the Energy to Lead

FINAL REPORT

GTI PROJECT NUMBER 21496

Subsurface Multi-Utility Asset Location Tool

DOT Project # 490
Contract Number: DTPH56-13-T-000001

Reporting Period:
Final Report
September 1, 2013 through August 31, 2014

Report Issued (Period Ending):
August 21, 2014

Prepared For:
Mr. Gabriel Kotsis
PHMSA Technical Manager

Prepared By:
Gas Technology Institute
Dr. Kiran Kothari
Institute Engineer/Program Manager
kiran.kothari@gastechnology.org
847-768-0893

Project Technical Team:
Dr. Kiran Kothari, Gas Technology Institute
Mr. Ching-Chen Wu, SoniVerse, Inc.
Mr. Scott Kleppe, Sensit Technologies

Gas Technology Institute
1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gastechnology.org

Legal Notice

This information was prepared by Gas Technology Institute ("GTI") for DOT/PHMSA (Agreement Number: DTPH56-13-T-000001.

Neither GTI, the members of GTI, Soni-Verse Inc. (SVI), Sensit Technologies (ST), the Sponsor(s), nor any person acting on behalf of any of them:

a. Makes any warranty or representation, express or implied with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights. Inasmuch as this project is experimental in nature, the technical information, results, or conclusions cannot be predicted. Conclusions and analysis of results by GTI/SVI/ST represent GTI's, SVI's, and ST's opinion based on inferences from measurements and empirical relationships, which inferences and assumptions are not infallible, and with respect to which competent specialists may differ.

b. Assumes any liability with respect to the use of, or for any and all damages resulting from the use of, any information, apparatus, method, or process disclosed in this report; any other use of, or reliance on, this report by any third party is at the third party's sole risk.

c. The results within this report relate only to the items tested.

EXECUTIVE SUMMARY

Objective:

In the past, Gas Technology Institute (GTI), SoniVerse, Inc. (SVI), PHMSA and Operations Technology Development, NFP (OTD) have successfully developed an operational device called Acoustic Pipe Locator (APL) to detect buried metallic and non-metallic pipes under various field conditions. The APL is currently manufactured by Sensit Technologies (ST) and is commercially available. However, limited test data were collected and analyzed for multiple utilities situations and no specific conclusions were drawn on the minimum distance required for multiple buried pipes to effectively separate pipes.

The proposed project objective is to determine parameters that would be critical to assure detection of multiple pipes. These parameters are at least related to pipe diameters, separation distance between pipes in both horizontal and vertical planes, stepping or scan distance, and buried pipe depths. It should be noted that the physical configuration of the locator developed in the past was not expected to change.

Technical Perspective:

The driving force behind this research effort is the significant need for technology to detect and locate buried underground natural gas pipes. Natural gas is distributed locally and over long distances by pipelines. Pipelines buried a few feet under the ground are subject to leaks and failures. The damage and injuries from accidental penetration of buried pipelines are costly and resulted in the development of APL.
The APL operates near the surface of the ground, is suitable for most soil conditions, and is simple to operate. A practical device, like APL, for locating buried gas distribution pipes and other underground utilities would prevent accidents leading to injuries and outages. This has potential of lowering costs of delivery of natural gas to the consumer, as well as improving public safety.

Results:

A fully integrated and commercially available acoustic pipe locator (APL) was used in a series of local area and real-world field tests under various soil conditions and field environments. Various operating modalities and test parameters were used in validating the overall APL system performance. The pipe locating system performed very well and was very easy to operate.

The preliminary APL system performance was validated and tested in the controlled and simulated field settings – indoor and outdoor pipe beds. A wide range of real-world utilities – gas mains and service lines, electrical conduits, water mains, and sewer drains and laterals – were surveyed and located under concrete, asphalt, gravel, topsoil, and grassy coverings during the field trials. The field test results showed very good system performance and robustness in overall system operation.

A total of more than two hundreds (200^{+}) real-world test locations were surveyed in Northern California and Indiana areas. Overall, the average pipe detection accuracy of the APL system is well within 9". The APL detection system is able to resolve multi-utilities with spacing less than 15" for the stepping distance of 6". In general, the accuracy of the overall system detection performance was well above 80% for the detection criteria of ±18". The test results have been validated by utility markers, mapping information, and visual inspection methods. Although there were some minor operating malfunctions during the field trials, the APL system was able to recover from these minor glitches.

Table of Contents

EXECUTIVE SUMMARY ii
BACKGROUND 1
PROJECT OBJECTIVE 1
TECHNICAL WORK 1
Results of Prior Research Program 1
Work Plan 2
Work Performed and Results **3**
1. Prepare Device and Evaluate in Local Area 3
2. Tests 4
3. Commercialization 8
SIGNIFICANT RESULTS AND CONCLUSIONS 9
REFERENCES 11

FIGURES AND TABLES 12
Figure 1 Newly developed Acoustic Pipe Locator (APL) from Sensit Technologies. 12
TABLE 1 Test Matrix and Parameters – Relative Performance & Effect 13
Figure 2 APL demonstration, with multiple pipes installation, conducted near the SVI facility in Sacramento, CA area. 14
Figure 3 Local area tests conducted nearby SVI facility, test site # 1, with multiple utilities: (a) lawn area, (b) concrete sidewalk, (c) asphalt pavement, and (d) typical test result shown on the APL system. 15
Figure 4 Local area tests conducted nearby SVI facility in a residential neighborhood, test site # 2, with multiple utilities on (a – b) topsoil/grass, (c - d) gas and sewer pipes, and (e) typical test results shown on the APL system. 16
Figure 5 Local area tests conducted nearby SVI facility in a residential neighborhood, test site # 2, with water line on asphalt: (a - b) water line, (c - d) cracks (trenching effect) on both sides of the utility, and (e) typical test results shown on the APL system. 17
Figure 6 Local area tests conducted nearby SVI facility in a residential neighborhood, test site # 2, with (a-b) sewer pipe on topsoil (mixture with gravel): (c) soil characteristics, and (d) typical test results shown on the APL system. 18
Figure 7 Local area tests conducted in a pipe farm near SVI facility – multiple pipes buried in various depths, test site # 3, (a) asphalt covering, (b) concrete slab, (c) topsoil/grass field, (d) soil characteristics, and (e) typical test results shown on the APL system. 19
Figure 8 Background noise measurements conducted in a pipe farm – multiple pipes buried in various depths, test site # 3, (a) topsoil surface, (b) native soil/clay, and (c) gravel covering. 20
Figure 9 Local area tests conducted near SVI facility in industrial settings: (a - b) joint box, test site # 4, with electrical and water lines under mulch/soil and asphalt coverings, (c - e) gas main and water line, test site # 5, under asphalt, and (f) typical test results shown on the APL system. 21
Figure 10 Design guideline and configuration for the pipe-bed facility at Sensit Technologies facility: (a) single pipe (detection) spacing: > 3 feet and (b) multiple pipe (detection and resolution) spacing > ±1 foot. 22
Figure 11 Layout (top view) of the pipe-bed facility at SENSIT Technologies. 23
Figure 12 APL local area test at the pipe-bed facility: (a) project members conducted test on the pipe bed, (b) close-up view of the compacted gravel covering on the test pipe bed, and (c) result of single pipe detected, and (d) multiple pipes test result. 24
TABLE 2 Pipe separation performance of the APL system in Local Area Test 25
TABLE 3 Detection accuracy of the APL system in Local Area Test 25
Figure 13 APL field tests conducted in Valparaiso, IN: (a-b) gas main and electrical line under grassy area, (c) single pipe detected, and (d) multiple pipes test result. 26
Figure 14 APL field tests conducted in Valparaiso, IN: (a-c) gas main and electrical line under grassy area, (d) single pipe detected. 27
Figure 15 APL field tests conducted in Valparaiso, IN: (a-d) water main under asphalt and grassy coverings, and (e) the detected result. 28
Figure 16 APL field tests conducted in Valparaiso, IN: (a-b) multiple utility lines – electrical, gas, and water, (c) close-up view of electrical (red) and gas (yellow) line markers, and (d) test result of the multiple pipe detection. . 29

