THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

# UQ PROJECT PROPOSAL

## Department of Industry, Innovation and Science Innovation Connections Scheme

**Title:**

Development of Dielectric Sensor System on Intelligent Amphirols for Mud Farming Tailings Facilities

**Research Personnel:**

Dr. Yifan Wang (Project Supervisor) at 0.1FTE;

A/Prof. Alexander Scheuermann (Project Supervisor) at 0.1FTE;

Prof. Amin Abbosh (Project Supervisor) at 0.05FTE;

One Nominated Postdoc Fellow (Research Associate) at 0.7FTE;

**School/Institute:** School of Information Technology and Electrical Engineering
Faculty of EAIT, the University of Queensland, St Lucia QLD 4072

AND

School of Civil Engineering
Faculty of EAIT, the University of Queensland, St Lucia QLD 4072

**Project Term:** 12 months (commencement and end dates subject to the Commonwealth Grant Agreement).

**Proposal Summary:**

Australia is a nation with a world leading mining industry. In 2016, Australia exported non-petroleum minerals valued at more than $151 billion sustaining Australia's position as a top five producer in the world of many important commodities, such as aluminium, iron ore and coal. However, the international mining industry became target of heavy criticism caused by the recent failures of Tailings Storage Facilities (TSF). The failure rate of TSFs is 100 times larger than the one of conventional water retaining structures. With about two failures every year, the failure rate of TSFs has not changed in the recent 50 years. The physical reasons for failures are manifold and frequently connected to the insufficient compaction of the tailings. Liquefaction due to seismic events or static liquefaction are frequently considered as the primary reason for failures. The compaction state of the tailings, however, does not only impact the safety of TSFs, it also has great implications on the economic viability of the mine, as larger volumes of tailings can be stored in TSFs if it can be compacted to a higher degree.

One possibility to improve management of tailings is the accelerated mechanical consolidation (AMC) – or "Mud Farming". The process expedites the transition of soils from the slurry state to a solid condition, often transitioning through non-Newtonian phases. These phases are associated to different mechanical behaviours during shearing leading either to softening or hardening. Given this change in material behaviour through this transition, it is not a simple task to predict or in many cases, track performance nor is sustaining machine control a simple task. Tracking the performance of Mud Farming can be significantly improved by monitoring in real-time the current density state during the operation of the Amphirol. On the one hand, areas of low density within the tailings can be preferably treated to maximise the overall volume gain. On the other hand, the controlling of the automated Amphirol can be improved since the density of the tailings material governs its shear strength as well

as settling/densification behaviour, and as a consequence the controlling of the Amphirol during operation.

Electromagnetic techniques are feasible and advantageous for measuring the density of the tailings material based on the dielectric properties (permittivity and conductivity). These properties depend on the water content and the porosity of the tailings material, and their relationship can be mathematically described using suitable models or mixing equations. The dielectric properties are derived from the measured changes in amplitude and phase of a reflected electromagnetic wave. These changes can be captured using proper antenna array operating at a suitable frequency band making this method non-invasive and contactless. The captured data are then further processed using either reflectometer beamforming, wavelet transformation or Eigen value decomposition to receive a real-time mapping of the density of the tailings material. The Significance of the topic is evident through the fact that TSFs are more prone to failures than any other similar storage facility. Every year, 15 billion tons of mine waste is produced globally that will be stored in TSFs. There is an urgent need of methods to improve safety and efficiency of TSFs.

**Objectives:**

This project aims to develop a method for quantifying in real time the density of soil waste and soft soil based on electromagnetic measurement results to improve TSF management and safety. In the first stage, a specific designed RF architecture (include the contactless dielectric probe) in the theoretical level will be developed in the EM simulation and laboratory environment; in the second stage, a proof-of-concept prototype as a minimum viable product (MVP) will be built and tested in the real environment for collecting the measurement data, and reshape the data into the form representing the dielectric properties of the soil wastes.

**Methodology:**

The development of such a method is possible by a multi-disciplinary collaboration involving electrical engineering, geophysics, geotechnics and mechanical engineering. The Main Innovation of this proposal is the application of electromagnetic methods for measuring the complex dielectric permittivity of soil wastes in real time during operation of an amphirol. The knowledge of the density and density gain during operation will improve the overall safety of TSFs and maximises their storage capacity.

**Expected Outputs:**

To achieve the objectives of this project, the following outputs are expected to be produced during the project.

a) Develop antennas for measuring the relative complex dielectric permittivity of soils and soil waste for targeted frequency windows.
b) Determine the dielectric spectra for selected tailings materials to quantify the targeted frequency windows that can be used to quantify the density of the tailings.
c) Integrate the antennas into the existing on board system including data transfer. .

