PhD and MPhil Scholarship Opportunities 2020

AUSTRALIAN RESEARCH COUNCIL

INDUSTRIAL TRANSFORMATION TRAINING CENTRE FOR INTEGRATED OPERATIONS FOR COMPLEX RESOURCES

THE UNIVERSITY of ADELAIDE

University of South Australia

Curtin University

Background

The purpose of this Training Centre is to deliver the vital enabling tools – advanced sensors, data analytics and artificial intelligence – for automated, integrated and optimised mining. Automating a mine requires the integration of all stages of the mining and processing system so that intelligence across the value chain can be automatically generated, delivered and exploited. The Training Centre will train the next generation of engineers and scientists in the development and application of these enabling tools, a current knowledge priority for the mining industry.

The Training Centre comprises three university partners (University of Adelaide, University of South Australia and Curtin University), two mining companies (BHP and OZ Minerals) and 20 mining equipment, technology and services companies and organisations.

We are seeking applicants with a strong background in one or more of the following areas: mining engineering, mineral processing, metallurgy, chemical engineering, mechanical engineering, applied geology, physics, computer science, geostatistics, mathematics. More information is provided under the Selection Criteria below. Successful applicants will conduct their research in an integrated, inter-disciplinary environment and will spend a total of 12 months of their research project in one or more of the industry partner companies.

Higher Degree by Research (PhD and MPhil) projects spanning the mining and processing production chain

1. Cross-borehole seismic interferometry to interpolate rock mass and geometallurgical variables (Curtin University), PhD.
2. Draw-point and cave operations and fragmentation sensing (University of Adelaide), PhD.
3. Wireless sensor network radio frequency identification for continuously deployable tagging (University of Adelaide), PhD.
4. Gold sensing (University of Adelaide), PhD.
5. Vibration and accelerometer sensing for early stage roping detection in hydro cyclones (University of Adelaide), PhD.
6. Pulp chemistry monitoring for leach applications (University of South Australia), PhD.
7. Integration and analytics of drill sensor information to derive geometallurgical attributes (University of Adelaide), PhD.
8. Fingerprinting ore types and blends by fusing hyper-spectral and other sensor data using assisted machine learning (University of South Australia), PhD.
9. Ore tracking model from uncertain resource model to belt sensors and run-of-mine stockpiles (University of Adelaide), PhD.
10. Integration of sensors to maximise crushing plant throughput (University of Adelaide), PhD.
11. Integration of grinding circuit sensors including ultrasonics for particle size distribution to maximise mill throughput (University of Adelaide), PhD.
12. Integration and analytics of pulp chemistry sensor information with in-stream analysis for flotation plant optimisation (University of South Australia), PhD.
13. Integration of in-stream and particle size measurements in flotation (University of South Australia), PhD.
14. Rapid updating of resource knowledge with sensor information including structures (University of Adelaide), PhD.
15. Measuring and monitoring particle size distributions so as to divert low value waste (University of Adelaide), MPhil.
16. Linking the resource to down-stream products (University of Adelaide), PhD.

Industry and government partners

BHP	Magotteaux
OZ Minerals	Manta Controls
AMIRA	Maptek
Boart Longyear	METS Ignited
Bureau Veritas	MZ Minerals
CRC ORE	Orica
Datanet Asia Pacific	Petra Data Science
Dassault Systèmes	Rockwell Automation
South Australia Department for Energy and Mining	RoqSense
EKA Software Solutions	Scantech

The training environment

The Centre is offering 16 Higher Degree by Research (HDR) scholarships (15 PhD and one MPhil) that will provide a unique training opportunity including:

- World class facilities and experts across the participating universities, industry partners and other organisations.
- An integrated Training Centre research agenda with inter-disciplinary projects.
- 12-month PhD placements and an up to eight-month MPhil placement with partner organisations.
- Research skills and career development workshops.
- Competitive support for national and international conference travel.
- Generous project support.
- Delivering the next generation of scientists and engineers in the critical areas of sensors, data analytics and AI for complex resources.

Eligibility

PhD applicants must be acceptable as candidates for a PhD degree at the University of Adelaide, University of South Australia or Curtin University and MPhil applicants must be acceptable as candidates for the MPhil degree at the University of Adelaide.

PhD applicants require one of the following to gain admission to the programme:

- a relevant Honours degree from one of the three universities (or the equivalent from another university), with at least a second-class Honours (upper division) or equivalent;
- a postgraduate coursework degree which contains a significant research component and meets the minimum Grade Point Average (GPA) requirements;
- a relevant Research Master degree from one of the three universities (or equivalent).

MPhil applicants require one of the following to gain admission to the programme:

- a relevant Bachelor degree from the University of Adelaide (or the equivalent from another university), in which the candidate has achieved a minimum of a distinction average;
- a relevant Honours degree from the University of Adelaide (or the equivalent from another university), with at least a second-class Honours (upper division) or equivalent;
- a relevant Master by Coursework degree from the University of Adelaide (or the equivalent from another university) that contains less than 15 credit points (or one-third of the degree) of research, and in which the candidate has achieved a Grade Point Average (GPA) of 6.0 or higher;
- a relevant Master by Coursework degree from the University of Adelaide containing a minimum of 15 credit points (or one-third of the degree) by research, with an overall GPA of 5.0 or higher and a GPA of 6.0 or higher in the Research Component;
- a relevant Master by Research degree from the University of Adelaide (or the equivalent from another university).

