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Integrated UAV and Ground Vehicle Semi-airborne EM System for Groundwater Estimation

A Project White Paper

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This white paper provides a comprehensive overview of the importance of groundwater, the challenges in its estimation, and a proposed system featuring AEM technology for deployment by both drones and ground vehicles.

Introduction

Groundwater is a cornerstone of global food and water security, constituting 35 percent of global water use, 33 percent of irrigation water, and meeting the drinking water needs of over 2 billion people. However, the dual pressures of climate change and population growth are putting immense stress on these vital resources. Dry and semi-dry regions increasingly rely on groundwater during droughts, but worsening droughts driven by climate change and excessive groundwater extraction threaten the sustainability of aquifers that support large populations and economies globally. Accurate and timely assessments of groundwater storage changes are urgently needed to promote groundwater sustainability and bolster drought resilience [1].

Challenges in Groundwater Estimation

Effective groundwater management requires precise monitoring of groundwater changes over time and at appropriate spatial scales. Long-term groundwater estimates with regular sampling intervals are essential for understanding seasonal variations, long-term trends, and the overall condition of groundwater systems. Various techniques such as groundwater monitoring wells, ground based resistivity measurements, and airborne electromagnetic (EM) surveys, are used to estimate groundwater at different scales. Despite these diverse techniques, achieving accurate and timely groundwater estimates remains challenging globally, particularly in areas where monitoring wells are limited. Moreover, monitoring wells are expensive to install and often lack comprehensive spatial and temporal coverage.

EM geophysical exploration aims to map the distribution of electrical conductivity in the subsurface, covering depths ranging from a few meters to over a kilometer based on the application. The electrical conductivity at these depths is largely determined by the presence of pore fluids, pore connectivity, metallic conductors like ore deposits, and the concentration of clay minerals. All EM methods use EM induction to measure the Earth's response to a varying EM field or current. A key benefit of EM induction methods is their ability to detect field responses from above ground level, allowing airborne EM surveys to cover large areas quickly. However, manned aircraft operations are expensive and limited to specialized entities [2].

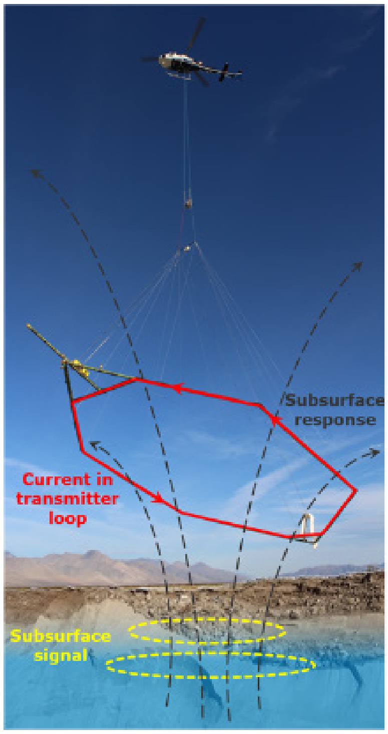

Figure 1. Illustration showing how the AEM works [2]

Semi-airborne EM involves using powerful ground-based transmitters and a passive sensor platform that measures the induced magnetic field while flying over the area of interest. Due to the separation of transmitter and receiver and the dependence on a land-based EM source, this procedure is called semi-airborne EM [3].

The semi-airborne EM method has gained interest for its ability to explore deeper targets and higher efficiency compared to other methods. The Unmanned Aerial Vehicle (UAV) implementation leverages advancements in multi-copter technology to offer high spatial survey granularity, reduced costs, and ease of use. Despite challenges like payload and flight duration, UAVs provide flexible flight speeds and altitudes, making them viable for semi-airborne EM surveying and a potential alternative or complement to traditional manned airborne surveys.

Proposed System

Current semi-airborne EM methods rely on a stationary transmitter at a fixed location, and then it must be manually relocated to subsequent positions. To address these challenges, we propose developing a semi-airborne EM system deployable by a single drone for deploying the receiver and enabling dynamic, automated configuration of the transmitter. This can be achieved by utilizing ground vehicles for mobile transmitters. The ground vehicles will be utilized to generate an EM field, while the drone tracks them and receives the reflected signals. This method advances existing semi airborne EM systems that rely on fixed ground-based transmitters, utilizing advancements in UAV and EM technologies to offer a cost-effective, flexible, and high-resolution solution for groundwater estimation.

