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Haul Road Monitoring in Open Pit Mines Using Unmanned Aerial Vehicles: a Case Study at Bald Mountain Mine Site

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Abstract

Improved haul road conditions can positively impact mine operations resulting in increased safety, productivity gains, increased tire life, and lower maintenance costs. For these reasons, a monitoring program is required to ensure the operational efficiency of the haul roads. Currently, at Bald Mountain mine, monthly site severity studies, ad hoc inspections by front-line supervisors, or operator feedback reporting is used to assess road conditions. These methods are subjective and provide low temporal resolution data. This case study presents novel unmanned aerial vehicle (UAV) technologies, applied on a critical section of haul road at Bald Mountain, to showcase the potential for monitoring haul roads. The results show that orthophotos and digital elevation models can be used to assess the road smoothness condition and to check the road design compliance. Moreover, the aerial mapping allows detection of surface water, rock spillage, and potholes on the road that can be quickly repaired/removed by the dedicated road maintenance team.

Keywords Monitoring · Unmanned aerial vehicle · Drone · Haul road · Open pit mining

1 Introduction

Road quality has a significant impact on mining operations and is therefore identified as an area for improvement. Roads require constant monitoring because they are prone to defects caused by the daily wear and tear from heavy machinery and rough weather conditions. Insufficient or inadequate vigilance over the design and maintenance of haul roads can have detrimental consequences, negatively impacting productivity, costs, and safety. In addition, maintenance issues that arise due to poor road conditions can increase costs and requirement for countless man-hours, that could be used more effectively. Conversely, good road conditions can improve safety, equipment efficiency, lower fuel consumption, increase tire life, and reduce maintenance requirements. To this end, continuous haul road monitoring and optimization efforts are required to improve operational efficiency at mine sites.

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Thompson et al. [8] discuss the methods available for addressing deteriorating road conditions, which can involve routine maintenance, resurfacing, rehabilitation, and betterment. Some of the methods are simple, such as shallow blading and dust control. Other more complex tasks include ripping, re-graveling, and geometric improvements (betterment). Some of the common issues with haul roads in open pit mines are spilled material or boulders on the road, potholes, rough and uneven surfaces, and superelevation. In order to ensure that the appropriate repairs are performed, the road conditions must be continuously monitored and assessed.

To assess the road conditions and for informed decision-making, mining engineers rely empirically on local experiences and evidences. Critical decisions about road maintenance and design, which influence operational processes, are commonly achieved by relying on inefficient, subjective, and intermittent ground-based data collection methods.

Using drone technology for mining data collection and decision making is becoming significantly popular [1–3, 6]. Implementing drone technology for data acquisition can complement conventional data collection techniques for road maintenance and design. Using drone technology, a large area of road can be covered more accurately and efficiently. The aerial survey of roads with drones allows identifying road areas that need maintenance and repair (e.g., potholes), rock spillage on the road surface that needs to be cleaned up, inspection of as-built road curves, slopes, and superelevations, and detecting areas that require dust suppression. Aerial monitoring is fast, on-demand, and safe and equips mining professionals with a versatile tool.

2 Methodology

This section presents the location of the experiment site, the equipment used, and the image collection and data processing done.

2.1 Experiment Site

The experiment was conducted at Kinross Gold Corporation's Bald Mountain mine, an open pit mine complex located in Nevada, USA. The mine is an active multi-pit operation, spanning a large area. Due to the large mining area, there is a complex road network at the site which makes monitoring the roads both challenging and critical for efficient operations. Moreover, since there is a limited number of ancillary road maintenance equipment, it needs to be carefully managed in order to ensure the appropriate road locations are maintained. Furthermore, if severe damage to the road is identified, routine road maintenance may be stopped, and the equipment is dispatched to address the critical issue.

The current road management system involves the following:

- Shift supervisors dispatch graders and water tanks to critical locations.
- When a spilled rock boulder is observed on the road surface, it is reported and removed by a grader.
- A site severity study is done on a monthly basis to inspect road conditions at the mine site. This is done by visual inspection of the road conditions including undulations, spillage, turning radius, loading point, and support equipment. Several senior mining staff are involved in this study. The results of this study are subjective and intermittent because it is based on the road condition during the inspection time, and the report may not be issued immediately after the observations.

