ELECTRIC POWER RESEARCH INSTITUTE

Geolocating Underground Utility Infrastructures

Review of Ground Penetrating Radar and Future Research Plans

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Technical Update, December 2017

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Electric Power Research Institute (EPRI)

Between the Poles

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ABSTRACT

Accurate distribution network models and the geospatial information system (GIS) data from which the network model is typically derived is becoming the one of the most critical barriers to the integrated grid. This is particularly critical in cities where the concentration of customers is large and is exacerbated by the assets typically being underground. The Information and Communication Technology for Distribution Project Set (PS161C) is studying ways of using data and machine learning to obtain and analyze information on underground assets.

This report consists primarily of material given in a webcast by Geoff Zeiss on June 24, 2014. In this report, the leading method of locating underground assets, ground penetrating radar (GPR) is discussed along with the economic justification for performing an underground asset survey. Avenues of future research by PS161C will be presented.

Keywords

Geospatial Information System (GIS)
Geographic Information System (GIS)
Ground Penetrating Radar (GPR)
Smart Cities

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KEY RESEARCH QUESTION

This report investigates methods to improve the output of ground penetrating radar and reduce the cost of processing the data to extract information.

RESEARCH OVERVIEW

This secondary research was meant to explore the need and advantages of improving geospatial information with regards to underground assets. Several calculations of return on investment (ROI) are presented. Research into improving the processing of ground penetrating radar will be explored.

KEY FINDINGS

- ROIs for improving underground geospatial data vary widely.
- Typical ROIs are in the range of $2-$6 per dollar spent.
- One study suggested an ROI of $21 per dollar spent.
- The most common method for mapping underground assets is ground penetrating radar (GPR).
- The analysis of GPR data is time consuming and expensive.

WHY THIS MATTERS

This technical update is meant to be a survey to determine if research into data analysis for ground penetrating radar is beneficial. GPR data analysis is costly and time consuming. Use of machine learning (a type of artificial analysis) is being explored to increase accuracy and reduce cost and risk of GPR analysis.

HOW TO APPLY RESULTS

The results included in this report are meant to inform the reader of the current state of EPRI thought in the area of geospatial information research. The report addresses the specific problem of underground asset identification and geolocation and includes a path of research to improve the current state of the art.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- Other reports that may be of interest in this area of research include:
  - *Detection and Geolocation of Power Distribution Infrastructure Using Public Domain Photographic Imagery*, Electric Power Research Institute, Palo Alto, CA. 2017. 3002011490.
  - *Geospatial Information System Data Cleanup: Building Out of Distribution Secondary Models*, Electric Power Research Institute, Palo Alto, CA. 2017. 3002007922.
  - *Monetizing the Geospatial Information System (GIS): The Value of GIS Data Quality for Electric Utilities*, Electric Power Research Institute, Palo Alto, CA. 2011. 1024303.
- GIS, smart city, and utility operations professionals are particularly in need of underground asset locational information. This report was developed with these professionals in mind.

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PROGRAM: Information and Communication Technology for Distribution (Project Set 161C)

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INTRODUCTION

Section Overview

Geolocating of underground utility infrastructure, sometimes referred to as subterranean utility engineering, is growing within the geospatial sector. Investment necessary for the institution of proper underground infrastructure location and documentation estimates range from $24 to $53 trillion, expected to be derived largely from the private sector [1]. Navigant Research projects a compound annual growth rate (CAGR) of 13%, thus $3.7 billion by 2017 and that geographic information systems (GIS) will assume a strategic role within the utility sector [2]. The current ground penetrating radar (GPR) market is projected to be approximately $100 million, with 5 to 10 times that figure represented within the associated service industries. Currently, the marketplace includes a few large players, located in North America and Europe, and many smaller ones throughout the world. The purpose of this report is to provide an overview of the applications and challenges related to GPR, to provide case studies illustrating innovative uses of the technology, and to discuss various studies related to the return on investment (ROI) and standards/rating systems used around the world related to geolocation of underground utility infrastructure. Finally, a project to use machine learning to increase the usability of GPR data will be described.

