IDENTIFICATION OF UNDERGROUND MINE WORKINGS WITH THE USE OF GLOBAL POSITIONING SYSTEM TECHNOLOGY

by

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Abstract. Identification of underground mine workings for well drilling is a difficult task given the limited resources available and lack of reliable information. Relic mine maps of questionable accuracy and difficultly in correlating the subsurface to the surface, make the process of locating wells arduous. With the development of global positioning system (GPS), specific locations on the earth can be identified with the aid of satellites. This technology can be applied to mine workings identification given a few necessary, precursory details. For an abandoned mine treatment project conducted by the University of Oklahoma, in conjunction with the Oklahoma Conservation Commission, a Trimble ProXL 8 channel GPS receiver was employed to locate specific points on the surface with respect to a mine map. A 1925 mine map was digitized into AutoCAD version 13 software. Surface features identified on the map, such as mine adits, were located and marked in the field using the GPS receiver. These features were then imported into AutoCAD and referenced with the same points drawn on the map. A "rubber sheeting" program, Multric, was used to tweak the points so the map features correlated with the surface points. The correlation of these features allowed the map to be geo-referenced with the surface. Specific drilling points were located on the digitized map and assigned a latitude and longitude. The GPS receiver, using real time differential correction, was used to locate these points in the field. This method was assumed to be relatively accurate, to within 5 to 15 feet.

Additional Key Words: mine well siting, mine restoration.

Introduction

Identification of underground mine workings is an arduous task given the lack of reliable information and difficultly in correlating the subsurface environment with the surface topography. Remediation efforts are hampered by the uncertainty of locating desired points within the mine along with the costs associated with the drilling of extra wells because the location was missed. Occasionally, abandoned mines have descriptive maps associated with them. Unfortunately, the detail and accuracy of these maps are questionable, and the use of these maps for site identification can produce less than reliable results. Some of the problems associated with identifying well drilling locations can be avoided by using modern techniques. The global positioning system (GPS) can provide an added advantage in subsurface-surface correlation. A technique for identifying mine voids was utilized in a remediation demonstration project in eastern Oklahoma. The University of Oklahoma in conjunction with the Oklahoma Conservation Commission, is undertaking an abandoned mine reclamation project in which specific points in the mine had to be located from the surface. Remediation efforts involved the introduction of an alkaline coal combustion by-product (CCB) into a mine void with the intent of altering the internal aqueous chemistry. The desired result would be a mine water with elevated pH, increased alkalinity, and a reduced metal load. Strategically locating specific points inside the mine is essential to the success of this *in-situ* remediation. If the injection well

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is located in a point that does not influence mine water quality, then the treatment will be ineffective. Subsequently, a method was devised that would accurately and easily identify the appropriate locations. Developing a reliable process evolved out of several attempts and ideas, which will be discussed in the following sections.

The goal of this paper is to convey the results and findings generated from the well siting aspect of the study, and also to provide practical information regarding the use of GPS technology for locating specific points in underground coal mines. This is accomplished by providing background information on the study, GPS technology, and the project site, followed by a description of the methods employed, and concluding with a results and discussion section.

Background

Project Description

Numerous treatment methods have been devised to address the adverse environmental impacts associated with acid mine drainage (AMD). However, these developments have historically relied on control devices which fall short of addressing the problem. Control technologies are often expensive (estimated to exceed one million dollars a day nationwide, Kleinmann 1991), elaborate, and require regular attention. Thus, many of the control techniques are impractical in the treatment of AMD from abandoned mine sites.

With respect to underground mines, a more practical approach may be the reclamation of AMD through treatment with CCBs. Water collects within the mine workings to form pools or reservoirs of AMD, creating a body of water similar to a karst aquifer. If this "aquifer" can be treated *in-situ*, then the adverse effects associated with the discharge can be avoided or prevented. This technology involves the introduction of a CCB slurry at influential locations within the mine void. Coal combustion by-products will address the problem by altering the chemical conditions in the injection area. When placed in contact with acid mine water, CCBs can neutralize existing acidity, increase pH, and precipitate metals. As a result, mine drainage will have an elevated pH, increased alkalinity, and a reduced metals load. Strategically locating specific points inside the mine is essential to the success of this *in-situ* remediation.

Relying solely on a mine map to identify drilling locations is a risky venture. Map quality is dependent upon the original purpose of the map and the amount of effort invested in its development. Some maps were created for descriptive reasons to show air flow patterns and emergency exit routes. Others maps were more laboriously developed using the best available methods of surveying. However, turn-of-the-20th century technology is archaic when compared with today's standards. Fundamentally, the chances of hitting a void depend on the amount of coal that was left in place. For instance, if 50% of the coal was removed, then the chances of entering a void are 50/50. Moreover, just because a void is located does not mean that the position of the well corresponds to the assumed location on the mine map. If a specific location is desired, a more reliable locating method is required.

