" on ground surface
- Static base station is deployed and a rover unit is used to collect target center location
- The precise location of these targets is used in image stitching
- Accuracy of output imagery using this technique is ± 1-3 centimeters

Image Processing

- Images are downloaded from camera and post-geotagged if necessary (Sony A7R)
- Images and GCP text file are loaded into image stitching software for processing
- Images are auto arranged according to geotagged GPS location – *imprecise*
- A rough first step orthoimage is created
- GCP targets are identified and marked on this rough orthoimage - *precise*
- A Digital Surface Model (DSM), point cloud, and orthoimage are then created
- Point cloud filtered and final data products output
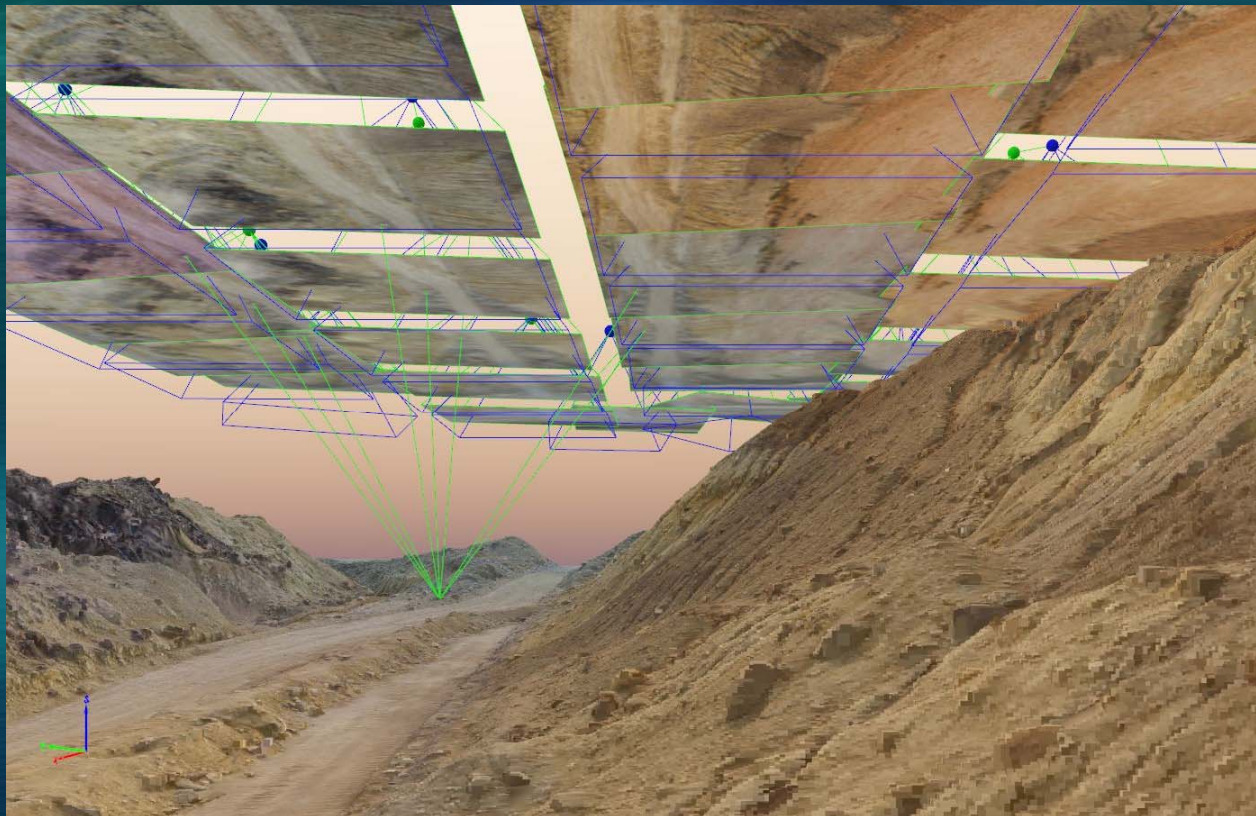
Results of M600 Pro Mapping

