STATE OF THE ART FOR PIPE & LEAK DETECTION

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A Low-Cost GPR Gas Pipe & Leak Detector

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PIPE DETECTION OVERVIEW

There is a limited arsenal of tools available for pipe detection. However, the diversity of techniques shows that each has advantages and shortcomings. For example, only GPR can claim to reliably detect non-metallic pipes, but may fail to detect pipes in some soils. The main categories of pipe detection tools in common use are summarized below.

Pulsed Induction

Pulsed Induction methods detect pipes by generating a conductive current at the surface and trying to detect eddy currents induced in a metal object underneath. This is the technique used in most standard metal detectors[1]. Pulsed induction equipment is used generally four different ways depending on the application: as an inductive locator, an inductive tracer, a conductive tracer, or as a passive receiver. [2]

Inductive Line Location

One positions the Transmitter Box in front, the Receiver Box behind. By walking a grid pattern, one can discover the location of buried metallic objects, with a signal tone indicating their locations. Marking the pavement with chalk reveals a pattern that shows the location of the underground objects.

Inductive Line Tracer

When one point of an underground linear conductor (such as a pipe or cable) is known, the transmitter box can be placed over it while the user swings the receiver box around in either direction, listening for the audio signal tone. As one walks away from the transmitter box tracing farther down the line, the transmitter signal will become faint. The transmitter box can then be moved closer so that tracing can continue to the end of the line, or two operators can walk together.

Conductive Line Tracer

This is the preferred method of tracing. If one can make electrical contact with a conductive pipe, a signal can be transmitted along it. One can then walk along the ground, following the pipe. This would typically involve following a line from the basement of a house. Plastic pipe is now usually laid with an embedded metal tape or a tracer wire alongside it to allow tracer detection. Otherwise a plumber's snake can be used.

Passive Line Tracer

This mode relies on a power line to supply the transmission signal. For example, with the receiver tuned to receive 60Hz, the antennas will be sensitive to signals given off by buried power lines.

High-end units measure depth using two coils separated some distance, so that the signal return from the pipe can be compared. The accuracy is reportedly quite good (<10%) under ideal conditions. However, depth estimates are thrown off by several factors: poor induction by the transmitter, poor signal strength at the receiver, adjacent utilities or T's or elbows, and soil that is too dry or overly saturated.[3] [4] Another shortcoming of these systems has to do with detecting large diameter pipes (≥ 60cm (24")), since the signal gets diffused away. Following pipes that are close together is also difficult, as well as tracing pipes that have gasketed joints that interrupt signal conduction. Power line interference can also interfere with the signal.

Magnetic Locators

These devices take several forms, all of which rely on measuring changes in an induced magnetic field to detect the presence of a ferromagnetic object. They locate buried ferrous objects while rejecting non-magnetic objects such as aluminum cans and bottle caps.

They are especially useful in detecting valves and junction boxes associated with metal lines, since these are generally undetectable with the pulsed induction pipe locators.

Cast-iron or steel pipe laid end to end will produce a strong signal to the magnetic locators at each joint — even if the pipes are welded together – since these devices are most sensitive at the ends of magnetic objects.[5]

EM Locators

Basically the same as magnetic locators, EM locators use more sophisticated processing. They typically have the transmit and receive magnetic coils separated by distances of up to several meters, whereas the magnetic locators have them co-located. The larger separation means that deeper objects may be detected, although at a loss of spatial resolution. The EM locators may use pulses, for a transient time domain solution, or they may use a sinusoidal wave. This can be either a fixed frequency, or multiple variable frequencies such as GSSI's GEM-300.[6] These devices are capable of locating large concrete pipes.

Resistivity Methods

Resistivity locators have been used for pipe location, but the method is generally cumbersome and time consuming, often requiring several probes drilled into the ground.[7]

Acoustic Techniques

An acoustic pipe tracer locates buried plastic gas lines by introducing an identifiable acoustic signal into the pipe. The receiver detects the sound waves that radiate from the pipe into the surrounding soil. The system operates through a variety of surface materials and is safe for use by suitably trained gas industry personnel.

