Detection of water leakage using laser images from 3D laser scanning data

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Abstract: A methodology has been developed to detect water leakage by using a grey-scale laser image from 3D laser scanning data. With some 3D laser scanning systems, not only can 3D point clouds be obtained, but also reflex intensity of each point can be measured simultaneously, therefore the grey-scale intensity image also can be captured. The intensity image from 3D laser scanning data is a grey-scaled digital image, with each pixel corresponding to not only its image co-ordinates, but also its 3D co-ordinates based on 3D laser scanning data. As the reflex intensity is different between water leakage and its background, some image processing techniques have been applied to detect the boundary between water leakage and its background. In addition, location and area of a water leakage can also be measured from 3D laser scanning data. A case study at a tunnel in Sweden has been performed. Different types of tunnels, i.e. TBM tunnel and blasting tunnel, have been tested with different settings of scanning data, such as different scanning distances from the scanner to the objects at different resolutions. By artificially controlling the amount of water flow, different water leakage flows have been tested to see if they can be detected from intensity laser imaging. By using different image processing techniques, water leakage is successfully detected for all different types of tunnel walls. From different image features, not only water leakage but also water flow, with different amounts of water, can also be detected. As each pixel on the image is corresponding to its 3D co-ordinates, water leakage and water flow can also be located in a tunnel. The presented methodology can be used for hydraulic mapping inside the tunnel, so both quantitative and spatial information of water leakage and water flow can be evaluated in a tunnelling project.

Résumé: Une méthodologie a été développée pour détecter de la fuite d'eau en utilisant une image laser gris à l'échelle de 3D laser scruter les données. Avec quelque 3D laser scrute des systèmes, les non seulement nuages de point de 3D de boîte sont obtenus, mais l'intensité aussi réflexe de chaque point peut être mesurée simultanément, donc l'image d'intensité gris à l'échelle peut être capturée aussi. L'image d'intensité de 3D laser scruter les données est une image numérique gris-escaladé, avec chaque pixel correspondant à non seulement son co-ordinates d'image, mais aussi son 3D co-ordinates basé sur 3D laser scruter les données. Comme l'intensité réflexe est différente entre la fuite d'eau et son fond, quelques techniques de traitement d'image ont été appliquées détecter la frontière entre la fuite d'eau et son fond. En plus, l'emplacement et le secteur d'une fuite d'eau peuvent être mesurés aussi de 3D laser scruter les données. Une étude de cas à un tunnel dans Suède a été exécutée. Les types différents de tunnels, c.-à-d. le tunnel de TBM et exploser le tunnel, a été essayé avec les cadres différents de scruter de données, scruter les distances telles que différentes du dispositif de balayage aux objets aux résolutions différentes. Par contrôlant artificiellement la quantité de flux d'eau, les fluxs de fuite d'eau différents ont été essayés pour voir s'ils peuvent être détectés de l'intensité imagerie laser. En utilisant les techniques différentes de traitement d'image, la fuite d'eau est détectée avec succès pour tous types différents de murs de tunnel. De l'image différente présente, non seulement la fuite d'eau mais aussi le flux d'eau, avec les quantités différentes d'eau, peut être détecté aussi. Comme chaque pixel sur l'image correspond à son 3D co-ordinates, la fuite d'eau et le flux d'eau peut être localisé aussi dans un tunnel. La méthodologie présentée peut être utilisée pour la cartographie hydraulique dans le tunnel, donc l'information quantitative et spatiale de fuite d'eau et de flux d'eau peut être évaluée dans un projet de tunnelling.

Keywords: 3D laser scanning, Laser image, water leakage, hydraulic mapping, grey-scaled intensity image, 3D point cloud, TBM and blasting tunnel.

