STATE-OF-THE-ART
IN
DETECTION OF UNAUTHORIZED CONSTRUCTION EQUIPMENT
IN PIPELINE RIGHT-OF-WAYS

U.S. Department of Energy
National Energy Technology Laboratory
Strategic Center for Natural Gas

Infrastructure Reliability for Natural Gas

by

James E. Huebler
Gas Technology Institute
1700 S. Mount Prospect Road
Des Plaines, IL 60018

Gas transmission pipelines are buried in utility right-of-ways marked with warning signs. These right-of-ways are well maintained. Nevertheless, pipelines are sometimes damaged by construction equipment not owned by the pipeline company. Referred to as third-party damage, it is the major cause of damage to natural gas transmission pipelines (ref. 1). A single incident can be devastating, causing death and millions of dollars in property loss. One highly publicized incident occurred in Edison, NJ, in 1994. Flames shot 125 to 150 meters (400 to 500 feet) into the air near an apartment complex. Nearly 100 people were treated in hospitals as a result of the accident. Damage from the incident exceeded $25 million (ref. 2).

As urban areas expand, buildings are increasingly constructed near pipelines that were previously in rural areas. More construction near pipelines increases the probability and consequences of damage. Concerns about safety can cause the operating pressure to be reduced. Lower operating pressure means less carrying capacity. In addition, fear of additional incidents increases public resistance to locating new transmission lines near populated areas, even given the public benefits from this clean source of energy.

"One-call" systems and greater legal penalties have reduced, but not eliminated, the number of incidents. A backhoe, trencher, or auger (for digging post holes) can move into the right-of-way, begin excavation, and damage the pipeline in less than 30 minutes. A boring machine can travel beneath the surface of the ground for greater than 30 meters. This type of equipment can damage the pipeline without ever having the aboveground portion of the equipment in the right-of-way.

While third-party damage can be devastating, it occurs infrequently—much less than one hit per kilometer of pipeline a year. Every year, many intrusions occur in the right-of-way. Most of these are benign with no possibility of injuring the pipeline. (e.g., mowing the right-of-way, people walking, motorcycle and ATV traffic). Any third-party/interference detection system must be able to distinguish a benign activity from a potentially hazardous one, or the false positive count will be too high and the system will not be accepted.

Ideally, impacts would be prevented, not detected after they occur. A cost-effective, continuous monitoring system that successfully detects right-of-way interference and alerts operators to potentially hazardous activities before they start will solve a long-standing problem of the natural gas industry.

There is no commercially available method for detecting or preventing third-party damage that is acceptable to the industry. Nor is there a system to detect interference by construction equipment in the pipeline right-of-way. Concepts have been suggested and are in various states of development. All have serious drawbacks including cost, difficulties in minimizing false positives, and/or impractical application to the U.S. industry. These are described in more detail below.

One method is to use satellites to visually monitor the right-of-way. Black and white satellite visual images at a one-meter resolution can be used to locate and track trespassing violators. However, these images are affected by weather, require sunlight, and are difficult to manually interpret. Because the images cover a broad area, the right-of-way must be known to minimize the area surveyed. It is easiest to notice changes from photo to photo. A possible application is the replacement of weekly flyovers by small aircraft. Currently costs are too high for monitoring every 30 minutes. Proposals have been made to combine multi-spectral images from active long wave radar, active infrared, and passive red, yellow blue, and ultraviolet to enable much easier identification and discrimination of trespass violators. This would extend the detection period to include overnight and bad weather. Unfortunately, these images are not available from the same satellite. Methods of automatically overlaying such images would need to be developed along with detection and discrimination algorithms. Costs would have to be substantially lowered to be economically viable.

A ground-based visual surveillance system can be set-up using commercially available camera equipment. For full coverage, camera locations are limited by line-of-slight constraints. This is too expensive because it requires constant human monitoring. An automated system that recognizes interference is required to reduce costs. This is difficult because of the many benign encroachments and the very rare occurrence of hazardous encroachment. Such a system may not detect encroachment by directional boring equipment if the entry point is far from the right-of-way. A camera system capable of seeing one hundred feet to the side of the right-of-way would have to discriminate against many more benign encroachments. Long wave infrared cameras are a similar form of surveillance that must solve the same problems. These units require thermo-electric cooling.

A cathodic protection monitoring system that detects when construction equipment breaks the coating on the pipeline, shorting the pipeline to electrical ground, is another approach that detects rather than prevents damage. Such systems have been under development in Japan (refs. 3-5) and the U.S. One method superimposes a 220 Hz AC current on top of the normal DC cathodic protection current. The AC pipe-to-soil voltage and the AC current are monitored. The pipe-to-soil resistance is calculated. When construction equipment shorts the pipe to ground, the pipe-to-soil resistance value changes, indicating potential damage to the pipe. A measuring system was developed and installed on a 28.3-kilometer (17.6 mile) section of transmission line. Simulated damage on this section of pipeline was detected. Because it requires no or very few breaks in the coating, it may not be applicable to older pipelines in the United States. Development of this technique in both Japan (ref. 6) and the U.S. has stopped.

A European gas company is developing a system that uses a global positioning system (GPS) and a computerized map of the pipelines (ref. 7). The goal is to have the locations of construction equipment appear on a map of the pipeline with an alert when the equipment gets too close. In addition to the technical problems that must be solved, the major drawback of this system for U.S. application is obtaining willingness to place this system on every piece of construction equipment.

