MISSOURI S&T

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

Formerly University of Missouri-Rolla

SHORT TERM RESEARCH PROPOSALS FOR THE ALPHA FOUNDATION FOR THE IMPROVEMENT OF MINE SAFETY AND HEALTH

PROPOSAL TITLE:	Proposal for the Development of a Method for Full-Field Automated Detection of Precursor Movement in Underground Pillars and Backs using LIDAR
GENERAL FOCUS AREA:	Safety: Technology or engineering control innovations that significantly enhances mine safety… Alternative protocols for assessing and sampling mine conditions and identifying safety … hazards.
INSTITUTION:	The Curators of the University of Missouri on Behalf of Missouri University of Science and Technology 300 W. 12th Street 202 Centennial Hall Rolla, MO 65409-1330 Telephone: 573-341-4134 Fax: 573-341-4126 Email: research@mst.edu
PRINCIPAL INVESTIGATOR:	Dr. Norbert H. Maerz 1006 Kingshighway Rolla MO 65409-0660 Telephone: 573-341-6714 Fax: 573-341-4368 Email: norbert@mst.edu
AUTHORIZING OFFICER:	Dr. K. Krishnamurthy, Vice Provost for Research Administrative POC: Ms. Michelle Smith 300 W. 12th Street 202 Centennial Hall Rolla, MO 65409-1330 Telephone: 573-341-4134 Fax: 573-341-4126 Email: research@mst.edu DUNS Number: 8048837670000
PERIOD OF PERFORMANCE:	January 1, 2014 to March 31, 2015
REQUESTED FUNDING:	$148,497

The Curators of the University of Missouri on behalf of Missouri University of Science and Technology

K. Krishnamurthy 12/12/13

Dr. K. Krishnamurthy — Date

Vice Provost for Research

SECTION A: RESEARCH PLAN

1. Executive Summary

In underground mines, roof falls and pillar failures can often be predicted because they are usually preceded by very small accelerating distressing movement. Measurement of such movement can alert the mine to the immanent danger of rock falls, giving the mine an opportunity for remedial action to prevent the failure or to evacuate the area and mitigate injury and damages. The current technology used to measure minute deformations that can predict catastrophic failure consists mainly of mechanical/electric devices such as extensometers that need to be installed (typically involving drilling) each in a single location. Unfortunately, these devices must be installed exactly at the point of failure and are not useful if the failure propagates from a different location. It is too expensive to effectively monitor any more than a few isolated locations. Consequently these techniques are rarely used proactively, i.e. before problems are encountered. Rather they are used reactively when problems have advanced significant near or past catastrophic failure. What is needed is a more cost effective method to detect these deformations over large areas of a mine, before they fully develop. LIDAR (LIght Detection And Ranging) scanning technology provides such an opportunity.

LIDAR scanning technology can be used to measure small amounts of movement over large areas but, currently, LIDAR data collection and analysis methods are labor-intensive, and imprecise. This proposal seeks funding to develop sub-millimeter accuracy and precision of the LIDAR data collection process in mines, and develop software algorithms for automatically registering images and automatically analyzing small deformations (change detection) over time and over large fields, and implement and test the methods in a local mine.

This proposed research addresses two of the criteria in the broad mining health and safety arena:

- Technology or engineering control innovations that significantly enhances mine safety or health beyond current levels by strategically addressing gaps or preventing catastrophic conditions from occurring.
- Alternative protocols for assessing and sampling mine conditions and identifying safety or health hazard using technologies that can improve accuracy, provide information as not currently attainable, and/or provide opportunities for faster and more effective resolution.

The impact of this proposed technology will be to ultimately make mines safer – saving lives, reducing injuries, and minimizing the loss of equipment and mining areas. This technology will change the prediction of rock fall from a reactive process (where predictive measurements are made in localized spots only after problems have manifested themselves) to a proactive approach (where measurements over large areas can be used to anticipate problems before they happen).

A small pilot study has been undertaken that shows the ability to measure small deformations. These deformations can be measured at resolutions approaching 0.001".

2. Problem Statement and Assessment of Barriers to Solving the Problem

2.1 Problem Statement

In underground mines, roof falls and pillar failures can have serious consequences to personnel. In addition to direct injury and death, personnel can be trapped, or they can be injured by a concussion wave. In many cases, these types of failures can be predicted if the appropriate measurements can be made. For example, in deep mines, microseismic monitoring can predict rock bursts. In all mines, early measurements of minute convergence movements can predict rock falls and bursts. Figure 1 shows a typical strain-time curve for time-dependent deformation that is typical of most rock failures. Very often, catastrophic failures, as shown on the right side of the graph, follow a period of steady-state small-scale deformation. Typically, once an acceleration of the deformation occurs, catastrophic failure follows. If movement can be measured, then the accelerating deformation that leads to catastrophic failure can be predicted and

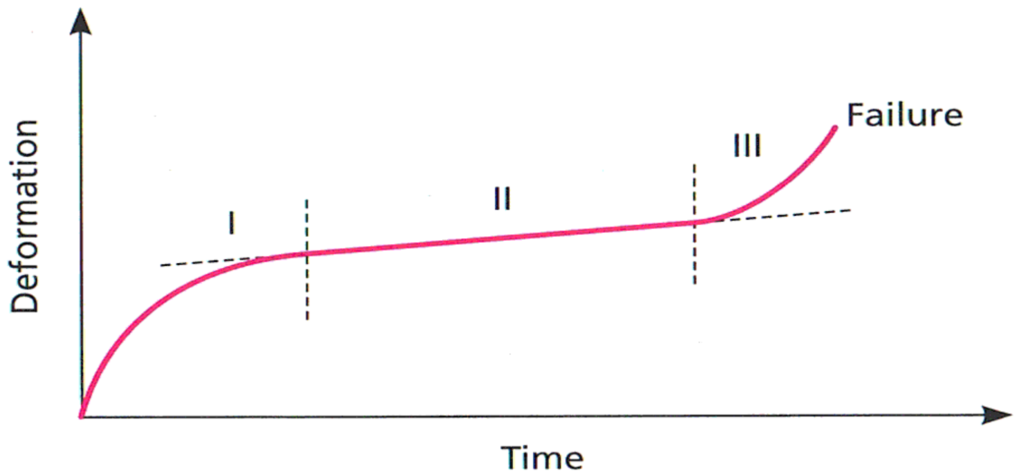


Figure 1: Time dependent deformation curve [1]. Primary or transient creep (I) changes to secondary or steady state creep (II) as the initial stress conditions have been relieved. This phase can last a very short time or a very long time. As the material gets damaged over time it may enter the tertiary of accelerating creep phase (III) leading inevitably to catastrophic failure.

in many cases, remediation or reparation efforts can prevent the catastrophic failure or at least catastrophic consequences.

