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Exploring utility system SDI – Managerial and technical perspectives

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ABSTRACT

Spatial Data Infrastructure (SDI) has increasingly been important with the more widespread use of Geo-IT. The term is not new to countries which have adopted geo-information technology for a long time such as Australia, Germany and the United States. In Hong Kong, increasing attention to SDI has been paid from a number of government departments and related professional bodies in recent years. Yet, their work has primarily been concentrated on features on topographic surface. Our underground utility system which consists of diverse types of pipes, power lines and cables in fact also calls for an urgent need of a SDI to ensure both smooth and secure daily operations as well as system management and planning. To achieve setting up a utility SDI for as-built record, identification of essential components with proper definition is the first task, followed by translation into commonly agreed geometric and topologic primitives. From this proposed project, it's also preferable that a prototype platform with representative tested data be developed to enable simple query and network analysis. It is hoped that deliverables from this project can be demonstrated to the industry, making a start to promote Geo-IT technology in enhancing utility data management.

1. Introduction

Utility system refers to the laying of pipes, networks or cables for the provisions of everyday life essentials especially for the urban people. This includes water, sewerage, gas, electricity, telecommunication and so on. Information on where, what and functions of these systems are usually owned by individual party and is seldom shared among different parties (Boukhelifa and Duke, 2007). There are two probable reasons – confidentiality in view of competition and the lack of a systematic and thorough inventory. Such practice is not desirable for both operational and security reasons. In Hong Kong, accidents do happen in past years when workers mistakenly broke a gas or water pipe; it takes a long time to trace and fix the problem of a sudden blackout of electricity, water and gas supply. A wide range of underground utilities' condition survey, assessment and diagnostic technologies (Sterling et al., 2009; Hao et al., 2012) is available for input the blackout records to the utility system spatial data infrastructure. Compliance check of the surveyed results can be made according to various data quality levels suggested in USA (ASCE 38-02, 2002), UK (BSI PAS 128, 2014) and Canada (CSA S250, 2011). After carrying out the survey with fairly acceptable accuracy in the compliance check, it is therefore necessary to set up a such a system (Chen and Cohn, 2011) and database (Royal et al., 2010; Malinowska and Hejmanowski, 2010) to at least identify the main layouts of the different systems. Despite the needs for efficient and effective city administration, the task is challenging in view of the different formats held and the long history of records that are not easy to be retrieved (Beck et al., 2009). Integration or correlation of such information correctly is not an easy and simple task.

The recognition of an integrated data from various sources due to existing data inconsistency is always a popular concern, in which a number of projects have been carried out by various government departments in Hong Kong. This includes integrating the diverse address formats by the Rating and Valuation Department, geographical data modeling services for computerized land information system by the Land Information Centre of Survey and Mapping Office of the Lands Department, implementation of data alignment measures and situational analysis review by the Housing, Planning and Lands Bureau. In particular, integration of condition assessment records of both transport infrastructure/street works at the road surface and the underneath buried utilities is required to build an total management system of city's infrastructures (Rogers et al., 2012). Similar projects have also been carried out in a more complete fashion worldwide. For instance, United States Geological Survey (USGS) has set up a data portal: Geodata http://edc.usgs.gov/geodata/ for public access to its geospatial data. Not only topographic and imagery data, but also social and economic datasets have been integrated for public access. The

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Swedish demographic database project integrated population datasets (http://www.ddb.umu.se/index_eng.html) for all residents over the past few decades, with which the users can track individual migration at a very detailed level. Yet these are all about mapping socio-economic data on topographic surface. The utility spatial data infrastructure (USDI) is still a very new and challenging idea to be explored. In doing so, the necessary components or features of the different utilities have to be identified and the various feature definitions, spatial format and resolution be standardized. This paper therefore first examines the conventional recording methods and formats of utility data and identifies the problems in contributing to a common spatial database. With the data provided by several utility companies for the same region, a prototype is built to illustrate the concept and suggest further improvements for realizing an integrated and interoperable platform of USDI.

2. Conventional data structure for utilities

In the past, utility records such as position, depth, material, length were often kept in "Book Form" (Mahoney, 1986). During 1970s and early 1980s, AM/FM was emerged to manipulate utility records in the form of digital records, i.e. a utility database (Armstrong, 1992). Being a computer aided cartography (AM) and a system to record business and manage information associated with a map (FM) (Mahoney, 1986), it has the capabilities for automated mapping processes, record keeping, spatial data analysis and data/application integration in two-dimensional space. This technology allows utility companies to perform network analysis, marketing analysis, facilities mapping, keeping records of maintenance and usage.