INTRODUCTION

Distribution of water leakage in a tunnel is often one of the most important parameters required to investigate the hydraulic features of the fractured rocks surrounding the tunnel. By recording water leakage features, e.g. location and amount of water leakage, one can evaluate the hydraulic behaviour in the surrounding area of the tunnel. Therefore, the more accurate the data recording for water leakage, the more helpful it is for understanding and controlling the hydraulic behaviour in a tunnel project.

Currently, the most common documentation method is performed by field observation in a form of text description on paper or by taking a photograph with a camera, and then recording some qualitative parameters (e.g. drop or flow for describing water amount, linear or area shape for informing water leakage distribution) for further evaluation.

Obviously, the current recording methods have some limits in providing more accurate data of water leakage features for further hydraulic evaluation. So, a more effective method is now becoming more useful in tunnel hydraulic mapping projects.

With the recent development of 3D terrestrial laser scanning technology, it is now possible to provide more accurate documentation of water leakage in a tunnel by 3D digital scanning data. In this way, water leakage distribution can be accurately (mm) located, and water amount can also be quantitatively described. By using a proper 3D laser scanning system, water leakage can be quickly recorded (e.g. a coverage of several hundred square meters is recorded in a few minutes), and water leakage features can be quantitatively described and stored in 3D digital format. Thereafter, more accurate evaluation of hydraulic behaviour of surrounding rocks in a tunnel becomes available.

In this paper, a methodology for detecting water leakage from the grey-scaled intensity image of 3D laser scanning data is introduced, and the results of a case study for water leakage mapping in a tunnel are presented.

LASER SCANNING SYSTEM AND ITS SCANNING PRINCIPLES

3D terrestrial laser scanning techniques have been developed since the middle of the 1990s. These are especially applied in recording large objects in 3D digital formats and can be registered in a real 3D coordinate system. These techniques are now becoming more and more popular for 3D documentation and modelling in the processing industry, architecture documentation and civil engineering construction. The most important advantage of this technology is that they can quickly digitize a large object with a high resolution (mm) and a high point density (almost full-coverage scanning). So, it is a more useful method for field data recording.

The existing 3D laser scanning systems in the market are usually designed based upon three scanning principles: triangulation, pulse-based and phase-based techniques. As different terrestrial 3D laser scanning systems have been developed for different applications in the current market, it is important to choose a proper scanning system for a specific application. Considering some factors (e.g. scanning distance corresponding to its available resolution and accuracy, scanning speed, darkness in the tunnel) for the application to water leakage mapping in a tunnel, a 3D laser scanning system, called Leica HDS4500 (also called Z+F Imager 5003), was utilized in this study. It was initially developed for mobile robot navigation and inspection tasks, but also for other applications related to 3D mapping and modeling. The Leica HDS4500 was specially designed based on phase-based technique for high-speed, high-performance and eye-safe scanning tasks with indoor and outdoor medium-range applications (0.1 - 54 m).

The scanning device (Figure 1a) consists of two major components: the single-point laser measurement system and the mechanical beam deflection system (Figure 1b). The point-sensor laser measurement system comprises the laser head, the high frequency unit and the signal processing unit for data pre-processing. It is an infrared laser, so there is no need for illumination during scanning in a tunnel. This part controls the emitting, receiving and processing of the laser beam. By using the dual frequency AMCW (amplitude-modulated, continuous-wave) method in conjunction with a coaxial transmitter/receiver design, the receiver measures the phase difference between the original and returned laser signal at both modulation frequencies and the power of the reflected laser light, both range and reflectance of a target point can be obtained, and good measurement accuracy (within mm-range) can be achieved. The scanning distance is in the range of 0.1 – 54 m with an optimal accuracy of 3 --5 mm (Mettenleiter M, et al., 2000). The mechanical beam deflection system consists of a special mirror and the motor control unit. The mirror is used for deflecting the emitted laser beam generated from the laser head at the bottom, and for collecting the back-scattered laser light cone. The motor controls the mirror rotation in the horizontal and vertical direction, which can make a scanning field overview of 360 degrees in azimuth and 310 degrees in elevation. Each scan takes about 1--13 minutes (depending on the resolution) with a high sampling speed up to 625 000 points per second.