The key aspect of the investigation is the reliable and accurate determination of the density of soil waste in real time during operation of the amphirol.

**Budget:**

| | |
|---:|---:|
| ***LABOUR COSTS*** | |
| | **Postdoc research fellow A06 @0.7FTE** |
| *Salary* | **$54,272** |
| *On-Cost* | **$16,281** |
| ***OPERATING COSTS*** | |
| *Travel* | **$500** |
| *Facility Hire (and associated costs)* | |
| *Personnel Costs* | |
| *Other Operating* | **$7,781** |
| | |
| ***OVERHEADS*** | |
| *Overheads* | **$21,166** |
| | |
| ***TOTAL Project Costs (excl. GST)*** | **$100,000** |
| ***Commonwealth Funding (excl. GST)*** | **$50,000** |
| ***Partner Contribution (excl. GST)*** | **$50,000** |

# Work Packages for Innovation Connections Application:

## Phibion Pty Ltd and the University of Queensland

If both parties are able to secure the Innovation Connections funding from the Commonwealth of Australia, University of Queensland will perform all three work packages (WPs) in the Table below for a budget of AU$100,000 (Exc GST) in the first 12 Months. It is the clear intention of the participants to develop a work plan to continue the project for another 2~3 years with the aim to upgrade and commercialize the newly developed contactless dielectric sensors and data processing techniques.

The aim of the project is to develop a method for quantifying in real time the density of soil waste and soft soil based on electromagnetic measurement results to improve TSF management and safety. In this one-year project, a specific designed RF architecture in the proof-of-concept level will be developed in the EM simulation and laboratory environment, in the same time, a minimum viable product (MVP) prototype will be built and tested in the real environment.

As a future plan after this Innovation Connections program, the proposed contactless dielectric measurement system will be integrated on Phibion's Mud-master vehicle for the purpose of evaluating the density and water saturated condition of soil.

The following research and development activities will be carried out in this one-year Innovation Connections:

### WP 1: Project startup and definition of system capabilities

**Key Activities:**

- Site visit at Phibion (Eight Mile Plains, Queensland) and its remote factories to clarify the feature of the environment and Mud-master platform in which the system is to be developed and installed.

- Familiar with the dielectric properties of the inspected soil of various types and the relation with its density (include water saturation).

- Establish a three-dimensional (3D) numerical analysis program (based on electromagnetics propagation model) to determine the optimum range of working frequency and required RF power level.

- Conduct a link budget analysis to determine the antenna aperture size of the dielectric sensor and its distance to inspected soil surface.

**Expected Outcomes:**

- Understanding the working environment of the Mud-master platform and determine the possible positions to be installed with dielectric sensors.

- Acquiring the dielectric properties (permittivity and conductivity) of the inspected soil from database and imported those data into the numerical analysis model.

- Quantitative understanding of the electromagnetics propagation characteristics in the soil as well as its response to the dielectric properties.

- Specified the working frequency, RF power level and antenna type to be applied on the dielectric sensor.

**Dates:** Start date: 1 Feb 2019; End date: 30 April 2019

### WP 2: Contactless dielectric sensor designing and modelling in full-wave simulation environment

**Key Activities:**

- Implement the antenna design in terms of its working frequency and near-field characteristics.

- Design the RF circuit of sensor in connect to the designed antenna structure.

- Optimize the sensor geometry by computational EM simulator in order to achieve an acceptable impedance balance, near-field pattern, efficiency, and frequency-domain response

- Evaluate the sensitivity and reliability of the dielectric sensor in terms of different soil properties.

**Outcomes:**

- Preliminary design and configuration of the sensor geometry and dimension are determined.
- Specify the 3D topology and design parameters of the sensor, along with its feeding circuit.
- Confirm the sensor performance in realistic full-wave simulation environment and the dynamic range of dielectric measurement.

**Dates:** Start date: 1 May 2019; End date: 31 August 2019

### WP 3: Build up the proof-of-concept MVP prototype

**Key Activities:**

- Build up the antenna designed from WP2 and measure its near- and far-field radiation performance.
- Implement the RF feeding networks designed from WP2 and integrate it with the antenna body.
- Connect the developed sensor to the vector network analyser and capture the data over the specified frequency (from WP1) in both free space and homogeneous medium for calibration purpose.
- Install the MVP onto the mud-master platform and capture some raw RF signal from real application scenario.
- Interpret the collected RF signal and map the data with soil properties.

**Outcomes:**

- Verification of the 3D simulation model to present the realistic laminates with high reliability.
- Quantitative understanding of the system reliability and sensitivity of measuring the soil properties.
- IP protected, and a next-stage development and commercialization plan is proposed.

**Dates:** Start date: 1 September 2019; End date: 31 January 2020