Accident scene reconstruction in underground mining operations

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With safety being the number one value within mining, civil, commercial and industrial settings it is imperative that any breach of safety resulting in an accident or loss of life is investigated thoroughly. This can involve considerable amounts of time, effort and expense as investigators search for evidence and piece together the circumstances surrounding the event leading up to the incident.

The aim when investigating an accident, incident or crime scene is to gather enough information to permit suitable analysis of the circumstances preceding the event. The conclusion of a forensic investigation can have considerable implications on the entities involved where it can be used as evidence in a court of law or instigate changes to health and safety measures and policies within an organisation.

Since the mid 1990s a number of forensic investigations carried out by private and government detectives began to use three dimensional high definition laser scanning to record an accident or crime scene in a unique 3D format that preserves all visual features of an area. Capturing information in this way introduces many benefits that streamline the forensic investigatory process. These are detailed in this article with emphasis on the mining environment where incidents have far reaching impacts on working practices, health and safety policies as well as production downtime and company reputation.

Laser scanning
Laser scanning describes a method where a surface is sampled or scanned using laser technology. It analyses a real world or object environment to collect data on its shape and possibly its appearance (such as colour). The collected data can then be used to construct digital, 2D drawings or 3D models that can be used for a wide variety of applications [1].

The birth of the laser scanner created a totally new discipline of surveying. Laser scanners work by capturing thousands of 3D data points obtained by the EDM. Each point has its own unique coordinate with the distance between points often being less than a millimetre apart. The main advantage of laser scanning is the fact that it can record huge numbers of points (up to 976,000 points a second) with high accuracy in a relatively short period of time. The end result or "point cloud" is like a three-dimensional photograph with depth information.

Some laser scanners are capable of capturing the colour of measured points, resulting in point clouds much more representative of the scanned object. Other scanners include a digital camera directly referenced with respect to the point cloud, which is used to obtain colour from the scanner. The end products of this data include 3D animations of scenes and 3D physical models which for many, are easier to visualise and appreciate than a 2D drawing.

This technology is still in the early stages of being adopted by mining companies for day-to-day use. It has been readily used in some "pure surveying" applications such as measuring the volumes of tips and the surveying of stopes where the precision and accuracy of the measured data is comparable to those obtained by traditional surveying methods (e.g. traversing) [2]. However, the sheer volume of the data collected can be readily used for a number of other applications. In terms of safety, these have included:

- Analysing the structural states of buildings or objects in danger of collapsing or having collapsed
- Assessing possible deformations of structures over time, including rock face deformation in the mining industry
- Recording crime scenes and in the investigation of high consequence accidents

There is this last area that will be discussed in detail in this paper. To date laser
scanning has been used extensively in the US and Western Europe in the investigation of road collisions and the analysis of crime scenes. In terms of road collisions, the three main advantages cited for laser scanning [3] are operator safety (as scanners are reflectorless and therefore the operator does not have to put himself in a place of danger during surveying), cost (not necessarily in terms of the instrument, but in terms of savings with respect to the closure of roads or lanes or other active traffic measurement (it is estimated that a major road closure costs the economy €140 000 per hour [4]) and the speed of data acquisition.

**Current practices and shortfalls in mine accident investigation**

The production of a plan of an accident scene following an accident is a core element of the accident investigation process and is common in all industries, not just mining. The scale and detail of such a plan depends to some extent on the consequence of the accident, with detailed surveys being undertaken for high consequence accidents and cruder sketch maps being produced for lower consequence occupational accidents. The plan will often be the first item required by a mines inspector as part of their investigation. The purpose of this is that it gives the investigator and any other interested party a feel of the accident area i.e. the positions of personnel and equipment. This plan is generally a key part of the “data collection” stages of accident investigation that also requires a detailed site investigation and data capture by photography. This is a crucial part of collecting evidence. Typical surveying methods used here involve either tape and offset measurements and possibly total station single point mapping.

The main issues associated with tape surveying as part of an accident investigation are:

- The process is time consuming
- Can cause disruption of the accident during the investigation
- Some key dimensions may be missed
- The area in which the survey takes place could still be unsafe, thus putting the surveyor in danger

Some operators may use total station single point mapping or in the case of opencast operations, GPS mapping. Whilst the accuracy and speed is greatly improved over that of tapes, issues here include:

- Low detail
- Discrete points surveyed are chosen by the surveyor and sometimes key areas can be missed
- Data capture possibly coordinated by initial guesses at what caused the event rather than indiscriminately

The three dimensional models produced by a laser scanner can overcome all of the above shortcomings following a series of scans of the accident area. As well as plans, photographs are also taken as part of an investigation to help visualise the scene and provide an overview, and to collate evidence. Whilst these are useful they can be limited in terms of what information they provide, particularly in terms of measurements.

The following guidance for accident photographs is given in the ICAM (Incident Causation Accident Model) documentation [5].