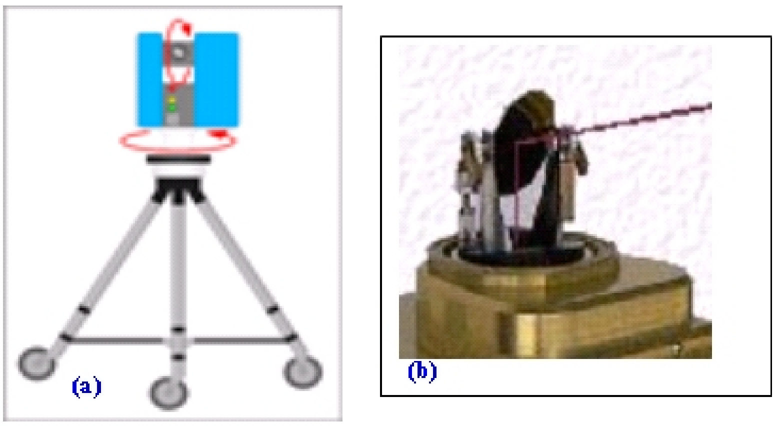


Figure 1. Leica HDS4500 laser scanner (a) and its scanning head (b)

The presented scanner was intentionally designed to measure the position and the reflectance intensity of each point simultaneously. Therefore, the 4-column (e.g. X-Y-Z-Intensity) raw data can be recorded. Comparing to other 3D laser scanning systems, the raw data can be displayed in different ways: i) clouds of points with 3D co-ordinates shown in Figure 2a; ii) 3D grey-scale image generated from both 3D co-ordinates and corresponding reflectance intensity values shown in Figure 2b; iii) 2D grey-scale image created from reflectance intensity shown in Figure 2c. In this case, a scanned object can be displayed not only geometrically but also visually. Therefore, the presented scanner was called a 3D visual laser scanner, which is specifically useful for geological mapping and documentation.

WATER LEAKAGE MAPPING IN A TUNNEL

This laser scanning system was used for water leakage mapping in this study. A typical procedure includes three steps: 1) Field data capture; 2) Processing of laser scanning raw data; 3) Analysis of laser image.

Field data capture

Two types of data need to be captured in the field, including laser scanning data and surveying co-ordinates of some reference targets, which are used for registering all scanning data into the same coordinate system. So, all scanned objects are converted in their correct location, and then distribution of water leakage can be quantified in 3D space. In order to obtain a good quality of laser scanning data for water leakage detection, some influential factors must be considered during scanning, such as scanning resolution, distance and angle from the scanner to tunnel walls etc.

In this case study, a special facility was also designed for controlling water flow, so we could detect and quantify the corresponding relationship between laser image characteristics and water leakage features. As the rock surfaces of TBM tunnel and blasting tunnel have different reflex features for laser beams, the scanning data were captured in both TBM and blasting tunnels.

