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Interactive Sand Table Design to Train Fine Motor Skill for Children with Neurological Disorders

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***Abstract*— In this article, design of interactive sand table with watersheds modelling was reported. The prototype of an interactive sand table was designed to train fine motor skill for children with neurological disorders. The hands-on interactive sand table allowed users to create some interactive topographic models by shaping real beach sand which is augmented in real time by an elevation color map, topographic contour lines, and simulated water. A topographic model was generated from the projection of elevation maps and contour line colors that resembled sand topographic conditions using a depth sensor from Microsoft Kinect 360 camera, simulation and visualization tools, and a video projector. The interactive sand table had been successfully demonstrated without adverse events by constructing a miniature of island and watershed topography containing lines of contour, rivers, mountains, plateau, and low land for providing various challenges to the users using sand play experience.**

***Keywords*— Fine motor skills, children with neurological disorders, sand play therapy, topographic models, augmented reality**

I. INTRODUCTION

The utilization of fine motor skills plays an integral role in supporting everyday human activities. Children grappling with neurological disorders, such as autism and cerebral palsy, often encounter challenges related to fine motor skills, communication, collaboration, and social interaction. Addressing these issues requires therapeutic interventions aimed at helping these children relearn lost fine motor skills through repetitive tasks. The repetition of daily living activities can enhance their responsiveness, promote environmental control, and foster self-reliance. The primary goal of this therapy is to enable children with neurological disorders to manage their preferred environmental stimulation using simple behavioral actions facilitated by assistive tools [1]-[5]. This involves incorporating elements such as playing preferred videos or music, engaging with toys, or interacting with various stimulating sources that capture their attention. The regular practice of these activities serves to train and improve their functional impairments. However, extended sessions of repetitive tasks can pose a challenge for children with neurological disorders due to potential monotony or boredom. To address this, providing a diverse array of stimulation tools within various training environments becomes crucial. This approach not only enhances motivation but also promotes adherence to therapy, ultimately improving their motor learning [6]. Moreover, research indicates a positive correlation between the extent of repeated training tasks and the recovery of children with neurological disorders [6].

Enhancing the interactivity and motivation of fine motor skills training can be achieved through the integration of Sand Play Therapy (SPT) and Virtual Environments (VE). SPT, recognized as a global psychotherapy method for individuals, including children, adolescents, and adults facing mental health challenges [7][8], proves particularly effective for those who find verbal communication challenging and may be resistant to traditional forms of treatment. SPT shifts the focus of therapy from verbal expression to a non-verbal approach, leveraging play as a means of communication. In the context of children with neurological disorders, SPT plays a pivotal role in regulating their preferred environmental stimulation through rhythm and movement-based sand play [9]. The incorporation of fine motor actions within SPT has been shown to enhance communication, collaboration, and social interaction [9]-[12]. On the other hand, Virtual Environments offer the advantage of being free from real-world physical constraints, adapting seamlessly to diverse situations. The synergy between SPT and VE in fine motor skills training for children with neurological disorders creates an immersive experience. This combination not only sustains but also elevates motivation and adherence during extended training sessions. The interactive and dynamic nature of this approach provides a compelling and effective platform for fostering the development of fine motor skills in these individuals.

The objective of this pilot project is to design and create the prototype of interactive sand table with watersheds modelling to train fine motor skills for children with neurological disorders. In the preliminary test, we wanted to make sure whether it was safe to train fine motor on this prototype without adverse events and feasible to be immersed. The driving software is based on the Vrui VR development toolkit and the Kinect 3D video processing framework, and is available for download under the GNU General Public License.

Raw depth frames arrive from the Kinect camera at 30 frames per second and are fed into a statistical evaluation filter with a fixed configurable per-pixel buffer size (currently defaulting to 30 frames, corresponding to 1 second delay), which serves the triple purpose of filtering out moving objects such as hands or tools, reducing the noise inherent in the Kinect's depth data stream, and filling in missing data in the depth stream. The resulting topographic surface is then rendered from the point of view of the data projector suspended above the sandbox, with the effect that the projected topography exactly matches the real sand topography. The software uses a combination of several GLSL shaders to color the surface by elevation using customizable color maps, and to add real-time topographic contour lines.

