Rasberry Pi and BeagleBones: Evaluating a cost-effective GPS system for on-mine navigation.

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Abstract

The South African Mine Health and Safety Act (MHSA) requires the mine surveyor to inform the manager of all workings within 100 metres of other workings, abandoned areas and hazardous accumulations of water or gas. The main purpose of this requirement is to ensure that all employees are aware and can take all the necessary precautions against un-planned breakthroughs, falls of ground and subsidence. In the case where mines are mining through abandoned workings in order to remove remnant pillars and previously unmined reserves, the potential for subsidence and equipment falling into excavated areas become a reality. A single incident where a machine falls into a collapsed working can amount to in excess of R1 million per incident, excluding the risk of loss of life or serious injury. An unplanned collapse of workings in the specific case study can also lead to sufficient air flow into the old underground to cause spontaneous combustion of the remaining pillars. Although systems for navigation of drill rigs exist the cost to deploy a similar unit to all vehicles in the mining area is prohibitive. A low-cost system that can navigate a vehicle and indicate to the operator what the subsurface features look like in the direct surroundings of the vehicle was developed using off-the-shelf technologies. This paper discusses the process of developing a low-cost navigation system towards a real time information management system for a mining operation. Benefits from this system may be applied in underground navigation and guiding rescue services in the search of illegal miners in abandoned mines.

Key words: Navigation, Health and Safety, Mine survey, Mining hazards, Underground navigation systems, BeagleBone

Introduction

As the availability of green fields mineral resources diminish it may become more frequent practice to re-work established and abandoned mines for remnants and material that was either too difficult dangerous or uneconomic to mine at an earlier time. Opencast workings can in some cases be used to access such resources. In such instances, the mining method may expose mining personnel, equipment to the risk of coming into unplanned contact such as falling through into old workings.

Should these old workings be prone to material known for spontaneous combustion, flooded workings or containing material, it may pose a risk to personnel or equipment be exposed damage to equipment can result. The South African Mine Health and Safety Act (MHSA), Act 20 of 1996 regulates the procedures and risk assessments to be made in such cases.

The area used for the study is an opencast mine, mining through three coal seams which have been previously mined by underground bord-and-pillar methods from 1931 to 1969. It is estimated that as much as 93% of the original reserve was left underground. Some of the excavations underlying the current opencast workings, pre-dates the Coalbrook colliery disaster of 1960 which was believed to be the result of a massive collapse of support pillars (SA History on-line , 1960). In the case of this study excavation in the opencast areas create “breakthroughs” into the underlying mined out areas causing spontaneous combustion. Spontaneous combustion of coal pillars occur when the coal reacts with oxygen causing an exothermic reaction (Ozdeniz, Sivrikaya , & Sensogu, October 2013).

Using off the shelf user programmable hardware to improve mine safety, GPS is a well-established navigation technology used by users worldwide. As GPS technology has evolved it has become more user-friendly and “instinctive” to use. Current systems requires very little user input and can be used by non-surveyors. On mines mapping and directing the mine workings is in the mine survey domain and few outside the surveying discipline understands or cares how this technology is applied.

Legal factors

According to the South African Mine Health and Safety Act (MHSA), Act 20 of 1996, the employer must take reasonable measures to ensure that the competent person is at all times aware of workings being advanced to come within Regulation 17(6)(b):

“50 (fifty) metres from any excavation, workings, restricted area or any other place where there is, or is likely to be a dangerous accumulation of fluid material, noxious or flammable gas. Such notification must include a sketch plan giving the distance to such place from the nearest survey station.” (DMR, 27 May 2011)

Regulation 17(7) of the MHSA requires the employer to ensure “reasonable measures” that, when according to 17(7)(b):

“workings coming within 50 (fifty) metres, from any other excavation, workings, restricted area or any other place where there is, or is likely to be a dangerous accumulation of fluid material, noxious or flammable gas are mined subject to such restrictions and stopped at such positions as determined by risk assessment.” (DMR, 27 May 2011)

Rock Engineering risk analysis hazard identification uses the Hill caving height formula (Hill, 1996) to determine and predict “sinkholes” within the mining area (Joel, 2015). Hill’s work in the area identified that sinkholes form above shallow board and pillar coal mines due to the collapse of the board intersection and the resultant progression of that collapse to surface. (Hill, 1996). The mine uses XPac software for planning and the prediction of high risk areas.

