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Janiszewski, Mateusz; Uotinen, Lauri; Szydlowska, Martyna; Munukka, Henri; Dong, Jiang Visualization of 3D rock mass properties in underground tunnels using extended reality

Published in: IOP Conference Series: Earth and Environmental Science

DOI: 10.1088/1755-1315/703/1/012046

Published: 23/04/2021

Document Version Publisher's PDF, also known as Version of record

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Please cite the original version:

Janiszewski, M., Uotinen, L., Szydlowska, M., Munukka, H., & Dong, J. (2021). Visualization of 3D rock mass properties in underground tunnels using extended reality. *IOP Conference Series: Earth and Environmental Science*, *703*(1), Article 012046. https://doi.org/10.1088/1755-1315/703/1/012046

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PAPER • OPEN ACCESS

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To cite this article: M Janiszewski et al 2021 IOP Conf. Ser.: Earth Environ. Sci. 703 012046

View the article online for updates and enhancements.

IOP Conf. Series: Earth and Environmental Science 703 (2021) 012046

Visualization of 3D rock mass properties in underground tunnels using extended reality

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Abstract. The term extended reality (XR) refers to a family of technologies that cover Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). The main benefit of XR is that it can offer a new viewpoint on the surrounding environment by augmenting it with digital data and visualizations. Recent developments of XR enable its deployment for rock engineering applications, including underground tunnels. In this paper, we demonstrate two cases of the use of XR in an underground tunnel to display spatial information on the tunnel surface. One of the tunnels in the Underground Research Laboratory of Aalto University (URLA) was digitized using Structure-from-motion (SfM) photogrammetry. As a result, a high-resolution 3D point cloud and textured model of the tunnel were created. Next, the rock joint planes were obtained semi-automatically from the digitized rock surfaces. The results are then represented in their actual positions in the tunnel geometry. In the first case, we used VR to display the rock joint planes on the textured model of the tunnel. In the second case, the data was displayed in realtime in tunnel conditions through a mobile device. The results demonstrate that XR technology can be successfully used in underground construction to digitize the workplace and provide a new perspective on the work environment, which can potentially lead to an increase in safety and productivity.

1. Introduction

Extended reality (XR) refers to a group of immersive technologies that merge the virtual and physical world and include Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) (see Figure 1). The main benefit of XR is the ability to enhance the existing environment with an additional dimension of data and information. With the recent developments of XR, the technology is ready to be deployed in rock engineering applications [1]-[2]. This, combined with the recent findings on the use of photogrammetry for digitization of underground tunnels [3]-[4], allows us to augment the underground environment of hard rock tunnels with rock mass spatial data collected from high-quality photogrammetric scans. In this paper, we demonstrate two case applications of XR technology in an underground tunnel to display 3D spatial rock mass quality information on the tunnel surface.

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Figure 1. Extended Reality (XR) technologies.



Figure 2. High-resolution point cloud of the tunnel section with camera positions of 369 images (a), and a zoomed section of the textured mesh model (b) [4].

2. Digitization of an underground tunnel site

The proof of concept was conducted in the Underground Research Laboratory of Aalto University (URLA). The test area was the mapping tunnel of URLA with the length 100 m, width 6 m, and height 5 m. The tunnel is exceptionally well lit and the lighting can be adjusted at four levels: 0 %, 33 %, 66 %, 100 %.

2.1. Photogrammetric scan of the test site

URLA was digitized using Structure-from-motion (SfM) photogrammetry. As a result, a high-resolution 3D point cloud and textured model of the tunnel were created (see Figure 2 and Figure 5a-b). For a more detailed description of the photogrammetric scanning procedure, please refer to [4].

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Figure 4. Spatial information of rock joint planes: 10 m (30-40).

2.2. Extraction of spatial 3D rock mass information

In the next step, the rock joint planes were obtained semi-automatically from the digitized rock surfaces. The algorithm developed by Riquelme et al. [5] was used to process the point clouds of the URLA mapping tunnel wall, and points were grouped into planes that belong to the same joint set. In total, four joint sets were identified.

The spatial information was exported as a colored point cloud containing information on rock joint plane identification at two scales: the complete tunnel 100 m long segment (Figure 3) and a 10 m long segment (Figure 4) at 30 m to 40 m. Both data sets were provided at subsampling rates ranging from 100 %, 75 %, 50 %, 25 %, 10 %.

