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DEVELOPMENT OF DUMP EDGE AND VEHICLE PROXIMITY WARNING SYSTEM USING GPS AND WIRELESS NETWORK COMMUNICATIONS TO IMPROVE SAFETY IN OPEN PIT MINES

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ABSTRACT

A dump edge and vehicle proximity warning system is being developed at the Colorado School of Mines using GPS and wireless local area networks to improve the safety of off-highway trucks in open pit mines. After two years of research, software development, and testing in the laboratory, field tests are currently being carried out at operating limestone quarries and open pit mining operations to evaluate the effectiveness of the system under rugged operating conditions. This paper describes the progress made on this NIOSH-funded project and discuss, tests carried out recently, at the Morenci open pit copper mine in Arizona.

INTRODUCTION

During the last decade, the Mine Safety and Health Administration (MSHA) has reported a significant number of accidents related to off-highway dump trucks.

Between 1990 and 1996, 136 accidents resulting in 26 fatalities involved off-highway trucks going over the edge of the dump during the backup process. In 1999 alone, there were four fatal accidents resulting from trucks going over the dumps.

Between 1990 and 1998, 133 accidents involving 23 fatalities occurred as a result of collision of an off-highway truck with another object, vehicle or person in open pit mines. In 1998 alone, 13 fatalities occurred in metal/nonmetal and open pit coal mines when off-highway trucks ran over either a small vehicle or person hidden from view in the blind spot off the truck.

The objective of the NIOSH-funded research project was to develop a software system by using The Global Positioning System (GPS), wireless communications networking, and 3D mapping technologies to reduce the number of accidents involving off-highway trucks in order to improve the working conditions in open pit mining operations.

The envisioned system had to meet the following goals:

The system should be capable of tracking the vehicle with respect to the edge of a dumpsite as well as to other vehicles in real-time and warning the driver of close proximity or collision.

The system should be user friendly and easy to understand by the driver using simple and representative computer graphics.

The mine vehicle will be integrated with a screen monitor linked to the system's computer to give the driver a real-time picture of the vehicle with respect to its surroundings.

The system should be sub-meter accurate regarding its position with respect to the safety berm and with respect to the position of other vehicles.

The system should be capable of 3D contour mapping on demand, in order to monitor a vehicle's position with respect to the mine's geometry.

The vehicle's position should be shared among all the operating vehicles using a wireless-radio network. This system should further be able to update the mine's geometry on demand, based on remote vehicle's coordinates and the system must be tested in a mining operation to check for its operability, effectiveness, and operator acceptance.

SYSTEM DESCRIPTION

The development of the system involved the incorporation of three different state-of-the-art technologies: a GPS mobile computer system, a wireless communication network system, and a 3D mapping and graphical interface software system. All of these technologies are combined and controlled in a real-time software system called VirtualMine.

A brief description of how the system works is as follows: As seen in Figure 1, the system mounted in the truck cabin receives a GPS signal from the GPS receiver mounted on the truck. The GPS system calculates the true position by using signal correction received from the base station trough wireless radio antennas. The system calculates the position of the truck with respect to the Digital Terrain Model (DTM), generates/updates DTMs on the screen of the computer mounted on the truck and sends this information to other trucks and base station using the IEEE 802.11b wireless radios. The base and other vehicles receive the information in XYZ packets. These packets are used to map and display the truck position on the DTM of the mine.

The position and terrain Information is sent to the base station by way of an on-board radio in a given truck, the base station receives the data through an access-point, connected to a computer on the main wired network. If the network is routed to the internet, the monitoring of equipment on the updated terrain maps can be carried out from any computer connected on the internet. See Figure 1.

The same process is repeated when sending position and terrain information from vehicle to vehicle in a peer to peer TCP/IP scheme.

The hardware and software components of this system are discussed in detail next.

GPS and Computer Hardware System

The GPS System Hardware is manufactured by Trimble and currently marketed by Caterpillar. The GPS receiver is configured to output ASCII NMEA code, and it is connected to the PC screen through a serial port. The pictures following were taken during the installation of the GPS equipment on Caterpillar 793 truck. See Figure 2, and Figure 3.