In order to further mitigate the risk of collapse, pillars are drilled and blasted in order to collapse the void before the material is finally excavated. In some cases such blasting may not be completely effective in filling the voids, machines are as far as possible still located on the original pillar positions to reduce risk as far as possible. When loading takes place the load and haul equipment has no means of orientating their parked positions relative to the underground excavations.

Problem statement

This study was conducted to determine the feasibility of implementing a user defined, low cost GPS navigation system for mining equipment directly involved in the excavation and loading of material mined from old mine workings by opencast mining methods. The equipment needs to meet two criteria namely to display a map of the old workings on a screen and secondly, to be capable of sub-meter accuracy. The requirement of the system is to indicate to supervisors, foremen and machine operators where the underground excavations are situated relative to the surface equipment position in order for them to position the heavy excavation and transport equipment on the more stable pillar remnants rather than voids. Such positioning should go a long way in preventing incidents of mining machinery falling through the overburden into mined-out cavities, causing major damage and substantial financial losses.

Technology currently available

Three systems was tested for application. System 1 is currently used but is considered too expensive to maintain. System 2 was tested for agricultural applications and only limited results became available. The accuracy for the application was considered not to be viable. System 3 provides promising results at a fraction of the cost of system 1.

System 1. A mid-level accuracy GIS GPS system

The operation currently uses seven (7) Leica CS10 Handheld GPS systems. This is a high accuracy unit capable of loading **.dxf* files of the underground workings directly onto the controller. This system has been in use for approximately three years. In order to reduce costs, a way had to be found to connect the base station and the handheld GPS without using a base on each of these systems for accuracy.

The operation wished to use Wi-Fi signal to get correction from a nearby NTRIP but it was determined that it would not be possible as the Wi-Fi signal was not stable on site. On site large spoil heaps, benches and product stockpiles causes interruptions in signal and in some cases caused total signal loss. This is due to the Wi-Fi signal not being able to flow around or through these dumps. A solution had to be found to obtain signal for correction from the base station to the hand held GPS's in the mining benches.

The second option was to use the GSM signal to receive the correction to improve GPS accuracy on site. Even with this system it remained a challenge to get signal down in the mining benches, which can be as far as 60metres below Natural Ground Level (NGL). A semi-permanent cellular repeater station that can be moved as required, was installed to boost the signal and allowed the manipulation of the signal at 55^{o} vertical and 65^{o} horizontal into the pit.

Each of the mined seams are displayed with a different colour to prevent confusion. The plans are uploaded from the existing survey plans and are not required to be updated frequently as the underground workings does not change or shift. Each hand held is checked monthly to ensure that all plans are still relevant and available on the hand held device, as the files are up-loaded as jobs and can easily be deleted by accident.

System 2. The Canmore GT-750F GPS receiver and data logger

A tablet with Windows as the operating system linked with a small external GPS model KT750 (canadagps, 2017) to be able to obtain sub-metre accuracy and is not dependent on any network. Looking at a complete setup cost of below R10 000 per machine, this would be a significant investment if the reduction in cost and mitigation of risk is considered. The equipment was tested extensively over two days in an area with unobstructed view of the horizon in all directions. Comparisons were made between the values of a Survey grade GPS, a GIS grade GPS, a standard Garmin GPS and the KT750 GPS system.

