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DRONE-BASED TECHNOLOGY SOLUTIONS FOR THE MINING INDUSTRY

Krunal Kalbende[1], Srikant Annavarapu[2]

Abstract

The implementation of new technologies in the mining industry often lags behind that in other industries due to the harsh environmental conditions and the lack of awareness and exposure to these technologies in remote locations. Few mineral industry professionals are able to implement such solutions without a technology company and technology companies often resist implementations in the remotely located mining operations. Drones have the ability to carry a set of sensors for measuring various parameters and collect this information over a large area quickly. Geotagging of each datapoint allows the assessment of a large number of parameters with the required spatial reference and the analysis of this data can yield interesting and useful results and correlations if viewed or assessed by a competent mineral industry professional in association with a data scientist. The number and complexity of the sensors used for the collection data depends on the requirements of the mine site. Compliance with relevant regulations can also be made more convenient using drone-based technologies using various sensors. This paper presents some innovative drone-based technology solutions which may improve the quality and quantity of significant data collected from the mines and enhance productivity while lowering data acquisition costs.

Keywords: *drones, exploration, metal mining, open pit mining, sensors, underground*

1. Introduction

The design and fabrication of drones (also referred to as Unmanned Aerial Vehicles or UAVs and Micro Aerial Vehicles or MAVs) is carried out in different countries to address the needs of the major industries in those countries. Drones come in various configurations based on the type of motion such as Single-Rotor Drones, Multi-Rotor Drones, Fixed-Wing Drones, Fixed-Wing Hybrid Drones, Tactical Drones, Reconnaissance Drone, Large Combat Drones, Non-Combat Large Drones, Target and Decoy Drones, GPS Drones, Photography Drones (Hassanalian and Abdelkefi, 2017, Vergouw et al, 2016). Drones have been utilized for different types of missions by civilian and military agencies around the world. When integrated with various sensors including single and stereo cameras, LiDAR, spectral imaging, thermal imaging, magnetic resonance, drones can map the earth surface for various visual, chemical, biological and mechanical characteristics with appropriate geotagging, if GPS systems are enabled on the drone. The data can then be used for the development of digital elevation models (DEM), material movement assessments, 3-D mapping, fragmentation assessments, stability monitoring, geotechnical assessments, illumination assessments, environmental impact monitoring, and many more such evaluations for enhancing productivity or optimizing the use of resources at the mine.

In the mining sector, drone-based technology solutions have the potential to significantly reduce manual labor in spatial surveying, geotechnical assessment and slope monitoring, collection of surface and sub-surface data, sample collection, pipeline and conveyor belt inspection, aerial mapping of mineral prospect zones, disaster mitigation, management and monitoring, machine life tracking, infrastructure structural monitoring, mine and mill safety, and security surveillance (Hagemann, 2014). The collected data can be integrated and used for the development of mine plans and schedules and can also help in mine operations through machine and operator tracking, traffic monitoring, environmental and ecological monitoring (Lee and Choi, 2016).

Drones have been used for mapping of the working and disturbance areas with respect to lease boundaries and compliance with requirements of forest clearance through the mapping of the forest boundaries adjacent to the mining areas. The planning and monitoring of reclamation efforts, including monitoring of the status of the vegetation in the reclaimed areas, can also be efficiently conducted using drone mounted sensors often used in the agriculture. Drones have also been used to drop saplings encased in a nutritious hydrogel in precise locations in inaccessible areas.

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2. Drone technology for mines

The large areal extent of surface and underground mines, and the hazards in accessing remote areas make drone-based technologies an obvious choice for data collection and assessment. Mounting advanced job-specific sensors help collect the required information from the site at different stages of a mining project.

At the time of exploration, drones provide an opportunity for the explorer to get an aerial view of the area to be explored for planning the exploration program in the first place (Figure 1). Drone aerial surveys allow the explorer to look ahead into the area of exploration and plan the approach to the designated targets. The ability of the drone to carry basic sensors also helps focus the exploration effort in specific areas based on the initial information collected from closer to the ground than standard aerial surveys. Drone surveys are also easier to conduct and more cost effective. Once basic exploration is completed, heavier drones carrying more sophisticated sensors for conducting aeromagnetic and other surveys can be deployed to gather more relevant information for designing the possible drilling programs. Drones may be used for a variety of tasks including mineral deposit mapping, exploration target surveying, mineral exploration through remote control (Le at al, 2020).

