Dam Health Monitoring with VR

Pedro Leitão
Instituto Superior Técnico, University of Lisbon
Lisbon, Portugal
pedro.de.leitao@tecnico.ulisboa.pt

Nuno Verdelho Trindade
INESC-ID, Instituto Superior Técnico, University of Lisbon
Lisbon, Portugal
mail@nunotrindade.com

Sérgio Oliveira
Laboratório Nacional de Engenharia Civil (LNEC)
Lisbon, Portugal
soliveira@lnec.pt

Alfredo Ferreira
INESC-ID, Instituto Superior Técnico, University of Lisbon
Lisbon, Portugal
alfredo.ferreira@tecnico.ulisboa.pt

***Abstract*—Structural Health Monitoring (SHM) is a crucial procedure when it comes to ensuring the safety of the structures. SHM is mainly done through traditional methods, but with the evolution of immersive technologies such as Virtual Reality (VR), this is rapidly changing.**

The goal of this work is to explore the benefits and challenges of applying VR in the SHM of dams. For this, related work concerning applications of VR in different areas was explored and discussed. An application, named VRCabrilAnalysis, was also developed and tested.

VRCabrilAnalysis is a VR application where users can move through a model of the Cabril Dam and interact with the sensors that are present there. It is possible to visualize the data measured by the sensors and analyze the damage evolution of the dam over time.

***Index Terms*—virtual reality, digital shadow, immersive environments, structural health monitoring for dams, dam analysis over time, damage evolution**

I. Introduction

Structural Health Monitoring (SHM) is the evaluation in real-time of a physical structure and the materials that compose it, to detect failures as early as possible. This minimizes the risks and ensures the safety of the structure [1].

Laboratório Nacional de Engenharia Civil (LNEC) performs SHM analysis of dams through the use of traditional methods, needing to be on-site to analyze and monitor the safety of the dam in real-time.

Immersive analytics is a field that combines data visualization, visual analytics, human-computer interaction, and immersive technologies such as virtual reality (VR) and mixed reality (MR). It has the goal of facilitating the connection between the data, the users, and the tools used for analysis [2].

To study the benefits and consequences of applying immersive analytics in the SHM of dams, we developed a VR application, called VRCabrilAnalysis, where the users can analyze the measurements from the sensors installed at the Cabril Dam.

This work is a first step towards a digital twin VR application of the Cabril Dam, allowing users to analyze and monitor the health of the Cabril Dam and then act accordingly.

II. Related Work

Augmented Reality (AR) has previously been applied in the inspection and monitoring of dams, with a system named DamAR [3]. With VRCabrilAnalysis, we will be testing the application of VR in the same field.

To support the development of our application, we analyzed related work concerning VR applications in architecture, engineering, and construction (AEC) industry and the benefits they provide.

One example of this was British Columbia Hydro Corporation's Life Safety Model (LSM) [4], a VR computer system where users could generate and analyze different dam emergency scenarios. Geographic Information Systems (GIS) and census data were used to provide the necessary means to develop this system.

Hoover Dam: IndustrialVR [5] is a VR serious game that allows its users to explore the Hoover Dam and learn about its components and how they work. An innovative documentary-style approach was used in the development of this application.

Another VR serious game applied in the exploration of the Hoover Dam was VR Hoover Dam [6]. This historically based VR serious game allows its users to explore the Hoover Dam while they learn about its construction and its impact on the population, the economy, and the natural environments.

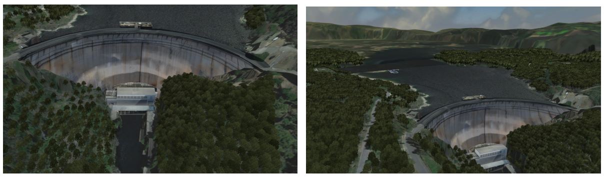
Web-Based Game-Like VR Construction Site Simulator (WWGVRSS) [7] is an interactive and collaborative VR rule-based system. For its development, a Computer-Aided Design (CAD) interface and a web-based VR interface were used to support an online BIM platform for the integration of projects in the AEC industry.

A VR-integrated workflow in BIM-based projects [8] was developed to allow multiple users to collaboratively visualize and analyze a specific BIM model in the same virtual environment.

III. Prototype

VRCabrilAnalysis is a VR application where a specific user can see a representation of the Cabril Dam 1(a) and its surrounding area 1(b). The model contains different types of sensors, which the user can interact with.

