BREAKING THE BARRIER: CONSIDERING HOW IOT CAN HELP BRAZILIAN TAILINGS DAMS *

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Abstract
Monitoring systems are highly critical components in the safety of tailings storage facilities (TSF). Internet of things (IoT) platforms present a unique way to improve TSF monitoring systems. Since there are so many available IoT technologies, this conference paper aims to create a focused list of IoT options for improving TSF safety. To achieve this aim, a brief qualitative review of available literature and state of the art technologies is presented in Section 2. The article further assists this aim by summarizing the benefits of IoT platforms which have been found in the literature. With respect to findings, literature suggests that while sensor technologies have existed as solutions for tailings dams for many years, IoT greatly reduces the cost of deploying, monitoring, maintaining, and gaining insight from these sensors. Additionally, IoT removes the need for manual data collection from sensors, enabling the monitoring of tailings dams from miles away and the use of new sensor technologies. Therefore, as a conclusion, this article recommends that IoT capable monitoring systems be considered for use in TSF monitoring.
Keywords: Internet of Things (IoT), Tailings Storage Tacilities (TSF), Remote Sensing, Safety.

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1 INTRODUCTION

There has been an increase in the rate of tailings dam failures in recent years (1). Brazil has been in the international spotlight in this regard due to two recent and tragic dam failures. First, the Fundão tailings dam near Mariana, which occurred in 2016, was probably the world's largest environmental tailings dam related disaster in terms of material displaced (43 million m3) (2). Second, the 2019 Córrego do Feijão tailings dam disaster near Brumadinho, which displaced 13 million m3 of material and killed nearly 300 people (1).

Just as technology has been part of the problem, this paper proposes that it may be part of the solution by presenting a discussion of internet of things (IoT) technologies specifically for their applicability in enhancing the safety of tailings storage facilities (TSF).

2 BACKRGOUND

Several factors contribute to the growing risk associated with tailings dams, such as lower ore grades which require larger tailings dams than in the past (3), technological improvements in bulk mining processes, economic pressure on mining companies, issues with legislation and negligent enforcement of environmental law (4, 5), shortages of qualified personnel in the industry and incentives for risk taking at the corporate level (1, 3).

Despite progress made in IoT technology, it remains underutilized at mine sites (6, 7). For instance, bi-weekly field inspections were used prior to the Feijão disaster (8). These inspections detected no alteration to the state of the dam just three days prior to the event. Manual inspections are still important, however they suffer from a number of factors that lead to systematic problems (9).

According to Berghe, Ballard (10), inadequate tailings dam monitoring systems are listed as a risk factor for being both severe in impact and likely in occurrence. Poor documentation throughout the construction process, modifications of tailings storage facilities (TSF) designs beyond their initial planning, unexpected chemical reactions, frequently operating at "Max Load", anisotropic and heterogenous material characteristics, inadequate site inspections, inaccurate modeling, external hazards, and high water level constitute other TSF risk factors are shown in Table 1.

Table 1. Risk factor matrix for TSF. Source: adapted from Berghe, Ballard (8).

Probability of Outcome	Consequence of Outcome				
	Insignificant	Minor	Moderate	Major	Severe
Nearly Certain		Poor documentation of construction process		Frequently operating at "Max Load"	High water level
Likely		Original design does not consider final height		Heterogeneity and anisotropy	Inadequate monitoring system
Neither Likely nor Unlikely			Unexpected chemical reactions	Inadequate site inspections	
Unlikely					Inaccurate modelling
Rare					External Geohazard

3 REVIEW OF SENSOR TECHNOLOGY

Different monitoring sensors are presented within this section. Each of these sensors, which have been used traditionally, may also be incorporated into an IoT platform that enables them to be monitored in near real-time.

3.1 Thermistors

These sensors act as temperature gages. They can be used to determine locations that are heating up or cooling off more rapidly than others. They can be used to create a temperature profile of a TFS, which allows for the early detection of defects such as seepages, leakages and settlements (11).

3.2 Piezometers

Piezometers are devices used to measure the piezometric head of a TSF. Piezometric head is essentially a measurement of the height of a body of water above a reference point. Piezometers use transducers that convert static hydraulic pressure into an electrical reading which is used to establish the height of the water (12).