English language proficiency requirements also apply:

IELTS (ACADEMIC)	TOEFL (INTERNET BASED TEST)	PEARSON TEST of ENGLISH (ACADEMIC)	C1 ADVANCED
Overall Score 6.5 Writing, Speaking, Listening and Reading 6.0	Total score 79 Writing 21, Speaking 18, Listening and Reading 13	Overall Score 58 Writing, Speaking, Listening and Reading 50	Overall Score 176 Writing, Speaking, Listening and Reading 169

Selection Criteria

The Training Centre provides a unique inter-disciplinary approach to complex inter-disciplinary problems. Successful applicants will work within this inter-disciplinary environment and be expected to integrate their work with disciplines other than their own. Relevant disciplines include mining engineering, mineral processing, metallurgy, chemical engineering, geostatistics, applied geology, mechanical engineering, computer science, mathematics, statistics, and related areas. Proficiency in computer programming is required for most of the projects. In assessing applications, preference will be given to applicants who can demonstrate an ability to work across disciplines. For example, an applicant may have a degree in mining engineering with a final-year project or specialisation in geostatistics or stochastic optimisation; or have a degree in computer science with an honours-year project in which machine learning was applied to a geological, mining or processing problem. When applying for a particular project, please state briefly and clearly the relevant of your degree and/or your experience to the project description.

Stipend

PhD scholarships will be for a period of three and a half years and the MPhil scholarship will be for a period of two and a half years. The PhD and the MPhil scholarships have an indicative stipend of AUD$34,013 (indexed annually) per annum as set by the Australian Research Council. International applicants are encouraged and those of sufficient merit will be eligible for a tuition fee waiver scholarship.

Enquiries

Further general information on postgraduate research degrees can be found at the hosting universities' websites: The University of Adelaide, UniSA and Curtin University.

Queries regarding specific projects should be directed to the relevant contact shown in each project.

General queries regarding the Training Centre should be directed to:

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Project ID: HDR1 (PhD)

Cross-borehole seismic interferometry to interpolate rock mass and geometallurgical variables.

Project details	Approach: P-wave diffraction seismics detected by fibre optics on cores and between boreholes. This project will focus on seismic sensor strings in drill-holes. The sensor proposed will be a fibre optic cable using distributed vibration sensing via Rayleigh scattering, when combined with a dedicated interrogator, should produce data suitable for standard P-wave tomography and possibly S-wave tomography. Firstly, this fibre-optic data allows seismic tomography to provide integration with lithology (e.g., cluster enhanced inversion from measured core data with other sensor information on down-hole logs) to determine or predict many ore-host rock properties. Furthermore, recorded body waves may be inverted to produce elasticity of the rock (velocities and densities). Full Waveform Inversion (FWI) will enable the computation of engineering parameters such as Young's modulus, Shear modulus and compressibility that are essential to characterise rock mass and provide an idea of the primary rock response framework to be used for geometallurgical response modelling. A volumetric 3D tomographic model of Rayleigh wave inverted S-wave velocities could also be derived using mine noise. In addition, active seismic sources could be used to provide robust additional information such as structural complexity, distribution of P-wave velocities and distribution of different rock formations (lithologies).
Industry partners	RoqSense Boart Longyear
Location	Curtin University (enrolment)/University of Adelaide (located, with occasional travel to Curtin).
References	Williams, P.K., Urosevic, M. Kepic, A. and Whitford, M. (2012). Recent experience with use of high definition seismic reflection for nickel sulphide exploration in Western Australia. 74th European Assoc. of Geoscientists & Engineers Conference & Exhibition. Urosevic, M., Bona, A., Ziramov, S., Kepic, A., Egorov, A., Pridmore, D., Dwyer, J. (1997), Seismic for mineral resources – a mainstream method of the future: Exploration '17: The Sixth Decennial International Conference on Mineral Exploration, Toronto, Canada: Seismic Methods & Exploration Workshop. Asgharzadeh, M., Grant, A., Bona, A., and Urosevic, M. (2019). Drill bit noise imaging without pilot trace, a near-surface interferometry example. *Solid Earth*, 10(4), 1015-1023.

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Project ID: HDR2 (PhD)

Draw-point and cave operations and fragmentation sensing.

Project details	Approach: Fragmentation sensing by size and lithology for blast control and sensing of sub-level caving and sub-level open stoping. Control of rock fragmentation is essential for successful extraction of underground stopes using either sublevel open stoping or sublevel caving. Fragments that are too fine can reduce the productivity of the operation, increase the risk of dust related problems and potentially increase dilution due to over-blasting. Fragments that are too coarse can have significant impact on energy consumption in subsequent processing (e.g., crushing, milling/grinding) and may cause serious hang-up problems near draw-points. The post-blast size distribution of rock fragments depends on many factors including, for example, rock properties (e.g., physical and geomechanical), blast design (e.g., stope shape, ring design, powder factor, charge arrangement and detonation sequence) and operational issues (e.g., drilling accuracy). New opportunities to optimise mining value chain include integrating correlated drill rig sensors, draw-point and LHD lithological fragmentation sensors and data-driven blast and cave operation models[1-6]. The objective of the project is to establish a more realistic model for the size distribution of post-blast rock fragments, taking into account the key factors listed above. Sensed information will be incorporated into the model, which may include drilling parameters (e.g., penetration rate, torque, abrasivity), rock type/lithology, heterogeneity, geological structures, rock fractures, geophysical logging information (e.g., density, wave velocity, acoustic impedance, fractures, porosity) [7]. LiDAR or photogrammetry will be used to sense rock fragmentation from draw-points, or within the stope, and the FRAGx system[8] will be used to measure fragmentation. These data will be used to calibrate draw-point and stope fragmentation models to obtain a more realistic model, which will be used to design the stope extraction to optimise rock fragmentation. In combination with sensed grade data (where available), the model will also be used in the optimisation of the stope production schedule and the transport of ore from draw-points to the mill, accounting for stockpiling, ore blending and the costs of haulage, crushing and milling/grinding.
Industry partners	Orica, Maptek, Boart Longyear, Bureau Veritas, Petra Data Science, OZ Minerals, BHP
Location	University of Adelaide
References	(1) Chung, S.H. and P. Katsabanis (2000) Fragmentation prediction using improved engineering formulae. Fragblast 2000. 4(3-4): p. 198-207. (2) https://www.oricaminingservices.com/uploads/Fragmentation/open%20cut%20metals/100104_Case%20Study_Fragmentation%20Measurement%20to%20enable%20Reduced%20Drill%20and%20Blast%20Costs_Junction%20Gold%20Mine_Australia_English.pdf (3) Kent, J. and Xu. C. (2018) Maximising value return through blast design at the Kanmantoo Open Pit copper mine, University of Adelaide honours research project conference. (4) Sepulveda, E., Dowd, P. A., Xu, C. (2018) The optimisation of block-caving production scheduling with geometallurgical uncertainty. Mining Technology, 127(3), 131-145. (5) Hou, J., Xu, C., Dowd, P. and Li, G. (2019) Integrated optimisation of stope boundary and access layout for underground mining operations. Mining Technology, 128:4, pp. 193-205. (6) Kim, Y. (2015) Quantitative performance assessment for large open stope design, MSc., Univ. Adelaide. (7) Dong, S., Zeng, L., Lyu, W., Xu, C. (2020) Fracture identification by semi-supervised learning using conventional logs in tight sandstones of Ordos Basin, China, Journal of Natural Gas Science and Engineering, https://doi.org/10.1016/j.jngse.2019.103131. (8) https://www.petradatascience.com/casestudy/machine-learning-ai-enters-underground-mining/

