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System Modelling Approach Based on Data Acquisition and Analysis for Underground Facility Surveillance

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Abstract

Recently, we have a number of underground facilities included the water supply, the sewer management, the underground railway lines, and the parking lots. Their facilities has several meanings depends on the term of context used utility and facility functional operations, the infrastructure has the underground cables and pipes networks supported with all related assets. This paper presents a system architecture for monitoring underground facilities and provides a model for data acquisition from heterogeneous sensing sources and the analysis of such data. The system architecture for monitoring underground has an efficient data acquisition and processing procedure. An acquisition data and analysis information can provide an efficient method for monitoring and forecasting critical issues in the underground facilities and may assist in the maintenance efficiency as well.

Keywords: *Underground facilities, Monitoring, Data acquisition, Data analysis*

1. Introduction

Underground facilities play important roles to support the residents and save ground surface area for other uses. Underground facilities has several meanings depends on the term of context used utility and facility functional operations. And the infrastructure represents the underground cables and pipes networks supported with all related assets.

Underground facilities may include several systems but this report presents the general concept based on the monitoring of underground facilities such as water supply lines, sewerage system, subway structures, oil and gas distribution *etc*. A typical underground monitoring system consists of a data acquisition infrastructure regarding various factors concerning the health of the underground facilities, data input system and a data processing infrastructure.

For example, an underground monitoring and risk analysis was deployed for the expansion of Incheon international airport, South Korea. The design considerations and settlement risk management along with the construction plans to continue operation of the airport during tunneling under the runway has been described by Kim *et al*. [1]. The crossing of an operational runway presented many challenges as the airport is constructed over reclaimed land between two islands and hence the sub-soils of the area are composed of soft soils. Intensive ground investigations were under taken to identify and prove ground conditions.

Other examples include the study by Sturk *et al.* [2] for the risk analysis for the Stockholm ring road tunnels and underground analysis for the rail project in Thailand [3]. A detailed view of the risk analysis for underground facilities in urban areas is presented

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by Cagno *et al.*, [4]. All these scenarios shows the importance of underground data acquisition and processing system. The heterogeneity of the sensing hardware presents issues for the acquisition and processing of the data in a single system or process. Some of these desperate techniques have been described in the following paragraphs.

Systems architecture is the conceptual model that defines the structure, behavior, and more views of a system [5]. An architecture describes a formal representation of a system, organized in a way that supports reasoning about the structures and behaviors of the system.

This paper presents the system architecture based on the monitoring of underground facilities such as water supply lines, sewerage system, subway structures, oil and gas distribution *etc*. The underground monitoring system consists of a data acquisition infrastructure regarding various factors concerning the health of the underground facilities, data input system and a data processing infrastructure. An efficient data acquisition and processing system is an important factor in the efficiency of underground monitoring systems. We support a crucial approach as critical problems for the management and maintenance of their facilities in such facilities can directly affect lives. Advanced monitoring systems based on state of the art technologies with effective data acquisition and processing models can help predict such critical problems and assist the management to efficiently maintain the underground facilities.

The rest of the paper is structured as follows; Section 2 explains the existing related work describing underground technologies Section 3 describes the system architecture for monitoring underground facility. Section 4 presents the data acquisition and analysis model. Section 5 gives a description about the conclusion.

2. Related Works

Mayers presents a data acquisition and data management system model [6]. Such a system is the base of an underground monitoring and provides an insight into the technologies required for the implementation of an underground monitoring system. Such a system is used by contractors and tunneling crew which manages the Tunnel Boring Machines (TBM) [7] guidance system and the other machine sensors, owners/clients and the authorized guests who evaluate the works as the client representative at the jobsite. These data management systems focus on the Key Process Indicators (KPI) for the quantitative and qualitative evaluation of underground tunnel driving and also for the entire sensor network as part of the surface instrumentation.

The construction of a the middle section of Warsaw metro line 2 presented many challenges according to this aspect and may studies were performed i.e. 650 drillings were ordered to a total length of 14800 meters to collect data on the land and water conditions within the construction site [8]. A monitoring infrastructure was deployed for risk assessment and construction process control using data from 7993 measuring sites and collected by 11 devices. The devices would send the data to a monitoring center where construction process would be controlled based or generated alerts by the risk analysis system.