Figure 17 APL field tests conducted in Valparaiso, IN: (a-b) sewer drain under asphalt and the test result, (c-d) sewer lateral under grassy area and test result, and (e-f) gas service line under grass covering and the detected result. 30
TABLE 4 Detection accuracy of the APL system in Field Tests (Valparaiso, IN) 31
Figure 18 APL field test near Modesto, CA (residential area with gravel surface covering and buried gas mains): (a - b) soil condition and system setup and (c) typical test result of the pipe detection. 32
Figure 19 APL field test near Modesto, CA (residential area with asphalt surface covering and buried gas and water utilities): (a - b) soil condition and system setup and (c) typical test result of the pipe detection..... 33
Figure 20 APL field test near Modesto, CA (water treatment facility with gravel surface covering and buried water mains): (a - b) soil condition and system setup and (c) typical test result of the pipe detection..... 34
Figure 21 APL field test near Modesto, CA (retail outlet with grassy/topsoil surface covering and gas service and water utilities): (a - b) system setup and test result of grassy field, (c – d) multi-utility and system setup on topsoil, and (e) typical test result of the multiple pipe detection..... 35
Figure 22 APL field test in Modesto, CA business district with asphalt/concrete surface covering and buried water and sewer utilities: (a - b) soil condition and system setup and (c) typical test result of the pipe detection. 36
Figure 23 APL field test in Modesto, CA (residential area with gravel surface covering and buried gas mains): (a, c - d) soil condition and system setup and (b & e) typical test results of the pipe detection. 37
TABLE 5 Detection Accuracy of the APL System during Field Test in Modesto, CA. 38

APPENDIX 39
Appendix A List of Initial Local Area Test Setup (Sacramento, CA) 39
Appendix B List of Test Setup in Pipe-bed Facility, IN 42
Appendix C List of Field Test Setup, Valparaiso, IN 43
Appendix D List of Field Test Setup, Modesto, CA 45

SUBSURFACE MULTI-UTILITY ASSET LOCATION TOOL

BACKGROUND

In the past, Gas Technology Institute (GTI), Operations Technology Development, NFP (OTD), and PHMSA have funded a project to develop an acoustic-based technology to detect buried metallic and non-metallic pipes. The concept is to send the acoustic signal into the ground and detect reflected signal from the pipe at the ground level. The device has been successfully tested in the laboratory and at several utility locations under variety of field conditions to detect pipes buried up to 10 feet. The pipes were buried under concrete, asphalt, topsoil, and grassy surfaces. The device requires less than two seconds at each location to collect data (called a slice). Several slices of data are collected separated by six or 12 inches apart (stepping distance) to give a scan. The slices data are analyzed, with no interpretation by operator, in real-time to provide information on a buried pipe. The process is repeated a few times by moving the device 10-15 ft. in the potential direction of pipes to obtain several scans. The alignment of indicated locations of pipe in the scans indicates a buried pipeline/conduit. In the past, the device was tested on a limited basis under the PHMSA/OTD program to find multiple utilities in the local area. However with the limited data, no specific conclusions were drawn on the separation distance required to detect multiple pipes/conduits.

PROJECT OBJECTIVE

The proposed work is to improve the APL performance and develop a guideline for detecting subsurface multi-utility asset location tool. The proposed project objective is to determine parameters that would be critical to assure detection of multiple pipes. These parameters are at least related to pipe diameters, separation distance between pipes in both horizontal and vertical planes, stepping or scan distance, and buried pipe depths. It is believed the physical configuration of the locator developed in the past will not change and any modification required will be in the software.

TECHNICAL WORK

Results of Prior Research Program

In the previous work, see Ref. 1, the initial acoustic-based, pipe inspection system was developed and tested. The initial system was used during several field tests for applicability of the device in real-world situations to detect buried pipes. In the next phase of the project, the integrated locator was developed and fields tested, see Ref. 2, and resulted in transferring the technology to Sensit Technology for commercialization. Extensive and complete system documentation was provided to Sensit Technologies. Three major documented categories covered hardware (electronics, transducers, and packaging), software (system operation, user interface, and signal processing), and bill of material (component data sheets, fabrication material specification, and schematic and CAD drawings) for the entire detection system. Operational and fabrication issues were successfully discussed, analyzed, and resolved.

Initial prototype units were designed, fabricated, and tested by Sensit Technologies. The sample alpha system referred as Acoustic Pipe Locator (APL) performed very well and met the design requirements. Several units were manufactured and re-tested in the field. The final and commercial version of the APL was used at the beginning of this project.

Work Plan

The basic locator and associated software have been developed and the commercial device is available for detecting buried pipes. The proposed project will define the capability of detecting multiple pipes and establish criteria to separate multiple pipes. It is expected the current commercial device will include a simple guideline as it relates to pipe separation capability of APL.

Since the APL system is not a focused array instrument, the size of the transmitting element and its associated beam width influence the horizontal pipe resolution. The transmit frequency determines the pipe size that can be detected in a specific range of buried depth. In the APL operation, the stepping distance and the transmit frequency are two prominent operating parameters that can affect the system performance in resolving the pipe detection process. Other physical factors like soil attenuation, frequency dispersion, pipe size, and buried depth can also affect the final pipe detection result.

The following provides specific tasks for the project:

Task 1. Prepare Device and Evaluate in Local Area

As indicated, no major change of the currently available beta prototype of the locator is needed. However, the device will be tested to assure its operational functionality and software updates for the proposed project work. A test plan will be developed and reviewed with PHMSA. The proposed plan is to conduct tests at the existing facilities of SVI and Sensit Technologies. Both facilities have buried pipes separated by specific distances, and if required, additional pipes will be installed. The device will be tested at these controlled facilities in the local areas. The pipe detection software will be updated using the data generated during these tests. The test results will be analyzed to define a plan for the field evaluations of the locator.

Task 2. Field Tests

GTI will arrange a conference call with PHMSA, participating utilities interested in field trials, Sensit Technologies, and SVI to discuss the test results from the local area. Input from participants will assist in finalizing field locations and various test parameters. The proposed work include two field trials and the plan includes tests to be conducted in city areas where several buried utility pipes or conduits (gas, water, sewer, electrical conduits, etc.) are expected in the near-by area. These field tests will be performed under various ground coverings (e.g., concrete, asphalt, grass, dirt) to detect buried multiple pipes. The updated software in the Task 1 will be improved, if required, for the pipe separation determination. The data from the field trials will be analyzed to provide the guidelines on the locator to separate pipes.

Task 3. Commercialization

With the direct involvement of commercializer, Sensit Technologies, the modifications and commercialization is expected to be straight forward process. The data and associated improvements will be available to Sensit Technologies and the information will be incorporated immediately.

Task 4. Reporting and Project Management

The monthly, quarterly, draft final, and final report will be prepared and submitted to PHMSA. GTI will be responsible for the project management activities to ensure the project is on track and within budget.

Work Performed and Results

At the start of each test, a system ramp-up cycle time was performed to bring the system back to its active status. Laboratory bench tests were conducted to ensure the system software is up-to-date and the system electronics performance meets the specification and design requirements.

1. Prepare Device and Evaluate in Local Area

The Acoustic Pipe Locator (APL), Figure 1, was supplied by Sensit Technologies as the project cost-share and was sent to SVI for the system evaluation and local area tests. Preliminary system validation process was performed to ensure system's performance is up-to-date. The initial test unit received had limited test parameters available for the desired evaluations.

Major test parameters included transmit frequency, stepping distance, and region-of-interest (ROI) range and are critical to the overall system performance. Discussion of APL system hardware and software implementation (user interface and usage) was communicated between all involved parties to ensure smooth operation during the initial local area tests, and then in the field trials.

A project kickoff meeting was held near the SVI facility in California. In the meeting, project task assignments and schedules were discussed. The overview of the project including timelines, milestones, and deliverables were discussed and presented. Preliminary field test matrix and parameter settings as shown in Table 1 were also discussed. A plan for the pipe-bed facility to be developed at Sensit Technologies was also discussed. The APL system performance evaluation as well as verification and validation of the test parameters to be evaluated in the field tests were outlined.

As indicated in Table 1, major test parameters like transmit frequency and stepping distance are critical to the overall system performance. Other parameters like transmitting pulse duration and pulse rate affect the vertical resolution of target and can determine the system performance. The discussion during the meeting identified the following test parameters as the initial test criteria:

- Transmission frequency at 900Hz,
- Locating pipe of size range from 1" to 4" in diameter buried up to 5' deep, and
- Finding minimum resolvable pipe spacing in horizontal plane.

The APL system demonstration, as shown in Figure 2, was conducted after the meeting. The APL system performed well and detected buried utilities as expected.

2. Tests

Local Area Test in Sacramento, CA.

Local tests in the near-by SVI area were conducted and additional information was generated for the future field tests. Several test sites with various surface coverings, as shown in Figures 3 through 9, were tested during the initial local field test.

In test sites # 1 and # 2, Figures 3 to 6, utilities were detected in the residential areas. Both Normal and Deep modes – two transmission frequencies – were selected and operated during the tests. Soil surface coverings included grass, asphalt, and concrete and APL was tested and evaluated. Utilities like gas, water, and sewer pipes were detected during these tests. The observation from these tests concluded that pipe(s) could be detected under Deep mode when the Normal (shallower depth) mode operation failed to detect the utility pipe. As known, situations like surface cracks and trenching effect contributed to erratic detection (false-positive) during the system operation.