This proposed research addresses two of the criteria in the broad mining health and safety arena:

- Technology or engineering control innovations that significantly enhances mine safety or health beyond current levels by strategically addressing gaps or preventing catastrophic conditions from occurring.
- Alternative protocols for assessing and sampling mine conditions and identifying safety or health hazard using technologies that can improve accuracy, provide information as not currently attainable, and/or provide opportunities for faster and more effective resolution.

2.2 Assessment of Barriers Toward Solving the Problem

Instruments such as extensometers are routinely used for measuring movement leading up to catastrophic failure [2]. There are many different types of extensometers, including single and multiple point borehole extensometers [3], tape, wire, rod extensometers [4], and newer optical and laser extensometers. Some use manual measurements, some require manual transcription of measurement results, and others are automated with remote data collection. In laboratory settings over short distances, measurements of less than 0.01 mm are possible. Installing one of these devices and monitoring displacement at these minute levels can result in an excellent predictive ability.

While this technique works very well, one extensometer can only measure movement in a single small location, making placement of the instrumentation of tantamount importance. Placing many extensometers in a mine would enable that mine to cover larger areas, but the expense related to the technology - including instrumentation, installation, and data analysis costs – makes that solution cost-prohibitive. It is hard to comprehend that any mine could afford to install even a tiny fraction of the instrumentation that might be required. For that reason, instead of taking a proactive approach, mines install these devices only in localized areas after serious problems manifest themselves.

In the past, surveying techniques have been used to measure change detection over larger areas, but have not had the required precision. Also, collecting LIDAR data has been a very labor-intensive process. Data reduction and preparation are also slow, labor-intensive processes, and change detection algorithms are not yet widely available. Current commercial LIDAR technology and processing software can be used to accurately measure the geometry of large areas in just a few minutes. However, the single-point accuracy of out-of-the-box LIDAR data typically exceeds 8 mm – too coarse to measure the type of sub-millimeter movements required for detecting pre-collapse rock mass movements. In addition, both the registration process and post-processing environment for change detection in LIDAR data are unrefined and very labor intensive.

3. Innovation Identification and Goals

3.1 Innovation Identification

The problem, as stated earlier in this proposal, is that while deformation/convergence can be used to predict spalling/rock fall (Figure 1), existing technologies can only make cost effective measurements in single locations or very small areas. LIDAR measurements, on the other hand, can make measurements over large areas from a single scan or multiple areas by moving the LIDAR.

As a distance measuring device, LIDAR replaces traditional methods of laser surveying, which take individual measurements, and require reflective targets to measure distances and angles. LIDAR is more analogous to radar, in that the scanning laser can make up to 1,000,000 point measurements per second, returning a dense point cloud, which can be used by sophisticated software to create a very detailed surface map. At Missouri S&T, a Leica ScanStation II®, a Leica HDS6000®, and a Faro Focus3D®, are all terrestrial LIDAR scanners that have been used for similar projects. These have a range of over one hundred meters, and a sampling resolution of less than 1 mm, allowing the measurement of differences of less than 0.025 mm in some circumstances.

While basic measurements are possible now with specially developed software (deformation, Figures 2 and 3, and rock fall, Figures 4 and 5), current methods rely on human interaction in many of the phases. This proposal seeks to automate the entire positioning, scanning, data transfer, and data analysis processes, as well as significantly increase the precision and accuracy of the measurements.

Figure 2: Bridge span loaded with gravel filled trucks.

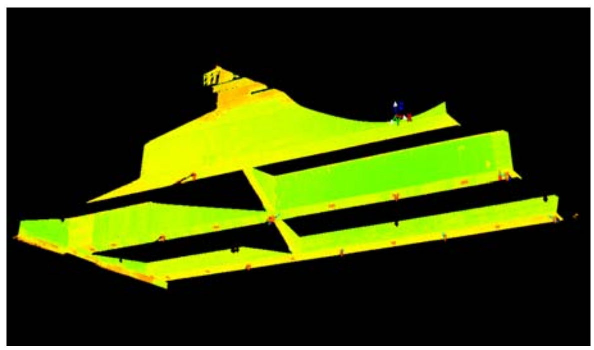


Figure 3: LIDAR scan (point cloud) of the underside if the bridge, measuring deflections from the loaded trucks within 0.1 mm.

The innovations of this proposed research are:

1. To develop and enhance the LIDAR measuring technology to sub-millimeter resolution, while maintaining a fast and wide ranging scans.
2. To develop highly accurate automated registration and change detection algorithms.

Recent research conducted at Missouri S&T has addressed both of these issues. Measurement precision can be significantly increased by use of specialized statistical methods and over-sampling. When thousands of individual, precisely registered points are analyzed using advanced statistical methods, sub-millimeter displacements can be detected. Similarly, the use of large spherical registration targets can result in marked increases in registration accuracy, due to the fact that thousands of LIDAR measurements can be made and mathematically processed to derive a single high-precision coordinate value representing the center of the spherical target. Preliminary research in applying these advanced techniques has demonstrated that detection of sub-millimeter deformation is possible using LIDAR.

LIDAR surveying technology can make very accurate measurements over large areas. As an example of high resolution measurements, the authors conducted a study to measure the health of Missouri bridges, in which several

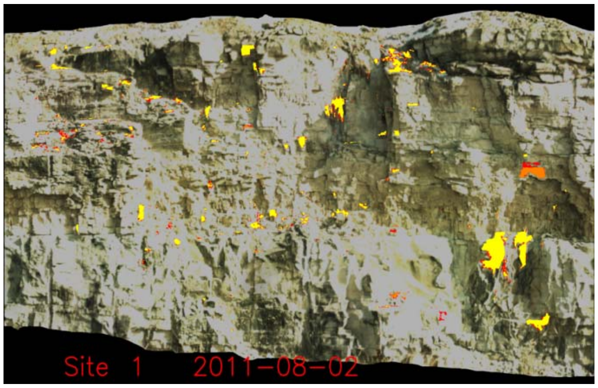


Figure 4: Progressive raveling on a quarry ledge. Yellow, 7/15/2011, brown 7/26/2011, red 8/02/2011.

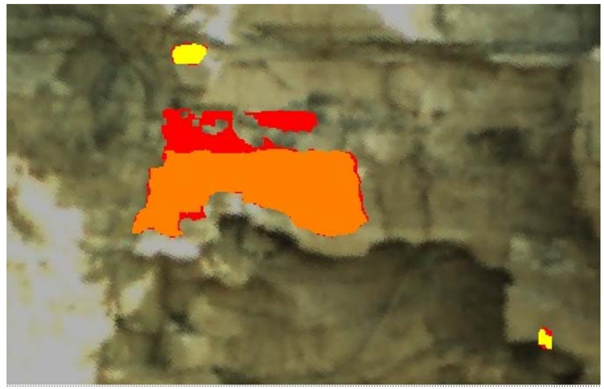


Figure 5: Close-up of progressive raveling measurements.

bridges were loaded using heavy trucks (Figures 2 and 3). The deflection of the bridge was measured using before and after LIDAR scans. Deflections of between up to 2.5 mm were measured with an error of less than 0.1 mm in most cases.