Simultaneously, we conduct a background simulation of water flow utilizing the Saint-Venant set of shallow water equations [13][14]. These equations, a depth-integrated version derived from the Navier-Stokes equations governing fluid flow, serve as the foundation for the simulation. This process is facilitated through an additional set of GLSL shaders. The simulation represents an explicit second-order accurate time evolution of the hyperbolic system of partial differential equations, with the virtual sand surface serving as boundary conditions. The application of this method closely aligns with the guidelines presented in [13][14], incorporating elements such as a basic viscosity term, open boundary conditions at the grid perimeters, and a second-order strong stability-preserving Runge-Kutta temporal integration step. The simulation is configured to maintain the natural speed of water flow, assuming a 1:100 scale factor. However, adjustments are made if turbulence in the flow necessitates an increased number of integration steps, a consideration made to accommodate the processing capabilities of the current graphics card (currently an Nvidia Geforce 780).

II. METHOD

A. Design and Construction Interactive Sand Table

An AR Sandbox requires the following hardware components: 1) a computer with a good graphics card, running any version of Linux. The AR Sandbox software, in principle, also runs on Mac OS X, but we advise against it. We strongly recommend using desktop computers over laptop computers. For one, laptop computers powerful enough to run an AR Sandbox are typically more expensive than desktop computers of comparable power; second, laptop computers with high-end Nvidia graphics cards often contain so-called Nvidia Optimus technology to reduce system power usage by dynamically switching between the high-performance discrete graphics processing unit (GPU) and the main CPU's low-performance integrated graphics processor (IGP). Optimus is not fully supported on Linux, and may prevent access to the discrete graphics card entirely. The AR Sandbox does not run under Windows, and neither does it run from within a virtual machine. It either requires a PC exclusively running Linux, or a dual-boot setup with Linux and Windows; 2) a Microsoft Kinect 3D camera. The AR Sandbox software, or rather the underlying Kinect 3D Video Package as of version 2.8, supports all three models of the first-generation Kinect (Kinect-for-Xbox 1414 and 1473 and Kinect for Windows). All three are functionally identical, so get the cheapest model you can find. Note: The second-generation Kinect (Kinect for Xbox One or Kinect for Windows v2) is experimentally supported by the AR Sandbox software as of version 2.4, when using version 3.4 of the Kinect 3D Video Package; 3) A digital data projector with a digital video interface, such as HDMI, DVI, or DisplayPort; 4) a sandbox with a way to mount the Kinect camera and the projector above the sandbox; 5) sand.

The interactive sand table design, illustrated in Figure 1, consists of several key components. These include a projector employed to enhance the visual representation of beach sand within the sand table, a Microsoft Kinect 360 3D camera utilized for capturing the topography of the sand, and a computer equipped with a high-quality video graphics card. Additionally, the physical setup features a sand table constructed with a vertical steel pipe designed to secure both the projector and the Kinect depth sensor above the surface of the sand. To provide a visual representation of the implemented interactive sand table, please refer to Figure 2, which showcases the practical execution of this design. The synergy of these components allows for a dynamic and engaging user experience, where the projector augments the sand's appearance based on the input from the Kinect 3D camera. This integration facilitates interactive manipulation and visualization of topographic features, creating an immersive and educational environment for users.

