Applications of mixed and virtual reality techniques in site characterization

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ABSTRACT During the last five years there has been a dramatic increase in the use of Mixed (MR) and Virtual (VR) Reality techniques in mining engineering. The majority of these applications have focused on improving visualisation of engineering projects including open pits and surface mine reclamation. MR/VR can be also used on geotechnical site characterization. EasyMap MR is a Microsoft HoloLens application developed for direct mapping of the lithology and structure of rock masses in surface and underground environments. Using EasyMap MR significantly improves mapping process and data interpretation, by allowing users to draw traces directly over the rock faces, and displaying geospatial data such as drill holes. Another MR/VR application is developed for virtual core logging and building a virtual core shed. Holographic measurement of discontinuity roughness has been developed using a virtual joint roughness profiler, which allows interactive calculation of roughness coefficients in varied directions in addition to qualitative holographic comparison of roughness profiles with Barton's joint roughness profiles. Finally, applications of holographic techniques in landslide and rockfall hazard investigations are demonstrated with reference to the 2014 Jure landslide in Nepal.

Introduction

During the past five years there has been a dramatic increase in the use of Mixed and Virtuality Reality, MR/VR, techniques in mining engineering. The majority of these applications have focussed on improving visualisation of engineering projects including open pits and surface mine reclamation. Trimble (2019) developed an application where holographic open pits placed on boardroom tables allow communication between mine engineers in a mine production and truck haulage capacity. BGC Engineering used Mixed (MR) / Virtual (VR) Reality and holographic images to communicate the life stages of an Alberta oil sands mine emphasizing the environmental reclamation of the site in a unique communication format (Loook, 2017). MineLife is a VR software for mine site planning developed by LlamaZOO (2018). At SFU, the Engineering Geology and Resource Geotechnics Research Group has used MR technology on numerous engineering projects including landslides and open pits (Onsel et al., 2018) (Fig. 1).

In this paper, we demonstrate the application of MR/VR approaches for geotechnical site characterization using the Microsoft HoloLens (HL) headset. This MR system comprises a short distance 3D scanner that can be used on site for data collection and mapping. It is also capable of visualizing 3D multi-sensor remote sensing data, both in the field and at the office.

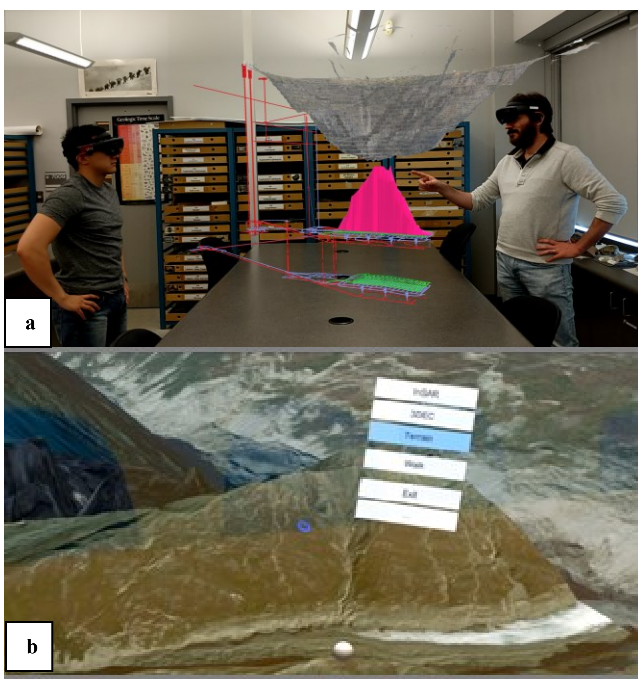
Methodology

Multi-sensor remote sensing techniques

The Engineering Geology and Resource Geotechnics Research Group at Simon Fraser University is developing the application of state-of-the-art multi-sensor remote sensing approaches for the comprehensive investigation of high rock slopes. Remote sensing techniques include long range (up to 4 km) terrestrial laser scanning (TLS), high-resolution (up to 50 megapixel) photography (HR), terrestrial digital photogrammetry (TDP), ground based and aerial structure-from-motion (SfM), infrared thermography (IRT), and hyperspectral imaging (HSI). These techniques are used to perform varied geological and geotechnical analyses, including discontinuity mapping, rock slope damage characterization, blast damage mapping, lithological mapping, groundwater seepage analysis, rockfall investigation, weathering and alteration mapping. HR, IRT, and HSI datasets are draped on 3D TLS models to allow significant improvements in mapping. Monitoring datasets, such as ground- and satellite-based radar data, change detection results, borehole inclinometer logs, and micro-seismicity data can also be implemented, allowing for an in-depth characterisation of slope movements and the factors controlling deformation. Remotely sensed datasets, together with traditional field-based mapping data, are used as input for advanced 3D numerical modelling analyses, using a wide range of codes, such as Slide 3 (Rocscience, 2019a), RS3 (Rocscience, 2019b), FLAC3D (Itasca, 2019), 3DEC (Itasca, 2016a), Slope Model (Itasca, 2016b), and IRAZU3D (Geomechanica, 2019).

