Enhancing Mining Efficiency and Safety with Autonomous Drone Technology

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Abstract

Recent technological advancements, particularly in the domain of autonomous drones, have catalysed a transformative era in the fields of volumetric analysis and geotechnical observations. These advancements have opened up opportunities for gathering data in areas that were once difficult to access, sparking a significant transformation in the mining industry. This study investigates the capacity of the "MagArrow," a drone-based Magnetometer, to conduct geophysical surveys aimed at identifying valuable mineral deposits. The MagArrow is distinguished by its remarkable precision and cost-effectiveness. Furthermore, this paper meticulously delineates a comprehensive methodology for deploying drone-based Ground Penetrating Radar (GPR) as a non-destructive geophysical technique for prospecting. GPR excels in delivering intricate subsurface information with exceptional cost-efficiency and efficacy, especially when coupled with other geophysical modalities such as magnetic and electromagnetic surveys. Finally, the paper introduces the Hovermap platform, a cutting-edge autonomous mapping solution founded on Simultaneous Localization and Mapping (SLAM) technology, meticulously tailored for underground mining applications. Hovermap not only amplifies accessibility and data security but also emerges as an indispensable tool for augmenting mining operations and fortifying safety protocols through the integration of specialized payloads. Utilizing drones for mapping has significantly enhanced both the safety and efficiency of workflow processes. The MagArrow technology has amplified cost-effectiveness and efficiency when it comes to delineating mineralized zones during mineral exploration. Ground-penetrating radar (GPR) stands out as a non-invasive technology for efficiently mapping geotechnical and lithological features, particularly in shallow-depth mineral exploration. The introduction of autonomous drones into the mining sector not only enhances safety for both humans and machinery but also streamlines and boosts the overall efficiency of the mining process.

Keywords: Drone Based; Hovermap; MagArrow; Ground Penetrating Radar

Introduction

Geophysical Survey Using Drone-Based Magnetometer – MagArrow: The purpose of this article is to explore the potential of using a drone-based Magnetometer - MagArrow for the exploration of mineral deposits through drone-based geophysical exploration. This study will focus on evaluating this method's accuracy, effectiveness, and cost-effectiveness of this technology. Geophysical studies were carried out using a drone-based magnetometer (MagArrow) at a known test site for Critical Mineral deposits by Squadrone Infra and Mining Private Limited. In every case, drone magnetometers have many scientific benefits in the basket. The advanced technology of the cesium vapor helps in identifying the magnetic intensity of the earth's magnetic field which also helps in omitting the unwanted areas for drilling or mineral exploration.

Geophysical Survey Using Drone-Based Ground Penetrating Radar (GPR): Prospecting using drone-based ground penetrating radar (GPR) is a geophysical method that transmits electromagnetic waves underground and measures the reflected signal to identify subsurface features, including non-ferrous minerals. Drone-based GPR works by sending high-frequency electrical signals to the ground using a transmitting antenna. The pulse travels on the ground and interacts with the underground data, returning to where it was detected by the antenna. The reflected signal is then processed to create an image of the underground. The minerals have dielectric properties that differ from the surrounding rocks and soil, which can cause them to reflect electromagnetic (EM) waves differently and create a unique signature. This signature can be used to identify the presence of non-ferrous minerals.

GPR is a non-destructive method that can provide detailed information about subsurface features, including their depth and dimensions. It can be used in many places, especially in rocky terrain and green areas. It is also fast and cost-effective compared to traditional drilling and sampling methods. The transmitted EM signal is also attenuated or scattered by certain ground materials such as clay or water. Additionally, GPR surveys require trained personnel and specialized equipment, increasing research value. GPR has shown great results as a mineral exploration tool, especially when combined with other geophysical methods such as magnetic and electromagnetic surveys. This article aims to contribute to the growing research on drone-based technologies for mineral exploration by using drone-based Magnetometer and drone-based Ground Penetrating Radar.