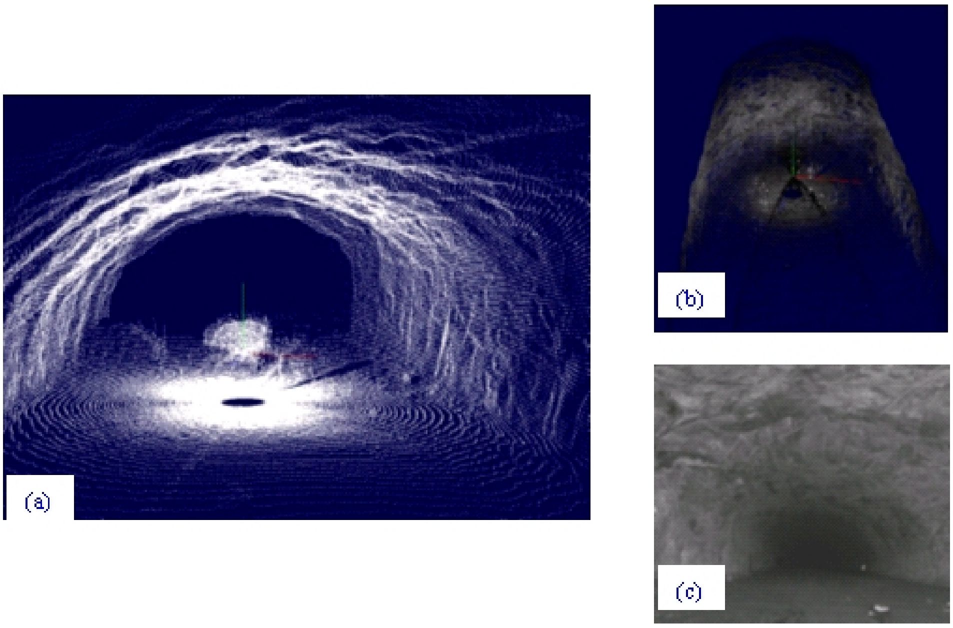


Figure 2. 3D laser scanning data showing in different ways

Processing of laser scanning data

The collected scanning data needed to be pre-processed for further analysis, including two main procedures: 1) registration of all scanning data together into the same co-ordinate system; 2) pre-processing of the laser image for further image processing.

Registration of laser scanning data can be performed by computer software, and the purpose is to co-ordinate all individual scans together and convert them into the same co-ordinate system. In this case, spatial information of water leakage such as leakage location and water coverage can be accurately quantified in real space. Figure 3 shows two scanned tunnels, one TBM tunnel and another blasting tunnel, registered in the same co-ordinate system.

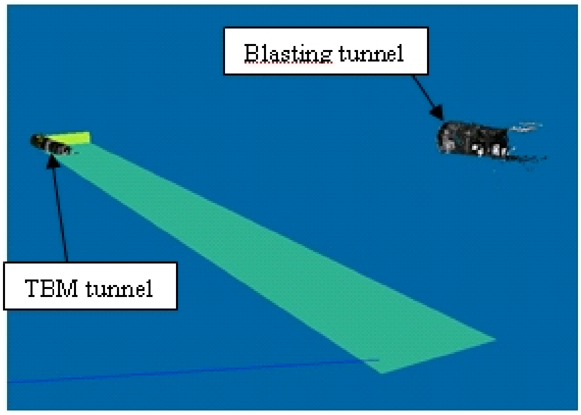


Figure 3. Two scanned tunnels registered in the same co-ordinate system

An intensity laser image is similar to a 2D grey-scaled image, but not exactly. It is a grey-scaled image stored in a special format, with every pixel linking to its corresponding x-y-z coordinates. In other words, it is a 3D grey-scaled image, and different with normal 2D image in scale and data format. So, it is not good to use directly for image processing, and therefore a pre-processing of the intensity laser image is necessary. A typical pre-processing method was to convert them into ortho-projected images, so the whole image has the same scale, and the image can be converted and stored as a normal 2D image format, for image analysis in any image processing software. Figure 4 shows a 3D laser image converted into a 2D ortho-projected grey-scaled image.

