Borehole Deviation Control Using Electronics: An Euler's Approach

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Abstract

The consequences of rock blasting with explosives are directly related to the accuracy of drilling and, because they have an effect on fragmentation and ground level, they should be controlled to ensure a problem free production, increase work safety and reduce environment impact. Safety control is one of the most important processes in detonation, since it can compromise the worker security on site and, eventually, neighboring communities. Due to the technology advancements, it is possible to build a hole deviation control device with "of the shelf" parts, and for that reason the authors decided to evaluate the possibility of measuring hole deviation by creating a portable prototype using an electronic sensor capable of measuring the acceleration on objects, that is, to measure the own acceleration of a system, known as "accelerometer" and a micro-controller to handle and treat data. The main idea behind this paper is to validate the power of the Euler method, given the stepping limitations of the sensor and micro controller in order to reproduce of the hole shape. A case study was carried out, comparing the measurements of borehole deviations made by a traditional equipment and the prototype. A mobile application was also created in order to recover and treat and display the data to the user. For validation of the prototype, several holes were measured using the two devices. A residue analysis was used to validate the data obtained. After analyzing and confirming the effectiveness of the new equipment, the normality tests prove a symmetric distribution with null expected residual mean and minimum variance. Consequently, the accuracy of the prototype is evidenced. Thus, the authors aspire to emphasize the potential of using these sensors allied to a traditional numerical method for analysis of hole deviation.

Introduction

Rock blasting aims to divide a certain amount of rock mass into smaller pieces (at the lowest cost possible). This procedure is applied in the majority of mining operations, quarries, civil engineering applications and even in some cases of ornamental rock operations. Therefore, the conditions that the rock blasting process is carried out affects directly the operation´s results (Bhandari, 1997). For this, the precision in the steps of rock blasting to achieve the planned objectives and the knowledge of the rock conditions are essential in order to obtain the desired fragmentation (López Jimeno, López Jimeno, & Garcia Bermudes, 2017).

Drilling is one of the most important steps in this process. Consequently, the control and the prior knowledge of drilling results is essential to proceed with the planned blast, maintaining the necessary economy throughout the cycle of mining operations (Leite, Miranda, & Palangio, 2018). It is called a drilling deviation when a hole is subjected to an unintended abnormality of a planned trajectory. The deviation of the path of the planned hole can lead to problems such as high cost of drilling, fragmentation issues, fly rocks, irregularities in the floor or ramps, damages to the instrument, among others (Harris, 1999). In addition, the analysis of the profile of the borehole with the use of deviation measurement equipment allows the control and minimization of toe generation, over excavation, slope stability and monitoring of drilling operations (Miranda & Leite, 2018).

The focus of this project was the research and creation of a prototype of a hole deviation measurement equipment, named as *O-PitDev*. The main idea behind this work was to validate the power of the Euler method, given the size of the pitch generated by the sensors used in the equipment, for the reproduction of the hole shape. A case study was conducted comparing the results of hole-deviation measurements performed by traditional equipment compared to the developed one, communicating it with *O-Pitblast* installed in a mobile application to manage the equipment. For the validation of the prototype, the measurement of several holes was taken through the 2 (two) methodologies. A residue analysis was used to validate the data obtained and after the analysis, the effectiveness of this tool was confirmed, considering that the normality tests proved a symmetrical distribution with zero residual mean and minimum variance. Thus, the researchers proved throughout this article the potential of the use of these sensors allied to a traditional numerical method for the analysis of deviations of holes.

Figure 1. O-PitDev Developed System

Deviation Issues

For many rock blast operations there is the need to protect the surround environment. Drill deviation can originate vibrations, noise, fly-rock and other problems that can be avoided with caution blast procedures and blast analysis.

Production Issues

Larger blocks that require secondary blast or excess fines may result from poorly designed shots or from adverse geological conditions. Damage to the hanging walls and dilution are other examples of production issues caused by irregular drilling. The same in over break caused by imprecise drilling (Bhandari, 1997).

Deviated holes can lead to bad fragmentation, due to the increment on burden and spacing along the borehole from the collar to the bottom. To one hole near the crest, if the inclination is higher than the plan a higher concentration on powder factor will be generated near it– condition that can reduce the efficiency on the borehole bottom and the production of toes. In the other side if the subdrill is smaller due to drill errors, the probability for toe generation will increase along with the cost for drilling, load and haul (López Jimeno, López Jimeno, & Garcia Bermudes, 2017).