In this study, a section of the haulage road between the Top 2B pit and its waste rock dump was selected for the unmanned aerial vehicle (UAV) experiment. The section of road was approximately 1.2 km long and 40 m wide. It was selected because it was one of the most utilized roads at the mine. Figure 1 shows the section of road covered. Additional road sections were considered to test the repeatability of the methodology; however, they were not covered due to unfavorable weather conditions during the time available on site.

2.2 Equipment Used

The UAV system used was a DJI Inspire 2, with a flight time of approximately 25 min. It was selected due to its simple setup, fast battery charge, and ease of handling and transporting. Moreover, it was the drone used for routine surveying at the mine site. A Zenmuse X5S 20.8 MP camera was used along with a Olympus M.Zuiko 45mm/1.8 lens to obtain higher resolution images. The lens was upgraded from the default 15 mm/1.7 ASPH prime to provide more image detail due to enlargement. Using a longer focal length reduces the field of view and increases the number of images required to cover the same area [5]. The section of road is located at an elevation ranging from 2225 to 2320 m above sea level, which was accounted for in the experiment by installing high-altitude propellers on the UAV system. These propellers improve performance of the system so that flight

Fig. 1 Haul road section surveyed by drone identified in orange

Fig. 2 DJI Inspire 2 UAV

time is not adversely impacted by high altitude. Figure 2 shows the DJI Inspire 2 UAV used for the data collection.

2.3 Image Collection and Processing

Generally, photogrammetry refers to any process by which a 3D model is created from 2D images [4], obtained from the UAV system. Overlap between photos, distance from the target, flight height, lighting conditions, weather conditions, lens focal length, and camera resolution can impact the resolution of the 3D point cloud. When calculating the flight height, it is necessary to select an appropriate ground sampling distance (GSD), the ground distance covered between pixels, for image capture. The GSD influences the size of the smallest identifiable feature in a 3D model.

For this experiment, two parallel flight lines on either side of the road centerline were used to collect images. Front and side image overlaps of 60% and 80% were used, respectively. The flight height was considered 100 m above the road, resulting in GSD of 10 cm/pixel. This flight height was chosen based on a balance between regulatory limits (<120 m) and flight time. If the flight height was lower than 100 m, with constant image overlap, then the flight time would be increased beyond the UAV system's limit with one set of batteries. A flight height greater than 100 m would decrease flight time but it would also decrease model resolution. The 1.2-km road was covered by the UAV with a flight time of 24 min. The total time spent in the field was 1 h and 28 min. A total of 601 images were collected during these flights.

Crosses marked on the ground were used as ground control points (GCPs). The use of GCPs improves the location accuracy of the 3D point cloud, and consequently the analysis of the 3D model. Furthermore, they can be used to verify the location error of the point cloud. Currently, there are systems that can be integrated into UAVs to reduce the requirements for GCPs such as post-processing kinematic (PPK) georeferencing. Using these systems can reduce the field time and further improve the efficiency gains realized by the use of UAVs.

The images were then processed in an open-source software package, OpenDroneMap [7], to generate an orthophoto and digital elevation model (DEM) of the road. The total time spent on model generation was 1 h and 13 min. Figure 3 shows the orthophoto generated with two cross sections through the road. The DEM is a raster representation of the road survey elevations.

3 Analysis

Using the cross sections presented in Fig. 3, it is possible to calculate superelevation of the road at different segments which is critical for safe operation of the haul trucks on the road and can have detrimental impacts on the wear and tear of the truck frames and tires.