Consider the angles at which the photographs should be taken and whether reference items (e.g. rulers and coins) are required to give the picture size perspective. All photographs used in the report shall be numbered and captioned. Captions shall explain in detail what the picture is intended to show. Captions will include type of equipment, date of the incident, and location of the incident. The direction toward which the photograph was taken may be included; for example, NE and SW. Photographs taken at the incident scene may include the following:
• An overall view of the incident site taken from a minimum of four directions.
• If movement of equipment was involved, record a view of the path of the equipment from point of initial and major impact to the place where it came to rest. Impact marks are vulnerable to rain and traffic; therefore, a photographic record of this type of evidence should be collected as soon as possible.
• Aerial views of the incident scene (equipment and weather permitting)
• Photos of objects struck by the equipment
• Larger portions of the equipment damage
• Detailed photographs of suspected failed parts that contributed to the incident
• Photos of failed personal protective clothing and equipment and the agents suspected of causing the failure
• Photograph and measure any vehicle skid marks, ground scars, and so forth
• Any other photographs deemed of interest to the investigation team

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**Laser scanning and benefits to mining accidents**

The screenshot in Fig. 1 shows an image of an underground mine that has been obtained from a static laser scanner. Whilst such 2D screenshots do not do justice to what can be observed in a full 3D model, it does give some indication of the benefits, particularly in terms of detail. In this image it is possible to see the roadways, the texture in the sidewall and roof, the position and location of roofbolts, pipe ranges and other services.

In order to compile a detailed and complete 3D model, a number of scans will need to be undertaken from different positions in order to gain maximum coverage which minimises the blinding of positions. The data obtained from these different setups can be merged together using a number of different registration techniques to create one overall model which gives a permanent visualisation of the accident scene. The resolution of the scan is governed by the smallest detail of the structure that needs to be recognisable in the model. However the higher the resolution, the more points need to be scanned which will increase the time of the scan, the number of points captured and the storage size of the dataset, so some trade off here is necessary.

The time taken to complete one scan depends very much on the resolution and can take from 5 minutes to an hour. Once these scans are undertaken, registration of the point clouds can take place and then processed into the final deliverable.

As well as the advantages highlighted previously, there are two other additional advantages that can be gained from the use of 3D models.

- It is quick and straightforward to obtain distance measurements between objects in the model at any point during or following its development. This has the advantage that there is no need to take numerous measurements during the investigation and eliminates the risk of missing or not taking such a separate measurement.
- The digital model allows for the scene to be observed from different views, and views can be changed in a matter of seconds. This allows for different witness viewpoints and can define definitively what can and cannot be seen from a certain position.
- Including the full view of the scanner whilst on site costs very little and includes much contextual detail which can prove incredibly useful down the line. Whilst much of this may be viewed as unnecessary and conventionally would be costly, the value of this data can, experience shows, be enormous and help eliminate ambiguity.

**Practicalities and implementation**

As mentioned, for road collisions and crime scenes laser scanning is gaining popularity with investigators due to its many benefits throughout an investigation. Despite this happening above ground, the underground mining industry has not embraced the technology with the same enthusiasm. There are several likely reasons for this, namely access to laser scanners is limited, often due to the remote location of many operations and the time required transporting a scanner and operator to site makes it difficult to utilise scanning equipment in the crucial early stages of an accident investigation. The awareness of laser scanning and its benefits to investigations is limited and in addition, specialist software has traditionally been required to view and interpret point cloud data making the "deliverable" less accessible and sometimes misunderstood by the wider audience.

Nevertheless laser scanning technology is improving with specialist software and applications of scanning now being exposed to graduates at university level, arming them with new skills to bring to underground mining. It is at this level where the correct method of laser scanning must be established because the principals of traditional surveying remain critical for this tool to be properly utilised. This also underlines the importance that the use of laser scanners for accident
investigation should remain in the hands of a surveyor.

**Case study**

By means of conclusion, the screenshots in Figs. 2, 3 + 4 serve to provide a simple case study of where laser scanning has been used to create a 3D model of an accident in an underground mine and used in its subsequent investigation. In this accident an operator was crushed between the front bucket of a moving LHD and the sidewall, as the driver was trying to avoid a collision with a parked LHD ahead of him.

The scans and the subsequent model can be used to show a plan view of the scenario (Fig. 2) showing the position of the two vehicles, the junction and the roadway width (this is a typical 2D plan view as would have traditionally been produced in an investigation).

The viewpoint can then be moved to within the mine to a position slightly in front of both vehicles and this allows a view of the person who was stuck and the roadway (Fig. 3).

And finally the viewpoint can be moved to that of the LHD driver to show how much of the person could be seen immediately prior to the collision (Fig. 4).

Whilst these screenshots do not do justice to the full 3D model, it is possible here to see the benefit of being able to switch viewpoints, and how much more details these models give when compared to a 2D line drawing. The 3D model also helps identify important issues that need following up in the investigation such as why was the first LHD in that position ahead of a stop sign?

**Conclusion**

Laser scanning is becoming more widely used in many industries including mining, and its use to create 3D models for accident investigations has numerous advantages in terms of speed, detail and accuracy over more traditional methods of surveying. It is one of many potential applications that laser scanning has in the mining industry and will ensure that the role of the surveyor will become more important in the future as the custodian and processor of such information.

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**References**


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