Drone-Based Geophysical Surveying and Real-Time AI/ML Analysis for Sustainable Production of Critical Minerals

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SUMMARY

New approaches are needed for rapid characterization of secondary mineral resources and waste streams to support real-time management of field operations. To this end, we are developing instrumentation, data processing and analysis tools, and cloud-based software for data management and results delivery for electromagnetic (EM) geophysical imaging conducted from unoccupied aircraft systems (UAS) (Figure 1) potentially involving air-to-air and air-to-ground and configurations (Figure 2).

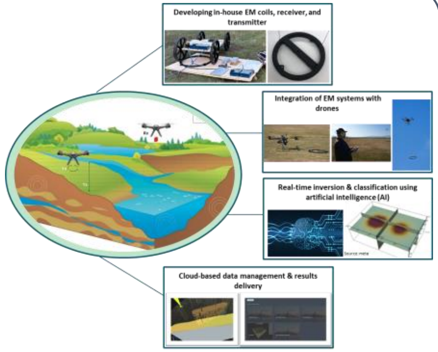

Figure 1. Schematic showing the R&D tasks required to achieve UAS-based, real-time EM imaging and automated interpretation. The project includes R&D related to instrumentation, rigorous 3D FDEM simulation on high performance computers, AI-based real-time data analysis and automated interpretation, and management and delivery leveraging Amazon Web Services.

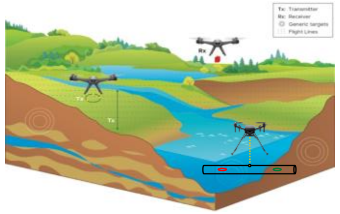

Figure 2. Schematic showing single drone, drone-to-drone, and surface-to-drone configurations.

EM MODELING

- pGEMINI (**P**arallel **G**eophysical **E**lectromagnetic **M**odeling and **I**nversion of **N**atural and **I**nduced sources) (Figure 3)
- Massively parallel software that can simulate and invert EM data for controlled-source EM, airborne EM, ground EM, and magnetotelluric data
- Capability to represent metallic infrastructure to account for impact on EM data (Figure 4)

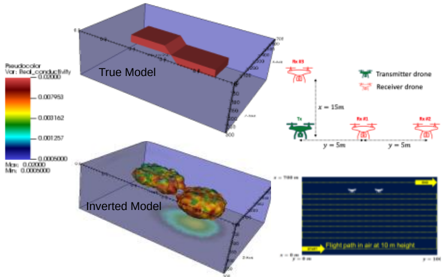

Figure 3. Synthetic example with true model (top left), inverted image (bottom left) for FDEM data acquired using a transmitter and multiple receivers on UAS.

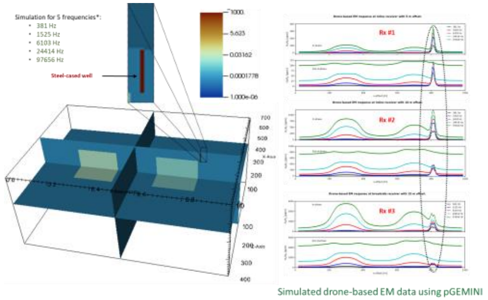

Figure 4. Synthetic example showing the capability within pGEMINI to simulate EM data in the presence of discrete, highly conductive metallic features (e.g., a steel-cased well). This provides a basis for accounting for metallic infrastructure on multi-frequency EM data.

INSTRUMENTATION

- Development of novel multi-frequency EM acquisition technology with physically separate transmitter & receivers (Figure 5)
- Hardware supports use of multiple receivers
- Transmitter can be ground-based or airborne
- Tested in ground-based field tests at PNNL (Figure 6)

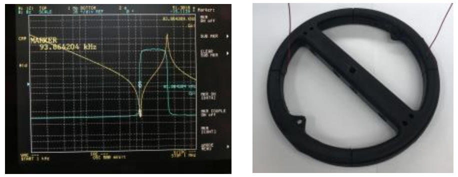

Figure 5. Photograph of transmitter testing data (left) and wound receiver coil (right).

Figure 6. Photographs of field tests of the new multi-frequency EM data acquisition system at PNNL. The transmitter (large antenna) was stationary and the transmitter (small antenna) roving. Data acquisition was controlled, and data were transmitted to a field laptop running custom software.