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Project ID: HDR3 (PhD)

Wireless sensor network radio frequency identification for continuously deployable tagging.

Project details	Approach: Develop a low-cost, rugged radio frequency identification (RFID) tagging system with sensors to track the resource from in situ to mill. Identifying the lithological composition of ore exiting the mine is a key factor for critical performance measures such as optimising ore processing settings to reduce energy consumption and improve metal recovery. RFID technology is a promising method for tracking the real-time locations and composition of ore[1-3]. This project will: (i) investigate sensor-enabled ultra-low-cost RFID tags, fed into the ore delivery system at an ore pass or elsewhere, for tracking and modelling the flow and composition of ore in real-time at critical points such as stock piles and mill feeds; and (ii) develop tracking algorithms that can improve the visibility of ore along the production chain and accurately capture the ore profiles at the stockpiles and mill feeds. The mine environment imposes a number of challenges for the efficient and accurate tracking of ore using RFID technology. Whilst RFID tagging is used in industry[4], the issue in ore tracking is to collect reliable data from low-cost RFID tags from mine to mill. Detecting RFID tags on high-tonnage belts is particularly difficult. This project will address some of these challenges, in particular, the environment in which the tags operate, the ability to read the tags and the sensed information collected by them, and the ability to locate and extract the tags at the destination site. Consequently, a key issue in this project is to track the ore using noisy and uncertain information from RFID tags. This will require the development of estimation methods to track the flow of the resource to the mill using uncertain information from an underlying networked RFID system. In addition, the sensed data must be integrated into the resource model to help operators identify the source of the ore, optimise the ore mix and maximise recovery and production efficiency so as to maximise profit.
Industry partners	Datanet Eka Software Solutions OZ Minerals
Location	University of Adelaide
References	(1) Jurdziak, L., Kaszuba, D., Kawalec, W. and Król, R. (2016). Idea of Identification of Copper Ore with the Use of Process Analyser Technology Sensors. IOP Conference Series: Earth and Environmental Science, 44 (042037); doi:10.1088/1755-1315/44/4/042037 (2) Jurdziak, L., Kawalec, W. and Król, R. (2019) Guidelines for Ore Tracking System in the Complex Underground Transportation Got from the DISIRE Project. IOP Conference Series: Earth and Environmental Science. 221: p. 012101. (3) Bardzinski, P., Jurdziak, L., Kawalec, W. and Król, R. (2019) Copper Ore Quality Tracking in a Belt Conveyor System Using Simulation Tools. Natural Resources Research, 2020. 29(2): p. 1031-1040. (4) Worthy, M. (2012). Metso's smarttag™ - The next generation and beyond. Aufbereitungs-Technik/Mineral Processing, 53(3): 64-72.

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Project ID: HDR4 (PhD)

Gold sensing.

Project details	Approach: Integrate multiple sensor techniques and correlate response against different gold samples. Gold has high value and contributes significantly to revenue, even as a by-product for complex copper ores. Prompt-gamma neutron activation analysis (PGNAA) has very good sensitivity to gold at the percentage level but gold occurrences are measured in parts per million (ppm) and may be very unevenly distributed. Thus, gold sensing has been a challenge in run of mine ore and fine particle slurries for which traditional x-ray fluorescence (XRF) is insufficient. Gamma Activation Analysis (GAA) has been studied in an attempt to address this situation(1), in which an electron accelerator (8 MeV) and high flux power (5 kW) are used to penetrate particles up to 2 mm(1). As this technique involves dangerously high gamma radiation it is only usable in controlled laboratory environments(2). Additional techniques use photonic phenomena to sense gold, including the use of surface plasmon resonance effects(3). These techniques all aim to directly detect gold but have their own unique limitations. An alternative approach is to sense gold indirectly through assessment of ore alteration and the host minerals where gold is found(4). SEM and MLA are common techniques for determining modal mineralogy at small size fractions and, when correlated with hyperspectral, X-ray mapping and visual interrogation of core samples can be used to determine mineral hosts of gold(4,5). This project will analyse different gold-bearing mineral samples and their size fractions using methods such as fire assay, PGNAA, hyperspectral, XRF, MLA and SEM, as well as optical spectroscopy, fluorescence analysis and visual microscopy. This will establish best-practice methods of correlating different gold analysis techniques for application in the mining industry to provide faster and more meaningful information.
Industry partners	OZ Minerals Boart Longyear Bureau Veritas Scantech
Location	University of Adelaide
References	(1) Tickner, J., et al. (2017). Improving the sensitivity and accuracy of gamma activation analysis for the rapid determination of gold in mineral ores. *Applied Radiation and Isotopes* **122**: 28-36. (2) Sokolov, A. D., et al. (2017). Industrial gamma-activation assay system for gold ore analysis. *Minerals Engineering*, **116**: 179-181. (3) Zuber, A., et al. (2016). Detection of gold nanoparticles with different sizes using absorption and fluorescence based method. *Sensors and Actuators*, B: Chemical 227: 117-127. (4) Tusa, L., et al. (2019). Mineral mapping and vein detection in hyperspectral drill-core scans: application to porphyry-type mineralisation. *Minerals*, **9**, 122. (5) Warlo, M., et al. (2019). Automated quantitative mineralogy optimized for simultaneous detection of (precious/critical) rare metals and base metals in a production-focused environment. *Minerals*, **9**, 440.

