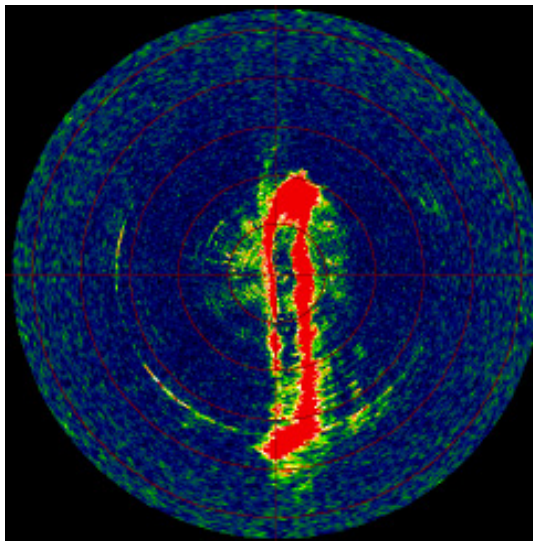


Sonar Imaging of Flooded Subsurface Voids

Phase I: Proof of Concept

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for the
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Office of Research and Development



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Sonar Imaging of Flooded Subsurface Voids Phase I: Proof of Concept

FINAL REPORT

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This report does not constitute a standard, specification or regulation.

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1. INTRODUCTION

Damage to Ohio highways due to subsidence or collapse of subsurface voids is a serious problem for the Office of Geotechnical Engineering (OGE) at the Ohio Department of Transportation (ODOT). These voids have often resulted from past underground mining activities for coal, clay, limestone and gypsum but may also result from dissolution of bedrock as with karst formations. These voids are flooded if they lie below the local drainage and may be partially flooded or open if they lie above the local drainage. The effective depth of potential significant surface damage resulting from subsidence of underground mines is generally regarded as 10 times the height of the void (Piggot and Eynon 1978). However, in Ohio, mine voids are typically less than 5 ft. high and show subsidence expressions to depths of 200 ft. or more.

Several methods are used to remediate a problem area with underground voids. If the voids are shallow and open (i.e., not flooded), then they can be excavated and filled. Dewatering may also be needed for filling of shallow voids. Otherwise, the voids are drilled and grouted. Occasionally, for very important highways, a land bridge (possibly with drilling and grouting) may be constructed over an area with subsurface voids. This was the method chosen for remediation of the I-70 collapse in 1995. Typically, this method is applied to sites that may experience differential settlement but not catastrophic failure, previously collapsed mine voids or voids with significant overburden cover. More than 1700 roadway sites overlie underground mines in Ohio. The age of the majority of abandoned underground mines ranges from 50 to 150 years. In most cases, the existence and accuracy of records of void location and geometry is limited at best. The Ohio Department of Natural Resources, Geological Survey (ODNR-GS) maintains a GIS-based interactive map which includes archived underground mine maps. It is estimated that fewer than two-thirds of all past underground mining activities are known due to lost mine maps and reports over the years. This is especially true for older, pre-1930s, mine workings due to the lack of regulations requiring the retention of these records (Painter et al. 2010).

Since past records are of little use to establish the location of underground voids, subsurface investigation and grouting methods essentially consist of a random or grid-based drilling pattern.

This method is expensive because many unusable holes are drilled into existing pillars, walls and unmined areas. Considerable savings of time and drilling costs can be achieved if more information on void geometry can be obtained prior to drilling. This technique is the so-called “frontier drilling” concept, where information from existing holes is used to decide where the next hole should be drilled. Such information can be obtained using downhole investigation equipment, such as cameras, laser scanning and sonar. These methods can delineate the geometry of an underground void network to guide further drilling and remediation activities and tie the location of such voids to surface features and maps. Even for mapped mines, there is still a need to verify the location of the map relative to existing surface features and design layouts. Downhole cameras and laser scanning are suitable for open voids but are of little use for the majority of voids that are flooded and may have persistent turbidity in the water.

Due to the potential cost savings, the ODOT OGE is interested in the acquisition or development of downhole void investigation and mapping equipment capabilities. ODOT funded this Phase I project to investigate the feasibility to develop equipment with such capabilities to improve the quality and efficiency of ODOT’s subsurface void investigation program. This report presents the findings of this Phase I investigation and makes recommendations concerning Phase II implementation.

2. BACKGROUND INFORMATION

Abandoned mines underlying transportation infrastructure have caused damage to roads, bridges and building structures. These underground features can manifest slowly as sinkholes or other subsidence events or rapidly in catastrophic failures. Property damage and potential loss of life require appropriate actions to correct these situations. Understanding the condition of abandoned underground mine workings and their extent enables engineers and geologists to make decisions regarding remediation strategies.

Both surface-based and downhole technologies are available to investigate the geometry and extent of underground voids. Surface-based methods have the advantage that no drilling is

required. These methods include spectral analysis of surface waves (SASW) (Cascante et al. 1999), electrical resistivity (Hutchinson and Barta 2003; Hutchinson and Vidarsson 2006), seismic tomographic imaging (Gritto 2003; Grandjean and Leparoux 2004) and ground penetrating radar (GPR) (Daniels 2004). While these methods are effective for the general detection of subsurface voids, the location and geometry information provided is generally not sufficiently precise to guide real-time “frontier drilling” operations. For example, although GPR is a popular method for mapping underground features, it often creates reflection artifacts, especially in areas of complex geology that can make interpretation difficult (e.g., overlying clay soils, multiple aquifers). Resolution also decreases with depth for surface-based methods, making them most suitable for shallow voids. Cross-hole technologies, such as electrical resistance, GPR, and tomography, require drilling and can provide more detailed information at depth but generally also lack the necessary resolution (Hanna et al. 2006). The best resolution can be obtained using actual downhole imaging of the void itself.

In March 1995, ODOT was faced with a major catastrophe when a subsidence feature in a section of I-70 collapsed due to a pillar/roof support failure of an abandoned underground mine. Currently, there are 33 Ohio counties with underground mines; the most problematic areas are located in Belmont, Stark, Harrison, and Jefferson counties. To investigate such voids, OGE purchased a relatively inexpensive GeoVISION borehole camera in 2000. This low quality, low capability video system had some serious drawbacks, including inverted black-and-white images, lack of low light resolution, and lack of pan/tilt/zoom. In addition, this camera had to be withdrawn from a borehole to switch from vertical view (downward) to horizontal view using a mirror. During this time, the OGE sometimes borrowed a high resolution downhole camera from the Office of Surface Mines (OSM) in Pittsburgh to investigate underground voids for important projects. In 2009, OGE purchased new high quality GeoVISION camera that was substantially improved with capabilities for color non-inverted images, 360° scan, low-light, and pan/tilt. Although this camera system provides good video capability to the OGE, it provides little benefit for future investigation and grouting of flooded voids – which make up the majority of mines (> 80%) in Ohio. The development of downhole video/laser/sonar capabilities would greatly enhance ODOT’s ability to characterize subsurface voids at all stages of investigation and remediation.

Within the context of this research, the methods for downhole investigation of subsurface voids are video, laser scanning and sonar. Borehole-deployable cameras (Wells 1999; Mark Products 2002) are the most widely used method for void investigation. Cameras provide visual data and are relatively inexpensive. The primary disadvantage is that cameras provide limited quantitative information. Distance measurements are generally not provided with cameras and thus void geometry and volume are not generally measured, although with statia this is possible. As a result, boreholes must be densely distributed across the mine area, which increases drilling costs. In addition, borehole cameras are relatively ineffective for flooded voids, which make up the majority of voids in Ohio. Drilling into flooded mines produces significant turbidity that requires additional time to clear. Advantages of borehole cameras include lower expense and the ability to identify the condition of the borehole and roof rock prior to further investigation with more expensive equipment.

