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Smart Sensing for Mineral Exploration through to Mine Closure

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Abstract: This presentation provides an overview of advanced sensing systems to monitor various aspects of mining operations from mineral explorations through to mine closures. A review of the case studies utilising multispectral, hyperspectral, thermal, LiDAR and RADAR sensors, in both surface and underground mines, is highlighted with the associated capabilities and challenges. The examples include sensors mounted on satellites, aircrafts and more recently Unmanned Aerial Vehicles (UAVs)/drones. Monitoring for socio-environmental aspects of mining at regional and site levels are outlined. The appropriateness of a sensor-platform combination has been found critical for different applications in mining. Finally, an integrated intelligent sensor system network is projected for a futuristic mine vision.

Keywords: remote sensing, mine environment, UAV, multispectral, hyperspectral, LiDAR and RADAR

1 Introduction

In the recent past, there have been significant advancements in the development of remote sensing platforms (satellite, aircraft and Unmanned Aerial Vehicles – UAVs) as well as sensor systems (multispectral, hyperspectral, thermal, light detection and ranging (LiDAR) and radar). However, the selection of appropriate remote sensing techniques for a mining application remains complex and requires scrutiny on multiple scales including spatial, temporal and imaging capabilities (Banerjee and Raval 2016).

To this end, the Australian Centre for Sustainable Mining Practices (ACSMP) at the University of New South Wales (UNSW), Sydney, Australia has developed a very unique Laboratory for Imaging of the Mining Environment (LIME) in 2010 to apply smart sensing technologies to advance sustainable mining practices. LIME is engaged in developing applications of smart sensing for mining by using satellite, airborne, UAVs and ground-based sensors.

2 Regional Scale Surveillance

The large consortium of current satellites provides effective and near-real-time observation opportunities for environmental and safety monitoring at a wider spatial extent. Aircrafts and UAVs are also constantly advancing their flying capabilities to cover larger area at a regional scale.

2.1 Exploration

Traditionally, hyperspectral sensors on satellites (Hyperion, ASTER) and airborne systems (HyMap, AVIRIS, CASI, HySpex, CHAI) have been used for mineral exploration. However, recent advancements in drones and light-weight sensors, such as hyperspectral, provide renewed opportunity for higher spatial and spectral data collection with higher signal to noise characteristics.

2.2 Vegetation

The historical time series data from satellites, such as Landsat (1972-present), SPOT (1986-present), and World View (2007-present) are very useful in identification of long-term changes in vegetation health as well as in establishing baseline conditions, if no reliable historical data is available. Data acquired from satellite and airborne platforms now provide improved ability to assess biodiversity and vegetation stresses (Jin et al 2013) through multispectral and hyperspectral sensors. Raval et al (2014) indicated usefulness of satellite data in estimating biomass of the experimental production plots on reclaimed mine sites established in Wise County, Virginia (USA).

The new generation of low-flying hyperspectral sensors present an emerging opportunity to map bio-physio-chemical constituents of baseline vegetation status at much finer level (Banerjee et al 2017a). The UAV-LiDAR systems are able to provide better understanding and accuracy around vegetation community structural attributes. Digital sensor technology-based assessment of progressive rehabilitation (Raval et al 2013) will assist, both regulators and operators, to better quantify the success by removing subjectivity in the observations (Figure 1).

A recent study at LIME used a set of thirteen vegetation health indices related to chlorophyll, xanthophyll, blue/green/red ratio, and structure from airborne hyperspectral reflectance data collected around abandoned