Researchers at Missouri University of Science and Technology have extensive experience in LIDAR imaging, focusing on creating automated data collection protocols and developing efficient automated software algorithms. The focus of our LIDAR research has always been to develop methods and software for accurate measurement with less effort and more automation. Our techniques include:

1. Forgoing traditional survey control whenever possible (for increased speed and accuracy).
2. Tight referencing on scanner position to decrease secondary error levels.
3. Synthetic recovery of base LIDAR position using advanced surface-correlation techniques to match unique topographic surfaces.
4. Automatic high-precision registration methods based on dense scans of pre-positioned stationary spherical targets.
5. Using single scans rather than multiple scans wherever possible.

Related projects include:

1. Completion of a study to measure the health of bridges by loading the bridges with heavy trucks (Figures 2 and 3). The deflection of the bridge was measured using before and after LIDAR scans. Deflections of between 0.5 to 2.5 mm were measured with a calculated error of less than 0.1 mm in most cases.
2. Several years of experience with measuring rock falls from quarry benches and highway rock cuts. Figures 4 and 5 show a rock cut with the missing (fallen) rock areas highlighted. The smallest rock fragment that could be reliably identified was about 9 mm across. In a sixteen month study rock fall episodes were correlated to rainfall, seismic activity (nearby blasting) and freeze-thaw cycling [5,6].
3. Development of a totally remote-controlled robotic crawler (Figure 6) capable of moving unattended through potentially dangerous spaces such as underground openings and of mapping the underground spaces (Figures 6 and 7) [7].
4. Development of new and novel “smart” software filters to identify and remove vegetation from LIDAR data. These filters maintain the high-frequency spatial characteristics of rock surfaces and edges while eliminating non-rock features such as vegetation (Figures 8 and 9) [8].
5. Working to complete a project to determine the depth of delamination of bridge decks under the process of hydro-demolition (Figures 10 and 11).

Figure 6: Robotic crawler with remote controlled LIDAR, camera, navigation, lift table, and stabilizing legs, inside the Missouri S&T experimental mine

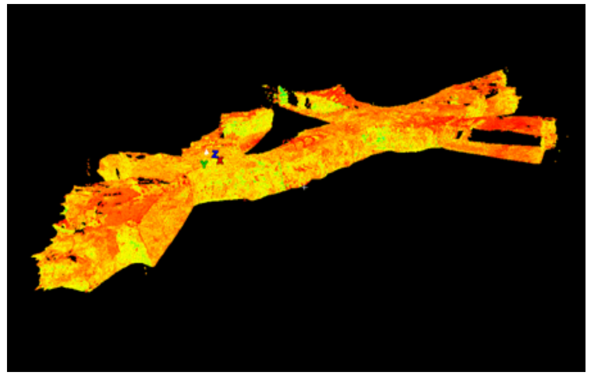


Figure 7: LIDAR mapping of the inside of the Missouri S&T experimental mine.

Figure 8: LIDAR scan of a rock face with vegetation.

Figure 9: LIDAR scan of a rock face with vegetation removed by 'smart' software filters.

Figure 10: Bridge deck scanning after hydrodemolition.

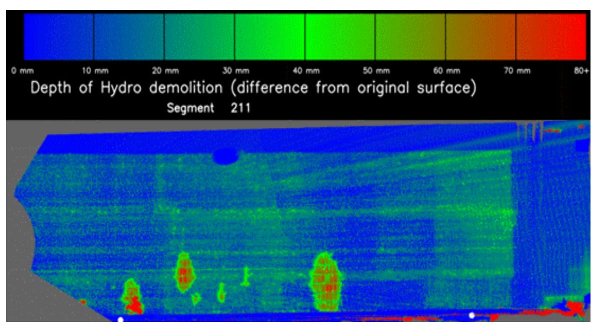


Figure 11: Bridge deck scan results, showing thickness of hydrodemolition.

3.2 Goals and Objectives of the Innovation and Research Approach

3.2.1 Long Term Objectives of the Research Team

The long term objective of the research team is to implement a completely automated method of measuring very small deformations of roofs and pillars of mines as a predictor of future instability, using a LIDAR scanner that is mounted on a completely automated unmanned mobile platform. The LIDAR scanner would continuously move through a pre-programmed loop in the mine, stopping at pre-determined locations to repeatedly scan the mine roofs and pillars. Change detection algorithms will identify minute movements and would warn the mine when these movements increase and trend towards rock fall and catastrophic failures. Pending funding of this proposal, funding will be sought to completely automate the measurements.

3.3.2 Objectives for this Proposed Research Project

The current objectives for this proposed research are to develop the methods for sub-millimeter change detection in large areas of underground facilities. In addition, these methods will measure, in an operating mine, rock fall shapes, sizes, locations and total quantities, and these will be related to precursor movements at the site of the failures, large or small.

The objective of this research proposal is to ***develop a LIDAR-based, deformation measurement capability that can scan entire sections of underground openings***. This will require the following individual steps:

1. Develop LIDAR "whole room" scanning routines that can return sub-millimeter measurements.
2. Improve existing and develop more powerful algorithms for registering successive scans and performing high resolution change detection on the whole room scans. The goal is sub-millimeter change detection.

The objective is to be able to measure both the location and size of fallen rock (similar to Figures 3 and 4), and the movement (convergence) of the rock over all the back, walls, and pillars that are in the line of sight from an individual scan. Ultimately in addition to providing this capability, the goal is to develop relationships between convergence and spalling/collapse, not only on a temporal basis, but also on a spatial basis.

3.3 Impact of the Research

The impact of this proposed technology is that it will ultimately lead to safer mines - saving lives, reducing injuries, and reducing the loss of equipment. This technology will change the prediction of rock fall from a reactive process (where measurements are made in localized spots only after problems have manifested themselves) to a proactive approach (where measurements over large areas can be used to anticipate problems before they happen). The cost of this dramatically increased capability, once developed, will require only a modest amount of capital equipment costs, and negligible operating costs.

Currently, no cost effective deformation detection technology exists for the monitoring of large separate areas within a mine environment.

Upon completion of the work, funding will be sought to implement the completely automated mobile application and to explore the feasibility of commercializing the product to make it widely available.

4. Research Strategy

4.1 Research Approach

The approach to this research will be to first develop the methodology, including hardware and software adaptations, to make these precise measurements over large areas and then to demonstrate that the technology can work in an operational mine to predict and measure actual roof and pillar instabilities.