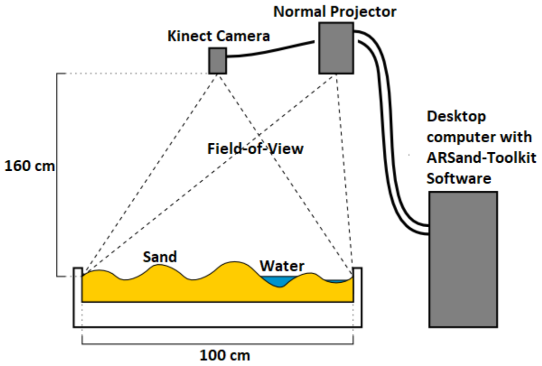


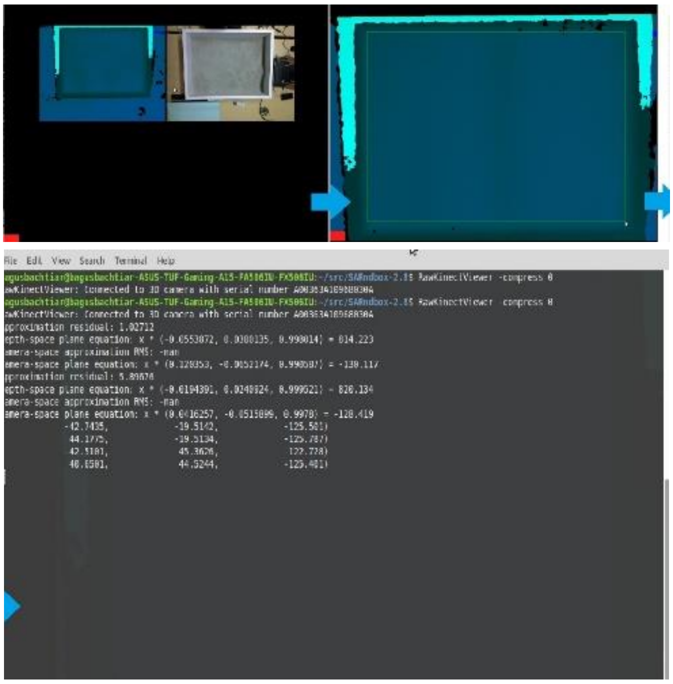
Figure 1. Design interactive sand table for fine motor skill training

Figure 2. Interactive sand table complete overview; 1: sand box; 2: beach sand; 3: a Microsoft Kinect 360 camera; 4: an Epson EB-e500 projector; 5: a desktop computer; 6: 3D virtual environment

B. Kinect Camera Calibration

The first step in this process is to extract camera-space plane from raw depth map generated from sand surface scanning process by Kinect depth camera. Camera-space plane denotes the zero-elevation surface or base plane of the sand box as water level. To measure camera-space plane is to use RawKinectViewer. When raw depth map is extracted using RawKinectViewer, it is obtained two plane equations, namely depth-space and camera-space. Interactive sand table just needs camera-space. Camera-space equation format as follows: Camera-space plane equation: x * <some vector> = <some offset> where <some vector> denotes three values in centimeters showing the X-Y-Z direction in camera coordinates, while <some offset> denotes vertical position of base-plane below Kinect depth camera. It is in centimeters and negative value. The camera-space plane result has to be saved into the BoxLayout.txt file in etc/SARndbox-2.8 inside the SARndbox source directory. Base-plane equation in BoxLayout.txt has format as follows: <some vector>, <some offset> where direction vector and offset are separated by a comma.

After base-plane configuration is completed, we need to measure the inside 3D corners positions in the raw depth map of the sand table to limit the water simulation and update the line below base-plane equation in BoxLayout.txt. as shown in Figure 3.



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agusbachtian@bagusbachtiar-ASUS-TUF-Gaming-A15-FA506IU-FX506IU:~/src/SARndbox-2.8$ RawKinectViewer -compress 0
awKinectViewer: Connected to 3D camera with serial number A00363A169680304
pproximation residual: 1.02712
epth-space plane equation: x * (-0.0553072, 0.0300135, 0.998014) = 814.223
amera-space approximation RMS: -nan
amera-space plane equation: x * (0.120353, -0.0052174, 0.990587) = -130.117
pproximation residual: 5.89676
epth-space plane equation: x * (-0.0194391, 0.0240924, 0.999521) - 820.134
amera-space approximation RMS: -nan
amera-space plane equation: x * (0.0416257, -0.0515099, 0.9978) = -128.419
          -42.7435,           -19.5142,           -125.501)
           44.1775,           -19.5134,           -125.787)
           42.5181,            45.3626,            122.728)
           40.6501,            44.5244,           -125.401)
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Figure 3. Kinect calibration process to measure base-plane and 3D table corner positions

