The Technology of 3D Laser Scanning Applied to Cavity Backfill Governance

Zhan Kai, Chen Kai, and Zhang Da
Beijing General Research Institute of Mining and Metallurgy, Beijing, China
Beijing Key Laboratory of Nonferrous Intelligent Mining Technology, Beijing, China

ABSTRACT

There are a large number of different sizes and shapes cavities when mines use the openstope method to mine, and these cavities will have influence on mine condition, then cause serious geological hazard such as the roof fall, rib spalling, closure deformation of the cavity, even surface collapsing, all of geological hazard can threaten mine safety. Using backfill method to deal with dangerous cavities is the best efficient method which will prevent wholesale ground pressure activity. However, it is difficult to obtain cavity shape and calculate backfill amount if mine uses backfill method to deal with dangerous cavities. To solve this problem, this paper introduces the 3D laser scanner for mine which is developed by Beijing General Research Institute of Mining and Metallurgy to scan cavity before mine backfill and probe the whole or part shape and real time condition of cavities, then obtain whole, comprehensive, continuous point cloud data. point cloud data will be converted into line model, entity model, profile data, these data will provide intuitive information to constitute backfill process for cavity and calculate backfill amount precisely to solve the problem which is difficult to check backfill amount of cavity.

INTRODUCTION

There are a large number of different sizes and shapes cavities when mines use the openstope method to mine, and these cavities will have influence on mine condition, then cause serious geological hazard such as the roof fall, rib spalling, closure deformation of the cavity, even surface collapsing, all of geological hazard can threaten mine safety. Using backfill method to deal with dangerous cavities is the best efficient method which will prevent wholesale ground pressure activity. However the backfill cost is expansive, when mines choose backfill method to deal with cavity, they just backfill part of cavity, so it will be the key technology difficult problem to judge treatment effect of cavity how to confirm cavity shape and backfill height when mines design.

Cavity have these attribute which is latent, ruleless space distribution, irregular shape, so it will provide precise basis for cavity treatment safety and efficiently if mine obtain cavity shape scientifically. 3D laser scanner for mine scans cavity before mine backfill and probe the whole or part shape and real time condition of cavities, then obtain whole, comprehensive, continuous point cloud data. After dealing with point cloud data, mine can obtain complex cavity geometric information, such as length, area, volume and so on, then form 3D model of cavity. Using this information, mine can calculate backfill amount and height of cavity to provide scientific guide for cavity backfill.

This paper chooses a 3D laser scanner for cavity named BLSS-PE (shown in Fig. 1) which is produced by Beijing General Research Institute of Mining and Metallurgy. BLSS-PE comes from a National key 863 Hi-Tech research program. It provides an efficient and practical solution for 3D modeling of mining engineering, providing spatial analysis, volume calculation, profile extraction, deformation calculation, caving measurement, stope blasting evaluation, cavity monitoring, slope modeling, etc.

Figure 1. 3D laser scanner for mine (BLSS-PE)

3D LASER SCANNING PRINCIPLE

BLSS-PE which integrates many high technologies is a new type 3D coordinate measurement instrument, which can obtain geometry of the array, 3D point cloud data of the target object surface and its principle is shown in Fig.2:

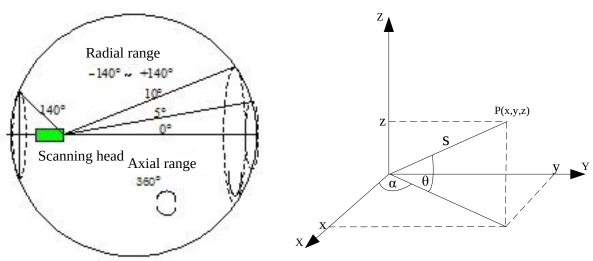


Figure 2. 3D laser scanning principle

BLSS-PE uses the time of flight method which calculates round-trip time of the laser. This method is a high-speed laser technology which can be applied to measure the distance. By taking the time of flight method, the point coordinate's calculation formula is as follow:

$$\begin{cases} x = s\cos\theta\cos\alpha \\ y = s\cos\theta\sin\alpha \\ z = s\sin\theta \end{cases}$$

HIGH PROTECTION AND PACKAGING TECHNOLOGY

The environment of mine is usually bad, it is high temperature, moist, dusty environment. For the purpose to guarantee the 3D laser scanner work normally in the mine, it is necessary to take measure to improve the protection of the 3D laser scanner. According the actual condition of mine, this paper use sealing ring to seal the mechanics hull, glass lens to prevent dust, professional box to package the 3D laser scanner. At the present, the ingress protection of 3D laser scanner is IP66.

Sealing Ring Protection

The 3D laser scanner takes strict protection method to guarantee the effect of waterproof, dusty proof. Every joint is processed into indentation, and then put the sealing ring in the indentation. Using the sealing ring, the dusty, water will be difficult to get into the inner of 3D laser scanner.