It is suggested that the use of an integrated multi-sensor remote sensing characterisation-monitoring-numerical modelling approach combined with MR/VR would significantly improve our understanding of the structural and geotechnical control on observed pit slope deformation, Figure 1a.

Fig. 1. Example application of MR/VR for the geovisualization of engineered and natural slopes. a: Palabora mine, South Africa b: Fels landslide, Alaska



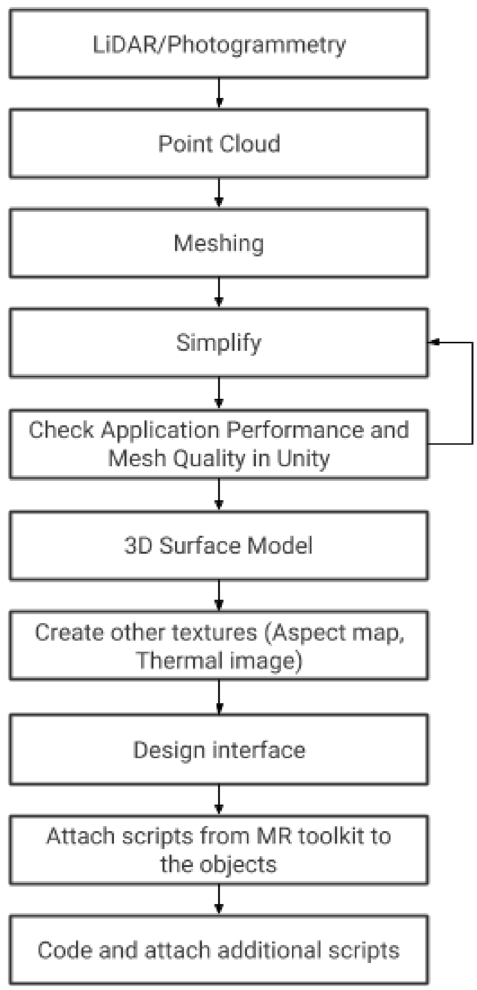
Developing MR/VR applications

The Microsoft HL is a Windows 10 computer, powered by a 32-bit Intel Atom Processor with 2GB RAM memory, running Universal Windows Platform (UWP) applications. UWP applications for HL can be created in Unity game engine software. Mixed Reality Toolkit, an open source project supported by Microsoft, provides primary scripts in order to accelerate the development of HL applications using the Unity game engine.

Unity supports 3D mesh files and bitmap image files. 3D datasets collected using remote sensing techniques (e.g., TLS, TDP, SfM) that can be used to create mesh files. 2D remote sensing datasets (e.g., HR, IRT, HSI) can be used to create textures that can be overlain onto the 3D meshes. Due to current HL limited processing power and memory, however, a simplification of the datasets may be required to increase the performance of the applications.

Users can interact with the imported objects using voice commands and hand gestures. These interactions are controlled and governed by scripts written using the C# programming language in MS Visual Studio. Fig. 2 shows the workflow for the development of MR applications.

Fig. 2. MR application development process (Onsel et al. 2018)



Site characterization with MR/VR

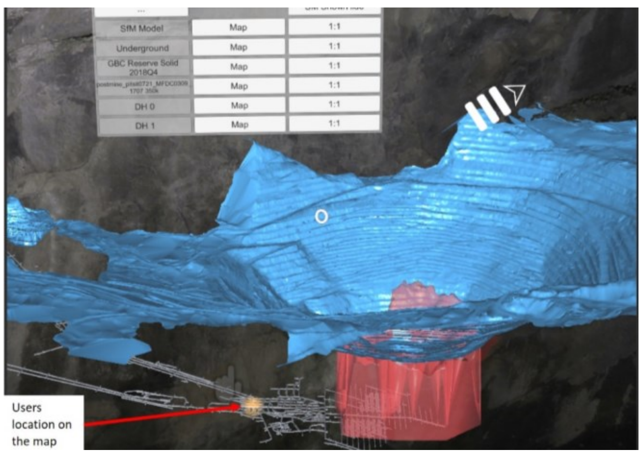
In this paper, we present various applications that were developed for site characterizations and data interpretation.