In the field test of 60 staked out points, the dY difference was an average of 1.965m and a dX average of 4.483m when compared to the GIS grade GPS and a Survey grade GPS systems used for the control of the experimental observations. Tests of this system proved that the system could be efficient, but that the time for accuracies to "stabilize" took too long and the initial results deemed to be insufficiently accurate.

System 3. A microcontroller system

Accuracy of GPS receivers can be improved through Differential Global Positioning System (DGPS) or Real Time Kinematics (RTK). It has been argued that advances in technology has improved the accuracy of the far cheaper L1 equipment to be "as accurate" as dual frequency (L1 and L2) equipment (Unknown). The principle of this technology is to use two receivers as a "moving base" of a fixed length and is referred to as a "moving baseline Real Time Kinematic (RTK)". In this method the base receiver is moving and linked to the "rover" from which a relative position can be calculated. The moving vector solution between base and receiver can provide relative positioning accurate to centimeters (Lightbody & Chrisholm, 2010). According to Lightbody and Chisholm, autonomous systems can provide accuracy up to 5metres. The implementation of a 1 minute by 1 minute Geoid file (Pavlis, 2013) is used to improve the accuracy of the system.

In the field of microcontrollers the Rasberry Pi is considered as the first cheap single-board computer that started the "maker revolution" (Leonard, 2013). The BeagleBone Black is a low-cost development platform that can be used by a range of users from developers to hobbyists (BeagleBoard.org Foundation, 2017). When combined with the BeagleBone "tracking cape" (ciudadoscura, 2014) or third party designed plug-in board, L1 (1575.42 MHz) frequency GPS navigation becomes possible. The details of the specific unit used for testing on this site is considered to be proprietary as user-defined enhancements have been made. The BeagleBone provides interface, power, storage and connectivity to the GPS cape (BeagleBoard.org Foundation, 2014). For the purposes of this study the BeagleBone unit was chosen over the Rasberry Pi due to the ease of setting up, the on-board 2GB storage capacity of the BeagleBone as well as the potential 92 connection points, 5 UARTS (serial interfaces) and expandability in the form of "capes" available on the unit.

Combining the BeagleBone GPS receiver with a graphical interface of the underground mine plans will allow users in mining machinery to orientate the equipment relative to the position of the old underground excavations immediately beneath the equipment in order to reduce the risk of unplanned breakthroughs into the old workings. Mine plans of the three seams are imported into the software as a *.dxf (Drawing Exchange Format) into the system (Beresford, 2015). C++ language used for the interface link and RTKLIB , an open source program package for Global Navigation Satellite System (GNSS) positioning designed by T. Takasu (Takasu, 2007-2013) and com-0-com software to create virtual serial port drivers, This virtual COM port setup is used to transfer GPS RTK position results Global mapper 14 from Blue Marble Geographics which then allows the antenna and plots the antenna position centred on the machine on the graphic interface. This provide the operator with a real-time image of the machine's position relative to the old underground workings on three different seams on a 10" tablet screen in the machine's cab. The interface on the tablet is via Global mapper on which a *.dxf file with the mines old workings of all seams have been loaded. From machine the tablet has a Wi-Fi network that can be remotely accessed by a supervisor.

Test work performed

An initial test was done covering the entire mining area. The mine covers an area of 1300 hectares. A random point in each "cut" was surveyed by a survey grade GPS and checked by a short observation with the BeagleBone system. The results from this check indicated promising results in most cases.

Table 1. Reconnaissance values obtained.

		dY	dX
Ramp	11	-0.305	-1.043
Ramp	12	0.625	0.728
Ramp	13	0.766	1.872
Ramp	14	-1.150	-0.304
Ramp	15	-1.199	0.707
Ramp	16	0.434	0.244
Ramp	17	-3.557	0.114
Ramp	18	0.420	1.197
Ramp	19	1.369	-1.485
Ramp	20	-0.018	-0.033
Ramp	21	-0.431	-0.795
Ramp	22	0.509	-0.320
Ramp	23	-1.023	-0.766
Ramp	24	1.362	2.440

In order to verify the data obtained from the initial “reconnaissance observations”, a 1.5metre baseline between fixed base and Rover on a vehicle was tested on three fixed benchmarks on a 639.4m long baseline. An additional point approximately 700metres away from the baseline was checked using the same set-up. At each point the rover was placed on the benchmark while the “base” remained in the fixed position on the vehicles roll-over frame. Data was recorded every second for 5 minutes. The results of the raw data obtained with no transformation or editing were as follows:

Benchmark 1.

