Equipment Mounted Multi-Sensory System to Locate Pipes

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Abstract

The demand for new buried utilities is growing with new construction, reconstruction, and the growth of the subsurface infrastructure worldwide. As a result, contractors are busy digging and trenching to bury new pipes. Because the machinery needed for placing the new utilities underground, such as backhoe excavators, trenchers, augers, drills, and plows, don't "feel" when they are getting close to already buried object, utilities are easily damaged. Despite great efforts in locating existing utilities before a contractor is allowed to dig, accidents occur in great numbers. The core idea of the concept presented in this paper is to provide the equipment operator with his own system that alerts him of the danger rather than to depend on the hand-held approach alone. A sensing platform, operating like a subsurface "X-ray", has been attached directly to the machinery, hence providing the operator an opportunity to "see" and be warned when the machine tool gets close to an existing utility. This paper will not only present the results of initial field tests but more importantly the results of an effort in integrating the EMI with a GPR (Ground Penetrating Radar) and some exciting applications for the future.

Introduction

The congressional Transportation Equity Act for the 21st Century, TEA 21, Title VII, Subtitle C, SEC. 87301, states that: "...unintentional damage to underground facilities during excavation is a significant cause of disruptions in telecommunications, water supply, electric power, and other vital public services, such as hospital and air traffic control operations, and is a leading cause of natural gas and hazardous liquid pipeline accidents."

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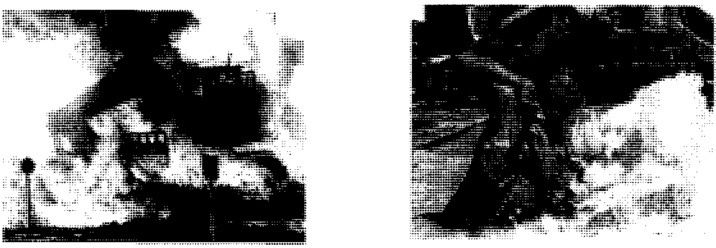
Underground Focus Magazine (1999) is one source that publishes an Accident File in every issue containing spectacular reminders of what can happen, as shown in Figure 1. According to the list seven major accidents occurred from December 8th until December 11th 1998. On the 9th a fiber optic cable was cut by an excavation contractor that supported the 911 service for five counties in Jacksonville, Texas. The most tragic accident, however, occurred on Dec. 11 when "a crew using an "anchor cranker" to install a guy wire anchor for a telecommunications pole augured into a gas main." four people were killed and fourteen injured when the gas exploded in St. Cloud, MN.



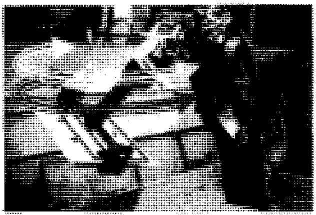
a) Backhoe in flames after hitting a gas line b) Backhoe loader broke water main

Figure 1: Examples of Accidents Caused by Damaging Underground Utilities

There are many different parties, actively and passively, involved in the excavation and trenching process. Active participants include: 1) owners of a new facility, 2) designers, 3) planners, 4) contractors, 5) utilities, 6) locators, 7) construction workers, and 8) equipment operators. In most U.S states, a contractor is required by law to call a "One-Call Center" 48 or more hours before he digs.

Despite the successful implementation of the One-Call systems in most of the U.S states, the accidents caused by damaging underground utilities result in wide variety of impacts reaching from a clogged residential sewer lines to a gas explosions with deaths and destruction. The list of impacted parties that are economically impacted comprises not only the contractor, utility and property owners, people in the vicinity of the accidents, but also the customers of a disrupted utility. Some of these groups are: a) private homes, b) governmental agencies, c) service companies, d) schools, e) hospitals, f) industrial firms, g) transportation systems like airports, taxi services, freight trains and trucking, h) retailers, and i) the utilities themselves. Overall, the direct and indirect costs of such accidents are staggering making the use of more sophisticated prevention approaches also economically prudent.