Direct HoloLens mapping of rock outcrops

EasyMap MR (EMMR) is a HL application developed under a joint Mitacs Accelerate project between SRK Consulting and SFU. This application takes advantage of the built-in 3D scanner in the HL to collect data on site. When the HL user looks directly toward an object at a distance between 0.8 m and 3 m, the HL scanner creates a mesh of the object with a resolution of ca. 5 cm. Therefore, the EMMR user simply needs to walk along, and view the investigated outcrops to create a mesh in quasi-real time. Users have the option to view, hide, and colorize the mesh. After finishing the scan, the user may visualize a small- scale preview of the mesh, before saving the 3D dataset.

Georeferencing can be performed using a compass (to set the north in the application) and a survey point located on the outcrop (to convert the local HL coordinate system to a project or realworld system). Once the registration process is complete, additional georeferenced data may be imported into EMMR. For example, meshes and drillhole data exported from Leapfrog Geo (Leapfrog, 2016) will appear in their real-world coordinates, allowing the user to visualize data collected at a different time, allowing for more sophisticated on-site interpretation (Fig. 3).

Fig. 3. Examples of 3D objects imported in EMMR.



Users can perform HL geological, structural, and geomechanical mapping by drawing traces along the observed features (Fig. 4). The user can define the feature type, before the trace is saved as a 3D polyline. The shape can also be annotated using a form that is visualized by selecting the 3D polyline. Different form templates can be used, depending on the structure type (e.g., fault, joint, lithological contact, etc.). The 3D polylines that can be exported as comma separated values (csv) files. Georeferencing data is maintained during this process, eliminating the need for any post-processing.

An orientation measurement tool was also developed to determine the dip and dip direction of joint surfaces (Fig. 5). When the user looks at the joint surfaces, EMMR instantaneously computes the dip and dip direction, based on the orientation of the mesh. The user is then able to save the orientation data and display it in real time on a stereonet. This tool significantly speeds up geomechanical mapping, as there is no need read the orientation data from the compass (or smartphone). It also improves the safety of the user, as it allows the structure to be mapped without physically climbing onto the rock. Finally, the user can run a Fuzzy K-Mean algorithm (Hammah and Curran, 1999) to estimate the number and average orientation of the joint sets. A Ruler tool can be used to measure the length of structures (Fig. 6). EMMR can also display charts such as joint roughness profiles from Barton and Choubey (1977) (Fig. 7). Users can also take photographs and record videos directly on the HL.

Fig 4. Traces drawn onto the outcrop in EMMR.

Fig 5. The use of EMMR for joint surface orientation measurement.

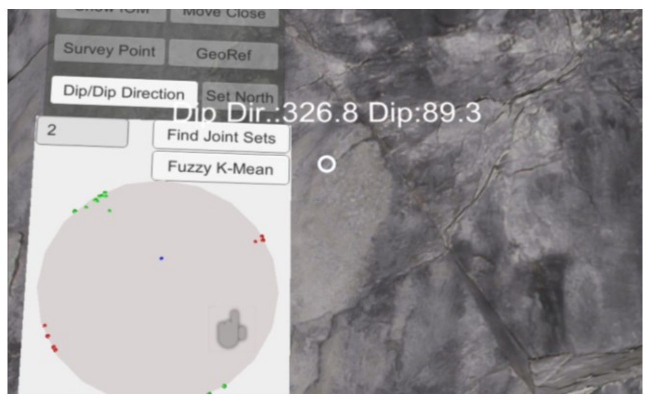


Fig 6. 3D measurements performed using the ruler tool.

