ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

AR Sandbox

Team #3

HAOZE GAO (haozeg2@illinois.edu)
HAOWEN ZHENG
(haowenz5@illinois.edu)
QIRAN PAN (qiranp2@illinois.edu)
YIHENG ZHANG
(yihengz5@illinois.edu)

Advisor: Timothy Lee

February 27, 2024

Contents

1 Introduction

1.1 Problem Statement

We are introducing a smart sandbox with augmented reality (AR) capabilities that projects contour maps in real-time onto the sand surface, making geography education for children not only informative but also significantly more enjoyable. However, currently available educational sandboxes are mostly cumbersome and limited to public spaces like activity centers rather than serving as personalized learning tools.

Furthermore, the existing AR projectors designed for sandboxes exhibit primitive features, characterized by a notably low refresh rate and harsh direct light. We are committed to addressing these drawbacks and are working towards the development of a new and improved AR sandbox. This innovative solution aims to overcome the limitations of bulkiness, offering a more accessible and personal learning experience. Additionally, we are focused on enhancing the AR functionality to deliver a smoother experience with higher refresh rates and reduced glare, ensuring a more comfortable and engaging educational tool for children.

1.2 Solution Overview

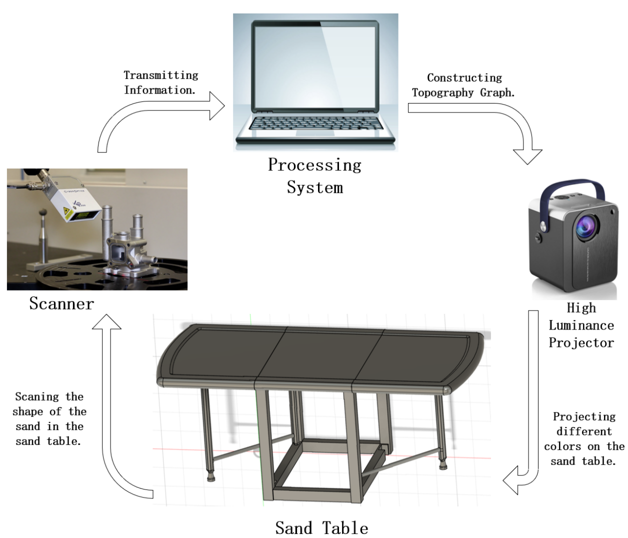

Figure 1: Visual Aid for AR Sandbox Project

We would develop a next-generation sandbox with AR projection and interaction capabilities. In comparison to the popular versions available in the market, our AR projector is set to achieve a higher refresh rate, easier control without external touch screen, and the overall structure will be designed to be foldable while ensuring both high load-bearing capacity and stability.

1.3 High-Level Requirements

- The AR module must have a refresh rate of projected topography of at least 30 Hz and low latency.
- The AR module must be able to correctly exclude human hands from the height change of sand.
- The AR module must be easy to use, pushing one button to start and interact with people only through the projected screen.
- The sandbox must be portable and foldable for easy transportation and storage.
- The AR module must be able to adapt to different kinds of sand and sand table.

2 Design

2.1 Subsystem Overview

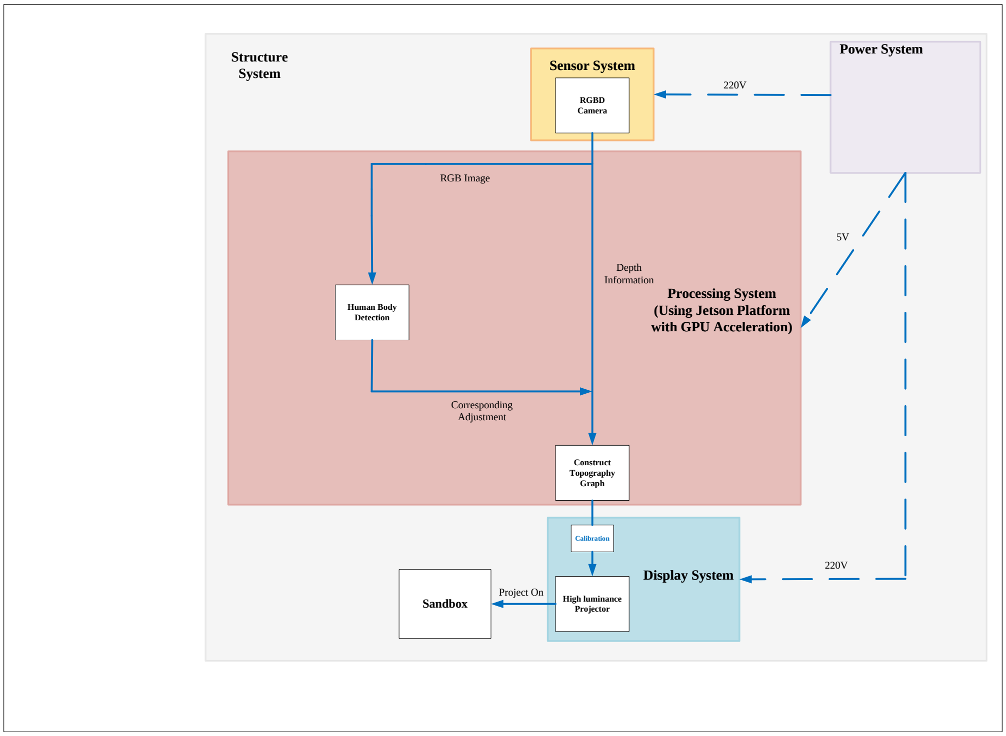

Figure 2: Block Diagram for AR Sandbox Project

2.1.1 Sensor Subsystem

The sensor subsystem must be able to provide depth information with higher than $30\,\text{fps}$ refresh rate. The height information should have at least 1cm resolution with tolerance of at least $0.5\,\text{cm}$. It communicates with the processing unit through USB protocal.

