Expansion of the Augmented Reality Sandbox to Include Additional Water Sources for Guided Educational Experiences

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Abstract

Augmented Reality sandboxes can be found in schools and museums across the world teaching users about topography, runoff, and other topics. They use physical sand, a projector, a depth camera (to sense the topography in the sand), and a computer (to calculate the responsive topographic height map and waterflow). The sandboxes provide a mixed reality experience as the users manipulate the sand but view simulated water. Traditionally water can be added as rain to the whole terrain, via the keyboard, or in a specific area, via a hand gesture. After observing many hours of sandbox use, both facilitated by educators and free play by students, the need for additional water sources was evident. In this work, an adjustable strength point source as well as continuous waves and single waves were developed to extend the educational applicability of the sandbox. These features enable guided exploration of a wide range of hydrology applications.

Keywords

Educational technology, Augmented reality sandbox, Hydrology, Wave motion

Introduction

The Augmented Reality (AR) sandbox combines actual sand with a depth camera and projector to create an interactive experience. The most widley used open-source augmented reality sandbox was created around 2016 by researchers at University of California, Davis (UC Davis) and other partners under a National Science Foundation grant.[1,2] The common components paired with ready to compile software has resulted in thousands of the sandboxes being built for schools, museums, researchers, and other groups around the world. Users modify the sand surface, the computer calculates the contour lines of the topographical map, and projects them onto the surface. A hand gesture or keyboard command adds water to the terrain as rain either over the entire topography or to a local region. A numerical simulation of the waterflow on the topography is projected onto the surface with a water-like visual treatment.

The custom software performing the simulation uses the second-order strong stability preserving Runge-Kutta temporal integration scheme with a second order positivity preserving central-upwind scheme.[3] The simulation assumes a 1:100 scale and utilizes graphical processing unit (GPU) processors to parallelize the algorithm and achieve real-time simulations. The sandbox platform has been the foundation for many commercial, research, and educational extensions. Some, like the simulation of volcanoes, require just a few modifications to the existing solver and visual treatments. The open source nature of the software allows for easy distribution and adoption of new features such as snow.[4] Commercial products, such as SimBox,[5] have simulation capabilities including wildland fire training, agent based modeling, and defense applications. These algorithms are not open source.

After observing many hours of sandbox use, both facilitated by educators and free play by students, the need for additional water sources was evident. In this work, an adjustable strength point source as well as continuous waves and single waves were developed to extend the educational applicability of the sandbox.

Water Sources

The AR sandbox allows local and global rain as the only mechanism for adding simulated water to the scene. Water exits the simulation at the physical boundaries as well as through absorption into ground. The absorption rate and rain strength are both configurable. The new water sources are controlled through a configuration file. This enables a user or facilitator to initiate or modify the water sources without restarting the sandbox software. This is especially useful for initiating tidal waves.

Point Source

The point source has a fixed position in the the lower right corner of the table. The strength of the source is controlled by the height of sand surface. The source is strongest when the sand height at the source location is at or below the water table elevation. This is indicated by the blue elevation contours. Increasing the sand height at the source location will reduce the strength of the source and can completely stop or block the source. At the default strength, the water generated can be balanced by the water exiting the simulation to create a steady stream or river that doesn't overflow the banks. Figure 1 shows the water strength for two different elevations of sand at the source location.

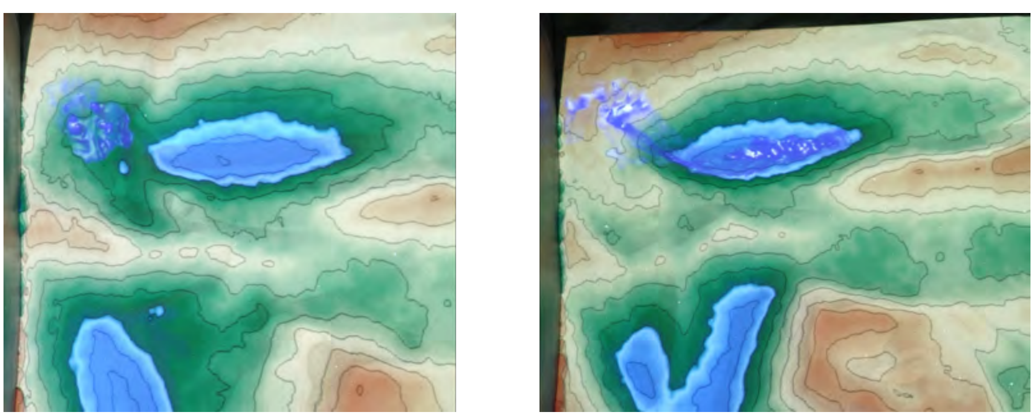

Figure 1: Point source: Lower bathymetry resulting in a strong water source (left), higher bathymetry resulting in a weaker source (right)