Previous remediation projects involving subterranean drilling have had mixed results. For instance, a study conducted by Aljoe and Hawkins (1993) found there to be a lack of precise correlation between the surface and the mine workings presented in the map. As a result, five of the fifteen wells drilled at the Keystone site entered voids and ten hit coal, a 33% success rate. Missed wells, those that entered the coal, still provide some information, but additional wells often have to be drilled so that enough data can be generated. As a result, there is an added economic cost along with the logistical concern associated with site identification.

Some of the problems associated with identifying well drilling locations can be avoided by using modern techniques. The global positioning system can be advantageous in subsurface-surface correlation.

GPS

The Global Positioning System is a satellite based positioning system operated by the U.S. Department of Defense. It has been under development since 1973, with the initial mission to provide navigational support to military operations. Today, that mission has been expanded to include an ever-growing civilian based user community. This paper illustrates just one of these evolving applications.

The GPS system consists of three segments. The control segment tracks and monitors each satellite's navigation messages. If necessary, adjustments can be made in the messages or in the satellite's orbit. The operation of this segment is centered at Falcon Air Force Base (Colorado Springs, Colorado) along with four monitoring stations scattered around the world. The space segment consists of the constellation of NAVSTAR satellites (space vehicles (SVs)) broadcasting GPS navigation signals. The system is considered fully operational when there is a minimum of 24 operating SVs. Since 1993 there has been at least 24 operational SVs. The SVs are distributed in six orbital planes, inclined 55° to the equator, at an altitude of 12,600 nautical miles (20,000 km). Each satellite has several atomic clocks and is identified by a unique code superimposed on the GPS signal. The third segment, the user, consists of GPS receivers calculating positions for military or civilian applications.

Accurate GPS positioning relies on the ability of the receiver to calculate the relative distance between it and at least four SVs. This distance is derived from measuring the time it takes for a particular sequence of codes to travel from the SV to the receiver. This requires the SV and the receiver to be generating the same code in synchrony. In addition, all SVs are time synchronous due to their onboard atomic clocks. Using a technique known as trilateration, the receiver calculates its position using the calculated distance to three SVs. A fourth SV is used to correct for inaccuracies in the receiver's clock. The geometry of the SVs can greatly affect the precision of the position calculation. As an index of this geometry, the receiver calculates the Position Dilution of Precision (PDOP). A low PDOP indicates better precision. For submeter accuracy, a PDOP of <4 is desired.

Receivers are classified according to the way they process the GPS signal. Coarse/Acquisition (C/A) receivers process information within the SV signal, while carrier phase receivers analyze the radio signal characteristics to calculate a position. For this application the GPS receiver (Trimble ProXL) was operated in the C/A mode. Although the ProXL is capable of carrier phase processing and, under certain conditions, is more accurate than C/A processing. However, restrictions such as the inability to maintain a constant lock on all satellites due to obstructions such as trees and brush prevented the use of carrier phase processing.

Accuracy of a GPS receiver can be affected by a variety of factors. Some can be controlled by the operator, while others cannot. A major contributor to error in GPS positions measured in the field can be attributed to the presence of selective availability (SA). Selective availability is a deliberate degradation of the SV signal to cause inaccurate position calculations. Selective availability is applied to the GPS signal by the Department of Defense. The effects of SA can be almost completely removed by differential processing. There are two methods of differential processing. One involves collecting position data with a roving receiver and postprocessing that data in conjunction with a computer file of accurately known positions collected at a base station. Errors measured at the base station are used to differentially correct field collected position data. For this study, post processed GPS positions used a base station located at Fayetteville, Arkansas, approximately 90 miles northeast of the project site. The other method, known as real-time differential correction (RTCM), involves using a GPS beacon receiver feeding base station data into the GPS receiver in the field. The GPS receiver calculates a position and differentially corrects the data in real time. The GPS beacon used in this study was operated by ACCQPOINT (Fort Smith, Arkansas), approximately 50 miles from the site.

Site Description

The project site is located in southeast Oklahoma, 160 miles east-south-east of Oklahoma City, near the town of Red Oak (S½, SE¼, Section 1, Range 21 east, Township 4 north, Latimer County). The area of interest is located in the Interior Province, Western Region Coal Field (Shannon 1926), or more specifically, in the Howe-Wilburton Coal District. The district is located in the McAlester Marginal Geomorphic Province (Johnson 1974) and is in the Arkoma Basin.

Bache and Denman Coal Company operated the mine from 1907 until at least 1925. Ownership and time of operation were based on several mine maps obtained from the Oklahoma Department of Mines, (Oklahoma City, Oklahoma); however, there is no readily available official record of ownership. All calculations and quantitative estimates are based on measurements from these engineering mine maps and best professional judgement.

