An Introduction to Underground Utility Mapping Technologies

By John E. Scaife, P.Geo. and Eric D. Timoshenko, B.Sc.

Mapping the buried utility network within urban areas can be successfully completed through the utilization of high resolution geophysical techniques. The results of these investigations can be imported into existing GIS databases to provide a permanent digital GIS record of the actual position of the buried infrastructure. This information benefits the facility owners, design engineers, the property owners and the general public.

Various geophysical tools including electromagnetic induction techniques and ground penetrating radar technology can be utilized to map the position and depth of buried utilities. Each of these techniques has their benefits and limitations but through a careful and diligent application, a comprehensive understanding of subsurface utility network can be obtained.

Introduction

Every day, new facilities are installed beneath city streets, private commercial and industrial properties, further complicating the network of underground infrastructure. The location of this buried infrastructure is of critical importance to those who wish to excavate for construction, install new underground infrastructure or maintain existing systems. To the average citizen, the placement and routing of buried utilities rarely crosses their mind; the flick of a switch engages power to the lights and a turn of the tap produces water; until an excavation breaks a buried electrical cable or gas pipe, often with disastrous results.

Accurately locating and mapping the position of buried services is a problem in established urban areas throughout the world. The modern-day investigative techniques have been built on historical research and have been greatly improved through the advent of digital technology. The majority of modern detection systems utilize electromagnetics; either by measurement of induced electromagnetic fields or through the recording of electromagnetic pulses.

The objective of this discussion is to provide a brief introduction to some of the investigative technologies currently being used in the realm of utility locating and mapping. The results of these investigations can be captured and incorporated into base plans, legal survey drawings, integrated with topographic surveys or other GIS databases.

Subsurface Mapping Technology

Similar to the current medical process of X-rays, CAT Scans or Ultra-sound technology that allow doctors to view the interior of the human body, instrumentation exists to permit scientists to image or locate features below the ground surface. Virtually all of these "geophysical" techniques originated with the resource exploration industry as scientists searched for a way to remotely map deposits of oil, gas and various minerals. Recent advances in digital technology, along with the concern with environmental issues, have led to the development of high resolution electromagnetic systems that detail features within a few metres

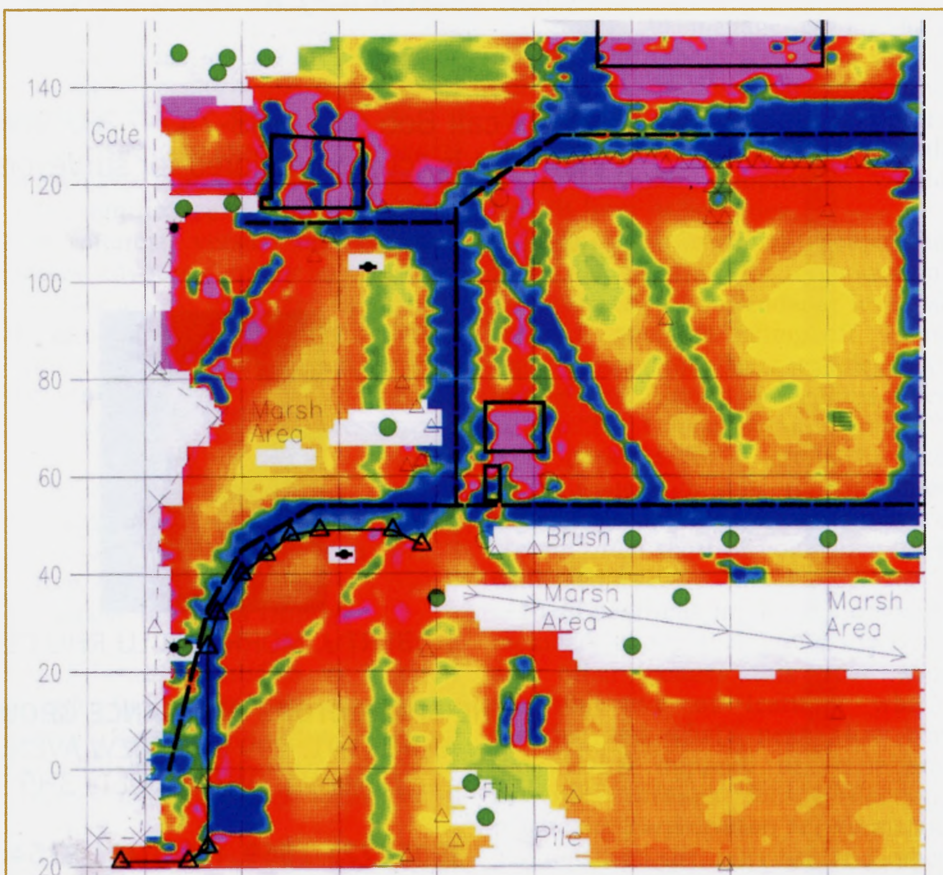

FIGURE 1
Colour contoured electromagnetic data showing 'anomalous' linear trends inferring the position of buried metallic infrastructure.