In 1993, the Construction Automation and Robotics Laboratory (CARL) at North Carolina State University (NCSU) started an initiative to address the national problem of detecting and locating underground buried utilities. The core idea was to provide the equipment operator with his own system integrated with the equipment that alerts him of the danger rather then to depend on the color marks made by the locator sent by the One-Call center. As shown from Figure 2 a sensing platform was attached directly to the machinery hence providing the operator with an opportunity to "see" and be warned when the machine tool gets close to an existing utility.



a) EMI antenna mounted to excavator boom

b) Control and feedback box for operator

Figure 2. Backhoe Mounted BUDS System

The original system was based on the Electro Magnetic Induction (EMI) technology that was integrated with PC-based software to process and analyze the signal coming from an antenna. Using a traditional coil, the antenna generates its own magnetic field and senses the existence of ferrous and non-ferrous material. The analogue output of the controller is then digitized and plotted on the computer screen. By taking advantage of this capability, the technology was used to retrofit backhoe excavators, trenchers, and augers. A simple user interface was created by creating a control box for the operator, consisting of two buttons for operating the articulated sensory platform and a red-yellow-green light as feedback (see Figure 2 b).

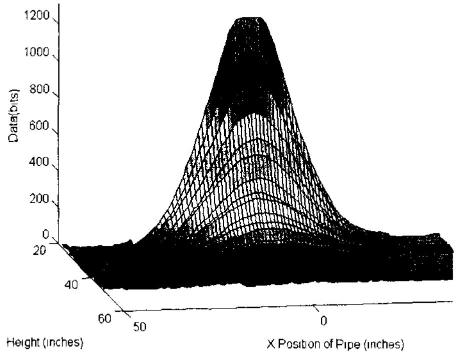
Utilities, such as gas lines and optical communication cables, are mainly non-metallic making the EMI technology useless since these utilities are "invisible" to the magnetic field detector. Other non-metallic objects underground include sewer lines made of concrete, clay and plastic. One sensor that has been successfully used even in archeology is the Ground Penetrating Radar (GPR). The GPR transmits RF signals and detects the signals reflected by changes in the ground. When translated on the surface it provides a cross-sectional image of the material below the ground surface. Details of how this image is decoded, problems faced and implementation details are discussed later.

Integration of Multiple Sensors

Anything metallic present in the ground can be induced to create a magnetic field, which can be detected by an antenna. The magnetic field is caused by a signal emitted by the transmitter coil. A receiver coil "listens" to this reflected signal and gets a measure of the metal around it. This can be done by either Continuous wave EMI or Pulse EMI.

Figure 3 presents the output of the Pulse EMI mounted on a trencher used for experimental testing in the field. As on can clearly see from Figure 3 b), the signal strengths varies with increasing depth of burial, a phenomenon that has to be expected. In addition to depth, the signal strength varies with the size of the pipe.

a) Field experiment with trencher

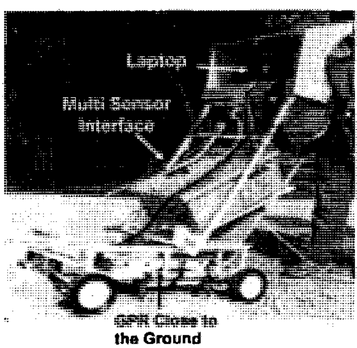


b) Data for variable depths of burial for steel pipe

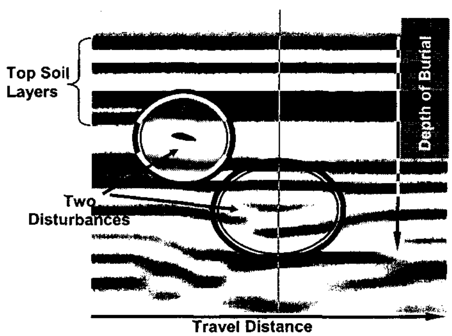
Figure 3. EMI Mounted on Trencher Driving Across Buried Pipe

Each pipe diameter provides a different curve, which could be used for identification. Unfortunately, however, the signal variations due to depth and size overlap un-distinguishably. Only if one unit is known can the other be calculated. Thus, a method has to be found that allows one to do that.