3.3 Inclinometers

As the name implies, these sensors are used to measure the incline or slope of a TSF with respect to gravity. These sensors are sometimes referred to as tilt meters and they are a direct measurement of the angle of the tailings dam slope. They are ideal for detecting slope displacements. Cumulative shear strain from any depth can be easily deducted from inclinometer measurements, which makes it easy to create a shear profile of the TSF (10).

3.4 Surveying

Traditional surveying is used to measure the surface displacement of material on a TSF. This is often done manually with the aid of a Global Positioning System (GPS).

However, weather conditions at the site as well as many other effects have been known to cause systematic problems to manual surveying (9).

3.5 InSAR

More recently, TSF surveys have used Interferometric synthetic-aperture radar (InSAR) as a way to detect surface displacements under 1 cm. InSAR surveys can be conducted via satellite as well as through equipment that can be deployed to the TSF (13, 14).

3.6 SOFO Sensors

SOFO ® is named from the French acronym of "Surveillance d'Ouvrages par Fibres Optiques", which means structural monitoring by optical fibers (15, 16). These sensors are long fiber optic cables which can be used to measure direct changes in deformation. These types of sensors are more commonly used in commercial dams, but they are seeing increased use in TSF.

While each of these sensors and techniques work well on their own, it can be difficult to bring the information gleaned from each of them into an accurate and working TSF model. Thus, it becomes important to measure from all sensors at as near to the same time as possible. There is a clear need for the near real-time monitoring of the condition of the dam. IoT can bring these sensors together into one unified operation.

4 INTERNET OF THINGS

4.1 IoT Overview

The term, Internet of Things (IoT), has been used to define a system of vast amounts of connected devices (17). IoT provides a method for managing data flow cycles. For example, data flows from devices, such as the sensors on a tailings dam, to data warehouses or cloud computers, were it is used to create dashboards in near real-time. If desired, IoT can also enable information to flow from remote locations and back into devices (18). The result of IoT is an integrated platform that enables faster, more informed decisions to be made from the available data. Through IoT, the physical world can be transformed into a type of information system (19).

4.2 Results of IoT

Through effective IoT strategies (20), most mining operations experience results in the following ways:

1. Maximizing product yield and production throughput
2. Decrease their energy demand and operating labor requirements
3. Increase their ability to improve and track safety concerns
4. The ability to better establish and visualize key performance indicator (KPI) metrics in near real-time for continuous improvement at the operation
5. Models of the manufacturing process and the ability to tracking real-time variation from planned performance
6. A reduction in equipment failures and unscheduled production downtimes

4.3 Barriers broken by IoT

While IoT promises many interesting results, there have been many barriers to the real deployment of sensor node arrays at TSF. These barriers generally fall into one of three categories as shown in Table 2. All of these categories have a solution that comes from IoT innovation, which is also shown in the table.

Table 2. Traditional barriers broken by IoT for TSF.

Category	Traditional Barriers (9)	IoT Solutions (21, 22)
Power supply requirements:	• Expensive • Difficulty replacing batteries • Solar recharge not always available • Remoteness of TSF	• Cheaper longer-lasting battery technologies • Efficient sensor nodes run on less energy • Signal distance up to 15 km
Configuration and compatibility requirements:	• Limited software processing power • Limited to only one software application • Difficulty interfacing with other sensors	• Applications programmable interfaces (API) • Separation from applications layer and network layer • Cloud computing
Network requirements:	• Changes in network topology • Impractical and costly to provide sensors with global address • Signal fade and network connectivity maintenance	• Dynamic network topology • "Self-healing" network systems • 5G wireless network soon to be developed

As highlighted in the table above, IoT platforms may be used to overcome the traditional barriers around deploying, maintaining, and gaining insight from a TSF monitoring system. These barriers are power supply requirements, configuration and compatibility requirements and network requirements.

5 CONCLUSION

IoT has improved dramatically over recent years, and it has shown the ability to break the barriers involved in TSF monitoring. Speculation to its future usefulness continues to accelerate, especially as cyber-physical systems and industry 4.0 continue to develop. Considering Brazil’s unique need for equipment robust enough to operate in remote and hazardous conditions, and perhaps more importantly, at low cost, IoT offer many feasible solutions. The question remains whether companies, research groups, and governmental organizations will invest the necessary capital to develop the beneficial IoT program that meets these needs. Increased education, training, research and development, as well as involvement from all stakeholders will be imperative to the success of this type of endeavor.

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