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Project ID: HDR5 (PhD)

Vibration and accelerometer sensing for early stage roping detection in hydrocyclones.

Project details	Approach: Installation of sensors on operating cyclones to measure cyclone performance. Hydrocyclones are used in mineral processing to separate coarse and fine particles according to their size and/or to separate minerals according to their density. The focus of this project is separation on the basis of particle size and density. A mineral slurry enters the hydrocyclone and is subjected to an induced cyclonic flow. In an ideal situation, fine particles will exit at the top of the hydrocyclone as overflow and proceed to flotation; coarse particles will exit at the bottom as underflow to be subjected to further grinding in a ball mill before being returned to the hydrocyclone. In practice, hydrocyclones are subject to a range of operational problems, the most common of which are roping and plugging. Roping occurs when the number of mis-classified particles in the overflow is too high. Plugging occurs when the bottom of the hydrocyclone is blocked and all material exits as overflow. To detect roping, ultrasonic sensors and vibration sensors are attached to the underflow discharge and roping is identified when the signals exceed a baseline threshold [1]. However, the consistency of the current roping detection methods is highly variable, especially when the hardness and geometallurgical characteristics of the ore are constantly changing [2]. If roping and plugging are not detected in time, downstream recovery, grade, and mineral processing throughput will be significantly adversely affected. Early stage roping is characterised by increased particle size and significant changes in the particle size distribution (PSD) in the overflow combined with structural vibration signal changes in the underflow. A better understanding of this will be obtained by using experimental data to model the relationships between overflow PSD, underflow vibration signals and the stages of roping formation [3]. This will be achieved through a newly developed PSD sensor to be installed on hydrocyclone product discharge spigots. This HDR project will use experimental data generated by the PSD sensor to create an early-stage-roping-detection model that is not sensitive to changes in the composition of the processing feed. The model will be used for automatic operational control to prevent roping and thereby increase downstream recovery and mineral processing throughput.
Industry partners	Manta Controls Dassault Systèmes Rockwell Automation
Location	University of Adelaide
References	(1) Mohanty, S., Gupta, K.K. & Raju, K.S. (2015), 'Vibration Feature Extraction and Analysis of Industrial Ball Mill Using MEMS Accelerometer Sensor and Synchronized Data Analysis Technique', *Procedia Computer Science*, vol. 58, no. C, pp. 217-224. (2) Maron, R., et al. (2014). Process optimization at Rio Tinto Kennecott using real-time measurement of coarse material in individual hydrocyclone overflow streams. IMPC 2014 - 27th International Mineral Processing Congress.

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Project ID: HDR6 (PhD)

Pulp chemistry monitoring for leach applications.

Project details	Approach: Combined pH, Eh, and Ferric/Ferrous Ion Sensor for Leach Circuits. New sensors using hybrid fluorescent organic/inorganic materials will allow for simultaneous in-line measurement of pH, Eh, and Ferric/Ferrous ion ratio for acidic leach conditions. Metal Organic Framework (MOF) materials are porous inorganic/hybrid crystalline solids that have applications in catalysis, separation analytics, and in sensing. They are increasingly being developed and tested in the areas of metal ion, small molecule, and biomolecule sensing in aqueous media. The sensing modality is primarily based on absorption of emission of light, often with fibreoptic light delivery and recovery, making it ideal for sensing in complex mixtures and in harsh environments. This HDR project is the second stage in our efforts to develop sensors based on these materials for leaching applications in mineral processing. The synthesis and testing of the materials as bulk solid sorbents for target analytes (protons, dissolved oxygen, ferric/ferrous ions) will be completed at the time of enrolment of the student on this project. This HDR project will comprise the development, fabrication and testing of fibreoptic probes that use MOF materials as the sensing medium. This will be followed by the design and implementation of fibreoptic sensing in the existing pulp chemistry monitoring platform of the primary industry partner, Magotteaux.
Industry partners	Magotteaux BHP Manta Controls
Location	University of South Australia
References	Bétard A., Fischer R.A. (2012) Metal-organic framework thin films: From fundamentals to applications. *Chem Rev.*;112(2):1055-1083. Dou Z., Yu J., Cui Y., et al. (2014) Luminescent metal-organic framework films as highly sensitive and fast-response oxygen sensors. *J Am Chem Soc*.;136(15):5527-5530. Li M., Yang W., Qiu P., et al. (2018) Two efficient pH sensors based on heteronuclear metal-organic frameworks. *J Lumin*. 2019;205:380-384. Chen C.H., Wang X.S., Li L., Huang Y.B., Cao R. (2018) Highly selective sensing of $Fe^{3+}$by an anionic metal-organic framework containing uncoordinated nitrogen and carboxylate oxygen sites. *Dalt Trans*.; 47(10):3452-3458.

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Project ID: HDR7 (PhD)

Integration and analytics of drill sensor information to derive geometallurgical attributes.