Safety Issues

Non-controlled blast can compromise the viability of a project, whether due to community complains, damage to adjacent structures resulting in legal problem and putting live at risks. Drilling error (low subdrilll, excess subdrill, hole very close to a free face) can lead to bad fragmentation followed by ground movement, vibrations, air blast, toxic gases and fly rocks.

Deviation Measurements

The need to control your blasts' results is always increasing and, having that in mind, the mining companies are continuously seeking for ways to improve and predict outcomes. The measurement of a borehole deviation is an important step to that market, that's why the companies are always evolving and introducing new devices to the market. In this chapter the authors will give some examples of equipment that are already present in the mining world.

Measurement Devices

There is a diverse number of equipment with a common objective: measurement of boreholes deviation. As an example, the market has the Boretrak from Carlson, Blasthole Probe from Pulsar and even an Android smartphone (Miranda & Leite, 2018).

Blasthole Probe

This tool allows the user to see the inclination, heading, depth and presence of water of the holes. The procedure is simple: the operator lowers the probe and take measurements by an interval defined by him. This probe has a winch and a cable attached. The accuracy of this device is ± 0.25º for the inclination and ± 1º for the azimuth (Ewer, 2018).

Rodded Boretrak

The Rodded Boretrak is can be used in metal operations and is composed by multiple bars that allow the operator to measure the borehole deviation meter by meter. Also, it can be used in upholes that are very commons in underground mines. It has an accuracy of 0,1º and it can take inclinations until 45º (Renishaw, 2017).

Cabled Boretrak

This device has a different usage methodology. In this case, the device is attached to a cable that is marked meter by meter. It can't be used in metal operations and its only prepared to do downholes. It's based on a digital compass and a dual axis tilt sensor. The accuracy and maximum inclinations are the same as the rodded boretrak®: 0,1º and 45º, respectively (Renishaw, 2017).

Figure 2. Rodded Boretrak (left) and Cable Boretrak (right)

Android Smartphone

This new technology based on a smartphone, that was presented by in Fragblast 12' (Miranda & Leite, The use of 3D accelerometers and gyro sensors in smartphones to measure the blasthole deviation in non-magnetic rock, 2018), it's apparently less complex, easy to use and cheaper. The research uses the accelerometer and the magnetic sensor present in the Samsung Galaxy S8 to make the measurement of the hole deviation. The operating mode is based in two apps where the operator puts the offset and the range, in meters, that he wants to make the measurements. In the end, the data from both phones is combined and the result is a file that contains the borehole data: number, inclination and time of measuring.

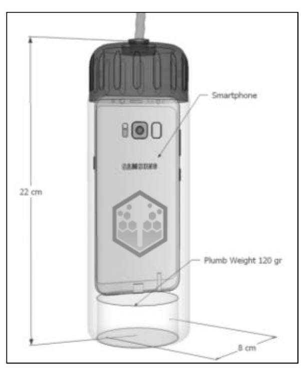


Figure 3. Smartphone used to measure holes

Measurement Results

After the field procedure, either with smartphone technology or any other device with the same propose, the operator gets the information of the real inclination, heading and depth of the borehole. With that information and with a blast design software, it’s possible to analyze different situations/problems such as:

- Critical profiles: rows too near/far from the free face;
- Critical burden;
- Projection risks: hole not drilled correctly (their inclination/azimuth is wrong) causing fly rock risks;
- Burden distribution;
- Deviation values; y
- Real angle: possibility to see if the planned hole and the real one has the same angle;
- Toe error: generation of toe due to a wrong drilling.

All this information can be agglomerated and simulated like shown in the Figure 3. where the color gradient can tell the user that the first row is too close or far away from the free face. This situation can generate fly rock projections and could be avoided due to the information taken from the hole measurement device.