4.1.1 Research Facilities

Research will at first be conducted using Missouri S&T research facilities, which are ideally outfitted to support this type of activity. The S&T Rock Mechanics and Explosives Research Center (RMERC) houses multidisciplinary researchers specializing in Geological Engineering, Mining Engineering, Geology, Computer Science, and Computer

Engineering. The RMERC contains a fully equipped machine shop with all the capabilities required for the manufacture of components to support this research. In addition, the RMERC contains a modern electronics lab staffed with specialists and systems engineering. Development of all software and hardware, and initial testing will be accomplished at the RMERC facility. In addition, outdoor space is available for initial trials.

The research will then continue at Missouri S&T's Experimental Mine – a real mining environment near campus used for teaching and for surface and underground mining and explosives technology research (Figure 12). An instrumented steel frame rock wall deformation simulator will be used within the S&T Experimental Mine to test the process under real (dusty, high humidity) mine conditions.

Final testing will occur at Doe Run's Buick Mine – an active lead/zinc mine in south-east Missouri (Doe Run is a supporting partner for this research) (Figure 13). This testing will not be limited to developing the actual methodology, but actually testing the implementation, and establishing a correlation between precursor deformation and rock fall.

Figure 12: Missouri S&T's underground experimental mine.

Figure 13: Spalling pillar in Doe Run's Buick Mine.

4.2 Research Plan

4.2.1 Task 1- LIDAR scanning method and protocol

A LIDAR scanner will be used to image roofs and pillars. A state-of-the art (fastest possible) scanner will be used for this project. The researcher's current capabilities include two Leica scanners and a new Faro scanner.

The key to high-precision change detection is high-precision, orientation, localization, and registration. The operation of the LIDAR at each scanning station will be fully automated - the only human action required will be to set up the LIDAR over a pre-positioned benchmark and to initiate the scanning. First, a low resolution scan of the immediate area (surrounding pillars and room geometry) is conducted and sent to a stored map of that scanning station. This first pass will permit the identification and scanning of small spherical targets prepositioned within each area to be scanned. Each spherical target will be scanned at a high resolution, resulting in thousands of surface points in a LIDAR point cloud for each target. These surface points will be processed by software already developed at Missouri S&T to determine the exact center of the spherical targets.

Subtasks include the following:

1. Develop strategy for LIDAR scanner position and orientation accuracy requirements.
2. Develop scanning protocol, for both target data and rock roof/pillar data.
3. Design database to hold orientation and target information for each scanning station.
4. Investigate methods to detect disturbed or altered targets

4.2.2 Task 2 - LIDAR point cloud image registration

Automatic methods will be developed to detect and correct for small residual errors in the applied conformal 3-D transformation. These small residual errors typically manifest themselves as slight tips or tilts relative to the base reference surface. Methods will be developed to employ automatic surface re-orientation to minimize the effects of these types of residuals errors. Research will also be required to determine the limits of synthetic positional recovery for small positioning errors. After precise coordinates are obtained for all the pre-placed spherical targets, transformation coefficients for a 7-parameter 3-D conformal transformation will be computed to permit the registration of all subsequent LIDAR data to the base coordinate system established for that scanning station.

Subtasks include the following:

1. Refine registration process based on multiple spherical targets.
2. Explore advanced statistical methods to analyze refined difference surfaces.

4.2.3 Task 3- LIDAR change detection algorithms

Once precise registration is achieved, a basic 'difference' surface is created by spatially subtracting the most recent surface scan from the base scan for that station. The resultant difference surface contains both real and artificial data artifacts which must be analyzed before any conclusions can be drawn on rock fall volume or degree of rock surface deformation. Missouri S&T has already developed many specialized techniques for automatically discriminating between various types of data artifacts present in a difference surface, but additional research will be required to address many anticipated issues unique to a mine environment, such as determining the effect of dust accumulation on high-precision registration targets, detecting missing targets, and dealing with targets that may have been accidentally displaced by nearby mining operations.

Research will be conducted on the best ways to characterize and measure the properties of detected fallen rock fragments. Advanced spatial techniques such as applying filters based on the area, depth, volume, shape, and boundary sinuosity will be explored to determine what factors can be used to differentiate real rock fragments from similarly appearing data artifacts.

At each scanning station location, the system will be capable of detecting individual and aggregate rock falls. It will record the individual or aggregate rock position, radial area, volume, shape, and time/date of observation. The resultant spatial-temporal database can be used to predict trends and identify active areas.

Similarly, research on characterizing slight rock deformations will explore how correlation of displacement vectors over time might contribute to an overall understanding of the magnitude and direction of localized rock mass movement.

Research involving automation of parameter tuning will use sensitivity analysis techniques to determine the effect that an individual parameter has on the end result in a tightly controlled, bounds-limited regime. The more compute-intensive algorithms will be ported to a massively-parallel GPU environment to achieve the required real-time performance.

Subtasks include the following:

1. Develop spatial-temporal database to hold both deformation trends and fallen rock fragment metadata.
2. Develop automated techniques to differentiate artifacts from real lost-rock fragments.
3. Conduct sensitivity analysis to enable automatic parameter tuning.
4. Conduct formal instrumented detectability tests to determine whole-system capabilities for sub-millimeter displacements and minimum detectable fallen rock size.

4.2.3 Task 4 – Deformation and Rock fall Measurements at Doe Run's Buick Mine

The final task will be to monitor the deformation and rock fall in a small loop in the Doe Run's Buick mine over a period of 4-6 months. Measurements will be made once per week, or more often, depending on the rate at which deformations occur. Of most interest will be the relationship of precursor movements for fallen rock. Ultimately in addition to providing this capability, the goal is to develop relationships between convergence and spalling/collapse, not only on a temporal basis, but also on a spatial basis.

4.3 Proof of Concept Pilot Demonstrations

4.3.1 Measurement of a Layer of Paint

To demonstrate the feasibility of using LIDAR to detect sub-millimeter wall deformation, an experiment was conducted at the Missouri S&T Experimental Mine using procedures similar to those proposed for this research. A section of mine wall was prepared by installing spherical registration targets, marked with a circular pattern which would receive varying number of coats of paint, and metal tabs which would be used to accurately measure the thickness of applied paint (Figures 14 and 15)

After a baseline LIDAR scan was acquired, paint was applied (Figure 14) to the test area using a different number of coats for each color zone. The thickness of the paint simulated the type of slight wall deformation that could be expected. After registration, a “difference” surface was created by subtracting the “after” scan from the “before” baseline data. The data was then processed to find statistically significant variations – representing the type of slight wall deformations that generally occur prior to a collapse. The resultant displacements (Figure 15) represented the varying thickness of paint applied. Subsequent analysis of this data revealed that displacements (paint thicknesses) as low as 0.5 mm could be detected by this method.