The test site # 3, a controlled test environment in the previously constructed pipe farm (see Figures 7 and 8), was used for extensive tests and the APL system evaluation. This pipe farm consists of several pipes with different sizes and buried at various depths. Occasionally, the strong sonic reflection (due to local native soil's high moisture and hard clay) was observed and failed to detect pipe when test points were too close to the pipe farm wall(s). Nonetheless, the test data were very consistent and clean (i.e., quiet) as the propagation medium in this test field was homogeneous and obstacle free. System limitations, like maximum depth for any given pipe size with respect to various surface coverings, in pipe detection were easily identified in test results.

At test sites # 4 and # 5, as shown in Figure 9, the APL was tested with various utilities, mostly under asphalt surface covering. Test site # 4, contains a junction/joint box under mulch covering several utilities and this site was tested with both Normal and Deep modes. As expected, the capability of detection system in resolving buried pipes did not perform well. The main reasons for this limited performance were: 1) system hardware was not configured for such detection task, and 2) desired test parameters of the system software were not implemented and could not be changed during the tests. Test site # 5 is a typical construction area and includes gas and water utilities and these utilities were well marked and visibly identifiable to compare against the APL performance.

Overall, a total of 92 tests (nine were static background check and noise measurement) were conducted during the local tests near the SVI facility. The accuracy of the overall detection by APL was well above 80% for the detection criteria of ±18". The validation methods were mostly based on visual inspection and/or ground markings. The test conditions of the local tests near the SVI facility are listed in the Appendix A for reference.

Based on the usage of the APL system and the local area test results, the following provided a few guidelines for the planned field tests:

For the System Operation:

- Top-down system deployment if possible; otherwise, adjust/correct both transmitter's and receivers' seating by wiggling or rocking the transducers after placing on the test ground; this operation will also prolong rubber pad's long-term usage and prevent premature wear and tear.
- Reduce spring tension on the transmitting actuator: beneficial to long-term operator physical use and to ensure full ground contact during data collection stage.
- Smaller stepping distance, like 3", may not be practical for the existing system footprint and design, due to: lack of detail insight regarding transducers' acoustic characteristics, pipe size and depth is not well defined in this detection range, and the transmission parameters need significant modifications to accommodate such stepping distance selection.

For the System Performance:

- Positioning the system away from the ground cracks (at least two stepping distances) to avoid false-positive due to strong reflection caused by distinct acoustic impedance mismatch; this practice also applicable to grassy field that has patchy root system or ground void.
- Provide available transmission frequency up to 1.2KHz for small pipe buried within 1 to 2 feet; the stepping distance and transmit pulse-width may need to be reduced accordingly.
- Increase transmission repetition rate: to improve signal-to-noise ratio for pipe detection and, especially, to enhance acoustic intensity into deeper depth; total system processing timing will be affected due to longer data collection period.
- Selectable ROI settings after data acquisition for flexible pipe viewing and depth selection; the setting can be adjusted in conjunction with sensitivity and threshold settings.
- Experimental transmitting pulse-width settings, for all depth modes: to be better resolve pipe separation and/or to reduce occurrence of the surface ping leakage into ROI region.

A pipe-bed design, see Figure 10, was established and submitted to Sensit Technologies for the construction. This controlled field environment (i.e., pipe-bed facility) was intended to be used as a reference field situation for calibrating the APL system performance with emphasize on the pipe separation capability. The design configuration and test parameters were analyzed and discussed between the technical team members. Figure 10 shows design guidelines and pipe configurations for the pipe-bed facility.

Local Area Tests at Pipe-bed Facility, Valparaiso, IN.

The past background on the APL development, the project status, and future plan were presented and discussed with the PHMSA Technical Manager in a meeting before conducting tests in the newly constructed outdoor pipe-bed facility. The pipe-bed facility included an area approximately 10' x 20', see Figure 11. The pipe-bed facility consists of three pipes, 2-inch in diameter, in a trench over 5 ft. deep. The 20 ft. long pipes were buried at the 10 inch horizontal separation in beginning and ending at the 24 inch separation. The soil, compacted in 12 inch lifts, is mostly sand and covered with a compacted gravel layer, see Figure 12. The side walls of the trench are cut out at approximately 45 degree angle to minimize potential impact of wall detection by APL. Three sections of the pipe-bed were selected for tests with APL – with estimated buried pipe spacing of 22", 17", and 11" referred as Section 1, 2, and 3, respectively. The system evaluation from these

tests was focused on the pipe separation performance of the APL. The transmission mode (two frequencies) and stepping distance (two stepping distances) were tested and evaluated. It should be noted that the pipe detection results were displayed on the APL screen immediately. Test data log is shown in Appendix B for the reference.

Table 2 shows the overall pipe separation performance of the APL system from the test data collected from the local pipe-bed test facility. The success rate (in %) of detecting pipe was based on the capability of the APL system in detecting the buried pipe at the outdoor pipe-bed facility. The success rate of detecting a single buried pipe in any test section of the pipe-bed was 100% for all stepping distances used during the test. However, the accuracy of the detection varies with pipe spacing and stepping distance.

It's clear from the Table 2 that the APL system had no issue and was able to resolve buried pipes in the pipe-bed with stepping distance of 6" during pipe detection process. For example, at test Sections # 1 and # 2, all pipe locating processes were able to detect at least two buried pipes in the pipe-bed using 6" stepping distance. For pipe spacing greater than 17", the detection processes using 6" stepping distance were able to detect all three buried pipes with 75% success rate. The detectability of resolving three buried pipes was reduced to half when the pipe spacing was less than 11" at test Section # 3.

For the 12" stepping distance, the resolvable pipe separation went down to 50% when the pipe spacing was larger than 17" – Section # 1 and Section # 2. Only one pipe can be detected with the stepping distance of 12" when the buried pipe spacing was about 11" (Section # 3). Nonetheless, the 12" stepping distance process was able to detect at least one pipe at all test Sections of the pipe-bed. All three pipes could not be detected simultaneously at any test section of the pipe-bed when the 12" stepping distance was deployed.

Table 3 lists the pipe detection accuracy (not the pipe separation capability) at test Sections of the pipe-bed facility. The data analysis includes all detected pipes at any given section using various combinations of test parameters. The overall accuracy of the detected pipe is better than 8". The following summarized the effect of test parameters on the pipe separation performance:

- Smaller stepping distance will improve pipe separation capability of APL.
- Acoustic signal transmission mode (Normal and Deep) has limited effect on resolving shallow pipe than deeper pipe.
- Larger stepping should be normally deployed when expected pipes are larger diameter(s)and buried deep.

Field Test in Valparaiso, IN.

A series of real-world field test was conducted in an industrial park area near the Sensit Technologies facility in Indiana. More than 38 test data sets from test sites with various soil conditions were conducted and evaluated. Appendix C lists all test log of the field tests conducted for the system performance evaluation. The surveyed utilities included gas, electrical, water and sewer installations and ranged from 1" to 12" diameter.

Figure 13 shows the field test conducted on the tall grassy area with buried gas main. The detection accuracy was estimated ± 9". Both "Normal" and "Deep" transmission modes were tested. Because of soil attenuation property, no pipe was detected under "Normal" mode and hence the "Deep"

transmission mode was used for this field. A high pressure gas main under grass covering was located (see Figure 14). The utility was surveyed at a long stretch of lawn field of more than 100 feet. The test accuracy was estimated to be around ± 12". Figure 15 shows several field tests of locating a water main under native grassy field. The APL accuracy for detecting water main was better than ± 19".

Figure 16 shows pipe detection under buried multiple utilities - electrical and gas main - situation. The APL detection accuracy was better than ± 10" for both these utilities. Figure 17 shows pipe detection processes in locating several utilities – sewer drain, sewer lateral, and gas service lines. The average detection accuracy of ± 5" has been achieved for this test group.

Table 4 summaries the pipe detection accuracy of the APL system during the field test. Overall, the accuracy of the entire field test was better than ± 9" in resolving the detected utilities under various field situations.

Field Test in Modesto, CA.

The second real-world field trial was conducted in both residential and industrial field sites near the city of Modesto in California. More than 55 test data sets from test sites with various soil conditions were collected and evaluated. Appendix D lists all test logs of the field tests conducted for the system performance evaluation. The surveyed utilities included gas, electrical, water and sewer installations and ranged from 1" to 36" diameter.

Figure 18 shows the field test conducted on the roadside gravel surface with buried gas mains near a residential area. Several locations were selected for the test area along an 80^{+} feet stretch of gravel road bed. The detection accuracy at the field site was estimated ± 7". Both "Normal" and "Deep" transmission modes were tested. Two (6" and 8") gas mains were located and validated with utility mapping. The field test used both 6" and 12" stepping distances for the pipe detection.