Evolution of Hovermap: Underground mining operations are perennially plagued by an array of formidable accessibility challenges. Mines grappling with additional complexities, such as the ever-present specter of seismicity, finding effective hazard management, an even more Herculean task. Over the past few decades, a noticeable decline in companies' willingness to subject their workforce to such perilous conditions has become increasingly apparent. Simultaneously, the growing emphasis on safety has translated into heightened demands on labor, time, and costs associated with conducting additional inspections.

In this milieu, the development of an autonomous drone-based mobile mapping platform emerges as a pragmatic and imperative solution to these multifaceted challenges. This innovative platform facilitates remote data acquisition from areas that would otherwise remain inaccessible due to pressing safety concerns, thereby enabling inspection and analysis without imperiling the well-being of personnel. The transformative solution presented herein involves the integration of a specialized payload, equipping commercially available drones with the capacity to navigate seamlessly in GPS-denied environments. This ensures the secure acquisition of vital data in the harshest and most hazardous terrains. In essence, this approach not only serves as a potent risk mitigator but also serves to optimize mining operations, paving the way for safer and more efficient practices within the mining industry.

Materials and Methods

Methodology of Drone-Based Geophysical Survey Using MagArrow for Mineral Exploration: Drone-based geophysical surveys using magnetometers are becoming increasingly popular for mineral exploration, and environmental and archaeological research.

Nonferrous metal minerals such as copper, gold, silver, and zinc often have strong magnetic fields due to the presence of iron-bearing minerals in their geological setting. By measuring the magnetic gradient, the MagArrow can pinpoint the location of minerals.

MagArrow is based on a Cesium vapor magnetometer which is highly sensitive, stable, and has the ability to measure both the magnitude and direction of the magnetic field. Flight routes should cover the entire target area with sufficient overlap between adjacent flight routes. The drone must maintain altitude and speed at all times, and magnetometers must be calibrated before each flight. Make sure the areas your drone can fly in are safe and legal.

The collected data are processed with special software to remove background noise and extract magnetic anomalies caused by minerals. The resulting data can be displayed as contour plots or 3D models to visualize the distribution and intensity of mineral deposits. Interpretation of the processed data to identify areas of potential mineralization and prioritize further exploration. Additional geological and geophysical data can be combined for better interpretation. Drone-based geophysical surveys using magnetometers are just one tool in mineral exploration, and results should be confirmed by surface surveys and other exploration methods. An in-depth understanding of the geological setting and expected pattern of mineralization of the area is essential to ensure the effective development and execution of exploration programs.