The construction of a the middle section of Warsaw metro line 2 presented many challenges according to this aspect and may studies were performed *i.e.*, 650 drillings were ordered to a total length of 14800 meters to collect data on the land and water conditions within the construction site [9]. A monitoring infrastructure was deployed for risk assessment and construction process control using data from 7993 measuring sites and collected by 11 devices. The devices would send the data to a monitoring center where construction process would be controlled based or generated alerts by the risk analysis system.

The acoustic pressure wave method analyses the rarefaction waves produced when a leak occurs. SmartBall [5] is an acoustic-based technology that detects anomalous acoustic activity associated with leaks or pockets of trapped gas in pressurized pipes. The SmartBall is composed of an aluminum alloy core that contains a power source, electronic components and instrumentation (including an acoustic sensor, tri-axial accelerometer, triaxial magnetometer, GPS synchronized ultrasonic transmitter, and temperature sensor). The SmartBall assembly is deployed into the flow of a pipeline, traverses the pipeline, and is captured at a point downstream.

Image processing is another tool for the monitoring of underground infrastructure. Examples include structural health monitoring [9-11], displacement monitoring [10] and crack detection and development in underground structures [12-13].

Damage assessment and integrity monitoring is performed by periodical video recording of lining surface images by a system of moving cameras [14]. This technique is only limited to the visible parts of the surface. The first tool designed for live inspection of large diameter water mains, the Sahara® Pipeline Inspection System [15] is one of the most accurate tools available for detecting leaks, pockets of trapped gas, and structural defects in complex networks of large diameter water mains.

3. System Architecture for Monitoring Underground Facility

We present the system architecture based on the monitoring of underground facilities such as water supply lines, sewerage system, subway structures, oil and gas distribution *etc*. Figure 1 illustrates the conceptual system architecture for monitoring underground facilities. The main components for a facility monitoring, as shown in the figure, includes a sensor network for acquiring the data from the infrastructure of the underground facility. The type of sensors and the data acquired from through them is dependent on the facility being monitored and the requirement specifications of the monitoring system. For example, for water supply lines, the monitoring system should have data related to underground leakages, water contamination, and water pressure levels from source to the consumer points *etc*.

The second component of a system architecture for monitoring underground facilities, as shown in the Figure 1, is a point or sink for the data generated by all the sensors in a specific area. In the figure, this data sink is labeled as the gateway for the underground sensor network. Gateways provide a communication bridge between the sensing infrastructure and the brains of the system where all the data processing takes place. The gateways act as an abstraction layer for the heterogeneous hardware platforms of the sensing nodes and provide an easy approach to scalability of the system.

The third component of a system architecture for monitoring underground facilities is the data processing system labeled as server in the figure. The server is a system or a cluster of systems to provide storage and processing services for the data acquired from the sensing network by the gateways and sent to the servers in real-time. The server implements various data analysis and data processing algorithms to filter, clean, analyze and correlate data in order to detect various events (leakages, blockages, contamination *etc.)* in the underlying facilities being monitored. It also uses the same data to perform risk analysis of the system and predict or forecast events. The server provides notification service in order to convey, notify or alert the concerned entities once a real time event is detected or forecasted as a result of the data analysis and processing. The risk analysis data is also used in conjunction with the maintenance and safety control services. Specifically, the maintenance and safety service is of immense importance with regards to the underground facilities.