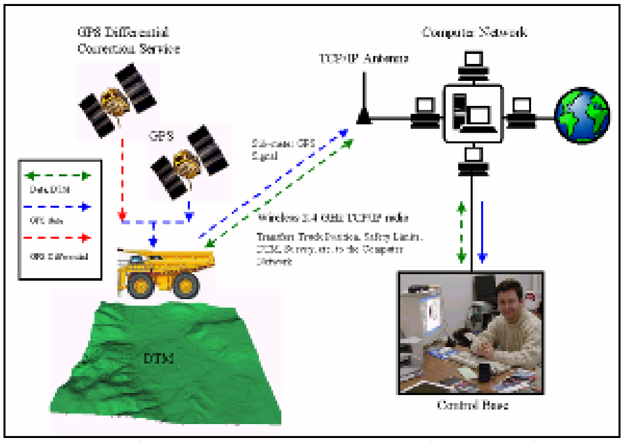

Figure 1: Schematic representation of the configuration used to monitor a remote truck from the central office.

Figure 2: A picture showing the installed rugged flat panel computer CAT 793 truck.

The system can operate either using Differential GPS or RTK-GPS receivers. The RTK-GPS receiver is a Trimble 4400, which is connected to the GPS antenna and 900 MHz TCP/IP-upgraded Trimble radio. When using the RTK-GPS system one has to establish a base station to broadcast coordinate corrections to the GPS units on the trucks to make this system centimeter accurate. When the system is configured for differential GPS the Trimble AG-GPS 132 receiver is used. This GPS unit provides sub-meter accurate truck locations.

An Xplore PC screen system is used as the onboard computer and display device. Xplore was selected among other similar systems since it was a PC embedded screen, very rugged and touch screen enabled. The Xplore PC-Screen is shown in following Figure 3.

The Xplore unit is a Pentium III PC computer based on windows 98 and runs at 500 MHz. It is mountable in any vehicle and, has one serial port and 4 USB ports. It has an internal PC card, which could be used to install an IEEE wireless radio card.

Wireless Communication Network System

The wireless network system used is TCP/IP compatible and it can use both, the upgraded Trimcomm 900 radios from TRIMBLE or IEEE 802.11b compatible radios from Orinoco.

The wireless network is used by the system to broadcast coordinates between mine vehicles to keep track of their positions in real time. These coordinates are also used by the system in order to generate Digital Terrain Models (DTM) in 3D on demand. Testing is being done to transmit operative data, like ore/waste, tonnage grade, truck condition, road condition, etc.

Figure 4 is a schematic representation of the system configuration when the vehicle is using 802.11b wireless communication protocol to send data to an internal network through a TCP/IP compatible access-point also using the 802.11b protocol. Using this configuration the vehicle can be monitored from a central office using an internal network.

Figure 3: The Rugged flat PC-panel used in VirtualMine System

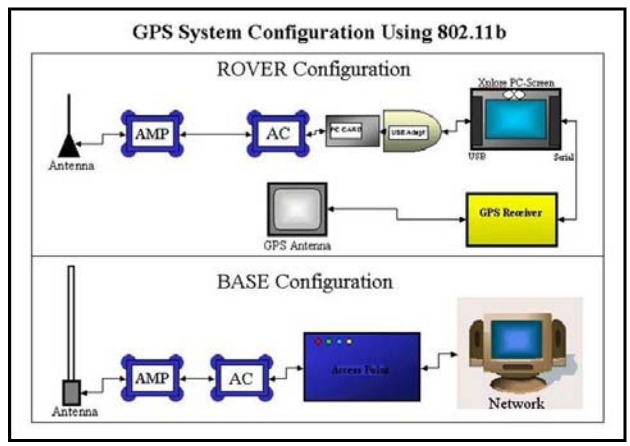

Figure 4: Schematic representation of hardware configuration for rover and access-point.