The mine was a down-dip slope operation that undermined approximately 46.5 acres. From a mine map dated January 1925, the entire mine volume was estimated to be 8.1×10^6 ft^3. Mine map measurements indicated that approximately 30 to 50% of the coal was left in place to act as support. As a result, the actual mine void volume was calculated to be roughly 5.7×10^6 ft^3.

Methods

The need to develop an accurate method for identifying specific points in the mine was made evident by the economic and strategic needs of the project. However, the best method of identification was not realized at the inception of the project. Having limited experience in correlating the mine workings with the surface topography, a series of attempts was made to determine the best process for identifying drilling locations. As a result of this learning process, three methods for correlating the mine void with the surface workings were investigated. These methods will be specifically discussed in the following paragraphs.

Method 1

Originally, the mine map was to be used as template for locating the mine void. A photographic image of the mine map was generated and scaled to 1 inch = 24,000 inches. A negative of the mine map image was applied to an acetate film which produced a transparency. At this scale, the mine map transparency could be overlain on a 1:24,000 USGS quadrangle topographic map. The original mine map had a section line which could be used to align the transparency with the topographic map. If the transparency method seemed feasible, than a blow up of the mine site could be used to mark desired drilling sites on the map, and latitude and longitude coordinates could be determined for each point.

However, the overlay technique was not accurate enough for the detail necessary for mine well location. Aligning the mine map transparency with the topographic map produced uncertain results. The section line on the mine map did not correlate with the section line on the USGS map. Over the past 70 years the mine map had been subjected to humidity and other conditions that caused the paper to age, wrinkle, and tear, resulting in map distortion. When the transparency was made, the wrinkles, unevenness, and inconsistences were incorporated. As a result, the transparency did not align with the USGS map. In addition, the topographic map has an inherent accuracy of ±20 meters (66 ft). This variability, along with the transparency error, would produce uncertainty that could be greater than 100 feet.

Method 2

Unfortunately, the variability in the mine map could not be corrected since it was the only map available. However, the accuracy of the surface map could be improved. The use of GPS technology was an obvious possibility for this venture. Specific points at the mine project site were logged using a GPS receiver and correlated to the mine map. The satellite system provides a relatively unbiased technique for geo-referencing with the subterranean mine. The design of the system involved the computer digitization of the mine map into AutoCAD version 13. Once the mine workings were incorporated, then a grid of surface points was logged on a GPS receiver and down loaded into AutoCAD. The grid of surface points was then overlain on the mine workings. Theoretical drilling locations were identified on the mine map and correlated to the surface grid. Specific drilling locations in the field could be identified by measuring distances from the fixed surface points.

In order to establish the surface grid, the project site above the mine had to be cleared of dense woody vegetation. Next, a grid network of stakes on 25 foot intervals was laid out in a north-south and east-west pattern. A Trimble Pathfinder Basic receiver was used to log each of the points on the grid. The data points were corrected for the induced error at the office and loaded into AutoCAD.

Results from this method proved to be less than successful. When the data points were downloaded into AutoCAD the resulting grid pattern was erratic. Theoretically, the Trimble Pathfinder Basic unit is accurate too approximately 3 meters; however, the corrected averaged values were as far off as 5 meters (16.4 ft). Error values of this magnitude were better than 100 feet, as identified in Method 1, but still were not acceptable.

Method 3

Methods 1 and 2 failed to produce an accurate way to correlate the mine map with the surface. In addition, the inherent errors in the mine map, due to the deteriorated state, were not being accounted for. A third method was devised to minimize the errors associated with the mine map while linking the mine and the surface. A newer model GPS receiver, Trimble ProXL 8 channel unit, with expanded capabilities was employed. Accuracy of the ProXL model was far better than the Pathfinder Basic receiver. The accuracy of the ProXL receiver operating in RTCM mode was assessed by logging positions at a National Geodetic Survey monument which had been surveyed to 1st order accuracy. The site was identified as Q166/EK0384 located in Fanshawe, Oklahoma which was 7.25 miles northeast of the study area. Observation of RTCM corrected positions for 10, 20 or 30 second intervals did not differ from the true position by more than 2 feet. However, this accuracy may not be realized at the study area due to site conditions which could degrade the accuracy of the measurements. For example, site conditions at Q166 gave a clear view of the sky, while at the project site, trees and brush obscured parts of the sky at points where GPS positions were calculated. Signal reflections from trees and other obstructions inject multipath errors which effect the accuracy. It is believed that the positions calculated within the study area are submeter accurate due to other operating parameters that were followed. For instance, positions were calculated when PDOP values ranges between 2.1 and 3.5. Also, positions were calculated using a minimum of 5 satellites.