FIGURE 2
Locating multiple underground facilities as part of a pre-engineering design utility mapping investigation.

of the ground surface. Although originally designed for shallow geo-logic mapping, these systems can be ideal for mapping the position of metallic structures, such as underground storage tanks, pipes and cables.

Two of the most common applied techniques are electromagnetic induction and ground penetrating radar. Electromagnetic induction involves establishing measurable electromagnetic fields onto a target conductor (i.e. a steel pipe or cable) whereas the ground penetrating radar technique involves the transmission and propagation of pulsed electromagnetic energy and the subsequent recording of these energy waves. The following provides a brief discussion of the theory, instrumentation and application of three selected technologies. There are other technologies which can be used to map underground infrastructure, but the three tools described here are the most widely used today.

Geophysical Electromagnetic Tools

Several models of geophysical instrumentation are available, which can be utilized to map underground infrastructure. These typically involve deployment of a fixed frequency electromagnetic field to induce the flow of secondary electromagnetic fields on subsurface conductors. As these systems are passed over a conductive target (i.e. steel pipe or cable, underground storage tank, conductive refuse, etc.) they will record a local disturbance, or anomaly, with respect to the entire data set. These types of systems are very useful for mapping the changes in localized soil conductivity over large areas to provide reconnaissance level mapping of the underground infrastructure.

These data are normally spatially referenced by concurrent capture of GPS data or to a localized survey grid established over the area of interest. Depending on the measurement line and station spacing, literally thousands of data points can be acquired in one field day. These data are digitally logged during the survey and subsequently downloaded into plotting data bases.

In order to review the spatial variation in the recorded values, these electromagnetic data are normally compiled, processed and presented in colour contour map format. The contour maps allow simple review of anomalous trends (i.e. orientation of various pipes and cables) and the colour scale on the maps provides the interpreter a better comprehension of the dynamic range of the data. Any mapped utilities will manifest themselves as linear features, either positive or negative in sign versus the recorded background values, directly over the position of the target.

Figure 1 shows an example of a survey completed with a Geonics EM31 terrain conductivity meter to define relic underground infrastructure within a 2.5 hectare site. These data clearly show linear 'anomalous' features which correlate to the position of buried metallic pipes and cables abandoned in-place at a former industrial facility. The data were acquired at 2-metre intervals along survey lines spaced roughly 2-metres apart, which is sufficient for sampling since the measurement 'footprint' of the EM31 is roughly 5 metres in diameter. Geophysical interpretation of these data can be complex due to recording of interference from unwanted sources such as existing metallic cultural features including parked vehicles, fences, overhead cables, etc. and depth information is not readily determined.

Although this tool cannot be universally applied for many detailed utility mapping investigations, these results, captured in one field day, delineate the major features of an abandoned utility network to a reconnaissance level.

Electronic Pipe and Cable Locating Tools

In congested urban areas, the spatial position of the various active utilities within the area of interest can be determined and mapped using low frequency electromagnetic induction devices commonly referred to simply as 'electronic pipe and cable locators'. Although there are several manufacturers of this instrumentation, there are a few features on selected pieces of equipment, which provide additional flexibility, including: multiple operating frequencies, high power transmitters and software driven and easily upgradeable receivers.

The detailed mapping of underground utilities with this equipment is best achieved using the direct coupling method where an electromagnetic field is induced onto the target line via a transmitter clipped directly to the associated utility hardware. The receiver, tuned to the same frequency as the transmitter, is then swept across the anticipated position of the target line. The position of highest field intensity is identified with the receiver in "peak" mode. This position, inferred to be directly over the energized target line, can then be confirmed with the receiver tuned to "null" mode, in which case the position of the target line is inferred to be directly below the lowest recorded field intensity. It should be noted that these systems cannot define non-conducting materials (i.e. plastic, clay, asbestos, etc.) since they rely on the propagation of an electromagnetic field along the target conductor.

