Snowmelt Simulations in an Augmented Reality Sandbox: A Hands-On Learning Experience

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Abstract

Augmented Reality(AR) sandboxes, composed of a sand surface, a projector, and a depth sensor, have been used in education and outreach since their creation in 2014. These sandboxes measure the sand topography, calculate a responsive topographic height map, and project it onto the sand. AR sandboxes can be found in schools and museums across the world being used to teach people geologic concepts. Snowmelt runoff is a complex geologic topic taught in higher education civil engineering classes. This phenomenon impacts portions of the population via water availability and flooding events. By integrating a snowmelt simulation into the AR sandbox framework, educators can introduce snowmelt and related topics, such as freeze-lines and snow-based reservoirs. Along with the simulation, a set of educational guides was created for use in guided-learning experiences. This work shows how an AR sandbox with a snowmelt simulation can be used to demonstrate these concepts.

Keywords

Augmented Reality, Educational technology, Snowmelt runoff

Introduction

In some parts of the United States, snowmelt runoff accounts for up to 75% of the water supply.[1] Snowmelt runoff is runoff that occurs when a buildup of snow, a snowpack, melts. Engineers and scientists simulate snowmelt runoff to better predict its effect on the environment and ecosystem. These effects include flooding,[2] changes to streamflow,[3] and availability of water resources for agriculture.[4]

Typically, snowmelt is taught within the hydrology curriculum in higher education. However, the basic principles are taught earlier. In kindergarten through high school, the curriculum generally focuses on why ice melts and the water cycle then advances to runoff and erosion.

In recent years, schools have been acquiring new tools and equipment for use in the classroom. One of these tools is the Augmented Reality (AR) sandbox. Originally designed in 2014 by University of California, Davis (UC Davis) under National Science Foundation (NSF) funding, the goal of the project was to "raise public awareness and increase understanding and stewardship of freshwater lake ecosystems and earth science processes. . . ".[5] Additionally, studies have been done on the uses and benefits of an AR sandbox in the classroom. These include improvements in student engagement and spatial thinking skills.[6,7]

In the design by UC Davis, users can manipulate sand within the sandbox to create a desired landscape that is sensed by an XBox Kinect sensor. The depth data is processed to create a colored topographic map of the sandscape. This map is projected back onto the sand and updated as users further modify the sand topography, Figure 1. Users can also trigger simulated rainfall in the created landscape through hand gestures or keyboard commands.

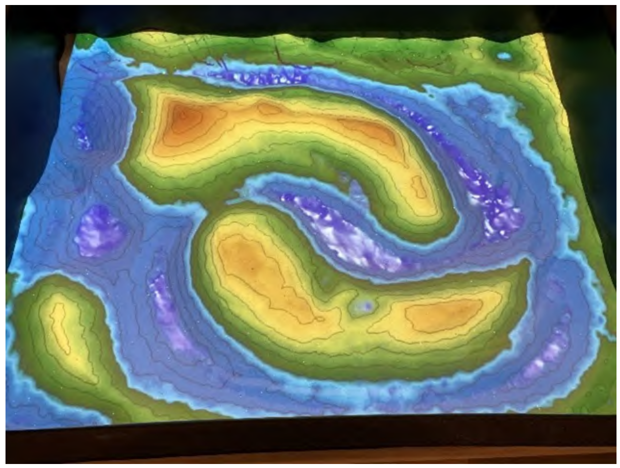

Figure 1: Contour map and simulated water projected on sand surface.

While AR sandboxes are becoming more widely used for education, in museums as well as schools, the base use case of simulating runoff remains largely unchanged. The creation of a simulated snowpack and simulated snowmelt runoff expands the use of an AR sandbox as a hands-on method of teaching these concepts. This paper details the process through which a snowpack and snowmelt simulation was developed and implemented into the existing AR sandbox code. It also includes a list of topics that can be demonstrated with the new model as well as a link to guided learning material.

Methodology

Snowmelt simulations vary from hand calculated degree day based methods[8] to high-fidelity calculations that can take many hours to run.[8,9] In order to retain the AR sandbox's real-time simulation, only the data available in the AR sandbox was used. The model presented here is based on the snow line, and the transient nature of snowmelt.