Borehole deployable laser scanning equipment is a relatively recent development that provides high quality quantitative geometry data for open voids. A camera is usually also included to give visual data of the borehole (i.e., during descent into a void). The probe conducts a 360° scan of the void from a single location. The data recovered from a borehole laser is converted into a 3D point cloud (Figure 1). Individual 2D vertical and horizontal cross sections and 3D void volume information can be obtained from this data.

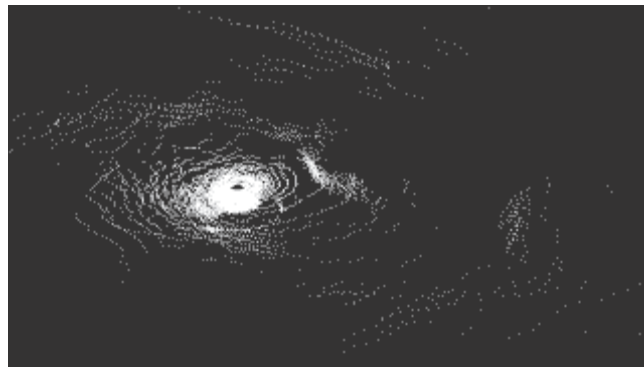


Figure 1. 3D point cloud for underground mine void (Morris et al. 2006a).

An example of a borehole laser, called the Ferret (Figure 2), was developed at the Robotics Institute at Carnegie Mellon University (CMU) (Morris et al. 2006a). The Ferret contains a single-point, long-range, low-reflectivity laser that has rotation and pan/tilt capability such that it can perform a semi-spherical scan of a void. The effective range of motion is 360° in the horizontal plane and 150° in the vertical plane. Ferret also contains a high resolution camera to aid in borehole deployment. In a Kansas City case study described by Morris et al. (2006a), the Ferret was used to guide “frontier drilling” operations and, as a result, the number of required boreholes was reduced by approximately 40%. Ferret is a rather large device that requires a large (> 6 in.) diameter borehole, which substantially increases drilling time and costs.



Figure 2. “Ferret” downhole laser scanning device (Morris et al. 2006a).

Borehole deployable sonar scanning equipment is operationally similar to laser equipment with the main difference that sonar is used to obtain the distance measurements. In comparison, broad sonar beams are less accurate than laser beams; however, sonar is the only method suitable for investigation of flooded voids. One prototype borehole sonar device is the “Wet Ferret” (Figure 3), also developed by the CMU Robotics Institute (Morris et al. 2006b). Wet Ferret was used for a Zanesville, Ohio, field demonstration described later in this report. Sonar technology has also been applied to cave exploration using a mobile platform (am Ende 2001).

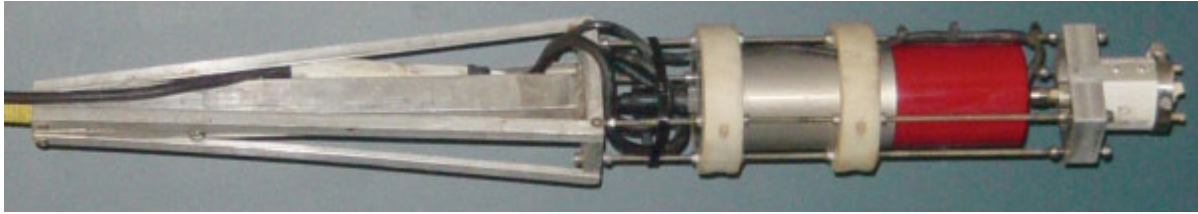


Figure 3. “Wet Ferret” downhole sonar scanning device (Morris et al. 2006b).

Images obtained for both laser scanning and sonar scanning can be limited by obstructed views due to roof falls (which depends on competency of roof and skill of drillers) and point of origin relative to mine features (e.g., pillars, walls, corridors).

3. RESEARCH OBJECTIVES

The objective of this proof-of-concept project was to conduct a feasibility study for the acquisition and/or development of a complete system for downhole investigation and mapping of underground voids. In particular, the OGE was interested to know if a single system was available to provide video, laser scanning and sonar and, if not, if such a system could be economically developed. Depending on the results of Phase I, Phase II was to consist of purchasing, research testing and training for all necessary equipment, including quality assurance/quality control (QA/QC) procedures and methods for data transfer and analysis. The training program was also scheduled to be conducted under Phase II for ODOT personnel on the safety and operation of the equipment.

4. GENERAL DESCRIPTION OF RESEARCH

The objectives of Phase I were achieved by completing the following tasks:

- a) Definition of equipment requirements
- b) Visits to CMU and OSM facilities
- c) Zanesville field demonstration test
- d) Identification of equipment vendors

- e) Equipment specifications and quotes
- f) Downhole void investigation service

5. RESULTS

The findings of the project are discussed in the following sections on a task-by-task basis.

a. Definition of Equipment Requirements

The definition of requirements for downhole equipment for investigation of subsurface voids evolved over the course of Phase I as more was learned about such methods in general and more information was obtained from manufacturers regarding new investigation and mapping technologies.

Ideally, the equipment should have the following features:

- Maximum void investigation depth = 300 ft. with full inundation
- Maximum borehole diameter = 6 in. (4 in. preferred, 3 in. ideal)
- Capability to provide tilt/pan/zoom camera (video) data for open voids with statia for distance measurements
- Capability to provide downward video view of borehole during descent and then lateral video of the void without having to pull up the device (i.e., remote camera adjustment)
- Capability to provide 3D laser scanning data
- Capability to provide 3D sonar data
- Capability to provide video, 3D laser and 3D sonar in a single modular unit
- Capability for real-time correction for establishment of distance to targets and x,y,z coordinates relative to surface features
- Capability to provide real-time field data processing and analysis to guide frontier drilling operations
- Software for data analysis, visualization and interpretation

- System resolution should be sufficient to identify timbers, pillars, roof falls and other pertinent features of underground voids
- Equipment should have good control or measurement of horizontal orientation so that void direction is well known relative to ground surface
- Equipment should be easily portable to and deployable for a variety of field site conditions (cable spools, winches, modular components).
- Downhole equipment should be of robust and smooth construction without sharp corners and exposed workings (i.e, wires, pulleys and belts)
- Downhole equipment should operate with a single bound cable to the surface

b. Visits to CMU and OSM Facilities

Dr. Fox visited the Subterranean Robotics Laboratory at Carnegie Mellon University (CMU) and the Office of Surface Mines (OSM), both in Pittsburgh, Pennsylvania, on October 18, 2006. A tour of the Subterranean Robotics Laboratory, hosted by Chuck Whittaker, allowed for direct inspection of the custom-built Ferret III laser scanner (Figure 4) and the Wet Ferret sonar scanner (Figure 5), neither of which is commercially available. Ferret III has automatic pan/tilt capabilities and can produce a 3D void image. The disadvantages of this device include requirement for large borehole (> 6 in. diameter), sharp corners and edges (which may tend to lodge the device in a borehole) and exposed workings (wires, pulleys, etc.). The Wet Ferret can fit within a 6 in. borehole but also has sharp edges and exposed workings. A number of other types of void investigation research equipment were discussed, including autonomous cave exploration vehicles and mobile robots suitable for downhole deployment. These other equipment types were not suitable for the scope of the current project.

A visit to the OSM facility was hosted by Bill Elher. The first item on the agenda was inspection of the new GeoVISION downhole camera (Figure 6). This is a good system but does have a fair amount of exposed workings. A custom-built long range camera (Figure 7) with high intensity lights for extended viewing into a void was also discussed. This device has an impressive design with no exposed workings but is limited in its range of motion for 3D visualization. The field vehicle for deployment of this equipment (Figure 8) was most impressive.



Figure 4. Ferret III at CMU Subterranean Robotics Laboratory.



Figure 5. Wet Ferret at CMU Subterranean Robotics Laboratory.



Figure 6. GeoVISION downhole camera at OSM.



Figure 7. Long range downhole camera at OSM.