The main objective of the point source is to allow users to explore the shaping and routing of the water bodies. A facilitator may demonstrate meandering rivers, erosion, river rise due to runoff, and water diversion using the new capability.

Continual Waves

Modeling waves in oceans, lakes, and even water tanks is much more complex than it initially appears. In oceans, there are not only local factors such as bottom topography, wind, and man-made objects (such as barrier walls, piers, etc) but also the planetary forces. High fidelity computational models of wave behavior have been conducted for decades.[6] Realistic visualization of water bodies with waves are a focus of computer graphics research as well.[7]

In this work, the focus is to generated a continuous wave water source within the AR sandbox. The limitation of a single visual texture to convey water depth and water motion required the implementation of a simple but configurable wave model. The sandtable visualization uses a random component to create the impression of movement and small surface wave interactions.[8]

The new wave sources are modeled as sinusoids with user-controlled factors for both the maximum strength and the period of wave, Figure 2. Note that the wave form contains both positive and negative amplitudes with a center point of zero. The model does not include spatial variation of the wave, so the effect is similar to the plunger initiated waves in wave exhibits in aquariums and museums.

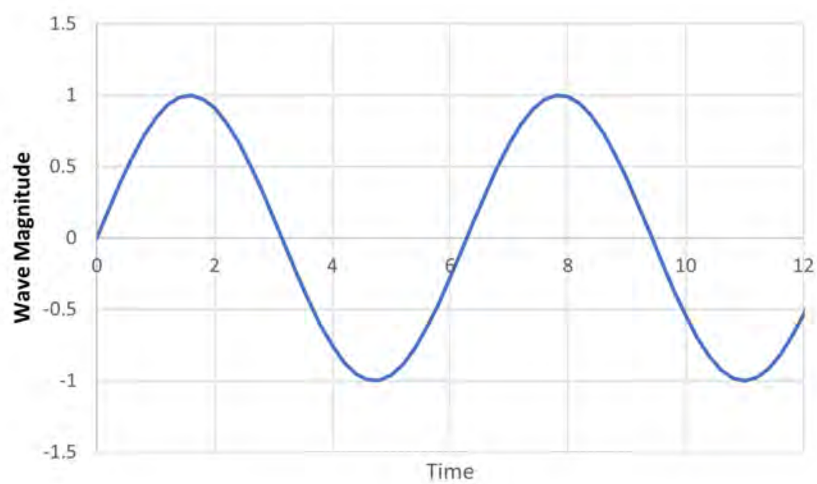

Figure 2: Driving function for continuous wave.

The wave is created by the addition of water with a specified velocity vector into the table. During the negative phase, a negative gradient is created but not all of the added water is removed from the table. This means that after the wave source is turned on, the total volume of water in the table increases. This allows modeling of sea-level rise as well as the influences of different terrain elements on the water motion. The negative phase assists in creating a visual wave front in the simulated water and slows the accumulation of water.

Figure 3 shows an image of the simulated wave after the capability has been running for a approximate two minutes. The dark blue is the crest of the wave. The nearly white band is the trough created by the negative amplitude portion of the sinusoid. The figure also shows that the although the wave is created as a uniform column of water, it is impacted by the sand topography to create multiple interacting wave fronts, labeled interaction.

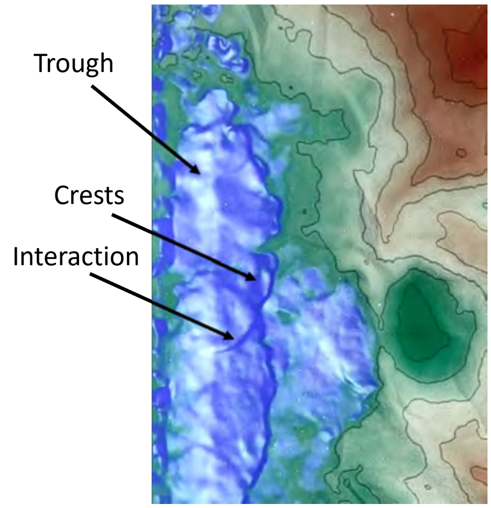

Figure 3: Components of wave visualization.

