Extending Augmented Sandboxes with Virtual Reality Interaction

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Abstract

Augmented sandboxes are often used as educative tools to create, explore and understand complex models. For the use case of a water cycle simulation, we extend the interaction space of augmented sandboxes into virtual reality to overcome limitations of current systems that include non-interactive 2D projections and shadow problems. We present our ongoing research and the prototypical setup of our VR sandbox consisting of a triple Kinect setup, depth sensing, VR, and hand tracking using Leap Motion. The setup shall help us to explore the space of haptic redirection. Further, we discuss our water cycle simulation use case and interaction scenarios that facilitate VR interaction and visualization.

1 Introduction

With interactive and augmented sandboxes, users can manipulate the physical medium sand with their bare hands, making use of their natural ways of expression while at the same time perceiving an interactive feedback, which is projected onto the sand and changes can be immediately experienced. A considerable body of tangible interaction research explores augmented sandboxes [1–6] and in many cases, sandboxes have been applied to offer a better understanding of spacial and geographical phenomena. Often, the setups use a projector mounted above the sandbox, projecting an image on the surface of the sand and a depth camera to track the sand surface. Using the image projected onto the sand surface, augmented information can be shown. For example, heat map-like colouring of the surface indicates different types of landscape (valleys appear in a green colour, sea level areas are blue and contour lines can be visualized), see Figure 1.

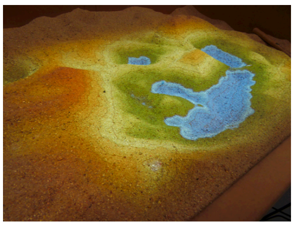

Figure 1 - Example of an augmented sand surface.
Image source: [1]

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However, the projection method has different drawbacks. First, the projected image is merely an output modality for input performed on the sand. Thus, users cannot directly interact with the projection, for example adding further 2D or 3D objects to the image or changing the visual appearance. Second, shadows caused by the hands of the user and unevenness of the sand distorts the projected image. The third limitation is the resolution of the projection. Sand does not offer ideal conditions for projection because the material lacks reflective capabilities in terms of grain size and sand colour. Finally, depth sensors that track from above in many cases produce only a height map, limiting the possible shapes to almost vertical slopes. In our effort to overcome these problems, we present an augmented sandbox that uses VR as an additional visualization and interaction layer, offering extended interaction with virtual objects, while at the same time reducing shadowing issues and increasing visualization capabilities. As our research is still ongoing, besides the presentation of our prototype, we discuss technical challenges that we encountered in the design process and also present interaction use cases that exemplify how augmented sandboxes can benefit from VR capabilities.

Recent research has been investigating how user's actions can be manipulated in VR. These techniques allow to make the user believe the interaction space is larger than it actually is, thereby reducing the required space or number of objects for the interaction. Skewing visual feedback (e.g. by warping the projection matrix of the output images or slightly shifting the the virtual camera), a user's motions can be redirected unconscious [7–9]. Out system should provide a technical foundation to build on existing redirection methods and to explore the redirection of haptic feedback further.

This work contributes to the development of virtual reality augmented interactive sandboxes for learning and exploring complex phenomena. The publication of these late-breaking developments is meant to inform researchers and developers that may currently pursue similar challenges in the booming area of VR.

2 Related Work

Mixed reality and augmented reality sandboxes use depth measurement and projection as a technical foundation. However, the literature is far silent on systems that include VR as a mode for interaction. We focus on sandboxes that are similar from a technical perspective, but differ greatly in the way they are used. In 2002, Piper et al. introduced the *Illuminating Clay* system for the analysis of landscapes in the landscape design process [1]. The setup consists of a clay model that users manipulate, a laser scanner for capturing of depth information, and a projector that closes the feedback loop for visualisation of different landscape analysis functions. The authors point out the simplicity and effectiveness of displaying 3D data directly onto the surface of a 3D model. *Sand Garden* [2] is a game where a digital landscape must be shaped, providing valleys, water, and mountains in order to make the virtual villagers happy. The system uses a projection and a second screen to display the game world. The sand itself is augmented and functions as a controller for the game. An educative use case for augmented sandboxes is presented by Sanchez et al. [3], engaging students to experiment with topographical maps for the exploration of the importance of water, erosion, or mountains in the evolution of the landscape. The advantages are the better understanding of abstract concepts, better involvement, and more efficiently experimentation using a sand model. *Inner Garden* [4] is a tool to support mindfulness practices, which is defined as "the act of playing a deliberate and non-judgmental attention to the present moment" where "positive impact of a person's health and subjective well-being" can be achieved. Users create a miniature world by playing with the sand and the natural elements of the world are connected to physiological measurements like respiration, helping to stay focused on the body. This system also offers a VR mode where users can explore their creation virtually. Another interesting use case has been developed by Audi [10] where users can form their own racing track in a sandbox. This race track is then imported in a driving simulator, offering direct perception of the user's creation by driving through the digital model. However, no direct interaction with the sand in VR is supported.

3 Virtual Reality Sandbox System

In this section we give an overview of our intermediate setup of the VR sandbox and discuss some central properties as well as technical challenges of the system.