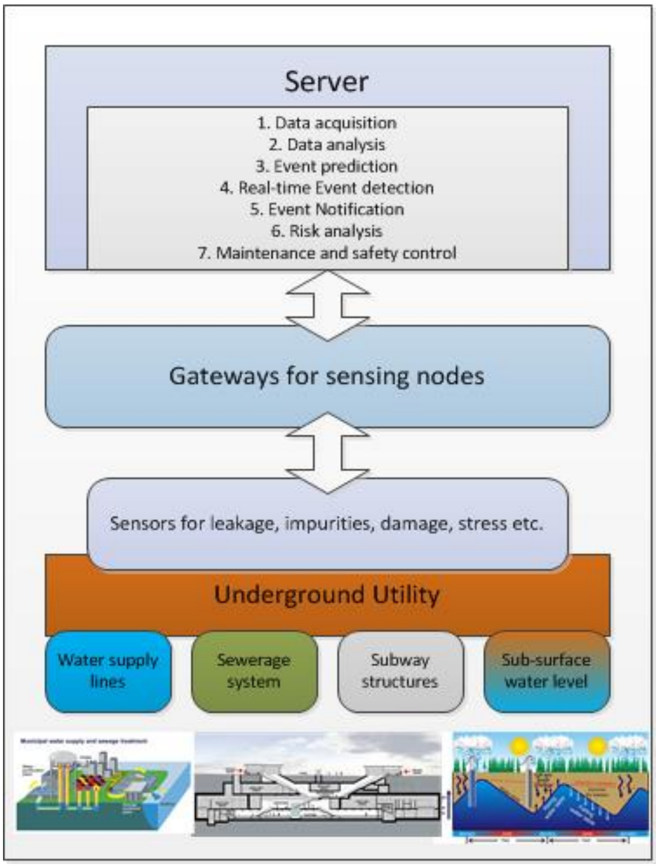

Figure 1. System Architecture for Monitoring Underground Facility

For example, Figure 2 presents a prototype model for monitoring underground water pipelines. The architecture of the system is basically the same as explained in Figure 1. As this is a model for specific scenario, the specifications of water supply pipelines are more concrete and hence shown in the figure. The monitoring of water supply pipelines will need sensing technology to detect any leakages in the pipelines, sensors for water flow monitoring and water pressure monitoring *etc.*, at various points from the source to the consumer.

As the water supply pipelines are an underground facility, the feature detection of the neighboring ground (displacement, sub-surface water levels, chemical composition *etc.*,) is also very important. As shown in the figure, all the sensing equipment is connected to the gateway which provides a communication link between these sensing devices and the server and also acts as a data sink for the connected sensing equipment. The gateway(s) gathers all the data from the sensors and send it to the server. The server receives the data and performs certain processing on the data to analyze and assess the state of the underground pipelines. If any immediate event in the form of leakage or blockage etc. is detected in the received data, an automated risk analysis of the system based on the detected event is performed and the danger notification service is activated. The notification service is used to dispatch an alert message containing the risk analysis results and the level of emergency to the concerned entities or authorities. If no such event is detected in the data received, the data is archived and stored for use in data analysis and forecasting procedures which require data from longer time frames.

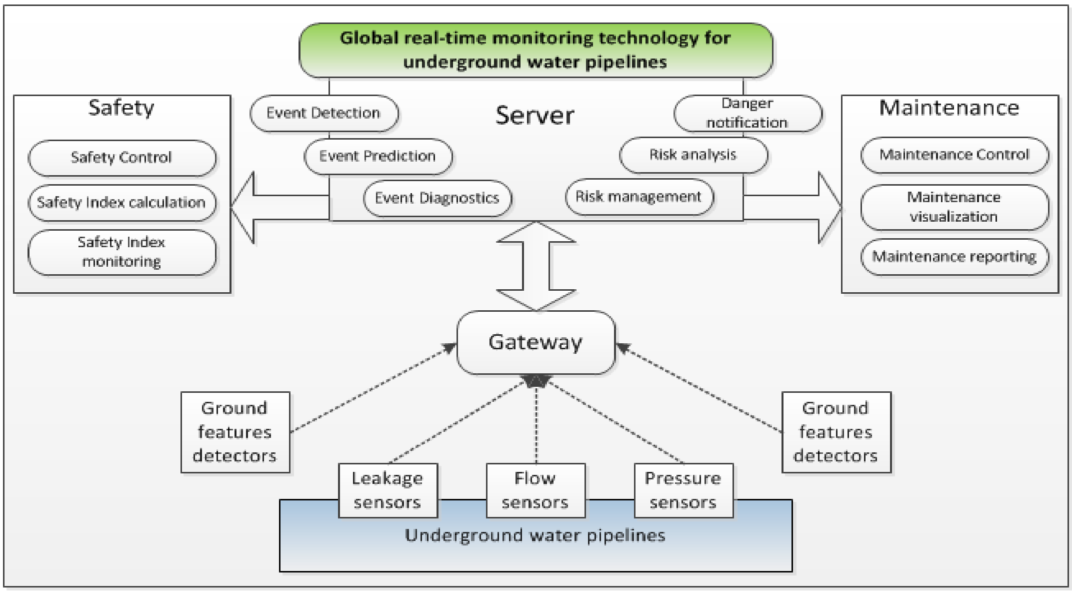

Figure 2. System Model for Monitoring Underground Water Pipelines

Such algorithms or procedures are termed as event prediction in the figure. Event prediction process analyzes archived data related to the system and based on pattern matching, filtering and cognitive algorithms, forecasts state of the underground system at time frame in the future. The system then uses the risk analysis and management processes with the event prediction process to formulate an event diagnostics report. The event diagnostics report consists of a suggested plan to tackle the problem while keeping in view the safety index of the system. The Safety control and management also works in conjunction with the maintenance monitoring and management. Safety checks and monitoring is an important aspect of the maintenance routines for underground facilities. The system checks the safety index of the underground facility and provides real-time feedback to the maintenance workers while visualizing their movements and receiving feedbacks from them in the form of maintenance reports. The system thus provides efficient monitoring of the underground water pipelines while ensuring the safety of the facility and the workers.