Techniques and Applications of Underground Utility Infrastructure Surveys

Advancements in GIS data acquisition tools over the past 20 years, including high resolution aerial photogrammetry, allow flights below 10,000 feet to obtain precision to near 4 centimeters [3]. Oblique imagery from the same altitude can now obtain 3D resolutions at comparable levels of precision [4]. Technology for geolocating underground infrastructures has also advanced in the last 2 decades as well. Known as GPR or ground penetrating radar, this technology has taken the lead position in European locations and elsewhere for locating and identifying underground infrastructures [19].

- Electromagnetic conductivity (EM)
- Ground penetrating radar (GPR)
- Very low frequency (VLF) profiling – electrical resistivity imaging
- Borehole geophysical and video logging
- Crosshole seismic testing
- Microgravity surveys
- Seismic refraction
- Magnetometry

While GPR tech has advanced in accuracy, it is commonly utilized via a pushcart and not comparable, in terms of speed, to surface photogrammetry such as LiDAR.

Additionally, GPR in the US is restricted within varying jurisdictions due to its reliance on a radio frequency (RF) transmitter, the presence and use of which is heavily restricted by the FCC. Europe does not face the same degree of restriction.

The following applications of GPR [19] range from measuring the thickness of concrete to exploring beneath the surface of snow:

- Concrete inspection
- Underground utility detecting
- Asphalt pavement inspection
- Bridge deck and concrete inspection
- Railroad ballast inspection
- Geological fault detection and investigation
- Tunnel scanning
- Archaeology
- Road inspection
- Rebar detection and mapping
- Landmine detection
- Snow scanning
- Borehole inspection
- Pavement thickness and road condition assessment

GPR does have some drawbacks. It requires a trained technician to interpret the results. The analysis can be time consuming and expensive. GPR doesn't work for all kinds of assets in all kinds of soil. GPR has difficulty detecting plastic pipes – it detects the contents of the pipe, such as water or sewage. Finally, soils, such as aggregate or clay, inhibit the performance. Some vendors use GPR with other techniques to overcome these limitations.

Current Efforts and Other Industry Practices and Statistics

Multiple other efforts to maintain accurate geolocation data have been made throughout the years. Tokyo and Sarajevo are among the earliest to set standards for underground infrastructure reporting. Tokyo has launched a nearly 3D system called ROADIC, which is also used in all of Japan's major cities. For 40 years, Sarajevo has required permits for any kind of excavation of roads and underground placement. As part of the permit, contractors must supply data regarding their as-built designs. Calgary, Alberta has also long required data, originally DGN files, which would map to the Joint Utility Mapping Project. Jalisco, Mexico; Edmonton, Alberta; and Penang, Malaysia have also set requirements for keeping track of underground infrastructure. Bahrain uses a repository called Intelligent Precision Support System throughout its entire kingdom. Sao Paolo, Brazil instituted a project entitled Geo con Dios, which integrates underground utility information. In terms of perhaps the largest undertaking, the entire country of France has resolved and begun to document everything underground to an accuracy of 40 centimeters.

Return on Investment

Multiple individual studies have been conducted on ROI. In 1999, Purdue University conducted a study on the United States Department of Transportation data, and concluded with an ROI of 4.62 [13]. In 2004, the University of Toronto, using the Ontario Sewer & Water Main Contractors Association information, came up with a figure of 3.41 [14]. In 2007, Pennsylvania State University, using data from the Pennsylvania Department of Transportation, returned a figure of $21 for every $1 invested [15]. In 2010, Toronto University did a retrospective on various studies within Ontario and reported ROIs ranging from 2.05 to 6.59 [16]. As mentioned previously, the Lombardy study estimated a return on their investment of 16 euros per 1 euro invested [6].

