Mapping surface moisture of a gold heap leach pad at the El Gallo Mine using a UAV and thermal imaging

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Special Extended Abstract

An understanding of the spatial and temporal variations of surface moisture content over a heap leach pad is essential for leaching production and to achieve a high ore recovery. The current leach-pad monitoring and data-collection practice remains highly labor intensive and exposes technical staff to cyanide solution, a hazardous material. To address these challenges, we propose using unmanned aerial vehicles (UAVs) equipped with thermal imaging sensors to remotely obtain image data with high temporal and spatial resolution for monitoring the surface moisture distribution over heap leach pads. A field study was conducted over a sprinkler-irrigated heap leach pad at El Gallo gold mine in Sinaloa, Mexico, and the acquired data were used to generate moisture distribution maps of the heap leach pad's surface. The created moisture maps provide direct visualizations of surface moisture variation over the surveyed area. Such graphical results are effective tools for inspecting heap-leaching operations.

Introduction

Heap leaching is widely used due to its high economic feasibility for the processing of low-grade ore deposits. A high metal recovery requires a uniform leach solution coverage over the entire heap leach pad's surface because an uneven distribution of moisture can lead to challenging operational problems, such as undesirable leaching agent percolation and surface ponding. Therefore, a fundamental task in heap-leaching production optimization is to collect representative data from the heap leach pad to monitor production performance.

In recent years, UAV technology has been applied in mining to improve data acquisition in terms of time efficiency, data quality and workplace safety. In this study, we used a UAV system equipped with a thermal camera to acquire thermal images over a heap leach pad. The collected data were used to perform a spatial analysis of the moisture distribution over the leach-pad surface, while in situ samples were taken manually during field experiments to obtain ground truth about the material moisture and validate the remotely sensed surface moisture maps.

Data collection

During March 5-8, 2019, a field study was conducted at McEwen Mining's El Gallo gold mine located in Sinaloa, Mexico. The heap leach pad was located north of the mine site, and the footprint of the heap leach pad was approximately 22 hectares. The heap leach pad used a sprinkler irrigation system with a sprinkler spacing of 3 m, and dilute cyanide solution was applied continuously during the field experiment. A commercially available UAV platform, DJI Matrice 600 Pro, was equipped with a thermal camera, DJI Zenmuse XT 13 mm, to perform data acqui-

Fig. 1 A generated orthomosaic of the heap leach pad using 620 acquired thermal images.

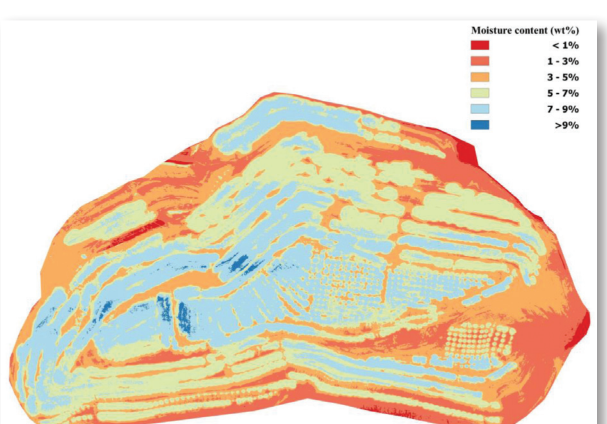

Fig. 2 A generated surface moisture map of the heap leach pad using an orthomosaic and the linear regression model.

sition over the heap leach pad. The spectral band captured by the thermal camera was 7.5 to 13.5 µm, which is the commonly used atmospheric window for aerial thermal-infrared sensing.

During the field study, two data collection campaigns were conducted in each surveying day at 10 a.m. and 2 p.m., respectively. The UAV system equipped with the thermal camera was used to acquire aerial images, while technical staff manually collected ground samples during the time of flights. These ground samples were sent to the on-site laboratory to measure moisture content, and the measurements were used as ground truth to facilitate and validate the remote-sensing results.

In each UAV data-collection campaign, the thermal camera was tilted down to the nadir to face the leach-pad surface. Front and side image overlaps were 85 and 70 percent, respectively. The flight height was considered as approximately 120 m above the leach-pad surface, resulting in a ground sampling distance of 15 cm/pixel. By the end of the field experiment, there were 3,714 thermal images collected, and each thermal image covered an area of approximately 96 by 77 m of the leach-pad surface.

Results and discussion

After acquiring data from the field experiment, data processing and moisture-map generation were conducted offline. The Agisoft Metashape software was used to generate thermal orthomosaics (also known as true orthophotos) to represent the surface temperature of the heap leach pad. Figure 1 shows an orthomosaic generated using the thermal images acquired during one of the data-collection campaigns. A linear relationship between the heap leach pad's surface temperature and material moisture content was then derived using the collected data. By applying the linear model to every pixel of the thermal orthomosaics, surface moisture maps were generated to visualize the moisture variation across the heap leach pad's surface directly. Figure 2 shows a heap leach pad's surface moisture map generated using a thermal orthomosaic and the linear model.

The results shown in Figs. 1 and 2 demonstrate the feasibility of mapping a heap leach pad's surface moisture distribution using remotely sensed thermal images. The generated surface moisture maps have a temporal and spatial resolution hardly achievable by conventional point-measurement methods. In addition, the proposed method is highly practical, which makes it beneficial to heap-leaching monitoring. The use of UAV-based remote sensing technique has the advantages of reducing time and effort in data collection and increasing the safety of personnel. A large survey area can be mapped without disrupting ongoing production operations, and the regions inaccessible by human operators can also be covered by the UAV system. Moreover, the proposed method is practical for its efficient product generation process. As soon as the linear model is developed, a moisture map can be generated within an hour of the data acquisition, and the spatial distribution of the moisture across the leach-pad surface can be intuitively visualized. This leads to an on-demand and near real-time data-acquisition and monitoring process.

Conclusion

This work provides a thorough case study of implementing the general workflow for surface moisture mapping of heap leach pads, starting from UAV-based data collection, followed by offline data processing, and ending with surface-moisture-map generation. The generated moisture maps provide direct visualization of moisture variation across the leach-pad surface, which gives decision-makers sufficient information to evaluate the leaching system and helps technical staff pinpoint operational concerns, such as surface ponding and sprinkler defects. The proposed method can be involved in the irrigation optimization process to quantitatively depict the performances of different solution application strategies, and the high practicality of the approach would facilitate an effective and efficient monitoring process for heap leach pads. ■

References

A list of all references is available in the full-text paper.

Development of a smelting reduction process for low-grade ferruginous manganese ores to produce valuable synthetic manganese ore and pig iron

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Special Extended Abstract

Manganese (Mn) ferroalloys are chiefly consumed in the steelmaking process as a deoxidizing agent or as an alloying element to produce high-quality steels. These alloys are typically produced in a submerged arc furnace using coke, fluxes