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Improving Safety in Open Pit Mines Using RTK - Differential GPS

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ABSTRACT. The National Institute of Occupational Safety and Health (NIOSH), has reported that, more than twenty-five fatal accidents related to dumping tasks and more than 23 fatal accidents related to vehicle collisions have occurred in USA since 1990. GPS technology is being used efficiently in large open pit mines in the area of truck dispatch systems and field surveying. In large open pit mines, the pit maps and dump maps are being built in real time and can be transferred directly to the on-board computers of the trucks. With the existing GPS equipment already on board, one can quickly determine exact coordinates of a given truck within sub-meter accuracy and evaluate if a given truck is dangerously close to the dumping edge of a waste dump. At Colorado School of Mines, Mining Engineering Department there is an ongoing research project on improving truck safety and productivity through GPS and wireless mobile network system using a state-of-the-art 3D interface, which could access SQL compatible databases. This paper presents the current progress on this work and discusses various issues that are needed to overcome in development of a rugged, reliable system.

1 INTRODUCTION

Coordinating several pieces of heavy equipment in an open-pit mine is not a easy task, the complexity factor is increased when this equipment scales up to house size trucks.

More than 25 fatal accidents have occurred when truck drivers performed dumping tasks since 1990 just in USA. This process requires the driver to move backwards toward the edge of a cliff tens of meters deep, and, over a surface composed of material that has been recently deposited, making this soil unpredictable fpr failure.

The requirement of a system to improve such conditions needs to be developed: the objective of this project is to develop a real time tracking system for these trucks so an intelligent system could automatically warn the driver, if he/she gets too close to the edge of the dumpsite, as well as, to indicate risk of surface-collapse.

Creating a virtual buffer safety-zone on the dump will permit the truck to move safely and efficiently in accordance with soil and truck characteristics in realtime.

The use of an accurate GPS system, which can handle sub-meter accuracy, is required to keep track on any movement of the truck respect to the edge of the dump, thus a differential GPS is used along with RTK (Real Time Kinematics) technology.

It is very important to remember that, differential mode using code phase is called DGPS. Using carrier phase is called *Carrier Phase* Differential (CPD). Real-time carrier phase differential has been called *Real-Time Kinematic (RTK).*

Potential implementation of this system is the monitoring of pit ramps surface conditions using vibration sensors on the truck, Collision Warning, improving safety on shovel-truck loading tasks, and in the near future: real-time dispatching driverless systems.

2 DESCRIPTION

This project involves mining operation and safety, and particularly focuses on the dumping process of mine trucks in open pit operations. During the last years the Department of Labor MSHA (Mine Safety and Health Ao^nmistration) and NIOSH, have followed statistically the number of accidents that have occurred due to this dumping task (1990 to 1996), resulting in 23 and 25 fatal accidents related to vehicle collision and off-highway, which also has caused losses of millions of dollars in equipment and opportunity costs.

Due to a large number of accidents that occur while a truck dumps a load at the edge of a waste dump, attention was focused on the danger associated with the proximity of the truck to the dump edge and the potential ground failure due to the high truck weight and the material strength of the waste dumps.

If soil conditions are safe for dumping this project is also taking into consideration factors like poor visibility or driver error. Figure 1 shows a open pit mine in Peru using GPS.

Thus this project focuses on creating a system involving state-of-the-art technologies available today such as:

- RTK differential GPS
- Better and more reliable radio communication, like Bluetooth local wireless networks.
- TCP-IP protocol for Internet compatibility using VRML Virtual Reality Modeling Language, and.
- Potential use of pseudolites

Figure 1. Mine in Peru using GPS technology.

3 SOFTWARE DESCRIPTION

These technologies must be put together in a simple and friendly form that can be quickly mterpreted by the truck driver and the main control office, and at the same, time this information must be shared m real time among other mobile equipment in the mine and even shared to offices located around the world.

In order to accomplish this task a visual two-dimensional interface written in Visual Basic language was developed, where the GPS data is read, collected, and compared with survey data and then displayed on a flat panel screen mounted on the truck.

A series of alarms (sound and visual) are also used to warn the driver if the truck is approaching a non-safe zone.

The safety zone is based on the soil conditions and on the truck size and load. The safety zone is represented by a series of lines distanced from the edge dump. This digital safety line is positioned with respect to the edge of the dump m real time depending on the truck and soil conditions, See Figure 2.

Figure 2. Cross section of a dumpsite showing the relative position of the truck represented by the dot against a buffer safety zone by the line

The Visual Basic algorithm takes in consideration the position of the truck İn real time given by the GPS unit. It also reads the 2D survey map of the dumpsite zone and then creates a "safety buffer line" zone.

