Going With The Flow: Using Immersive Analytics to Support Lifetime Predictions of Hydropower Turbines

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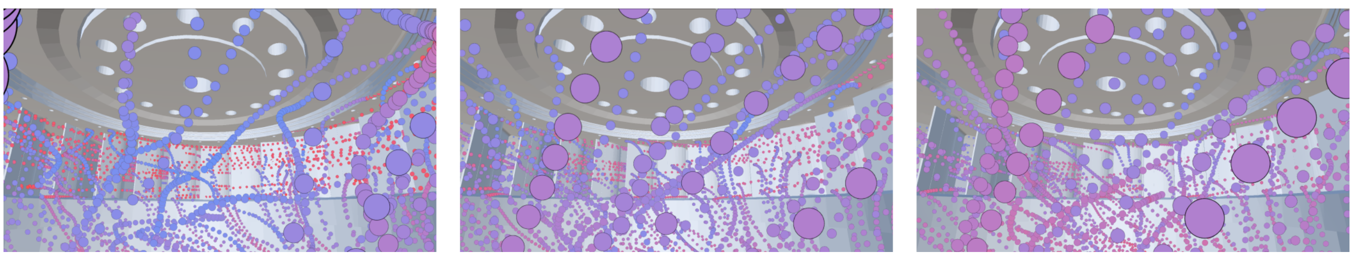

Figure 1: Visualization of flow simulation inside a turbine runner in three different power generation scenarios: 50% P/P_rated, 83% P/P_rated (best efficiency point), and 100% P/P_rated. The color dimension is related to the simulated velocity of each point, red is the highest value and blue the lowest.

KEYWORDS

Virtual Reality, Egocentric Navigation, Data Visualization

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1 INTRODUCTION

The efficiency of power supply chains plays a key role in developing a sustainable future. Currently, many hydroelectric power plants have been in operation for decades and were built for continuous power generation. But today, with the growth of new renewable energy sources, hydroelectric plants are also being used to regulate the grid according to demand, resulting in operating conditions different from those for which the equipment was designed. This can increase the need for repairs and shorten the life cycle of the system.

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The DIGI-Hydro project addresses these issues by combining and comparing simulated and sensor-measured data to enable data-driven predictions of the lifetime of the mechanical parts of hydroelectric power plants [3]. An initial numerical study to establish lifetime standards for hydro turbines on different operating conditions did not produce reliable figures. One problem is that the sensors cannot be placed where the maximum stress occur, and further investigation is needed [2].

Hydropower turbines are large-scale equipment that engineers can rarely examine their internal structure, in this sense, a full-scale immersive visualization setup can clarify some proportion and scale issues. This is also configured in a scenario described by Kraus et al. [4], in which immersive analytics setups can add value to data analysis. For our first prototype, we propose a virtual reality application that combines the spatial data of the 3d model of the turbine plus the position of the sensors and flow simulations visualizations of three different power generation scenarios. The users can navigate through the model in full-scale in flying mode, and toggle flow visualizations for comparisons.

2 METHODS

2.1 First Design Considerations

At first we proposed an augmented reality application to contextualize the data visualizations in a real turbine. To validate this option, we created a draft application to present different immersion possibilities to the experts. In this first design, a 3D model of the turbine runner was presented in a mixed-reality application for Oculus Quest 2, allowing the engineers to choose the level of immersion by changing the background of the visualization from the camera view to a simulated virtual skybox.

2.2 Expert Consultation

We consulted with experts from the Institute of Energy Systems and Thermodynamics at the Vienna University of Technology. They tried the first draft application and were introduced to the concepts of virtual, mixed, and augmented reality. After a discussion, it was decided that the first prototype should be in a virtual reality environment and that the first type of data to be visualized would be the flow data from the simulations along with the 3D model of the entire turbine. A full-scale data representation was chosen because the experts were already visualizing and interacting with the data in desktop applications.

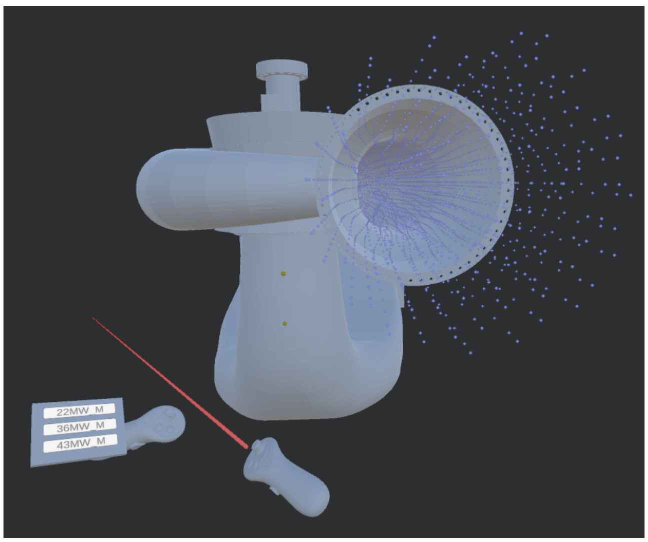

Figure 2: General view of the 3d model of the turbine, the simulated flow data, the controllers for navigation, and the menu to turn the flow visualizations on/off.

3 SYSTEM OVERVIEW

The application was developed in Unity-v.2021.3.4 using the OpenXR Plugin-v1.4.2. The application is designed to run standalone in an Oculus Quest 2, but can also be built for Windows platforms and other head-worn displays (HWD).

For data visualization, we used the Immersive Analytics Toolkit (IATK) developed by Cordeil et al. [1] to load comma-separated value (.csv) files containing the position and velocity of flow points from three different operating scenarios in relative power output, so called rated points (Figure 1). IATK creates 3D visualizations of 1m side size, we adjusted the scale of the flow visualizations to be in the real scale of the 3D model of the turbine and matched the origin of the visualizations with the 3D model. The velocity data was added to the points with a color scale from blue (slowest point) to red (fastest point). We added the positions of the sensors, marked them with spheres, and colored them in yellow so they would stand out in the scene.

3.1 Interaction Design

We used Unity's Interaction Toolkit v.2.4.3 to create the basic interaction framework. A simple function division was created between controllers, the left hand controller is for navigation and holds a simple menu, while the right hand controller is for visualization control.

The users can navigate in "fly mode" using the joystick input and the HWD rotation. There are no colliders in the 3d model or in the data visualizations, this way the user can pass through the model limits and navigate through the data points.

The user can toggle the visualizations of different simulated data using the raycast attached to the right controller, and toggle buttons located in the menu attached to the left controller.

4 FIRST RESULTS AND FUTURE WORK

Initial trials with our prototype show the impact of the full-scale immersive environment for data comparison and analysis. The differences between the three simulated operating conditions are clearly visible and easy to compare. The real scale gives spatial context to the location of the sensors, showing that they are relatively far from the most turbulent areas of the simulations.

For future work we will continue the feedback sessions with the experts to improve the project, add more exploration modes and frame references that have been proved valuable for data exploration [5], and add the data collected by the sensors for comparison. We also plan to conduct a quantitative and qualitative user study with standardized questionnaires and quantitative metrics to investigate the value of full-scale immersive visualizations for data comparison and correlation in large environments.

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