Introduction to Water Sampling

- Important to know the chemical composition and properties of water in the Berkeley Pit
- Currently Atlantic Richfield Employees and Contractors are not allowed in boats on the water due to safety risks
- Only way to collect water samples or water quality data is to perform remote collection
- Team decided to modify our existing M600 Pro platform for this purpose
- We proposed to remotely control an off the shelf fishing reel to raise and lower equipment into the pit water


- This will allow us to lower equipment into the water at any location in the pit while keeping all flight electronics away from the hazardous water
- Reel will also allow for "payload" to be transported close to center of gravity of UAV
- Physical water samples will be collected by a Kemmerer collection bottle or hydrosleeves
- Other in-situ data can be collected by other instruments

M600 Pro Modifications for Sampling

- By default M600 Pro has six open channels on A3 flight controller that can be controlled with UAV remote using the additional DJI Channel Expansion Kit
- These channels can be mapped to specific switches and knobs on Channel Expansion Kit

- These channels do not provide power, only a signal
- Each channel requires an individual wire to be routed through UAV body
- Project team developed a "hot swap" control cable and control board so prototypes can be tested and exchanged quickly without disassembling UAV
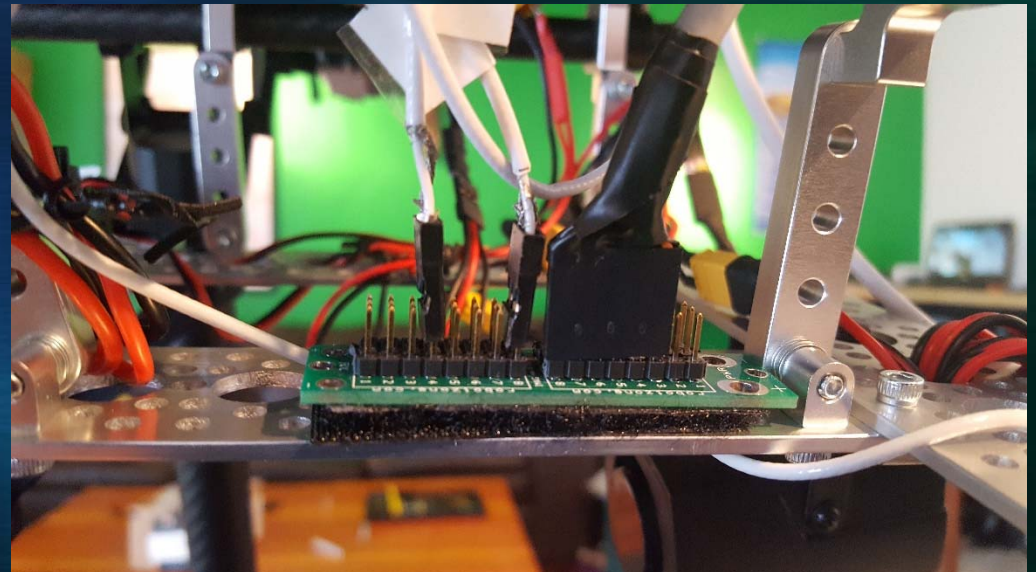
M600 Pro Modifications for Sampling

