Virtual reality geological modelling for the Horonobe Underground Research Project

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Keywords; Virtual Reality, Horonobe URL, geological information

Abstract

As high-level waste disposal programs are projects with great public interest, the site selection process should be conducted via open discussion with all necessary information being shared. Providing only information requiring expert knowledge for interpretation, such as conventional two-dimensional drawings (e.g. geological maps) and one-dimensional data (e.g. boring logs), may be insufficient to develop public understanding at discussion forums.
Virtual reality (VR) and construction information management technologies are effective for the collection, examination and visualisation of underground geological information, which cannot be easily visually confirmed. In this study, a VR model was created by integrating geological data, photographs and a three-dimensional profile of a tunnel face acquired during the construction of the Horonobe Underground Research Laboratory, which is owned and operated by the Japan Atomic Energy Agency. The unique and important element of the VR model is this use of field data.
In this VR model, various details can be viewed at any point and compared. The use of the VR model allows for the project staff to have simultaneous visual access to the geological information and to achieve smooth communication. In addition, the model provides visually clear discussion materials, such as allowing access to geological data obscured by concrete after construction. The model can also be used to plan subsequent construction work and research studies. The use of the VR model will not only provide information for the discussion forum during the investigation stage but also contribute to enhancing the safety and the interpretability of the disposal project by incorporating and updating the geological information acquired during the construction and operation of the repository.

1. Introduction

1.1 Background

High-level radioactive waste (HLW) generated by nuclear power plants has a very high level of radiation and contains various long-lived radionuclides. Therefore, it needs to be kept away from human living environments for many years. To isolate HLW from the biosphere, geological disposal, i.e. placing radioactive waste in bedrock at a great depth, is being studied internationally as a final disposal method. In some countries such as Finland, the construction and operation of geological disposal facilities are in progress. Japan has also selected geological disposal as a final disposal method for HLW, and this project will proceed from the selection of the repository site to its operation.

In the construction and operation of HLW disposal, collecting, analysing and visualising data concerning the disposal facility and its surrounding geological characteristics at each step of the project, e.g. site selection and facility construction, is important for the development of the project. Specifically, such information is useful for the planning, implementation and safe management of the construction work. Furthermore, the visualisation of such information using virtual reality (VR) and construction information modelling, an approach initiated by the Ministry of Land, Transport and Tourism Infrastructure of Japan, as well as conventional one- and two-dimensional depictions of data helps in building consensus with local communities and governments as well as with the entire nation.

Recently, in the construction industry, the visualisation of information related to construction projects using information communication technologies such as VR and building information modelling is being encouraged (Yabuki, 2016, Sato et al., 2009). The visualisation of such information is a particularly effective technique for underground regions that cannot be easily visually confirmed.

Using VR technology, this study was conducted to facilitate information sharing between project members by visualising geological data in the VR space and to increase understanding of geological information by modelling and reviewing various details together. In this study, geological information such as geological observation data, photographs and three-dimensional (3D) scanning data of the excavated rock surface acquired at the time of construction of the Horonobe Underground Research Laboratory (URL) was simulated in the VR space. In the VR space, various details can be viewed at any point and compared.

1.2 Site Geology

The Horonobe URL project is being conducted by JAEA in Horonobe, Hokkaido, Japan. This project includes fundamental research and development activities to verify the technical reliability of the geological disposal of HLW and to develop safety assessment methods. The planned elements of the Horonobe URL include (a) a ventilation shaft (diameter: 4.5 m) and east and west access shafts (diameter: 6.5 m) with depths up to 500 m and (b) experimental galleries/niches at depths of 140, 250, 350 and 500 m. The construction of the URL began in November 2005 (see Figure 1). As of June-end 2015, the ventilation and east-access shafts reached depths of 380 m, the west-access shaft reached a depth of 365 m and the experimental galleries at depths of 140, 250 and 350 m were completed. Currently, *in situ* experiments are being conducted using the 350-m-level galleries.