Near the same residential area, as shown in Figure 19, multiple utilities situation – water and gas main under asphalt – were surveyed and detected. The detection accuracy for this site was better than ± 8" for both utilities. Both 6" and 12" stepping distances were used for the pipe detection.

Figure 20 shows the field test conducted at a municipal water treatment facility. Soil surface coverings like concrete and gravel with buried, mostly, water pipes were surveyed and located. More than five test locations were surveyed at the test site. The detection accuracy at the field site was estimated to be about ± 6". Both "Normal" and "Deep" transmission modes were tested.

The fourth field site was conducted near a retail outlet area. The test site included a multi-utility setup – water and gas service lines buried under grassy and topsoil coverings, see Figure 21. Both "Normal" and "Deep" transmission modes were tested. The APL system was very effective in finding these multiple gas service lines separated by about 15" between each other. The detection accuracy at the field site was estimated ± 4".

Lastly, as shown in Figures 22 and 23, several field tests were conducted near the city business district with mostly concrete and asphalt surface coverings. Various underground utilities - gas, water and sewer - were surveyed and located. The field tests were performed with various combinations of transmission mode and stepping distance. Several test locations were selected for

multiple utility installations and surface coverings. The estimated detection accuracy at the field site was about ± 13".

Table 5 summaries the pipe detection accuracy of the APL system during the second field test with all combination of test parameters. Overall, the pipe detection accuracy of the entire field test was better than ± 8" in resolving the located utilities under various field situations.

A minor issue of delamination coupling pads attached to the transmit actuator and receivers during the test was experienced and reported to Sensit Technologies. However, the overall performance of the APL system was precise and robust, and the APL was easy to deploy and use.

The field data included a few cases where multiple pipes situations were close for the pipe separation analysis. At a test site in Modesto, California, the APL was able to resolve the pipes with 6" stepping process. At the water treatment plant in California, the pipe separation was resolved with both 6" and 12" stepping processes. The field tests showed that APL can resolve pipe separation of about 12 to 15 inches with the data collected at two field sites. Although, the theoretical (mathematical) limit of the system is close to the 6" pipe separation.

3. Commercialization

Several local field test data analysis and pipe detection assessment were reviewed. The main focus of the discussion was to enhance the performance of the current signal processing implementation and signal normalization within the region of interest (ROI). Two potential methods to improve the APL performance to detect and separate pipes have been proposed. These techniques are called normalization of data in the region of interest and dynamic threshold method.

A normalization process, among each test slice data, has been proposed. Traditionally, average/mean technique has been used for averaging out abnormality and singularity. Another technique is to apply root-mean-square (RMS) method to extract nominal reading. To normalize slice data, three regions of data stream (in time axis) can be selected to calculate normalizing factor of each test data set. As an example, the test regions can be divided into three regions: 1) region-of-interest (ROI), typically data collected from 10 to 40ms, 2) deep quiet zone with data from 50 to 60ms, and, 3) complete data from ROI to 60ms. Test data collected under ideal, laboratory type environment were emulated with several experimental signal processing techniques and provided encouraging results. However, the process will require significant work before it can be applied to expected field conditions. The enhancement from this proposed process may provide:

- Mask off possible glitch signal and hence better pipe detection result.
- Possibility of APL operation in the mixed terrain operation during one scan.
- Reduce false-positive situation during pipe detection.

A new “dynamic threshold” signals processing technique was also developed and applied to the data collected previously at the Sensit indoor facility. The new process used the standard deviation technique in searching and identifying the potential pipe location and showed some promise for improving APL data under generated under ideal, laboratory type conditions.

The details on these techniques have been discussed with the Sensit Technologies staff. The applicability of the new processing routines will be ultimately determined by Sensit technologies for the commercial application.

SIGNIFICANT RESULTS AND CONCLUSIONS

A fully integrated, commercially available acoustic pipe locating (APL) system was used in a series of controlled and real-world field tests having varying soil and surface conditions. Various operating modalities and test parameters were used in validating the overall APL system performance. The pipe locating system performed very well and was very easy to operate.

The APL system performance was validated and tested in controlled and simulated field settings using indoor and outdoor pipe beds with known pipe locations, depths and sizes. A wide range of real-world utilities – gas mains and services, electrical conduits, water mains, sewer mains and laterals – were surveyed and located. The soil and surface conditions included concrete, asphalt, gravel, topsoil, and grass. The field test results showed very good system performance and robustness in overall system operation.

In all, a total of more than two hundred (200^{+}) real-world field test locations were surveyed in Northern California and Indiana areas. Overall, the pipe detection accuracy of the APL system is well within 9" on average. In general, the accuracy of the overall system detection performance was well above 80% for the detection criteria of ±18". The APL detection system is able to resolve multi-utility with spacing of about 15". The test results were validated by utility markers, mapping information, or visual inspection methods.

- Several local area tests were conducted near the SVI and Sensit Technologies facilities. A pipe-bed facility was designed and constructed, and was used to evaluate the APL performance.

- Series of extensive field tests were conducted in the metropolitan area near Modesto, California and Valparaiso, Indiana. These field tests included various soil conditions and surface coverings such as concrete, asphalt pavement, grassy field, and top soil. The detected utilities included gas mains, gas service lines, electrical conduits, water mains, and sewer mains and laterals.

- The APL system performed well in all soil conditions and surface coverings. In all field tests, the average accuracy of the pipe detection is within 9". For the operation parameters used, the accuracy of the overall system detection performance was well above 80% for the detection criteria of ±18".

- The performance of the multiple-pipes detection with the APL was also evaluated in the pipe-bed facility and in field trials. The tests conducted at the pipe-bed facility showed that the pipe separation capability of the APL is improved with the smaller stepping distance. For pipe spacing of about 17", the detection process with 6" stepping distance was able to resolve the pipe separation with success rate greater than 75%. In the field tests, the APL system was able to resolve multiple utilities separated by about 15".

- The detection depth switching function of the “zone” modality worked flawlessly and as intended for various soil situations and surface coverings. As expected, the “Deep” mode performed well for most of the soil conditions and wide range of utility types. The “Normal” operating mode worked very well in locating pipes buried less than 3 – 4 feet in depth.

- Based on the usage experiences and test results during the entire local and field tests, the APL system has proven to be very easy to operate and robust in locating various utility pipes in a wide range of field situations and environments.

REFERENCES

1. "Underground Pulse-Echo Inspection System" by Robert W. Cribbs, Soni-Pulse Inc., GRI Contract 3 FRI-03-1, Final Report, August 2005.

2. "Acoustic-based Technology to Locate Buried Pipes" by Kiran Kothari, Ching-Chen Wu, and Maureen Droessler, Final Report for the PHMSA Contract # DTPH56-10-T-000020, July 2011.

FIGURES AND TABLES

Figure 1 Newly developed Acoustic Pipe Locator (APL) from Sensit Technologies.

TABLE 1 Test Matrix and Parameters – Relative Performance & Effect

Parameter / Performance	TX Frequency	Stepping Distance	Repetition Rate (TX[1])	Pulse Width (TX[2])
Pipe Size	O	Δ		Φ
Pipe Separation (Horizontal)	Φ	O	Φ	Φ
Pipe Separation (Vertical)	Δ	Φ	Φ	Δ
Depth (Detectability)	O	Φ	Δ	Φ

[1] Transmission Rate (acoustic energy), [2] Pulse Duration/Cycles

O : direct effect; Δ : related effect; Φ : indirect effect.

Figure 2 APL demonstration, with multiple pipes installation, conducted near the SVI facility in Sacramento, CA area.

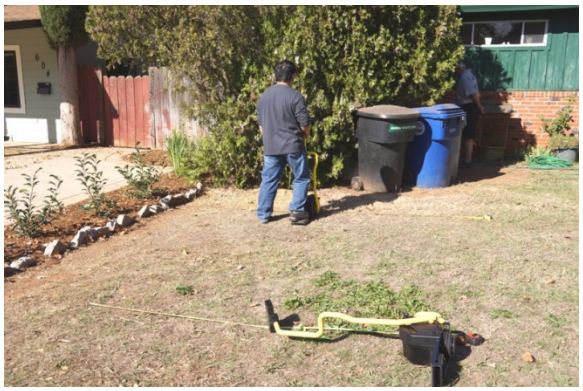
(a)

(b)

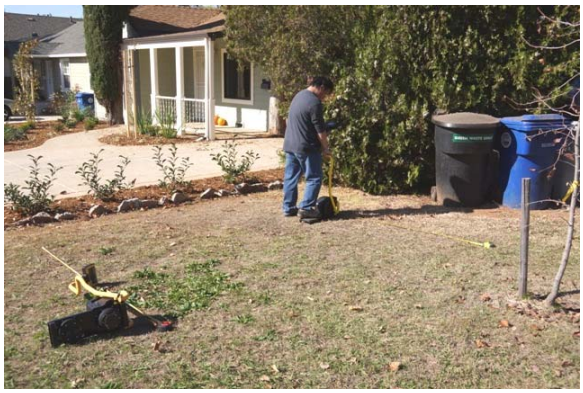
(c)

(d)

Figure 3 Local area tests conducted nearby SVI facility, test site # 1, with multiple utilities: (a) lawn area, (b) concrete sidewalk, (c) asphalt pavement, and (d) typical test result shown on the APL system.