- Initially we proposed using a continuous rotation servo to power the reel
- Not functional as high torque servo used too much power when holding weight or slowly unspooled
- Discovered a premium planetary gear motor with an encoder to drive the reel
- Reel is geared to motor and we have successfully tested a payload of 6 lbs
- Specialty servos are used to deploy Kemmerer "messenger" and can be used as a line cutter if releasing the payload is necessary
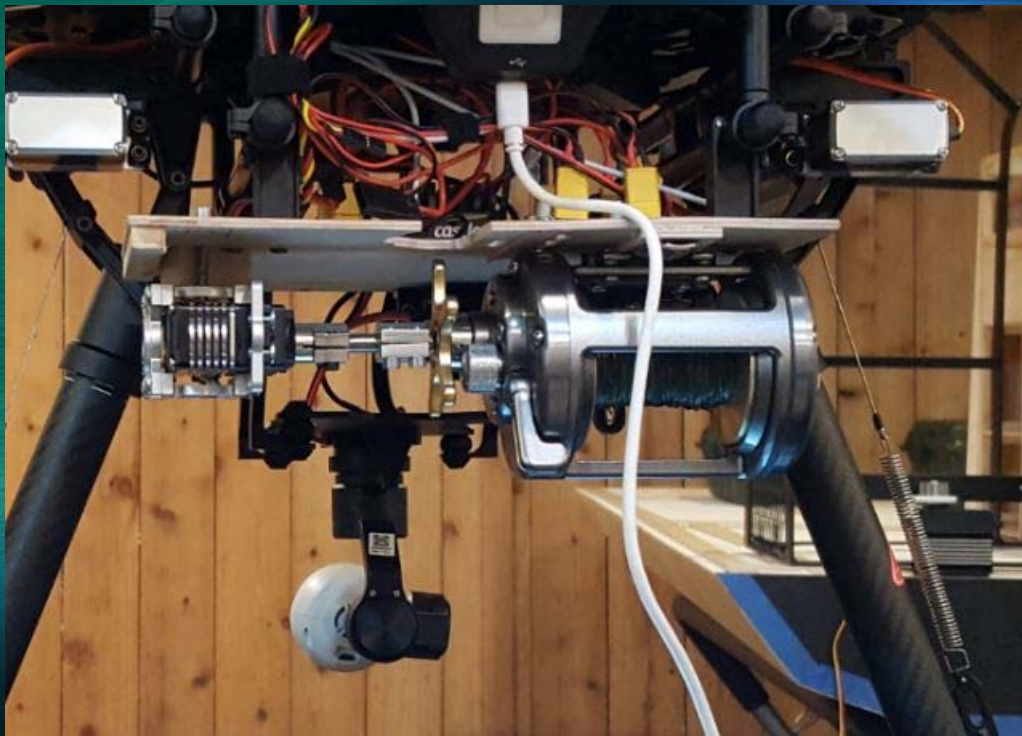
Future Modifications

- Transition to a two operator system
- DJI power distribution board modification to add standard LiPo batteries
- Independent power source for all external electronics
- Different UAV frames and propulsion systems
- RTK GNSS onboard UAV
- Control reel motor with external controls/computer
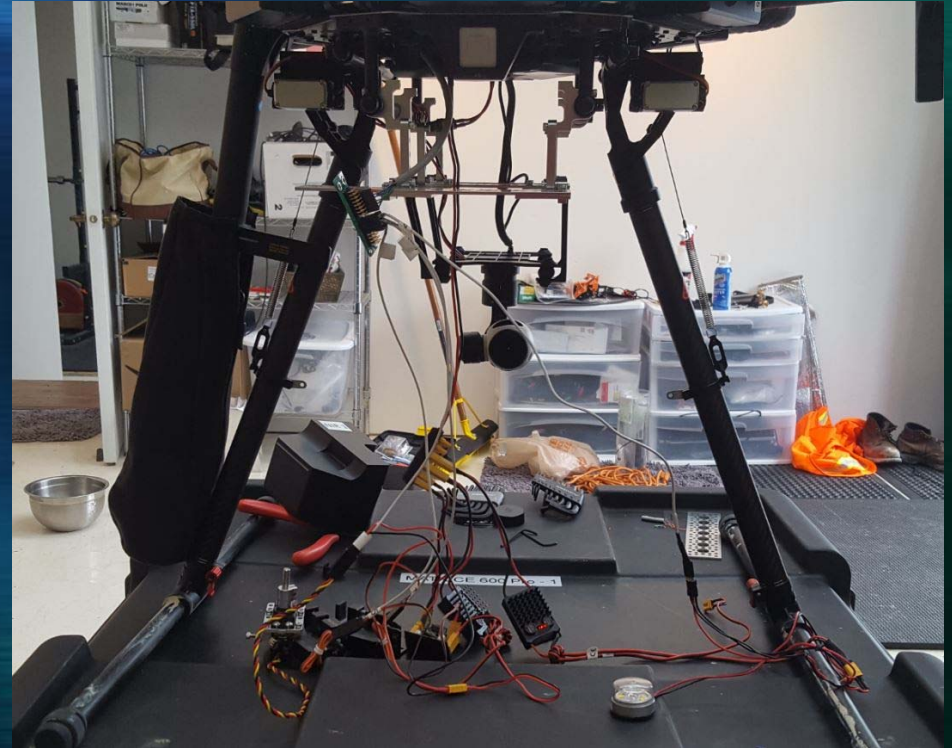
Commercial UAV Challenges