This pilot demonstration proves that the proposed methodology is viable. With further refinement of the registration process and automation of the statistical analysis, automatic detection of sub-millimeter movements over large areas throughout the mine can be achieved.

Figure 14: Deformation simulation test. Paint applied to a drift wall in the MST experimental mine.

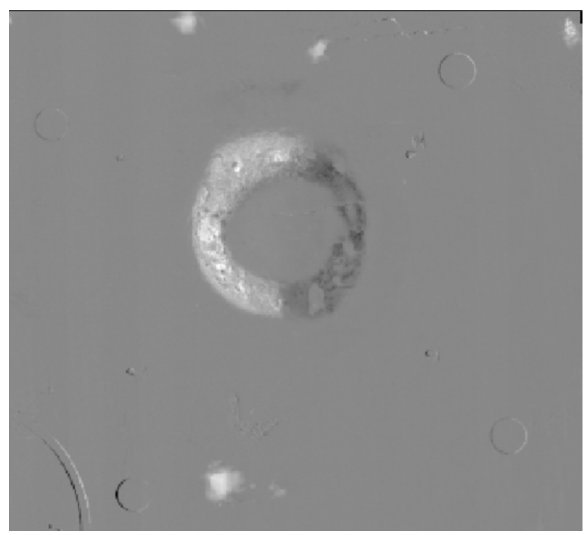


Figure 15: LIDAR difference map showing the ring of green paint (Figure 14) of about 0.5 mm.

4.3.2 Measurement of a Small Deflection

To determine the smallest surface displacement detectable using the proposed method, tests were conducted using a precise tilting plane fixture capable of moving at increments of one thousandth of an inch (figure 16). A baseline dataset was obtained by scanning a flat steel plate at a mesh resolution of 1 mm. Next, the steel plate was tilted by moving the top edge precisely 0.010 inches, simulating the magnitude of a typical wall deformation. A second scan was acquired, and a difference surface was created by spatially subtracting the second surface representation from the first. Two additional scans were acquired and processed, representing top edge displacements of 0.020 and 0.030 inches, respectively.

Analysis of the resulting difference surfaces indicated that displacements as small as 0.025 mm (0.001 inches) could be detected. Figure 17 illustrates the results after applying the three displacements. The color gradient indicates direction and relative magnitude of displacement (red = toward LIDAR and each solid color band represents approximately 0.001 inch of displacement.

Figure 16. Fixture to move a hinged flat steel plate in increments of 0.001" by rotation a threaded rod, verified by a dial gauge. Note that the plate is hinged at the bottom and tilts forward at the top.

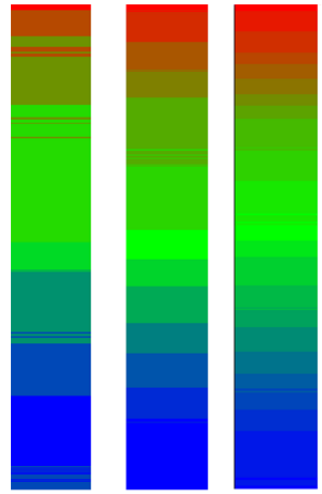


Figure 17: Results of Tilt Displacement Test - showing 0.008" displacement at the top (left image), 0.016" displacement (middle image), and 0.024" displacement (right image). Each solid color band represents a displacement of 0.001".

4.4 Justification of Proposed Work

1. **How is it different?** LIDAR has never been applied to this problem, nor has it been used at the accuracy and degree of automation required.
2. **Why is it different?** It is an entire new approach driven by new technology.
3. **Why does it have a chance to succeed where other approached have failed?** Other approaches can make measurements only over very small areas, so are normally used reactively after failures have initiated.
4. **Has it been done before for other applications?** LIDAR technology has been used by the authors of this proposal to measure rock fall in quarries and rock cuts, and to measure highly accurate deformations on bridge decks.
5. **Does it require any change in current mining practices?** Nothing other than heeding warnings generated by this technology.
6. **Does it require any variance of regulatory policies?** No.

4.5 Potential Follow Up Effort

Upon successful completion of this work, we will seek funding to completely automate this process. We envision a robotic vehicle continuously looping through a track circuit in the mine, stopping at predetermined stations, conducting automatic scans, automatically measuring deformation and rock fall (using the algorithms developed for this proposed research), and reporting the results to the mine, including alarms for emergency contingency planning. The system will ruggedized to survive in the harsh underground conditions, and equipped with sensors and artificial intelligence to protect itself and from interfering with mining operations, and to be self cleaning. The system will be installed in a mine like Doe Run's Buick mine for proof testing.

We anticipate the cost of the follow-up project at $550,000 and that would include the complete automation of the system, complete implementation, and 6 months of actual real data collection in a mine.

®ScanStation II and HDS6000 are registered trademarks of Leica Geosystems.
®Focus3D is a registered trademark of Faro.

SECTION B: PROJECT SCHEDULE AND DECISION POINTS

2.5 Section E: Project Schedules and Milestones

2.5.1 Milestones

The tasks and milestones are as follow:

Task 1 - LIDAR scanning method and protocol

- Task 1.1 - Develop strategy for LIDAR scanner position and orientation accuracy requirements.
- Task 1.2 - Develop scanning protocol, for both target data and rock roof/pillar data.
- Task 1.3 - Design database to hold orientation and target information for each scanning station.
- Task 1.4 - Investigate methods to detect disturbed or altered targets

Task 2 - LIDAR point cloud image registration

- Task 2.1 - Refine registration process based on multiple spherical targets.
- Task 2.2 - Explore advanced statistical methods to analyze refined difference surfaces.