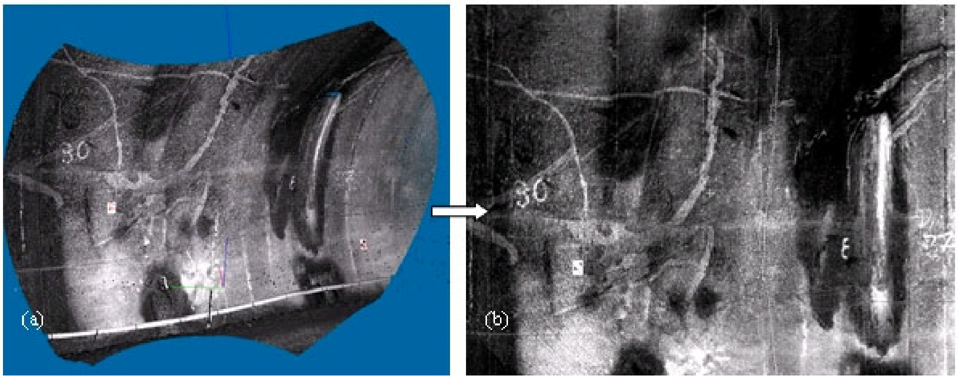


Figure 4 Convert from 3D laser image (a) to 2D ortho-projected laser image (b)

Analysis of laser image

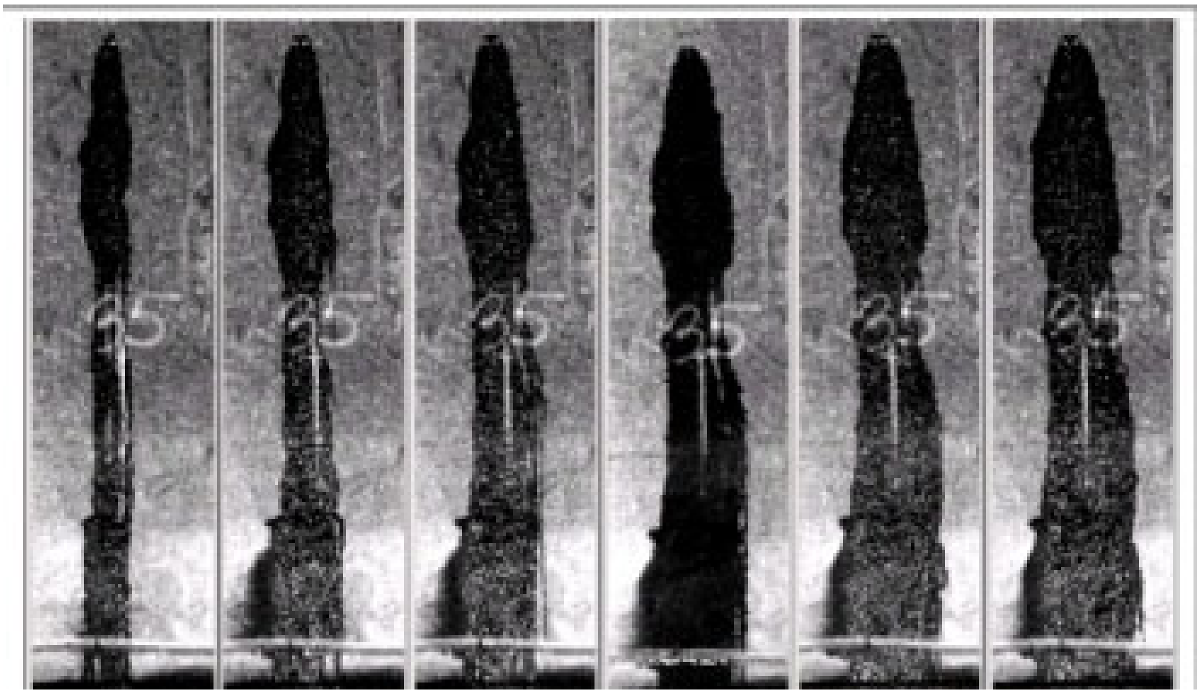
By using the presented laser scanning techniques, water leakage can be identified from the intensity laser image. This is because the scanning data from the Leica HDS4500 recorded not only x-y-z coordinates, but also the reflex intensity of each point. So, the laser image can identify the different intensity in grey-scale level between water leakage and the surrounding rocks, and also water leakage containing different amounts of water. Figure 5 shows water leakage exposed on a photo taken by a camera (a) and a laser image from laser scanning data (b).