At the first point, the start of a baseline, 233 observations were recorded at 1 second intervals. The raw data difference of the average unadjusted observations taken over 5 minutes from the known Benchmark 1 co-ordinates were calculated to be *dY* +0.645m and *dX* -0.936m.

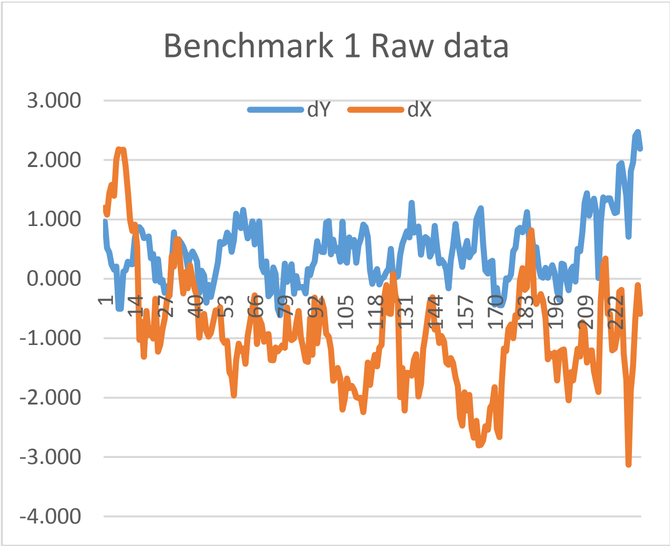

Figure 1. Raw results for Benchmark 1.

Benchmark 2.

Benchmark 2 is 288m from Benchmark 1. 300 observations were recorded at 1 second intervals. The raw data difference of the average unadjusted observations taken over 5 minutes from the known Benchmark 2 co-ordinates were calculated to be *dY* -1.266m and *dX* +0.654m.

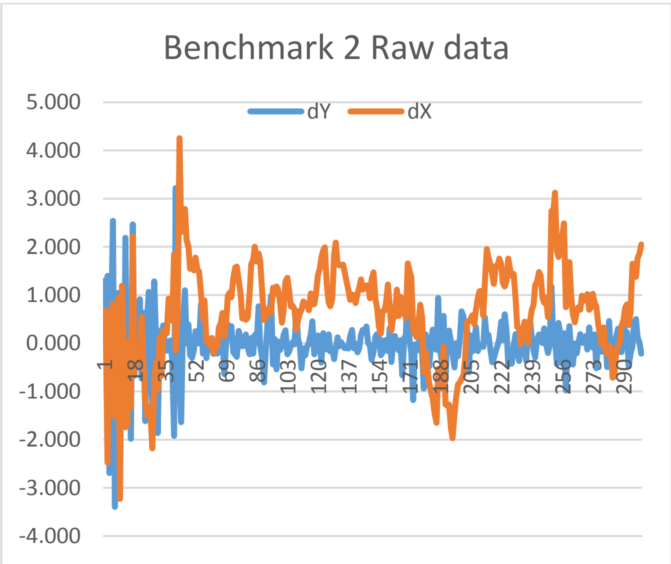

Figure 2. Raw results for Benchmark 2.

Benchmark 3.

Benchmark 3 is 351m from Benchmark 2. 300 observations were recorded at 1 second intervals. The raw data difference of the average unadjusted observations taken over 5 minutes from the known Benchmark 3 co-ordinates were calculated to be *dY* -0.564m and *dX* -0.900m.