Project details	Approach: Analytics on downhole geophysics, drill machine sensing, on-rig XRF sensing, and correlations to core geometallurgical/structural data. Sensing during drilling will be used to generate three-dimensional maps of P-wave velocity[(1)]. These velocities are directly related to many rock mechanics properties, and this project will establish the relationships between these properties and the sensed data. In particular, the project will establish the quantitative relationships between the drill sensor data and the geometallurgical attributes of the ore in the resource model. Multi-modal data such as imaging data, on-rig X-ray fluorescence (XRF) spectrometric and X-ray diffraction (XRD) data will also be inputs for analysis. These data include information on morphology/grain size/textures/structures, chemical composition and mineral speciation. The ultimate aim of this project is to obtain, integrate and analyse useful data on minerals in real time during resource drilling using multivariate statistics and/or statistical machine learning techniques. These data will be converted to information that can be used to understand the behaviour of the mined product in the crushing-grinding-concentration circuit, and to provide knowledge essential for optimising plant performance and maximising recoveries. A particular family of machine learning techniques, namely, Deep Learning, has demonstrated considerable potential for the analysis of complex images and audio data. They have recently been used in the analysis of mining data and show state-of-the-art performance[2]. The project will explore and develop deep learning models to achieve accurate close-to-real-time processing of drill sensor information of various types, and at the same time enable retrieval of relevant information from off-the-shelf resource knowledge databases. The project will deliver breakthrough technologies that will, in turn, enable new, close to real-time approaches to the determination of geometallurgical attributes, with potential for widespread deployment across the minerals industry.
Industry partners	Boart Longyear OZ Minerals
Location	University of Adelaide
References	(1) Williams, P.K., Urosevic, M. Kepic, A. and Whitford, M. (2012). Recent experience with use of high definition seismic reflection for nickel sulphide exploration in Western Australia. 74th European Association of Geoscientists & Engineers Conference & Exhibition. (2) Caleb Vununu, Kwang-Seok Moon, Suk-Hwan Lee, and Ki-Ryong Kwon (2018). A Deep Feature Learning Method for Drill Bits Monitoring Using the Spectral Analysis of the Acoustic Signals. Sensors (Basel). 18(8): 2634.

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Project ID: HDR8 (PhD)

Fingerprinting ore types and blends by fusing hyper-spectral and other sensors using assisted machine learning.

Project details	Approach: Spectroscopic analytics using laser-based spectroscopic sensors on cores, mixes, ore passes and belt samples to deconvolute ore sources on belts. An underpinning driver for this project is that for highest fidelity identification / quantification of minerals, multiple sensor data will likely need to be combined. Ore tracking can be constrained by using hyper-spectral, Raman, and laser induced breakdown (LIBS) spectroscopy. These approached will be validated by gamma-spectral data analytics with other techniques to fingerprint ore types. Minerals display characteristic surface interactions with light; however, no technique covers all minerals (either gangue or valuable). It has become increasingly clear that the potential of optical spectroscopy will not be realized until a suite of these are integrated, and the resultant large data sets combined in a data fusion approach(1). Collaboration will be established with relevant CI's in the ITTC to assist in processing large data sets, and data fusion tasks. Optical techniques will be explored and validated by established techniques such as Prompt Gamma Neutron Activation Analysis (PGNAA)(2). The opportunity is that laser based spectroscopic techniques have matured and now 'moved out of the lab' including hyperspectral infrared reflectance(1), Raman scattering(3), and LIBS(4) techniques. In addition, these systems now use more powerful laser-based probes reducing data acquisition times, and the easy availability of multi-spectral cameras will allow comprehensive and real-time sets of spectroscopically rich image data to be collected for processing and integration, and ultimately the development of smart heuristics. This HDR project will focus on applying and developing novel optical spectroscopic techniques and will require some background in electromagnetic radiation / optical science and skills such as data collection and signal processing would be of value. There will also be a period of candidature where the student will be placed with an industry partner to undertake components of their research. It is also anticipated that the industry partner will be able to advise on industry needs, as well as assist in acquiring either validated or unvalidated mineral samples (e.g., cores).
Industry partners	Boart Longyear Bureau Veritas
Location	University of South Australia
References	(1) Balzan, L.A., Jolly, T.D., Harris, A.R. and Bauk, Z. (2016). Greater use of Geoscan on-belt analysis for process control at Sepon copper operation'. IMPC 2016: XXVIII International Mineral Processing Congress Proceedings - ISBN: 978-1-926872-29-2. (2) Desta, F., Buxton, M., Jansen, J. (2020) Data Fusion for the Prediction of Elemental Concentrations in Polymetallic Sulphide Ore Using Mid-Wave Infrared and Long-Wave Infrared Reflectance Data. Minerals, 10(3), 235. (3) Zettner, A., Gojani, B., Schmid, T., Gornushkin, I. (2020) Evaluation of a Spatial Heterodyne Spectrometer for Raman Spectroscopy of Minerals' Minerals, 10, 202. (4) Khajehzadeh, N., Kauppinen, T.K. (2015)Fast mineral identification using elemental LIBS technique. IFAC Workshop on Mining, Mineral and Metal Processing MMM, Finland.

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Project ID: HDR9 (PhD)

Ore tracking model from uncertain resource model to belt sensors and run-of-mine stockpiles.

Project details	Approach: Model the passage of ore from resource draw-points to mill feed via haulage, run-of-mine stockpiles and feeders constrained by sensor information. Although downstream Run of Mine (RoM) cross-belt sensor information provides real-time tonnage and compositional information, it is not currently linked to upstream resource knowledge and models. Establishing this link would significantly improve decision-making and profitability. This project will model the passage of ore from the uncertain, *in situ* resource to the mill feed, via draw-points, muck piles, loaders, ore passes, conveyors, RoM stockpiles and feeders, possibly constrained by ore tagging technology (e.g., RFID tagging), other sensor inputs (e.g., ore fingerprinting using techniques such as hyper-spectral and gamma-spectral data analytics), and other data from underground mine operations to provide frequent updates of the resource knowledge and models. The project will focus on data analytics to derive a data-driven, real-time on-line ore tracking model using existing and new sensor suites and plant operating data feeds from operating sites including belt sensors and mill feed to cover the ore flow passage from resource draw-points to mill feed. Other aspects to consider are the re-distribution of particle sizes during the stockpiling processes, and the change in in situ sampled properties in stockpile e.g. moisture. The sensor outputs from this project will be used with other data from underground mine operations to constrain ore flow models from the in-situ resource to the mill feed linking belt and drill sensor information to resource knowledge.
Industry partners	Eka Software Solutions OZ Minerals
Location	University of Adelaide
References	Balzan, L.A., Jolly, T.D., Harris, A.R. and Bauk, Z. (2016). Greater use of Geoscan on-belt analysis for process control at Sepon copper operation. IMPC 2016: XXVIII International Mineral Processing Congress Proceedings - ISBN: 978-1-926872-29-2. Bennett, D., Miljak, D. and Khachen, J. (2009). The measurement of chalcopyrite content in rocks and slurries using magnetic resonance. *Minerals Eng.*, 22: 821-825. Pearce, C.I., Pattrick, R.I.D. and Vaughan, D.J. (2006). Electrical and magnetic properties of sulphides. *Reviews in Mineralogy and Geochemistry*. 61: 127-180. Zhao, S., Lu, T., Koch, B., Hurdsman, A. (2015). 3D stockpile modelling and quality calculation for continuous stockpile management. *Internat. J. Min. Proc.*, 140, 32-42. Myo, T., and Lu, T. (2013). Investigation of the bucket wheel reclaimer's cutting trajectory to define optimal voxel shape. *Trans. Control & Mech Systems*, 2(2), 54-60. Zhao, S., Lu, T., Koch, B., and Hurdsman, A. (2013). Dynamic modelling of 3D stockpile for life-cycle management through sparse range point clouds. *International Journal of Mineral Processing*, 125, 61-77. Lu, T., Xu, S. (2012). A fast stockpile simulation engine and its application in mineral ore handling. *Internat. J. Modelling, Simulation and Scientific Computing*, 3(2), 1-20.