The next generation of this software; a three dimensional version of this interface is being developed based on VRML (Virtual Reality Modeling Language), which is described later in this paper.

Creating a virtual buffer safety-zone on the dump will permit the truck to move safely and efficiently in accordance with the soil and truck characteristics İn real time. The current Visual Interface is shown next presenting three different scenarios where the mine truck is approaching the dump edge, and the safety buffer line: (See Figure- 3).

The use of a very accurate GPS system, which can handle sub-meter accuracy, is required to keep track of any movement of the truck with respect to the edge of the dump. Thus a RTK (Real Time Kinematics) differential GPS is used for this project. Utilization of GPS pseudolites (ground-based "pseudo satellites") next to the pit is also considered in order to increase reliability of the system and satellite constellation availability.

4 SOFTWARE DEVELOPMENT

Development of a Visual Interface is being carried out using the Visual Basic language, and consists on two main programs:

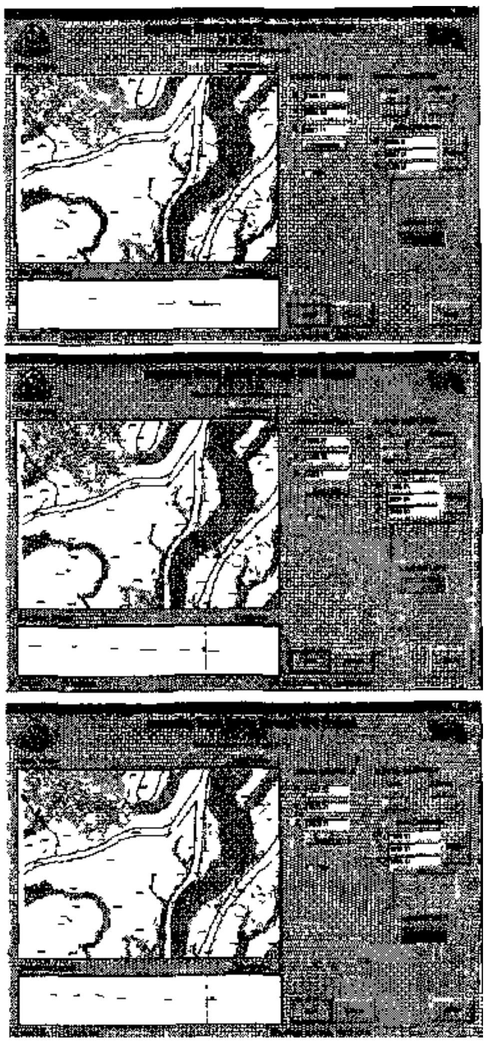


Figure 3 A series of snapshots showing the dumping process of a truck related to the dump edge and the safety zone

The first program consists of reading and interpreting data coming from the GPS receiver. GPS receivers commonly use NMEA (National Marine Electronics Association) protocol, which is the standard communication format, used in GPS.

4.1 *NMEA code*

Under the NMEA-0183 standard, all characters used are printable ASCII text (plus carriage return and line feed). NMEA-0183 data is sent at 4800 baud

The data is transmitted in the form of "sentences". Each sentence starts with a "$", a two letter "talker ID", a three letter "sentence ID", followed by a number of data fields separated by commas, and terminated by an optional checksum, and a carriage return/line feed. A sentence may contain up to 82 characters including the "$" and CR/LF.

If data for a field is not available, the field is simply omitted, but the commas that would delimit it are still sent, with no space between them.

Since some fields are variable width, or may be omitted as above, the receiver should locate desired data fields by counting commas, rather than by character position within the sentence.

The optional checksum field consists of a "*" and two hex digits representing the exclusive OR of all characters between, but not including, the "$" and "*". A checksum is required on some sentences.

The standard allows individual manufacturers to define proprietary sentence formats. These sentences start with "$P", then a 3 letter manufacturer ID, followed by whatever data the manufacturer wishes, following the general format of the standard sentences.

4.2 *Soßware Development*

At the first stage of this project, a DeLORME GPS receiver unit was acquired to perform some preliminary communication tests between the receiver unit and the PC.

Unfortunately the DeLORME unit sends encrypted data coordinates and a "NMEA-Binary translator" device had to be used on the PC computer port.

Currently it is being used a TRIMBLE 4400 Dual Frequency GPS receiver unit which had to be reprogrammed to output NMEA-Code.