Figure 4a presents the slope model of the road and Fig. 4b shows the instantaneous gradient of the road along 1200 m of the road centerline. This can be an indication of the road smoothness/undulating condition. Areas with high frequency of sharp peaks (e.g., ~ 50 m, and 650–720 m along the road centerline) are more undulated than the rest of the road. The sudden peak between 170 and 190 m along the centerline is attributed to the presence of a grader working on the road during the aerial survey. The image masking and data filtering features in OpenDroneMap were not working correctly during processing to remove the grader from data. It is highly recommended that any future work should mask images or filter point cloud data prior to DEM creation. This will ensure that the DEM represents the surface of the road section correctly.

Figure 5 shows the DEM of the road and the elevation change along the 1200 m surveyed road. The elevation changes from 2325 to 2160 m (165 m of elevation difference) along the 1200-m road length. Thus, the overall road gradient is about 13%. Figure 6 shows the geometrical analysis of the road including superelevation, gradient for different segments, and radius of the road curvature, as well as the road edges. The superelevation of the road has been measured at few locations. Using this information, the implemented superelevation in a certain part of the road may be flagged as not conforming to design. This should be further investigated, and corrective measures may be considered to improve the road quality.

Figure 6 also shows the road gradient for different segments of the road which varies between 1.8 and 20%. The 20% gradient for a short segment of the road near the exit from the ramp can be reduced to improve the road quality and improve truck operating efficiency. The turning radius of

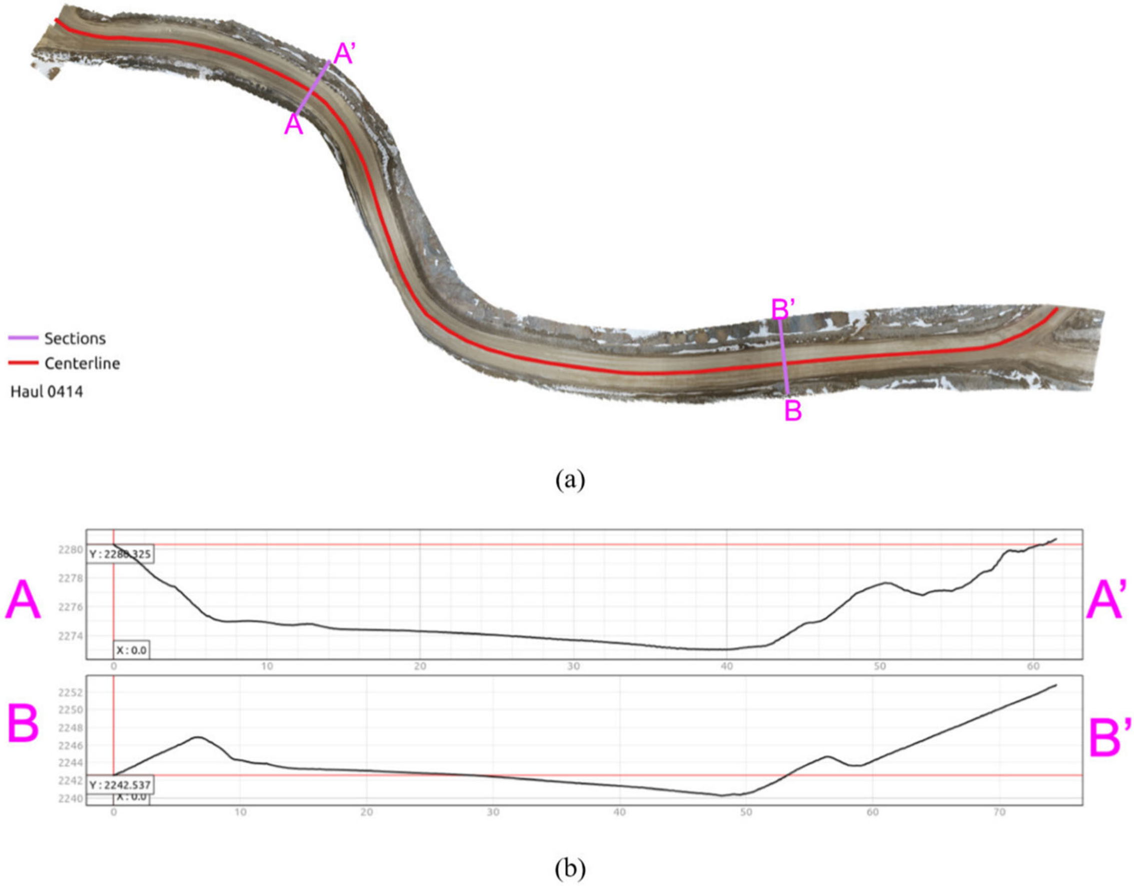

Fig. 3 **a** Orthophoto of the road between Top 2B pit and the waste rock dump; **b** cross-section of the road