GPR Pipe Detection

GPR has a long and sometimes checkered history of pipe detection. Although it is perhaps the best general pipe locator available, it is often mistakenly assumed to be a silver bullet. In fact, GPR has difficulty in highly conductive clay and silty soils. Sometimes clutter from other objects can obscure pipes. And most commonly, subtleties in processing and interpretation mean that less skilled surveyors may fail to detect pipes that would otherwise be clearly resolved.

This means that GPR can never be 100% successful at locating pipes. However, expanding GPRs capabilities into full 3D images has made detection much more robust, and interpretation much simpler. This means that GPR is really now entering into a new phase of capability, making it far more versatile than ever before.

There are two classes of GPR that are in general use. The most widely used is Impulse, where a single cycle (or several) is transmitted, and the resulting echo is sampled down to audio frequencies for processing. This radar corresponds to a Time Domain Reflectometer instrument. The second class of GPRs is Stepped CW[8]. In this, a single frequency is output and the receiver is allowed to come to equilibrium. This can take from 50 microseconds to milliseconds. The cycle is then repeated for many different frequencies, and the results converted to an equivalent time display via an inverse FFT. This radar corresponds to a Network Analyzer instrument. The Stepped CW system has a narrower beam than Impulse and so does not show the typical hyperbolas for pipe targets. This may make it harder to discriminate many targets nearby, and also makes it almost impossible to obtain direct depth verification. Depth accuracy can only depend on how well the soil dielectric constant is known. With Impulse, the shape of the hyperbola contains information on the average dielectric constant and the actual depth, and makes pipes more conspicuous.

Although several companies compete to produce ever-simplified tools for general use in locating underground utilities[9,10,11,12,13,14], our current proposal really has no good GPR prior art analog with which to compare it. Perhaps it should most fairly be compared to multi-element prototype systems that have recently been produced. An example would be the WTI system that produces a 3D picture after one swath of data has been acquired.[15] The Swedish company, Mala Geoscience AB, built the radar array in the CART Imaging System for WTI.

TABLE 1 - COMPARISON OF KEY ATTRIBUTES OF PIPE DETECTION METHODS

Method	Max Depth 25cm (10”) Metal Pipe	Depth Estimation Accuracy	Pipe Diameter Estimation	False alarm rate	Detection Problems	Survey Speed	Cost (capital + operating)
Pulsed_Induction							
Inductive Locator	3m (10’)	GOOD	NO	MEDIUM	Large Pipes; Plastic	SLOW	LOW
Inductive Tracer	3m (10’)	GOOD	NO	MEDIUM	Large Pipes; Plastic	MEDIUM	LOW
Conductive Tracer	4.5m (15’)	GOOD	NO	MEDIUM	Large Pipes; Plastic	FAST	LOW
Mag	1.8m (6’)	NA	NO	MEDIUM	Non-Mag	FAST	MEDIUM
EM	3m (10’)	POOR	NO	HIGH	Non-Metal	FAST	MEDIUM
Resistivity	3m (10’)	POOR	NO	LOW	Non-Metal	V. SLOW	LOW
Acoustic	?	NA	NO	HIGH	?	SLOW	MEDIUM
GPR	6m (20’)	GOOD	NO	LOW	Deep Clay Soils	MEDIUM	HIGH

GENERAL LEAK DETECTION OVERVIEW[1]

The current best practice for leak detection takes several forms depending on the situation. Much has been written on the subject and there are several good sites[16] and references[17] available.

Biological

Experienced personnel will walk along a pipeline, looking for unusual patterns nearby, smelling substances that could be released from the pipeline or listening to noises generated by product escaping from a pipeline hole. A metal rod can be placed against a pipe and to an ear, listening for escaping gas. Trained dogs are also used to smell substances released from a leak.