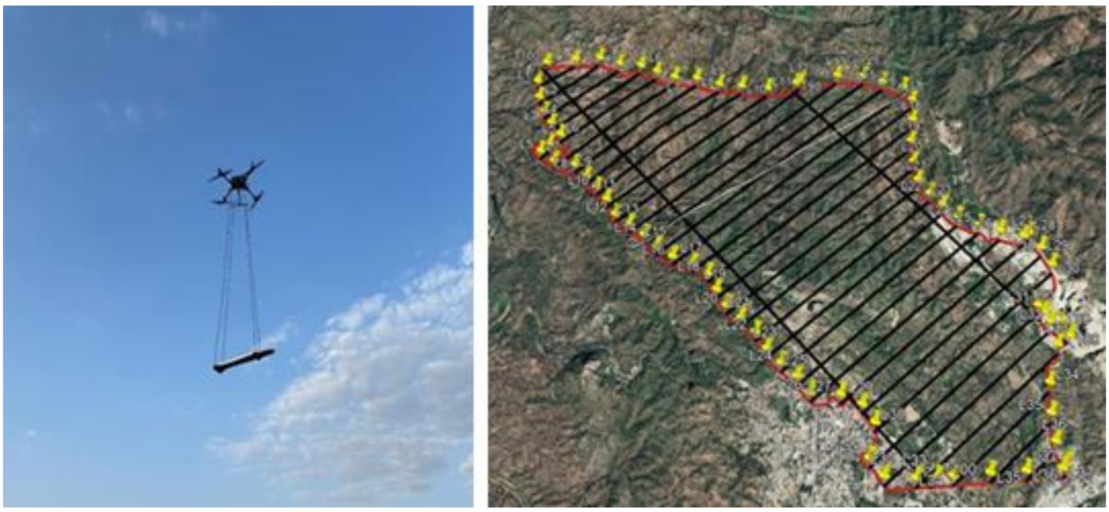

Fig. 1 (Left) Drone Based Magnetometer MagArrow. (Right) Illustration of flight path.

Methodology of Drone-Based Geophysical Survey using Ground Penetrating Radar (GPR) for Mineral Exploration:

Drone-based geophysical exploration using ground-penetrating radar (GPR) for mineral exploration can provide valuable data for identifying underground mineral deposits.

Ground Penetrating Radar (GPR) is a non-invasive geophysical method used to image and detect objects or subsurface features by sending electromagnetic pulses into the ground and analyzing the reflections that bounce back. It's commonly used for mineral exploration, archaeological, geological, environmental, and engineering applications.

GPR system consists of a transmitter and a receiver antenna. The transmitter emits short bursts of electromagnetic waves, typically in the microwave frequency range. Electromagnetic waves travel through the ground and encounter different materials with varying electrical properties, such as soil, rocks, water, and buried objects, they behave differently.

Drones equipped with GPR can cover a wide area quickly and efficiently. This is particularly useful for large-scale surveys or areas that are difficult to access on foot or with vehicle. Aerial GPR can provide high-resolution imaging of the subsurface due to the ability to maintain a consistent height above the ground and cover the survey area systematically.

Drone-based GPR systems offer real-time data analysis, allowing operators to make informed decisions during the survey itself. Combining drone-based GPR with other technologies such as LiDAR (Light Detection and Ranging) can create accurate 3D maps and visualizations of subsurface features, enhancing the understanding of the surveyed area.

Fig. 2 Drone based ground penetrating radar GPR.

Fig. 3 (Left) Drone Mounted Hovermap. (Middle) Handheld Hovermap/Bag pack. (Right) Car mounted Hovermap.

(a) Methodology of Drone-Based Hovermap: To effectively employ Hovermap with a drone for data collection and obstacle avoidance, follow a defined sequence. First, securely attach

Hovermap to the drone. Power on the drone to initiate Hovermap. Establish a Wi-Fi connection between a tablet and Hovermap for control. Ensure the operator's safe location away from hazards. Access tablet settings for collision avoidance and Visual Environment Sensing and Avoidance (VESH) configurations. Assign a unique operation name. Hovermap begins with an initial scan, creating a localized map. Carefully take off and guide the drone to waypoints or a rally points. Hovermap, using Simultaneous Localization and Mapping (SLAM), autonomously detects and navigates around obstacles. As the drone reaches the target area, it maximizes coverage of the Area of Interest (AOI). A live point cloud data feed is sent to the tablet for real-time monitoring and adjustments. This visual feedback ensures comprehensive coverage. When satisfied with the scan's extent, command the drone to return home. It efficiently retraces its path, avoiding obstacles. Upon a safe landing, the mission is a success, providing secure and comprehensive data collection through Drone-based Hovermap integration.

(b) Methodology For Handheld Hovermap: To deploy the Hovermap system effectively, it's essential to ensure proper setup and operation, tailored to the specific requirements of the mission. Initially, the Hovermap device should be securely mounted in the appropriate configuration, either handheld using a handle or attached to a backpack, which is particularly useful for longer scan times or when traversing challenging terrain. The power source is provided by the battery connected to Hovermap via a cable. Establish a Wi-Fi connection between Hovermap and a tablet for data visualization and control. Once the connection is established, assign a mission name and commence the operation. Proceed along the designated path that covers the target area, adjusting the walking pace to align with the desired level of resolution and detail needed for the task. A live feed of the visualization will be displayed on the tablet connected to Hovermap, facilitating real-time monitoring. During this phase, it's important to be vigilant for any potential blind spots in the scan coverage and take corrective action as required to ensure comprehensive data collection. Upon successful coverage of the target area, cease the scanning process, and disconnect the power supply to Hovermap. With these steps completed, the mission can be considered successfully accomplished, with data collected as needed for further analysis and evaluation. This approach allows for flexibility in data collection, accommodating different terrain conditions and scan duration requirements.