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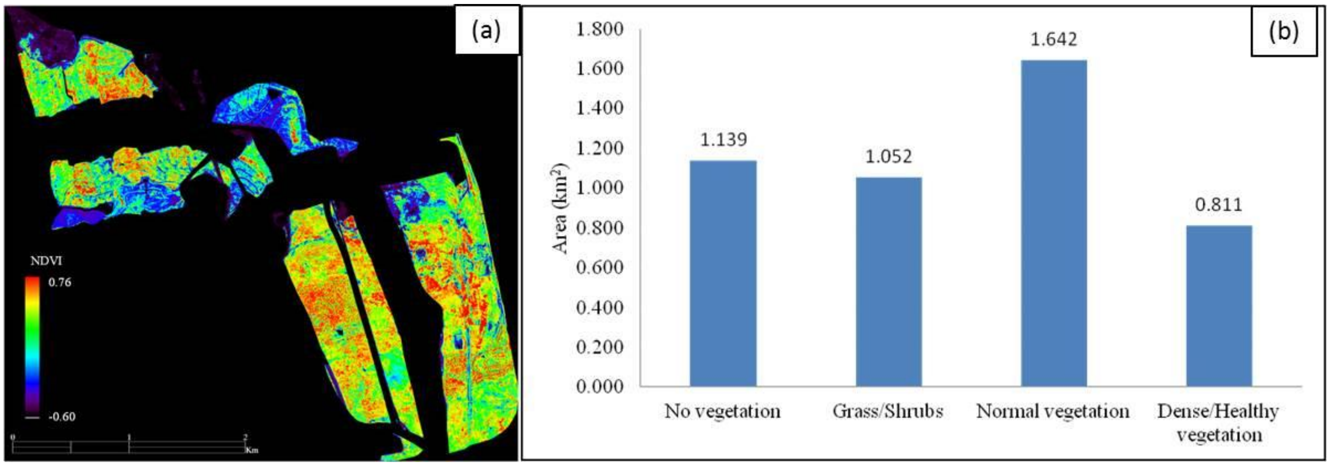

Figure 1 (a) Satellite based mine rehabilitation health assessments and (b) Quantitative reporting for progressive rehabilitation (Raval et al 2013)

mines area in Yerranderie, New South Wales, Australia (Banerjee et al 2017b). The study site has a total of eleven historic mine shafts and has a legacy of heavy metals and acidic leachates in a pristine ecosystem now recognised as Great Blue Mountain World Heritage Area.

2.3 Water

Spectroscopic techniques are used routinely on ground, from space and using airborne platforms to monitor acid mine drainage (AMD). Time-series data from satellite provides continuous change detection for surface water including wetlands that is subjected to potential mining impacts (Banerjee et al 2016). A digital elevation model (DEM) derived from optical satellite stereo pairs could provide vertical accuracy in the range of 15cm to 30cm; this could be useful to assess regional scale erosion patterns.

2.4 Air

Greenhouse gases (CO_2 and CH_4) and particulate matter are measured on a global scale using satellite spectrometry. More recently, lightweight environmental monitoring sensors on UAVs have made it possible to remotely measure the low altitude CO_2 (Malaver et al 2015) and dust (Alvarado et al 2015). These are important developments for a timely intervention to minimise the impact of mining operations on surroundings.

2.5 Soil

Various studies have investigated heavy metal pollution in soil using satellite based multispectral (Jin et al 2015) and airborne hyperspectral data (Shamsoddini et al 2014). New satellites with hyperspectral, thermal, and microwave L-band active sensors provide more detailed measurements of soil moisture although the lower resolution makes it unsuitable for a mine site application. The development of mini-SAR sensor mounted on a low-flying platform carries potential for soil moisture measurements (Acevo-Herrera et al 2010) at the accuracy required for mining operations.

2.6 Land use changes

Sustainable management of land requires regular acquisition of qualitative information regarding the status of its use. It is especially important to track the changes relating to the land's competitive development needs such as mining and agriculture. Raval and Shamsoddini (2014) demonstrated the use of satellite remote sensing data as cost-effective alternatives for the conventional methods of land use/land cover (LULC) monitoring. This study provided a practical framework for rapid mapping of the land cover changes around open-cut kaolin mining area using freely available Landsat data.

3 Site Level Vigilance

3.1 Operational aspects

A mine site has different monitoring and mapping requirements such as routine stock calculation of the extracted ore, monitoring the condition of haul roads and engineering inspections. UAVs based observations are emerging as effective techniques to address some of the day-to-day operational requirements at a mine site. Traditionally UAV photogrammetry and more recently UAV-LiDAR systems have been proved useful for accurate volumetric measurements of stockpiles. UAV based imaging system has a potential to assess haul road conditions autonomously and continuously. Furthermore, monitoring the condition of conveyor belts, draglines, and other engineering structures could be effectively done using UAV-RGB and thermal cameras. UAV-photogrammetry is also effective in updating the map of a dynamic mine site which is useful in future mine planning works. Paired with in-situ sensors on vehicles and machineries, a robust collision avoidance system could be achieved for underground operations.

3.2 Environmental aspects

UNSW LIME has used UAV-based thermal imaging to monitor the risk of the spontaneous combustion of coal stockpiles (Figure 2). In other areas, such as water quality monitoring application, UAVs could be equally effective.