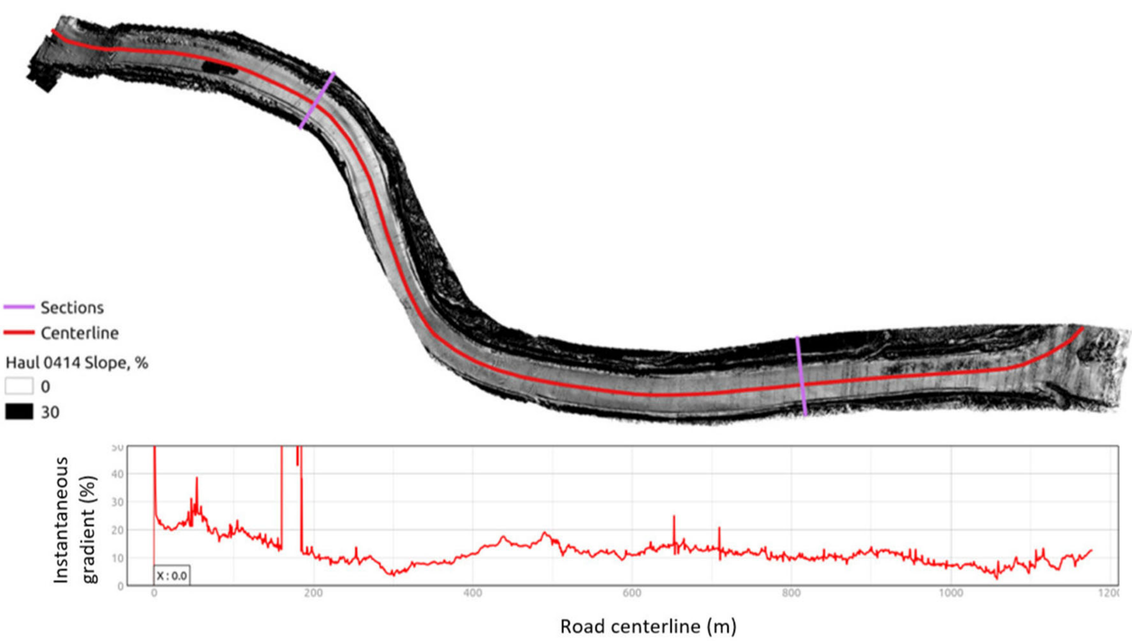

Fig. 4 **a** A slope model of the road; **b** the instantaneous gradient graph along the centerline