Task 3 - LIDAR change detection algorithms

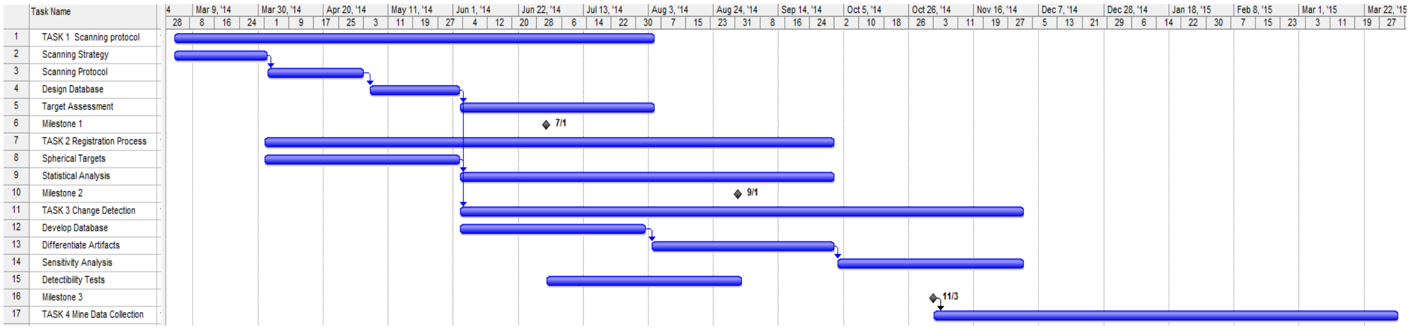
- Task 3.1 - Develop spatial-temporal database to hold both deformation trends and fallen rock fragment metadata.
- Task 3.2 - Develop automated techniques to differentiate artifacts from real lost-rock fragments.
- Task 3.3 - Conduct sensitivity analysis to enable automatic parameter tuning.
- Task 3.4 - Conduct formal instrumented detectability tests to determine whole-system capabilities for sub-millimeter displacements and minimum detectable fallen rock size.

Task 4 – Deformation and Rock fall measurements in Buick Mine

Milestone 1- LIDAR scanning method and protocol substantially complete.
Milestone 2- LIDAR point cloud image registration substantially complete.
Milestone 3- LIDAR change detection algorithms substantially complete.
Milestone 4- Deformation and Rock fall Measurements at Doe Run’s Buick Mine substantially complete.

2.5.2 Timeline

Below are project schedules for tasks and milestones as described in section 2.5.1 above:



Task 1 - LIDAR scanning method and protocol
Task 2 - LIDAR point cloud image registration
Task 3 - LIDAR change detection algorithms
Task 4 - Deformation and Rock fall measurements in Buick Mine

Milestone 1- LIDAR scanning method and protocol substantially complete.
Milestone 2- LIDAR point cloud image registration substantially complete.
Milestone 3- LIDAR change detection algorithms substantially complete.
Milestone 4- Deformation and Rock fall Measurements at Doe Run's Buick Mine substantially complete.

SECTION C: RESOURCES AND COMMITMENTS

1. Resources and Commitments

1.1 Facilities and Equipment

1.1.1Rock Mechanics and Explosives Research Center

The Rock Mechanics and Explosives Research Center at Missouri S&T (PI Dr. Norbert Maerz is a Senior Research Investigator associated with the Center) will provide space and support staff including technicians, machinists, and administrative specialists.

The center is equipped with a State of the Art Leica Scan Station II, which is capable of scanning 50,000 points per second with a modeled accuracy of 2 mm. In addition, we have a Leica HDS 6000 scanner capable of scanning 500,000 points per second and a FARO Focus 3-D capable of scanning 976,000 points per second.

The center is equipped with various state of the art image-analyzing computers, and image analysis software. Imaging equipment includes high-resolution analog and digital video cameras, digital still cameras, and scanners. The Scan Station II has a built in high resolution digital camera.

The Center will also supply support facilities. This includes a machine shop and welding bay equipped with extensive machining and fabrication equipment for manufacturing of field equipment/supplies. This includes three-axis and five-axis water jet cutting machines for custom fabrication. It also includes a well-equipped electronics shop with the capability to fabricate custom electronic components and systems. There are also data processing facilities with extensive computer capabilities.

Behind the Rock Mechanics Center is a field on which abandoned mining equipment is stored. This field will be used for early testing of the system.

1.1.3 Missouri S&T Experimental Mine

The Missouri S&T Experimental Mine is an underground mine located on a 19-acre mine / quarry site just one mile from campus. The mine has over 2000 feet of blast-excavated tunneling, dozens of rooms and pillars, vertical air vents, and is in the process of developing two deeper levels. The mine is conveniently close to the Rock Mechanics Center and will be used for intermediate-level testing of the robotic platform, buried wire navigation, and wall deformation measurement. Simulated deformation will be modeled by the paint method previously described, and by instrumented diaphragm structures to determine detectability limits.

1.1.4 Missouri S&T Robotics Competition Team and Mars Rover Team

These teams are comprised of enthusiastic graduate and undergraduate students with practical experience in robotic design, fabrication, construction, testing, and evaluation. Students specializing in Mechanical Engineering, Electrical Engineering, Computer Engineering, and Computer Science will be available to assist in the systems development aspects of this research.

2.2 Detailed Personnel Plan

2.2.1 PI and Project Manager – Dr. Norbert H. Maerz (0.1575 FTE – 16%)

The project will be managed by the lead PI, Dr. Norbert Maerz. Dr. Maerz will oversee the progress of integrating the efforts of all researchers. Dr. Maerz has extensive experience in solving engineering problems with LIDAR technology, including developing techniques for rapid and mobile LIDAR scanning, automated LIDAR scan registration, and automated LIDAR measurement techniques. He has developed solutions for automated LIDAR measurements for measuring discontinuity orientations, measuring rock raveling, collection of perishable data, reconstruction of the geometry of damaged structures, remote LIDAR surveying of the inside of dangerous structures, measurements of bridge deflection, and using LIDAR for autonomous navigation.

2.2.2 Software Engineer and Spatial Data Analysis – Mr. Kenneth Boyko (1.0 FTE – 100%)

Graduate student Kenneth Boyko retired from the U.S. Geological Survey as Chief, Branch of Research, Technology, and Applications. Mr. Boyko has 28 years of experience in raster and vector-oriented digital production systems development, photogrammetry, image processing, point cloud processing, and Digital Elevation Models. Mr. Boyko will head the software engineering effort, focusing on control systems, data processing, and algorithm development.

. Commitment from the Doe Run Mining Company

The Doe Run mining company has agreed to host field testing in their Buick Mine throughout the second year of the project. The estimated value of their in-kind support is $6,800, based on 170 hours of labor @$40 per hour. The Doe Run letter of support is appended at the end of this document and the following chart shows the breakdown of their expected services:

Personnel	# Hours	Service to be performed
Survey Control (2)	40	Surveying test loop area.
Scaler (1)	10	Scale test loop area.
Nippers (2)	20	Mob and demob test vehicle, mule, cargo container, and plus misc. supplies down shaft and out into mine
Engineering Support	80	Provide technical assistance for research.
Mine Support (1)	20	Hang 40-50 round styrofoam targets from ribs/back with high lift work basket.

SECTION D: BUDGET

1.0 Budget

The period of performance will be September 1, 2013 to August 31, 2015.