Table 1-1
Return on Investment Studies, 1999 to Current

Year	Location	ROI per Single Unit
1999	Purdue University-US DOT [13]	$4.62
2004	University of Toronto-OSWCA [14]	$3.41
2007	Penn State-Penn DOT [15]	$21.00
2010	University of Toronto-various [16]	$2.05 to $6.59
2014	Lombardy Region, Italy-2015 World Expo [6]	€16.00

2
SELECT UNDERGROUND ASSET SURVEYS

Case Studies

Lombardy Region, Italy

Lombardy, in its preparation for the 2015 World Expo, decided to determine the location of everything underground in a 230,000-square meter area. Their plan was to use GPR to detect electric power, water, sewers, gas, heating, and anything else underground, as well as research all historical records of the area. The research was thorough and included records from Roman and even Etruscan times. Within the scope of their plan, they decided to compare what their records indicated with what they discovered underground. Table 2-1 shows the discrepancy (in meters) between a GPR survey and the historical records. For known infrastructure average error in geolocation was about 30%, but much larger errors of up to 100% were also recorded. Their results reflected an average 34% discrepancy between historical data and what they recorded from the GPR analysis [4, 5, 6].

Table 2-1
Lombardy Project Area – Historical Records vs GPR Mapping [5]

Utility	From GPR Survey (Linear Meters)	From Historical Records (Linear Meters)	Difference (Linear Meters)	Difference (Percentage)
TLC	37.385	32.681	4.704	14%
Water	21.055	19.744	1.311	7%
Sewage	28.622	20.355	8.267	41%
Gas	22.592	23.467	-875.000	-4%
Electric	39.525	35.960	3.565	10%
Unknown	22.271	-	22.271	100%
Not in Use	3.908	-	3.908	100%
District Heating	7.192	4.284	2.908	68%
Total	182.550	136.491	46.059	34%

As a part of the study, the Italians analyzed ROI and found there to be a 16 to 1 return on their euro [4]. The Italian study benefited by virtue of the fact that their project was supported by their regional government, affording them a clear legal framework. The project also benefited because their choice of geolocation did not require digging. The experiment in Lombardy set a standard and was ultimately mandated for the 1500 municipalities in Northern Italy.

Heathrow Airport, London, England.

Heathrow has an extremely dense infrastructure with an average contractor population on any given day of 1000. Additionally, safety is critical because of the high degree of traffic with both planes and people.