From the laser image, water leakage can be accurately quantified. For example, location of a water leakage can be identified exactly in a tunnel based on the 3D co-ordinates of each point, and then the coverage of water leakage can be obtained.

In addition, by using image processing techniques, water leakage boundaries can not only be automatically detected from laser images, but also the amount of water in the different parts of a water leakage can be accurately quantified. In this study, a test was performed on both TBM and blasting tunnels. As different tunnel surfaces have different reflex features, different image processing methods were applied.

Figure 5. Water leakage showing in both photo (a) and laser image (b)

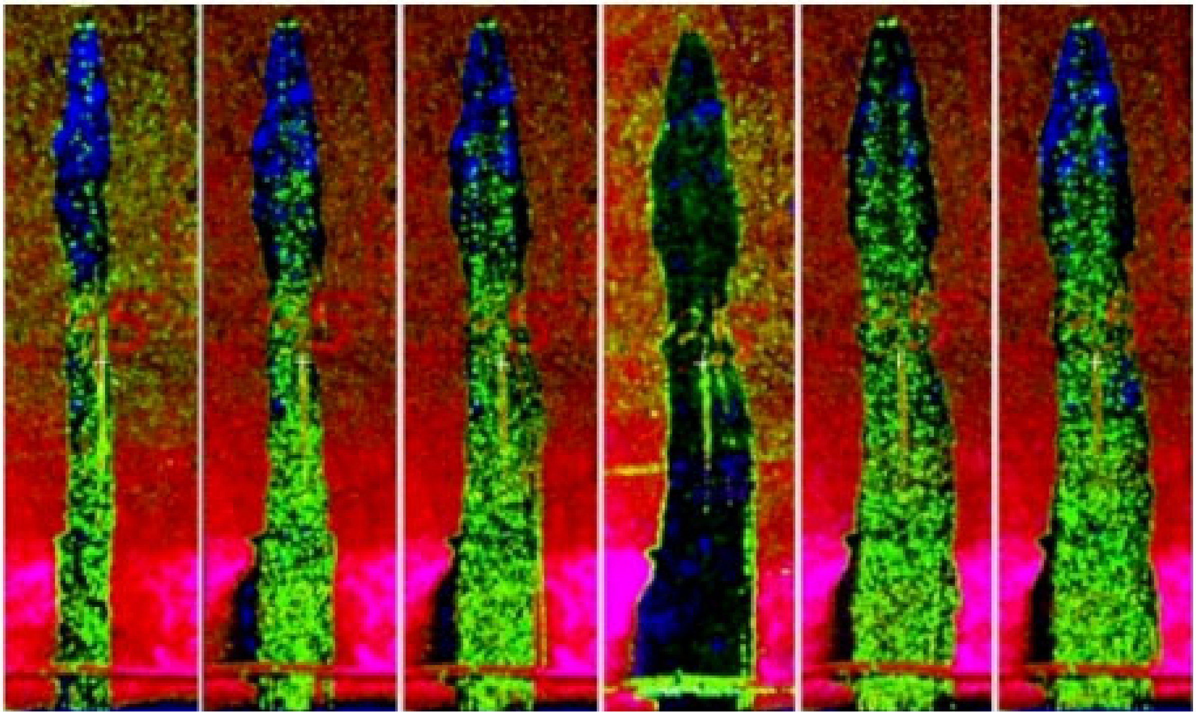
Comparing surfaces in a TBM tunnel and a blasting tunnel, it is easier to detect water leakage from the laser image on a TBM tunnel surface. Water leakage with different amounts of water are shown as a processed grey-scaled laser image in Figure 6, and a pseudo-colour image in Figure 7.