Budget broken out by task:

	Task 1	Task 2	Task 3	Task 4	TOTAL
Principal Investigator	$7,643	$7,643	$7,643	$2,548	$25,478
Fringe Benefits	$2,703	$2,703	$2,703	$901	$9,011
Graduate Students	$12,026	$12,026	$12,026	$12,026	$48,105
Undergraduate Students	$1,000	$1,000	$1,000	$7,000	$10,000
Salaries SubTotal	$23,373	$23,373	$23,373	$22,475	$92,594
Travel	$0	$0	$0	$5,000	$5,000
Expenses	$250	$0	$0	$1,000	$1,250
F&A (Indirect Costs)	$4,725	$4,675	$4,675	$5,695	$19,769
Equipment	$0	$0	$0	$10,000	$10,000
Student Tuition Fees	$4,971	$4,971	$4,971	$4,971	$19,884
TOTAL	**$33,319**	**$33,019**	**$33,019**	**$49,141**	**$148,497**

Task 1 - LIDAR scanning method and protocol
Task 2 - LIDAR point cloud image registration
Task 3 - LIDAR change detection algorithms
Task 4 - Deformation and Rock fall measurements in Buick Mine

Note: Equipment costs are for a an ATV (mule) that will be used to transport research personnel from the shaft to the research site at Doe Run, which is expected to be 5+ miles from the shaft, and a cargo box that will be set underground to store equipment including the ATV while the equipment is not in use.

Travel costs will cover multiple trips to the Doe Run Buick Mine for coordinating the circuit set-up and operational testing.

References

[1] Gonzales de Vallejo, L. I, and Ferrer, M., 2011. Geological Engineering. Taylor & Francis Group, London, UK, 678 pp.

[2] Shen,B., Fama, M. D., and Adhikary., F. D., 2000. Monitoring of Roof Deformation and Delamination using Deep Hole Multi Point Extensometers. http://www.acarp.com.au/abstracts.aspx?repId=C9069

[3] Roberts, A., 1977. Geotechnology, An Introductory Text for Students and Engineers. Pergamon Press, 355 pp.

[4] Hanna, T. H., 1985. Field Instrumentation in Geotechnical Engineering. Trans Tech Publications, 843 pp.

[5] Maerz, N.H., Otoo, J., Kassebaum, T., Boyko, K., 2012. Using LIDAR in highway rock cuts. 63rd Annual Highway Geology Symposium, May 7th-10th, 2012, Redding CA, 13 pp.

[6] Maerz, N.H., Otoo, J., Kassebaum, T., Boyko, K, 2013. Using LIDAR in highway rock cuts. Submitted to Journal of Civil Engineering and Architecture, April, 2013.

[7] Maerz, N. H., Kassebaum, T., Williams, D., Shea, K., Duan, Y., Xi, Y., Li, X., 2013. Visualizing and modeling interior spaces of dangerous structures using LiDAR The International Journal of Safety and Security Engineering, Vol. 2, No. 4, pp. 1-21.

[8] Maerz, N. H., and Boyko, K., 2012. Making Highway Rock Cuts Safer. AEG Annual Conference, Salt Lake City, Utah, Sept. 2012.

SECTION E: APPENDIX

Biographical Sketches of Key Personnel and Letter of Commitment

Principal Investigator: Dr. Norbert H. Maerz

Dr. Maerz earned his B.Sc. (1981), M.Sc. (1985), and Ph. D. (1991) from the University of Waterloo, and M. Sc. in Engineering Management (2010) from Missouri University of Science and Technology. He is currently employed as an Associate Professor and Program Head at Missouri University of Science and technology. Dr. Maerz has extensive research experience in the area of optical and LIDAR imaging. In the area of automated optical measurements, he has developed image analysis applications for the measurement of particle size distributions, performing particle shape analyses, measuring highway sign and pavement stripe luminance, measuring roughness of concrete, rock, and fractured metal surfaces, and for efficiently performing mobile highway infrastructure inventory measurements. He has developed LIDAR imaging applications for visualizing and modeling the interiors of dangerous spaces, for performing change detection on raveling highway rock cuts, for detecting small strain bridge deflections under load, for acquiring perishable geomorphological data, for measuring discontinuity orientations in rock structure, and for automated generation of finite element meshes from LIDAR data

Appointments

2006-Present *Program Head, Geological Engineering; Program Administrator, online M.E. Program in Geotechnics*
2004-2005 *Associate Professor*
1998-2004 *Assistant Professor*
Geological Sciences and Engineering Department, Missouri University of Science and Technology

1998-Present *Senior Investigator*
Rock Mechanics and Explosives Research Center, Missouri University of Science and Technology

2009-Present *President*
N. H. Geo Incorporated – Rock slope hazard rating, rock slope remediation and mitigation engineering, LiDAR training and studies.

1995-2006 *President and Founder*
WipWare Inc. – Software sales, services, and research and development for fragmentation and granulometry image analysis for the mining industry.

1990-1997 *President*
N. H. Geo Consulting Limited – Geotechnical consultant, custom software solutions, hydrogeologic consulting and well pumping contractor.

Recent and Relevant Publications

Maerz, N.H., Otoo, J., Kassebaum, T., Boyko, K, 2013. Using LIDAR in highway rock cuts. Submitted to Journal of Civil Engineering and Architecture, April, 2013.

Maerz, N. H., and Youssef, A. M., 2012. Remediation and Mitigation Strategies for Falling Rock Hazards along the Highways of Fayfa Mountain, Jizan, Saudi Arabia. Bulletin of Engineering Geology and the Environment, submitted, July 9, 2012.

Maerz, N. H., Aqeel, A., and Anderson, N., 2013. Measuring orientations of individual hidden sub-vertical discontinuities in sandstone rock cuts integrating ground penetrating radar and terrestrial LIDAR. Submitted to the International Journal of Rock Mechanics and Mining Science, April 2013.

Aqeel, A., Maerz, N. H., and Anderson, N., 2013. Mapping Subvertical Discontinuities in Rock Cuts using a 400 MHz Ground Penetrating Radar Antenna. Accepted for publication, Arabian Journal of Geosciences

Maerz, N. H., Youssef, A. M., Otoo, J. N., Kassebaum, T. J., and Duan, Y., 2013. A simple method for measuring discontinuity orientations from terrestrial LIDAR images. Accepted for Publication, Environmental and Engineering Geoscience, June 2012.

Maerz, N. H., Kassebaum, T., Williams, D., Shea, K., Duan, Y., Xi, Y., Li, X., 2013. Visualizing and modeling interior spaces of dangerous structures using LiDAR The International Journal of Safety and Security Engineering, Vol. 2, No. 4, pp. 1-21.

Otoo, J. N., Maerz, H. H., Li, X., and Duan, Ye., 2013 Verification of a 3-D LiDAR viewer for discontinuity orientations. Rock Mechanics and Rock Engineering, 12 pp.

Maerz, N. H., Magner, K, and Guardiola, I. 2012. Geotechnical Variability and Determining Optimum Number of Samples for Testing using Monte Carlo Simulations. Submitted to Journal of Geotechnical and Geoenvironmental Engineering.