The Trimble radio has two functions: one is to receive error correction from the base station, and two, since it is TCP/IP enabled, to transmit real-time data like current GPS coordinates to other TCP/IP Trimble radios.

Using Trimble TCP/IP radio configuration, the GPS receiver and the Trimble radio must be connected to the computer by way of two serial ports. Since the Xplore unit has just one serial port, an USB/serial adaptor is used in place of a second serial port. Figure 5 describes the connection layout of the system when using Trimble radios.

When using the 802.11b wireless configuration, a USB adaptor card is used to emulate a PCMCIA card-slot, which is used to connect the TCP/IP wireless radio card into the Xplore computer.

The default ranges of 802.11b systems are on the average, couple hundred meters; however, using 1 watt amplifiers connected to an omni directional antenna, the ranges have increased to approximately three kilometers. See Figure 6.

This is an inexpensive radio system and could potentially substitute 900 MHz radio systems. Figure 6, describes the connection layout of the 802.11b radios.

Figure 7 is a photograph showing Orinoco radios and antennas mounted on Caterpillar 793 truck and on a Chevy pickup truck.

Both vehicles were equipped with the VirtualMine system using 802.11b radio cards connected to 1watt amplifiers, which are in turn connected to omni-directional antennas shown in the photograph.

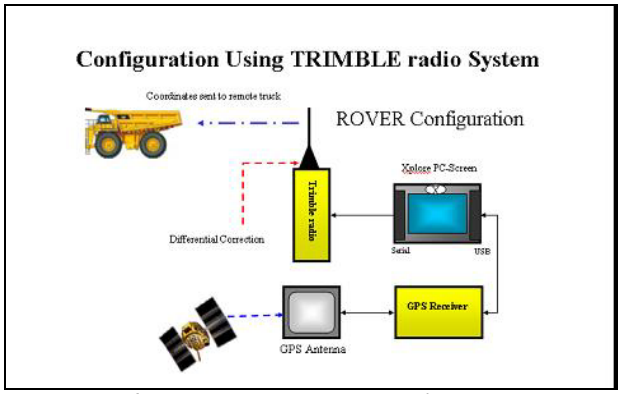

Figure 5: Schematic representation of the system using Trimble radio system

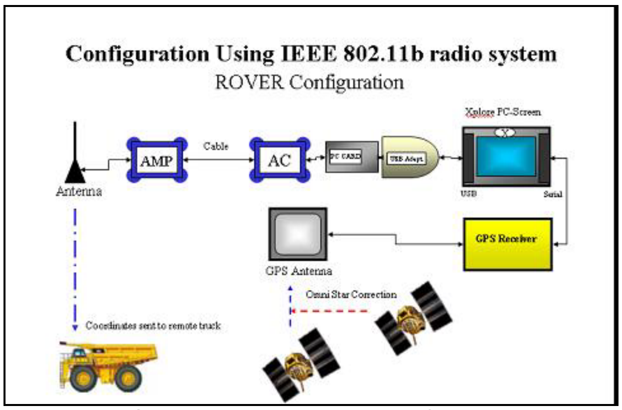

Figure 6: Schematic representation of the virtual reality wireless radio communication system using 802.11b protocol with 1-watt amplifiers.

Figure 7: A photograph showing Orinoco wireless radio antennas mounted on two different vehicles.

Virtual Mine Software

Development of the Virtual Mine Software and its visual graphical interface was carried out using Visual Basic language. The software is in charge of several functions:

- Reading and Extracting NMEA code coming from the GPS unit through a serial port.
- Converting NMEA code from its original geographic coordinates (Latitude and Longitude) into UTM coordinates.
- Transformation of DXF mine maps into 3D VRML maps.
- Visualization of 3D mine maps.
- Position tracking of local and remote vehicles in real time.
- Generation of 3D mine maps on-demand.
- Handling of the TCP/IP wireless communication protocol to transmit and receive positional and terrain data from remote vehicles.