REAL-TIME CLOUD-BASED PROCESSING AND DATA MANAGEMENT

- RTK GPS, radio TCP communication, orientation sensors
- Data management using HDF5 and AWS
- Custom GUI on the field laptop (Figure 7) and cloud-based interface to data and results (Figure 8)
- Real-time analytical correction to remove the primary field (Figure 9)
- Real-time visualization of data tracks
- Extraction of hyperspectral (or other) data from pre-loaded satellite or drone-based data products

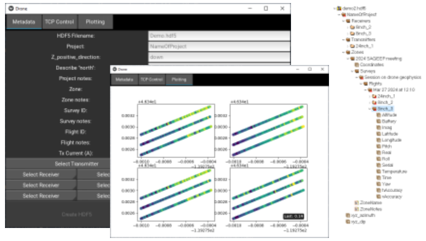

Figure 7. Custom GUI for field operations (left), which manages the local copy of the HDF5 database (right), controls communications with the instrumentation, and provides visualization of raw data as it's collected.

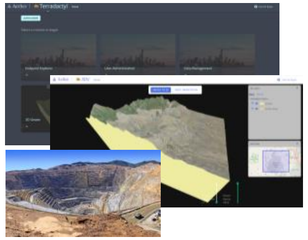

Figure 8. Screen captures from the cloud-based Terradactyl web interface.

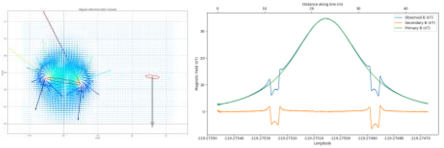

Figure 9. Analytical model for primary field (left), allowing for arbitrary transmitter/receiver offset and orientation, and application of the correction to data from field tests (right).

AI/ML-Based Inversion & Classification

- Deep-learning (CNN) algorithms trained to reproduce EM inversion codes for 2D soundings (Figure 10)
- Inversion of one million soundings takes several minutes on a laptop
- Using deep neural networks also for classification (e.g., ore-grade vs. non-ore grade) based on multi-sensor data

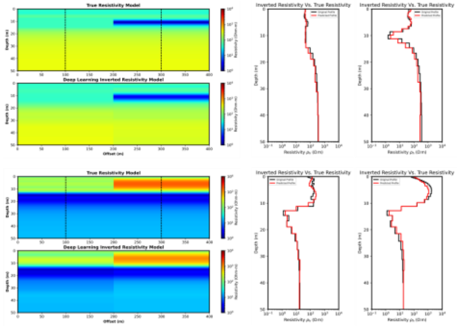

Figure 10. Synthetic examples for two different geologic models, showing simulated and inverted cross sections (first column) and true and inverted resistivity at two sounding locations (second and third columns).

FIELD DEMONSTRATION

- Field testing of the instrumentation has been ground-based (Figure 6)
- Field testing of UAS flying antenna coils without working electronics (Figure 11)
- All 'blue' technology (drones & payloads)
- Planning field demonstration with mining company and potential industry partner

Figure 11. Photographs of UAS field tests using 'dummy' geophysical payloads consisting of transmitter and receiver coils without electronics. A winch is used to control the drone-antenna offset.

STATUS

- Planning local field tests of UAS flying operating transmitters and receivers this quarter
- Aurelia X8 (Figure 12) on order for field demonstration, arriving in ~ 2 weeks
- Planning field demonstration with mining company
- Talking to prospective drone industry partner to demonstrate commercial potential and possibly enable a second field demonstration

- Diameter: ....6 ft (183 cm)
- Nominal Weight With Battery: 28.4 lb (12.9 kg)
- Maximum Takeoff Weight: ....52.9 lb (24 kg)
- Nominal Payload Weight: ....24.25 lb (11 kg)
- Nominal Max Flight Speed: ......35 mph (56 km)
- Nominal Flight Time
  - Full Payload: 25 minutes
  - No Payload: 50 minutes
- Nominal Maximum Distance Traveled
  - Full Payload: 14.5 mi (23 km)
  - No Payload: 29.1 mi (46.8 km)

Figure 12. Aurelia X8 photograph and specifications.

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Questions? Fred Day-Lewis @ frederick.day-lewis@pnnl.gov

Simulation for 5 frequencies*:

- 381 Hz
- 1525 Hz
- 6103 Hz
- 24414 Hz
- 97656 Hz