4. System Model for Sensing Data Acquisition and Analysis

System model for sensing data acquisition and analysis describes the type of data being acquired by a system and the processes or procedures applied to the data to obtain the needed information. Figure 3 shows the system model for sensing data acquisition and analysis in the underground facility monitoring system. The data collection part of the model includes the data related to the underground facility being monitored and the data about underground water levels and other geological features of the ground where the underground facility is located. The later part of the data collection is common to all underground facilities as monitoring the condition of the surrounding ground features and attributes is very important for the monitoring of all underground facilities. The surrounding ground features are monitored in the form of sub-surface water level data, ground cavities and deformations data and 3D imaging data of the surrounding ground for detection of cavities and displacements *etc*.

Figure 3. System Model for Sensing Data Acquisition and Analysis

Similarly, the underground facility monitoring data specific to the facility's infrastructure *i.e.* underground pipelines or subway structures is also obtained via sensing equipment. As the figure shows, the data related to underground pipelines includes pressure data at various points in the pipelines, flow readings and leakage monitoring data etc. while for the underground subway structures, the sensed or acquired data may include structure's stress data, 3D imaging based deterioration monitoring data and micro-crack sensing data etc. All this data along with the geological features data for an underground facility is first passed through a pre-processing stage. The pre-processing stage includes minor corrections and normalization of the data for efficient utilization by the data processing and analysis servers. The corrections are sometimes in the form of filling missing values from the data through simple techniques such as averaging or removing the redundant readings by cleaning the data for efficient processing.

After the pre-processing stage the data is sent to servers for analysis and storage for processing at a later time. The initial analysis procedures include detection of events such as leakages, blockages and contamination *etc*. If such events are detected then risk analysis and safety index evaluations are performed and a notification is formulated to dispatch it to the concerned entities. Otherwise, the data is stored and an event prediction or forecasting algorithm is run on all the archived data to correlate any changes in the data or find any patterns that could highlight the happening of an event at a later stage. Upon the prediction of any such event, the notification service is activated again and the alert is dispatched along with the event diagnostics report which suggests the best time and situation for avoiding or coping with the event in future.

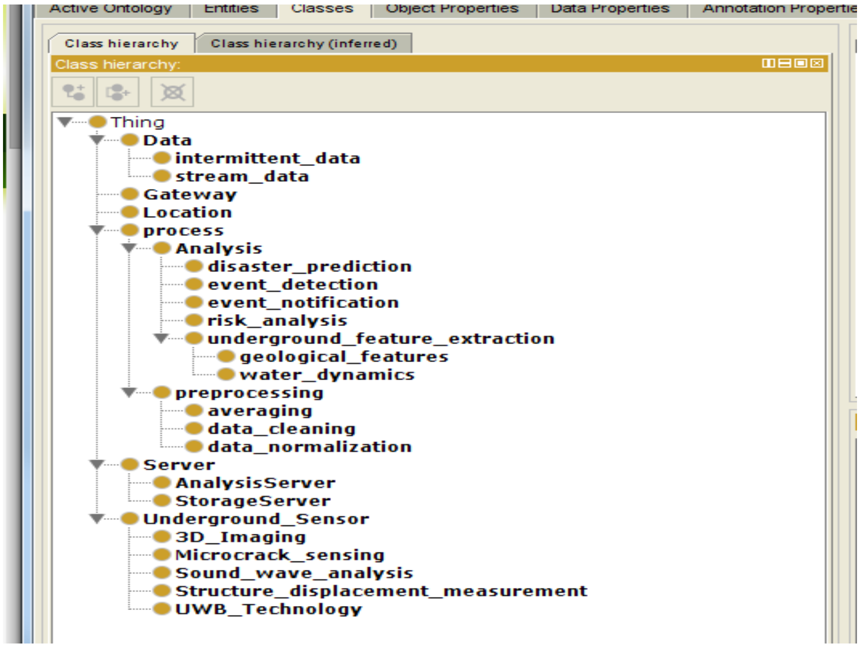

Figure 4. Entities of Semantic Model using Protégé for Monitoring Underground Facility

Ontologies provide a semantic structure for the data model of an underground facility monitoring. The benefit of semantic structure is that it adds meanings to the data which can be interpreted by the machine as well and hence effective reasoning can be performed over the data and its relations to extract the exact information with little input. A semantic model for the underground facility monitoring system is presented in this section.