INITIAL SOFTWARE DEVELOPMENT - 2D GUI VERSION

The initial approach followed for displaying a vehicle over a map, was to develop an algorithm written in VB to read and interpret vehicle coordinates coming from the GPS receiver to display the truck over a 2D DXF mine map.

The system user loads the DXF map of the mine and defines a dumping point. Once the GPS unit is activated, the system starts tracking the vehicle's position with respect to the dumping point over the map. A series of alarms (audio and visual) are used to warn the driver of proximity to the dumping point.

The dumping point is defined at a certain distance with respect to a safety line which could be seen as a "digital" safety berm to the dump's edge. See Figure 8.

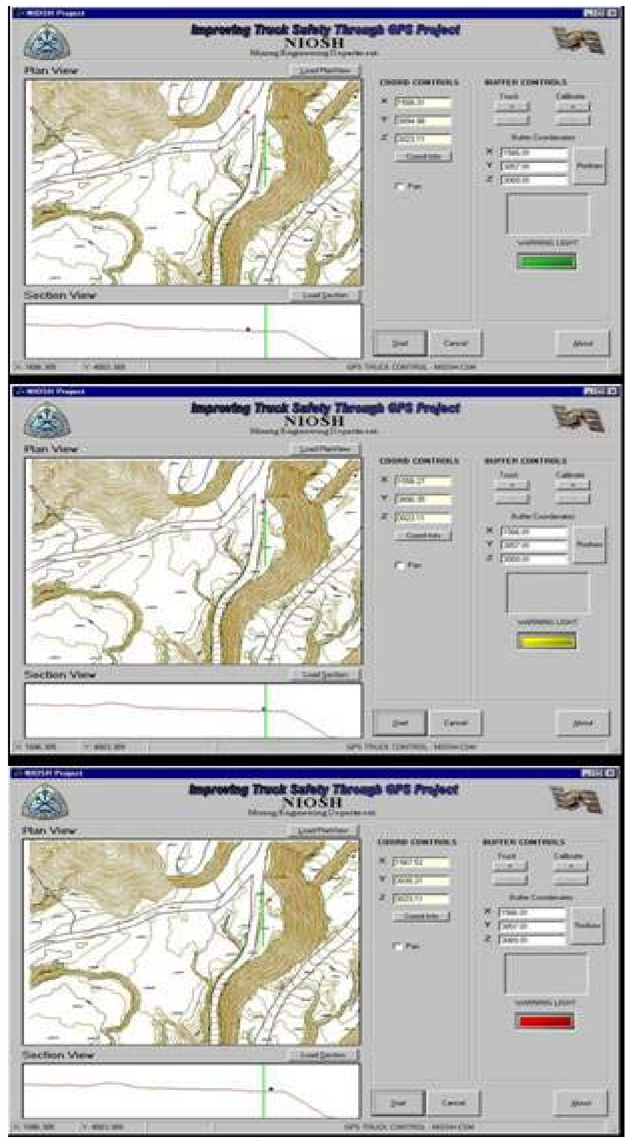

Figure 8: A series of snapshots showing visual alarms displayed as warning light as the truck approaches the dump edge

The software code receives the position of the truck given by the GPS system and, displays this position on previously uploaded DXF top map of the dumpsite. The location of the safety berm is also displayed with respect to the edge of the dump.

The 2D system is designed such that two separate views of the dumpsite are generated in the graphical interface: Plan view on the top part of the screen and the equivalent section view just beneath (See Figure 8). Using this format, the driver can track at the same time, his vertical position with respect to the dumpsite, and 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 soil conditions.

The mine geometry as well as the dump point information can be fed into the system by a radio modem link.

The software activates a series of visual and sonic alarms as the truck approaches to the virtual safety berm representing safe distance from the edge of the dump.

The pictures in Figure 8 show a visual sequence of alarms displayed by the software as the truck approaches the safety berm represented by the line drawn next to the haul road on the contour map of the dump.