The host rock of the Horonobe URL site is predominantly composed of diatomaceous mudstone up to a depth of 250 m and siliceous mudstone below 250 m and is subjected to an anisotropic *in situ* stress field (Morioka et al., 2008).

The Horonobe URL site is located in Neogene sedimentary rock. The diatomaceous mudstone of the Koetoi Formation is distributed up to a depth of 250 m, overlaying the siliceous mudstone of the Wakkanai Formation. Even though there is no accepted theory regarding the boundary between these formations, the boundary is marked here by the presence of opal CT in the Wakkanai Formation, i.e. it is defined by an opal-A/opal-CT transformation boundary. The Koetoi and Wakkanai formations have relatively large porosities, small unit weight and low strengths (Morioka et al., 2008) (see Table 1). Both formations are classified as soft rock according to their uniaxial compressive strengths of approximately 5 MPa for the Koetoi Formation and a maximum of 25 MPa for the Wakkanai Formation. The deformation coefficients of the Koetoi and Wakkanai formations are approximately 200–640 MPa and 900–1200 MPa, respectively (Morioka et al., 2008).

Several types of measurements were conducted during construction to monitor the rock mass behaviour and to confirm the support robustness.

Table 2 lists the measurement items, which are grouped into A and B depending on their objectives (Inagaki et al., 2014; Aoyagi and Kawate, 2015).

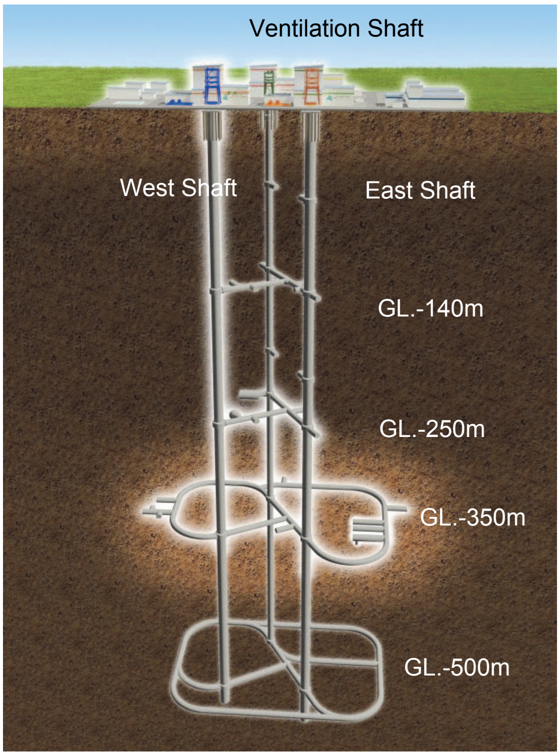


Figure 1. Layout of the Horonobe URL.

Table 1. Physical properties of the rock masses (Morioka et al., 2008).

Property	Koetoi Form.	Wakkanai Form.
Unit Weight [kN/m^3]	14–16	16–18
Porosity [%]	60–65	40–50
Uniaxial strength [MPa]	5	5–25
Hydraulic conductivity [m/s]	10^{-9}–10^{-8}	10^{-11}–10^{-6}

Table 2. Measurement items during the excavation of the gallery at −350 m (Inagaki et al., 2014; Aoyagi and Kawate, 2015).

Measurement group	Measurement item
A	convergence crown settlement fracture mapping
B	rock mass displacement stress of support elements borehole load test amount of groundwater inflow rock core observations fracture mapping of the tunnel floor cross-section profiling

2. Virtual reality modelling approach

2.1 Overview

The VR model was created to allow users to walk through the shafts and the galleries and to interact with point cloud data, photographs and geological observation data of the excavated rock surface acquired during construction as well as 3D models of underground structures such as the galleries and shafts using computer-aided design (CAD) software.