Once native a NMEA-code was received on the PC port, a small VB program was developed to read this data and extract the XYZ coordinates from the unit.

The VB program is a modification of a VB Modem Terminal, which consists of a text terminal that is connected to the COM1 of the PC. This program is able to read the output ASCII stream based on the NMEA code from the GPS unit, and extracts the XYZ coordinates. Figure 4 shows the terminal reading and extracting the longitude, latitude, and altitude.

The second part of the Visual Basic project, consists of a program for graphical visualization purposes, where a DXF reader module is incorporated mto the VB routine in order to be able to import DXF maps from AutoCAD or any other CAD program.

This interface is to be installed on a LCD screen next to the truck driver controls (See Figure 5), so the driver can track his position with respect to the map İn real time.

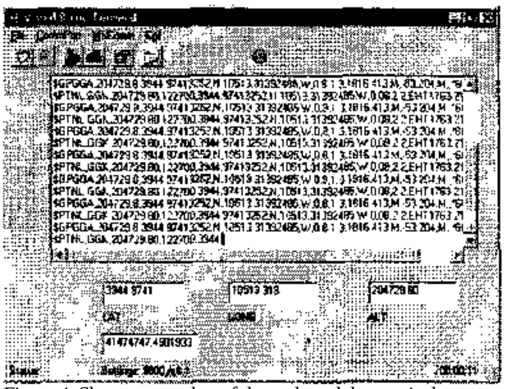
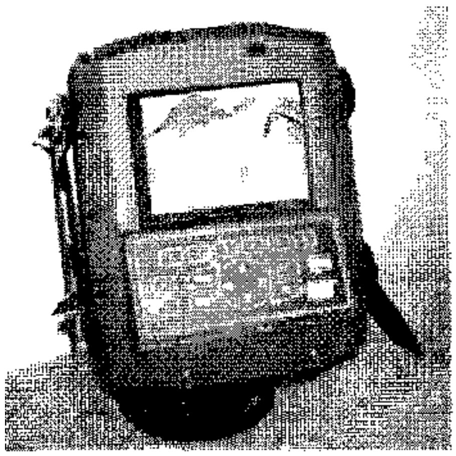


Figure 4. Shows a snapshot of the code and the terminal extracting Ihe XYZ cords form the GPS unit.



panel, (digitally composed).

The 2D map software is designed such that two separate views of the dumpsite are generated in the graphical interface; The plan view on the top part of the screen and the equivalent section view just beneath Figure 6. Using this format the driver can track at the same time his vertical position with respect to the dumpsite as well as the horizontal position. The program also displays a virtual line representing the safety boundary of the truck with respect to the dumpsite. The line distance with respect to the edge of the dumpsite varies according to the truckload characteristics and also with respect to the soil conditions.

This information can be fed into the program from the engineering center office to the truck by a radio modem link or directly by the driver. Once the truck approaches this safety line a series of visual and sonic alarms start to act depending on the proximity of the truck to the virtual safety boundary line (See Figure 6).

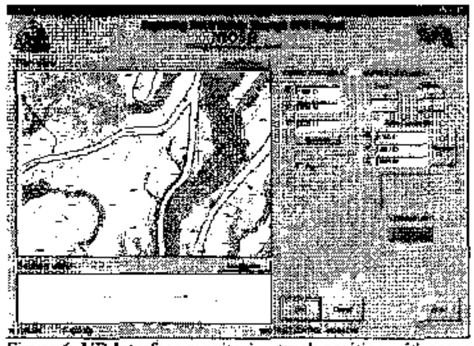


Figure 6. VB Interface monitoring truck position with respect to the dumpsite edge and the buffer safety line.

4.3 *VRML Project, THE 3D Interface*

In order to upgrade the above system from a 2D system into a Real Time 3D interface, the Virtual Reality Modeling Language VRML is being used.

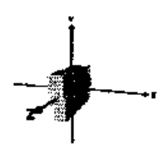
VRML is "an open standard for 3D multimedia and shared virtual worlds on the Internet."

Long before its official standardization VRML became the *de facto* standard for sharing and publishing data between CAD, animation, and 3D modeling programs; virtually every one of those programs now exports VRML or has a utility or plug in to convert its native file format'to VRML. VRML is included or referenced in the upcoming MPEG-4 standard, Java3D. and in other developing standards.

Being able to talk and work in a 3D shared virtual space was one of the earliest motivations of the VRML pioneers. The VRML works has a whole section on Internet that talks about the work that's being done to realize this vision.

Unlike previous 3D applications, using the Internet to share 3D objects and scenes was built into VRML from the very beginning. The standard is even published in HTML.