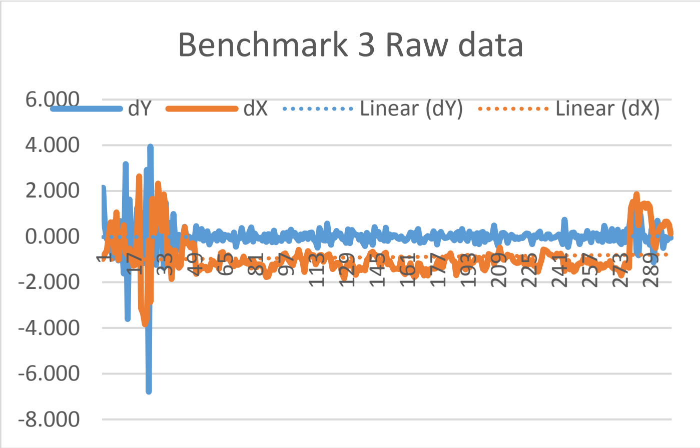

Figure 3. Raw results for Benchmark 3.

From the data it can be seen that the readings at all three benchmarks the values started stabilizing after 60 seconds. It is observed that after about 4.5 minutes the error increases again.

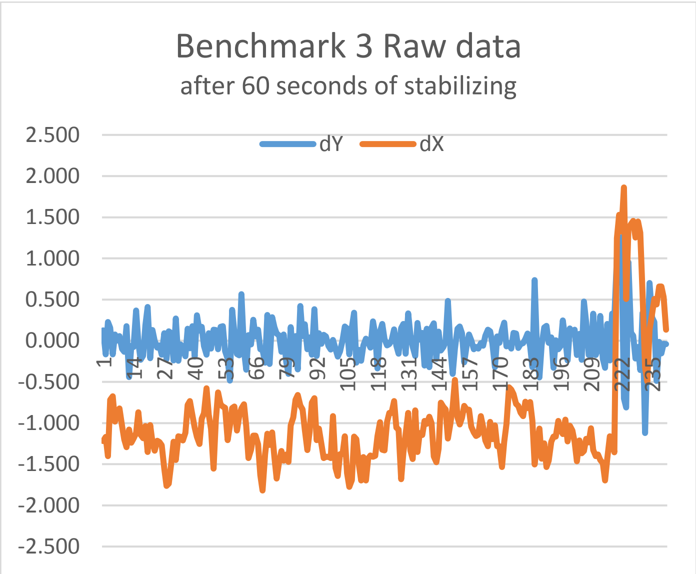

Figure 4. Raw results for Benchmark 3 after 60 seconds.

Benchmark 4.

Benchmark 4 is 729m from the baseline with Benchmarks 1 to 3. 300 observations were recorded at 1 second intervals. The raw data difference of the average unadjusted observations taken over 5 minutes from the known Benchmark 3 co-ordinates were calculated to be *dY* +0.628m and *dX* -0.111m.