By translating the point cloud data and CAD models into VR, the system provides users with a unique experience walking through the structure from a depth of 250 to 350 m in the east shaft and then to the ventilation shaft through the loop gallery located at a depth of 350 m.

In VR, users can observe the condition of the rock at the time of excavation of the shafts and the galleries. The photographs and images of the observational data of the excavated rock surface can be reviewed and compared at each observation point.

2.2 Geological information collected in the Horonobe URL

During the construction of the Horonobe URL, laser scan point cloud data, photographs and geological observational sketches of the excavated rock surface were acquired at every excavation step.

(a) Point cloud data

When constructing the Horonobe URL, point cloud data of the excavated rock surface were acquired using a 3D laser scanner (See Figure 2). The scanning interval was approximately 2 cm, and geometrical data such as the roughness of the rock excavation surface and the RGB colour information were recorded (See Figure 3 and Table 3).

The point cloud data were saved as text data and were then grouped and converted into VR. The coordinate accuracy was maintained by adjusting the reference coordinates.

(b) Photographs

Photographs of the excavated rock surface were captured using Nikon D70 cameras. These photographs were saved as digital data after correcting for lens aberration and curvature. The photographs were exported together with the point cloud of the excavated wall surface of the ventilation and east shafts in OBJ format and then incorporated into VR as a texture model.

(c) Geological sketches

When constructing the URL, observations of the excavated rock surface were made by geologists. Geological sketches were made onsite describing the rock types and bedrock condition and then were saved as CAD data. Image data of the sketches and the CAD model of each of shaft and gallery were exported in OBJ format and then translated into VR as a texture model.

(d) Underground structures

Three-dimensional polygon models replicating the shafts and galleries of the URL were created and incorporated into the VR model.

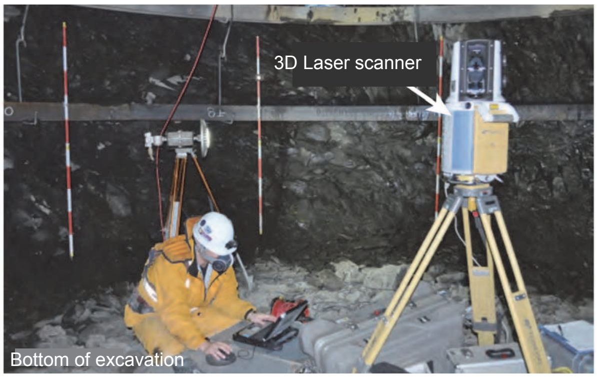


Figure 2. Collection of point cloud data in the shaft using a 3D laser scanner

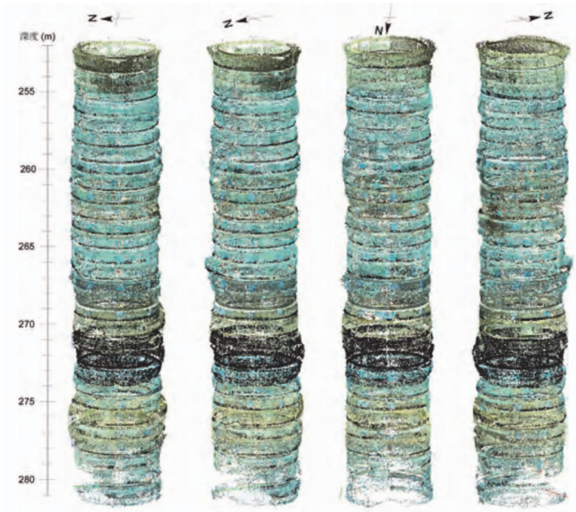


Figure 3. Shape of wall rock surface of the ventilation shaft obtained by 3D laser scanning (from a depth of depth 251 m to 281 m) (Tsusaka et al., 2012)

Table 3 Specifications of 3D Laser Scanner when used in shafts in the Horonobe URL

Horizontal scan line	
distance	16,650 mm
Field of view	360°
Scan angle	Max. 0.22°
Scanning interval	10 mm
Number of scan points	1,665
Vertical scan line	
distance	3,000 mm
Field of view	±35°
Scan angle	Max. 0.22°
Scanning interval	10 mm
Number of scan points	318 points
Total	
Scan points	Approx. 570,000
Scan speed	1,000 points/sec
Measurement time	600 sec

2.3 VR system configuration

VR content compatible with this system was created using Hybridvision, a VR system owned by Taisei Corporation.