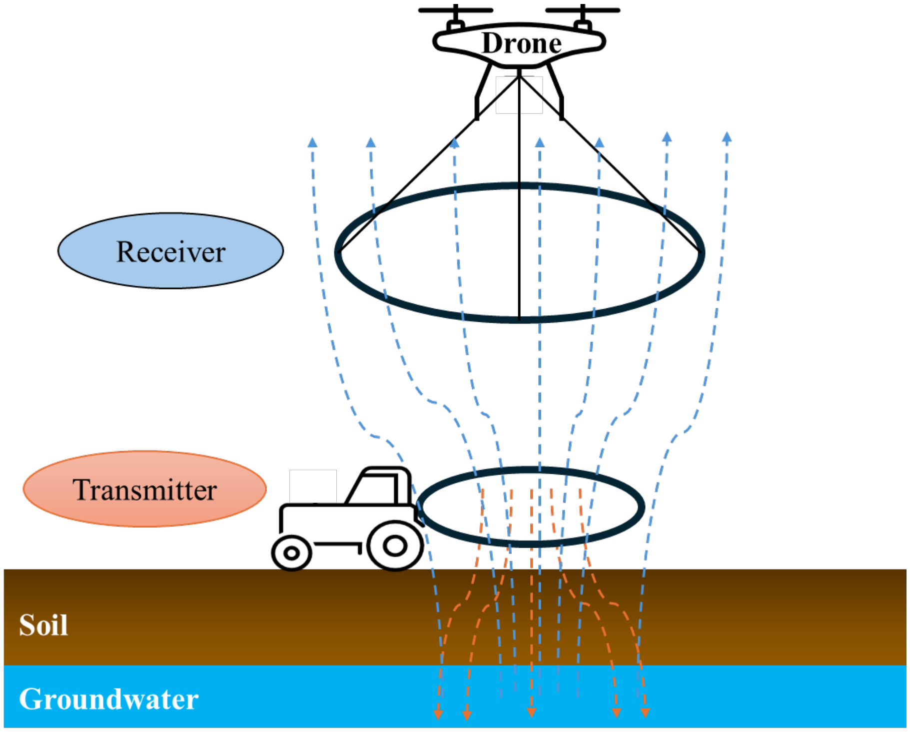

Figure 2. Schematic of the proposed system configuration

Advantages of the proposed system:

1. **Cost-Effective:** Utilizing UAVs and ground vehicles reduces the operational costs compared to traditional manned aircraft systems and current semi-airborne EM systems.
2. **Flexibility:** UAVs provide the ability to conduct surveys in difficult-to-reach or hazardous areas, and ground vehicles provide dynamic access to various locations, providing comprehensive spatial coverage.
3. **High-resolution:** The combination of UAVs and ground vehicles enhances the spatial resolution of the surveys, allowing for more precise data collection.
4. **Scalability:** The system can be easily scaled to cover larger areas or adjusted for more localized studies, providing versatility in application.
5. **Customizable and Versatile:** UAVs and ground vehicles offer adjustable scan speeds, customizable altitudes, and flexible maneuvers, allowing survey parameters to be tailored to meet specific project requirements.
6. **Autonomous Operation:** The proposed system enables automated groundwater estimation, as both the UAV and ground vehicles can operate autonomously.
7. **Commercialization Opportunity:** Once the proposed system is validated, the components can be readily obtained and integrated to complete the operational system. This system can be either commercialized independently or in partnership with established geoscience exploration companies, such as Collier Geophysics and AquaterreX [4, 5].

The proposed system has strong commercialization potential mainly in groundwater estimation, also, it can be extended to other sectors like environmental monitoring, resource exploration, and infrastructure development. The system's scalability and customization options allow it to be tailored to different project needs, while its autonomous operation offers faster, safer, and more efficient data collection in challenging environments.

Scope of Work

The main tasks for completing the development of the proposed system are as follows:

Design and procure the UAV: This involves designing a UAV platform that meets the project's requirement for payload capacity, maneuverability, and autonomous flight capabilities.

Design and procure the ground vehicle: The ground vehicle must be designed or selected based on terrain adaptability, payload capacity, and compatibility with the EM transmitter. It should support autonomous operation, including path tracking and obstacle avoidance, to ensure precise deployment and retrieval of the EM equipment.

Acquire the EM transmitter and receiver: Identify and acquire an EM transmitter and receiver that meet the project's specifications for data range, signal strength, and environmental compatibility. The transmitter will be mounted on the ground vehicle and the receiver on the UAV.

Integrate the EM transmitter into the ground vehicle: This step involves securely mounting the EM transmitter onto the ground vehicle, ensuring its stability during operation. Also, it includes the electrical and mechanical integration of the transmitter with the vehicle's power supply, control system, and communication modules.