- RGBD camera and associated software for acquiring RGB image and processing depth information.
- Considering the budgets, we may consider using a binocular vision camera as our depth sensor and try to increase the accuracy of depth information with additional textures projected on sand surface.

2.1.2 Processing Subsystem

With the use of GPU acceleration on Jetson Nano platform, it sends the correct topography graph to the display subsystem based on height information from sensor subsystem.

- Human body detection is necessary to overcome the interference from human hands and head. With this to enable multi-user collaboration. The projector should be capable of accurately projecting contour maps onto the sandbox with more than 1 people playing with sand.

- Real-time topography rendering constructs topography map from depth information with GPU acceleration. The refresh rate should be higher than 30 fps. To verify the correctness of the projected contour maps, we will artificially create distinctive landforms such as ridges, valleys, and saddles, and compare them with the projected contour maps to ensure accurate alignment.

2.1.3 Display Subsystem

Display subsystem projects real-time topography information onto the sand. It must align with the edges of the sandbox and clearly display to users under normal indoor lighting conditions.

- High luminance projector: To display on sand requires high luminance projector and associated calibration software, which needs to track for projected image alignment with the sandbox.
- Displaying on sand requires high luminance projector and associated calibration software,which needs to track for projected image alignment with the sandbox.

2.1.4 Structure Subsystem

This is the mechanical structure design subsystem that holds all components together.

- The sand table should be made of materials and designs with sufficient strength to carry sand and prevent people from damaging the wall of the sand table when in use.
- The sand table will be foldable, which will reduce the volume and facilitate carrying and storage.
- The sand table can be separated from the sand while folding, which will make the sand table more conducive to cleaning, increasing durability, and conducive to rapid deployment in different use scenarios.
- We will add an additional vibration device so that the sand surface can be quickly restored to level when necessary.

2.1.5 Powering Subsystem

The powering subsystem is responsible for providing power to the sensor, processing, and projection subsystems. The powering subsystem should be able to provide power to the sensor, processing, and projection subsystems with sufficient power and voltage. The powering subsystem should be able to provide power to the sensor, processing, and projection subsystems with high reliability and high safety.

The Kinect sensor and projector take 220 V AC power, while the processing unit takes 5 V DC power. We have a 220 V to 5 V power converter which is verified that can safely convert the 220 V AC power to 5 V DC power and provide 20 W at maximum for the processing unit. The Jetson Nano takes 5 V DC power and 2 A current at maximum. The power consumption of it is within the power supply's capacity.

We will use a power strip with fuse protection to connect the Kinect sensor, projector and processing unit to one plug.

2.2 Tolerance Analysis

The key component of our design is the speed of real-time topography rendering considering the interference of users' heads and hands. As we aim to reach a refresh rate of at least 30 Hz with low latency, the processing time of each topography frame should be less than $1000/30 = 33.3\,\mathrm{ms}$. With human body detection and hand gesture detection, the processing subsystem needs to have fast enough algorithm and hardware computation power that finish the computation of each frame within 33.3 ms. But as the resolution of RGB and depth image would not be very high, around 1280*720 would be enough, when designing a sandbox for 2 or 3 kids to use in normal conditions. Thus, we think the risk would be justified by the actual amount of data we need to process.

The refresh rate of our projector is highly depend pre-processing procedure on the receiving side. Our depth data is received in the form of 8 bits, and raw data goes into Jetson Nano. The Jetson Nano has 4 GB of 64-bit LPDDR4 memory, which is more than enough for pre-processing depth information from 8-bit binary inputs and for drawing projected images with resolutions up to 1920*1080. For 8-bit binary depth information processing, we will firstly use `median_filter` to remove `salt_and_pepper` noise, the processing time is 280.56 ms for a 512*512 test image, and secondly, we need to blur the input depth information in order to make it easier to colorize in the next step. We choose the simple Dehaze algorithm and the processing takes 1.0827 s.

3 Ethics and Safety

3.1 Ethical Issues

High luminance projector would be energy-consuming. It is possible that the user forget to turn of the AR sandbox after use. This would bring potential environmental issue. As stated in ACM code of Ethics and Professional Conduct, ”human well-being requires a safe natural environment. Therefore, computing professionals should promote environmental sustainability both locally and globally”[1]. In order to achieve this goal, we would explore ways to lower the power consumption during use and automatically detect the leave of users.

Also, consider the fact that people with different skin colors may have different reflection rates, the depth camera may not work well for people with dark skin. This would be a potential ethical issue and we need to consider seriously, as mentioned in IEEE Code of Ethics that ”to treat all persons fairly and with respect, and to not engage in discrimination based on characteristics such as race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression”[2]. We would consider adding more light sources to make the reflection more uniform.

3.2 Safety Concerns

There are a list of safety concerns towards our project:

- Falls: the sand in the box could be heavy. The structure needs to withstand the weight of sand and consider users leaning on it.
- High luminance light: the projector would be high luminance to display clearly on sand considering sand as a diffuse reflection surface. Users might look directly to the projector accidentally that might cause harm to eyes. We would consider adding human eye detection function to turn off the projector when necessary.

4 Conclusion

Our final goal is to have a redesigned AR sandbox that have a higher refresh rate, faster response, safer design and better human machine interaction than existing solutions. We wish it can be used for education and make kids interested in geology in an interactive way.

References

[1] D. Gotterbarn, B. Brinkman, C. Flick, *et al.*, "Acm code of ethics and professional conduct," 2018.

[2] *IEEE Code of Ethics*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html.