Figure 2 introduces the terminology used in the modeling. B is the bathymetry, or sand height at any given point. The water height is represented by h and the combined height w is the bathymetry and water height. The existing shallow-water algorithm[10] uses the slope computed from the bathymetry and gravity to move the simulated water downhill and create simple wave motion.

The snow line in this model is called critical height and can be modified at anytime by the user. Any existing or new precipitation above the critical height will be accumulated and visualized as snow. Any precipitation below the critical height will remain liquid water.

The conservation of water mass in the calculation was an important element of the melting model.

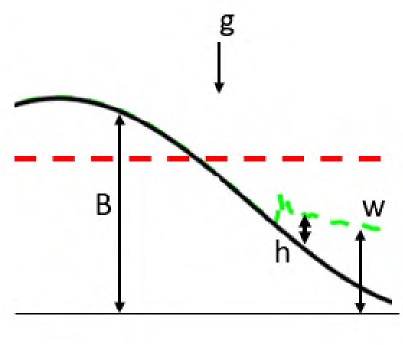

Figure 2: Terminology used in AR sandbox models.

In this model, the snow melts as a percentage of the existing snow at a given location. This means that more snow melts in early timesteps than in later ones. However, the large initial amounts are used to create a visual cue that melting is occurring and draw the users attention to that portion of the sandscape. To prevent needless calculation of infinitesimal amounts of snow, a minimum snow limit was implemented. During the melting process, if the remaining snow is less than the limit then the snow quantity is set to zero.

The final modeling consideration was to select an initial velocity for the melting snow. To maintain consistency with the initial velocity of the precipitation, a value of zero was selected. All water motion results from gravity moving water down-slope.

Implementation

The AR sandbox was designed as an open source tool for schools, museums, and research groups to build for their own use. To do this, the system uses off-the-shelf, relatively inexpensive components. A standard desktop computer outfitted with a higher-end graphics card is used for all calculations. The alternative would be a high-end computer or access to a multi-processor server to achieve the real time simulation. The system uses Graphical Processing Unit (GPU) computing which leverages the computing power of the graphics card to do the math needed for the water flow simulations and to create the multi-component images that are projected onto the sand.

A shader (function run on the graphics card) was written to convert the state of water at each location. The elevation of the sand relative to the critical height is used to freeze the water into snow or melt existing snow. This information is used by a separate shader to create the image projected on the sand surface.

Visualization

The AR sandbox creates the projected image (which includes the topography, water, and snow) using shaders as well. In the case of the water and snow, the shader checks the amount of precipitation in an area and adjusts the color accordingly.

The colors are coded in the sandbox using the Vector4 (vec4) format, a four component color datatype where the components are red-green-blue-alpha. The water color in the original code is created using a noise component that gives the appearance of ripples and motion over the blue base color.[11] The noise is based on the amount of water at the given location.

For the snow texture, the same technique is used. The snow texture uses a white base color with blue noise based on the height of the topography. This results in the snow texture being white with patches of light blue. Unlike the water, the noise patches don't move unless the user modifies the sand surface. The snow and water textures can be seen in Figure 3.

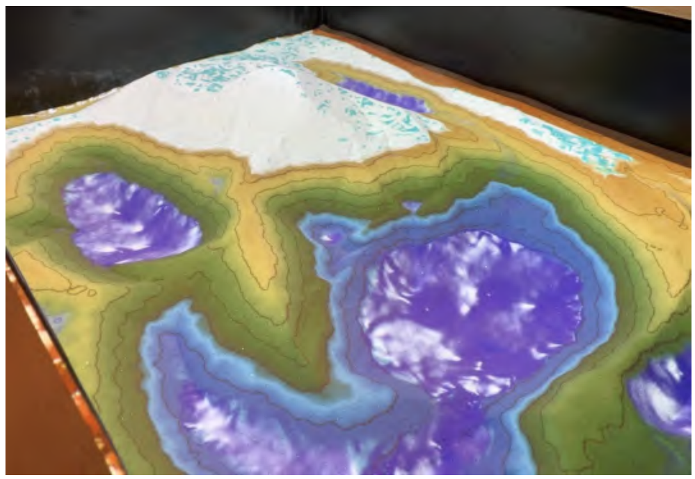

Figure 3: Snow and water colors as seen in the sandbox.