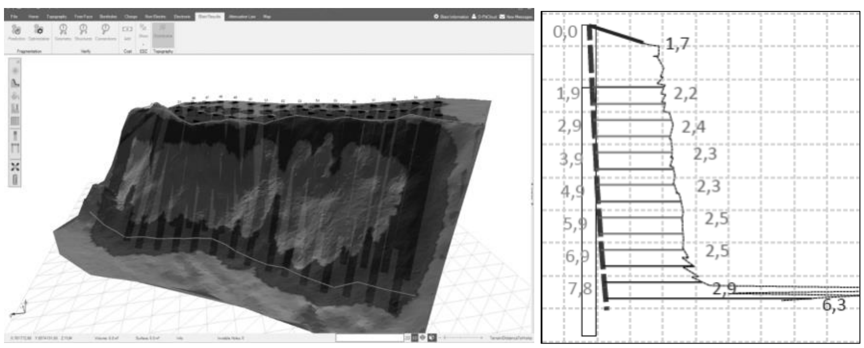


Figure 4. Critical Burden Detection (O-Pitblast)

Euler Method

In order to fix numerical problems with the format below, Euler proposed a solution based on the previously knowledge about the behavior of the function (Butcher, 2003) :

$$y'(t) = f\big(t, y(t)\big), \qquad y(t_0) = y_0$$ **Equation 1**

Starting from a known point, the next iteration is approached by the following equation:

$$y(t_1) \approx y_1 = \ y_0 + hf(t_0, y_0)$$ **Equation 2**

Where h is the size of the step used for each measurement.

The image Figure 5 shows the real solution for a generic example and the Euler’s approach for different steps (10 and 100 steps) and we can observe that for highest values of step the solution is closer of the real one.

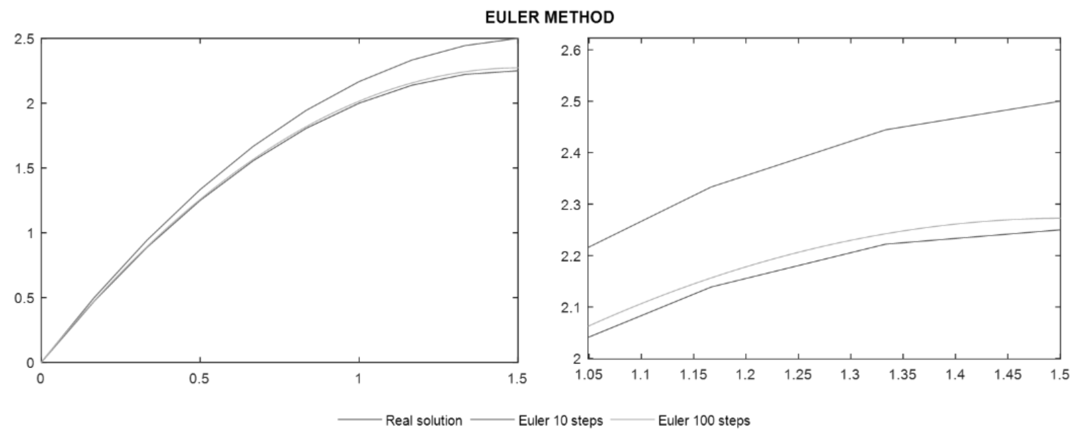


Figure 5. Euler method example

Methodology

Phone App

To make it possible to observe the results on the field immediately after the measurements were taken, an Android app was developed. The Android app works with both the traditional method, (measuring angle and heading meter by meter) and with the Euler method (measuring the linear acceleration as many times as the electronics allowed). After receiving the data, the app calculates the profile of the hole and displays it to the user.

Probe Electronics

A ESP32 microcontroller was used in this research due to the fact of being power efficient, fast, and having Bluetooth capability. The micro controller was paired with the sensor BNO055 from Bosch Electronics, a 9 DOF sensor with an accelerometer, gyro and magnetometer using I2C. In the traditional approach a combination of the three sensors is used to calculate heading and inclination, on the Euler method a "sensor fusion" method called linear acceleration is used in order to eliminate gravity from the results. An internal memory chip of 4MB was used to record all the data. According to our estimations, recording 3 different measurements (x, y, z) each millisecond, would allow us space for only 5 minutes of measurements.

Connection

Bluetooth was the choice of communication between the probe and the phone due to the high availability (a large portion of smartphones have it) and there is a Bluetooth module present in the ESP32 microcontroller we referenced earlier. The communication is not real-time since when the probe is inserted into the hole, the signal is lost. Internal memory is used while the probe is inside the hole. The data is transferred back to the phone as soon as the probe reconnects to it.

