Trackable Interactive Multimodal Manipulatives: Towards a Tangible User Environment for the Blind

Muhanad S. Manshad[1], Enrico Pontelli[1], and Shakir J. Manshad[2]

[1] Computer Science Department, New Mexico State University (NMSU), New Mexico, USA
`{mmanshad,epontell}@nmsu.edu`
[2] Math Adoptive Technology Lab for Students with Disabilities, NMSU, New Mexico, USA
`smanshad@nmsu.edu`

Abstract. This paper presents the development of Trackable Interactive Multimodal Manipulatives (TIMM). This system provides a multimodal tangible user environment (TUE), enabling people with visual impairments to create, modify and naturally interact with graphical representations on a multitouch surface. The system supports a novel notion of active position, proximity, stacking, and orientation tracking of manipulatives. The platform has been developed and it is undergoing formal evaluation.

Keywords: Haptic Feedback, Graphing, Accessibility, Blind and Visually Impaired, Multitouch, Multimodal, TUI, Diagrams, Tangible User Environment (TUE), NASA TLX, Subjective Workload, Manipulatives, Fiducials, Markers.

1 Introduction

Through their K-12 years, blind and visually impaired students are taught to construct, manipulate and browse the physical world using the sense of touch through free hands. This method is ubiquitous in reading braille and in all learning interactions (Fig. 1 and 2). Fundamentals of science and math are taught using simple inexpensive materials, requiring little to no learning curve. Dominant materials used in everyday classrooms are manipulatives, such as cubes, number lines, and combinations of corkboards, pins and rubber bands [13]. Manipulatives are tangible objects that are part of a hands-on learning environment. Through design and constant manipulation, a student can create mental models "images" of important concepts in algebra, geometry, measurements, and science. It is through multiple experiences that students gain true conceptual understanding [13]. There are, however, several concerns. E.g., each manipulative must be easily distinguishable, color properties have to be replaced by braille, and an unambiguous area for placement of manipulatives must be provided, to render interaction without distress for loss of position, orientation, and proximity of cubes. Another type of commonly used manipulatives relies on corkboards, pins and rubber bands (Figure 2). This form is used to create graphs, charts, and geometric shapes. This involves inserting pins on a wooden board with a raised grid and wrapping rubber bands around the pins to form a touchable graph. This is a simple method, but has

K. Miesenberger et al. (Eds.): ICCHP 2012, Part II, LNCS 7383, pp. 664–671, 2012.

several drawbacks. Pins can fall off if not placed correctly. If a pin is removed by mistake, the rubber bands can also fall off, causing the loss of the representation and possible injuries. The setup of this form is tedious and lacks feedback (e.g., audio) to denote correct or incorrect interactions. The static nature of manipulatives requires continuous manual intervention and validation (e.g., by the teachers).

Fig. 1. Two-handed uses for Braille and manipulatives [2], [10], [13], [14]

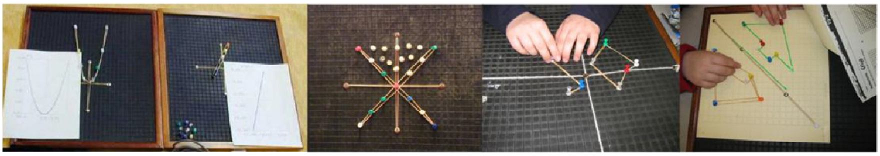

Fig. 2. Two-handed interaction when constructing diagrams/graphs [13]

The emergence of digital manipulatives [11] offers a new approach to address some of these issues. These manipulatives are based on the concepts of Tangible User Interfaces (TUIs), which provide a new compelling approach to enhance people's interaction with digital information [12]. The concept of TUI was first introduced in 1997, by Ishii and Ullmer – they define a user interface that can "augment the real physical world by coupling digital information to everyday physical objects and environments" [5]. TUIs naturally employ a two handed approach, which fits perfectly with the existing classroom practices for blind and visually impaired students. However, the technological developments and the associated research implications of TUIs for these groups of students are still in their infancy. McGookin et al. developed a TUI system that tracks markers on a table-top surface [9]. Their results demonstrate the potential offered by this approach in providing non-visual access to charts. However, their system only allows for data browsing of statistical data, without construction and other types of interaction. Subjective workload evaluations were not provided. In this project, we investigate TUIs for students with visual impairments further.

2 Background and Motivation

This paper presents an extension of our previous work (abstract): MICOO (Multimodal Interactive Cubes for Object Orientation) [7]. The limitations of existing approaches and the belief that TUIs might provide break-through ways to engage blind and visually impaired students in learning mathematical and scientific graphical concepts are at the foundation of TIMM. With TIMM we provide a general digital tangible manipulatives platform with the following characteristics:

1. It is general and programmable: we envision TIMM as a set of manipulatives that are flexible and provide an open API – allowing them to be programmed to meet the needs of different applications (e.g., presentation and manipulation of different concepts from algebra, geometry, and other scientific domains);
2. It is capable of providing multi-modal feedback;
3. It supports both presentation of graphical structures as well as their manipulation (e.g., creation and transformation).
4. It maintains a visual component, to enable interaction between blind, visually impaired students and sighted students/instructors.