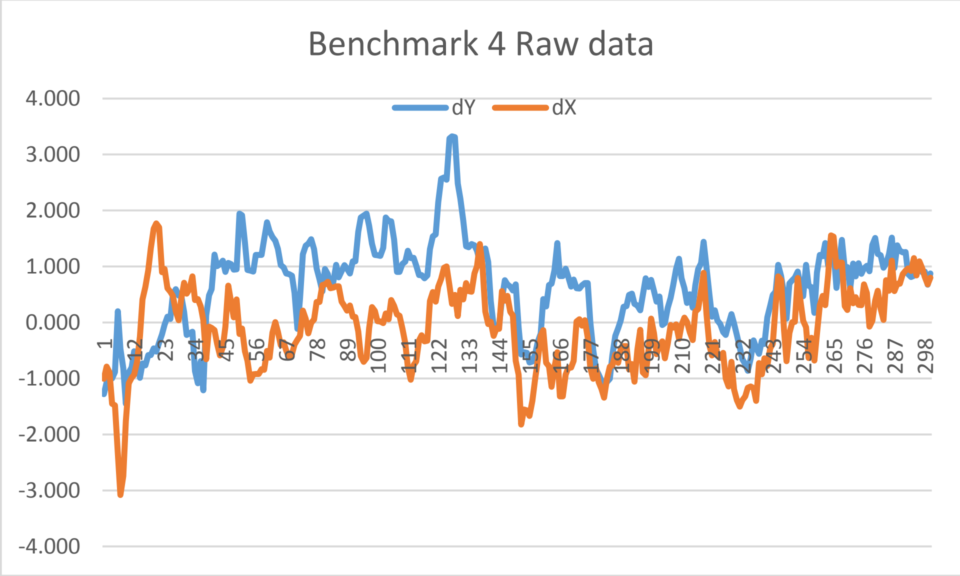

Figure 5. Raw results for Benchmark 4.

Conclusions, future improvements and recommendations

Prior to the implementation of the hand-held system, approximately seven to ten machines per year would fall into collapsed voids caused by the old workings. This resulted in a cost of R100million in damages per annum. The damage costs have since reduced by 70% to R30million in damages per annum (van der Walt, 2016). Although the current damage costs are still considered high, the project can still be considered a success. Especially taking in consideration major benefits achieved with minimal startup costs. The result of this systems efficiency is that fewer machines are falling into old workings which equates to less damage and lost production time. The risk of an employee exposed to a life threatening position has been reduced. This system has therefore been included as a critical control in this operation’s procedures. (van der Walt, 2016)

Although the implementation of this system has been a success so far, further improvement can still be made. One disadvantage of the system is the manual recharging of mobile data every quarter for each unit using a standard service provider. The controllers require data to receive the correction from the TrigNet station. Although the financial cost of recharging data is not considered high, the logistics involved in collecting the units from the mining unit operators and reloading the data is considered time consuming and an unnecessary waste of time. (van der Walt, 2016).

In the beta test of the system the user interface must be adapted in a way to display the antenna positon as a virtual machine footprint around the cursor position. It is proposed that two L1 GPS antennas per unit (machine) will be used as it will create a moving base RTK principle, one antenna acting as a rover and the other as a base. By applying a network of GPS receivers a Mesh network (Roos, 2017) where units can communicate with each other and provide corrections between units. Once the mesh network for data communication is established, a test using only one unit per machine will be evaluated.

Current best practices on site

With the current hand-held devices, the foreman needs to inspect the screen and ensure the accuracies of the unit are within an acceptable range. This is indicated by the 3DCQ, 2DCQ and 1DCQ indicators on the bottom of the screen. Where standards of acceptable accuracy is defined in the following manner:

1. 3DCQ: Vertical/Horizonal Combined Accuracy (less than 0.15 desirable)
2. 2DCQ: Horizonal Accuracy (less than 0.05 desirable)
3. 1DCQ: Vertical Accuracy (less than 0.08 desirable)
4. Position Dilution of Precision (PDOP)[1]: Positional Accuracy Multiplier (Under 5 desirable) (transitandlevel.com, 2017)
5. In cases where the measurement made falls outside the acceptable range of two meters, a warning notification appears that warns the operator that optimal accuracy has not been achieved.

These parameters should be made standard practice regardless of the system used. The standard of accuracy will depend on the mine defined accuracy for machine positioning. It is recommended that a ratio of the machine footprint to the board-and-pillar dimensions be used to determine that value.

Calibration

It is essential that calibration of the units are performed as elevation measurements can be affected by weather conditions, local interference and satellite configurations (Zhang, Unger, Kuai-Hung, & Kulhavy, 2015). It is recommended that test sites on different locations of the mine be established to calibrate on a staked-out roadway intersection (cross) to calibrate and test the accuracy of the units. Such a calibration site should simulate a 8*8metre board and pillar roadway intersection with the corners of four pillars. The required accuracy should be determined but it is suggested that it should be one third of the dimensions of the mining vehicles used in the area.

