

The Wireless Sensor Network (WSN) Based Coal Ash Impoundments Safety Monitoring System

E J Sun^{1,2}, A Nieto^{3,4} and X K Zhang¹

¹ China Academy of Safety Science and Technology, Beijing, 100012, CHINA

² Mining and Mineral Department, Virginia Tech, VA 24060-7550, USA

³ Laureate Education 650 S. Exeter Street Baltimore, Maryland 21202-4382, USA

⁴ 122 Hosler Bldg., Engineering, Penn State University, Penn State, 16802, USA

enjisun@gmail.com

Abstract. Coal ash impoundments are inevitable production of the coal-fired power plants. All coal ash impoundments in North Carolina USA that tested for groundwater contamination are leaking toxic heavy metals and other pollutants. Coal ash impoundments are toxic sources of dangerous pollutants that pose a danger to human and environmental health if the toxins spread to adjacent surface waters and drinking water wells. Coal ash impoundments failures accidents resulted in serious water contamination along with toxic heavy metals. To improve the design and stability of coal ash impoundments, the Development of a Coal Ash Impoundment Safety Monitoring System (CAISM) was proposed based on the implementation of a wireless sensor network (WSN) with the ability to monitor the stability of coal ash impoundments, water level, and saturation levels on-demand and remotely. The monitoring system based on a robust Ad-hoc network could be adapted to different safety conditions.

1. Introduction

Coal-fired power plants is the world's largest coal consumer industry. Coal consumption accounts for almost 70% of China's primary energy consumption. The proportion of coal-fired power plants is more than 50% of national coal consumption. [1] The amount of coal ash emissions from coal-fired power plants have increased 2.5 times in the past eight years. The production of coal ash has reached 375 million tons, which can reach 424 million cubic meters. It has become the largest single source of industrial solid waste emissions in China. [2] Coal ash is inevitable product of coal-fired power plants and its amount produced by power plants increases along with the expansion of installed capacity of power generators. [3] It is the toxic waste formed from burning coal in power plants to make electricity. The second largest industrial waste stream in the U.S. According to the American Coal Ash Association's Coal Combustion Product Production & Use Survey Report, nearly 110 million tons of coal ash was generated in 2012. A total of 1.25 billion tons of coal ash is stored in China with an annual emission of 1.5 million tons. [4] Hundreds of contaminated sites and spills have been documented among the 1,400+ coal ash waste dumps across the U.S. [5] Many coal ash dumps lack basic safety features and regular inspections, leaving communities at risk of large scale disasters like those in Kingston, Tennessee and North Carolina. [6] Coal ash impoundments are inevitable production of the coal-fired power plants. It contains a range of toxic constituents that are known to leach, leak, or spill out of coal ash disposal sites and adversely affect human and environmental health.



[7] Two dozen homes were destroyed or damaged by the 2008 coal ash spill in Kingston, Tennessee as shown in Figure 1.

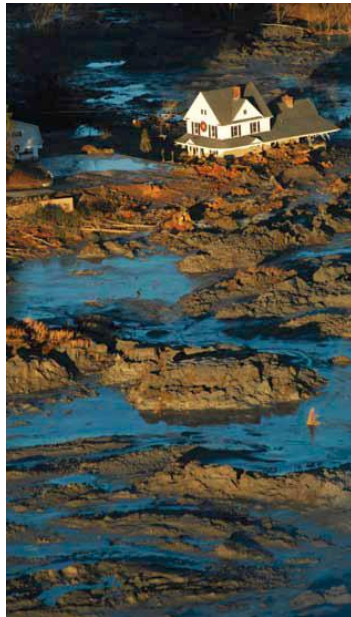


Figure 1. Two dozen homes were destroyed or damaged by the 2008 coal ash spill in Kingston, Tennessee.

All coal ash impoundments in NC, USA that have been tested for groundwater contamination are leaking toxic heavy metals and other pollutants. Coal ash impoundments are toxic sources of dangerous pollutants that pose a danger to human and environmental health if the toxins spread to adjacent surface waters and drinking water wells. Several coal ash impoundments failures produced serious water contamination and toxic heavy metals pollutions.

There are twenty-nine known coal ash sites in Michigan, USA. Nineteen are within five miles of a Great Lake or a bay of a Great Lake, with several sitting directly adjacent to a bay. Three sites are within twenty miles of the Great Lakes. Every single coal ash impoundment or landfill sits on or near one of the state's lakes, rivers, streams, and wetlands. To improve the coal ash impoundments safety, a coal ash impoundments safety monitoring system (CAISM) was proposed based on the wireless sensor network (WSN) with the ability to monitor the impoundments stability, water level and the saturation levels remotely. This system has a robust Ad hoc network, which could adapt different kind of coal ash impoundments conditions.