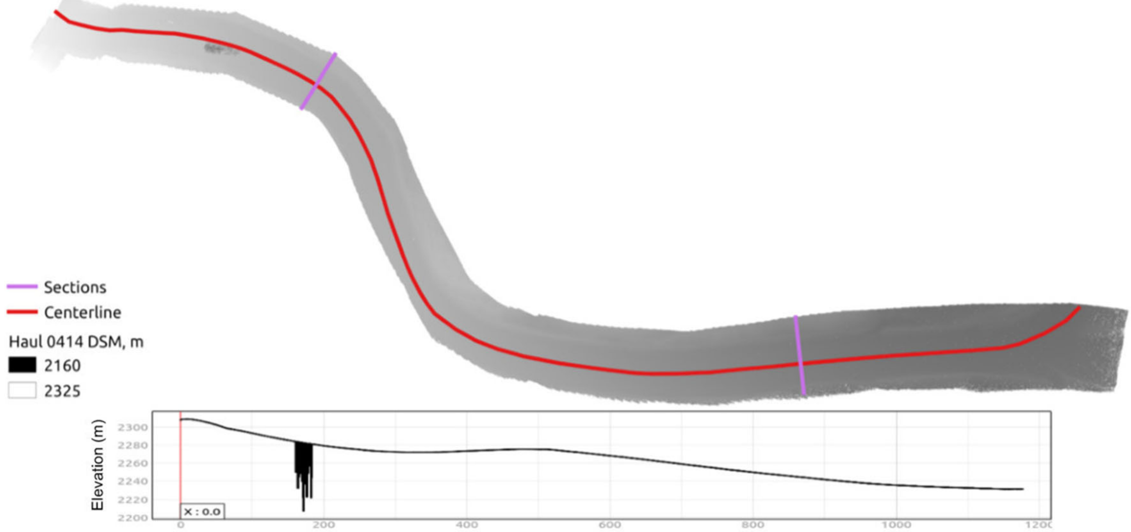

Fig. 5 Digital surface model of the road showing the elevation change along the road

the road is calculated along the road which can be used to determine if additional road width must be included, for both reducing vehicle overhang and decreasing driving difficulty.

Figure 7 shows the presence of surface water on the road, particularly along the edges of the road from the exit of the ramp in the left side of the figure until the first turning curve, where the road has a higher elevation. While a majority of the surface water are drained using ditches alongside the haul road, the model indicates that part of the surface water is accumulated on the edges of the road. Thus, cleaning of the ditches along the roadsides during the rainy and snow melting seasons can improve the surface water collection and address some of the identified issues. Image analysis of the drone survey data can be also used to identify potholes along the road, like the one shown in Fig. 7. In addition, the 3D model can be used to locate rock spillage along the road. The information can be communicated with the road maintenance team for fast repair and cleanup.

4 Discussion

The analysis presented shows the significant information that can be collected by an aerial survey of the road. All this information can be rapidly and easily assessed to determine the conditions of the road. The results of the conducted aerial survey were processed and obtained in less than 3 h. The aerial survey can provide more accurate and near real-time information on water puddles, spillage, inappropriate road