T2 < 0.1 T3 = 0.45 T4 =1.0 – 1.4 T5 =1.4 T8 = 2.3 T10X > 2.3

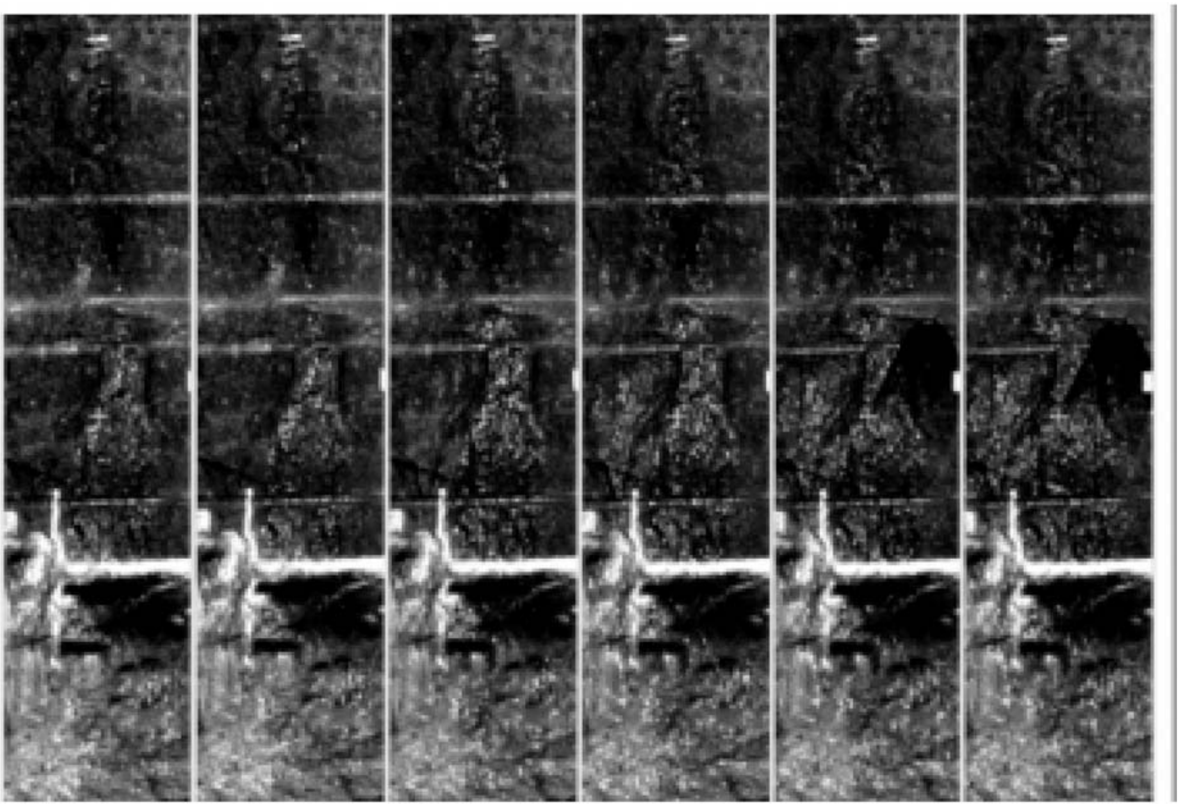
Figure 6. Different water leakages shown as a grey-scale image of the TBM tunnel wall

In the blasting tunnel the rock surface is quite rough, so water leakage can not be easily identified from the grey-scaled images, shown in Figure 8. But after applying some image processing techniques, pseudo-colour images, shown in Figure 9, can help us to detect different water leakages.