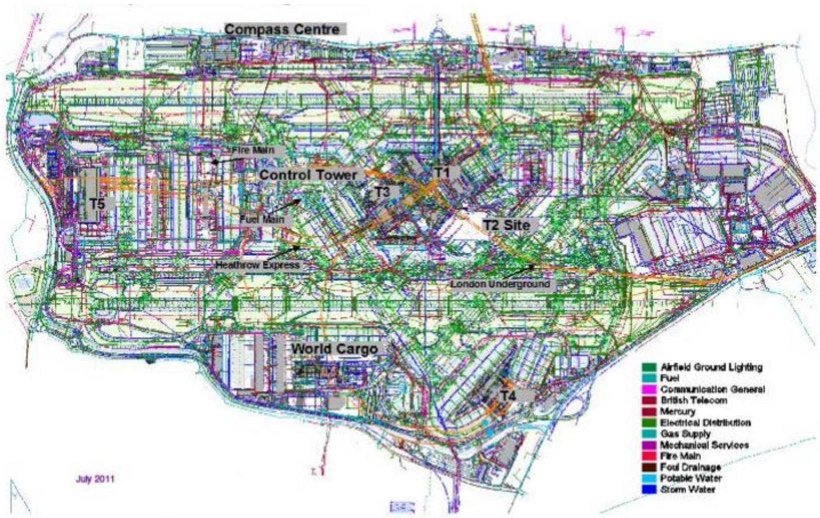

Figure 2-1
The Dense Underground Asset Environment of Heathrow Airport

The area contains 13 different types of underground infrastructure at risk where even minor accidents can become serious problems. With their 181,000-daily passenger load and 81 miles of aviation fuel lines, there is no room for error [8]. To help facilitate success, Heathrow implemented a Common Data Environment, encompassing, as its name suggests, data on the location of all underground structures, which goes a long way to ensuring reliable data quality. Beginning in 2002 with a 40% accuracy rate at ½-meter, Heathrow, by current expert estimates, is now very close to 90% accurate within a ½-meter. To perpetuate accuracy practices, they have instituted the Validation Life Cycle, which promotes continuous improvement in geolocation. Heathrow boasts improvement by a factor of 6 between the years of 2000 and 2011 [9, 10]. To further promote good maintenance, Heathrow created a Base Station, which is essentially an as-built electronic application. As in the case of Lombardy, Italy, this new step has been mandated for new construction in the Heathrow location.

The City of Las Vegas, Nevada

A major problem identified by the City of Las Vegas (and a problem many utilities face) is when underground structures are hit during excavations. Workshops conducted by a local consulting company brought the city and utility agencies together to understand how to address this problem and provide an introduction to 3D modeling and visualization. Industry estimates suggest that some structure underground is hit every 60 seconds, ranging from telecommunication cables, electric power cables, gas lines, water, and other utility infrastructure. This is attributed to the absence and inaccuracy of paper records. The challenge behind this statistic is that the locational information of many underground utility assets has not been placed according to plan and/or in many cases the location is not well known. The City of Las Vegas initiated a pilot project to model above and underground facilities along one and a half miles of Main Street in an older part of Las Vegas. Standards for underground utility infrastructure have been developed and are detailed in the next section.

Figure 2-2
3D Infrastructure Model for the City of Las Vegas

Some of the advantages of the 3D infrastructure model initiative are as follows:

- Improved safety.
- Lower costs - Reduced operating costs resulting from fewer truck rolls for cable/pipe locate operations.
- Enables automated clash detection to identify potential problems during design phase of construction projects.
- Because of success of the initial pilot, the project has been substantially expanded.

The case study provides a good example of how multi-organizational collaboration to improve wide area situational awareness of underground assets can provide benefit to all parties involved, improve project efficiency and safety, and reduce costs.

Current Efforts and Other Industry Practices and Statistics

Multiple other efforts to maintain accurate geolocation data have been made throughout the years [12]. Tokyo and Sarajevo are among the earliest to set standards for underground infrastructure reporting. Tokyo has launched a nearly 3D system called ROADIC, which is also used in all of Japan’s major cities. For 40 years, Sarajevo has required permits for any kind of digging up of roads and underground placement. As part of the permit, contractors must supply data regarding their as-built designs. Calgary, Alberta has also long required data, originally DGN files, which would map to the Joint Utility Mapping Project. Jalisco, Mexico; Edmonton, Alberta; and Penang, Malaysia have also set requirements for keeping track of underground infrastructure. Bahrain uses a repository called Intelligent Precision Support System throughout its entire kingdom. Sao Paolo, Brazil instituted a project entitled Geo con Dios, which integrates underground utility information. In terms of perhaps the largest undertaking, the entire country of France has resolved and begun to document everything underground to an accuracy of 40 centimeters.

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Standards/Rating Systems

There are multiple standards for rating underground infrastructure location and identification accuracy.

- The American Society of Civil Engineers ranks dependability with use of letters A through D. This is the method that's practiced widely in the United States. D indicates the presence of paper records; C indicates that one has taken a physical look of the area, noting existence of manholes, etc.; B means that electromagnetic exploration or possibly GPR, or something similar; and A indicates that a hole has been dug.
- The United Kingdom uses a similar system but adds to the letter B ranking a degree of accuracy from B1 to B4. The United Kingdom has named its system PAS128.
- France uses an accuracy benchmark of 40 centimeters. As a result, the letter A indicates accuracy to better than 40 centimeters, while B indicates between 40 centimeters and 1.5 meters, and then C, the lowest level on their scale, indicates less than 1.5 meters accurate.
- Heathrow Airport has set its accuracy requirement even higher. On their A-D scale, D includes a walk survey and looking at whatever is indicated on paper to be present. C means that underground tools are used. B rating says that 2 techniques have been used, and A means that you have dug a hole and are accurate to 2.5 centimeters.