Figure 4 shows simulation at three points in time. The initial image (left) shows the water not fully covering the flat portion of the terrain and the source location becoming completely dry during the negative phase. The middle image shows a time at which more water has accumulated on the terrain and both the trough and crest portions of a wave are visible. The final image shows the water spilling into the future tidal pool as well as two active waves.

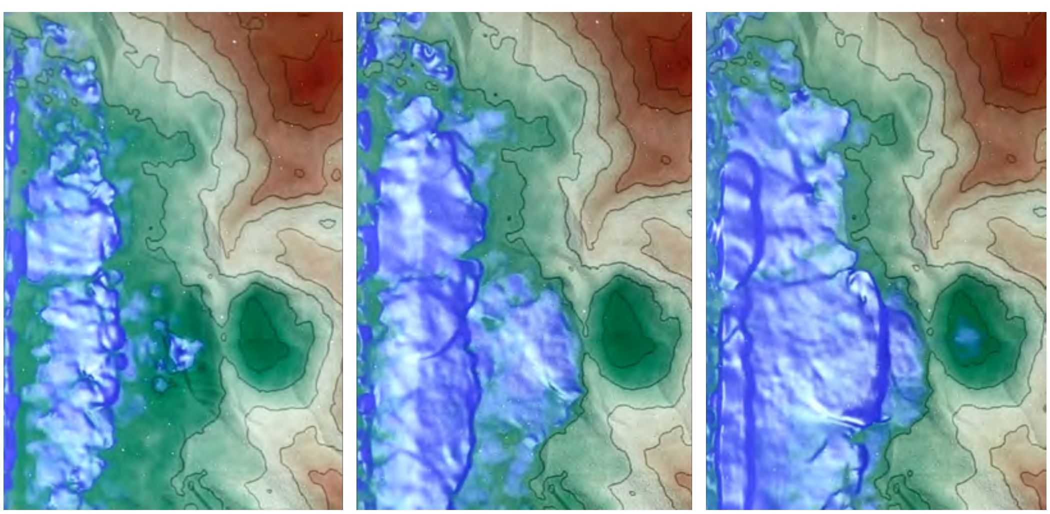

Figure 4: Time progression of continuous wave motion.

Single Wave

The single wave capability is implemented as a step function of water with a velocity into the table. The user can initiate these waves through the configuration file but not control their attributes. The intent of this wave is to model tsunami like events. The combination of the sand surface and the tsunami wave allow the study of terrain impact on the wave propagation. The after effects of the wave, such as water collecting in low lying areas behind barrier terrain, is easily modeled and discussed with the simulation. The following series of images shows the wave as it enters the table (Figure 5), at a position halfway across the table (Figure 6), and just after it has reached the end of the table (Figure 7).

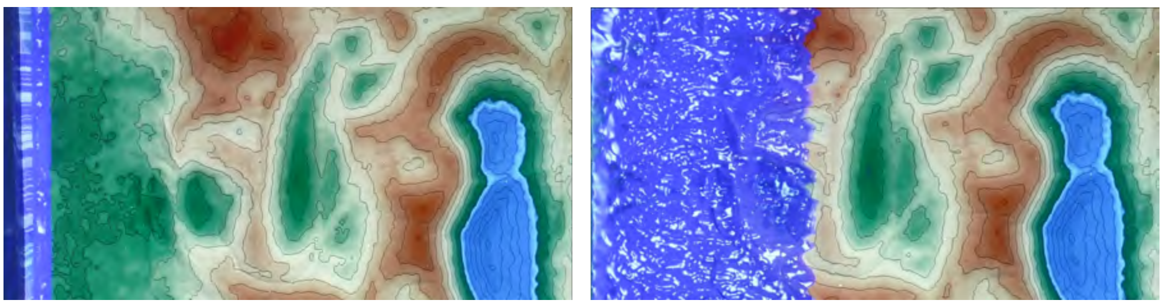

Figure 5: Single wave entering table from the left and moving right.