Hybridvision is a rear projection system comprised of two stereoscopic projectors and a large screen with a height of 2.4 m and a width of 4.2 m (see Figure 4). The projected image can be controlled using a 3D mouse and a joypad. Stereoscopic viewing is possible when wearing a pair of liquid crystal shutter glasses. Several of its functions and their definitions are summarised below.

(a) Large screen

The use of large screens is effective when project members and stakeholders meet together and helps develop discussions while watching reproduced images.

The use of large screens facilitates the extraction of problems and makes it easier to form a consensus for solving them, thereby reducing the discussion time. Further, the use of a large screen where the entire field of view fits on the screen provides a sense of immersion.

(b) Stereoscopic vision

It is difficult to provide a sense of space, 3D effects and the scale of a structure when only using drawings, models and movies. Stereoscopic vision is effective when a greater degree of realism is required or when the 3D behaviour of various physical phenomena needs to be confirmed.

(c) PC-compatible content

Two-dimensional content that runs on Windows® PC was prepared along with content compatible with Hybridvision even though it cannot be used to produce 3D stereoscopic images.

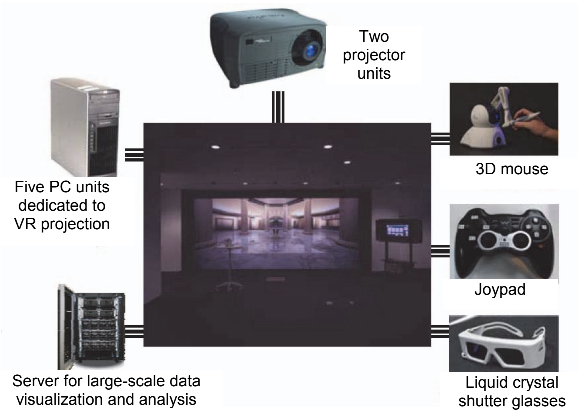


Figure 4. System configuration of Hybridvision. (Sato et al., 2009)

3. Virtual reality model

The VR model of the Horonobe URL was created by converting each type of geological data into a format compatible with the VR system and by incorporating it into the VR space. Figure 5 shows an overall image of the created VR model is shown, and Figure 6 shows the control panel of the model. Figures 7 and 8 show the 3D laser scanning data of the shaft and gallery walls, and Figure 9 (b) shows photographs of the shaft wall.

The information incorporated into the model extends from the surface to a depth of 380 m in the URL, where construction and data acquisition has been completed. As for the photographs, only a part of the photos of the ventilation and east shafts were imported into the model due to time constraints on the conversion of the data and the creation of the models.

In the VR model, it is possible to move the viewpoint to an arbitrary location using a 3D mouse or controller. The models can be viewed from both the inside and outside of the galleries.

The user can move to an arbitrary location and browse the 3D laser scanner data, the photographs of the excavated rock surface and the wall observation data at an arbitrary point by switching the displayed objects. For example, it is possible to compare the geological maps with the photographs and then use them to identify the occurrence of a fault (see Figure 9). Figure10 shows that it is also possible to compare two screens side by side.

However, the identification of the geometry and direction of the fractures and the fault structure was unsuccessful owing to the poor resolution of the original data even though it was initially assumed to be possible.

Figure 5. Geological map and underground structure of the Horonobe URL.

Figure 6. User interface.