To operate a UAV for commercial purposes you must:

1. Obtain a Remote Pilot license from the FAA
2. Register all UAV's with FAA
3. Follow all of FAA Part 107 Operating Rules:
   - UAV's must weigh less than 55 pounds, including payload, at takeoff
   - Fly in Class G airspace*
   - Keep the UAV within visual line-of-sight*
   - Fly at or below 400 feet*
   - Fly during daylight or civil twilight*
   - Fly at or under 100 mph*
   - Yield right of way to manned aircraft*
   - Do not fly directly over people*
   - Do not fly from a moving vehicle, unless in a sparsely populated area*
4. Airspace waiver took 6 months to attain for Berkeley Pit
5. Maintenance and logbook

UAV Challenges Berkeley Pit

- Berkeley Pit lies entirely within Class E airspace, an airspace waiver is required to fly here
- Pit encompasses large area ~675 acres
- Entire site is at high elevation ~5500 ft
- Inclement weather often present
- Remote location in Montana, raptors and waterfowl sometimes present
- Radio interference with other mining operations
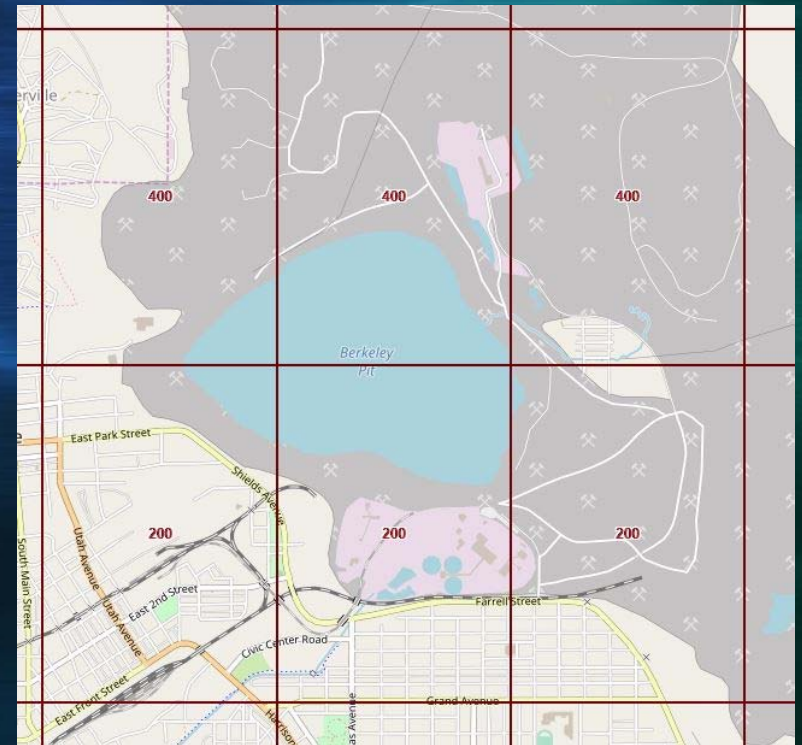
Closing

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