Non-metallic objects that are buried underground include pipes made clay and plastic. Today, gas distribution pipes in neighborhoods are primarily made of plastic without any way to detect them using conventional methods or even EMI. Ground Penetrating Radar (GPR), used in land-mine detection (Gader et al., 2001) might provide the necessary solution to this problem. The GPR is a remote sensing short-range radar system, which measures short pulse electromagnetic (EM) reflections due to variations of the electrical properties of the investigated medium. Figure 4 presents a picture that shows a field test with a GPR mounted on a cart.



a) Cart mounted mobile GPR

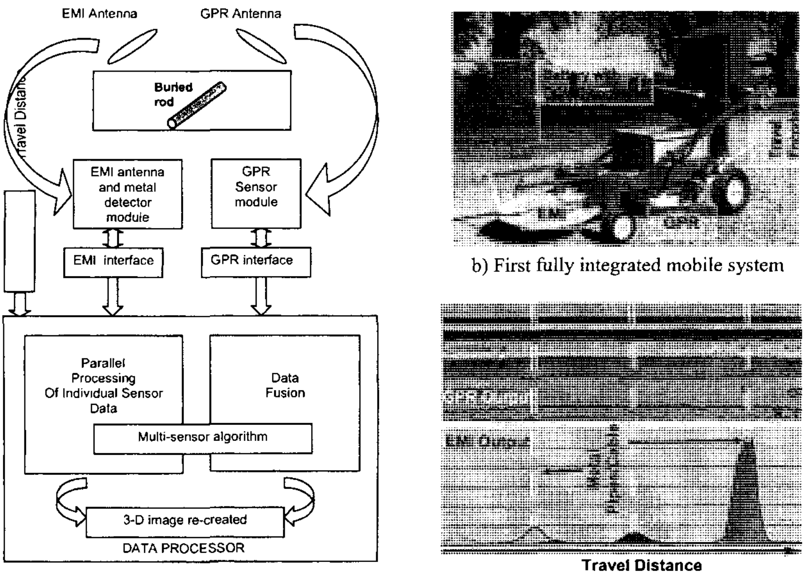


b) Display of GPR showing two possible pipes

Figure 4. GPR Finds Unknown Plastic Pipes for Contractor

The electromagnetic wave, which is radiated from a transmitting antenna, travels through the material at a velocity that is related to the electrical properties of the material. If the wave hits an object or a boundary with different electrical properties then part of the wave energy is reflected or scattered back to the source. The wave, that is reflected back, is captured by an antenna and an image is created that is reflective of the materials and boundaries present beneath the surface.

The significance of Figure 4 is the fact that the depicted first prototype mobile system was able to find plastic water pipe for a contractor working on a sewer extension for the NC State University's School of Veterinarian Medicine. Since plastic pipes can't be found with traditional methods the locator was not able to find them.



a) Data flow diagram for integrating GPR and EMI

b) First fully integrated mobile system

c) Interfaced GPR and EMI sensory data

Figure 5. Concept of Multi-Sensor Fusion for Mobile Utility Detection System

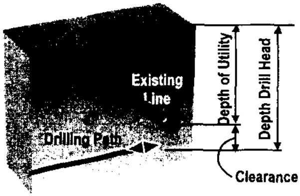
Figure 5 presents the first fully integrated mobile buried utility detection system (Mo-BUDS) which was also successfully tested in the field. Powered by a DC battery, the system integrates three sensors: a) EMI, b) GPR, and c) a potentiometer measuring the distance of travel. As shown in Figure 5 c) travel distance allows the alignment of the data output from the two detection system before they are being processed and fused. Figure 5 a) depicts that eventually the operator will be provided with a 3-D CAD image of what the system sees, similar to a fish-finder. At present, only a green-yellow-red light interface exists.

According to Klein (1993), data fusion is a multilevel, multifaceted process dealing with the automatic detection, association, correlation, estimation, and combination of data and information from multiple sources. The type of fusion architecture used to combine sensor data depends on the application. There are three broad 'levels' where data fusion can be incorporated: a) direct fusion of sensor data, b) feature vectors and c) high-level inferences. Since the multi-sensor data in our case is not commensurate, we can either represent data obtained from each sensor via feature vectors, with their subsequent fusion; or perform individual processing of each sensor's data to achieve independent high-level inferences or decisions, which are combined to make a collective decision.

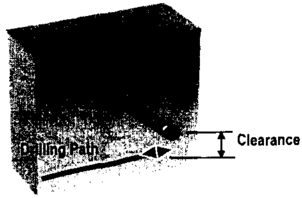
The overall process consists of four main parts: Preprocessing the signal from the sensor, feature/contour extraction, feature/property selection, and classification. Figure 6 shows the adapted version of a common data fusion model to MS-BUDS (Multi-Sensory Buried Utility Detection System). The data from the two sensors are initially conditioned by independent signal processing modules which later feed into a parallel processor running a multi-sensor algorithm. The parallel processor uses a feature recognition and classification algorithm that operates on sensory data and 'learns' with a knowledge base as it goes along. The development and testing of this software is presently underway.