(c) Methodology for Vehicle-Mounted Hovermap: To effectively integrate the Hovermap system with a vehicle for data collection, a series of meticulous steps should be followed. Begin by securely attaching the specialized mountings designed for Hovermap to the vehicle. It's crucial to ensure that these mountings are strongly affixed, and it's advisable to perform a double-check to confirm their stability. Once the mountings are in place, proceed to mount the Hovermap device onto these fixtures, taking care to secure it adequately. If necessary, provide additional support to ensure that the device remains stable during the operation. Next, establish a reliable power supply for Hovermap by connecting it to a battery via the appropriate cable. Ensure that the connection is secure to prevent any interruptions during the mission. Establish a Wi-Fi connection between Hovermap and the tablet for data visualization and control. With the connection successfully established, assign a mission name and initiate the operation. It's important to adhere to a speed limit of no more than 20

km/h for optimal results during data collection. This controlled speed allows for accurate data acquisition and minimizes potential inaccuracies in the scan. As the vehicle moves through the Area of Interest (AOI), Hovermap will collect the required data. Once the designated AOI is completely covered, halt the scanning process, and proceed to safely unmount the Hovermap device. Following these meticulous steps ensures a systematic and effective approach to vehicle-based data collection using Hovermap, facilitating precise and comprehensive results.

Results

Results for Drone Based Magnetometer (MagArrow):

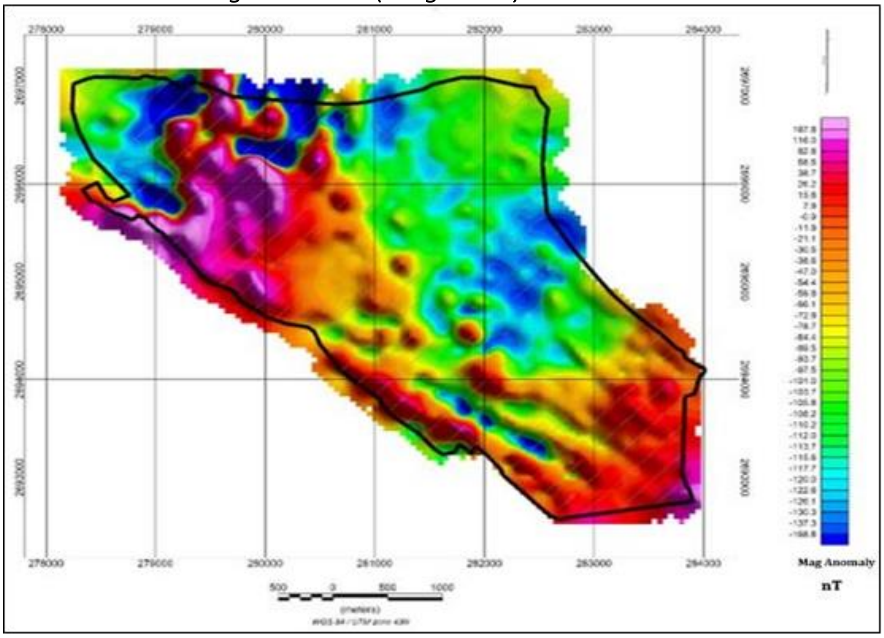

Fig. 4 Drone-based Magnetic Anomaly Map.