Figure 1: Exploration team using drones

Once the exploration is completed and a mine is being constructed, drone surveys can provide information regarding the progress of mine construction and help identify bottlenecks so that the construction schedule can be maintained. Most mines bleed money due to delays at the time of construction and some part of it can be circumvented through the acquisition of adequate information for decision making based on drone reconnaissance. Active overviews of the construction site help in optimizing the process and address problems before they cause delays.

Several mining companies have already started implementing drone-based solutions in mines using imaging systems mounted on the drones to collect primarily photogrammetry data for general survey, stockpile management, and excavation assessment because it allows for quicker and more accurate volume calculations and greater efficiency, leading to increased profits. Drones can collect multiple sets of data over large areas of the mine and the data can be analyzed to assist the mining and monitoring teams for facility management, construction management, mine safety management, excavation stability, thermal and spectral mapping, and mine operation analysis (Biljecki et al, 2015).

Drones with unique sensor technologies can also provide instant inspection of mining areas to provide necessary governance and compliance information and can also help in the identification of hazards in the mining area. Tata Steel has used drones in the Noamundi Iron Ore Mine to help stop illegal mining, monitor the compliance with the mining plan, production, dispatch, and royalty payment (Satija et al, 2017).

2.1. Drone applications in surface mining

Surface mines have been using drones for tracking excavation progress and for volume calculations of excavations and stockpiles, which can be used to develop guidelines for mine planning and safety (Figure 2). A drone equipped with a hyperspectral frame camera was employed to monitor the safety of a surface mining operation. Equipment tracking and maintenance at times of breakdown has also resulted in better management of the mining equipment and the restoration of the equipment to production mode.

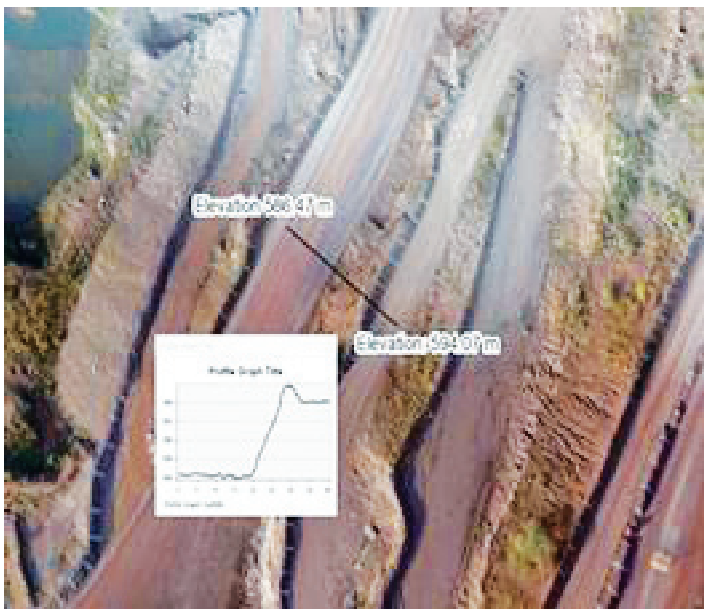

Figure 3: Drone photograph of slope between two benches in Noamundi Iron Ore Mine (Satija et al, 2017)

The monitoring of the stability of critical stopes through videography and remote data collection helps in the optimization of slope angles in the pit, which is critical for reducing production costs, increasing mining efficiency, and recycling resources (Sibanda et al, 2021). The use of special sensors has also provided data on ground stability and for water management, which are critical to the safe operation of the open pit. The mapping of discontinuities for the assessment of slope and dump stability can be accomplished using terrestrial LiDAR technology.