Figure 4 shows entities of semantic model for the proposed underground facilities monitoring system. The model has been created using the Protégé software for semantic modeling. The model describes the Server, Sensor, Location, Gateway, Process and Data as the basic semantic entities which are extensions of the abstract entity Thing. Each of these basic entities has been then classified into sub-entities and the relations have been shown in the figure. These sub-entities in the semantic model represent derived classes or the actual objects/activities that are part of the underground facilities monitoring system. The most common and basic classes and subclasses as created in protégé are shown in the figure.

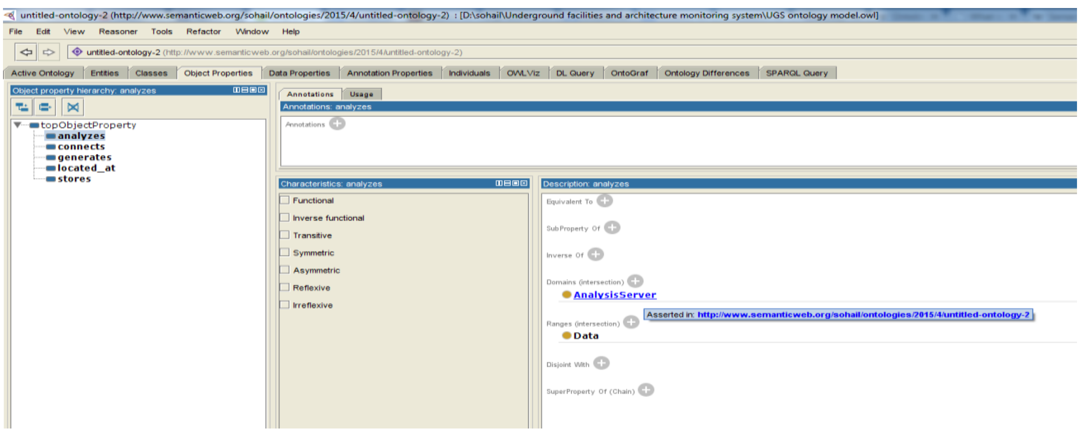

Figure 5. Object Properties of Semantic Model using Protégé for Monitoring Underground Facility

The semantics associations among entities and the actions or procedure performed by entities over other entities is represented as object properties. Figure 5 shows the basic object properties defined over the entities of the underground facility monitoring system. The right side of the figure shows various characteristics associated with each of these object properties. For example, the figure shows the domain and range entity types for the Object property ‘Analyzes’, which are ‘AnalysisServer’ entity and the ‘Data’ entity respectively. The information in these properties will help in associating various data objects with each other and provide an opportunity to infer more information through reasoning on the model.

The model presented in Figure 6 is a generic representation of how the system can be represented through ontology. This figure shows the semantic model using OwlViz generated graph for monitoring underground facility. While the specific model does not seem to provide significant information regarding the system, an in-depth requirement analysis of the system actors, objects and the activities can improve the model and by combining the model with existing ontologies developed e.g. the SSN ontology for sensors, a comprehensive semantic model for the system can be achieved. Such a comprehensive model can then be used for reasoning purposes in order to query the status of the system, automate and/or control the operation of the system.

Figure 6. Semantic Model using OwlViz Graph for Monitoring Underground Facility

8. Conclusions

This paper discussed the importance of a system design for monitoring underground facilities as a safety service of the modern urban society. The paper presented the system architecture for monitoring underground facility. This architecture will enable the use of desperate sensing technologies for data acquisition regarding various aspects of the underground facility health and functions. And we apply the architecture and data model for the monitoring of underground water supply pipelines. Also, we propose a system semantic model for data acquisition and analysis, this model supports to represent an identification and relationship of entities for monitoring underground facility.

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