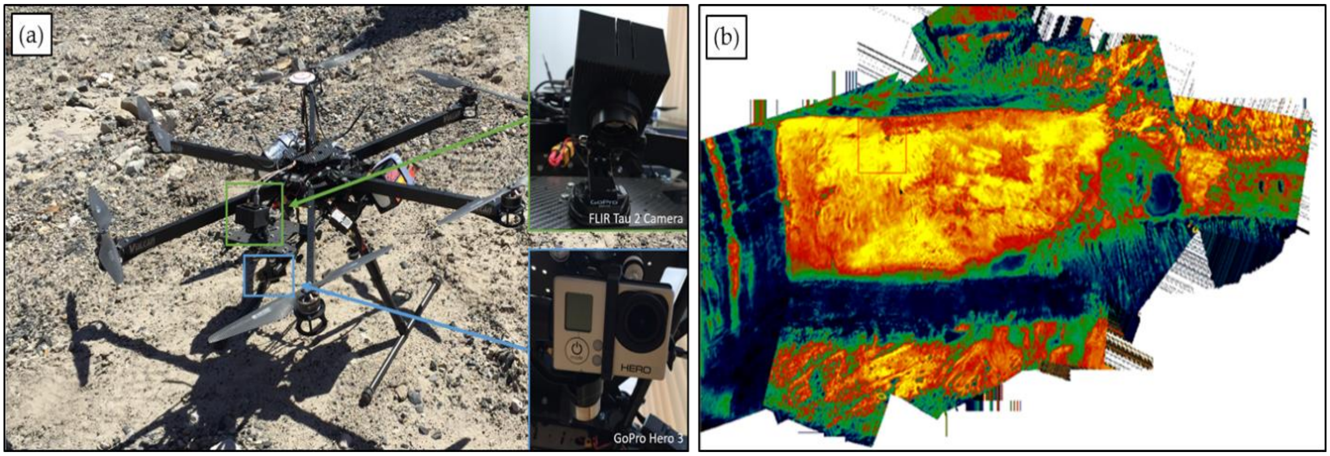

Figure 2 (a) A UAV integrated with a FLIR Tau2 and a GoPro Hero3 camera system and (b) thermal anomaly map of the coal dump

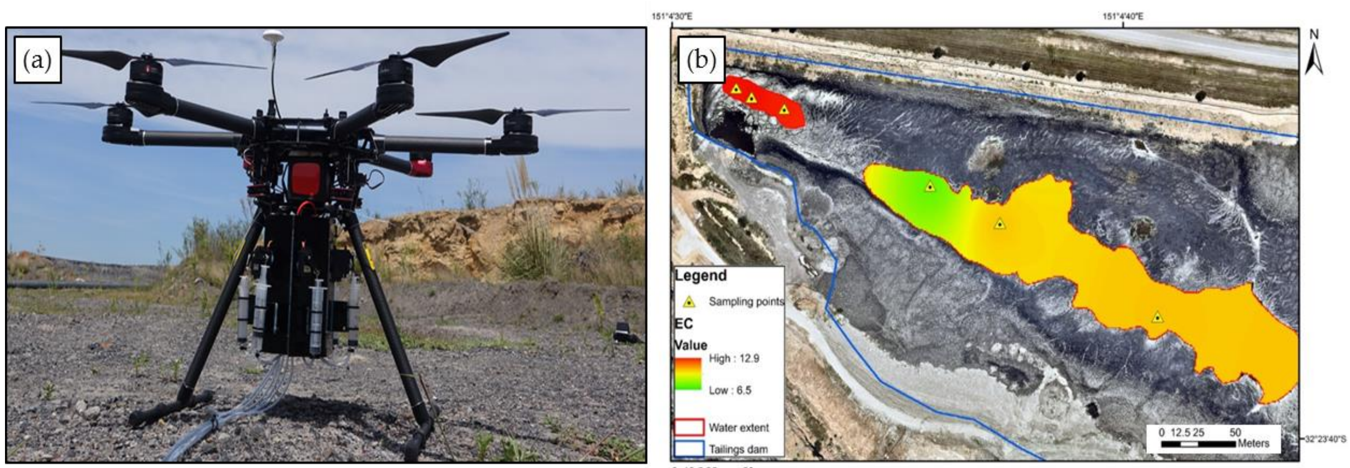

Figure 3 (a) A UAV integrated with a water sampling system designed in LIME and (b) interpolated map of Electric Conductivity (EC) for the tailing dam water

UNSW LIME has recently integrated and tested a UAV based water quality sampling system for mine tailings (Figure 3). The test has demonstrated that UAV based water collection devices could be effective in collecting water from hazardous environments such as mine tailings without influencing the chemical properties of the water.