VIRTUAL MINE SOFTWARE DEVELOPMENT USING 3D GRAPHICAL INTERFACE

A new 3D concept was incorporated into the system. For this, a new software code was developed in Visual Basic utilizing VRML routines available from Parallel-graphics™ Cortona's VRML library. (See details on using Cortona components in www.parallelgraphics.com/cortona.)

Cortona libraries for 3D rendering in VRML format can be programmed using Visual Basic to create and animate 3D scenes or objects. Cortona also enables 3D Scene Stereo Viewing since it supports VR 3D Glasses for 3D scene stereo viewing. VRML is an open standard for 3D multimedia to share virtual objects on the Internet. See Andrea (1997).

The approach followed to construct the 3D graphical interface for this project was to create first a Visual Basic program, which could translate DXF files into VRML 3D lines.

Thus, a mine map defined in a DXF format, could now be visualized in 3D. This view can be dynamically changed in real time, instead of using 2D sections.

The first step to translate DXF polylines to VRML was to create a program in Visual Basic, able to read the DXF file coordinates of those lines to generate the new VRML file, containing the 3D equivalent map.

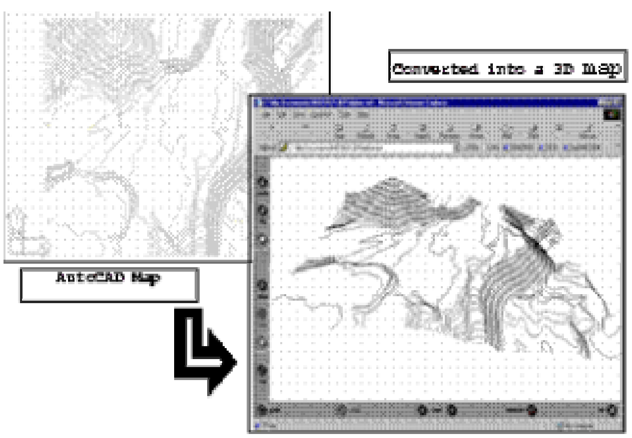

Figure 9: Representation of the conversion process from a DXF (AutoCAD map) into a 3D map (VRML map)

Figure 9 represents the process of translating a DXF contour map into VRML format using the VirtualMine translator routine. In Figure 9 the transformed VRML map is displayed using an Internet browser. Currently, the system can import DXF maps from ACAD R.12 or DXF maps generated by SURFER using the DXF export contour lines command for contour maps.

The software system generates a 3D truck model, which is dynamically positioned on the map based on the XYZ coordinates coming from the GPS unit. The system then monitors the 3D truck position with respect to the mine map as shown in Figure 10.

Figure 10: 3D truck models shown on a given contour map.

The software can also generate a 3D spherical bubble to indicate the safety zone around a given truck (Figure 11).

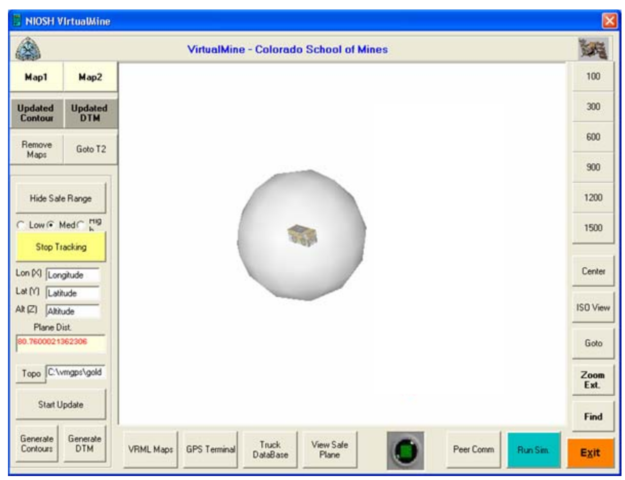

Figure 11: 3D Model of the truck in a safety bubble

The VirtualMine system can also monitor the 3D truck position and the distance with respect to a virtual safety berm represented by a plane. (See Figure 12). The position of the virtual safety berm is previously fixed with respect to the edge of the dumpsite, depending of the truck characteristics and soil conditions. If the truck approaches or crosses this plane, a series of alarms are triggered to warn the operator. (See Figure 13).