Probe Case

To introduce the sensors and electronics so that they remain intact and running through a hole, an AISI 304 stainless steel cap was designed. In the planning of the capsule, it was investigated that stainless steel does not isolate the radiofrequency necessary to communicate the data between the equipment and the receivers installed in PC and in mobile phone, thus dispensing with the installation of an external antenna for connectivity between both. In addition, the choice of stainless steel was due to its famous resistance to corrosion, giving a longer life than other materials and elements. But despite being the main feature, there are several other advantages of using stainless steel (Frank, 2009) such as:

- Physical (mechanical) resistance equal to or greater than ordinary steel;
- Ease of cleaning;
- Low surface tension;
- Hygienic appearance;
- Inert material (does not react to contact with other materials);
- High durability and shelf life
- Ease of modulation and welding;
- Stability in extreme temperatures;
- Visual beauty (modernity, cleanliness and brightness);
- Great cost benefit;
- Recyclable material.

The steel case was design on AutoDesk Inventor Professional and resisted the water present in some holes, the impact on the descent to the bottom of the hole, and the friction with the wall of the hole due to the hoisting of the equipment. It has enough weight and density to overcome the thrust with fluids present in the holes, because a casing made essentially of stainless steel, material of considerable density (7.85 g / cm3) was used (Solução completa em Usinagem, 2018).

The initial idea of this first equipment was to test in the laboratory and in the field the electronic components and its connectivity and system of acquisition of data and radiofrequency transmission. The prototype cable connected to the capsule was marked every meter to set the interval for the measurements.

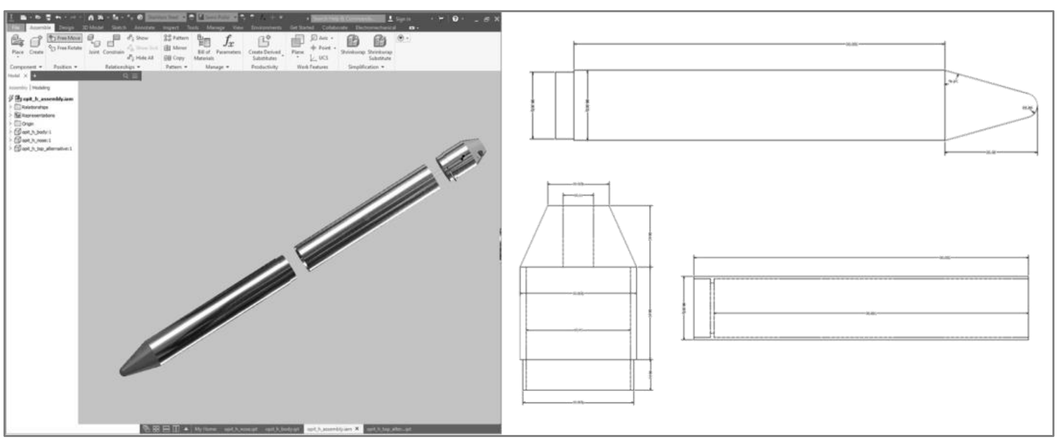


Figure 6. Case Design

Field Procedure

The field test was carried out in Madalena quarry (Vila Nova de Gaia – Portugal) explored by Solusel, Lda. The field tests included:

- Scan of the free face with Drone;
- Registration of holes position;
- Measurement of hole’s profile with a Cabled Boretrak;
- Measurement of hole’s profile with the developed methodology Figure 7;

- Deployment of the *O-PitDev* in the bottom of the borehole;
- Measurement of the offset;
- Record the first time of the first measure in the bottom of the hole;
- Pull the probe until the borehole collar making stops at each meter - 3.2 ft - and collect the time at those stops;
- Match both information from phone app and probe – time, angle and azimuth.

Figure 7. Field Procedure from left to right: probe assembling; probe deployment; offset measurement; measurement time record

Data Analysis

Multiple measures were recorded, inside of the borehole, at different positions. Before lowering the equipment into the borehole is define the measure interval – 1 measure at each meter (3.2 ft). In case of the hole having a size that is not multiple of the interval, the difference between the position of the first measurement and the remaining will be different. This difference is usually called off-set, while the other measures will have a difference that is equal to the interval adopted (Miranda & Leite, 2018).

Results

The researchers found some restrictions (at least with the this first approach) using the Euler's methodology due to the limitations of the sample rate Figure 8. It was possible to get around 300 samples/second which is low number when trying to obtain displacement from acceleration (applying the Euler method 2 times).