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Project ID: HDR10 (PhD)

Integration of sensors to maximise crushing plant throughput.

Project details	Approach: Analytics of acoustic, crushing and machine sensors to maximise crushing plant throughput. The fundamental problem with operating grinding circuits is that they are very sensitive to process changes yet are poorly automated and instrumented [1]. Different ores, or even the same types of ores with different geometallurgical characteristics, may have different optimum particle sizes (critical size) that will generate sufficient liberation to release enough gangue from the valuable mineral and, therefore, maximise the processing plant metallurgical performance an net smelter return [2]. Particles that are too coarse will result in inadequate liberation and particles that are too fine will increase grinding costs and reduce recovery rates. Therefore, it is quite desirable for milling plant operators to know the running information about mill charge dynamic content and motion, so that optimal control can be achieved for maximum plant throughput with robust instability, consistent particle size, and minimum structural wear. Spatial vibration sensing in the milling plant will deliver information on induced vibrations as an indicator of grinding circuit performance [3]. In this HDR project, these new sensor outputs will be integrated with spatial and temporal information together with other operating parameters to determine particle size distributions. Changes in ore hardness, due to ore heterogeneity, will cause changes in the mill load which, in turn, is controlled by water addition and mill feed tonnage. The new particle size distribution model obtained from the vibration sensing method will not only optimise plant operation and maximise throughput but also help refine the resource model and improve mine planning in subsequent mine operations.
Industry partners	Manta Controls Dassault Systèmes Rockwell Automation
Location	University of Adelaide
References	(1) Mohanty S., Gupta K.K. and Raju, K.S. (2015). Vibration Feature Extraction and Analysis of Industrial Ball Mill Using MEMS Accelerometer Sensor and Synchronized Data Analysis Technique. *Procedia Computer Science*, vol. 58, no. C, pp. 217-224. (2) Tang J., Yu W., Chai T., Liu Z. and Zhou X. (2016). Selective ensemble modelling load parameters of ball mill based on multi-scale frequency spectral features and sphere criterion. *Mechanical Systems and Signal Processing*, vol. 66-67, pp. 485-504. (3) Maron R., Russell J., Rothman P., O'Keefe C. and Newton D. (2014), Process optimization at Rio Tinto Kennecott using real-time measurement of coarse material in individual hydrocyclone overflow streams. IMPC 2014 -27th International Mineral Processing Congress.

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Project ID: HDR11 (PhD)

Integration of grinding circuit sensors including ultrasonics for particle size distributions to maximise mill throughput.

Project details	Approach: Analytics of particle size distributions, vibration sensors with other grinding circuit sensors to derive an on-line model for optimisation. In mining operations, ensuring operational stability of the grinding mills is crucial. Significant savings can be achieved if mills operate constantly at their optimum capacity[3]. This is achieved through in-line sensing and automatic control of several operating parameters, such as mill loading and rotational speed, solids and water feed rates, power consumption, particle size, etc[4], [5]. Early detection of malfunctioning can be achieved by vibration sensors mounted on the hydrocyclones at the product discharge, which ultimately controls the product particle size[1]. This HDR project will integrate real-time data collected by an existing set of circuit sensors with new vibration sensors to derive an on-line model for optimising the grinding mill throughput within particle size and mineralogical constraints. Predictive grinding circuit models will be built from these sensor inputs and new optimisation methods based on sensor inputs to optimise the milling process will be developed. Optimisation methods that will be used and developed in this context include evolutionary algorithms and other bio-inspired optimisation approaches[2] which have successfully been applied to a wide range of optimisation and engineering problems.
Industry partners	Manta Controls Dassault Systèmes Rockwell Automation BHP
Location	University of Adelaide
References	(1) Bowers S.V., Bassett T.S., Banerjee T., Schaffer, M. and Nower D.L. (2016) Patent WO2016051275A2: Monitoring and controlling hydrocyclones using vibration data. Downloaded from: https://patents.google.com/patent/WO2016051275A2/en. (2) E. Eiben, James E. Smith (2015): Introduction to Evolutionary Computing, Second Edition. Natural Computing Series, Springer, ISBN 978-3-662-44873-1, pp. 1-258 (3) Fuerstenau D.W. and Abouzeid A.-Z.M. (2002). The energy efficiency of ball milling in comminution. *International Journal of Mineral Processing*, 67, 161-185. (4) Gugel K.S. and Moon, R.M. (2007). Automated mill control using vibration signal processing. *2007 IEEE Cement Industry Technical Conference Record.* Charleston, USA: IEEE. (5) Gugel, K., Palacios, G., Ramirez, J. and Parra, M. (2003). Improving ball mill control with modern tools based on digital signal processing technology. *Cement Industry Technical Conference,* Dallas, USA: IEEE. (6) Pontt, J. (2004). MONSAG: A new monitoring system for measuring the load filling of a SAG mill. *Minerals Engineering*, 17, 1143–1148.