(a)



(b)

(c)

(d)

(e)

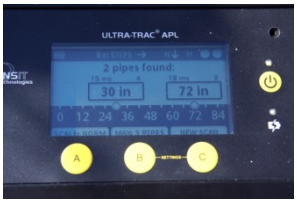
Figure 4 Local area tests conducted nearby SVI facility in a residential neighborhood, test site # 2, with multiple utilities on (a – b) topsoil/grass, (c - d) gas and sewer pipes, and (e) typical test results shown on the APL system.

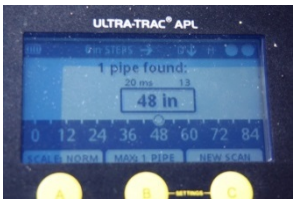
(a)

(b)

(c)

(d)

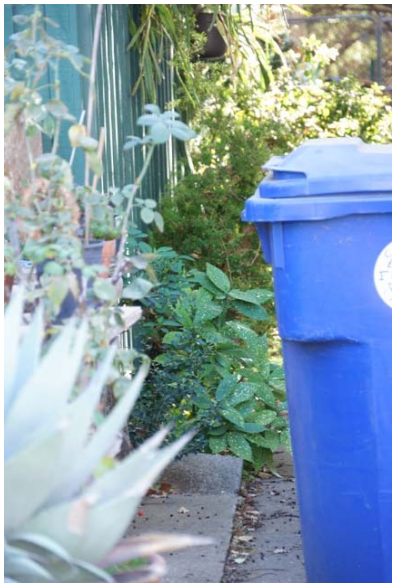




(e)

Figure 5 Local area tests conducted nearby SVI facility in a residential neighborhood, test site # 2, with water line on asphalt: (a - b) water line, (c - d) cracks (trenching effect) on both sides of the utility, and (e) typical test results shown on the APL system.

(a)



(b)

(c)

(d)

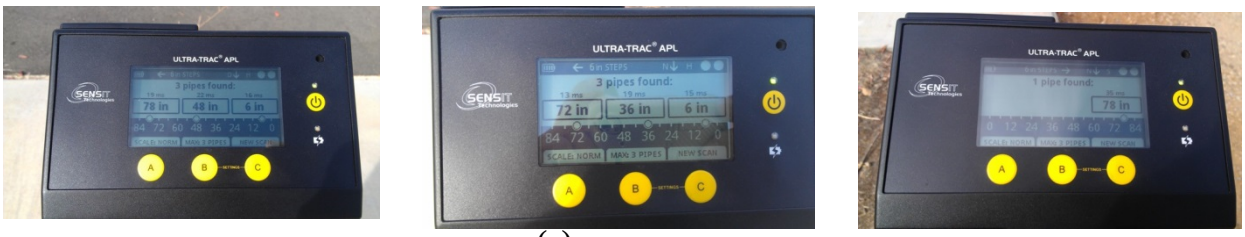
Figure 6 Local area tests conducted nearby SVI facility in a residential neighborhood, test site # 2, with (a-b) sewer pipe on topsoil (mixture with gravel): (c) soil characteristics, and (d) typical test results shown on the APL system.

(a)

(b)

(c)

(d)



(e)

Figure 7 Local area tests conducted in a pipe farm near SVI facility – multiple pipes buried in various depths, test site # 3, (a) asphalt covering, (b) concrete slab, (c) topsoil/grass field, (d) soil characteristics, and (e) typical test results shown on the APL system.

(a)

(b)

(c)

Figure 8 Background noise measurements conducted in a pipe farm – multiple pipes buried in various depths, test site # 3, (a) topsoil surface, (b) native soil/clay, and (c) gravel covering.

(a)

(b)

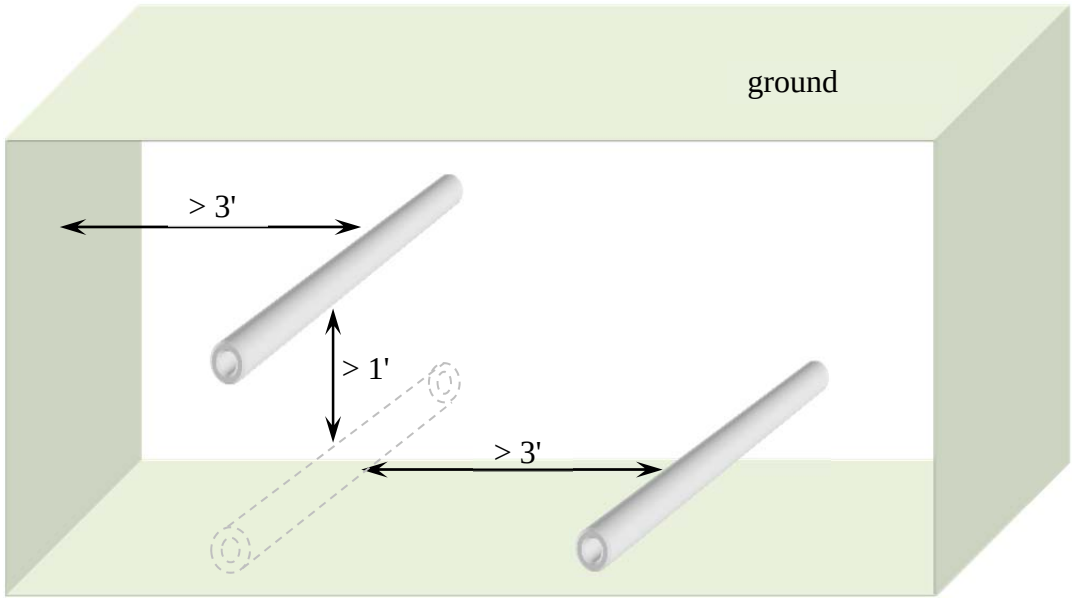
(c)

(d)

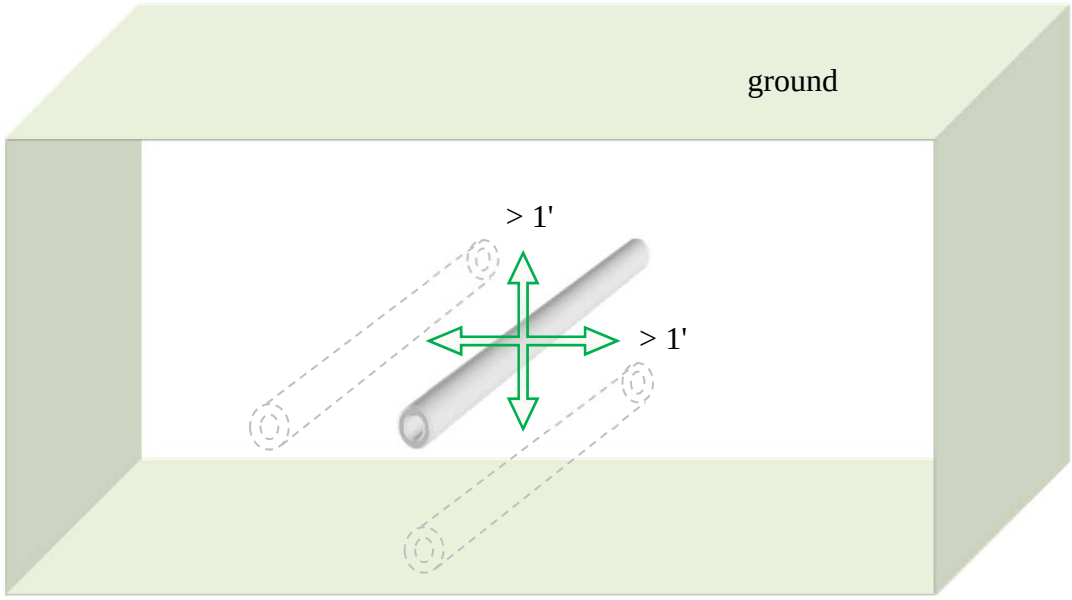
(e)

(f)

Figure 9 Local area tests conducted near SVI facility in industrial settings: (a - b) joint box, test site # 4, with electrical and water lines under mulch/soil and asphalt coverings, (c - e) gas main and water line, test site # 5, under asphalt, and (f) typical test results shown on the APL system.