2. CAISM Framework

2.1. The System framework

Some coal ash impoundments are rated for the degree of danger they pose to the communities and environments downstream. Dramatic failures aren't the only source of surface spills; smaller spills occur when impoundment dikes and dams leak less significant amounts, or impoundments overflow in heavy rains or floods.

On these conditions, the coal ash impoundments safety monitoring system (CAISM) aims to monitor the coal ash impoundments safety on anytime, in anywhere, which is based on the wireless sensor network (WSN). The entire system datum are acquired by all kinds of wireless sensors, processed by the cloud-computing platform, and then broadcasted to the terminals either on PDA or the other clients. The framework of CAISM is displayed in figure 2.

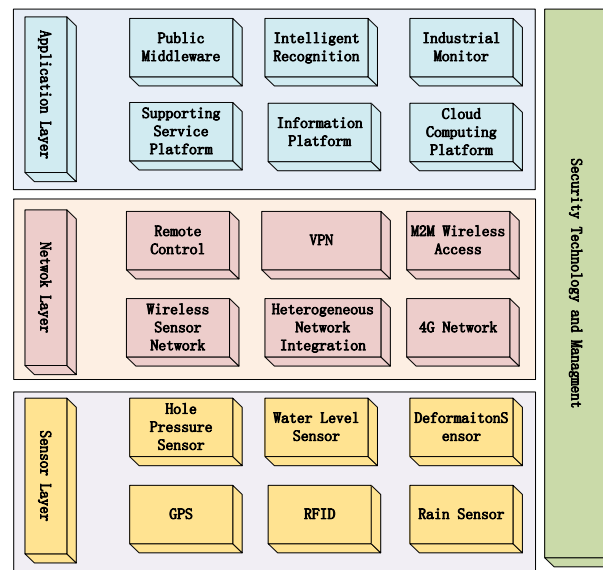


Figure 2. System framework of CAISM

2.1.1. Sensor Layer. Far more common than a coal ash dam break is the leaching of contaminants from ponds and landfills: the process by which toxic materials in coal ash dissolve in water and percolate through the earth. Leaching can expose people to dangerous toxicants at levels above safe drinking water standards.

Sensor layer of CAISM includes the hole pressure sensor, water level sensor, rain fall statistic sensor and the wind information sensor to monitor the key factors of the coal ash impoundments. Hole pressure sensors focus on the coal ash pond depth and dam saturated degree. Water level sensors monitor the water in the coal ash ponds, which could combined with rain fall statistic sensors. Especially, it is pivotal to calculate the water level according to the rainfall under heavy rainfall conditions. Coal ash also follows land and air pathways to result in human exposure. Coal ash disposal operations can generate dangerous quantities of airborne ash, due to mismanagement of both ponds and landfills. Coal ash is dangerous if inhaled, making fugitive dust a serious health concern. The health threat arises from minute particles of dust known as particulate matter, which may be composed of various substances. Wind sensors provide the information of the toxic coal ash direction, which are useful to judge the contamination area combined with the GIS map.

2.1.2. Network Layer. Coal ash is the second-largest industrial waste stream in the U.S., after mining wastes. [8] Coal ash is disposed in approximately 2,000 dump sites across the nation: at least 629 wet ash ponds [9] and 311 dry landfills at power stations, at least 100 offsite dry landfills, [10] and 750 inactive dumps, [11] and hundreds of abandoned and active mines. [12]

Network Layer of CAISM is a key component to transmit remote monitoring data back to control centre by using the wireless sensor network (WSN), 4G Ad Hoc network and M2M wireless access. Network layer makes sure the real-time data are encrypted under the security technology and managements. As the most of coal ash sites are relatively far from the city or community. WSN formed by a large number of sensor nodes where each node is equipped with a sensor to detect coal ash ponds safety features. The WSNs are regarded as a revolutionary information gathering method to build the information and communication system which will greatly improve the reliability and efficiency of infrastructure systems. Compared with the wired solution, WSNs feature easier deployment and better flexibility of devices.

2.1.3. Application Layer. The aim of CAISM is to provide key safety features to the users. The application layer of CAISM contains public middleware, intelligent recognition, information platform and supporting service platform.

The public middleware of CAISM is much easier to install on the user's devices. User friendly interface is important to show the monitoring results directly. Information platform broadcast up-to-date information on the health and safety related to the local residents lived near the coal ash impoundments. Supporting service platform provide a sponsored packet switched data service including receiving a request in a wireless network for a sponsored packet switched data service from a user, determining a sponsor for the requested service in accordance with stored policies, and monitoring a session between the user and the sponsor. The application layer of CAISM provide necessary services to ensure that effective communication with another application program in a network is possible.