Figure 8. Field deployment vehicle at OSM.

c. Zanesville Field Demonstration Test

Workhorse Technologies was contracted by ODOT to perform a field demonstration test of their downhole void investigation equipment on March 8, 2008. The full report is provided in Appendix A. The field site was located on both sides (north, south) of the overpass of SR 93 and I-70 in Zanesville, Ohio. The purpose of the work was to demonstrate the capabilities of both the DryFerret (laser scanning) and WetFerret (sonar scanning) equipment for investigation of open and flooded underground voids, respectively. During the subsurface investigation, the workings on the north side of I-70 were revealed to be flooded and the workings on the south side of I-70 were dry. Thus, the WetFerret was planned for use on the north side and the DryFerret was planned for use on the south side. The purpose of the investigation was to determine the extent and volume of unmapped voids prior to site remediation using the drilling and grouting technique. A photograph of the investigation on the north side is shown in Figure 9.

The contractor dewatered the workings prior to the field test. Upon arrival at the project site, the holes scheduled for mapping were sounded and revealed that the south side void had squeezed together from 24 in. to 6 in. in thickness, which precluded the use of the downhole tools. Hole

P6 on the north side remained opened for a thickness of 30 in., but was again inundated after dewatering. Therefore, the WetFerret was utilized to map the north side void from P6. The DryFerret was not used at all during the field demonstration.

Based on the sonar scan, the unmapped void on the north side was situated at a depth of approximately 30 ft. and had average dimensions of 2.5 ft. in height, 15 ft. in width and 70 ft. in length, with an estimated volume of 96 yd³. Figure 10 shows the sonar image obtained using WetFerret from hole P6. The actual grout volume placed in hole P6 was 90 yd³, which is in close agreement with the calculated volume. As such, the field demonstration test of the WetFerret equipment was considered a success.



Figure 9. Void investigation using the WetFerret at hole P6 for field demonstration test in Zanesville, OH.

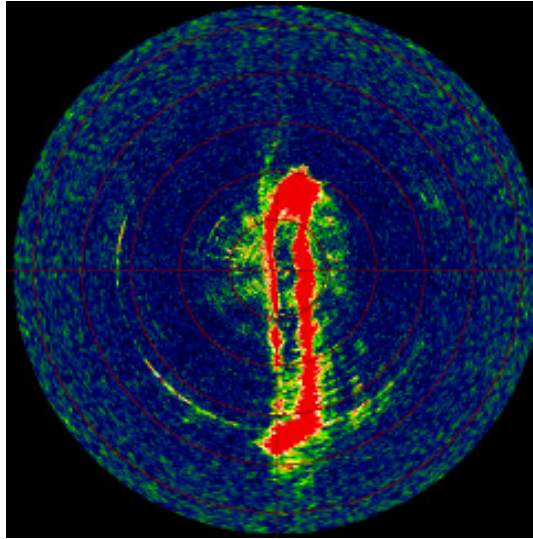


Figure 10. Sonar image for subsurface void on north side of field demonstration site in Zanesville, OH.

d. Identification of Equipment Vendors

Although it is easier to acquire completely separate and independent video, laser and sonar probes, a single modular probe with all capabilities is preferred. This eliminates time delays associated with lowering/raising different probes and changing probes for a given borehole and allows the camera to view down a borehole as the probe is being lowered into a void to look for obstructions. A thorough search has indicated that there is no manufacturer that makes a single modular probe with combined video/laser/sonar capabilities.

With regard to the development of new downhole void equipment for ODOT, conversations were held with Workhorse Technologies in Pittsburgh to provide individual laser scanning and sonar scanning probes and also a combined laser/sonar probe. Contact information is:

Workhorse Technologies, LLC
5225 Siesta Dr.
Pittsburgh, PA 15236
412-268-1119 (contact: Chuck Whittaker)

A search was also conducted to identify manufacturers that provide “off-the-shelf” downhole void investigation equipment. Sources included the internet and word-of-mouth from other equipment users, such as the Office of Surface Mines (OSM) in Pittsburgh and Blackhawk of Zapata Engineering in Golden, Colorado. Leading manufacturers for each type of void investigation equipment were identified as:

Downhole Video

GeoVISION

1243 Burnsville Rd.

Williamsville, VA 24487-2147

800-255-1353 (contact: John Wilson)

Downhole Laser Scanning

Measurement Devices US LLC

17555 Groeschke Rd.

Houston, TX 77084

281-646-0050 (contact: Brad Husack)

Downhole Sonar Scanning

Imagenex Technology Corp.

209 – 1875 Broadway St.

Port Coquitlam, BC

V3C 4Z1 Canada

604-944-8248 (contact: Steve Curnew)

Descriptions for various equipment options are discussed in the next section.

e. Equipment Specifications and Quotes

All equipment quotes are provided in Appendix B. This section provides specifications of the various equipment options.

d.1 New Equipment Development – Workhorse Technologies

Quote 2007-Q-005.1 was obtained from Workhorse Technologies for the following items:

- Downhole laser scanning probe – DryFerret 200
- Downhole sonar scanning probe – WetFerret 100
- Combined laser/sonar scanning probe – Ferret Combined Wet and Dry Systems

The DryFerret 200 has the following specifications:

- Borehole-deployable LiDAR for 3D (pan/tilt) mapping of open voids
- Minimum borehole diameter = 4.5 in.
- Maximum depth (cable length) = 300 ft.
- Maximum range of laser = 300 ft. (resolution of 1 in. at 150 ft.)
- Gyro-stabilized compass for orientation measurement
- Single Kevlar-reinforced cable with integrated fiber optics
- Software for 3D modeling and visualization, laptop computer and other hardware
- Total cost = \$203,150

The WetFerret 100 has the following specifications:

- Borehole-deployable sonar for 3D (pan/tilt) mapping of flooded voids
- Minimum borehole diameter = 4.5 in.
- Maximum depth (cable length) = 300 ft.
- Maximum range of sonar = 300 ft.
- Maximum resolution of sonar = 0.4 in.
- Low-light underwater camera
- Gyro-stabilized compass for orientation measurement
- Single Kevlar-reinforced cable
- Software for 3D modeling and visualization, laptop computer and other hardware

- Total cost = \$146,640

The Ferret Combined Wet and Dry Systems probe has the following specifications:

- DryFerret 200 and WetFerret 100 combined in single probe
- Total cost = \$261,690

d.2 Existing Equipment – GeoVISION Downhole Camera

A quote was obtained for a Deluxe GeoVISION Borehole Camera System. This system has the following specifications:

- Black-and-white ultimate low-light camera with 3.6 mm lens and motorized pan/tilt movement
- Camera resolution = 450 vertical lines
- Light source = 8 LEDs mounted on camera
- Maximum view distance = 50 ft. (100 ft. with supplemental halogen light source)
- Maximum depth (cable length) = 325 ft.
- 7 in. high resolution monitor with DVD recorder
- Speed controlled motorized winch with tripod
- Magnetic compass for orientation measurement – viewed directly on screen
- Software
- Total cost = \$14,349

d.3 Existing Equipment – MDL Downhole Laser Scanner

Quote Q-72035 was obtained for a MDL C-ALS Robotic Laser Cavity Surveying System. This system has the following specifications:

- Class 1 eye-safe laser scanning probe with motorized pan/tilt movement
- Laser range = 150 ft.
- Laser accuracy = 1.97 in.
- Laser resolution = 0.39 in.
- Laser sampling rate = 240 points/second
- Nosecone camera to assist borehole deployment
- Probe diameter = 1.97 in.