(a)



(b)

Figure 10 Design guideline and configuration for the pipe-bed facility at Sensit Technologies facility: (a) single pipe (detection) spacing: > 3 feet and (b) multiple pipe (detection and resolution) spacing > ±1 foot.

Figure 11 Layout (top view) of the pipe-bed facility at SENSIT Technologies.

(a)

(b)

(c)

(d)

Figure 12 APL local area test at the pipe-bed facility: (a) project members conducted test on the pipe bed, (b) close-up view of the compacted gravel covering on the test pipe bed, and (c) result of single pipe detected, and (d) multiple pipes test result.

TABLE 2 Pipe separation performance of the APL system in Local Area Test

Detectability[0] (%)	Sect.#1 (22")[1]		Sect.#2 (17")[1]		Sect.#3 (11")[1]		Note
	6" step	12" step	6" step	12" step	6" step	12" step	
3 pipes	75%	0%	75%	0%	50%	0%	all freq.[2]
2 pipes	100%	50%	100%	50%	75%	0%	"
1 pipe	100%	100%	100%	100%	100%	100%	"
no pipe	n/a	n/a	n/a	n/a	n/a	n/a	

0, success rate (%) of detecting pipe(s)

1, test section with different pipe spacing (ref. APPENDIX A)

2, all frequency: Deep and Normal mode

TABLE 3 Detection accuracy of the APL system in Local Area Test

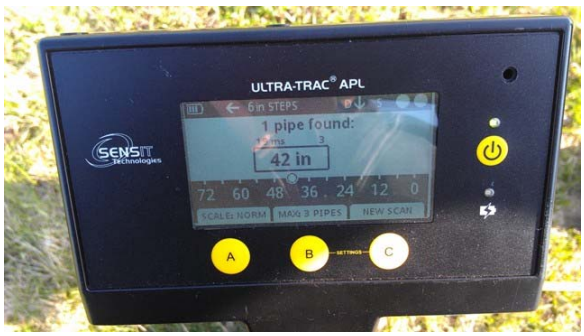
Accuracy (inch)	Sect.#1 (22")[0]		Sect.#2 (17")		Sect.#3 (11")		Note
	6" step	12" step	6" step	12" step	6" step	12" step	
all pipes	6.7"	8.0"	8.7"	8.0"	6.7"	9.0"	all freq.[1]
Overall	7.9"						

0, section with different pipe spacing (ref. APPENDIX A)

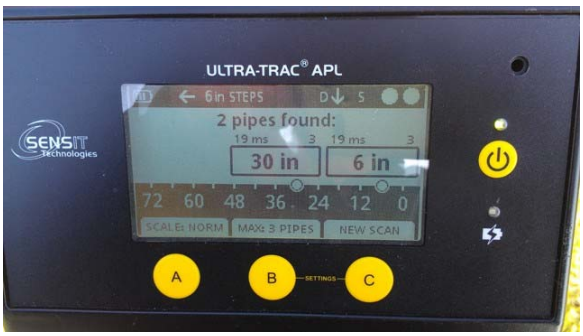
1, all frequency: Deep and Normal mode

(a)

(b)



(c)



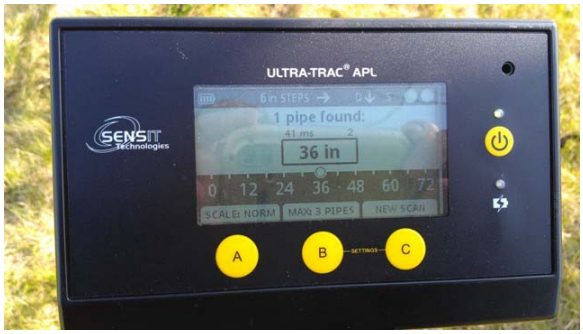
(d)

Figure 13 APL field tests conducted in Valparaiso, IN: (a-b) gas main and electrical line under grassy area, (c) single pipe detected, and (d) multiple pipes test result.

(a)

(b)

(c)



(d)

Figure 14 APL field tests conducted in Valparaiso, IN: (a-c) gas main and electrical line under grassy area, (d) single pipe detected.

(a)

(b)

(c)

(d)

(e)

Figure 15 APL field tests conducted in Valparaiso, IN: (a-d) water main under asphalt and grassy coverings, and (e) the detected result.

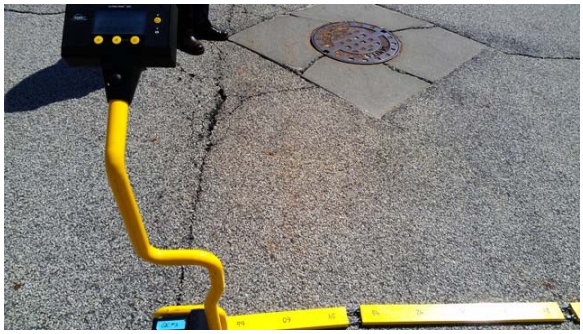
(a)

(b)

(c)

(d)

Figure 16 APL field tests conducted in Valparaiso, IN: (a-b) multiple utility lines – electrical, gas, and water, (c) close-up view of electrical (red) and gas (yellow) line markers, and (d) test result of the multiple pipe detection.



(a)

(b)

(c)

(d)

(e)

(f)

Figure 17 APL field tests conducted in Valparaiso, IN: (a-b) sewer drain under asphalt and the test result, (c-d) sewer lateral under grassy area and test result, and (e-f) gas service line under grass covering and the detected result.

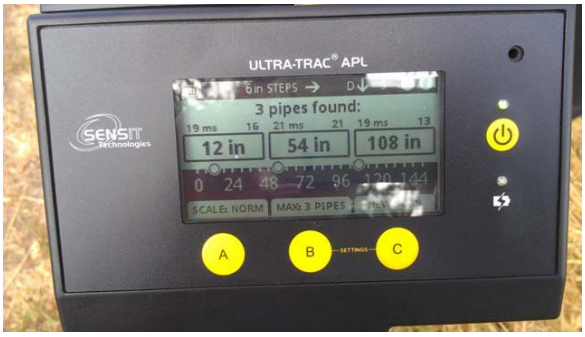
TABLE 4 Detection accuracy of the APL system in Field Tests (Valparaiso, IN)

Accuracy (inch)	Gas main[#3] (2" - 4")	HP Gas[#4] (4" – 6")	Water[#5] main	Electrical[#6] & Gas	Sewer[#7a] Drain	Sewer[#7b] Lateral	Gas[#7c] service
all pipes	**9"**	**12"**	**19"**	**10"**	**6"**	**6"**	**3"**
Overall	**9"**						

#?, area and utility tested during the field test (ref. APPENDIX B)

(a)

(b)



(c)

Figure 18 APL field test near Modesto, CA (residential area with gravel surface covering and buried gas mains): (a - b) soil condition and system setup and (c) typical test result of the pipe detection.

(a)

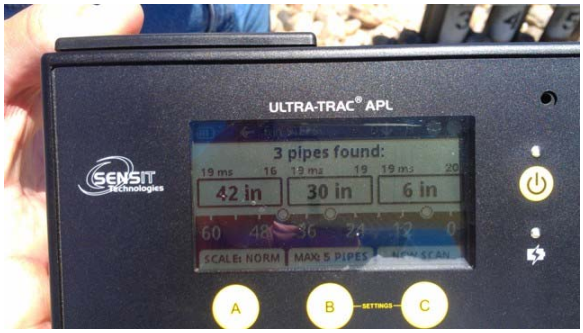
(b)

(c)

Figure 19 APL field test near Modesto, CA (residential area with asphalt surface covering and buried gas and water utilities): (a - b) soil condition and system setup and (c) typical test result of the pipe detection.

(a)

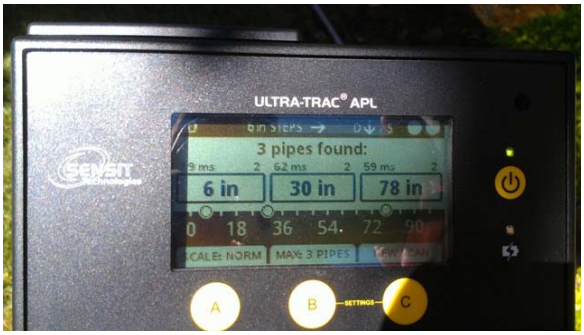
(b)



(c)

Figure 20 APL field test near Modesto, CA (water treatment facility with gravel surface covering and buried water mains): (a - b) soil condition and system setup and (c) typical test result of the pipe detection.