Hardware Design. The sandbox has a volume of 140 x 80 x 30 cm. The ground and the inner walls are covered with pond foil. This size provides a good balance for single user as well as for collaborative scenarios in the future. For tracking, three Kinects v1 are mounted on a railing at a height of 120 cm above the sand surface. The tracking volume is captured from three angles of an isosceles triangle, by that reconstructing a full 3D point cloud of the sand model. For virtual reality, a HTC Vive [11] is used, also opening the opportunity to track additional objects. A Leap Motion [12] sensor, mounted to the HMD, provides information about the user's hand and arm positions. Besides rendering for an enhanced immersion, the volume occupied by the hands is subtracted from the depth data coming from the Kinect sensors. The application runs on a Windows 10 System with an Intel i7 3,4 GHz and 16 GB of RAM. The full setup is shown in Figure 2.

Figure 2 - Early prototype of the VR sandbox

Software Design. We chose Unity3D as our core engine. To generate the tracked volume, the voxel engine Cubiquity [13] is used. Before construction, a 3D model of the sandbox was designed. To match the positions of the real and the virtual sandbox, all components need to be calibrated precisely. We calibrate the position of the sandbox relative to the Vive tracking system by placing a Vive controller on the sandbox, so the virtual representation of the interaction environment matches. To fuse the Kinect sensors, the relative orientation of each depth camera was computed using OpenCV [14, 15]. In the next step, the point cloud data is generated using the Kinect Fusion toolkit [16]. After the fusion, hand data from the leap motion device are subtracted from the tracked point cloud. Finally, the points are fed into the voxel engine and rendered. Figure 3 gives an overview of the incorporated modules.

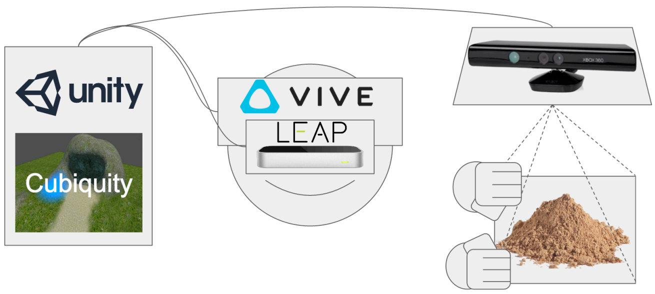

Figure 3 - System component overview

4 Application Scenario: Water Cycle Simulation

As our application scenario, we present an explorative environment for learning about the hydrological water cycle of the Earth. Playing with the sand, users can explore cause and effects of different parameters and their impact on the simulation. With this use case, we aim to understand how a VR sandbox can contribute to an immersive, interactive, and informative experience. As our implementation of the water cycle simulation is still in progress, we lay out how the simulation will function and how users can interact with the model. As climate and weather simulations tend to be very complex and hard to understand for users without prior explanation, we decided to reduce the complexity of our simulation to only a few variables. We base our simulation on the following environmental parameters: three pressure zones, average annual temperature (depends on latitude and elevation), temperature range (latitude and distance to coast line), and a simple wind model [17][18]. Regarding the water cycle, we implement evaporation of liquid water into the atmosphere, condensation and precipitation using simple approximations. In the following, we introduce use cases to illustrate how the interaction with the simulation and the sand can look like with our prototype.

Interaction with virtual and tangible objects. When interacting with the sand, currently, users are only able to form the sand structure, but lack the ability to change further aspects of the environment. For example, in a water cycle simulation, wind plays an important role. For this, we plan to explore how tangibles that are tracked either by visual markers or by the VR setup and merely virtual assets, only visible in the VR scene, can be used for an extended interaction. In the wind example, virtual wind turbines could be placed directly in the scene, offering new and interesting water movements. Further, the sun could be replaced, making it easy to explore the dependency of this factor on the simulation. Tangible objects that can be placed on the real sand can introduce similar aspects, but offering a haptic component. Further scenarios could include the introduction of wind or weather barriers by placing two objects, air pollution emitters to observe how particles are distributed in the world, civilization artefacts that change the climate behaviour, or springs for the creation of rivers.

Dynamic UI - Everything is a button. With the VR approach, it is possible to assign functionality to certain areas of the sand surface, so that users can model and layout UI elements with the sand.

Interactive exploration. When playing with the sand, users constantly change the environmental conditions. For a better understanding of what causes certain effects, users can zoom into their model in VR, exploring what happens below the surface. It is also possible to add and stack layers of information to the virtual model so that additional information can be visualized, for example surface temperature, wind movements, or the distribution of climate zones.

5 Conclusion

We presented our ongoing research on VR sandboxes. We provided an overview of our water cycle simulation, technical challenges of our prototype, and addressed limitations of the discussed systems. Our multi sensor setup allows tracking of full volumetric shapes of the sand surface for tactile 3D interaction. Adding VR to sandboxes extends the interaction with virtual content, allowing richer models and further application areas like sculpting, design, rapid prototyping, maker culture, previsualisation for creative industries, or contextual 3D modelling. In future work, we aim to understand how the distinct haptic and visual perception of users can be used for redirected haptics [7–9] so that redo and undo tools can be implemented, how gains in touch perception can be applied for interaction and how far redirection can be facilitated [8]. Further, how do users perceive interaction with real material while output is virtual, how can real tools be combined with a virtual environment, and how tracking of small objects can be accomplished.

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