Instead of creating a fixed grid on the surface and measuring distance from individual points, the mine map was geo-referenced by computer so that specific latitude and longitude measurements could be assigned to specific points. The mine map was correlated with the surface by identifying surface features on the map that still remained in the field. For instance, the fan house and other mine audits, building foundations, railroad lines, section markers, and roads all served as links between the mine map and the surface. Refer to Figure 1 for a depiction of the mine map and the identified points.

The success of this method depended on the accuracy of the map. That is, the locations of surface icons were accurately surveyed with respect to the mine workings. Once these features were digitized, errors in the mine map, due to aging, could be accounted for by "correcting the fit". Several points identified in the field did not necessarily line up with the locations on the map. Subsequently, a rubber sheeting method, Multric, was employed to adjust and tweak the points so that the alignment was closer. Once this was accomplished, the mine map was geo-referenced to the surface with, presumably, better accuracy. Identifying drilling points on the surface could then be accomplished by selecting locations on the digitized map. From the mine map, a latitude and longitude was determined and the coordinates were entered into the GPS receiver. With the stored coordinates in the GPS receiver, each surface site was located using the RTCM navigational capabilities of the unit. The receiver guided the operator to the point in the field. The induced error was accounted for by using real time differential correction.

Results and Discussion

Method 3 proved to be a convenient and relatively accurate method for identifying well locations. During the siting process, three well locations had to be changed in the field due to obstructions, for example, thick vegetation and property boundaries. The advantage of this technology was that a site location could be changed in the field. Field changes would not be possible without having real time correction capability. This feature eliminates the need for postprocessing the data to remove the induced error. A portable computer, with the digitized mine map stored in AutoCAD, was used in the field to identify the coordinates of the replacement points. These points were then programed into the GPS receiver and located at the site. Having this capability made the process of identifying wells flexible and saved a tremendous amount of time.

In addition to the flexibility, the accuracy of this method was impressive. Five of the six wells entered rooms within the mine, as desired; only one entered a coal pillar. This equates to an 83% success rate which was better than the theoretical 30 to 50% success rate expected from random well location, and far better than the results observed from other attempts--33% success (Aljoe and Hawkins 1993). Assuming 50% of the coal remained in place for structural support, there was a 50% chance of successfully hitting a void for each drilling event. Statistically comparing the observed mean with the theoretical mean produced a significant result assuming $\alpha=0.01$. In other words, this method is expected to be more accurate than randomly drilling holes 99% of the time.

An unavoidable factor of this technology is that the bias associated with this method is uncertain. That is, there is no way of determining if the drill holes are located in the desired locations. However, the overall accuracy of this method was estimated to be within 5 to 15 feet. As discussed earlier, the GPS positions are believed to be accurate to within ±3 feet. The accuracy of rubber sheeting the mine map to the earth's surface is difficult to assess. Unfortunately, when the site was cleared of woody vegetation, many of the surface features that were plotted on the mine map were destroyed before they could be accurately located with GPS. This limited the number of points that could be used in the rubber sheeting process. As a result, some of the drilling locations were located outside of the area enclosed by the control points. Therefore, the geographic location of these points were adjusted by extrapolation based on the adjustments calculated by Multric using the four control points identified in Figure 1. The drill locations were situated in voids at places in the mine where the distance to coal pillars ranged from 5-15 feet. Although no verification was done to determine if the drilled wells were in fact positioned in the desired location, a 5 to 15 foot accuracy was assumed to be reasonable based on best professional judgement. Unfortunately, this accuracy may not necessarily be transferred to other mine sites. The condition and quality of the mine map are the essential factors in determining accuracy.

Summary

Correlating, with any degree of accuracy, the surface topography with the underground workings of an abandon mine can prove to be difficult, if not impossible. Changes in surface features, inaccurate coordinates, and the lack of reliable information can hinder the identification process. Improvements in the ability to identify subsurface points can be made through the use of GPS technology. This technology can be applied to mine workings identification, given a few, necessary, precursory details. Specifically, an accurate mine map with identifiable surface features is needed. Surface icons identified in the field, such as mine adits, are referenced with the same points on the mine map. A "rubber sheeting" program, Multric, running in AutoCAD can be used to tweak the points so the mine map features correlated with the surface points. Desired drilling locations are identified on the mine map and assigned a latitude and longitude. A GPS receiver, using real time differential correction, is used to locate the drilling points in the field. Navigational capabilities of GPS receivers allow easy identification of the surface points by directing the operator to the appropriate location.

For this particular application the accuracy was assumed to be within 5 to 15 feet, based on the uncertainty of the mine map and the GPS error. Overall, this method proved to be an effective and versatile means of correlating the subsurface with present-day topography. Of the six wells drilled, five entered rooms within the mine, one entered a coal pillar, which equates to an 83% success rate.

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