3. Application of CAISM

The CAISM is a 24/7 automatic coal ash safety monitoring system. Considering the system safety, all the users are required the system security access validation. After checking the user's roles correctly, the main interface of CAISM is presented in figure 3. This is a coal ash impoundments with twelve saturated lines monitoring spots and one dam water level monitoring spot. The green labels that presented on the screen are the accumulated 3D deformation in millimeter unit and the pink labels that displayed on the screen are the saturated lines. Judging by the pre-alarm parameters, the alarm information will flash on the screen if any sensor value is beyond the safety pre-alarm value. The options of different selections help the users to choose the concerned monitoring category to show on the screen.



Figure 3. The main monitoring interface of CAISM

The CAISM real time partial water level monitoring data is shown in figure 4. The water level of the coal ash impoundments rises almost two meters in the past one month. In the late April, the water level increased almost one meter in about twelve days.



Figure 4. CAISM real time water level monitoring data

The storm and rain have great effects on the coal ash impoundment safety. In the rain season, flood regulation model is crucial to keep coal ash ponds safety. CAISM provides the flood regulation model as shown in following:

$$Q_{mp} = 0.278F \left[\frac{S_p}{\tau^n} - \mu \right] \quad (1)$$

$$\tau = \frac{0.278L}{mj^{0.333}Q_{mp}^{0.25}} \quad (2)$$

Where τ means the convergence time (h). Q_{mp} stands for the peak flow (m³/s). F is the drainage area (km²). 0.278 is the unit conversion coefficient. s_p is the rain power in twenty four hours(mm/h). L is maximum the flow length in the drainage. n is the rain decreasing coefficient. μ is the loss coefficient. m is the drainage coefficient. j is the average longitudinal slope.

According to the hydrographical manual, flood process shape coefficient $\beta = 3600\tau Q_p / W_p$, and the flood peak flow $W_p = 1000hF$. The five-hundred year period flood peak flow process Q_m .

As the flood regulation capacity is full-size, the flood water level increases are not obvious. The drain time is time-consuming because of the drain flow is a little low. For the five-hundred year flood regulation, as the water level raises 0.96m, the left beach length is 99m. After 24 hours drainage, the beach length will be 114.4m. After 72 hours later, the beach length will be 190.2m. The flood regulation result is displayed on figure 5.

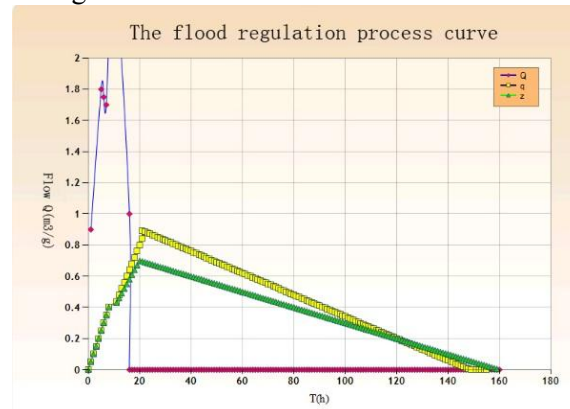


Figure 5. Flood regulation process cure, Five hundred years

Coal ash impoundments safety has a close relationship with the rainfall and drainage ability. The floods and landslides of coal ash impoundments that were triggered by the rainfall will cause a number of deaths and resulted in widespread damage to houses, roads and other infrastructure. CAISM can adjust the drainage according to the rainfall condition, which could avoid the failures and water pollutions.

4. Conclusions

Coal ash impoundments are widely spread all over the world as long as the coal-fired power plants are the vital energy source. The failures of ponds and leaching of contaminants have been proven to be of significant concern, which can produce serious ground water pollution. The toxic substances commonly found in coal ash, including mercury, lead, vanadium, selenium, and arsenic, are known to pollute water and could pose serious public health risk. Many disposal sites lack adequate safety regulation such as protective liners or groundwater monitoring and many of the impoundments are nothing more than earthen dams. It is highly risky to ignore the problem of

structural instability of coal ash impoundments due to all the risk factors mentioned above. It is thus necessary to properly monitor the impoundments using a system similar to the one proposed in this paper.

Currently, there is no regulation for monitoring coal ash impoundments. The CAISM aims to monitor the coal ash impoundments safety based on wireless sensor network (WSN) on demand and remotely. It has the ability to monitor the key features of the coal ash impoundments. Combining with the rainfall sensors, CAISM provide the water level varieties under rainfall condition to prevent any kind of spill or failures. Coal ash impoundments safety is crucial to environment and surrounding ground water. CAISM needs to be further developed to integrate the toxic substances plume prediction, which will be more efficient to monitor the ground water pollution.

Acknowledgment

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