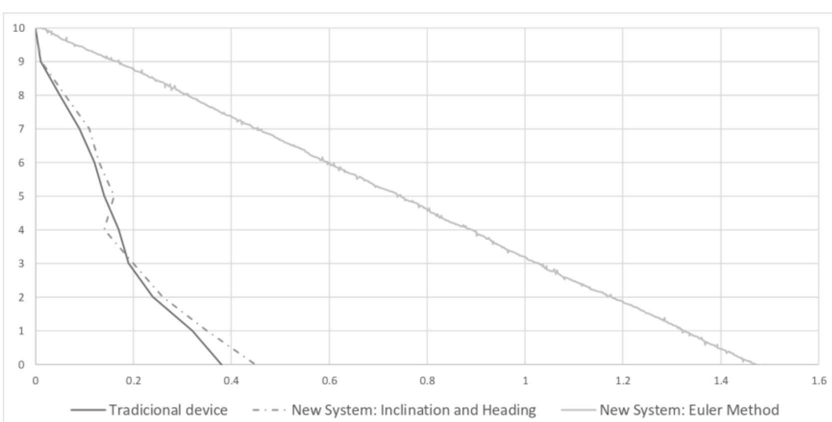


Figure 8. Comparison between Euler's methodology, heading and inclination

Visually the results are quite similar as observed on Figure 9. (using the inclination and heading at each meter).

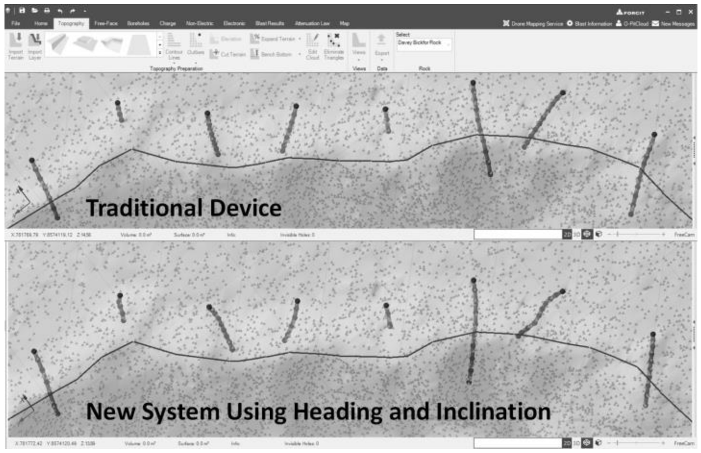


Figure 9. Comparison of devices using heading and inclination

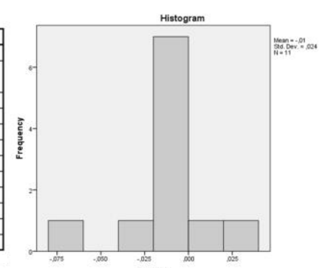
Statistical Analysis

Analyzing the residue between both data (measure with actual system and the developed one), using inclination and heading, the data shows that the new system results are equivalent to the traditional one:

- P-Value shows the acceptance of the null hypothesis (Shapiro-Wilk with 95% of confidence level) - Figure 10 meaning that the data follows a normal distribution;
- The zero is contained within the confidence interval.

Descriptives

			Statistic	Std. Error
Residue	Mean		-,0147	,00727
	95% Confidence Interval for Mean	Lower Bound	-,0309	
		Upper Bound	,0015	
	5% Trimmed Mean		-,0141	
	Median		-,0100	
	Variance		,001	
	Std. Deviation		,02412	
	Minimum		-,07	
	Maximum		,03	
	Range		,10	
	Interquartile Range		,02	
	Skewness		-,678	,661
	Kurtosis		3,127	1,279



Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Residue	,232	11	,102	,895	11	,159

a. Lilliefors Significance Correction

Figure 10. Statistics

Limitations

Besides the excellent results presented by this research the authors decided to outline a couple of limitations associated with this product. This product was developed to be used only in non-metallic mines due to the effect on the magnet sensor. Some adjustments must be done on the case and the electronic system to improve a better user experience – (decrease probe weight, app design and connectivity).

Conclusions

Using the Euler's methodology, the authors found some restrictions about it. As mentioned on the results increasing the sample rate will be possible to obtain best results. On the research due to the limitation of the sensors used it was not possible obtain better solution. However, the results obtained using heading and inclination on the new product are extremely interesting. Be able to reproduce the obtained values with a lower cost product will definitely open new doors to small operations in order to control drill accuracy, improving safety and production. This product allows a fast and immediate action due to the easy access to the information. The data analyzed shows a direct relation between the conventional method and the new one, proving the quality of the methodology presented. The equipment is very practical to use, the required training is low and the integration with smartphones potentializes the use of technology with the blast operation, saving time to the blast engineers.

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