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Project ID: HDR12 (PhD)

Integration and analytics of pulp chemistry sensor information with in-stream analysis for flotation plant optimisation.

Project details	Approach: Integration of data of different types and from multiple sources to design predictive analytical methods for optimization of flotation plant performance.. The project will integrate data from multiple sensors in a mineral processing plant with other non-sensor data obtained in the laboratory and other sources to build predictive models for optimization of a flotation operation, together with identifying key missing data needed to improve performance prediction and, importantly, rapid detection of adverse process trends and events. The approach will be to examine, on a plant scale, with parallel, controlled laboratory measurements, model interrelationships between liberation variation, pulp chemistry and process outcomes (recovery and grade). For plant studies, time series sampling, in parallel with pulp chemistry monitor (PCM) measurements will be undertaken, over several hours. Plant samples, for QEMSCAN liberatio analysis and laboratory flotation tests (where appropriate). Fundamental laboratory studies will also be undertaken, using controlled variations in value mineral using synthetic composites. The latter synthesis has been previously developed in work on composite particle flotation at UniSA. Initial analysis of liberation and pulp chemistry data (together with plant operating conditions, e.g. reagent addition, hydrodynamic variables) against plant/bank performance will be undertaken to ascertain liberation variability feeding flotation, sensitivity of plant performance (recovery, grade) and identifying the need for specific, additional sensor data. Integration of the fundamental liberation-chemistry-performance test work will also aid in identifying limitations for detection (thresholds, significance) of plant data changes and trends. Various mathematical and statistical analysis tools will be employed to extract key interrelationships and trends in the data. The project aims to design and develop effective and practical predictive optimization tools that can assist in rapid recognition and reaction to trend data. It is anticipated that outcomes will provide an important extension to research elsewhere in the Training Centre concentrated on specific sensing strategies for liberation. Project outcomes will include research publications presenting the methods and models that have been developed, and also their implementation on site and implications for industry end-users. The student working on this project is expected to have an honours degree or equivalent from a relevant area of engineering (metallurgical, chemical), with an interest in instrumental analysis and the application mathematics and computer science, and to be able to demonstrate strong programming skills and strong mathematical knowledge
Industry partners	Magotteaux BHP Manta Controls Dassault Systèmes Rockwell Automation
Location	University of South Australia
References	Haavisto, O., Kaartinen, J. and Hyötyniemi, H. (2008). Optical spectrum-based measurement of flotation slurry contents. *International Journal of Mineral Processing,* 88(3-4): 80-88.

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Project ID: HDR13 (PhD)

Integration of in-stream and particle size measurements in flotation.

Project details	Approach: Analytics and in-stream information with particle size for flotation plant optimisation. This HDR project will measure particle sizes in mineral processing streams using novel fluid flow systems and in-line detection of slurry characteristics using light scattering/obscuration and ultrasonic techniques. Mineral processing depends significantly on particle size in almost all methods of separation and concentration. Flotation recovery depends on both the size of the particles (optimally between 10 and 50 microns) and the liberation of the particles (i.e., each particle is solely one mineral). Effective treatment of tailings depends on the size of the waste particles, with smaller particles being less likely to undergo rapid settling. And lastly, the particle size, and thus the available surface area, critically influences the leaching rate in material for hydrometallurgical extraction. In spite of their importance, there are few straightforward methods that provide real-time measurement of particle size and particle size distributions directly in mineral processing streams. This project will develop a slurry handling/fluid flow device that will sample mineral suspensions and use a combination of light scattering/obscuration (and possibly, ultrasonics) to determine the range of particle sizes. This sensor will be integrated with a sensing platform a (Pulp Chemistry Monitor, developed and commercialised by Magotteaux), to give combined size/pulp chemistry information, which can be used as a means of advanced process control to optimise flotation.
Industry partners	BHP Manta Controls Dassault Systèmes Rockwell Automation
Location	University of South Australia
References	Yang, X.M., Drury, C.F., Reynolds, W.D. and MacTavish, D.C. (2009) Use of sonication to determine the size distributions of soil particles and organic matter. *Canadian Journal of Soil Science*, 89(4): 413-419. Shukla, A., Prakash, A. and Rohani, S. (2010) Particle Size Monitoring in Dense Suspension Using Ultrasound with an Improved Model Accounting for Low-Angle Scattering. *AIChE Journal*, 2010, 56(11): 2825-2837.

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Project ID: HDR14 (PhD)

Rapid updating of resource knowledge with sensor information including structures.