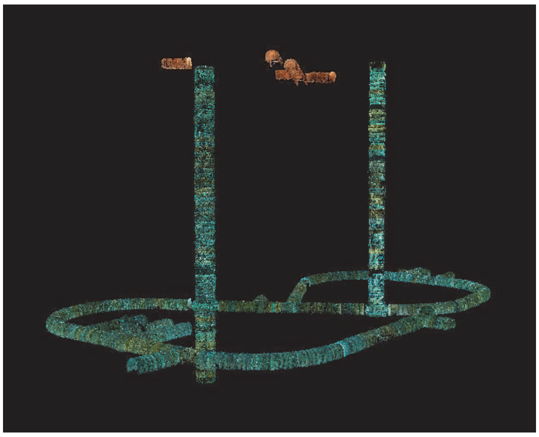
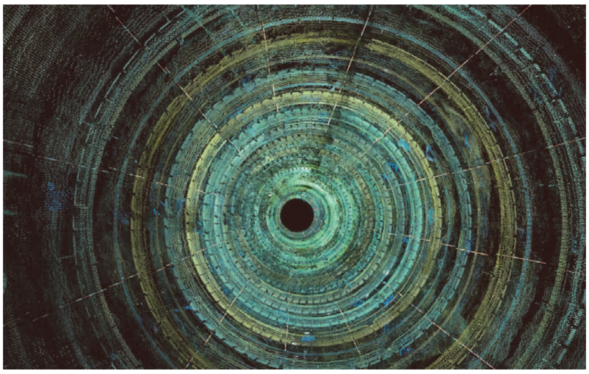
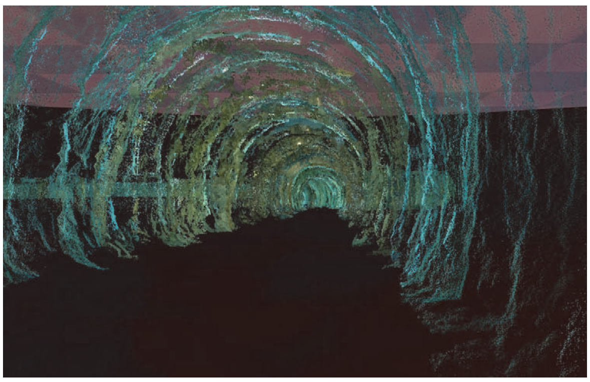


Figure 7. Point cloud in VR.