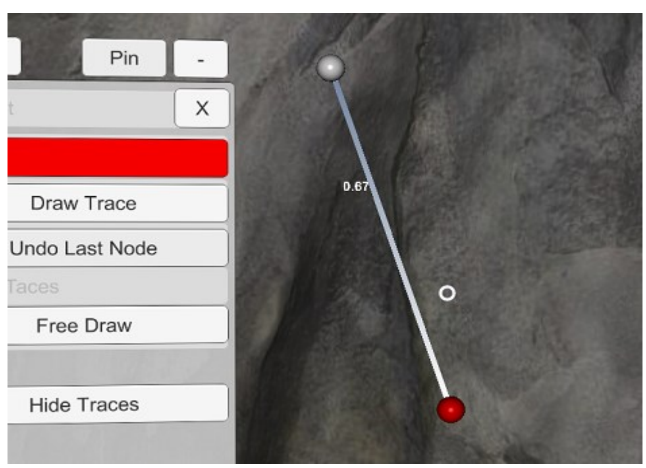
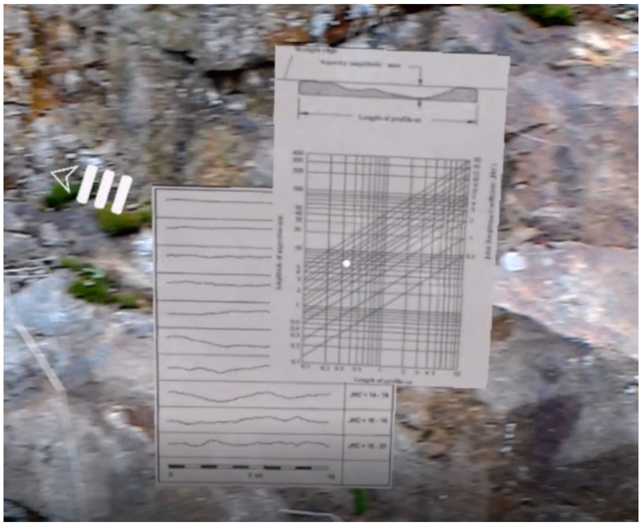


Fig 7. Joint roughness charts visualized in EMMR.



Holographic core logging

Core logging is an essential component in mining, civil, petroleum and geotechnical site investigations. The quality of the core logging is critical in ensuring both optimum safety and profit. To standardize geotechnical mapping and core logging, empirical classifications such as RQD (Deere, 1963), the Q-System (NGI, 2015), and GSI (Hoek et al. 2013) have been introduced (and are routinely employed) to ensure representative rock characterization.

Despite standardization, there remains the potential for human errors due to bias, naming conventions, and engineer/geoscientist inexperience. These errors can cause subtle but important features to be overlooked. Furthermore, re-assessment of the physical core can be costly and time consuming as core sheds often tend to be in remote regions. Storing core adequately is essential but can be challenging and laborious since core cannot be misplaced. Errors and non-optimal practices may result in increased costs due to poor understanding and misinterpretation of in situ geological conditions.

To minimize errors, drilling datasets can be enhanced by implementing point data, such as TerraSpec Halo (Malvern Panalytical, 2019), two dimensional data, such as hyperspectral scanning results (CoreScan, 2019; Enersoft, 2019), and three dimensional data sets, such as Acoustic Televiewers data (DGI Geoscience, 2019) or fullbore formation micro-imager (FMI) data (Schlumberger, 2013).

With recent advances in MR/VR technology, remote re-examination of core runs is possible. Researchers within the Engineering Geology and Resource Geotechnics Research Group at Simon Fraser University are conducting research to improve quality control in site investigation practice by developing holographic core logging core procedures.

Prototypes for a 3D core scanner have been constructed and proven to be successful (Fig. 8 and 9). Since the core is holographic, other data sets such as IRT, HSI or TLS results can be overlaid on the surface of the core (Fig. 10). The user can then quickly visualize and toggle between various spatial datasets. The user can also compare selected core boxes without risk of misplacement, and increased errors associated with repetitive moving of core within core boxes.

Point data (1D) can be displayed along the virtual core such as destructive point load test results or infrared imaging data. A thin-section can also be displayed as a point dataset along the core (Fig. 11). The thin-section can be toggled between polarized and unpolarized light and freely rotated or zoomed to examine specific areas of interest.

Finally, three-dimensional data can be viewed holographically. FMI results for example, can be observed in a VR environment allowing the user to visualize the dataset from within the borehole (Fig. 12). Results derived from micro-seismicity such as lithology (Fig. 12b), discontinuities (Fig. 13) and bioturbation can be observed. Since the user can see the FMI results in VR/MR, visual comparison between the physical core and its holographic representation can be undertaken, allowing easier quality check and structural interpretation.

Fig. 8. Real core compared to its virtual holographic counterpart. Structures are more evident in the holographic core due to upscaling in contrast.