Mo-BUDS for Drill-Head Mapping

The interference free control of the drill-head of an HDD depends on the availability of accurate and complete information of: 1) Position and size of existing utilities, and 2) location of drill head relative to the buried utilities. At present much is being done to achieve sufficient accuracy in sensing the depth of known lines and the depth of the drill head within an absolute coordinate system. In reality, however, it is not important how deep the two objects are as long as they are separated enough so that the back reamer will not damage the existing utility. Thus, it is more important to know the relative distance between the drill head and the utility rather than their depths. Figure 6 presents the differences in calculating clearance from depth measurements and directly sensing the clearance of the drill head relative to an existing line.



a) Present method base of subtracting sensed depths



b) Proposed method of assessing clearance

Figure 6. Methods for Tracking Clearance with Buried Utility

The present approach to tracking clearance starts with locating known lines. The many challenges facing this method include difficulty in sensing depth accurately and the existence of lines that are not known.

Both those problems can be circumvented by deploying the second method utilizing a modified Mo-BUDS system. As was shown, both EMI and GPR don't need a priori information about the presence of a buried utility since they work independent of an outside signal. In addition, EMI and GPR can work for different depths. Figure 8 presents the envisioned system to include the following components: a) Autonomous drill-head follower, b) Mo-BUDS, c) wireless communication and c) virtual-display for HDD operator.

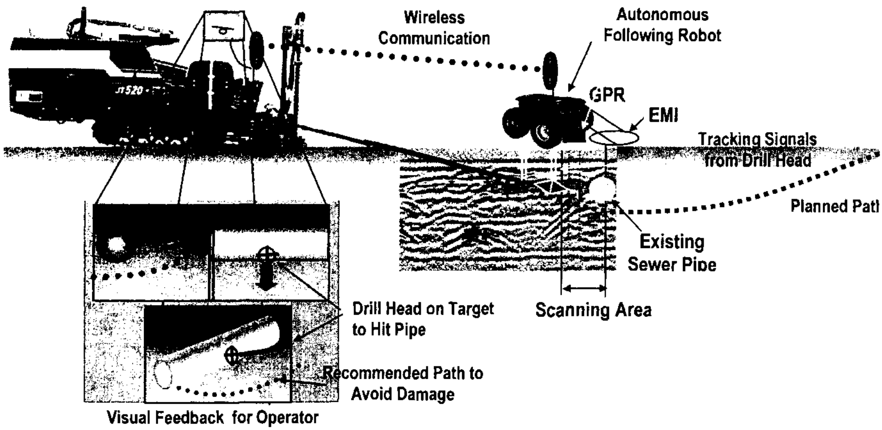


Figure 7. Schematic of Fully Integrated 3-D Mapping

The main goal of the follower is to stay on top of the drill head by tracking the signal that it emits. This technology has long been developed for the warehousing industry for vehicles that stack and retrieve pallets autonomously by following a signal from an emitter in the floor. Mounted on this all terrain vehicle are the different sensors and a wireless sender, which communicates with a receiver mounted on the drill. Besides visual information, the system could be integrated with the drill itself to override the operator in emergencies. The wheel based follower vehicle could first be utilized to create an investigative underground map for planning purposes that creates the planned path as shown in Figure 7.

Conclusions

Damage to buried utilities can cost lives and damage to property and equipment. This paper presented a novel technology that integrates two common sensory equipment, the Pulse EMI and GPR, into a multi-sensory real time underground utility detection system. The premise of fusing the two main sensory data stream is to maximize reliability/accuracy while minimizing false positives. Two experimental facilities have been built to study the effect of various soil and object conditions on the features of the sensory outputs. In order to improve the safety of Horizontal Directional Drilling (HDD), it is proposed to use an drill-integrated "tracker" on four wheels capable of following the drill head guided by the signals emitted from the drill head in the ground. This carrier is equipped with the Mo-BUDS technology and a wireless communication interface. Data is being sent real-time to the HDD operator providing him with 3-dimensional images of the utilities and their actual distance with the drill. Work is continuing on improving the BUDS technology and the fusion of the two main data sources, the EMI and GPR.

Acknowledgement

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