Other UAV based solutions such as air quality monitoring around mine site is becoming increasingly promising for near future applications.

3.3 Safety aspects

UNSW LIME is involved in promoting InSAR based subsidence monitoring. Earlier studies involved ENVISAT (Ng et al 2011) and ALOS PALSAR (Ng et al 2012) data. Later, advanced PsInSAR (Morgan et al 2013) approaches were adopted to monitor the ground displacement at sub-centimetre scale.

It is critical yet challenging to effectively map the structure of pit-walls at the required textural and spatial scales that would enable geotechnical analysis and early warning of slope failure. UNSW LIME has integrated a state-of-the-art LiDAR system (Phoenix Aerial Scout) on a UAV platform (Figure 4) for advanced structural characterisation of the rock mass.

Several underground safety aspects such as the stability of the tunnels and roof support structures can now be monitored through mobile scanning systems. These mobile scanning systems (handheld or UAV borne) provides improved characterisation of discontinuities, early warnings of potential stability hazards, frequent reconciliations and reporting of positional changes, etc. Other technologies for continuous in-situ sampling of temperature, gas (CO_x, NO_x, SO_x), moisture, etc. are being presently under development at UNSW LIME.

4 The Future

4.1 Futuristic mining regions

Mining industry continuously seeks improvement in environmental performances to set leading practice examples across the globe. To this end, there is a need to develop an automated system that could integrate varied sources of

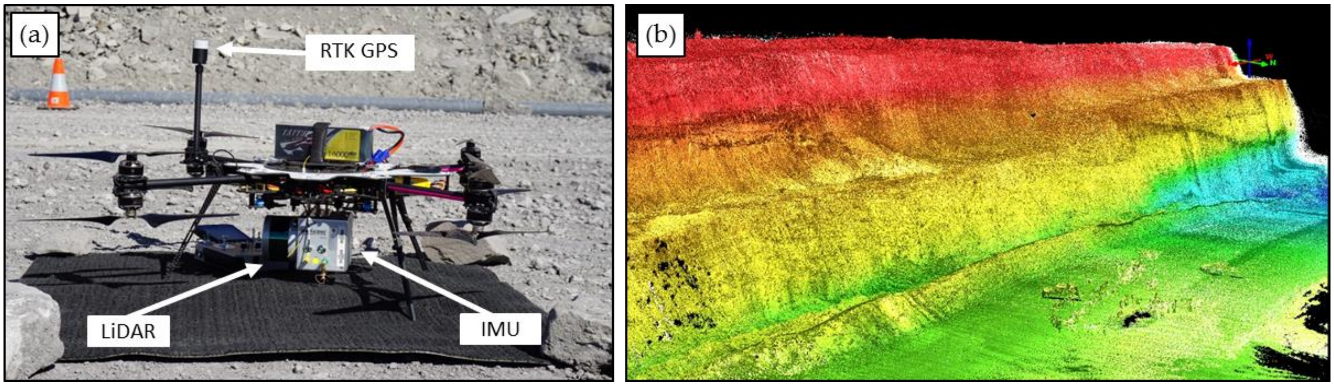

Figure 4 (a) A UAV integrated with a Velodyne LiDAR, IMU, and RTK GPS (Phoenix LiDAR system) and (b) colourised point cloud map of the highwall

remotely obtained data from various platforms to detect changes in sensitive ecosystem within active and post mining landscapes. A 4D (space and time) data visualisation tool could be developed to facilitate quick and holistic review of the functioning of the ecosystem elements exposed to potential mining impacts. Data mining routines will be developed to operate on thematic, non-thematic, backscatter data products acquired from multi-imaging platforms (satellites, aircrafts, UAVs) and GIS layers. The assessment will produce spatio-temporal trajectories of vegetation, water, and land parameters to assist multi-stake holders (mining industries, regulators, communities) in decision-making. This smart integrated sensing system will provide improved confidence in tracking the changes for timely interventions.

4.2 Futuristic mine sites

Technological advances over the last six or seven years have made so many more things possible, and the systems continue to advance at a rapid rate. Not only do we have access to increasingly powerful, light weight and cost-effective sensors but, simultaneously, we have access to increasingly powerful drones/UAVs with a higher load carrying capacity. On the other hand, algorithms to handle the generated data are getting smarter too. What is necessary is to intelligently mould them for specific applications. The futuristic vision for a mine site is to have a number of smart sensors making automated observations that feed into an integrated system to predict areas of concern and mitigate against them leading to a zero harm mining.

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