Multi-Touch Tabletop Computing for Early Childhood Mathematics: 3D Interaction with Tangible User Interfaces

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Abstract: Research is motivated by advances in early childhood mathematics, the design of virtual manipulatives, and the development of multi-touch, tabletop computing combined with tangible user interfaces. Requirements include: 1) horizontal tabletop design affords physical support for material objects, keeping same interaction structure as users move between physical, virtual, and tangible interactions; 2) tabletop configurations have shown to facilitate greater collaborative activity where students interact with artifacts on surface simultaneously.

Issues Addressed

Multi-touch user interfaces are a growing area of interest, particularly in the field of education. Direct interaction with virtual manipulatives has significant potential for the process of learning (Iishi, 2008; Stanton, et al., 2001). We are developing a multi-touch tabletop system targeted at teaching mathematical and geometric concepts to young students. Most research in multi-touch user interfaces is focused on user interactions in two dimensions. Our system is fundamentally different in that we employ side-mounted cameras to track user interaction, thus enabling the perception of depth from participants' hands to the tabletop's surface. We consider the implications and potential of interaction in three dimensions.

Potential Significance

Our system is distinguished by its ability to observe user interactions in all three dimensions. By employing side-mounted cameras instead of a single bottom-mounted camera or sensor technology, the system is able to observe the distance from the user's hand to the tabletop's surface, thus enabling depth perception (see Figure 1).

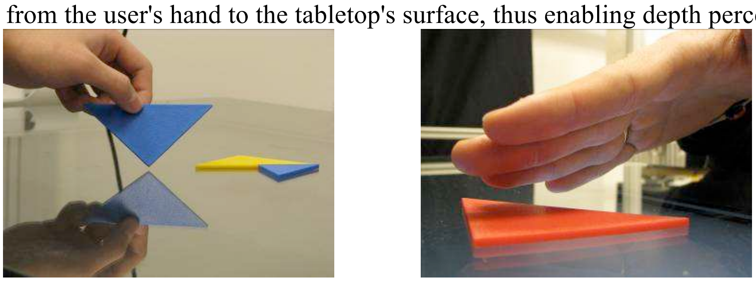

Figure 1: Perceiving depth from the user's hand to the table's surface.

Interaction in all three dimensions has significant potential for the process of learning. We hypothesize that a three-dimensional model more closely resembles the "real world" model that children naturally develop to interpret their physical surroundings than a traditional, two-dimensional user interface. This model has the potential to more effectively develop spatial cognition and geometric concepts by utilizing all three dimensions of interaction. Depth perception enables hand gestures that can provide an immersive, interactive computing environment. Imagine pinching and lifting a virtual block over another or flipping tangram pieces with the flip of a wrist. Three-dimensional gestures can also be integrated with traditional, two-dimensional user interfaces; consider pinching and lifting a virtual document and flinging it off screen to throw it away. One could also zoom into or out of a document by moving the hand into or out from the screen. The potential of depth perception in developing immersive, three-dimensional applications is limited only by software. Consider that a tangram application can support three-dimensional interaction by allowing pieces to be flipped by flipping the wrist rather than clicking a counter-intuitive, two-dimensional button that represents a three-dimensional action. Imagine a drawing application that enables students to draw "off the canvas," or a block stacking application that explores stacking virtual blocks in three-dimensional space with a two-dimensional representation mirrored on the screen.

Technical Solution Based on Tangible User Interactions

The horizontal touch surface is a 30" liquid crystal display covered with a sheet of glass for a smooth, protective surface. Two side-cameras are mounted at adjacent corners of the surface and point toward one central point on the display. Video streams from the cameras are processed on a Mac desktop system. Since no specialized hardware is used, the cost of the system is relatively low compared to projector-based multi-touch tables such as the Microsoft Surface or SMART Technologies SMART Table.

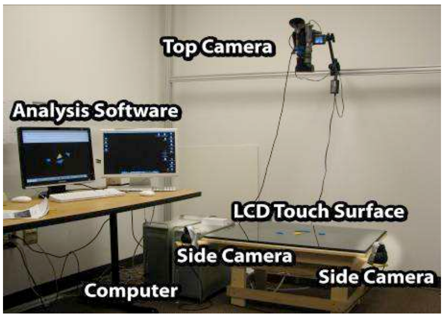

Figure 2: General apparatus and perspective of system.

Given that no specialized hardware is used, the system is mostly software-oriented. Prior to interacting with the system, the software first goes through a learning phase to compose a library of recognized shapes. These shapes are based on physical pieces that are placed on the touch surface. After the learning phase, the user may either interact with the physical pieces or directly manipulate virtual representations of the pieces. To track user interactions, the two video streams are combined to form one coherent, three-dimensional model of the touch plane. The system employs edge detection algorithms to track user fingertips and resolve occlusion when only a portion of a piece is visible.

Preliminary Findings, Conclusions, Implications

One of the greatest technical challenges of using side-mounted cameras to perceive depth is occlusion resolution. Occlusion occurs when a user's hand obstructs a camera's line of sight to a piece. The system must continue to observe the piece's translation and rotation when only a fraction of the piece is visible. Occlusion is resolved by mapping visible points of interest (e.g. corners and edges) to its corresponding library entry. Once this entry is identified, the blocked portion of the shape may be extrapolated. As a result, only a fraction of the shape must be visible to accurately observe the movement of the entire piece.

In addition to the benefits of depth perception, this approach inherits the benefits of traditional multi-touch systems. Research suggests that direct interaction with physical or virtual manipulatives more effectively develops geometric concepts than traditional, two-dimensional, graphical user interfaces (Clements, Sarama & DiBiase, 2003). Multi-touch surfaces are also shown to keep children's' attention longer and horizontal surfaces increase the creative process more so than vertical surfaces (Moulin, Lenne, Abel & Gidel, 2009). Virtualizing user interactions enables the system to monitor the collaborative process in real-time. This can potentially be used to streamline the analysis of user interactions and provide feedback to participants in real-time (Noss & Hoyles, 2006). This feedback has been shown to influence the participation of users; those that dominate the collaborative process tend to decrease their contributions, while those that have participated less increase their contributions (Bachour, Kaplan & Dillenbourg, 2009). Unlike with physical manipulatives, user interactions with virtual manipulatives may be moderated to influence the collaborative process. For example, child A may control only red pieces while child B may control only blue pieces. Moderating control over the collaborative process has also been shown to increase collaboration (Stanton et al., 2001).

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Acknowledgments

We will acknowledge funding source & additional team members should proposal be accepted.