Professional Lens Protection

The laser module ingress protection of 3D laser scanner is IP67, but if we do not take protection measure, the laser module will be easy to stick dusty, and measurement range will be shorter. At the same time, the lens of laser module is very expensive, it is necessary to protect the laser module lens. According to the actual condition, this paper design a lens protection device (shown in Fig. 3) which include lens protection hull and optical filter glass which is the K9 optical glass platting antireflection coating to ensure the 905nm laser penetration rate higher than 99%. The lens protection device is disassembly and convenient to replace.

Figure 3. Lens protection device

Professional Packaging Protection

The 3D laser scanner will be applied to mine, the course of moving 3D laser scanner is rude. So it is necessary to provide professional package box to protect the 3D laser scanner. We choose the professional pelican box which is the famous protection box company to ensure 3D laser scanner safe. We put the 3D laser scanner, cable, calibration target into the protection box (shown in Fig. 4), it is convenient to carry the key parts.

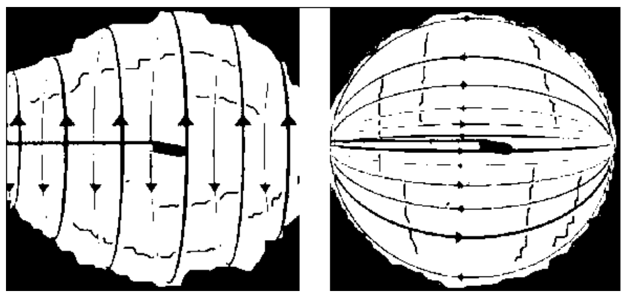
Figure 4. Professional protection box

SCANNING MODE

For scanning cavity's inner construction, the system needs to control the 3D laser scanner. Scanning control mode is divided into axial priority scanning mode and radial priority scanning mode according to scanning sequence, and scanning control step is divided into standard step scanning and self-adaptive step scanning according to the scanning step.

Choice of Scanning Mode

Scanning control mode is divided into axial priority scanning mode and radial priority scanning mode according to scanning sequence. The scanning sequence is shown in Fig. 5. In view of radial priority scanning mode will lead to the laser scanner rotate frequently, it will be harmful to signal transmission cable and cooling system, so it is preferred to choose the axial priority scanning mode.



(a) axial priority (b) radial priority

Figure 5. 3D laser scanning mode

Optimization for Scanning Mode

When using standard step scanning mode, the system will scan the cavity in fixed step, it means the scanning angle will be divided into the same angles in every loop. After the system finishes the cavity scanning, the whole cavity point cloud data will be formed. The standard step scanning mode is easy to be implemented, and point cloud is fix basically, this mode is appropriate to these conditions: cavity is regular shape cavity, and the 3D laser scanner can reach the middle of cavity.

However, for the most cavities, standard steps canning mode has many disadvantages. The fig.6 shows the schematic drawing for cavity scanning. According to Fig. 6, standard step scanning mode will cause some problems. First, the 3D laser scanner length compared with the cavity length is short, and

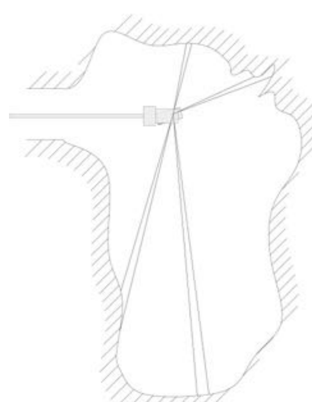


Figure 6. Self-adaptive scanning principle

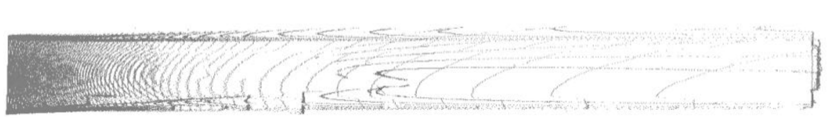
the rock-wall near to the tunnel is near to the 3D laser scanner, so the point cloud data resolution of the rock-wall near to the tunnel is high. But if using the same scanning angle to scan the cavity, the point cloud data resolution of the rock-wall far away the tunnel will be low. Second, the angle between laser direction and normal direction of the rock-wall in some place is big. If using the standard step scanning mode, the resolution of point cloud data of the rock-wall is also low. Using different scanning mode, point cloud data resolution will be affected by real environment. Standard steps canning mode is not suitable to most condition. So it is necessary to take measure to optimize the scanning to make point cloud resolution similar or improve the point cloud data resolution in some place.