- Probe watertight and dust resistant
- Maximum depth (cable length) = 300 ft.
- Internal compass for orientation measurement
- Ruggedized tablet PC and Voidworks software for on-site data acquisition, visualization and analysis
- Total cost = \$110,880

d.4 Existing Equipment – Imagenex Downhole Sonar Scanner

Quote #125423 was obtained from Imagenex Technology Corp. for a downhole sonar scanning system. This system has the following specifications:

- Model 881A digital multi-frequency profiling sonar with end mount connector
- Pitch/roll and heading (orientation) sensor
- Power supply and serial-to-USB converter
- Sonar range = 300 ft.
- Sonar resolution = 0.08 in. (at 3 to 12 ft.); 0.4 in. (15 ft. and further)
- Probe diameter = 3.125 in.
- Maximum depth (cable length) = 330 ft.
- Software for data acquisition and visualization suitable for PC
- Total cost = \$20,420

f. Downhole Void Investigation Service

A leading void investigation contract service is provided by Blackhawk, a division of Zapata Engineering in Golden, Colorado. The contact information is:

Zapata Engineering, Blackhawk Division
 301 Commercial Rd., Suite B
 Golden, Colorado 80401
 303-278-8700 (contact: Jim Hild or Kanaan Hanna)

Blackhawk conducts investigations of underground voids using video, laser scanning and sonar scanning. The equipment used by Blackhawk for these services is:

- Downhole Video Camera – The GeoVision Model JR M6 camera provides black and white video records of void conditions (e.g., size of the collapsed/fill materials, nature and characteristics of the pillar/roof/floor) at a distance range of approximately 20 ft. Video from the camera is displayed in real time and can be recorded. PVC rods are used to lower the camera into a void and also provide directional orientation.
- Downhole Laser – The MDL Model Cavity Auto-scanning Laser System (C-ALS) is a miniature, ruggedized three-dimensional (3D) profiling laser scanner. The unit is capable of taking measurements to a distance of 500 ft, in horizontal or vertical planes from the borehole centerline on a 360-degree scan. This sensor provides a near real-time 3D image of the shape of open void spaces encountered by drilling and also provides the dimensions of those spaces. The downhole tool has a diameter slightly less than 2 in., and uses a nose-cone video camera for obstacle avoidance and limited distance video recording. The tool is lowered on fiberglass rods which give directional orientation for the void measurements relative to surface coordinates.
- Downhole Sonar – The Imagenex Model 881A Digital Multi-frequency Profiling Sonar consists of a digital sonar unit, internal magnetic compass, and an end-mount tether connector. The Model 881A is capable of taking range measurements up to 300 ft in 360-degree horizontal planes referred to as scans. Scans are referenced using the depth from the ground surface, borehole surface coordinates, and the internal magnetic compass (azimuth). By taking a series of scans at different elevations, a 360-degree 3D model of the void can be produced. The scanned void can then be geo-referenced with a magnetic compass.

Output from the Blackhawk systems include: video, volume calculation, 3D point cloud of void wall coordinates; void geometry superimposed on AutoCAD surface map of highway alignment.

The ODOT OGE has contracted with Blackhawk, and others, for void investigation services in the past and continues to utilize this option for jobs around the state. The cost for Blackhawk services varies from job to job depending on the number and depth of holes and the overall complexity of the work requested. Preliminary cost estimates for contract work could not be obtained from Blackhawk.

6. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions are reached as a result of the foregoing investigation of possible solutions for the ODOT subsurface void investigation program:

- Downhole equipment can effectively map subsurface voids and provide significant additional information to guide subsurface investigations, including ground truth, for a mine grouting project.
- Video cameras are essential for vertical (downward) viewing during initial descent into a borehole to look for obstructions and can provide important qualitative information for open voids, such as condition of the void roof, mine pillars, obstructions, and water levels.
- Laser scanning can provide detailed geometry data for open voids, including 3D point clouds and void volume measurements, haulage ways, roof collapses and stowed rooms,
- Sonar scanning can provide detailed geometry data for flooded voids, including 3D point clouds and void volume measurements.
- Sonar effectiveness is limited in turbid waters, which can be caused by drilling operations.
- The development of a single modular probe with video/laser/sonar or laser/sonar capabilities and that can fit down a narrow (4 in.) borehole is not feasible at the current time due to lack of sufficiently small gyroscopes.
- Off-the-shelf equipment is available for independent video, laser and sonar scanning of underground voids.

- Good estimates of mine void volume were obtained using sonar mapping for the Zanesville field demonstration project.

Recommendations

After consideration of the capabilities and costs of downhole void investigation equipment and services, the following recommendations are provided:

- ODOT should continue to use direct subsurface investigation and mapping methods to guide drilling and grouting activities for remediation of underground voids.
- ODOT has recently purchased a GeoVISION camera and thus the decision with regard to downhole video capability has already been made.
- Initially, a consulting contract service, like Blackhawk, should be used for laser and sonar investigations of underground voids until suitable equipment can be purchased.
- ODOT should invest in a downhole sonar probe due to the low cost (approx. \$20k) and the high percentage of flooded mines in Ohio. This purchase will save drilling costs and drilling time and also increase schedule flexibility and decrease response time. It is recommended that ODOT purchase the sonar 881A probe from Imagenex.
- The downhole laser scanner is more expensive (approx. \$110k) and the percentage of open mines is much lower than flooded mines in Ohio. Thus, ODOT may or may not wish to purchase a downhole laser. It is recommended to use a contract service for laser investigations of open voids until a cost/benefit analysis can be conducted.
- A field deployment vehicle should be purchased to facilitate rapid response and ease of equipment use.
- Due to the expected high cost of such work, it is not recommended that ODOT engage in the development of new equipment, such as a single modular video/laser/sonar probe, at this time. Instead, OGE should make use of existing equipment to the greatest possible extent. Thus, Phase II is not recommended and should only be considered if there is clear evidence of favorable benefit-to-cost ratio for such investment. In particular, smaller and more cost effective gyroscopes will be needed prior to the development of a single modular device with video/laser/sonar capability.

7. IMPLEMENTATION PLAN

Implementation of this work will occur once ODOT reaches a decision whether or not to proceed with Phase II. If Phase II is approved, the final specifications and cost of the custom downhole equipment should be reviewed and approved by ODOT prior to purchase. If Phase II is not approved, ODOT should proceed with the use and possible purchase of existing off-the-shelf equipment. Contract work with a downhole void investigation service, such as Blackhawk, will be needed until the necessary equipment can be purchased and tested. The drawback to using a service, however, is potential high cost over time and possible lack of availability of equipment on short notice.

If ODOT purchases additional downhole equipment (laser, sonar), the following issues will need to be addressed:

Personnel – training, maintenance, labor, time in field

Equipment – maintenance, storage, transport

Potential for Loss – equipment caught in hole during insertion or extraction

Software – training, labor required for processing

8. REFERENCES

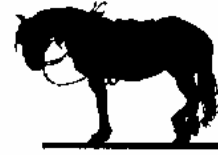
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APPENDIX A

WORKHORSE TECHNOLOGIES REPORT

APRIL 1, 2008



**Stable Construction Company, LLC
Ohio Department of Transportation
Mapping Investigation – Zanesville, OH
Demonstration Project**

Prepared for:

**Stable Construction Company, LLC
5995 Taylor Road
Painesville, OH 44077**

&

**Ohio Department of Transportation
1600 West Broad Street, Room 1105
Columbus, Ohio 43223**

Release Date: **April 1, 2008**

PO No: **088002-4**

Prepared by:

**Workhorse Technologies, LLC
5225 Siesta Drive
Pittsburgh, PA 15236**

Introduction

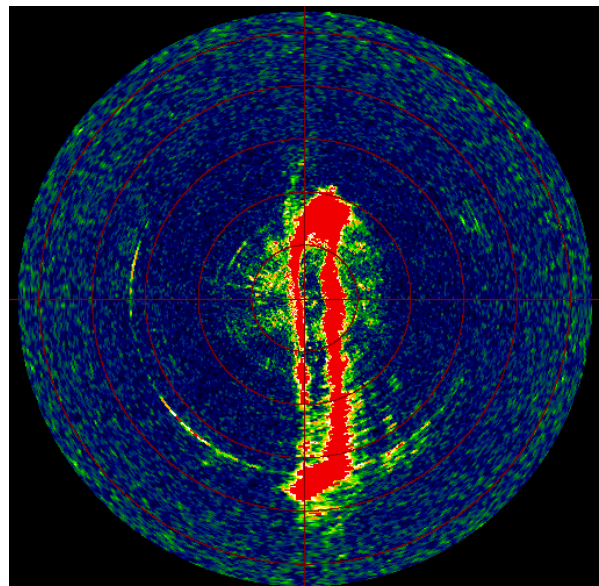
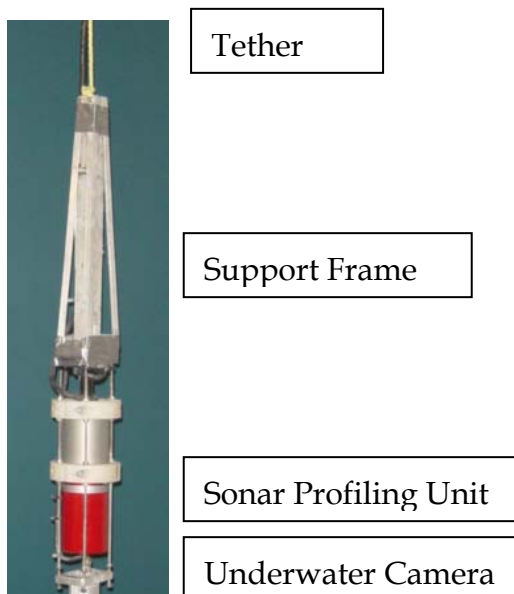
Workhorse Technologies, LLC, conducted sonar mapping of the flooded voids associated with an abandoned coal mine underlying the interchange of SR 93 and US I-70 west of Zanesville, Ohio. This project was planned to demonstrate the capabilities of the Workhorse down hole modeling instruments in both dry and flooded mine voids.

The field work was conducted on March 8, 2008 with ODOT personnel present. Sonar void investigations were conducted in 2 holes to model the mine voids and only 1 of the holes had a void to model. Field reconnaissance determined that previously dry holes had fill above the mine roof and were no longer available for laser investigation.

This report and the accompanying electronic data detail the results of our investigation.

Wet Ferret Sonar Scans

The data was obtained using the Wet Ferret, a tool developed for subterranean mapping. Wet Ferret Figure 1 consists of a profiling sonar unit, color underwater camera, support frame, and tether. The Ferret uses the profiling sonar unit to take range measurements in horizontal planes. By taking scans at different elevations we gather enough data to produce a 3 dimensional model of the void. Scans are referenced using the depth from the surface, relative surface coordinates, and mechanical tubing to maintain orientation. Figure 2 shows a screen capture of a raw sonar scan for review in the field. By examining the data in the field informed decisions can be made on what supplemental scans are needed to completely map a void or plan a next hole.



The Wet Ferret is deployed by hoist from a tripod set up over the hole. Square tubing sections are added to the deployment stack as it is lowered. The square tubing stabilizes the instrument and provides a connection to the surface for pointing the instrument. Sonar data and camera images are recorded through a laptop computer operated from inside the van.



Figure 3 Deployment at hole P6

Analysis

Hole #P6

- Top of casing id flush with the top of the roadway surface
- Water line from surface 29' - 4"
- Roof of the mine void 31' - 6"
- Bottom of hole 34'

- Instrument is oriented parallel with the road and facing north.

Hole #P6 sonar scans revealed a 2.5ft high 15ft wide mine void laying parallel with the road extending 25 ft to the north and 45 ft south. The edge of the void is 5ft west of the hole and 10ft east. The volume of the measured void is approximately 100 cu. yds. Sonar scans did not have clearly defined edges indicating soft material and cloudy water. Typical sonar scans in clear water have resulted in crisp edges for a mine. Post processing algorithms to create models were adjusted to interpret the sonar data. A 3-D model was produced then sectional and orthogonal views of the mine void were produced (Figures 4, 5).

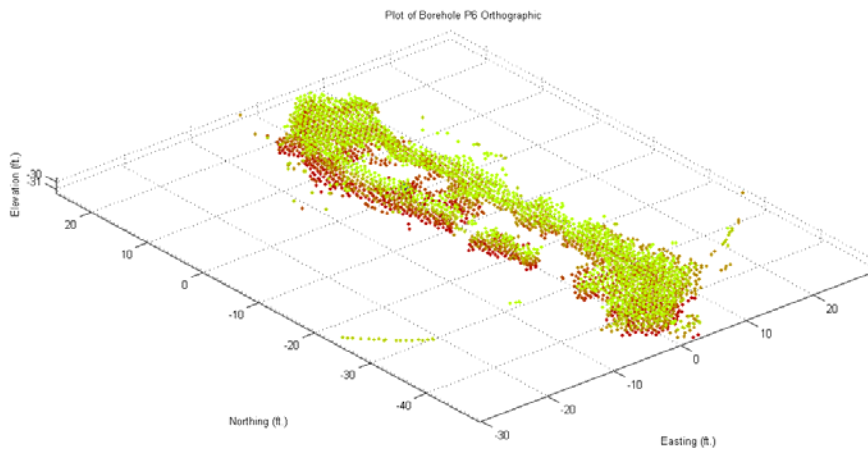


Figure 4 Orthogonal view of P6 Mine Void

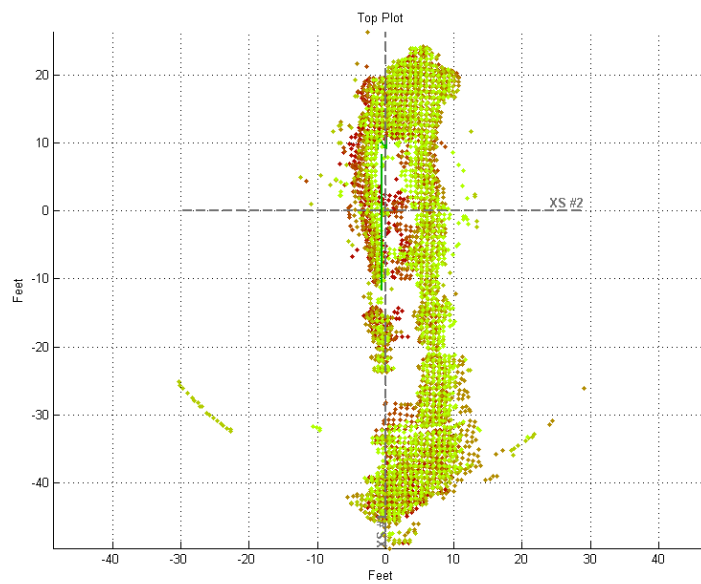


Figure 5: Top View of P6 Mine Void

Hole # O7

- Top of casing was flush with the top of the roadway surface
- Water line from surface 30' 9"
- Bottom of hole 33' 0"
- Instrument is oriented parallel with the road and facing north.

Hole #O7 showed no void in either the sonar or the camera to the bottom of the hole. No sonar data was collected.

Summary

Conditions at this site allowed characterization of only 1 flooded mine void associated with hole P6.

Acknowledgements

Thank you to Stable Construction and Ohio Department of Transportation for this opportunity.

Index to the Electronic Data

The data and analysis is summarized in this written report however the electronic files accompanying this report contain the complete data sets, models and images relaying our investigation. The index of all of the files on the media follows this orientation to the data. The electronic data is presented in several forms:

- 3 dimensional point cloud models – These files consist of a plot in space of all the collected data points and the resulting model is referred to as a point cloud. Perhaps the greatest insight into voids comes from studying these files. By watching the model while manipulating the scene the reviewer often can pick out details not apparent in the sectional plots. The files are in a .wrl format and can be viewed by VRML web based data viewers. Recommended software to view vrml file is *vrmlView* by SIM. This can be downloaded from <http://www.sim.no/download/>.
- 2 dimensional plots – Model plots and screen captures of selected sonar scans are presented in .bmp .jpg or .tif formats.