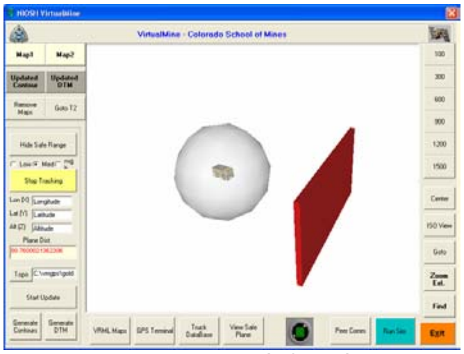

Figure 12: 3D Truck model, Safety Sphere and Safety Virtual Berm represented by a plane.

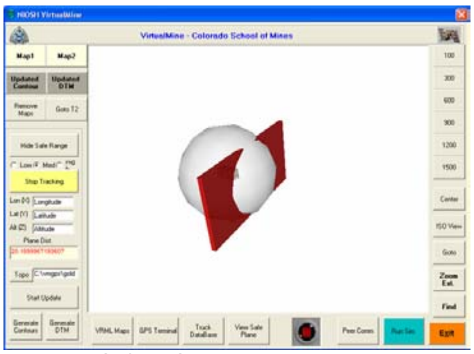

Figure 13: 3D Safety Sphere intersecting with the Safety Virtual Berm.

It is envisioned that if another vehicle comes within the safety sphere of a given truck the system would warn the operators of both trucks of impending danger. See Figure 14.

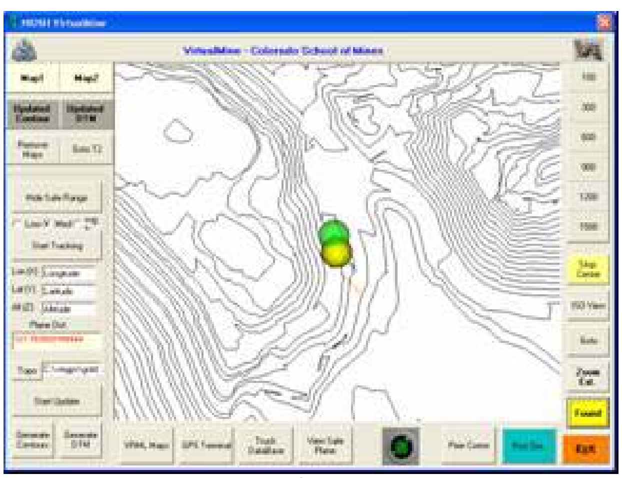

Figure 14: Two Trucks in a Close Proximity

The VirtualMine system also has the capability to update the contour map of a given section of the mine on demand using XYZ information coming from actual truck locations as well as the location of other vehicles such as dozers. This is accomplished by saving the XYZ coordinates received through the wireless network from all of the authorized remote vehicles; this information is then used to generate a topo-grid file that is automatically contoured and displayed on demand on the onboard computer screen. (See Figure 15.)

Another feature of VirtualMine has the ability to send, receive, and SQL-query data coming from remote trucks or a central office. This process updates a central database containing all data related to the mining operation. (See Figure 16).

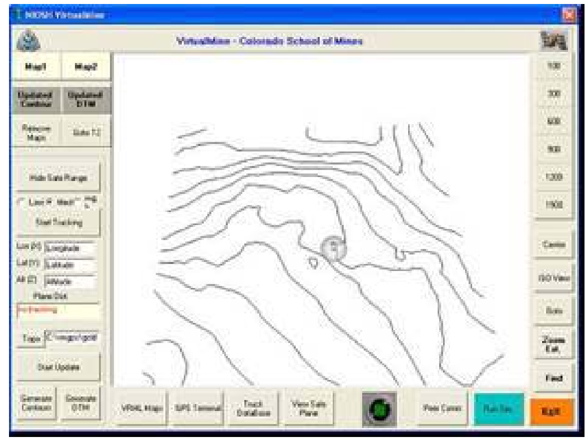

Figure 15: 3D contour map generated on-demand by driving at the CSM campus.