3
PROPOSED RESEARCH

Three Promising Areas of Research

Ground penetrating radar has become the staple for underground asset identification tasks. The technique remains as much of an art as a technology. New methods of data acquisition, such as unmanned aerial vehicle and car-based acquisition, have evolved to gather data more quickly but the analyzing the mountain of data available has become daunting, expensive, and time consuming. Other sectors and research areas are also interested in finding and identifying underground and otherwise hidden objects. The recently discovery of a cavity in the Great Pyramid in Egypt using infrared thermography and muon radiography is one example [18].

EPRI is proposing three areas of research to address the location and identification of underground assets. This research will be conducted in the Information and Communication Technology for Distribution project set in conjunction with EPRI's Distribution and Underground Transmission programs.

1. Research new GPR data collection technologies for feasibility with underground utility assets.
2. Research existing GPR technologies to see if they are suitable for use with machine learning algorithms to identify underground assets.
3. Research new underground imaging technologies for use with utility underground assets, with special attention being paid to technologies unfamiliar to utilities.

4
CONCLUSION

Summary

Accurate and dependable geolocation of underground infrastructures serves to improve safety by reducing hazards and costs of construction. Implementing a survey-before-you-dig policy for those areas not previously surveyed with dependable tools will decrease the risk of costly and dangerous hitting of underground infrastructure. Additionally, once an area is properly surveyed, it will serve to attract developers, as cost estimates can be lowered when underground collision risk is at a minimum. Because of these factors and others not listed, there is a groundswell around the world moving towards instituting some type of underground geolocation policy prior to construction. The reality is that construction ROI is improved and has shown results ranging from advancement over current ROI to dramatic improvements. Newer, much more easily utilized technology with excellent visualization capacity is further serving to prompt development. And while a certain degree of skill is still essential, these benefits and advances in the industry do indicate a strong trend toward true growth and wide adoption.

5
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A
MAPPING PROJECTS

Cities, Regions, Nations with Underground Mapping Projects Cities

- Chicago – Innovative pilot to collect photos of excavations, extract 3D data and share.
- France – A nation-wide multi-billion euro project underway to map France's underground utility infrastructure to 40 cm. PLAN CORPS de RUE SIMPLIFIE* (PCRS) - http://cnig.gouv.fr/?page-id=1444.
- Penang, Malaysia – Penang-s Sutra D'Bank, Penang State Government Subterranean Data Bank is maintained by a joint venture company EQUARATER (PENANG).
- Bahrain – Bahrain's Intelligent Decision Support System (iDSS) provides single repository for all underground facilities.
- Sao Paulo, Brazil – The City of Sao Paulo's GeoCONVIAS project integrates data from 20 to 30 utilities which operate in the city of Sao Paulo.
- Rio de Janeiro, Brazil – The City of Rio de Janeiro has a similar project, GeoVias, funded by the government of the City of Rio de Janeiro and four utilities.
- Tokyo, Japan (now deployed in major Japanese cities) – Many years ago Tokyo developed the mainframe-based Road Administration Information Center (ROADIC) system
- Sarajevo, Bosnia – Over 40 years ago as part of the permitting process, Sarajevo mandated the recording of the location of all utility and telecommunications infrastructure in the city.
- Calgary, Alberta – A number of years ago the City Government passed a by-law which mandated that all utilities and telecoms working within city limits must provide data showing the geolocation of their infrastructure to the city's Joint Utility Mapping Project (JUMP).
- State of Jalisco, Mexico – The Instituto de Información Territorial del Estado de Jalisco developed an integrated infrastructure database for the State of Jalisco.
- Edmonton, Alberta – Edmonton, Alberta has a shared-facilities mapping database.

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