This paper put forward a solution called self-adaptive scanning way. Setting the scanning step of 3D laser scanner as $D(\alpha,\beta)$, d is the distance from the target to 3D laser scanner, and the first point distance subtract the next point distance is Δd, k is correction factor, $D'(\alpha,\beta)$ is the optimization scanning step. The paper provide a formula:

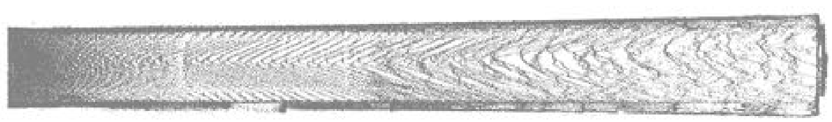
$$D^{'}(\alpha,\beta)=k\frac{D(\alpha,\beta)}{d\cdot\Delta d}$$

According to the formula, the system scans the cavity point and obtains coordinate (x,y,z), when the laser meets gap or slant rock-wall, the motor will move different angle according to the real step—$D'(\alpha,\beta)$, which will improve the cavity space consistency. Fig. 7 shows the result in different scanning mode.

So self-adaptive scanning way is useful to unknown, complex shape cavity where the 3D scanner is difficult to put into.



(a) Standard step



(b) Self-adaptive step

Figure 7. The result of different scanning mode

DATA PROCESSING

The point cloud usually exist some noise because of the environment and system factor when the 3D laser scanner scan the cavity, and the noise will have a bad effect on using point cloud in future. For the purpose to solve the problem, this paper put forward the discrete noise removing algorithm basing on the Kd-tree structure. Next this paper will introduce this algorithm simply. The algorithm mainly calculate the average value μ and standard deviation σ of the distance between the point cloud and neighborhood, after obtaining the average value μ and standard deviation σ, this paper will set the threshold $\mu\pm\alpha*\sigma$, if the distance of neighborhood point is out of the threshold $\mu\pm\alpha*\sigma$, this point will be considered into noise point.

The step of realizing the algorithm is as follow:

1) Create the Kd-tree of point cloud P;

2) Traversal point cloud P, calculate the KNN $N_p^k = \{p_{1,}p_{2,}, \cdots p_{k,}\}$ of anyone point p of point cloud, k value depend on the size of point cloud;

3) Calculate the Euclidean distance $D = \{d_{1,}d_{2,}, \cdots, d_{k,}\}$ from every point of KNN N_p^k to the point p;

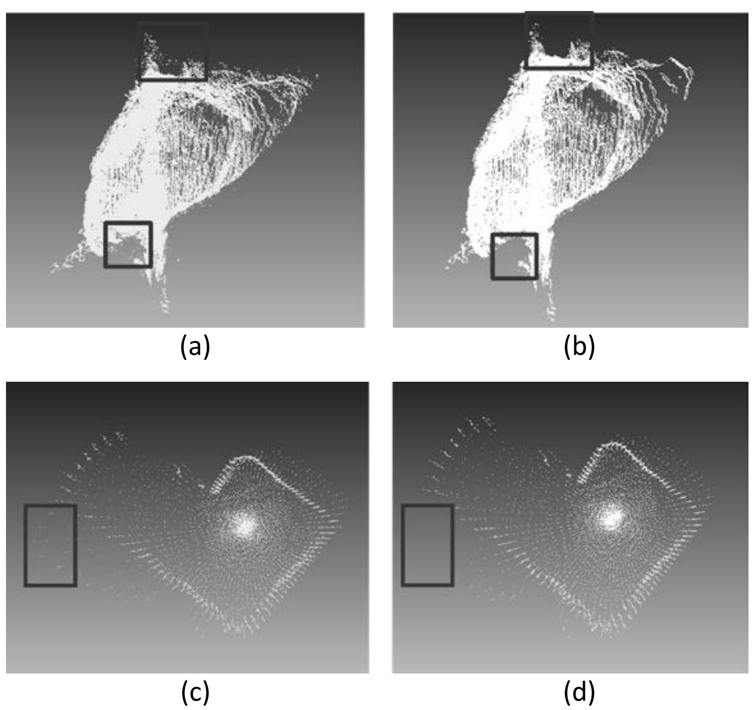
4) Calculate the average value μ and standard deviation σ of distance $D = \{d_{1,}d_{2,}, \cdots, d_{k,}\}$;

5) If the distance d_i of any point p is out of the interval $\mu \pm \alpha * \sigma$, this paper will remove point p;

6) The value of α depend on the size of point cloud neighborhood;

Parameter α and k should be set according to the real condition of point cloud, because the point cloud may be dense, dilute and the noise point may be near to point cloud, far away to point cloud. The point cloud of cavity in this paper is dense and the noise, point cloud is different obviously. The effect of removing noise point will be well if setting the denoising range to $\mu \pm \alpha * \sigma$. To verify the denoising effect of point cloud, this paper chooses two group point cloud to have experiment. It is found that if setting the parameter $\alpha = 1$ and $k = 30$, a lot of noise point is removed obviously. The result is shown in Fig. 8.