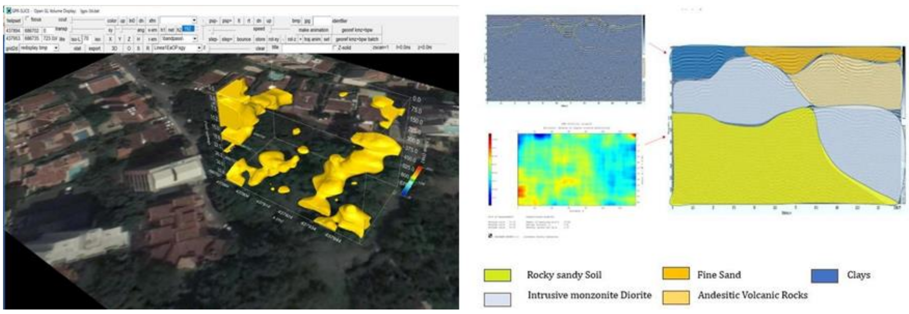

Fig. 5 (Left) Isosurfaces in 3D highlighting anomalies. (Right) The output from the GPR data captured shows the different lithological values of permittivity.

Advantages of Drone-Based Magnetometer:

- Efficient in Critical Mineral prospecting in severe terrain, harsh Deserts, and inaccessible areas.
- Mineral Prospecting in thick forests without disturbing the ecology
- Mineral Prospecting in densely populated areas-villages, towns, without entering the area.
- Very high-resolution outputs with LOW-flying SLOW-flying.

- No approach roads required
- Precision flying in harsh terrain Excellent for highly detailed magnetic survey, water detection, boreholes, well detection Centimetres data sampling intervals
- Fully autonomous flight of Magnetic sampling at 1000 samples per second

Results for Drone-Based Ground Penetrating Radar (GPR):

Advantages Drone-Based Ground Penetrating Radar (GPR):

- Lithological Characterization and Stratigraphic Modelling
- Tailing dam in mines ((Strength & Leakage analysis))
- Cavity – land//underground monitoring
- Mineral prospecting.
- Detection of Underground tunnels, Structures, and pipe leakages.
- Stability Analysis and Subsidence Evaluation

Hovermap Outputs:

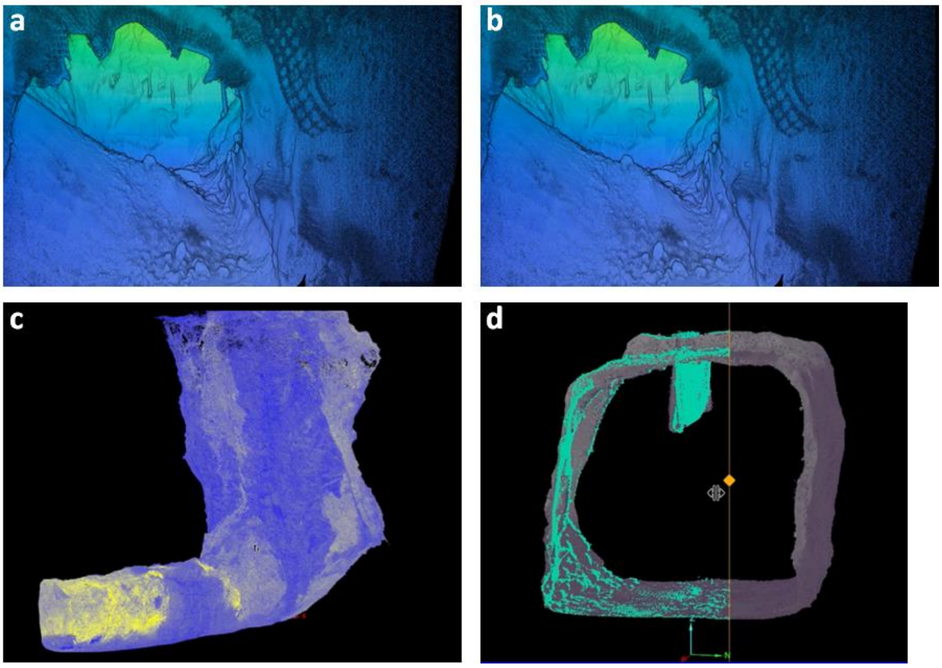

Fig. 6 (a) Digital Twin of Stope. (b) Draw point Inspection. (c) As Designed vs As Built. (d) Change detection.