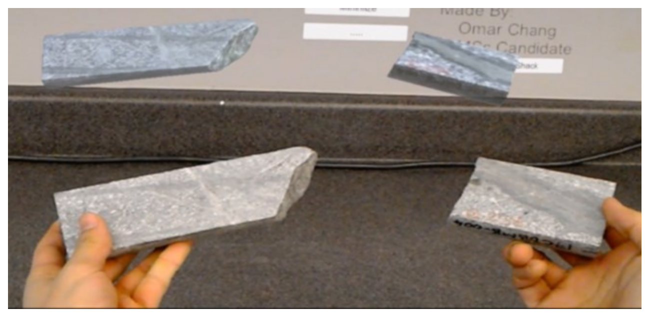


Fig. 9. Holographic stick of cores that can be rotated, scaled and moved to highlight specific features.

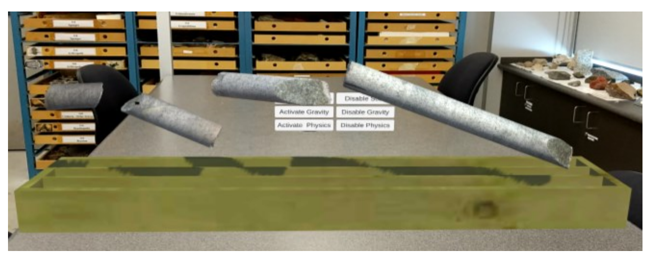


Fig. 10. Hyperspectral data derived by Enersoft (2019) delineating high contrast material along the holographic core

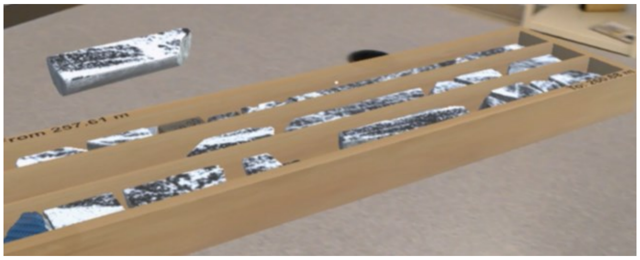


Fig. 11. Holographic thin section that can be rotated and viewed in polarized or unpolarized light.

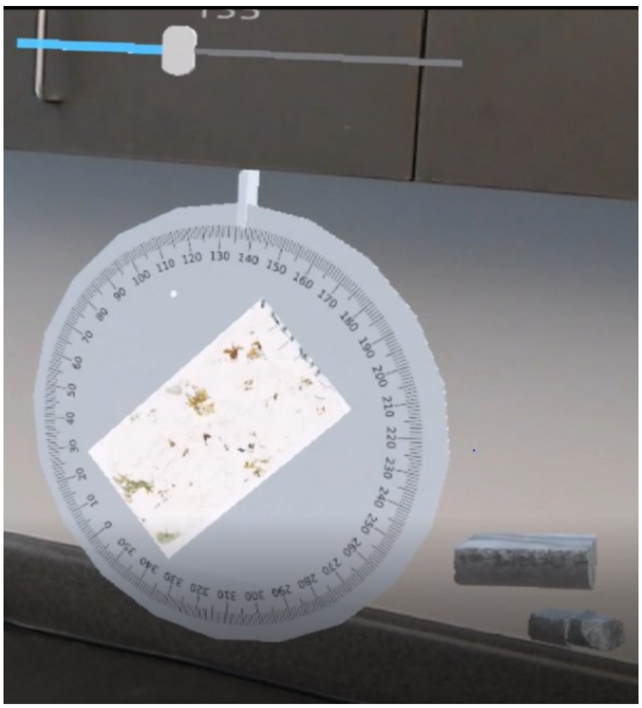


Fig. 12. Borehole wall logging data observed holographically from inside the hole. a: FMI results, white streaks are due to 80% borehole coverage; b: lithological results shown with depth along borehole wall.