Project details	Approach: Rapid, stochastic updating of resource models with sensor information for high resolution reconciliation and rapid decision-making. This project will focus on rapidly updating the resource knowledge with upstream (drill) and downstream (belt) sensor information, with partner company Maptek. The upstream and downstream information will constrain the resource knowledge close to the mining stage and allow rapid reconciliation of the ore attributes for upstream and downstream use. Resource models are generally constructed from directly observed data (e.g., grades of drill cores) that have relatively high accuracy. Resource models are, however, limited by the scale on which the data are collected. As mining progresses more information becomes available on different scales from various types and sources of data. Drill cuttings from blast holes provide in situ data on smaller scales. Sensors on drilling rigs and on conveyor belts provide data in near real-time as do draw-point sensing and Load Haul Dump (LHD) sensors. All these types of data – drill core, drill sensors, draw-point sensors, LHD sensors, belt sensors – measure different volumes in different ways and have different levels of accuracy, all of which must be accounted for when integrating the various types of data. Although most data will be quantitative (e.g., grades) some will be qualitative (e.g., structures such as geology or domain types). Integrating these types of data requires a stochastic approach to account for the different levels of accuracy (uncertainty) and the different volumes of measurement. To enable rapid decision-making, the resource model must be updated with newly acquired data in near real-time. The project will involve calibrating the various types of data, integrating/fusing the data and developing and/or adapting methods for rapidly (near real-time) updating resource models with newly acquired data. Data integration will include accounting for the different levels of uncertainty of the various types of data[1, 2, 3, 4]. Methods to be explored for updating resource models include the various forms of the Kalman filter[5, 6].
Industry partners	Maptek OZ Minerals
Location	University of Adelaide
References	(1) Soares, A., Nunes, R. and Azevedo, L. (2017) Integration of uncertain data in geostatistical modelling. *Mathematical Geostatistics*, 49, 253-273. (2) Dowd, P.A. and Pardo-Igúzquiza, E. (2006) Core-log integration: optimal geostatistical signal reconstruction from secondary information. *Applied Earth Sciences*, **115**, (2), 59-70. (3) Dowd, P.A. and Pardo-Igúzquiza, E. (2005) Estimating the boundary surface between geological formations from 3D seismic data using neural networks and geostatistics. *Geophysics*, **70**, (1), 1-12. (4) Adeli, A., Emery, X. and Dowd, P.A. (2018) Geological modelling and validation of geological interpretations via simulation and classification of quantitative covariates. *Minerals*, **8** (1): 7, doi:10.3390/min8010007 (5) Benndorf, J. and Buxton, M.W.N. (2016) Sensor-based real-time resource model reconciliation for improved mine production control – a conceptual framework. *Mining Technology*, 125:1, 54-64, DOI: 10.1080/14749009.2015.1107342 (6) Wambeke, T. and Benndorf, J. (2017) A simulation-based geostatistical approach to real-time reconciliation of the grade control model. *Mathematical Geosciences*, 49, 1 -37.

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Project ID: HDR15 (MPhil)

Measuring and monitoring particle size distributions and grade so as to divert low value waste.

Project details	Approach: Develop analytical and modelling techniques to measure and analyse the liberation characteristics of rocks at coarse particle sizes. The objective of this project is to predict mass and value flows to accept and reject streams. The focus of the research will be on grade engineering[1] to measure and model gangue liberation and yield curves together with the preferential deportment of grade to specific size fractions during rock breakage[2]. The project will provide a basis on which low value waste can be diverted out of the mining value chain prior to expensive and environmentally deleterious comminution and processing operations. This involves rejecting material at relatively coarse particle sizes (typically 10mm to 200mm in size) prior to fine crushing and SAG milling. Very little is known about the inherent particle grade distributions that are present in these coarse particle size ranges. The approach will be to model gangue liberation and yield curves together with preferential grade deportment to predict mass and value flows. Two major contributors to this challenge are the amount of material that must be sampled and analysed at these coarse particle sizes (as determined by Gy's formulae[3,4]), and the general lack of analytical and modelling techniques that can measure and analyse the liberation characteristics of rocks at these coarse particle sizes. By contrast, fine particle liberation measurements in grinding mills and flotation plants have been routinely captured for over three decades using process mineralogy tools such as QemSCAN (Quantitative Evaluation of Materials by Scanning Electron Microscopy) and MLA (Mineral Liberation Analyser).
Industry partners	CRC ORE OZ Minerals Scantech
Location	University of Adelaide
References	(1) CRC ORE. http://www.crcore.org.au/images/GradeEngineeringSW.pdf (2) Walters, S.G. (2016) Driving productivity by increasing feed quality through application of innovative grade engineering® technologies. https://crcore.org.au/images/CRC-ORE/papers/Walters-S-2016-Grade-Engineering-Whitepaper.pdf (3) Pitard, F.F. (2019) Pierre Gy's Sampling Theory and Sampling Practice. Third edition, CRC Press. (4) Minnitt, R.C.A. (2017) A version of Gy's equation for gold- bearing ores, *Journal of the Southern African Institute of Mining and Metallurgy*, 117; 119-132.

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Project ID: HDR16 (PhD)

Linking the resource to down-stream products.

Project details	Approach: Use conditional machine learning and/or stochastic predictive modelling with variable volume and time scales to link the resource to down-stream products. This project will develop an integrated knowledge-based system based on data analytics, stochastic predictive modelling and/or machine learning that can be used for the monitoring, performance assessment and prediction of the mining and processing operations to contribute to optimising the entire value chain from mine to the final product. Significant amounts of data are routinely collected on-site in mining operations and processing plants including, for example, drilling performance data, grade control and face samples, digging and hauling data, fleet management system data, crushing and milling performance data, and flotation and recovery rate. These data are rarely used in practice (e.g., mining operational data), or are used locally in isolation of the entire process (e.g., mineral processing data) (1). This research project will establish a framework to explore the operational context and learn the dynamic performance relationships in the various stages of the operation and integrate these relationships into a single digital twin like system(2). By collecting the data through the IoT (Internet-of-Things), the learning and integrating processes will be done in near real-time so that the system can be used to help optimise the short-term operations including, for example, micro-adjustment of operational parameters, predicted maintenance or adapted design accounting for local conditions. The system will also be linked to potential long-term strategic optimisation of the value chain by examining the possibility and benefit of updating the resource model, altering the mine design and mine planning, and/or changing the mining and processing designs based on new information. The focus of the research will be to establish the most significant performance components in the operational chain in terms of their impact on the entire mining system, not on the integration platform itself. For the latter component, the use of the Petra MAXTA digital twin(1), the CRC ORE Integrated Extraction Simulator(3), Matlab Simulink(4) and the Dassault Systèmes digital twin(5) will be explored.
Industry partner	Dassault Systèmes Petra Data Science OZ Minerals BHP
Location	University of Adelaide
References	(1) Stewart, P., Cowley, S. and Carpenter, J. (2019) Digital Twin Value Chain Optimisation, Future of Mining Australia 2019. https://www.miningmonthly.com/partner-content/partner-content/1360871/digital-twin-value-chain-optimisation (2) AVEVA, 2019, Digital mining transformation, available from https://sw.aveva.com/mining (3) https://www.crcore.org.au/ies (4) https://au.mathworks.com/products/simulink.html (5) https://www.3ds.com/

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