3. Visualisation of the 3D spatial information using XR

The spatial information in the form of the coloured point cloud of the joint sets is then represented in their actual positions on the tunnel surface using two XR technologies. In the first case, VR is used to display the rock joint planes on the textured model of the tunnel visualised in a VR headset. In the second case, the data is displayed in real-time in tunnel conditions through a mobile device-based AR system.

3.1. VR tunnel visualisation system

The photogrammetric model of the URLA mapping tunnel was then implemented into Virtual Underground Tunnel Environment (VUTE) - a VR learning system developed at Aalto University (see Figure 5c) [6]. VUTE was built using the Unity game engine and is aimed at providing virtual field exercises for students. VUTE can be run at either PC-wired high-quality VR headsets (such as HTC Vive Pro, or Varjo VR1) or standalone headsets (such as Oculus Quest).

The colored point cloud consisting of 563 000 points representing the rock joint planes was implemented into VUTE using the Pcx plugin for Unity that enables point cloud import and render. The point cloud can then be visualized in real-time while running the system on a VR headset, with the option to toggle on and off using a button press. An example of the joint plane spatial data overlaid on the virtual tunnel surface in VR can be seen in Figure 6.

The system allows the user to clearly see which surfaces belong to a specific joint set, which helps with interpreting the rock mass quality and aids in the design process. Such an approach can enhance the typical rock mass investigation process by allowing virtual site visits. The rock face is first digitized when visiting the site and is then analyzed to extract additional information, which is implemented into the VR system. This allows multiple virtual revisits of the site and eases the communication and decision making.

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Figure 5 The mapping tunnel of the Underground Research Laboratory of Aalto University (URLA) (a), a photogrammetric model of URLA (b), Virtual Underground Tunnel Environment (VUTE) (c). Modified after [3].



Figure 6. Discontinuity sets extracted from the tunnel wall (a) and visualized on the virtual tunnel surface in VR (b). Modified after [6]

3.2. Mobile AR positioning concept

During the offline stage, the VimAI scanning App was used to scan the indoor space. The scanning app collects vision data of the space and uploads to a server. The server trains a model for localisation purpose. After that, the point cloud of the tunnel was aligned with the trained model. As a result, both the model and the point cloud obeyed the same coordinate system.

During the online state, the trained model was downloaded and a localisation algorithm was used to calculate the camera pose of the mobile device. Based on the accurate camera pose and the pre-aligned point cloud, the point cloud was rendered at the correct position in the space [7]. This model allows indoor positioning and overlaying of spatial information over the image seen through a mobile device such as a mobile phone or a tablet. The image below shows an example of the coloured points belonging to specific joint sets overlaid over the tunnel surface in real-time (Figure 7).

The main drawback of the method is the poor ability to display massive point clouds. The original clouds had to be downsampled to 6000 points for the software to run smoothly. A possible remedy is to calculate polygons instead of points, which would considerably reduce the number of points while not sacrificing accuracy.

To test the influence of lighting condition, the overlaying of information over the camera image was attempted at three different light levels: 100 % - 66 % - 33 %. The 100 % model worked quickly, the 66 % model worked after a considerably longer time, and the 33 % model did not work at all. The model was trained with the light level of 100%. The system requires similar light condition to work reliably and promptly. The need for light can be a problem in underground conditions and may require portable lights to be used.

Also, requiring online access during the offline access stage is a severe limitation considering underground usage. However, in some tunnels, there may be Wi-Fi already in place or mobile Wi-Fi is possible to arrange.



Figure 7. Sparse 100 m model viewed through the mobile device camera (left) and a dense model viewed through the camera (right). The colours of the points correspond to the joint set plane they belong to.

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4. Conclusions

This study demonstrates that XR technology in the form of Virtual and Augmented Reality can be applied in underground construction to overlay an additional dimension of spatial information on the tunnel surface. Both the VR and AR systems were successfully used to overlay the coloured point cloud of rock joint planes on a tunnel rock face. However, the VR system is advantageous in terms of the ability to display more than 500 000 of point as compared to the 6000 points in the AR system. Also, the AR system requires a lot of light to display the cloud reliably and promptly in an underground tunnel setting. In contrast, in the VR system, light is only needed for the digitisation of the tunnel surface. XR technology helps to visualize more complex data in an underground setting and provides new perspective on the work environment. Therefore, it can improve communication and can potentially lead to an increase in safety and productivity.

Acknowledgement

Aalto University supported this work as part of the Aalto Online Learning educational development project and the financial support for MIEDU, EDUROCK, and COVE pilots is acknowledged. The authors also kindly acknowledge the financial support from EIT Raw Materials Booster funding.

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