This color combination was chosen to be similar to the natural colors found in snow and ice. Opacity is used to show the amount of snow in an area as it accumulates or melts. The more transparent the color becomes the less snow there is in the area.

User Interface

A file monitor (which automatically checks to see if the file has changed) attached to a configuration file '`snowConfig.cfg`' was implemented to allow the facilitator to control the critical height and melt rate without interrupting the users experience. Due to the main screen being the sand projection, a second screen is needed to display the terminal window and a text window with the snow configuration file. The '`snowConfig.cfg`' file includes comments that describes the two variables included and outputs the initial value to the terminal window on sandbox start-up and when the configuration file is saved.

Results

This work resulted in the creation of a working snowpack and snowmelt simulation for use in augmented reality sandboxes and resources for guided-learning experiences. The model can be added to any existing AR sandbox that was based on the UC Davis code. Care was taken to extensively document the new capability and the steps to implement it. Resources were created to show possible options for educational displays that can be used to alongside the new simulation.[11] The following sections describe the usage and results of the snowmelt capability.

Adding snow to the sandbox

Figure 4 shows the sandbox before and after precipitation. Precipitation is initiated using either the keyboard key for the global 'rain' function or the rain hand gesture. The critical height used in this case is 3.5. The blue contours begin at zero and represent the water table. Critical height is measure with respect to the water table line with positive values being above the water table and negative values below it. Precipitation landing at elevations above the critical height are visualized as snow and have not velocity. Precipitation landing at elevations below the critical height remain liquid water and run down-slope to create pools or leave the sandbox along the edges.

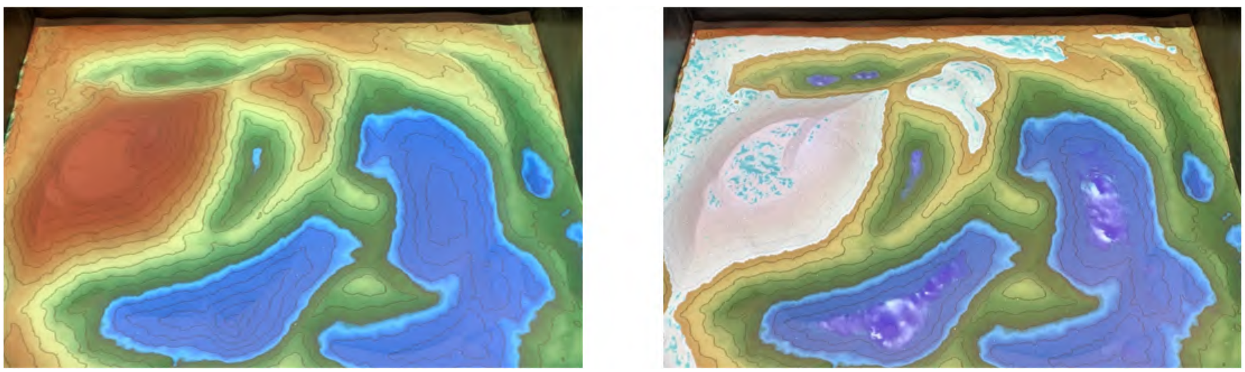

Figure 4: AR sandbox before precipitation (left) and after precipitation (right).

Melting the snow

While there is snow in the sandbox, the critical height can be changed in the configuration file to melt the snow. Figure 5 displays the melting behavior in four stages. The critical height starts at 3.5 and is adjusted to 7.5 in order to melt the snow that exists in the region between 3.5 and 7.5. As the snow melts the transparency of the snow increases with time. In images (b) and (c) the simulated water can be seen running down-slope from the melting snowpack. In the final picture (d) the water level of the "lake" in the lower right of the image is higher as a result of the snowmelt runoff.