Example:



```
#VRML V2.0 utf8
# The VRML 2.0 Sourcebook
Shape {
        appearance Appearance {
           material Material { }
        }
        geometry Box {
            size 1.0 3.0 5.0
        }
    }
```

The approach followed to construct a VRML world for this project was first to create a VB program, which could translate DXF files (contour lines in 3D poly-lines format) into a VRML 3D Lines.

Thus a mine map coming in a DXF format (which is the most common form), could now be visualized in a 3D view which can be dynamically viewed in real time, instead of using 2D sections.

The 3D visualization in VRML can be thought of as a VirtualWorld, or in this case: a VirtualMine since the user can move inside this "world" in real time using a standard keyboard or mouse. Eventually interactive devices like goggles and gloves will allow the user to immerse itself into this "VirtualMine" from any location since it İs INTERNET based.

The first step to create this DXF to VRML translator was to create a program in VB to read the DXF file (ASCII file), and use it to determine the beginning of each individual poly line. Once this step was completed successfully, the program then was able to create 3D points in VRML floating in space representing the survey data coming from the mine map.

The next step was to "link" these points with lines to create 3D lines in VRML, thus creating a 3D map of the mine.

The next step is to create the 3D representation of the truck, which will be dynamically positioned İn the map by following the XYZ coordinates coming from the GPS unit. The truck then interacts with the safety buffer zone represented by a 3D plane. Thus, if the truck approaches or crosses this plane, a series of alarms will be trigged.

Again, this safety buffer plane will be moving with respect to the edge of the dumpsite depending of the truck characteristics and soil conditions.

This program was, once again written in Visual Basic. As an example the same dumpsite map used in the 2D interface is now shown in an isometric view.

5 FUTURE DEVELOPMENT

GPS application in mining is becoming more and more reliable and less expensive, due to the implementation of new technologies like differential GPS and the relaxation of government policies, such as the recent announcement coming from the USA government in order to cancel GPS selective availability, as well as the use of the Russian GPS equivalent: GLONNAS.

Now, for the first time, İt is economically feasible and reliable to monitor in real time any moving equipment in an open pit mine.

At Colorado School of Mines, Mining Engineering Department, we are using this GPS technology with a new state of the art visual interface based on VRML (Virtual Reality Modeling Language). The product code is named "Virtual Mine".

At this stage, *"Virtual Mine"* can translate DXF contour mine maps into VRML files (called virtual-worlds) (See Figure 7), so the user can interact through this 3D environment using a stand-alone visual basic interface or even a web browser from any "real-world" location.

Combining these approaches feeding the system with topographic DXF files and feeding the location of every equipment working in the pit from a GPS, it will be possible to virtually supervise a complete mine operation in real time, moving through this digital model of the mine, *thus giving whole new approach m improving safety and productivity in mining operations.*

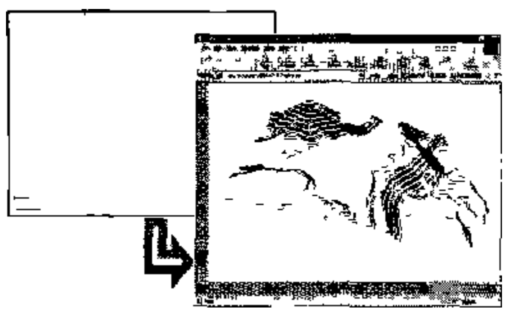
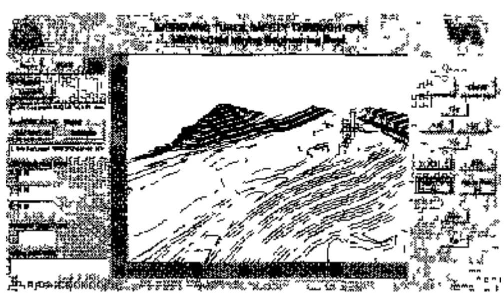


Figure 7. Translation from a DXF 2D contour map m ACAD mlo a VRML 3D image, viewed using a web browser

Figure 8 shows the current interface where the dump map and a mine truck (represented by a 3D cube) interact in this 3D environment.

This system could be also integrated into the concept of "Collision Warning Systems" for surface mining equipment which is also being sponsored by the the National Institue for Occupational Safety and Health (NÏOSH) (Todd M. Ruff).



FigureS Snap Shot Showing a 3D representation of the dump site translated from a DXF file and a truck.