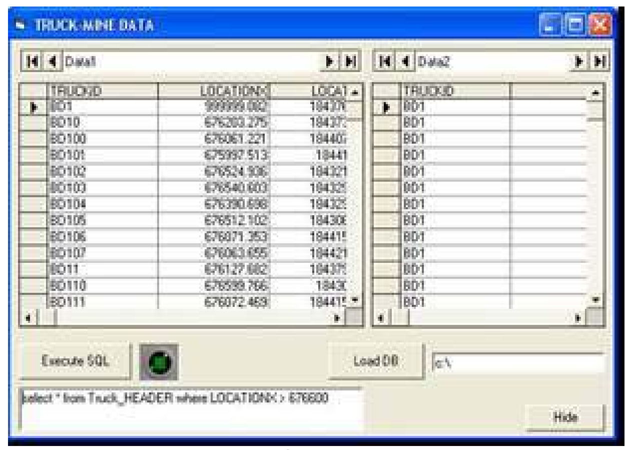

Figure 16: Database Interface used to transmit and receive data form central office to the truck

MORENCI TESTS

Various tests were carried out at the Morenci open pit copper mine, Morenci, AZ to check the applicability of the system. The descriptions of these tests are given below.

Vehicle Tracking and On-Demand Contouring

The first task after instrumentation was to test VirtualMine tracking and contouring capabilities in real-time. In order to run this task, VirtualMine was installed into a CAT 793 mine truck. (See Figure 17.)

Figure 17: A Picture showing the truck and pickup used for the testing at Morenci System.

In order to run this test in the field (Morenci Mine), the first step was to import Morenci survey data into the system. Morenci survey data are based in local coordinates, thus a transformation to UTM WS-84 was required.

Once the survey data was transformed into UTM WS-84 coordinates, a portion of the mine was translated to VRML format and then compared to the actual location of the truck to check for GPS/map consistency.

The next stage was to drive into the main pit, to collect new survey data as well as to confirm GPS positioning and map geometry.

This task was performed relatively quickly without any problem, the truck position was accurate with respect to the 3D map used, and the generation of contour lines was carried out without a glitch. The driver could see his/she own position with respect to the mine map and the system was able to update the pit contour map in real-time, while the truck was moving within the pit.

In Figure 18 and Figure 19, one can see the real pit at Morenci and the equivalent 3D contour map as seen through the VirtualMine interface. Notice the location of the CAT 793 truck in both pictures.

Figure 18: Picture of the main pit at Morenci

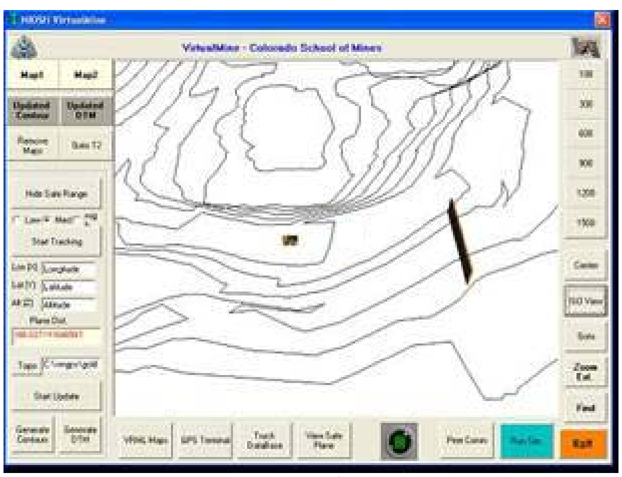

Figure 19: Virtual Equivalent of the main pit at Morenci as seen in VirtualMine

Vehicle Proximity Warning Tests

A proximity warning routine was also implemented in VirtualMine; the approach followed was to make the system broadcast the GPS location of the vehicle to a nearby vehicle, using the TCP/IP wireless network.

The system uses these coordinates to display both vehicles (local and remote) on the onboard computer screen.