An acoustic method (refs. 8-11) detects the sound pulse created by impact with the pipeline. It detects rather than prevents damage. When a piece of construction equipment impacts a pipeline, an acoustic signal is generated in the pipe wall and in the gas inside the pipeline. The acoustic signal in the pipe wall attenuates quickly because of friction effects with the soil. However, attenuation in the gas is smaller and acoustic signals can propagate for miles. A sensitive accelerometer mounted on the outside of the pipe wall can detect the impact signal that has traveled in the gas. Thus, access to the pipeline is limited to a few points. A method to distinguish impacts from background noises is required. This can be difficult because the background noise can be close to the sensor and therefore loud. On the other hand, impact signals created one kilometer away are highly attenuated by the time they reach the sensor. The resulting poor signal-to-noise ratio adds to the difficulty of signal discrimination. The main issue with background noise and impact signal is economic. The greater the background noise, the more closely spaced (~0.4 to 1.6 kilometers) the sensors must be to insure impact detection. Other drawbacks to the acoustic method are the requirement to mount the sensor on the pipeline and the fact that the signal can be a single pulse with only one chance to detect it. Research on this system is being actively pursued.

Two approaches using buried optical fibers to detect construction equipment have been investigated. One attraction of an optical fiber sensor is that it has the same long narrow form as a pipeline. A commercial optical fiber intrusion detection system (ref. 12) was tested for its ability to detect construction equipment. This system is used to monitor facility parameters and fence lines and is often used to create an alarm for visual surveillance. Detection of construction equipment approaching the sensor was successfully demonstrated. It was also possible to detect footsteps. A vibratory plow was used to install a fiber without damaging, it demonstrating an economical installation method of long optical fiber. To be economically viable, fiber lengths of several kilometers must be monitored from a single location. While it is possible to monitor much greater distances than this, the intrusion detection system measures total changes to the fiber along its length. Large disturbances, such as a slow moving train or highway traffic crossing a section of fiber, will dominate the signal preventing detection of other interferences. Also, it cannot determine the location of the interference. Although the commercial units can discriminate against some background noises, a robust discrimination system is needed that meets the severe requirements of the pipeline industry.

A second optical fiber technique (unpublished) demonstrated the use of a commercial optical time domain reflectometer (OTDR) and optical fiber to detect a backhoe. Commercial OTDR's are designed to precisely characterize optical fiber. A light pulse is periodically sent into the fiber. A "flaw" in the fiber reflects part of the light back to the OTDR. Research demonstrated that a backhoe driven over a buried fiber creates a detectable "flaw." The optical attenuation in "non flawed" sections of the fiber is very small, thus the signal-to-noise ratio degrades very slowly with distance, that is, long distances of fiber can be monitored. The round trip travel time gives the location of the flaw. Drawbacks to this approach are that measurement time is too long for use in characterizing rapidly moving construction equipment and no methods exist for discriminating benign from potentially hazardous encroachments.

Therefore, as the next logical step in the development of this technology, DOE NETL and GTI are developing a variation of optical fiber monitoring that characterizes signals from construction equipment and distinguishes them from benign encroachments.

BENEFITS AND DRAWBACKS OF THE TECHNOLOGIES

Each technology has cost and development issues that must be solved before it becomes practical.

Technology	Benefits	Drawbacks
Satellite monitoring at visible wavelengths.	No equipment to install on ground. Uses commercial satellites. Possible replacement for weekly flyovers of pipelines.	Requires sunlight. Affected by cloud cover. A method is needed to pick out activity over narrow pipeline in broad image.
Satellite monitoring at several wavelengths.	Could detect encroachment at night and through cloud cover.	Requires more than one satellite. A method is needed to pick out activity over narrow pipeline in broad image.
Ground-based visual surveillance.	Can use commercially available cameras.	System is needed to minimize the amount of human monitoring. May not see directional boring encroachment. Separate camera needed for each line-of-sight.
GPS system and computerized pipeline maps.	No equipment installed on pipeline.	Requires equipment on each piece of construction equipment. Requires equipment operators to maintain equipment.
Cathodic protection monitoring.	Continuous monitoring. Long distances can be covered. Could be used in conjunction with acoustic detection.	Detects rather than prevents damage. Requires breaking of coating for detection. Requires minimum breaks in pipeline coating—may not be applicable for older pipelines.
Acoustic detection of impacts.	Continuous monitoring. Localized installation of sensors. Could be used in conjunction with cathodic protection detection.	Detects rather than prevents damage. Sensors attached to outside pipe wall. Only one chance to detect transient signal. Issues of background noise must be solved. May be too costly if close sensor spacing is required.
Distributed optical fiber with interferometric detection.	Continuous monitoring. Same form factor as pipeline. Sensitive technique.	Continuous fiber must be installed along pipeline. Methods are needed to distinguish hazardous and benign encroachment. Detects changes to the entire fiber—cannot distinguish simultaneous events or events plus benign encroachment.
Distributed optical fiber with optical time domain reflectometry.	Potential to monitor miles of pipeline from each location. Continuous monitoring. Same form factor as pipeline. Can detect and distinguish simultaneous events at different points along optical fiber.	Continuous fiber must be installed along pipeline. Methods are needed to distinguish hazardous and benign encroachment.

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