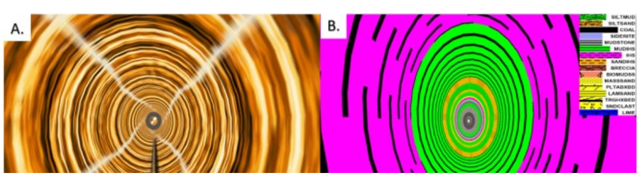
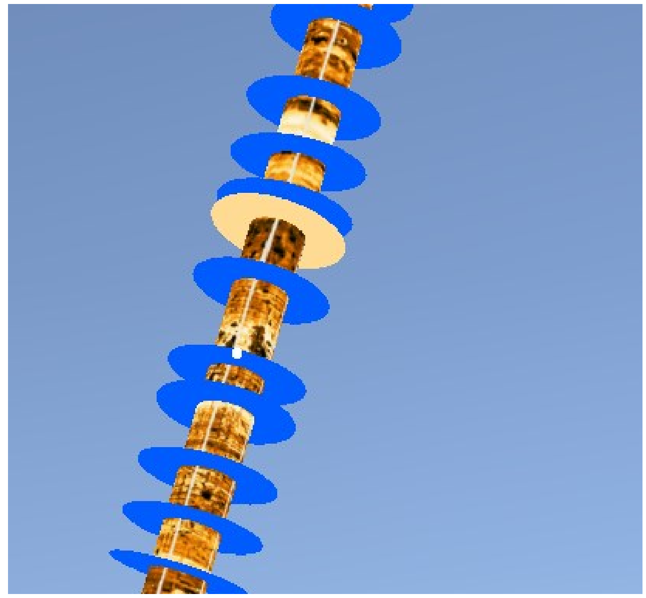


Fig. 13. 3D FMI results observed holographically from outside the core. Discontinuities are computed from the FMI (blue rings), scour marks (tan ring) and other discontinuities can be retrieved from CSV files.



Virtual joint roughness measurement

Various methods exist to quantify the roughness of discontinuity surfaces in the field. The joint roughness coefficient (JRC) is arguably the most widely applied method. In the field, a 2D profile of the joint surface is obtained using a roughness profiler, and then visually compared with a standard roughness profile chart. This technique provides a quick, although rather subjective, estimation of the roughness.

Using a very high-resolution laser scanner or photogrammetry, 3D models of a discontinuity surface can be produced and joint roughness estimated using a VR/MR approach. An application was developed, that allows the discontinuity surface roughness to be estimated in any direction. The user can position a virtual joint profiler, at any location and in any direction, on the discontinuity surface (Fig. 11). A profile is then automatically obtained, which can be visually compared with a virtual JRC chart, or used to calculate roughness coefficient using less subjective approaches, such as that described in Tatone and Grasselli (2010).

Fig. 14. Virtual joint roughness profiler placed on the 3D model of a discontinuity surface. The extracted profile is used to estimate roughness using JRC charts (right) or 3D real-time calculated coefficients developed by Tatone and Grasselli (2010)

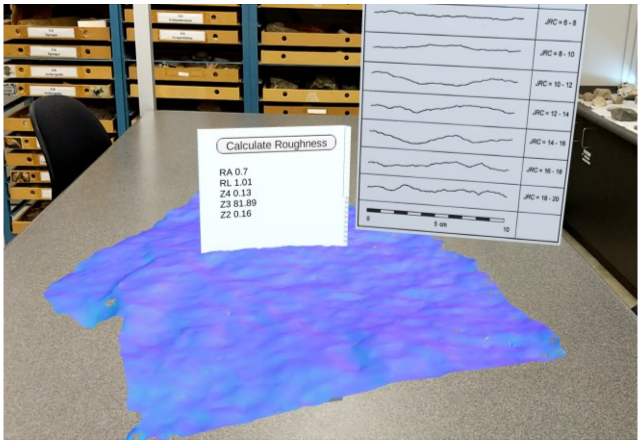
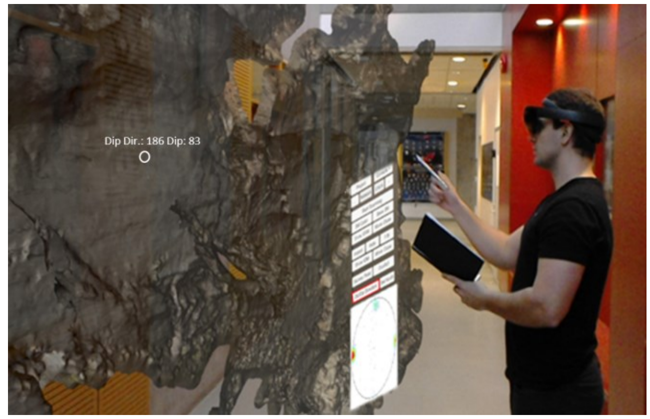


Fig. 15. Example of SFU MSc. student undertaking MR holographic discontinuity mapping, of a rock slope on the Jure landslide. One interactive orientation measurement option within the EasyMap MR software is illustrated. (Mysiorek et al., 2019a).