- Files on the accompanying CD
 - Report
 - P6
 - Photos
 - Results (post processed images and 3-D model)
 - Sonar (included to archive the project)
 - Notes
 - P7
 - Photos
 - Notes
 - Site Photos
 - Contact Information

APPENDIX B

EQUIPMENT QUOTES



WORKHORSE TECHNOLOGIES, LLC

Quote #: 2007-Q-005.1

Date: June 7, 2007

Company: Dept. of Civil and Environmental Engineering
and Geodetic Science
495A Hitchcock Hall
The Ohio State University
Columbus, Ohio 43210

Contact: Patrick J. Fox, Professor
Tel: (614) 688-5695
Fax: (614) 292-3780
Email: fox.407@osu.edu

Attached is a quotation for Workhorse's WetFerret™ 100 submersible modeling instrument and DryFerret™ 200 dry void modeling instrument. WetFerret provides borehole-deployable SONAR modeling capabilities for visualization and accurate measurement of flooded subterranean spaces. DryFerret provides borehole deployable LIDAR modeling capabilities for dry voids. Together the Ferrets provide a solution allowing fast, in-field analysis of underground conditions and delivers definitive information regarding the size, shape and location of dry or submerged subterranean spaces when accuracy matters

We appreciate your consideration. Please feel free to contact us.

Sincerely,

Chuck Whittaker
Operations Manager
Workhorse Technologies, LLC.

WetFerret™ 100

The WetFerret 100 is a borehole-deployable SONAR modeling device, specifically designed to produce three dimensional views of flooded underground spaces. Rugged and portable, the WetFerret 100 is deployable in any low-flow water scenario via borehole or vertical opening with a minimum 4.5-inch diameter. A 3.5 inch diameter version of the system will be made available based on the availability of a newly packaged gyroscope slated for production by 2nd quarter 2008. . WetFerret's imaging technology integrates highly accurate profiling SONAR with video and inertial sensing for quick, in-field assessments of underground conditions. Post-deployment, WetFerret data is fused into 3D models with the Workhorse's DataView software. DataView provides a wide range of functions such as visualization, measurement, volumetric calculations and data export. WetFerret with DataView are well suited for applications such as volumetric estimation for backfilling, mine map verification and correction, and analysis of existing support structures. The system produces 3 D scans by gathering horizontal scans while steadily lowering the unit. Optionally 3 D scans can be produced from a single elevation by implementing a pan and tilt allowing the sonar to look up and down not just horizontally.



SPECIFICATIONS:

WetFerret 100 includes the following:

- Multi-frequency Profiling SONAR
 - Equipped with a tunable frequency from 600 kHz to 1 MHz in 5 kHz steps
 - Capable of range resolution of 10mm (0.4")
 - Measurement range 150mm (6") to 100m (300 ft)
 - Rated maximum operating depth of 1000 m
- Low-light Underwater Video Camera
 - 87° Field of View
 - Adjustable LED array for illumination
- Orientation Sensors
 - Gyro stabilized compass with multi-axis gyroscopic inertial measurement
 - A heading gyroscope capable of maintaining a heading orientation of less than 2 degrees per hour.
- Integrated Kevlar-Reinforced Tether
 - Integrates power, communication, and the strength member
- Computer Interface Module
- Control Notebook Computer with
 - A 60Gb hard drive for in-field data logging
 - A CD-RW, DVD±RW for data archiving and file sharing
 - Integrated wired/wireless NIC for direct link-ups to interface module
 - GUI Control Software installed and configured
 - Microsoft™ Windows XP Pro SP2
- WetFerret 100 Storage Case

Options

- Option exists for a pan and tilt allowing for 360 degree scans on a 45 degree tilt .

- Option exists for a 3.5 inch diameter device
- Option exists for an integrated deployment system

RECOMMENDED CONFIGURATION

Item 1, Qty 1 WetFerret™ 100 \$98,950ea
 4.5 inch diameter borehole-deployable SONAR modeling device with integrated video and inertial sensing, 500 ft tether, control computer and software. This does not include a tether reel or means for deployment.

Item 2, Qty 1 DataView Modeling Software Included
 Data visualization and measurement software. **NOTE: One license of DataView is bundled with the WetFerret Control Notebook Computer. Up to three additional licenses may be purchased at \$1000 per computer with the purchase of a WetFerret product.**
TRAINING IS REQUIRED – PLEASE SEE BELOW

Item 3, Qty 1 WetFerret 100 Storage Case Included
 Protective case to store device while not deployed.

Item 4, Qty 1 Deployment Package \$25,420ea
 This option allow for integrated payout of the tether an automated scanning. Without this the operator must manually deploy the system and enter scan depths into the system Deployment equipment includes a portable powered tether reel system with an integrated payout sensor patched into the operating computer, an industrial tripod, pulleys, and an AC generator. Highly Recommended!

Item 5, Qty 1 Rugged Tether Case \$460ea
 Workhorse recommends casing all WetFerret components while not in usage.

Item 6, Qty 1 Rugged Equipment Case \$460ea
 Workhorse recommends casing all WetFerret components while not in usage.

Item 7, Qty 1 Conversion to a 3.5 inch Diameter tool No Cost
 This no cost option will allow a reduction in diameter from 4.5 inches to 3.5 inches. This option impacts time and is based on the availability of next generation heading gyroscopes scheduled for production in 2008.

Item 8, Qty 1 Pan and Tilt \$21,350
 This option allows for 3 D scans to occur at a single elevation and allows for looking above and below the top and bottom of the borehole opening in the void. To use this option a 2 ft diameter by 2 ft high cylinder of clear void must exist around the instrument. This will add a pan axis capability of 360 degrees, a tilt axis of 45 degrees, and the electronics and software necessary to control and produce modeling data.

DryFerret™ 200

The DryFerret 200 is a borehole-deployable LIDAR modeling device, specifically designed to produce three dimensional views of dry underground spaces. Rugged and portable, the DryFerret 200 is deployable in borehole or vertical opening with a minimum 4.5-inch diameter. A 3-inch diameter version of the system will be made available based on the availability of a newly packaged gyroscope slated for production by 2nd quarter 2008. DryFerret's imaging technology integrates highly accurate LIDAR and inertial sensing for quick, in-field assessments of underground conditions. Post-deployment, DryFerret data can be collected and imported into commercial data analysis software. DryFerret is well suited for applications such as profiling and orienting underground voids, verifying backfilling, and mine map verification and correction.



SPECIFICATIONS:

DryFerret 200 includes the following:

- High speed LIDAR unit
 - The high speed laser with electronics resides on the surface and an only the optical head is deployed down the hole.
 - Capable of ranges of greater than 50 meters to most types of surfaces with a measurement resolution of 25mm (1")
 - Rated maximum operating length of 100 m
- Orientation Sensors
 - Gyro stabilized compass with multi-axis gyroscopic inertial measurement
 - A heading gyroscope capable of maintaining a heading orientation of less than 2 degrees per hour.
- Integrated Kevlar-Reinforced Tether with fiber optic cables
 - Integrates power, communication, fiber optics for the LIDAR, and the strength member
- Computer Interface Module
- Control Notebook Computer with
 - A 60Gb hard drive for in-field data logging
 - A CD-RW, DVD±RW for data archiving and file sharing
 - Integrated wired/wireless NIC for direct link-ups to interface module
 - GUI Control Software installed and configured
 - Microsoft™ Windows XP Pro SP2
- DryFerret 200 Storage Case

Options

- Option exists for a pan and tilt allowing for 3 D scans from a single elevation. This adds 360 degree pan and a 45 degree tilt mechanism to the device.
- Option exists for a 3.0 inch diameter device
- Option exists for an integrated deployment system