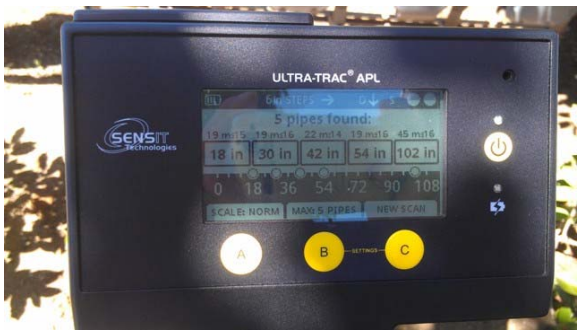
(a)



(b)

(c)

(d)



(e)

Figure 21 APL field test near Modesto, CA (retail outlet with grassy/topsoil surface covering and gas service and water utilities): (a - b) system setup and test result of grassy field, (c – d) multi-utility and system setup on topsoil, and (e) typical test result of the multiple pipe detection.

(a)

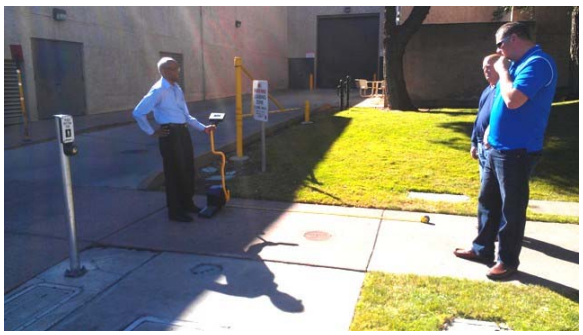
(b)

(c)

Figure 22 APL field test in Modesto, CA business district with asphalt/concrete surface covering and buried water and sewer utilities: (a - b) soil condition and system setup and (c) typical test result of the pipe detection.

(a)

(b)



(c)

(d)

(e)

Figure 23 APL field test in Modesto, CA (residential area with gravel surface covering and buried gas mains): (a, c - d) soil condition and system setup and (b & e) typical test results of the pipe detection.

TABLE 5 Detection Accuracy of the APL System during Field Test in Modesto, CA.

Accuracy (inch)	Gas main[#1] (gravel)	Gas & water[#2] (asphalt)	Water main[#3] (gravel etc.)	Gas & water[#4] (grass/topsoil)	Gas, water[#5], & sewer
all pipes	**7"**	**8"**	**6"**	**4"**	**13"**
Overall	**7.6"**				

#?, area and utility tested during the field test (ref. APPENDIX B)

APPENDIX

Appendix A List of Initial Local Area Test Setup (Sacramento, CA)

Test ID	Soil	Utility	Verification Method	Location
1	concrete	Sewer service	visual	CA, #1[0]
2	concrete	Sewer service	visual	CA
3	concrete	Sewer service	visual	CA
4	concrete	Sewer service	visual	CA
5	concrete	Sewer service	visual	CA
6	concrete	Sewer service	visual	CA
7	concrete	1", gas service	visual	CA
8	concrete	1", gas service	visual	CA
9	grass	Multi-utility[1]	visual	CA
10	grass	Multi-utility[1]	visual	CA
11	grass	Multi-utility[1]	visual	CA
12	grass	Multi-utility[1]	visual	CA
13	asphalt	Storm drain	visual	CA
14	asphalt	Storm drain	visual	CA
15	asphalt	Storm drain	visual	CA
16	asphalt	Storm drain	visual	CA
17	topsoil/grass	1", gas service	visual	CA, #2
18	topsoil/grass	1", gas service	visual	CA
19	topsoil/grass	1", gas service	visual	CA
20	topsoil/grass	1", gas service	visual	CA
21	topsoil/grass	1", gas service	visual	CA
22	topsoil/grass	1", gas service	visual	CA
23	asphalt	Water service	visual	CA
24	asphalt	Water service	visual	CA
25	top soil	Sewer service	visual	CA
26	top soil	Sewer service	visual	CA
27	top soil	Sewer service	visual	CA
28	top soil	Sewer service	visual	CA
29	asphalt	Pipe Farm[2] (u1041)	visual	CA, #3
30	asphalt	Pipe Farm[2]	visual	CA
31	asphalt	Pipe Farm[2]	visual	CA
32	asphalt	Pipe Farm[2]	visual	CA
33	asphalt	Pipe Farm[2]	visual	CA
34	asphalt	Pipe Farm[2]	visual	CA

35	asphalt	Pipe Farm[2]	visual	CA
36	asphalt	Pipe Farm[2]	visual	CA
37	asphalt	Pipe Farm[2]	visual	CA
Test ID	**Soil**	**Utility**	**Verification Method**	**Location**
38	asphalt	Pipe Farm[2]	visual	CA
39	asphalt	Pipe Farm[2]	visual	CA
40	asphalt	Pipe Farm[2]	visual	CA
41	asphalt	Pipe Farm[2]	visual	CA
42	concrete	Pipe Farm[2]	visual	CA
43	concrete	Pipe Farm[2]	visual	CA
44	topsoil/grass	Pipe Farm[2]	visual	CA
45	topsoil/grass	Pipe Farm[2]	visual	CA
46	topsoil/grass	Pipe Farm[2]	visual	CA
47	topsoil/grass	Pipe Farm[2]	visual	CA
48	topsoil/grass	Pipe Farm[2]	visual	CA
49	topsoil/grass	Pipe Farm[2]	visual	CA
50	topsoil/grass	Pipe Farm[2]	visual	CA
51	topsoil/grass	Pipe Farm[2]	visual	CA
52	concrete	Pipe Farm[3] (u1047)	visual	CA
53	concrete	Pipe Farm[3]	visual	CA
54	concrete	Pipe Farm[3]	visual	CA
55	concrete	Pipe Farm[3]	visual	CA
56	concrete	Pipe Farm[3]	visual	CA
57	concrete	Pipe Farm[3]	visual	CA
58	concrete	Pipe Farm[3]	visual	CA
59	concrete	Pipe Farm[3]	visual	CA
60	concrete	Pipe Farm[3]	visual	CA
61	concrete	Pipe Farm[3]	visual	CA
62	concrete	Pipe Farm[3]	visual	CA
63	concrete	Pipe Farm[3]	visual	CA
64	topsoil/grass	Pipe Farm[3]	visual	CA
65	topsoil/grass	Pipe Farm[3]	visual	CA
66	topsoil/grass	Pipe Farm[3]	visual	CA
67	topsoil/grass	Pipe Farm[3]	visual	CA
68	topsoil/grass	Pipe Farm[3]	visual	CA
69	topsoil/grass	Pipe Farm[3]	visual	CA
70	topsoil	Pipe Farm[3]	visual	CA
71	topsoil	Pipe Farm[3]	visual	CA
72	gravel	Pipe Farm[3]	background noise	CA
73	gravel	Pipe Farm[3]	background noise	CA
74	topsoil	Pipe Farm[3]	background noise	CA
75	topsoil	Pipe Farm[3]	background noise	CA

76	native soil/clay	Pipe Farm[3]	background noise	CA
77	concrete	Pipe Farm[3]	background noise	CA
78	concrete	Pipe Farm[3]	background noise	CA
Test ID	**Soil**	**Utility**	**Verification Method**	**Location**
79	asphalt	Pipe Farm[3]	background noise	CA
80	asphalt	Pipe Farm[3]	background noise	CA
81	asphalt	Multi-utility[4]	visual	CA, #4
82	asphalt	Multi-utility[4]	visual	CA
83	mulch	Multi-utility[4]	visual	CA
84	mulch	Multi-utility[4]	visual	CA
85	asphalt	4" PE, gas main	visual	CA, #5
86	asphalt	4" PE, gas main	visual	CA
87	asphalt	4" PE, gas main	visual	CA
88	asphalt	4" PE, gas main	visual	CA
89	asphalt	No pipe	visual	CA
90	asphalt	No pipe	visual	CA
91	asphalt	Water main	visual	CA
92	asphalt	Water main	visual	CA

[0] Total of five (5) test sites were selected and field tested.
[1] Multi-utility – electrical, water, and irrigation.
[2] Pipe Farm – 4" & 10" pipes buried 2 to 12 feet; tested with unit #1041.
[3] Pipe Farm – same as [2], except using unit #1047 for tests.
[4] Multi-utility – junction box: electrical/IT, irrigation, and water.