Drones equipped with thermal sensors are being used to monitor changes in the geographical and temporal distribution of surface moisture content in iron mine tailings (Sayab et al, 2018). Analysis of the correlation between moisture content and stability of mine tailings facilities, can be beneficial in the management of mine tailings. Mine mapping, stockpile mapping, optimized blast design, reconciliation and time lapse photography, high resolution photography, and identification of cracks in mine faces/hanging walls are all applications where drone technology is particularly helpful (Le at al, 2020).

2.2. Drones in underground mining

Underground mining poses a different set of challenges to mine operations and the data required for continued safe and productive operations often includes assessment of the stability of underground excavations and monitoring of air quality in remote locations. The long and often circuitous tunnels leading to the working areas as well as the production areas themselves need to be monitored to ensure safety before personnel are deployed for work in the area.

The deployment of drones in underground mines is also difficult due to restricted space, decreased visibility, increased dust, turbulence in the air currents, and the absence of reliable wireless communication systems (Green, 2013, Nieto et al, 2015). In addition, gassy coal mines restrict the use of powered equipment unless they are certified to be flameproof. These restrictions limit the usage of drones for data collection in underground mines. The navigation of drones using sensors which evaluate their position with respect to obstacles is an advantage in many cases (Figure 3), though this often limits the range of operation of the drones (Shahmoradi et al, 2020, Annavarapu and Chakravarty, 2016).

In spite of the above limitations, drones have been used for the inspection of large underground stopes where physical entry is not possible. Drones have also been used to assess the quality of the work atmosphere before the start of work in the production areas and to evaluate the conditions in a hazardous area before the entry of mining personnel. The processing and analysis of images captured from drones at the draw points can be used for assessing fragment size distributions after blasting in underground mines (Zhang et al, 2021, Afzal et al, 2020).

Figure 4 Autonomous Quadrotor drone flight in coal mine (after Annavarapu and Chakravarty, 2016)

As a result of their small size and dexterity, drones are able to access difficult-to-reach locations in underground mines, such as open stopes and ore passes, without putting personnel at risk (Rathore, 2015). In some mines, where a void has opened up above a working area, tele-operated drones could be navigated into the void and complete image of the void can be generated using a LiDAR scanner mounted on the drone. Repeated scans can reveal the sources of instability in the void and help assess the remedial measures to be taken for continued safety of mine operations. In operating open stopes, the results of blasting and the areas of movement in the stope walls can be assessed to help improve fragmentation and reduce dilution from the stope walls. The images from the drones can also be used to estimate the fragment size distribution within the stope and, with the right sensors, the possible grade of the material within the stope (Afzal et al, 2020)

Robotic vehicles integrated with drone automation have been designed for use during the monitoring of inaccessible regions and as part of rescue and recovery efforts (Jones et al, 2019). The detection of hazardous gasses, mapping and photography of freshly mined areas, and the evaluation of ground stability can also be undertaken using drones (Mochammad et al, 2016). Tunnel mapping using LiDAR sensors provides significant information about the stability of the tunnels (Tkáč and Mesároš, 2019, Ozaslan et al, 2017). With the advancements in sensor technology, drones now have the capability of mapping the orientation of geologic formations, constructing Discrete Fracture Network (DFN) models, and combining observations of seepage to build a hydrogeological flow model, which are useful for underground mining inspections and evaluations (Rogers et al, 2010)

3. Sensors used in drones for mining

Different types of sensors are available for the collection of required information in the mining industry. A combination of sensors can be mounted on the drones to collect data with a timestamp and with a geo-spatial tag so that the data collected can be overlaid for better understanding and analysis. Integration of the collected data with mine planning data can also help review actual mining progress and deviations from the mining plan, if any. The selection of sensors will depend on the type of information required and the selection of the appropriate drone will be based on the area to be covered and the weight and power requirement of the sensors.