The number of first group point cloud is 327728, the number of point cloud which is processed by denoising algorithm 325146; the percent of denoising is 0.8%. The number of second group point cloud is 26766, the number of point cloud which is processed by denoising algorithm 26658; the percent of denoising is 0.4%. Through the result of Fig.8, It is known that the effect of denoising is very well. The sharp of point cloud do not change after denoising.



(a)The first original point cloud (b) the denoising result of the first point cloud

(c)The second original point cloud (d) the denoising result of the second point cloud

Figure 8. The results of point cloud denoising based on KD-tree

CAVITY BACKFILL GOVERNANCE

Calculate Backfill Amount

Backfill rate is a very important indicator to guarantee cavity backfill effect. At present, there aren't specific norm and theory to conform cavity backfill rate. According to metal mine barren rock backfill experience, backfill rate should be 60% ～ 70%. If backfill rate less than this scope, lots of wall rock will be exposed, then backfill effect isn't obvious and there will produce ground pressure activity similarly. According to this experience, this paper choose S13P cavity of mine to calculate backfill amount which is 296051 m3. However cavity shapes is complex, it is difficult to conform backfill height. For solve this problem, this paper uses model segmentation method to conform backfill height.

Model Segmentation Method

There isn't still mature software to simulate cavity backfill process after obtaining 3D model of cavity at present, so calculating backfill height is difficult. These paper uses model segmentation method to conform backfill height. Specific steps are as below: first, using CAD software to form a plane with height. Second, import the plane and 3D model of cavity into software which is provided by BLSS-PE system. Third, use plane to cut 3D cavity model and delete the cavity model upon the plane. At last, calculate the cavity model volume under the plane till model volume equal backfill amount; the plane height is backfill height. These paper uses model segmentation method to conform S13P cavity backfill height, the result is that backfill height is -450.6m (shown in Fig. 9).

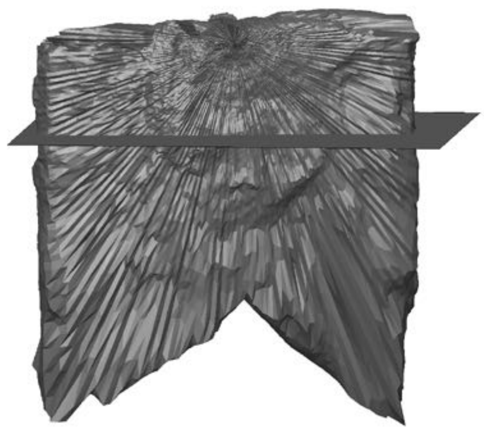


Figure 9. Calculate backfill height using model segmentation method

CONCLUSION

For the purpose to check backfill amount of cavity, this paper chooses a 3D laser scanner for cavity named BLSS-PE which is produced by Beijing General Research Institute of Mining and Metallurgy, then introduce the scanning principle, high protection and packaging technology of device, scanning mode, data processing. At the same time, this paper uses the device to have experiment which conform the backfill amount and backfill height with the model segmentation method, the result will provide precise data to guide the future cavity backfill.

REFERENCES

[1] WANG Yang, MA Zi, and HU Ying. 2009. Novel free-form surface 3D laser scanning system. Journal of Mechanical Engineering.

[2] Thorsten SCHULZ, and Hilmar INGENSAND. 2004. Terrestrial Laser Scanning—Investigations and Applications for High Precision Scanning. FIG Working Week.

[3] Dong Xiu Jun. 2007. The research of 3D laser scanning technology and application. Chengdu University of Technology.

[4] Pauly M, Mitra N. J. 2004. Uncertainty and variability in Point Cloud Surface data. Euro graphics Symposium on Point Based Graphics Zurich.

[5] Scholkeopf B, and Giesen J, SpalingerS. 2005. Kernel Methods for Implicit Surface Modeling Advances in Neural Information Processing Systems. MIT Press.

[6] Bassett R H, K immance J P, and Rasmussen C. 1999.Automated electro level deformation monitoring system for tunnels. Proceedings of the Institution of Civil Engineers.

[7] Kohonen T. 1982. Self-Organized Formation of Topologically Correct Feature Maps. In Biological Cybernetics.

[8] Ivrissimtzis I, Jeong W.K, and Seidel H. P. 2003. Using Growing Cell Structures for Surface Reconstruction. In Proceedings of Shape Modeling International.

[9] Jenke P, Wand M, Bokeloh M, and Schilling A. 2006.StraBer W. Bayesian Point Cloud Reconstruction. Computer Graphics forum.

[10] Surla Sphere Vide. 2005. Bulletin of the Academy of Sciences of the USSR. Classedes Sciences Mathematiques Naturelles.

[11] Lawson C.L. 2004.Software for Surface Interpolation. Mathematical Software.