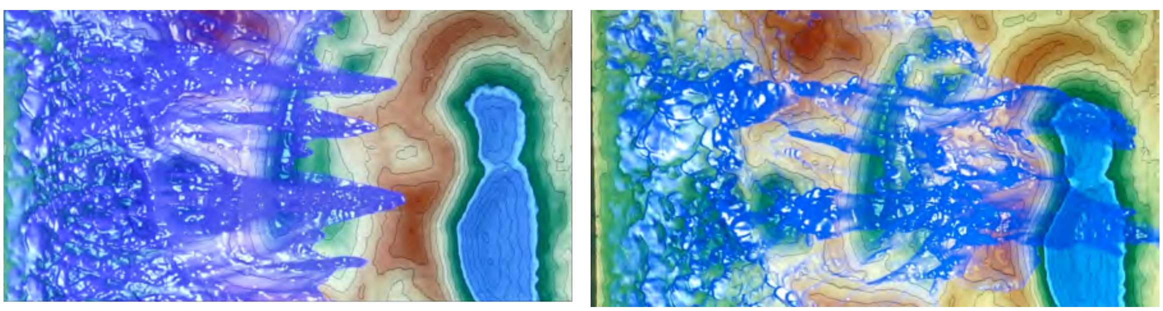

Figure 6: Evidence of terrain influencing wave progression.

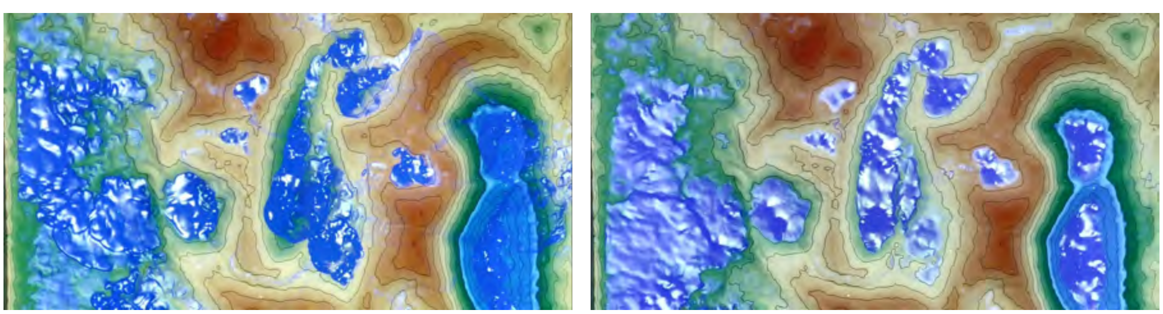

Figure 7: Sand table after wave has subsided, including water in low lying topographies.

Conclusion

The extension of the AR sandbox code developed by this research is open source and available for use or modification by the user community. The code, user-information, and images of expected results is all provided on GitHub: https://github.com/esmit248/ARSandbox_Snow. The three new water sources allow table users and facilitators to create water sources to demonstrate a large number of additional educational topics and provide a hands-on learning experience. These include storm surges and barrier islands through the use of the wave simulations and the effects of topography on river formation with the point source. Extending the usability and value of existing AR sandboxes based on the UC Davis code base.

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Dr. Elizabeth Smith, P.E.

Dr. Smith is an assistant professor in the Mechanical Engineering Technology program at the University of North Carolina at Charlotte. Prior to joining the Engineering Technology and Construction Management department, she spent 15 years in research and development performing on numerous Department of Defense (DoD) projects. She also holds a Professional Engineering License in the state of North Carolina. Dr. Smith's current research focuses on the development of tools for education including extending the capabilities of the Augmented Reality Sandbox as well as further development and validation of of an open-source human physiology engine (BioGears).

Tyler Ainsworth

Ms. Ainsworth is a PhD student in Mechanical Engineering at the University of North Carolina at Charlotte (UNCC). She is an active student ambassador of the College of Engineering at UNCC and a member of the Society of Women Engineers and the Society of Manufacturing Engineers. Ms. Ainsworth is currently working on research in the areas of augmented reality for educational applications as well as bioengineering with a focus on mechanical systems.