Landslides and rockfall hazards

The characterization of rock slopes can pose a high level of risk toward the engineer/geoscientist in the field due to inaccessibility and safety issues. During recent decades, rapidly developing remote sensing techniques, including TLS, TDP, and UAV-SfM are being increasingly employed in landslide investigation and risk assessment. These methods allow acquisition of three-dimensional data sets from previously inaccessible terrain with sub-centimetre accuracy. Processing 3D data allows integration within interactive 3D MR/VR geodatabase landslide models. An immersive and enhanced engineering 3D geovisualization experience is then possible; Figure 1b shows an immersive virtual reality holographic model of the Fels landslide, Alaska. MR/VR techniques can also be employed to conduct/compare discontinuity mapping on virtual landslide outcrops and allowing advances in both the understanding and communication of landslide site investigation data with improved significant potential for improved hazard/risk assessment.

A MR/VR approach was employed to investigate the Jure landslide, a large (~5.5 Mm^3), destructive landslide which occurred on August 2nd, 2014, near Jure village, 70 km northeast of Kathmandu, Nepal (Mysiorek et al., 2019 ab). The landslide dimensions are approximately 1500 m in length, 500 m in width (down valley), and 780 m in height with the main headscarp located at 1575 masl. Due to the steepness of the rupture surface, remote sensing surveys were conducted to complement the field-based investigation. Long range TLS, TDP, and UAV-SfM were used to collect 3D point clouds of the slope and accessible outcrops above the headscarp (Mysiorek et al., 2019a).

Point clouds were converted into mesh files. This enables the engineer/geoscientist while utilizing a HL with hand gestures and voice commands, to observe/interact in a virtual environment. The user is able to easily move around the virtual landslide slope to observe GPS, remote sensing field locations and different engineering geological features of interest (Onsel et al., 2018; Microsoft, 2019; Mysiorek et al., 2019ab).

A 3D model of the entire Jure slope was used to investigate the factors controlling the 2014 failure, and to identify potential rockfall hazards within the post-failure slope (Mysiorek et al., 2019b). Preliminary two and three-dimensional numerical modelling and analysis of the Jure landslide have been undertaken. To assess the Jure landslide failure mechanism and also evaluate future slope hazards, field and remote sensing data have been used to undertake kinematic analysis (DIPS), RocFall (Rocscience, 2019), limit equilibrium, (Slide/Slide3), Continuum (RS2/RS3; FLAC3D), and Discontinuum (UDEC/3DEC) modelling. Results such as numerical modelling can be integrated within an interactive MR/VR holographic environment, enabling improved communication and interpretation (Mysiorek et al., 2019ab). Comparative rockfall modelling analysis can be visualized by multiple engineers/geoscientists in a holographic MR Jure landslide geodatabase environment, by analyzing and comparing the 2D and real-time 3D Unity rockfalls as an interactive team (Mysiorek et al., 2019b). Mysiorek et al (2019b) describe the use of the 2D rockfall modelling software RocFall 6.0 and a 3D rockfall technique simulation using Unity3D game-engine technology (Fig. 16) with presentation of the results in a holographic environment.

Combined, remote sensing and numerical simulation data are being stored within a very large, integrated Jure landslide MR geodatabase. Managing, visualizing, interpreting, and sharing such a big dataset can be a challenging task using traditional visualization methods. In contrast, using MR, the user is able to visualize, interrogate, and more efficiently compare remote sensing datasets and numerical modelling results, in an immersive, fully 3D environment. This can provide a better understanding of the mechanisms underlying the deformation and failure of the slope, and may potentially provide a game-changing way engineers/geoscientist understand, communicate, model and mitigate geohazards (Mysiorek et al., 2019b) (Fig. 17).

Fig. 16. MR Microsoft HoloLens workflow for undertaking comparative analysis of Unity3D rockfall simulation and 2D Rockfall. A MR holographic approach provides an immersive, effective and efficient way to model/communicate rockfall hazards and results (Mysiorek et al., 2019b).