C. *Running the Interactive Sand Table*

The final step is to run interactive sand table using SARndbox -uhm -fpv command where the argument of -uhm shows that an elevation color map will be displayed to the surface of sand and argument of -fpv shows that data collected from the result of projector calibration will be used by SARndbox. Implementation of interactive sand table is shown in Figure 5.

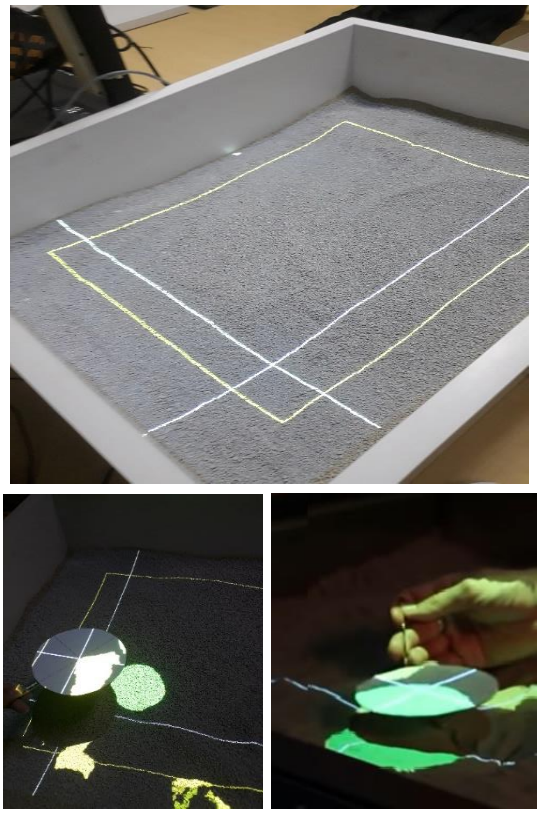

Figure 4. Projector calibration process using a calibration target

Figure 5. Running an interactive sand table

III. RESULTS AND DISCUSSION

The objective of this preliminary test is to determine whether it is safe and feasible to use the interactive sand table as an assistive tool to train fine motor skill in children with neurological disorders. Moreover, we wanted to know whether it was safe to exercise on the interactive sand table without adverse events and feasible to be immersed and feasible during a short-term repeated training by doing simple tasks based their daily routine activities. Sample of fine motor skill training activities in children with neurological disorders shown in Figure 6.

Figure 6. Sand play practice resulting from simple repetition task using interactive sand table to learn and acquire fine motor skills in children with neurological disorders

A. *System Testing*

All research participants were carefully chosen and enrolled with the approval of their teacher from the First State Special Needs School in Jember, Indonesia. The criteria for safety in this study were specifically centered around the absence of adverse events related to respiratory disorders, such as coughing, asthma, or triggering allergic reactions.

To evaluate feasibility, multiple metrics were considered, including attendance, total exercise time, the participant's ability to use both hands in completing simple tasks as instructed by the teacher (specifically, the creation of a miniature island by shaping beach sand), and engagement measured through the Witmer–Singer presence questionnaire (PQ) [15][17]. The PQ was specifically chosen to assess user presence when utilizing the interactive sand table. Although the complete PQ consists of 32 items, scored on a Likert scale from 1 (lowest) to 7 (highest), for the purposes of this research, only five items were selected (items 5, 10, 18, 23, and 32, as shown in Table I).