[1] The combination of both the Horizontal and Vertical components of position error caused by satellite geometry

References

BeagleBoard.org Foundation. (2014, July 18). *Tracking cape for BeagleBone*. Retrieved from BeagleBoard.org Foundation: http://beagleboard.org/project/trackingcape/

BeagleBoard.org Foundation. (2017, March 22). *BeagleBone Black*. Retrieved from Beagleboard.org: https://beagleboard.org/black

Beresford, M. (2015, February 15). *How to import gpx into Google Maps to make a GPS track viewer*. Retrieved from UrbanHikr: http://www.urbanhikr.com/how-to-import-gpx-into-google-maps/

canadagps. (2017). *CanmoreGT-750FL*. Retrieved from canadagps: http://www.canadagps.com/CanmoreGT-750FL.html

ciudadoscura. (2014, July). *BeagleBone Tracking Cape - Reference Manual*. Retrieved from TrackingCape for Beagle Bone: http://ciudadoscura.com/beaglebonecape/downloads/trackingCapeRefManual.pdf

DMR. (27 May 2011). *Mine Health and Safety Act No 29 of 1996.* Government Gazette .

Hill, R. W. (1996). *Safety and environmental risks associated with shallow bord and pillar workings.* . Johannesburg: Confidential COM elective project report. Report No: CE 9401.

Joel, F. (2015). *Sinkhole Risk management process within thermal collieries: a practical approach thereof.* Johannesburg: University of the Witwatersrand.

Leonard, M. (2013, July 18). *How to Choose the Right Platform: Raspberry Pi or BeagleBone Black?* Retrieved from http://www.michaelhleonard.com/raspberry-pi-or-beaglebone-black: http://makezine.com/2014/02/25/how-to-choose-the-right-platform-raspberry-pi-or-beaglebone-black/

Lightbody, S., & Chrisholm, G. (2010). *White paper: Techniques in relative TRK GNSS positioning.* Westminister, Colorado: Trimble Marine Division.

Ozdeniz, H., Sivrikaya , O., & Sensogu, C. (October 2013). Investigation of Spontaneous Combustion of Coal in Underground Coal Mining. *Mine Planning and Equipment Selection Proceedings of the 22nd MPES Conference, Dresden, Germany,*, pp 637-644.

Pavlis, N. (2013, April 29). *EGM2008 - WGS 84 Version*. Retrieved from Geodesy and Geophysics Basic and Applied Research NGA Office of Geomatics (SN): http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/egm08_wgs84.html

Roos, D. (2017, July 20). *How Wireless Mesh Networks Work*. Retrieved from How stuff works: http://computer.howstuffworks.com/how-wireless-mesh-networks-work.htm

SA History on-line . (1960, January 21). *More than 400 miners are killed in an underground collapse at Coalbrook mine* . Retrieved from SA History on-line: http://www.sahistory.org.za/dated-event/more-400-miners-are-killed-underground-collapse-coalbrook-mine

Takasu, T. (2007-2013). *, an open source program package for GNSS Positioning*. Retrieved from RTKLIB: http://www.rtklib.com/ 2007-2013

transitandlevel.com. (2017). *Leica GPS instructions*. Retrieved from transitandlevel.com: https://transitandlevel.com/wp-content/uploads/2014/08/Leica-GPS-Instructions.pdf

Unknown. (n.d.). *TRK GPS techniques for conituous positioning and monitoring of moving equipment.*

van der Walt, C. (2016). *Precise Deformation Survey final year project* . University of Johannesburg.

Zhang, Y., Unger, D. R., Kuai-Hung, I., & Kulhavy, D. L. (2015). GPS ELevation accuracy: tests with the GarminOregon 600. *The Forestry Source*, 14-15.