Appendix B List of Test Setup in Pipe-bed Facility, IN

Test ID	Soil Covering	Utility	Verification Method	Location
1	gravel	Pipe Bed, 2” PVC	marker, visual	IN, #1[0]
2	gravel	Pipe Bed, 2” PVC	marker, visual	IN
3	gravel	Pipe Bed, 2” PVC	marker, visual	IN
4	gravel	Pipe Bed, 2” PVC	marker, visual	IN
5	gravel	Pipe Bed, 2” PVC	marker, visual	IN
6	gravel	Pipe Bed, 2” PVC	marker, visual	IN
7	gravel	Pipe Bed, 2” PVC	marker, visual	IN
8	gravel	Pipe Bed, 2” PVC	marker, visual	IN
9	gravel	Pipe Bed, 2” PVC	marker, visual	IN, #2[0]
10	gravel	Pipe Bed, 2” PVC	marker, visual	IN
11	gravel	Pipe Bed, 2” PVC	marker, visual	IN
12	gravel	Pipe Bed, 2” PVC	marker, visual	IN
13	gravel	Pipe Bed, 2” PVC	marker, visual	IN
14	gravel	Pipe Bed, 2” PVC	marker, visual	IN
15	gravel	Pipe Bed, 2” PVC	marker, visual	IN
16	gravel	Pipe Bed, 2” PVC	marker, visual	IN
17	gravel	Pipe Bed, 2” PVC	marker, visual	IN, #3[0]
18	gravel	Pipe Bed, 2” PVC	marker, visual	IN
19	gravel	Pipe Bed, 2” PVC	marker, visual	IN
20	gravel	Pipe Bed, 2” PVC	marker, visual	IN
21	gravel	Pipe Bed, 2” PVC	marker, visual	IN
22	gravel	Pipe Bed, 2” PVC	marker, visual	IN
23	gravel	Pipe Bed, 2” PVC	marker, visual	IN
24	gravel	Pipe Bed, 2” PVC	marker, visual	IN
25	gravel	Pipe Bed, 2” PVC	marker, visual	IN
26	gravel	Pipe Bed, 2” PVC	marker, visual	IN

[0] Outdoor pipe bed: sand pit with gravel covering, all compacted soil; in different sections (#): # 1 – pipe seperation~22”, # 2 – pipe seperation~17”, and # 3 – pipe seperation~11”.

Appendix C List of Field Test Setup, Valparaiso, IN

Test ID	Soil	Utility	Verification Method[0]	Location
1	grass	Gas main 4” - 6”	visual	IN, #[4]
2	grass	Gas main 4” - 6”	visual	IN
3	grass	Gas main 4” - 6”	visual	IN
4	grass	Gas main 4” - 6”	visual	IN
5	grass	Gas main 4” - 6”	visual	IN
6	grass	Gas main 4” - 6”	visual	IN
7	grass	Gas main 4” - 6”	visual	IN
8	grass	Gas main 4” - 6”	visual	IN
9	grass	Gas main 4” - 6”	visual	IN
10	grass	Gas main 4” - 6”	visual	IN
11	grass	12” Water main	marking, visual	IN,#[5]
12	grass	12” Water main	marking, visual	IN
13	grass	12” Water main	marking, visual	IN
14	grass	12” Water main	marking, visual	IN
15	grass	Gas main, 2” – 4”	marker, visual	IN,#[3]
16	grass	Gas main, 2” – 4”	marker, visual	IN
17	grass	Gas main, 2” – 4”	marker, visual	IN
18	grass	Gas main, 2” – 4”	marker, visual	IN
19	grass	Gas main 4” - 6”	visual	IN,#[4]
20	grass	Gas main 4” - 6”	visual	IN
21	grass	Gas main 4” - 6”	visual	IN
22	grass	Gas main 4” - 6”	visual	IN
23	grass	Gas main 4” - 6”	visual	IN
24	grass	Gas main 4” - 6”	visual	IN
25	grass	Gas main 4” - 6”	visual	IN
26	grass	Gas main 4” - 6”	visual	IN
27	grass	Gas & Electrical	marker, visual	IN,#[6]
28	grass	Gas & Electrical	marker, visual	IN
29	grass	Gas & Electrical	marker, visual	IN
30	grass	Gas & Electrical	marker, visual	IN
31	grass	Gas & Electrical	marker, visual	IN
32	grass	Gas & Electrical	marker, visual	IN
33	asphalt	Sewer drain	marking, visual	IN,#[7a]
34	asphalt	Sewer drain	marking, visual	IN
35	grass	Sewer lateral	visual	IN,#[7b]
36	grass	Sewer lateral	visual	IN
37	grass	Gas 2” service line	visual	IN,#[7c]
38	grass	Gas 2” service line	visual	IN

[0] Verification Method: visual inspection, utility marker, mapping, marking, …, etc.
[3] Gas main – 4" gas main under native grass.
[4] Gas main – high pressure gas main under lawn.
[5] Water main – 12" water main under asphalt and grass.
[6] Multi-utility – gas main and electrical under native grass.
[7] Multi-utility – sewer main, sewer lateral, and gas service line.

Appendix D List of Field Test Setup, Modesto, CA

Test ID	Soil	Utility	Verification Method[0]	Location
1	gravel	Gas main 6” - 8”	map, marker	CA, #[1a]
2	gravel	Gas main 6” - 8”	map, marker	CA
3	gravel	Gas main 6” - 8”	map, marker	CA
4	gravel	Gas main 6” - 8”	map, marker	CA
5	gravel	Gas main 6” - 8”	map, marker	CA
6	gravel	Gas main 6” - 8”	map, marker	CA
7	gravel	Gas main 6” - 8”	map, marker	CA,#[1b]
8	gravel	Gas main 6” - 8”	map, marker	CA
9	gravel	Gas main 6” - 8”	map, marker	CA
10	gravel	Gas main 6” - 8”	map, marker	CA
11	gravel	Gas main 6” - 8”	map, marker	CA, #[1c]
12	gravel	Gas main 6” - 8”	map, marker	CA
13	gravel	Gas main 6” - 8”	map, marker	CA
14	gravel	Gas main 6” - 8”	map, marker	CA
15	gravel	Gas main 6” - 8”	map, marker	CA
16	gravel	Gas main 6” - 8”	map, marker	CA
17	asphalt	Gas, water, & sewer	map, marker	CA, #[2a]
18	asphalt	Gas, water, & sewer	map, marker	CA
19	asphalt	Gas, water, & sewer	map, marker	CA
20	asphalt	Gas, water, & sewer	map, marker	CA
21	asphalt	Gas, water, & sewer	map, marker	CA, #[2b]
22	asphalt	Gas, water, & sewer	map, marker	CA
23	concrete	Junction box	visual	CA, #[3a]
24	concrete	Junction box	visual	CA
25	concrete	Junction box	visual	CA
26	concrete	Junction box	visual	CA
27	gravel	Water pipes	visual	CA, #[3b]
28	gravel	Water pipes	visual	CA
29	gravel	Water pipes	visual	CA, #[3c]
30	gravel	Water pipes	visual	CA
31	gravel	Water pipes	visual	CA, #[3d]
32	gravel	Water pipes	visual	CA
33	gravel	Water pipes	visual	CA
34	gravel	Water pipes	visual	CA
35	concrete	Water mains	Marking, visual	CA, #[3e]
36	concrete	Water mains	Marking, visual	CA
37	concrete	Water mains	Marking, visual	CA
38	concrete	Water mains	Marking, visual	CA

Test ID	Soil	Utility	Verification Method[0]	Location
39	grass	Gas & water	visual	CA, #[4]
40	topsoil	Gas & water	visual	CA
41	topsoil	Gas & water	visual	CA
42	topsoil	Gas & water	visual	CA
43	topsoil	Gas & water	visual	CA
44	concrete	Gas, water, & sewer	visual	CA, #[5a]
45	concrete	Gas, water, & sewer	visual	CA
46	asphalt	Gas, water, & sewer	visual	CA, #[5b]
47	asphalt	Gas, water, & sewer	visual	CA
48	asphalt	Gas, water, & sewer	visual	CA
49	asphalt	Gas, water, & sewer	visual	CA
50	concrete	Gas, water, & sewer	visual	CA, #[5c]
51	concrete	Gas, water, & sewer	visual	CA
52	asphalt	Gas, water, & sewer	visual	CA, #[5d]
53	asphalt	Gas, water, & sewer	visual	CA
54	asphalt	Gas, water, & sewer	visual	CA
55	asphalt	Gas, water, & sewer	visual	CA

[0] Verification Method: visual inspection, utility marker, mapping, marking, …, etc.
[1] Gas main – 6" & 8" gas main under road side gravel, several locations.
[2] Multi-utility – 8" gas main, water, and sewer under asphalt, several locations.
[3] Multi-utility – junction box under concrete, water main/pump under gravel and concrete, several locations.
[4] Multi-utility – gas services and water main under grass and topsoil.
[5] Multi-utility – gas service, water, and sewer under concrete and asphalt, several locations.