Temperature change

Some leaks can be detected by temperature changes in the soil. Temperature sensors such as an optical time domain reflectometer, are used to detect changes of temperature in the immediate surroundings of a leak.[18]

Ground penetrating radar

GPR can accurately pinpoint buried pipeline leaks without digging. The leaking substances can be 'seen' at the source by the radar via the changes in the surrounding soil's electrical parameters. A handful of papers has recently been written, reporting results of GPR's effectiveness as a tool for detecting leaks in utility pipes.[19] Over the last 20 years, several important tests have been conducted mapping controlled releases of fluids in test pits using GPR.[20] These confirm GPR's sensitivity to subtle changes in soil moisture. Many other experiments have been reported under more realistic conditions where a pipe is actually leaking and the leak is in need of detection. Some have noted the difficulty of GPR in detecting these changes in wet, clay soils.

Acoustic devices

Noise is generated as the gas escapes from the pipeline. Due to the limitation of the detection range, it is usually necessary to install many acoustic sensors along the line.[21]

Sampling devices

If the product inside a pipeline is highly volatile, a vapor monitoring system can be used to detect the level of hydrocarbon vapor in the pipeline surroundings. This is usually done through gas sampling. The sampling can be done by carrying the device along a pipeline or using a sensor tube buried in parallel to the pipeline. The response time of the detection system is usually from several hours to days.

Negative pressure

When a leak occurs, a rarefaction wave is produced in the pipeline contents, which propagates both upstream and downstream. Pressure transducers can be used to measure pressure gradient with respect to time. Usually two sensors are used for each pipeline segment.

[1] Much of the leak detection overview information is derived from an article by Dr Jun Zhang of REL Instrumentation Limited, Manchester, UK., entitled *Designing a Cost Effective and Reliable Pipeline Leak Detection System*.

Flow or pressure change
If the flow or pressure rate of change at the inlet or outlet is higher than a predefined figure within a specific time period, then a leak alarm is generated.

Mass or volume balance
If the difference between an upstream and down stream flow measurement changes by more than an established tolerance, a leak alarm will be generated. This method allows the detection of a leak that does not necessarily generate a high rate of change in pressure or flow.

Dynamic model based system
This technique attempts to mathematically model the fluid flow within a pipeline. The method requires flow, pressure, temperature measurements at the inlet and outlet of a pipeline, ideally also pressure/temperature measurements at several points along the pipeline.

Pressure Point Analysis (PPA)
Based on the assumption that the pressure in the line drops due to a leak. An appropriate decrease in the mean value of a pressure measurement generates a leak alarm.

TABLE 2 - COMPARISON OF KEY ATTRIBUTES OF DIFFERENT LEAK DETECTION METHODS

Method	Leak sensitivity	Location estimate available	Work through operational changes	24 hour availability	False alarm rate	Maintenance requirement (expertise)	Cost (capital + operating)
Biological	YES	YES	YES	NO	LOW	MEDIUM	HIGH
Temperature change	YES	YES	YES	NO	MEDIUM	MEDIUM	HIGH
GPR	YES	YES	YES	NO	MEDIUM	MEDIUM	HIGH
Acoustic	YES	YES	NO	YES	HIGH	MEDIUM	MEDIUM
Sampling	YES	YES	YES	NO	LOW	MEDIUM	HIGH
Negative pressure	YES	YES	NO	YES	HIGH	MEDIUM	MEDIUM
Flow change	NO	NO	NO	YES	HIGH	LOW	LOW
Mass balance	NO	NO	NO	YES	HIGH	LOW	LOW
Dynamic model	YES	YES	YES	YES	HIGH	HIGH	HIGH
PPA	YES	NO	NO	YES	HIGH	MEDIUM	MEDIUM

Note that the above attributes are common features of the leak detection methods. In practice, the performance of each method varies considerably depending on the vendors, pipeline operating conditions and quality of the hardware/instrumentation system available. Examination of **Table 2** shows that there is no method that is rated “good” for all the attributes. In particular, **false alarm** appears to be a common problem for all the techniques except the biological and sampling methods, which cannot monitor a pipeline continuously.

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