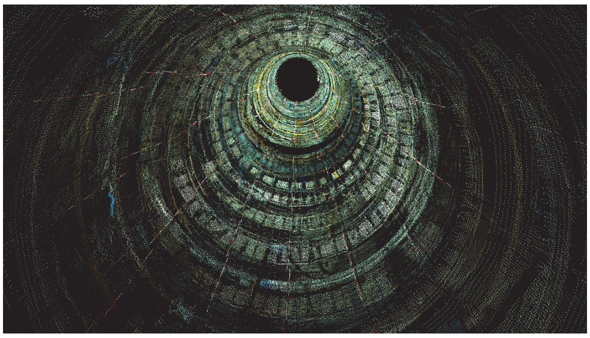


(a) Shaft

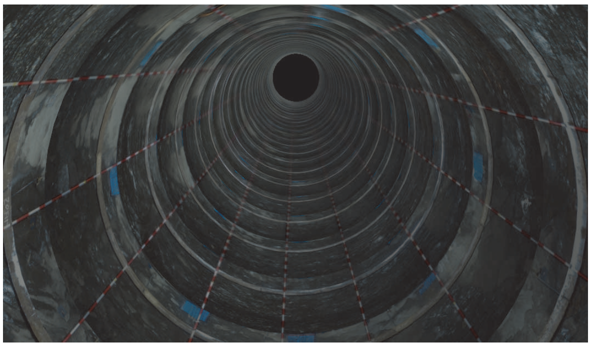


(b) Loop gallery

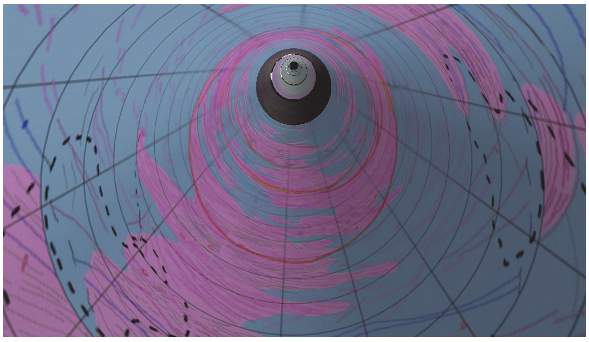
Figure 8. Visualisation of the roughness of the excavated rock surface using 3D laser scanning data.



(a) Point cloud



(b) Photographs of the excavated rock surface



(c) Geologic maps drawn using CAD

Figure 9. Comparison of different datasets at the same section and from the same viewpoint.

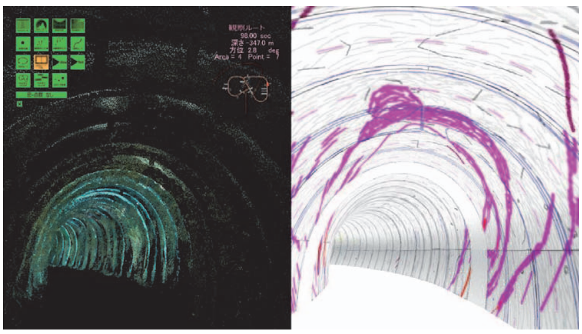


Figure 10. Comparison of point cloud and geological map side by side.

4. Discussion and Conclusions

In this study, a VR model was developed as a new communication tool using data collected during the Horonobe URL project. The application of the VR model allows for the project members to share the collected geological information and to achieve seamless communication by providing visually clear discussion materials, such as access to the rock surface even after the installation of concrete.

The VR model can also be used to plan subsequent construction work and research studies. For example, in construction projects that are implemented 24/7 such as the Horonobe URL, for all the construction members to meet and observe the condition of the excavated rock surface on site is difficult. Therefore, information sharing between the project members is a challenge and may cause delays in decision-making with respect to construction and safety. By improving the immediacy of our VR modelling, the model can contribute to prompt decision-making. The VR model is also expected to be useful for investigations at high-risk sites such as slopes and high places. As the current VR system requires a large screen, a system using a portable projector is being developed so that VR can be more accessible anywhere. (see Figure 11).

Using the 3D laser scanning data shown in Figure 6, the roughness and geometry of the excavated surface are effectively visualised. Understanding discontinuous structures such as faults and fractures is important to ensure the structural stability of subsurface structures. From the viewpoint of radioactive waste disposal, the safety assessment of the disposal facility is also important because highly permeable zones are potential flow paths for groundwater. Our future study will include improvements in the density of the point cloud data and the rendering speed, which will decrease as the amount of data increases, by locally changing the density of the data.

In this study, a model focusing on geological information was created as the first step towards building a VR model for the Horonobe URL project. However, in this project, not only geological data but also mechanical data—such as the stress and displacement of the rock masses and support elements—and groundwater data—such as groundwater pressure and water quality—are being acquired. Such data are also important for the safety and performance of underground structures. In radioactive waste disposal facilities particularly, this information is key for evaluating the capability of the environmental barriers with respect to nuclide confinement. Therefore, a future task is to incorporate these measurement data into the VR model to ensure safety during the construction and management of the project and to facilitate better communication.

Figure 11. Development of VR system using portable projector.

We are grateful to Mr. Hayano and researchers of Horonobe Underground Research Unit in JAPAN ATMIC ENERGY EGENCY for helpful discussions about geological interpretation and VR modelling.

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