The next task at Morenci was to carry out the proximity warning system tests between two vehicles. For this purpose the VirtualMine system had to be installed in a CAT 793 and in a pickup truck.

Once the system was activated and the GPS signal received, the next step was to activate the communication system using the peer-to-peer interface.

For example, Figure 10 shows the location of the trucks on the computer screen immediately after the TCP/IP connection is established at the Morenci Mine.

Figure 20: Picture taken at Morenci during the proximity-warning test.

The proximity warning system was tested at Morenci with very good results as shown in Figure 20: The computer screen located on the pickup truck is indicating that the remote vehicle (in this case CAT 793 truck) is touching the safety bubble, warning the driver of the close proximity of the CAT 793 tuck.

Dump Edge Proximity Warning Tests

For this test, the approach followed was to simulate a dozer pushing the material over the dump's edge. The dozer in this case was emulated by a pickup truck, performing the equivalent movements of the dozer as if it were pushing the material over the dump's edge. During this process, the haul truck was receiving and the dozer was broadcasting its XYZ coordinates as it moved on the dump.

Once the dozer had finished its task, the system updated the 3-D dump profile map by generating a new contour map of the terrain using the XYZ data received from the dozer. (See Figure 21)

Figure 21: PC-Screen showing the dump site map generated during the dumping process

As the trucks backs into the edge of the waste dump as seen in Figure 22, its location is immediately shown on the new map displayed by the truck's computer screen as shown in Figure 23.

Figure 22: The mine truck during the dumping process based on the new, updated map which was radio transmitted from the dozer

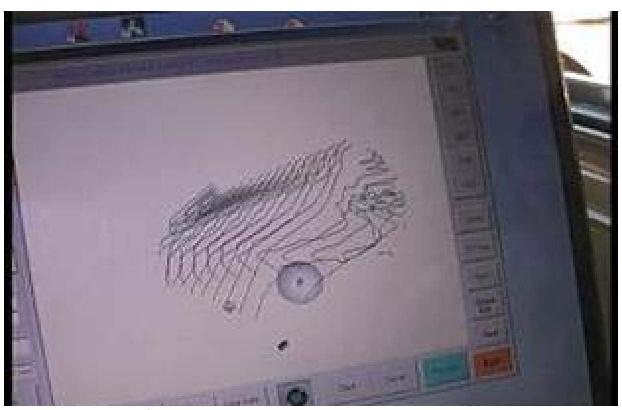

Figure 23: Compute screen mounted at the mine truck showing its position during dumping over the updated map

VIRTUAL MINE SYSTEM ACCURACY TESTS

A series of field tests were also carried out to check the accuracy of the GPS receivers used in the VirtualMine system.

In one of the test shown in Figure 24, the actual position of vehicles was compared to the vehicle location given by the VirtualMine GPS system. In

Figure 24(a), the actual distance between vehicles is measured based on the distance between the GPS antennas mounted on the vehicles.

Figure 24(b) shows in VirtualMine the equivalent calculated distance between the simulated trucks. The proximity warning tests validated the sub-meter accuracy predicted to be achieved by this system.

Figure 24 (a-top b-bottom): Measurements to check consistency between VirtualMine models and the vehicles on the actual field.

CONCLUSIONS AND RECOMMENDATIONS

Fatal accidents related to dumping tasks and vehicle collisions are indeed occurring at open pit mines. The VirtualMine system developed in this project could help improving safety in open pit mines and could reduce the number of these accidents.

The system tests carried out at the Colorado School of Mines campus as well as in actual mining operations such as the Morenci mine in Morenci, Arizona, indicated that "VirtualMine", is a system that could be used as a vehicle tracking, proximity and collision warning system. However, the system being developed has to be rigorously tested at open pit mine sites to check its reliability and effectiveness.

Further research is needed to continue developing this system into a mine expert system within the following scope:

- Dispatching systems
- Optimizing shovel operations (two sides loading)
- Real time mine planning and control
- Interface for driverless systems

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