Discussion

The paper explores the application of drone-based technologies in geophysical surveys for mineral exploration, with a specific focus on two primary methodologies: Drone-Based Magnetometer (MagArrow) and Drone-Based Ground Penetrating Radar (GPR), in addition to the innovative Hovermap technology for data collection in challenging mining environments. Drone-based magnetometer (MagArrow) stands out as a promising tool for mineral exploration. It excels in diverse terrains, including deserts, dense forests, and populated areas, eliminating the need for access road construction and proving cost-effective. MagArrow autonomously conducts high-resolution magnetic surveys, collecting data at an impressive rate of 1000 samples per second. This data is crucial for identifying mineral deposits and mapping magnetic anomalies, resulting in significant time and cost savings compared to traditional approaches. Drone-Based Ground Penetrating Radar (GPR) is also examined as a valuable asset in mineral exploration. GPR provides detailed insights into subsurface features, aiding in lithological characterization, stratigraphic modelling, and stability analysis. Its capabilities extend to detecting underground tunnels, structures, and pipe leakages, which are vital for safety and environmental concerns. The speed and cost-effectiveness of GPR make it an attractive choice, especially in challenging terrains. The innovative Hovermap system is introduced to address challenges in inaccessible and hazardous mining environments. It enables secure data acquisition through specialized mounts and drone integration, adaptable to various configurations. Hovermap enhances safety and efficiency by creating 3D maps and visualizations of subsurface features, while real-time data analysis and obstacle avoidance capabilities further improve data collection. The research underscores the growing importance of drone-based technologies in mineral exploration. These tools enhance safety, accuracy, efficiency, and cost-effectiveness in the mining industry, contributing to sustainable development. As technology continues to advance, its role in mineral resource discovery and extraction is expected to expand.

Conclusions

In conclusion, the methodologies outlined for drone-based geophysical surveys using MagArrow, Ground Penetrating Radar (GPR), and Hovermap represent innovative and efficient approaches to mineral exploration and data collection. These methods harness the power of modern technology to overcome traditional challenges associated with mineral prospecting in diverse terrains and environments. Drone-based magnetometer surveys with MagArrow demonstrate the utility of utilizing drones for geophysical data collection, particularly in challenging landscapes such as deserts, dense forests, and populated areas. The high-resolution data obtained through low and slow-flying drones provide valuable insights into mineral deposits and subsurface features. Furthermore, the fully autonomous flight capabilities of MagArrow ensure precision in data collection. Drone-based GPR surveys offer a non-invasive means of detecting subsurface features and are adaptable to various applications, including lithological characterization, tailing dam analysis, and stability assessments. The ability to cover large areas efficiently and obtain high-resolution data enables precise mineral prospecting and the detection of underground structures and pipe leakages. Hovermap, whether mounted on drones, handheld devices, or vehicles, provides a comprehensive and flexible solution for data collection, particularly in complex and rugged terrains. Its ability to autonomously detect and navigate around obstacles ensures the safe and effective coverage of the target area. Real-time monitoring and data visualization enhance the quality of the collected data, making it a valuable tool for mineral exploration and geological investigations. These methodologies represent a significant advancement in the field of mineral exploration. They offer a combination of efficiency, accuracy, and adaptability, making them invaluable tools for identifying mineral deposits, subsurface features, and geological structures. When applied alongside traditional exploration methods and geological knowledge, they contribute to a more comprehensive and effective exploration process, ultimately leading to the discovery and evaluation of mineral resources.

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