Other utility which is being incorporoated into the system İs "data access and transfering" (Figure *9);* the system is intended to be capable of transmit and receive data from central office into any otfier vehicle in the mine in real time. This process will update a central database containing all data related to the mining operation. The system is also capable of query data from the central data base using the SQL.

The system uses TCP-IP upgraded radios (Currently Trimble TRIMCOMM 900) to broadcast GPS signal correction, however testing is being done to transmit the truck related data. Like: tonnage of ore/waste moved, grade, truck condition, road condition, etc.

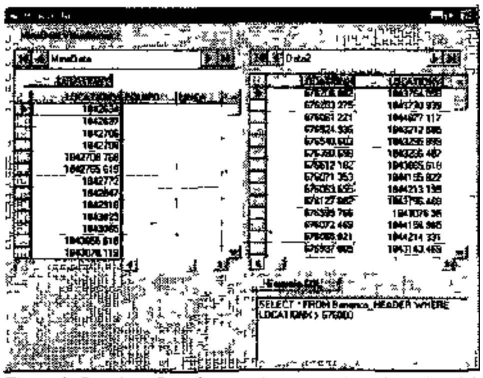


Figure 9. Database Interface used to transmit and receive dala form central office to the truck

As mentioned other potential implementations of this system besides dumping tasks are:

- Collision Warning Systems
- Monitoring of surface condition in ramps or roads using vibration sensors on the truck.
- Improving safety on shovel-truck loading tasks.
- Improving preventive maintenance.
- And In the near future: real-time driverless dispatching

6 CONCLUSIONS

The Importance of the GPS applicability in mining is increasing since GPS technology is becoming more and more precise and reliable, thanks to the development of new technologies and the availability of systems like GLONASS.

New technologies like pseudolites and differential GPS based on geostationary satellites' have a great potential in GPS applied in open pit mining, since increases the reliability of the GPS system, at a relatively low cost. Further investigation on the implementation of Üıese technologies is suggested.

Fatal accidents related to dumping tasks are indeed occurring in a significant number, (Since 1991 -1999, 23 and 25 fatal accidents in vehicle collision and Off-highway). Differential GPS applied in this field can impact dramatically in reducing it.

This project, besides having an important impact on reducing accidents also has the potential to generate a new GPS tracking generation mat very well could upgrade present GPS based systems, with better, more reliable, and cheaper systems.

REFERENCES

Ruff, Todd M , Feb 2001, Test Results of Collision Warning Systems on Off-Highway Dump Trucks. Phase2, NIOSH. Report of Investigations 9654.

Bennington, Ben, Johnson, David, and S lane 11 Dan 1999, "Mobile Communication System for the Construction and Mining Industry". Technical Report, Information Networking Institute, Carnegie Mellon

Richard B. Thompson, 1998, Global Positioning System (GPS) The Mathematics of Satellite Navigation, available on the web MathCAD library, *http://www.mathsoftcom/appsmdex.html,*

Dagdelen K., Alex Calderon A, May 2000, Geotechnical Investigation of Waste Dumps , Internal Report Mining Eng. Dept Colorado School of Mines.

Jonathan M. Stone, Edward A. LeMaster, Prof. J. David Powell, 1999, GPS Pseudolite Transceivers -and their Applications. Internal Paper, Department of Auronaticx, Stanford University

Trimble Navigation Limited, 1999, web presentation, All about GPS and Differential GPS *http //www trtmble com/*

Gilbert Strang, June 1997, The Mathematics of GPS, SIAM News, Volume 30, Number 5, available on the web, *http.//www-math mit edu/~gs*

Federal Radio navigation Plan, February 2000, U.S. Department of Transportation and Department of Defense Available on üne from United States Coast Guard Navigation Center, *http.//www navcen.uscg mil*

Global Positioning System Standard Positioning Service Specification, 2nd Edition, June2, 1995. Available on line from United States Coast Guard Navigation Center, *http //www.navcen uscg.mil*

NAVSTAR GPS User Equipment Introduction. 1996 Available on line from United States Coast Guard Navigation Center, *http-//www navcen.uscg mil/*

MSHA, Department of Labor, Internet, Mine Safety and Health Administration, Fatality Information-Fatal Grams. *http -//www msha.gov/sitemdex/sttem htm*

Andrea L. Ames, Daved R. Nadeau and John L. Morelnad, 1997, VRML 2 0 Sourcebook Sand Diego Supercomputer Center

Evangelos Petoutsos, 1998, Mastering Visual Basic 6 SYBEX Inc, Alameda, CA. number of 1285 pages.

Anon, 1998, Tnmble Users Conference Proceedings, CD Rom, available from Tnmble, Inc. San Jose, CA