RECOMMENDED CONFIGURATION

Item 1, Qty 1 DryFerret™ 200

155,000ea

| Item | Qty | Description | Unit Price | Total Price | Notes |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----------------------------------|------------|-------------|-----------------|
| Item 2, Qty 1 | | DataView Modeling Software | | | Included |
| Data visualization and measurement software. NOTE: One license of DataView is bundled with the DryFerret Control Notebook Computer. Up to three additional licenses may be purchased at \$1000 per computer with the purchase of a WetFerret product. | | | | | |
| TRAINING IS REQUIRED – PLEASE SEE BELOW | | | | | |

| | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|-------------------|
| Item 4, Qty 1 | Deployment Package | \$25,420ea |
| <p>This option allows for integrated payout of the tether and automated scanning. Without this the operator must manually deploy the system and enter scan depths into the system. Deployment equipment includes a portable powered tether reel system with an integrated payout sensor patched into the operating computer, an industrial tripod, pulleys, and an AC generator. Highly Recommended!</p> | | |

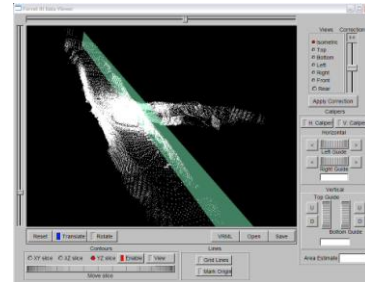
Item 5, Qty 1 Rugged Tether Case **\$460ea**
 Workhorse recommends casing all DryFerret components while not in usage.

| | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| <p>Item 7, Qty 1 Conversion to a 3.0 inch Diameter tool</p> | <p>No Cost</p> |
| <p>This no cost option will allow a reduction in diameter from 4.5 inches to 3.0 inches. This option impacts time and is based on the availability of next generation heading gyroscopes scheduled for production in 2008.</p> | |

| | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| <p>Item 8, Qty 1 Pan and Tilt</p> <p>This option allows for 3 D scans to occur at a single elevation and allows for looking above and below the top and bottom of the borehole opening in the void. To use this option a 2 ft diameter by 2 ft high cylinder of clear void must exist around the instrument. This will add a pan axis capability of 360 degrees, a tilt axis of 45 degrees, and the electronics and software necessary to control and produce modeling data.</p> | <p>\$21,350</p> |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|

DataView Software includes the following capabilities

- Ferret Data Fusion Algorithms for 3D Modeling
- Visualization and Measurement Utilities
- Volumetric Estimation Tools
- Data Export Utilities



Quoted Options

• DEPLOYMENT PACKAGE OPTION

The deployment package includes all the necessary components for a WetFerret field deployment. The motorized tether reel and integrated tether payout system simplify and streamline the deployment process, reducing time and improving the accuracy of the final model. Included in this package are:

- Heavy-duty Deployment Tripod
- Motorized Tether Reel
- Integrated Payout Sensor
- Enhanced Computer Controller
- Deployment Software integrated into User Interface
- Portable Inverter Generator



• RUGGED TETHER CASE

The tether case provides protection against damage to the tether during transport. Dangling lengths of tether can easily become crushed, pinched or cut when moving from site to site, so good tether care through proper storage is highly recommended.

• RUGGED EQUIPMENT CASES

Supplemental Ferret equipment cases provide protection and organization to additional device components. As with all DryFerret components, proper care and protection is important to the operational lifetime of the device.



• ADDITIONAL SOFTWARE LICENSES

Additional DataView licenses are available so that users are free to analyze logged WetFerret Data from their own computer workstation. Note: PC must be Windows based and support the requirements of the DataView software.

• ADDITIONAL 500 FT SONAR TETHER

A 500 ft SONAR only tether can be purchased to allow for operations greater than the

300 ft dual purpose tether provided with the DryFerret, This tether can be spooled onto the deployment system.

Ferret™ Combined Wet and Dry systems

By combining both the wet and dry systems common components such as the gyroscope, operating computer tether, deployment system pan and tilt, are common to each system allowing for savings. Operations will require the sensor to be configured as wet or dry and the operators will need to mechanically change out the wet or dry sensors on the surface.

Options

- Option exists for a pan and tilt allowing for 360 degree scans on a 45 degree tilt .
- Option exists for smaller diameter device
- Option exists for an integrated deployment system

RECOMMENDED CONFIGURATION

Item 1, Qty 1 Combined wet and dry ferrets 214,000ea
4.5 inch diameter borehole-deployable SONAR and Lldar modeling devices with integrated video and inertial sensing, 300 ft tether, control computer and software. This does not include a tether reel or means for deployment.

Item 2, Qty 1 DataView Modeling Software Included
Data visualization and measurement software. **NOTE: One license of DataView is bundled with the Ferret Control Notebook Computer. Up to three additional licenses may be purchased at \$1000 per computer with the purchase of a WetFerret product. TRAINING IS REQUIRED – PLEASE SEE BELOW**

Item 3, Qty 2 Ferret Storage Cases Included
Protective cases to store the device while not deployed.

Item 4, Qty 1 Deployment Package \$25,420ea
This option allow for integrated payout of the tether an automated scanning. Without this the operator must manually deploy the system and enter scan depths into the system Deployment equipment includes a portable powered tether reel system with an integrated payout sensor patched into the operating computer, an industrial tripod, pulleys, and an AC generator. Highly Recommended!

Item 5, Qty 1 Rugged Tether Case \$460ea
Workhorse recommends casing all WetFerret components while not in usage.

Item 6, Qty 1 Rugged Equipment Case \$460ea
Workhorse recommends casing all tFerret components while not in usage.

Item 7, Qty 1 Conversion to smaller Diameter tools No Cost
This no cost option will allow a reduction in diameter. This option impacts time and is based on the availability of next generation heading gyroscopes scheduled for production in 2008.

Item 8, Qty 1 Pan and Tilt \$21,350
This option allows for 3 D scans to occur at a single elevation and allows for looking above and

below the top and bottom of the borehole opening in the void. To use this option a 2 ft diameter by 2 ft high cylinder of clear void must exist around the instrument. This will add a pan axis capability of 360 degrees, a tilt axis of 45 degrees, and the electronics and software necessary to control and produce modeling data.

Item 9, Qty 1 500 ft SONAR tether

\$7,000

This option allows for the SONAR head to be lowered an additional 200 ft beyond the 300 ft LIDAR tether that can be used for both devices.

| |
|-----------------|
| TRAINING |
|-----------------|

Qty 1 ON-SITE INSTALLATION & PRODUCT TRAINING

To ensure proper and efficient utilization of the tools, product and software training is required.

Qty 1 IN-FIELD PRODUCT TRAINING

Training on the use of the dry ferret and data collection and verification at an actual site. Three (3) day minimum for up to three (3) trainees – scheduling and site to be determined. Training to be performed at time of equipment delivery.

\$5000 / day plus travel and subsistence at cost.

Qty 1 IN-HOUSE SOFTWARE TRAINING

Training on the use of the data analysis tools using pre-collected or simulated data. One (1) day minimum for up to three (3) trainees – scheduling and site to be determined. Training to be performed at time of equipment delivery.

\$2000 / day plus travel and subsistence at cost.

Qty 1 SUPPLEMENTAL TRAINING AND PHONE SUPPORT

Additional training is available at our standard field service rates

Standard hours - \$120/hr

Overtime - \$240/hr (applies for all hours after 6pm; all hours greater than 8 in a 24-hour period, all weekend hours)

RUSH - \$300/hr (< 72 hour notice, at Workhorse discretion depending on availability of personnel)

All travel and subsistence expenses at cost. Labor rate applies to all hours personnel are available on site regardless of whether they are required to perform operations or not.

Warranty, Standard Terms & Conditions – See attached.