AM/FM drawings are usually associated CAD, which record and visualize data in graphics or drawings, including depth, diameter, material and type of underground utilities. Different color schemes and/or patterns are adopted to differentiate types of mains/cables/culverts. Levels or layers are set to display different types of underground utilities, however, no spatial data such as depth, specific function can be retrieved. These layers can be switched on and off according to operational needs. Map scale should be controlled to avoid information congestion and confusion. The smaller the scale, the lower the level of details can be visualized. As AM/FM drawings are processed by CAD, they lack spatial relationship among entities (Xing et al., 1998) such as connectivity, adjacency and network zoning. Also, it is a two-dimensional system that emphasizes on creation and management of linear and point features rather than area features (Russomano, 1998), not to mention the three-dimensional complexity that actually occur in determining the laying of utilities underground. Under a two-dimensional CAD system, depth information of underground utilities are ignored and may lead to misinterpretation. Past practices has been using traditional typical sections, plan views and cross sections, which did not provide sufficient data for integration with 3D modeling (Pilia and Anspach, 2014). Even if a variety of surface geophysical methods like 3D Ground Penetration Radar Tomography has been developed for collecting depth information, it still poses a challenge for smaller utilities and those at great depths underground. As shown in (Fig. 1), Sewage Mains and Gas Cable, with different depths, seems to be overlapped and inter-connected by manholes/valve.

By late 1980s GIS started to embrace into AM/FM systems. Spatial information and attributes of entities were stored in a relational database management system (RDBMS) (Meyers, 1999) separately. With processing both geographical and attribute information, simulations and higher level analysis of facilities are enabled for decision-making, marketing and accounting (Berner et al., 1995). In recent decades, a number of commercial GIS have modeled individual utility system in a separate module taking into account of its own unique rules and cardinal relationships between different feature classes and sub-classes (Armstrong, 2011; Bentley, 2014). Yet, GIS application to utility data management is still limited. In the US, only half of the states use GIS application to manage utility conflict data. There is still a clear preference for traditional paper-based approaches to mark up printed drawings or maps (Quiroga et al., 2012). For a USDI, not only a detailed and up-to-date database for managing geo-referenced data and other attributes is essential, but also the challenging need of data integrity and data normalization between different databases. This project therefore attempts to integrate the databases of four common utilities, identifies the key information to be shared and the problems during data conversion and integration.

3. Utility records and semantics

A utility database, whether of CAD or GIS format, of detailed design or of schematics, usually consists of vast information peculiar to the management and operation needs of a particular network. When forming an integrated database, the identification of key or essential features is of prime importance before an agreed data structure and format can be formulated. Semantics inherent in the drawings or database should be well-understood so that features of common interest can be shared out to form a common database. In this project, record plans of four utility records – Fresh Water, Drainage and Sewage, Gas and Electric Cables supplied from the Water Services Department, Drainage Services Department, Hong Kong Town Gas and China and Light Power Limited respectively for a small (about 100 hectares), old but densely populated region in Tokwawan, Kowloon, Hong Kong are studied in an attempt to establish a prototype USDI.

3.1. Fresh water

Among the four studied utilities, only records of fresh water are operated and managed by a GIS. Features related to fresh water such as mains, valves, meters, pumping stations are stored in different layers with accurate 2-dimensional geometry (Fig. 2a) whereas their attributes such as ID, diameter are stored separately in an attribute table (Fig. 2b). A complete network is created whereby all mains are connected to valves with specific cardinal relationships. Hence, not only spatial and connectivity query are made convenient, but also tracing water flows from a source to users and detection of affected areas at times of defective pipe or valve is enabled in such a database.

3.2. Drainage and sewage

In the CAD drawings of sewage, foul and storm water pipes are shown by two different colors: red for foul water drainage and blue for storm water drainage (Fig. 3). The same colors apply to their manholes respectively. However, some storm water flowing through the box culverts are shown separately by blue dashed lines. Information concerning drainage ID, drainage diameter, manhole ID, manhole cover level, pipe diameters and depths connecting to the manholes, box culvert ID and its dimensions are all shown as labels in the drawings.

3.3. Gas

For the CAD drawings of Gas, different line colors are used to represent different pressure types (high pressure, mid-pressure, low pressure) of gas pipes, while pressure levels in bar units are