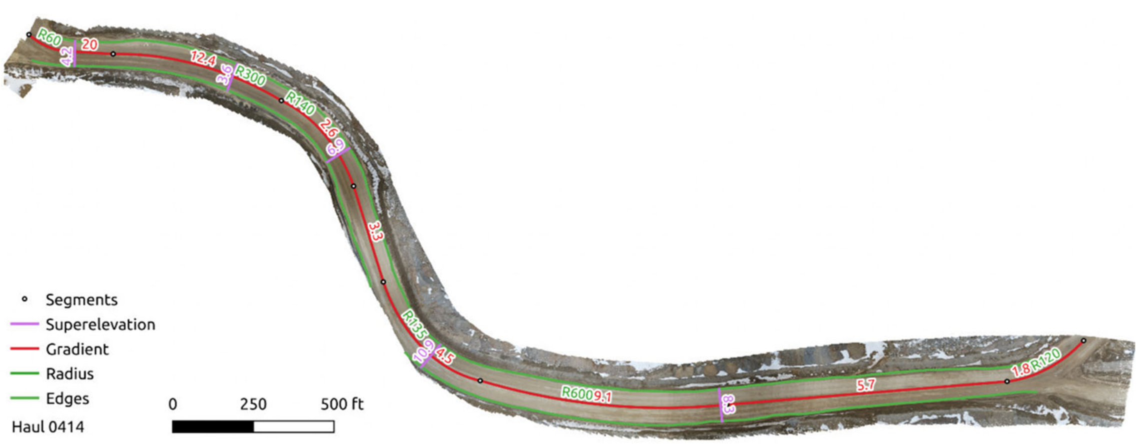

Fig. 6 Geometrical analysis of the surveyed road

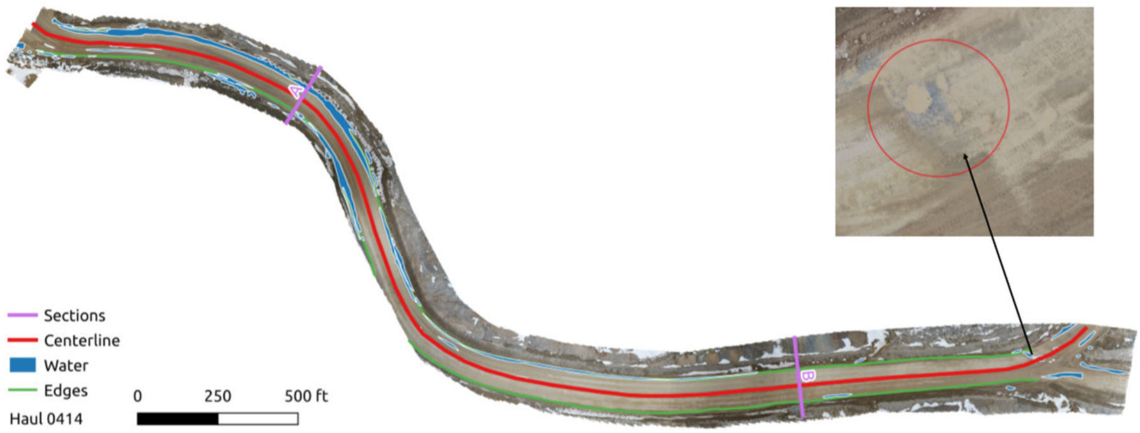

Fig. 7 Image analysis of drone data used to identify surface water on the road as well as the presence of potholes

grading, and road roughness. A further advantage is that a specific and large area can be covered. The aerial survey can be conducted on a regular basis during a working shift to improve the temporal resolution of the collected data.

To improve the aerial survey, a fixed-wing UAV system should be considered to cover more area in one flight. Implementation of this type of system requires a larger take-off and landing zone, more pilot training, and careful selection of camera parameters to reduce image blur. Another option that may decrease field time is the use of a team of UAVs to survey the same area. This may decrease total field time and increase the time available to increase model resolution; however, this approach is limited by the number of certified pilots available. With the use of a PPK georeferencing system, the field time can be reduced, further improving the efficiency of using the aerial approach. Furthermore, the image analysis can be automated for detection of potholes and spillage, using machine learning techniques such as deep neural networks.

Using UAVs for road monitoring can have a direct impact on the tire usage: better and smoother haulage roads, where spilled rocks have been removed and can improve tire life. This can result in significant cost savings for a mine operation in the scale of Bald Mountain.

Frequent monitoring of the main haulage road conditions using UAV system allows for a better road design and management of maintenance. Improvements in road quality can reduce the wear and tear of the haul trucks, reducing their maintenance costs. Moreover, time-savings can be achieved by improving communication of priority areas for maintenance at the mine site. The graders can be dispatched directly to the area of concern.

Additionally, roads built to design can result in increased truck speed and decreased haul cycle times. This can lead to significant cost savings per mile of road at the mine site with a main road network of approximately 19 km.

5 Conclusions

The experiment conducted at Bald Mountain mine demonstrates the applicability of UAVs as a platform for collecting high-resolution road data. This data can then be effectively integrated into a road management and maintenance system at a mine site. This approach is fast and on-demand, providing feedback to the site operations with minimal delay. Moreover, the collection of the data is relatively autonomous, does not interrupt operations, and is safe for the operators. These advantages can be leveraged for significant cost savings and operational improvements.

Despite all these advantages, some limitations still exist with the proposed approach. UAV flight is limited to days with favorable weather conditions, as current UAV systems cannot operate in extreme winds, rain, or snow. The UAV system needs to be cleaned and maintained to prevent dust accumulation from damaging it. Finally, as this approach relies on image quality, any conditions that decrease the quality of images such as dust in the air or poor lighting condition can reduce the effectiveness of the proposed approach.

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Data Availability Not applicable.

Code Availability Not applicable.

Compliance with Ethical Standards

Conflict of interests The authors declare that they have no conflict of interest.

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