These selected items are categorized into Control Factors (CF), Sensory Factors (SF), and Realism Factors (RF). The PQ data were collected on the final day of the training session, while attendance and training time were recorded daily throughout the training program. This comprehensive approach aimed to assess both safety and the practicality of the interactive sand table for fine motor skill training in children with neurological disorders.

TABLE I
PRESENCE QUESTIONNAIRE ITEM STEMS FOR SYSTEM TESTING

PQ No.	Item Stems	Factors
5	How much did the visual aspects of the environment involve you?	SF
10	How compelling was your sense of objects moving through space?	SF
18	How compelling was your sense of moving around inside the virtual environment?	SF
23	How involved were you in the virtual environment experience?	RF
32	Were you involved in the experimental task to the extent that you lost track of time?	CF

B. *Intervention*

he fine motor skill training spanned four days, with participants attending once daily during the fine motor class starting at 09:00 AM. Each training session was limited to a duration of 15 minutes, during which participants were tasked with creating miniature islands. The session would be concluded if participants experienced fatigue or if the training time surpassed the 15-minute limit. Ongoing observation for symptoms of adverse events was conducted to ensure safety throughout the training.

C. *Results and Discussion*

All participants successfully completed the four-day fine motor skill training test, demonstrating a 100% adherence rate with no reported adverse events related to the training. Participants expressed a high level of involvement in the interactive sand table, as evidenced by a mean PQ score of 32 (with a standard deviation of 0.6) out of a possible 35 on day 4 of the training program. Over the four-day period, participants engaged in training for durations ranging from 6 to 12 minutes per day (see Figure 6), accumulating a total training time of 29 to 42 minutes. While participants thoroughly enjoyed the sand play, reflected in the positive PQ values, none exceeded the specified playing time limit. This restraint was attributed to fatigue stemming from impaired hand function, underscoring the challenge of assessing fine motor development within a brief training period using the interactive sand table.of participants had completed four days fine motor skill training test. There was 100% adherence and no adverse event related to training test. Participants reported involvement in interactive sand table with a mean PQ score of 32 (with standard deviation 0.6), out of a possible 35 at day 4 of training program. Participants achieved between 6 and 12 minutes of training test in four days (see Figure 6), with a total of 29 to 42 minutes over the total training test period. Although the participants enjoyed the sand play which was shown with a good PQ value, but no participant had exceeded the specified playing time limit. This is due to fatigue arising from impaired hand function and difficulty in assessing fine motor development using this interactive sand table during a short training period.

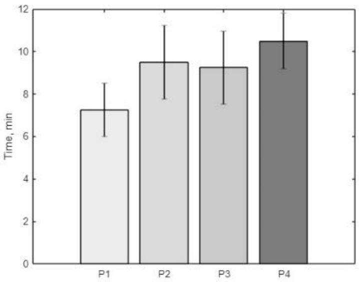

Figure 6. Average training time during four days for each participant

This is a preliminary test with a small number of participants in a short training period that should be interpreted with caution. Future testing may take place during long period to asses more safety, feasibility, and efficacy using interactive sand table for fine motor skill training. Finally, the Witmer–Singer PQ [10] has not been validated in a neurological disorder's population.

IV. CONCLUSION

This research article introduces an interactive sand table designed for fine motor skill training with a focus on watersheds modeling. The prototype enables users to craft interactive topographic models by shaping real beach sand, enhanced in real time through features like an elevation color map, topographic contour lines, and simulated water effects. The necessary hardware components for the prototype include a Microsoft Kinect 360 camera depth sensor, simulation and visualization tools, a video projector, and a sand-filled sandbox. The prototype underwent testing on children with neurological disorders, aiming to assess its safety and feasibility for fine motor skill training within a short-duration program. The preliminary results demonstrated promising outcomes. Participants exhibited a 100% adherence rate, encountered no adverse events, and reported positive engagement with the environmental conditions created by the interactive sand table. These findings suggest the potential effectiveness and safety of the prototype in facilitating fine motor skill training for children with neurological disorders.

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