3.1. Infrared light (IR)

Infrared Sensors (IR), sometimes known as heat sensors, are low-cost obstacle detector sensors that can detect the energy radiation emitted by objects in the near infrared spectrum. In general, all materials above absolute zero that are exposed to the infrared spectrum release waves. Despite their low resolution, infrared sensors are capable of detecting persons with ease. It also has the benefit of being able to detect through fog, smoke, and all hours of the day and night. The pictures captured by the sensor, however, may be distorted by flames and other high-temperature sources and do not function efficiently in highly dusty environments.

3.2. Ultrasonic sensors

Ultrasonic Sensors (US) are also low-cost sensors that can be used in a variety of applications, primarily related to the detection of obstacles and boundaries. These are the only common sensors in drone technology that are not dependent on electromagnetic waves (EM). Instead, they identify obstacles by emitting high-frequency sound waves and collecting reflected waves from the surrounding environment. Calculating the time-of-flight allows us to measure the distance between the obstacles and the aircraft. One downside is that, as compared to other sensors, they have a limited operating range (Suherman et al, 2020).

3.3. Red-Green-Blue (RGB) sensors

In surveying and mapping, road traffic monitoring, stockpile volume computation, security monitoring, and other applications, an RGB camera is often used to capture images. Depth assessment is performed with the help of two active stereo images or time-of-flight sensors. The selection of the RGB camera must be done with care, taking into consideration the drone's energy consumption. In typical circumstances, a tiny camera is ideal for fixed-wing drones since they are unable to transport large or heavy objects (Svensgaard et al, 2021)

3.4. Stereo cameras

The stereo camera, which is analogous to the human visual system, is fitted with two or more lenses that allow it to produce high-resolution 3D pictures. It is capable of producing three-dimensional pictures with great precision in a clean environment by using distinct image sensors. Due to the distortion of the light waves, stereo cameras perform poorly in foggy or smoky environments.

3.5. Laser range finders

Obstacle detection in drones is accomplished with the use of Laser Range Finders (LRFs), which are expensive sensors. In the LRF, a laser beam is directed towards an obstacle and the distance to the item is measured by receiving the reflected wave and taking the duration of flight into account. Because LRFs employ optical wavelengths, they are not appropriate for usage in the presence of fog, smoke, or dust.

3.6. LiDAR sensors

LiDAR sensors work by sending out pulses of laser light and measuring the time taken for these pulses to return after bouncing off the ground and the intensity of the return pulse. This enables a very precise direct measurement of the distance from the sensor to the ground.

3.7. Ultra-wideband radar (UWB)

Ultra-Wideband (UWB) radar detects barriers in the radio spectrum by producing electromagnetic waves in that range. Target distance is calculated in the same way as in the US and LRFs by computing the reflected wave and time-of-flight. Radio waves have a larger wavelength than visible light and infrared light, allowing them to penetrate deeper than visible light in dust, smoke, fog, and other unfavorable environmental circumstances (Svensgaard et al, 2021).

UWB radar is particularly well suited for use in mines because it is more accurate and has a greater picture resolution than ultrasonic sensors when used in hostile environments. In addition, UWB consumes very little energy (less than 1 watt) which saves a significant amount of drone battery power. The low spectral density of UWB causes the least amount of interference with other wireless applications such as flight controllers and telemetry links. UWB is also capable of detecting objects with a variety of properties such as edges and corners and can also determine the three-dimensional coordinates of an item closest to the user.

3.8. Hyperspectral Imaging

Several broad wavelength bands separated by spectral segments are detected by the majority of multispectral imagers, such as Landsat, SPOT, and AVHRR, which detect the reflectance of Earth's surface material. Hyperspectral Imaging (HSI) sensors, on the other hand, are small and lightweight devices which analyze the reflected radiation as a succession of narrow and continuous wavelength bands.

Hyperspectral sensors typically monitor these bands at intervals of 10 to 20 nanometers and provide information that may otherwise be inaccessible using conventional techniques. These sensors are frequently employed in geology, mineral mapping, and exploration.

3.9. Aero-magnetic sensors

Accurate measurements of the magnetic field are obtained through magnetic sensors which evaluate disturbances and changes in the magnetic field, including flux, intensity, and direction of the field. The weight of a Cesium magnetometer is about 0.82 kg in its natural state. The calculation of three-dimensional magnetic field gradients necessitates the use of four magnetometers, which weigh a total of 3.28 kg when assembled. These sensors are often used in mineral prospecting (Calou and Munschy, 2020).