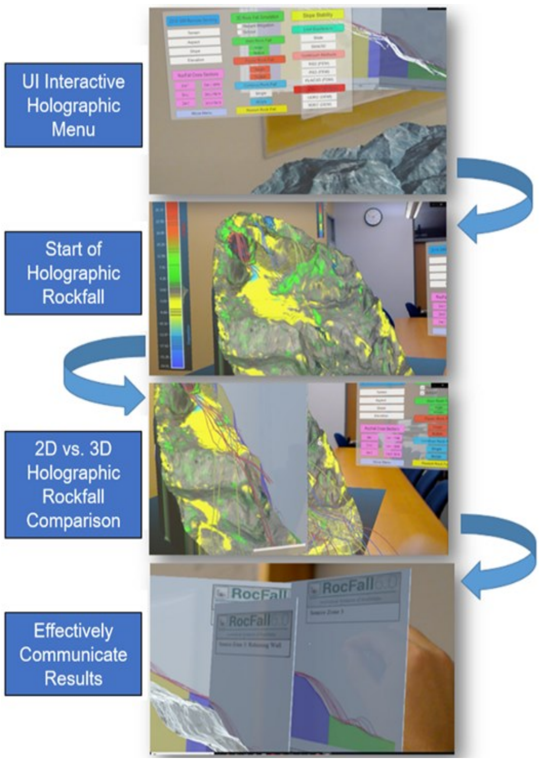
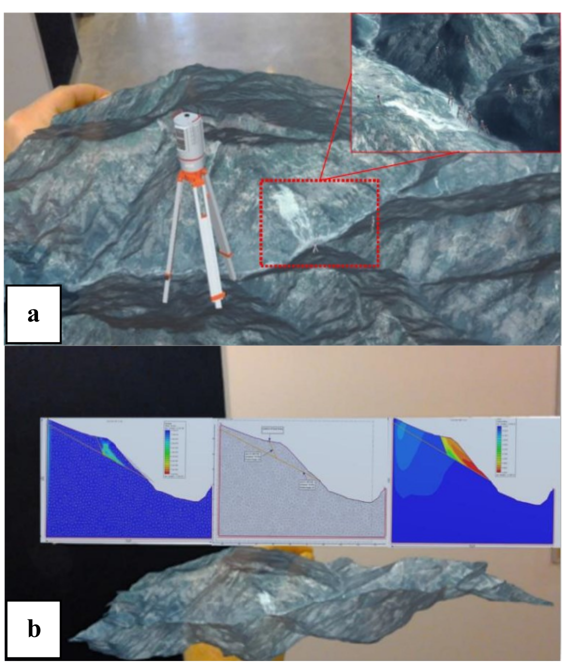


Fig. 17. MR/VR Jure landslide geodatabase. a: GPS field stations and Riegl VZ-4000 TLS, b: RS2 finite element numerical model results all displayed as holographs (Mysiorek et al., 2019a).



Future applications

MR/VR technology has the potential to revolutionize the geomechanical investigations both in the field and the office. We expect, within the next few years, that MR technology will rapidly advance, allowing for larger and more detailed datasets to be visualized using lighter, smaller, and cheaper headsets. As a result, the development and use of MR/VR applications will significantly increase in all the fields of education, industry, research, and entertainment.

Today, geologists and engineers commonly collect data in the field and perform data pre- and post-processing in the office. MR headsets allow to collect data and perform data processing almost in real-time, following a seamless workflow that starts with the mapping at the rock slope, and is concluded on site with a complete rock mass characterization. This innovative approach can optimize the time spent in the field, allowing more cost-effective investigations to be conducted. Additionally, the creation of virtual rock outcrops in the office allows the user to visualize the site at real scale, potentially allowing collected data to be verified or validated. In future, geologists and engineers will be able to build discrete fracture networks, run kinematic analysis, build and run preliminary numerical models directly in the field.

Recent advances in remote sensing techniques have greatly improved the quality, amount, and reliability of data collected from the rock face. This 3D data is displayed on 2D screens which limits perception of depth and scale. In contrast, the use of MR/VR methods allows the data to be visualized in an immersive 3D environment. This will allow multi-discipline and varying experience level users to examine the rock structure in real 3D holographic/virtual models and at 1:1 scale. Field observations can thus be made simultaneously available to users at remote offices and at multiple locations, allowing efficient control and validation of the collected data and, if needed, updating or revision of project designs.

This paper presented various application of the VR/MR technology, and particularly the Microsoft HL, developed for geotechnical site characterization. Described applications include direct outcrop mapping, engineering rock core logging, 3D joint surface roughness analysis, and the visualization and investigation of remote sensing datasets.

MR/VR is not only an extremely powerful tool for data communication and education purposes, but also can greatly enhance the interpretation and analysis of site investigation datasets at multiple scales. The hardware and software for MR/VR applications will undergo major advances in the near future: geoscientists and engineers need to be prepared to use this rapidly developing technology. We suggest that MR/VR techniques should be implemented into a comprehensive data collection workflow. However, we stress that traditional field techniques will remain critical for collecting intact rock and discontinuity data (e.g., uniaxial compressive strength, infill properties, etc.) that are of paramount importance for a correct characterization of the rock mass.

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