Order Form Deluxe Motorized Winch GeoVISION™ Borehole Camera System

| | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| The Two Year Limited Warranty applies to the GeoVISION Deluxe system when purchased with a stainless steel camera. 2YW = Parts covered by the Two Year Warranty | Cash Discount System Price |
| Motorized GeoVISION winch with tripod, OSD, control panel, centralizer, Camera Lights On/Off circuit for standard stainless steel cameras, and deluxe case. | \$8625 |
| Motorized Pan-tilt- 1¾ inch diameter - St/Jr cameras only (GVJR-1233) - 2YW | |
| Standard Stainless Steel B/W camera 1 5/8 inch Diameter (GVJR-1080) - 2YW | 3500 |
| 325 feet of cable – Approximately 100 meters (GVJR- 924) | 228 |
| Sony DVD recorder VRD-MC5 (MP-1603) | 400 |
| 7 Inch LCD High Resolution and high Brightness color monitor – Sun shade and winch mounting bracket (GVJR-1225) | 600 |
| Super Eight Light 2000 – 8 modified Mini Maglites and bracket (GVJR-1213) | 615 |
| Compass attachment - (GVJR-067A) | 25 |
| Inverter 300 Watt - true sine wave (MP-1450) | 195 |
| Microphone (MP-0195) | 45 |
| | |
| Sub Total | \$14,233 |
| Shipping, handling, and insurance | 116 |
| Total | \$14,349 |

| | |
|-------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Quote for: Patrick Fox Ohio Dept of Transportation ODOT, ROADWAY ENGINEERING 25 SO. FRONT ST., ROOM 620 Columbus, OH 43210 | Ship To: Patrick Fox Ohio Dept of Transportation ODOT, ROADWAY ENGINEERING Columbus, OH 43210 |
| Contact Information: 858-822-0431 | Billing and Payment Information: To be determined |
| Date: 14 January 2010 | Shipping instructions: UPS |

Eligibility for the Cash Discount Price requires that payment is made before shipment by cash, check, credit card, or money transfer. The retail price applies to any customer who receives credit. Credit is only granted to: 1. Established USA and Canadian institutions and corporations with AAA financial ratings and, 2. Businesses outside the USA that qualify for insurance through the US Import/Export Agency.

Marks Products, Inc. 1243 Burnsville Road, Williamsville, VA 24487-2147

For Marks Products information, sales, brochures, DVD's, and prices call John Wilson at **800-255-1353** toll free from the US and Canada, elsewhere 804-741-4274. Fax 866-871-9646, Email john@geovision.org, or website www.geovision.org
1 December 2008



Measurement Devices US LLC
17555 Groeschke Road
Houston, TX 77084
Phone: 281-646-0050 Fax: 281-646-9565
website: www.mdl-laser.com

QUOTATION

| Date | Quote #: |
|-----------|----------|
| 1/15/2010 | Q-72035 |

| |
|------------------------------------------------------------------------------------------------------------------------------------|
| CUSTOMER'S NAME |
| Ohio State University Dept. of Civil and Environmental Engineer Patrick J Fox 495A Hitchcock Hall Columbus, Ohio 43210 |

| |
|-----------------------|
| Customer Phone |
| 614-688-5695 |

| |
|---------------------|
| Customer Fax |
| 614-292-3780 |

| DESCRIPTION | QTY | COST | TOTAL |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----------|------------|
| MDL C-ALS BASE SYSTEM - ROBOTIC LASER CAVITY SURVEYING SYSTEM A self navigating, "motorized" robotic probe designed to enter and survey dry abandoned mine workings or natural cavities. | 1 | 85,000.00 | 85,000.00 |
| Additional 50M Cable to Base System | 1 | 4,000.00 | 4,000.00 |
| 50m Borettrak® Rod Upgrade | 1 | 10,000.00 | 10,000.00 |
| Ruggedised tablet PC for use on-site. Includes: WiFi, Bluetooth, & USB ports, additional battery and AC Power adaptor & Battery charger. | 1 | 4,700.00 | 4,700.00 |
| Daily Rate For MDL Personnel for Training or Equipment Operations - 4 Days For C-ALS * Customer is responsible for all travel related expenses * A detailed list of equipment and software being provided is attached to this quotation. * MDL Standard Terms & Conditions of Sale - Support Services apply (Copy Attached) Shipping charges are not know at this time so these will be billed when known. | 4 | 1,000.00 | 4,000.00 |
| Item #8005: Voidworks Software Advanced viewing, editing and modeling of C-ALS point clouds to form solids and calculate volumes. The Subtotal of the figures above. | | 15,500.00 | 15,500.00 |
| * A 10% Discount on the quoted prices will be given if an order is received within 30 Days from the date of this quotation | | -10.00% | -12,320.00 |



C-ALS

| | |
|-----------------------------------------|---------------------|
| Subtotal | \$110,880.00 |
| Sales Tax, if applicable (8.25%) | \$0.00 |
| Total | \$110,880.00 |

WIRE TRANSFER DETAILS:
Chase Manhattan Bank (Houston Region)
Houston, Texas 77002 USA
Account Number: 733590798
Sort code: 113-000-609 Swift Code: TCBKUS44

Payment Options
Payment In Full By CC, Check or COD
Wire Transfer to MDL's Bank Account
Setup Credit Account

Quotation is valid for 30 days.

Kindly Awaiting your response,

Bradley J. Husack

BRADLEY HUSACK
email: bhusack@mdl-laser.com

Should you have any questions, please don't hesitate to contact us.

Delivery Time: 3 to 5 Weeks After Receipt of Order



QUOTE

Imagenex Technology Corp.
209-1875 Broadway St., Port Coquitlam, BC, V3C 4Z1
Ph: 604-944-8248 Fax: 604-944-8249
imagenex@shaw.ca

DATE: JANUARY 14, 2010
IMAGENEX REF #125423

THIS QUOTE IS VALID FOR: 30 DAYS

TO Patrick Fox

| SALESPERSON | SHIPPING METHOD | SHIPPING TERMS | DELIVERY | PAYMENT TERMS |
|--------------|-----------------|---------------------------|---------------|---------------|
| Steve Curnew | TBA | F.O.B. Port Coquitlam, BC | 4-6 weeks ARO | Prepaid |

| ITEM # | QTY | DESCRIPTION | UNIT PRICE | LINE TOTAL |
|--------|---------|--------------------------------------------------------------------------------------------------------------------------------|-------------------------|--------------|
| 1 | One (1) | Model 881-000-420 "881A 1000 m Depth Unit" Digital Multi-Frequency Profiling Sonar, with Option -009 End Mount Connector | \$ 13,900.00 | \$ 13,900.00 |
| 2 | One (1) | -030 Pitch Roll And Heading Sensor | \$ 4,000.00 | \$ 4,000.00 |
| 3 | One (1) | Power Supply Box with built-in Sea-level Serial to USB Converter (Plug and Play Module) | \$ 1,200.00 | \$ 1,200.00 |
| 4 | One (1) | Option -033 100 m (330') Cable | \$ 1,320.00 | \$ 1,320.00 |
| | | | SUBTOTAL | \$ 20,420.00 |
| | | | GST (ZERO RATED) | 0.00 |
| | | | TOTAL | \$ 20,420.00 |

Quotation prepared by: Steve Curnew

This is a quotation on the goods named, subject to the conditions noted below:

All prices in Canadian dollars

All applicable Duties and Taxes are extra

IMAGENEX TECHNOLOGY CORP. NEW PRODUCT WARRANTY

Imagenex Technology Corp. warrants its products for a period of one year from shipment date against defects in materials and workmanship. Imagenex Technology Corp. will, at its option, repair or replace products which prove to be defective, within the warranty period.

Defective products must be returned to the factory, or an authorized repair depot, at the customer's expense. Imagenex Technology Corp. will pay return shipping charges if the repair or replacement is covered by the warranty.

No other warranty is expressed or implied.

Thank you for your interest in Imagenex products!