3.10. Visible and Near-Infrared Light (VNIR)

A wavelength in the visible and near-infrared (VNIR) section of the electromagnetic spectrum is between 400 and 1400 nanometers, and it is divided into two groups. From the visible to infrared end of the spectrum to the water absorption band at wavelengths between 1400 and 1500 nm, this range includes the whole visible spectrum as well as an adjacent portion of the infrared spectrum. The surface wetness of open pits, tailing dams, subterranean areas walls, and surfaces may be measured using VNIR sensors, which are often deployed on drones because of their compact size and low weight. Furthermore, each particulate mineral has a distinct signal in the VNIR spectrum, which is a benefit when mineral discovery is carried out by drones equipped with a VNIR sensor.

3.11. Air Quality Sensors

Sensors for monitoring air quality may be mounted on a drone to carry out specific jobs, such as air quality assessment, gas detection or dust monitoring. Optical-based air quality sensors, ultrasonic air quality sensors, and electrochemical air quality sensors are the most often used in environmental monitoring. These sensors may be mounted on a drone based on the type of monitoring, the time required for release, and the measurement specifications.

4. Conclusions

Technological innovations and implementations in mines are imperative to improve safety and productivity and drone-based solutions for data gathering and visualizations. The advances in sensor and drone technology can be used to great advantage to cover large distances in the mines and collect multiple types of data with geotags efficiently. While there are still some environmental issues which may restrict the use of drones in all situations, the ability of the drones to present large volumes of data for analysis and assessment will enable technical personnel to be deployed to areas of criticality in the mines expeditiously. As the use of drone technology grows in the mining industry, sensors can be developed for collecting data relevant to the mining industry. The development of appropriate navigational systems for use in the surface and underground mines, where GPS signals may not be available, is another area where research efforts can be directed to enhance the ability of the drones to be used in dusty, humid and confined areas.

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AWARDS

NMDC was conferred with the prestigious S&P Global Platts Global Metals Awards consecutively in 2018 and 2019 in the CSR Category for the emancipation of local communities. NMDC is the first Indian Company to win an award in this category. For our CSR initiatives, we have recently won -

- ASSOCHAM National CSR Awards 2020 for Women Empowerment
- Indian Chamber of Commerce (ICC) Social Impact Awards 2020 for Healthcare
- Best Practices in CSR Awards 2020 from Institute of Public Enterprises (IPE) for Education Development in Remote Tribal Areas
- Governance Now PSU Awards for the Best PSU (Navratna) Implementing CSR in 2021

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cross-border payments. But at least three vessels carrying coal set sail to India from Russian ports after Russia launched its invasion of Ukraine on Feb. 24, according to Refinitiv vessel tracking data and an industry source.

"Indian buyers are still getting coal from Russia into the market here, but are starting to find it increasingly difficult because banks are not willing to open letters of credit," the industry source said. "Bankable long-term customers are being handed over coal on a trust basis, while relatively new customers aren't able to procure coal because of financing issues," the source said.

V R Sharma, the managing director of Jindal Steel and Power Ltd (JSPL), said importing from Russia would be difficult unless there is a "rupee-rouble" trade. India is exploring ways to set up a rupee payment mechanism with Russia to soften the blow on New Delhi of Western sanctions imposed on Russia. "If rupee-rouble trade is approved, then we can get coal at affordable and cheaper prices from Russia," Sharma told Reuters. JSPL is among the importers from Russia in March, along with Tata Steel, Kalyani Steels and JSW Steel. JSW declined to comment, while Kalyani and Tata Steel did not respond to Reuters requests seeking comment.

A trader at Sibuglemet, one of Russia's major exporters, said the firm and his competitors are continuing to supply coal to India, but said "some issues are appearing." "Tomorrow, if they were to put strict controls on payments, then trade would be organised through buyers in other countries," he said.

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