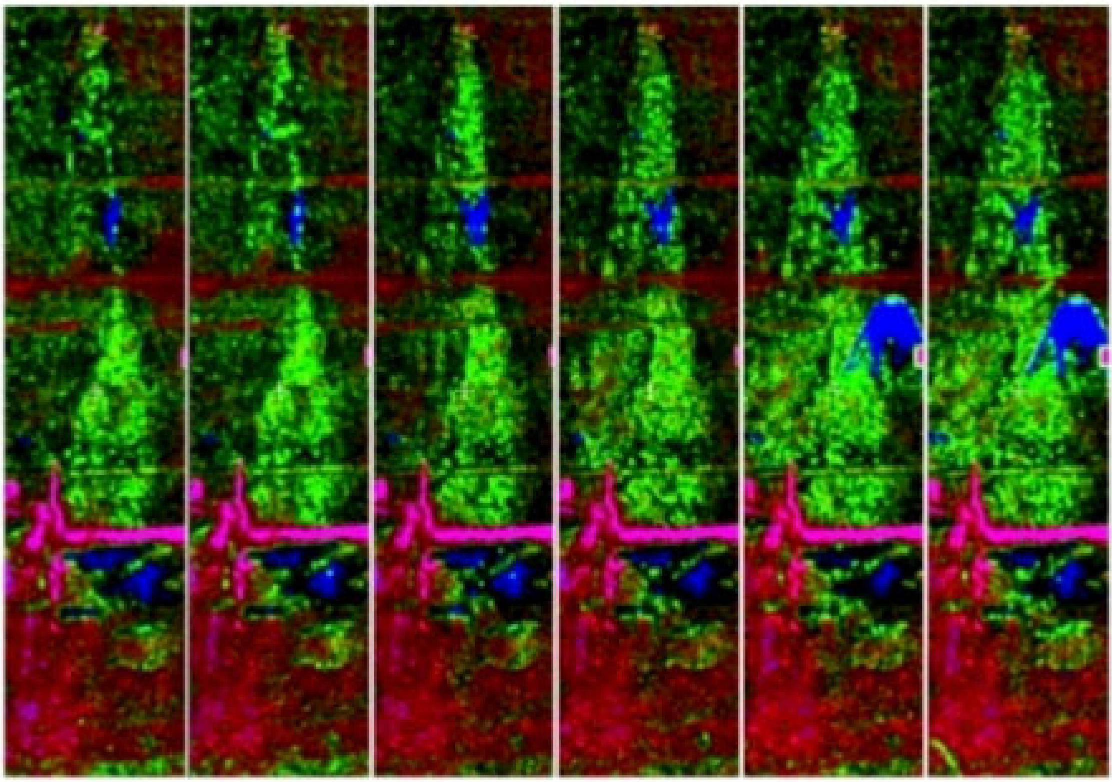
T2 < 0.1 T3 = 0.45 T4 =1.0 – 1.4 T5 =1.4 T8 = 2.3 T10X > 2.3

Figure 7. Different water leakages shown as a pseudo-colour image of the TBM tunnel wall



Z1b = 0.05 Z2 = 0.1 Z3 = 0.5 Z4 = 1.1 Z7 = 1.4 Z8 = 2.2

Figure 8. Water leakages with different flows shown as a grey-scale image



Z1b = 0.05 Z2 = 0.1 Z3 = 0.5 Z4 = 1.1 Z7 = 1.4 Z8 = 2.2

Figure 9. Water leakage with different flows shown as a pseudo-colour image

CONCLUSIONS

The presented study shows a possible technique for quantitatively detecting water leakage from laser images. The results provide the following tips for water leakage mapping by 3D laser scanning data: 1) water leakage can be quantitatively detected from grey-scaled laser images, and more easily identified in pseudo-colour images, by using some image processing techniques; 2) water leakage on the drilling surface of TBM tunnels is more easily detected, compared to those on the blast surface of a tunnel; 3) Image features of water leakage on the intensity laser image are mostly influenced by surface roughness and incidental angle. So, its' use is limited to detecting water leakage on rough surfaces, with large incidental angles.

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REFERENCES

Mettenleiter M, Härtl F, Fröhlich C, Langer D. 2000. Imaging laser for 3-D modelling of real world environments. Proceedings of the IASTED International Conference Modelling, Identification and Control, Innsbruck, Austria.