Youssef, A., and Maerz, N. H., 2012. Development, justification and verification of a rock fall hazard rating system. Bulletin of Engineering Geology and the Environment. Online first, v.71, pp 171-186.

Otoo, J. N., Maerz, N. H., Xiaoling, L, and Duan, Y., 2011. 3-D Discontinuity orientations using combined optical Imaging and LiDAR techniques. Proceedings of the 45th US Rock mechanics Symposium, San Francisco, CA, June 26-30, 2011, 9 pp.

Yongjian, X., Xiaoling, L., Ye, D., and Maerz, N., 2011. Virtual Navigation of Interior Structures by Lidar, SPIE Conference on Defense, Security, and Sensing 2011. Orlando, FL,, April 25-29 2011, 7 pp.

Maerz, N. H., and Hilgers, M. C., 2010. A method for matching fractured surfaces using shadow profilometry. Third International Conference on Tribology and Design 2010, May 11-13, 2010, Algarve, Portugal, pp. 237-248.

Youssef, A. M, and Maerz, N. H., 2009. Slope stability hazard assessment and mitigation methodology along eastern desert Aswan-Cairo Highway, Egypt. Journal of King Abdulaziz University Earth Sciences, vol. 20, no. 2, pp. 161-179.

Youssef, A., Maerz, N. H., and Qinfang, X., 2007. Rocksee: Video image measurements of physical features to aid in highway rock cut characterization. Computers & Geosciences, v. 33, no. 3, pp 437-444.

Walker, C. P., Maerz, N., and Hilgers, M. G. 2005. Surface reconstruction using shadow profilometry. Proceedings of the 2005 ACM Symposium on Applied Computing (Santa Fe, New Mexico, March 13 - 17, 2005). L. M. Leibrock, Ed. SAC '05. ACM Press, New York, NY, pp. 1250-1251.

Maerz, N. H., Youssef, A., and Fennessey, T. W., 2005. New risk-consequence rock fall hazard rating system for Missouri highways using digital image analysis. Environment and Engineering Geoscience, v. xi, no. 3, pp. 229-250.

Maerz, N. H., and Palangio, T. W., 2004. Post-muckpile, pre-primary crusher, automated blast fragmentation sizing. FRAGBLAST, The International Journal For Blasting and Fragmentation, v. 8, no. 2, June 2004.

Maerz, N. H., 2004. Technical and computational aspects of the measurement of aggregate shape by digital image analysis. Journal of Computing in Civil Engineering, v. 18, no. 1, pp. 10-18.

Zhou, W., and Maerz, N. H., 2002. Implementation of multivariate clustering methods for characterizing discontinuites from oriented boreholes. Computers & Geosciences, v. 28, no. 7, pp. 827-839.

Zhou, W., and Maerz, N. H., 2002. Identifying the optimum drilling direction for characterization of discontinuous rock. Environment & Engineering Geoscience, v. VII, no. 4, pp. 295-307.

Synergistic Activities

Courses Taught

Mi Eng 231 - Introduction to Rock Mechanics
Ge Eng 477 - Discontinuous Rock
Ge Eng 371 - Rock Engineering
Ge Eng 375 - Aggregates and Quarrying
Ge Eng 343 - Subsurface Exploration

Professional Affiliations

American Rock Mechanics Association
Association of Engineering Geologists
Association of Professional Engineers of Ontario
International Society for Rock Mechanics
Society for Mining, Metallurgy, and Exploration

Software Engineer and Spatial Data Analysis: Mr. Kenneth Boyko

Mr. Boyko received his BS degree from Michigan State University in 1973, majoring in Forestry with a minor in computer science. After serving as an officer in the U. S. Air Force, Mr. Boyko attended Missouri S&T (then, University of Missouri – Rolla), specializing in computer science, photogrammetry, and remote sensing, eventually completing 21 hours of graduate-level coursework in computer science. He is currently enrolled as a Ph. D. candidate in Geological Engineering.

Mr. Boyko retired from the U. S. Geological Survey as Chief, Branch of Research, Technology, and Applications. During his 28 year USGS career, he led the development of several digital production systems dealing with both raster and vector data. He wrote the Survey's first vector-to-raster conversion software which produced DEMs from 3-D stereo-model vector data.

Mr. Boyko is well-versed in several programming languages and has experience in many different software development methodologies. He has over 20 years experience in managing large systems development projects involving developers across multiple USGS mapping centers.

After retiring in 2006, Mr. Boyko served as a management consultant to the USGS, and resumed his academic pursuits – updating his skills in more recent programming environments. Mr. Boyko developed a high precision dual-camera 3-D structured light scanner as an undergraduate research project. During this time, Mr. Boyko was involved in the Missouri S&T Robotics Competition Team and made significant contributions to the machine vision components of their autonomous robot. Mr. Boyko led the Computing Group for the Robotics Team for a year, and helped the team with several technical and management issues.

In 2010, Mr. Boyko began work toward a Masters degree in Geological Engineering and over the past few years, has developed new techniques to detect and eliminate vegetation artifacts from LIDAR data. He has developed precision change-detection software, and has also developed several techniques to identify and segregate data artifacts in LIDAR data.

Mr. Boyko's background and experience in large systems development, and his ability to recruit and retain enthusiastic and productive graduate and undergraduate talent will be an asset for this project.

THE DOE RUN COMPANY

SOUTHEAST MISSOURI
MINING AND MILLING DIVISION
Viburnum, MO 65566

Date: December 6, 2013
From: Thomas Yanske, Tech Services Manager
To: Norbert Maerz, MS&T Program Head, Geological Engineering
Subject: Alpha Foundation "LIDAR Scanning" Funding Concept Proposal

Norbert,

I am sending you this letter as a "letter of support" for your concept proposal "Development of a Method for Full-Field Automated Detection of Precursor Movement in Underground Pillars and Backs using LIDAR Scanning", which you will be submitting to the Alpha Foundation for potential funding.

In support of this proposed project Doe Run is willing to permit MS&T to access our mines and carry out the proposed LIDAR scanning research. Doe Run will also provide necessary support in carrying out this research work at our mines. We estimate this support to amount to $6,800.

Doe Run has been extracting pillars over the last 22 years and is keenly interested in safety and any technology which will give us early warning of potential ground movements. The advancing of this technology would be a step in the right direction for the mining industry, whether it is for coal, or hard rock mining.

If this project should receive funding, Doe Run's support of the project will be contingent upon a "Master Service Agreement" being signed between Doe Run and MS&T.

I look forward to hearing of your success in winning a grant from the Alpha Foundation in order to move forward with this research project.

Thomas Yanske

Thomas Yanske
Technical Services Manager
SEMO Mining Division
The Doe Run Company