Develop an autonomous strategy for deploying and retrieving the EM transmitter from the ground vehicle: Create algorithms and control strategies that enable the ground vehicle to autonomously deploy the EM transmitter at designated locations and retrieve it after completing measurements. The system should be capable of executing these tasks without manual intervention, using predefined paths or real-time decision-making based on environmental conditions.

Design and implement the mechanism for deploying and retrieving the EM transmitter on the ground vehicle: Develop a physical mechanism that can automatically deploy and retrieve the EM transmitter. The design must ensure minimal interference with the vehicle's mobility and operation efficiency.

Integrate the EM receiver onto the UAV: This step includes mounting the receiver securely, connecting it to the UAV's power and communication system, and ensuring proper shielding from any EM noise generated by the UAV itself.

Develop path planning and tracking algorithm for the UAV and ground vehicle: This step involves creating advanced algorithms for both the UAV and the ground vehicle to navigate semi-autonomously or autonomously. Path planning algorithms must account for terrain, obstacles, and the need for coordinated movements between the UAV and the ground vehicle. Tracking mechanisms should enable both platforms to follow precise routes while maintaining synchronization, ensuring accurate data collection.

Plan and organize indoor and outdoor testing phases: Develop a detailed testing plan to evaluate the system's performance in both controlled indoor environments and real-world outdoor conditions. This includes identifying appropriate testing locations, setting performance benchmarks, and ensuring that all safety protocols are in place.

Execute testing procedures and evaluate performance: Conduct the planned tests, carefully observing the system's performance in deploying, retrieving, and collecting data using an EM transmitter and receiver. The testing phase will also include assessing system scalability, robustness, and the ability to perform in varied environmental conditions.

Process and validate the collected data: Analyze the data gathered by the system. This involves applying advanced signal processing techniques to enhance data quality and extract meaningful information. Use geophysical models and validation methods to ensure the accuracy and reliability of the results, correlating the processed data with known geological information for further verification.

Proposed Schedule

Planned Task	Estimated Completion Time
Contract initiation	3 months
Design and procure the UAV	2 months
Design and procure the ground vehicle	3 months
Acquire the EM transmitter and receiver	1 month
Integrate the EM transmitter into the ground vehicle	2 months
Develop an autonomous strategy for deploying and retrieving the EM transmitter on the ground vehicle	2 months
Design and implement the mechanism for deploying and retrieving the EM transmitter on the ground vehicle	3 months
Integrate the EM receiver onto the UAV	1 month
Develop path planning/tracking algorithms for the UAV and ground vehicle	2 months
Plan and organize indoor and outdoor testing phases	2 months
Execute testing procedures and evaluate performance	8 months
Process and validate the collected date	3 months

Detailed Budgest Estimate

The table below provides an estimated cost breakdown for the key components of the proposed system.

Component	Estimated Cost
UAV	$15,000
Ground vehicle including the EM transmitter mounting	$35,000
EM transmission components (e.g. generator, transmission lines, etc.)	$15,000
EM receiver components (e.g. receiver loop, recorder, etc.)	$20,000
Software and licenses	$20,000
Miscellaneous	$15,000
PI effort/salary	$60,000
Co-PI effort/salary	$60,000
Student/researcher/assistant salaries	$40,000
Total Cost	$260,000

Conclusion

This white paper highlights the critical role of groundwater in global food and water security, outlining the pressing need for accurate and timely groundwater estimates amidst growing challenges. It underscores the limitations of current methods and introduces the semi-airborne EM system based on UAVs and ground vehicles as a promising solution. By utilizing UAVs and ground vehicles, this approach offers a cost-effective, flexible, and high-resolution method for groundwater estimation. The proposed system's advantages include enhanced spatial resolution, scalability, customization, and autonomous operation, making it a viable alternative to traditional methods and essential for sustainable groundwater management.

References

[1] United Nations Educational, Scientific, and Cultural Organization, UN-Water 2022, United Nations World Water Development Report 2022: Groundwater: Making the Invisible Visible. Retrieved from: https://www.unwater.org/publications/un-world-water-development-report-2022.

[2] California Department of Water Resources. (n.d.). Airborne Electromagnetic (AEM) Surveys. Retrieved from https://water.ca.gov/programs/sgma/aem

[3] Kotowski P.O., Becken M., Thiede A., Schmidt V., Schmalzl J., Ueding S., and Klingen S., "Evaluation of a Semi-Airborne Electromagnetic Survey Based on a Multicopter Aircraft System," Geosciences 2022, 12(1), 26. https://doi.org/10.3390/geosciences12010026

[4] Collier Geophysics, Groundwater Geophysics. Retrieved from https://colliergeophysics.com/applications/groundwater/

[5] AquaTerrex, Our Technology. Retrieved from https://aquaterrex.com/our-technology/

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