Exploration Topics

AR sandboxes are used in structured settings like classrooms and field trips as well as informal educational settings like museums, school open-houses, and STEM day events. To aid both educators and informal users, posters with guiding questions and information are often posted near the AR sandbox. The developed snowmelt and snowpack simulation supports many new educational topics that are adaptable to different age groups.

- Freeze-Line - Explanation of the relationship between temperature and elevation. Snow

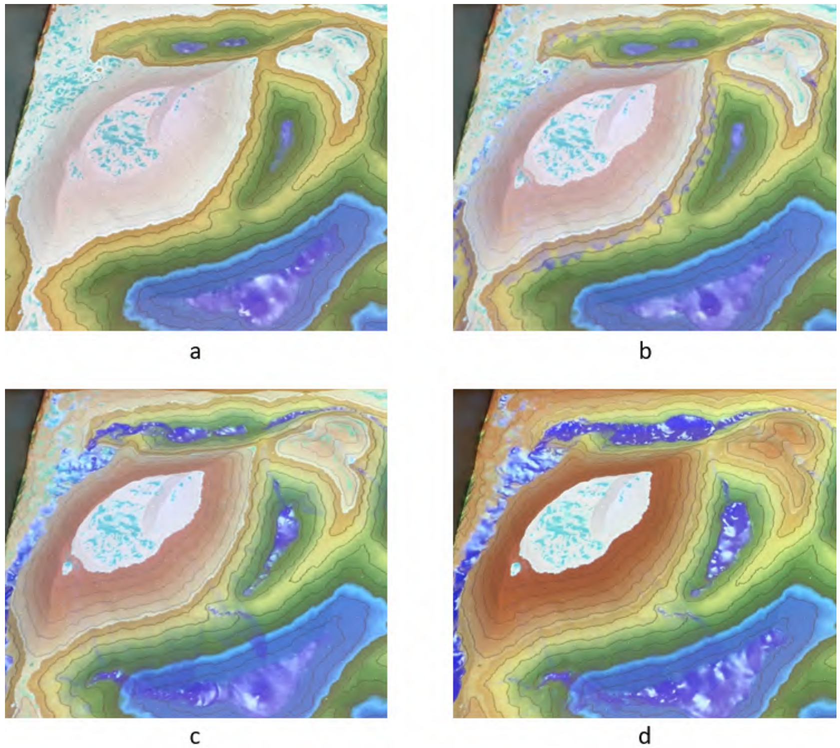

Figure 5: Snowmelt displayed in four stages. a: Starting height, b and c: Two stages of melting in progress, d: Fully melted at new height.

freeze above the critical height but not below it.

- Flooding - Once melting is initiated, flooding can be observed in the sandbox. The impact of local geology (slope, water table, etc.) on runoff can be discussed.
- Cyclical Water Resources - Observing river height when students initiate precipitation with and without the critical height allows them to understand that the frozen water isn't immediately available for use. Once melting is initiated, the resulting snowmelt displays the potential of too much water being available.
- Climate Change[12] - Modification of the critical height can show the effect of warmer climate and glacier melting. This can also be used to discuss lack of spring water sources if less snowpack accumulates.
- Water Absorption - The sandbox absorbs water at a user configurable rate. Snow is not absorbed by the soil.

Conclusion

AR sandboxes are useful hands-on tools that can be utilized in both research and education. The base code developed by UC Davis was designed to be able to teach geographical concepts such as watersheds and runoff. The expansion of the AR sandbox code to include a simulated snowpack and snowmelt runoff allows for both concepts to be introduced to a younger audience. The modifications to the base code were contained to the minimum amount of files necessary in order to be easily implemented into existing AR sandboxes in the open source community.

Educational resources were made as supplemental material for the snowpack and snowmelt simulation. These can be used as part of a hands-on display to demonstrate guiding questions for users to consider. The resources along with all of the code created for the snowpack and snowmelt simulation is available online on GitHub at https://github.com/esmit248/ARSandbox_Snow. This continues the open source precedent of the AR sandbox and allows others in the community to use, and potentially build upon, the new model.

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