978-8-3503-4573-57/22/$31.00 ©2022 IEEE



(a) The model of the Cabril Dam (b) The surrounding area

Fig. 1. The virtual environment of VRCabrilAnalysis

The types of sensors present in VRCabrilAnalysis are geodetic marks, benchmarks, plumblines, the GNSS antenna, the water tower, and accelerometers (either uniaxial or triaxial, as well as the data acquisition units). The sensors become highlighted when the user points to them, with a color that depends on whether or not they have their acquired data present in the application.

The user can select the sensors and teleport to a certain part of the scene. When selecting a certain sensor, an interactive menu appears on top of the controller that was used for that. The interactive menu contains information about the selected sensor. It also contains options for plotting the time evolution of the data acquired by the sensor and displaying additional information about the sensor.

The additional information depends on what type the selected sensor is. If the sensor is an accelerometer, it consists of information about seismic accelerations and about the corresponding earthquake such as its date and epicenter. If the selected sensor is not an accelerometer, the additional information consists of the last recorded values for each attribute the sensor measures, the names of those attributes, and the date and hour when those last values were registered.

The interactive menu automatically disappears when the option for plotting the time evolution of data is selected. It is possible to toggle between the menu being visible or invisible as well as the information tables.

The data charts differ depending on the type of the selected sensor. In case it is an accelerometer, the table contains one line chart, containing the time evolution of the accelerations, which can be the radial, tangential and vertical accelerations.

If the sensor is not an accelerometer, the table contains three line charts, one for the time evolution of the temperature, another for the time evolution of the water elevation, and the other for the time evolution of the displacements. The displacements that can be present in the chart are the radial, tangential and vertical displacements.

The user can interact with the data charts by using the controllers. When the user points to a certain part of a certain line chart, a tooltip appears, displaying the attribute, its value, and the date when that value was recorded.

With the buttons, from the left controller, the user can use the Pan feature by pressing the primary button and Zoom Out by clicking on the secondary button. From the right controller, the user can select a certain interval of data with the Brush feature by pressing the primary button and Zoom In by clicking on the secondary button.

In case a certain line chart has more than one attribute, it contains a legend on top that displays the name of each different variable and which line color represents it. The user can select which attributes he wants to see in the chart by clicking on the legend of that specific variable.

Fig. 2. Interacting with VRCabrilAnalysis.

IV. Future Work

VRCabrilAnalysis has the goal of obtaining results that help in our study. Those results are gathered through user tests. This application was developed as a proof of concept and will be continued with future projects. The results gathered by testing this version of the prototype will also be used to know the necessary adaptations that should be made in the application. The ultimate goal of this project is to have a digital twin of the dam, where it would be possible for multiple users to collaboratively perform the SHM of the Cabril Dam.

Acknowledgment

This work was supported by national funds and the European Social Fund (ESF) through Fundação para a Ciência e a Tecnologia (FCT), under projects UIDB/50021/2020 and PDTC/ECI-ECG/5332/2020 and grant 2021.07266.BD.

References

[1] D. Balageas, C.-P. Fritzen, and A. Guemes, Structural health monitoring. John Wiley & Sons, 2010, vol. 90.

[2] S. Malik, A. Ranjan, and R. Balakrishnan, "Interacting with large displays from a distance with vision-tracked multi-finger gestural input," UIST: Proceedings of the Annual ACM Symposium on User Interface Software and Technology, pp. 43–52, 2005. [Online]. Available: https://books.google.com/books/about/Immersive Analytics.html?id=vaVyDwAAQBAJ

[3] N. Verdelho Trindade, A. Ferreira, and S. Oliveira, "DamAR: Augmented reality in dam safety control," International Journal on Hydropower and Dams, vol. 26, no. 5, pp. 56–62, 2019. [Online]. Available: https://www.hydropower-dams.com/articles/damar-augmented-reality-in-dam-safety-control

[4] H. Assaf and D. Hartford, "A virtual reality approach to public protection and emergency preparedness planning in dam safety analysis," in Proceedings of the Canadian dam association conference, Victoria, 2002. [Online]. Available: https://www.researchgate.net/publication/258513135

[5] Hoover Dam: IndustrialVR on Oculus Rift, https://www.oculus.com/experiences/rift/1297777480332012/

[6] VR Hoover Dam – A Virtual Reality Game Exploring the History and Construction of an American Icon, https://vrhooverdam.com/

[7] J. S. Goulding, F. P. Rahimian, and X. Wang, "Virtual reality-based cloud bim platform for integrated aec projects," Journal of Information Technology in Construction, vol. 19, pp. 308–325, 2014. [Online]. Available: https://strathprints.strath.ac.uk/58018

[8] R. Zaker and E. Coloma, "Virtual reality-integrated workflow in bim-enabled projects collaboration and design review: a case study," Visualization in Engineering, vol. 6, 2018.