These pipe and cable locating systems can commonly be augmented by a transmitting sonde, which can be physically installed into vacant non-metallic conduits below the ground surface. This technique obviously requires physical access to each line to be investigated (i.e. culverts, conduits, drainage lines, etc.). The sonde transmits a signal at one of the receiver frequencies and is advanced through the conduit while its position is continuously mapped by the operator on surface.

Estimates of cover thickness are calculated by measuring the induced electromagnetic field gradient between the upper and lower receiver aerials, which is converted to a depth to the source of the respective electromagnetic field. According to typical manufacturer specifications, cover thickness estimates made in this fashion are accurate to within ±10% of depth to the centre of the induced field of a single isolated horizontal cable. These thickness estimates, however, are very susceptible to errors caused by changes in the electromagnetic field due to proximity of other induced fields from other buried infrastructure, fences, overhead power lines, etc., and must be used cautiously. The depth function on these tools is best used as an in-field quality control measure to confirm that the operator is locating the desired target line, not as an absolute measurement. When depth information is mission critical, all utility lines must be exposed and physically reviewed.

Experienced and diligent operators using a methodical application of these tools can provide detailed definition of the local underground utility network. Figure 2 shows an operator confirming the routing of several underground utilities using a Radiodetection RD400 system. These data were captured as part of a pre-engineering design utility mapping investigation within a congested area on a municipal road. The inferred position of these utilities is commonly marked with spray paint or flags. These markings can be captured and incorporated into base plans, legal survey drawings or topographic data to provide a complete and comprehensive record of above ground and subsurface features.

Ground Penetrating Radar

The mapping of unknown features, such as unmarked or abandoned utilities, plastic, vitreous clay or asbestos pipe, relic foundations, large rocks, etc. can be completed through the implementation of a ground penetrating radar (radar) survey.

Radar is similar in principle to seismic and sonar techniques. The radar produces a short duration pulse of high frequency (10 to 1000 MHz) electromagnetic energy, which is transmitted into the ground. The reflected signals are detected and amplified at the receiver and these received signals are digitized and stored for post-survey processing.

Radar penetration into geological material is controlled by the electrical conductivity of the material. As the electrical conductivity increases, the radar (electromagnetic) signal is dissipated as heat in the material. Geologic horizons that exhibit different conductivities from those above can be delineated by the radar by their contrast in electrical properties. Similarly, man-made objects (i.e. pipes, cables and conduits) and subsurface voids can be detected since these objects will have markedly different electrical properties than the host material.

FIGURE 3
Acquiring ground penetrating radar data over a series of parallel survey lines to map the underground infrastructure.

The radar system consists of a transmitting and receiving antenna, which is dragged along the ground surface continuously recording the reflected radar energy from the subsurface. Figure 3 shows an operator using a Sensors & Software Inc. Noggin 250 radar system recording radar data over a series of parallel survey lines. After completion of the field work, extensive post-survey processing permits the geophysicist to enhance the presentation of the data through a variety of processes including various gaining functions, filtering options, data splining and averaging along with different visual display options.

The radar data are presented as processed sections, which represent profiles of the subsurface with position on the horizontal axis and two-way travel time on the vertical axis. Through additional detailed investigations, the propagation velocity of the radar energy in the subsurface can be obtained to permit definition of a depth scale, which can be plotted alongside the processed radar sections. Lately, additional software capability permits the radar survey information to be compiled into digital block models to review the information as depth-slices, revealing the features within specific depth ranges, similar to looking at one particular layer in a layer cake. This feature is particularly useful for reviewing continuity of underground features and determining the routing and depth of multiple facilities mapped within the exploration range of the radar system. However, we again caution that where accurate depth information is desire, the utilities must be physically exposed.

Summary

The application of high resolution geophysical techniques for mapping subsurface utilities requires a detailed understanding of the electromagnetic survey technologies and their applications. A comprehensive, diligent and thorough investigation permits a comprehensive understanding of subsurface conditions.

The results of these investigations can be imported into to digital drawings and GIS databases to augment, improve or enhance the existing information to provide a permanent digital record of the actual positions of the buried infrastructure.

About the Authors:

John E. Scaife is the Director of Business Development and **Eric D. Timoshenko** is the Senior Project Manager at multiVIEW Locates Inc., a Mississauga based firm specializing in the application of high-resolution geophysical techniques for utility detection, engineering and environmental investigations, and concrete inspection. Each have been personally involved in numerous utility mapping projects including pre-design work in Canada and abroad, provision of contract locating services and facilitating private locates.