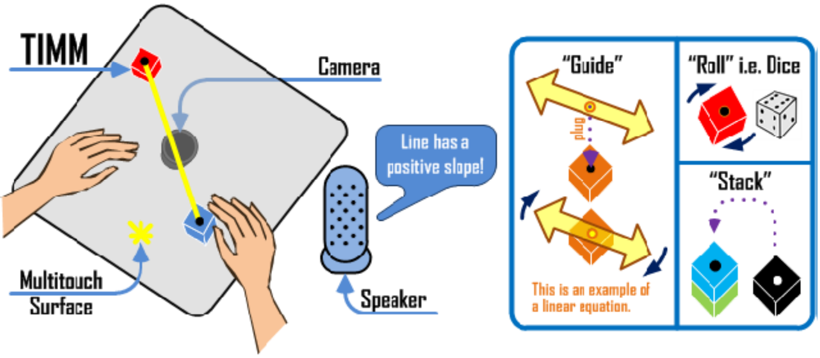

Fig. 3. TIMM Tangible User Environment

3 TIMM for Tangible User Environments (TUE)

Manipulatives are defined as a set of objects (e.g. blocks) that a student is instructed to use in a way that teaches or reinforces a lesson [4]. In a class room setting, manipulatives demand an environment that requires an interaction space (e.g., table-top, desk), active guidance/feedback (e.g., teacher), and a set of rules (e.g., lesson). Moreover, manipulatives in their class room setting provide a complete learning environment. We define a set of TUIs (manipulatives), their tangible interaction space (multitouch table-top), and a set of rules (applications) with active feedback (multi-modal), in a system which renders all interactions and user intention; thus, a tangible user environment.

We have developed a collection of manipulatives called *TIMM (Trackable Interactive Multimodal Manipulatives)* and a custom multitouch table-top to identify and track TIMM surface movements and interactions. This system renders active interactions by reading and tracking markers underneath each TIMM. In Figure 3, on the left we show the system. In this setup we provide an environment that is non-intrusive, providing look and feel of a typical table of a classroom setting. On the right of Figure 3, we describe the types of interactions that are possible with TIMM: "Guide", "Roll", and "Stack". The novel concept of "Guide" provides the ability to plug a tactile representation into a TIMM. This representation can be for example, a miniaturization of a graphical representation; in this case we show a line or a linear equation. Once a tactile representation is plugged into a TIMM, the system is then to actively rotate the representation to provide instant tactile feedback that matches a graphical object on that location. The “Roll” ability allows a roll action on the surface while accurately tracking the face of the object. This ability for example can be used to represent a virtual dice. The “Stack” ability allows several TIMMs to be stackable while actively track which TIMM is on top/bottom. The design of TIMM is guided by the following criteria:

1. *Natural active interaction:* Any system will naturally require a learning curve. However, employing a two handed input interaction approach (natural to students with visual impairments) will yield a reduced learning curve.
2. *Multiple points of interaction:* Existing research has extensively investigated uses of haptic technology (e.g., Wingman, PHANToM, Falcon). These devices require a user’s whole palm and hand-grip, leaving other receptors on the hand unemployed (single point of interaction). Manshad and Manshad designed a haptic glove, which provides vibration feedback through natural movement and position [8]. Their evaluations highlight the significance of providing multiple points of interaction – students browsed a mathematical graph faster than using single point interaction. McGookin et al. evaluations also supported this notion [9].
3. *Independence:* the system should provide active feedback in support of correct and incorrect interactions. This will lessen the need for manual intervention. (e.g., teachers).

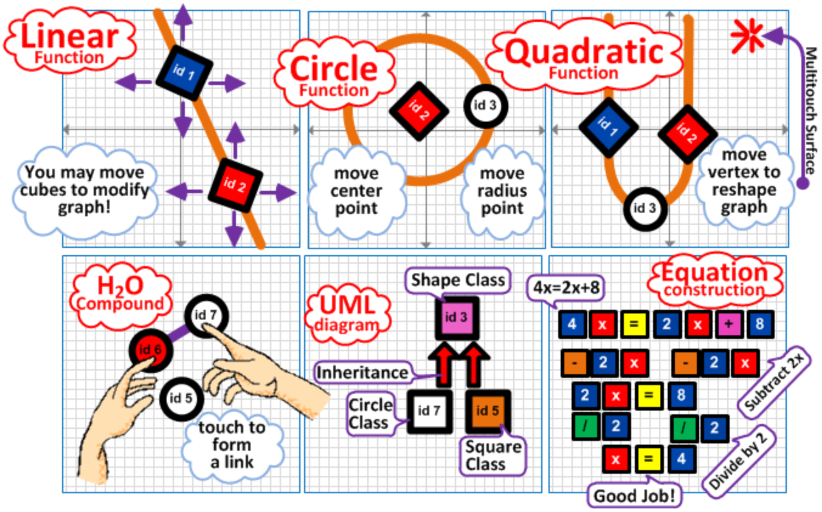

Fig. 4. Sample applications of TIMM

The initiative of TIMM is to develop a novel platform that adapts to a wide range of applications, particularly those found in everyday classrooms for blind and visually impaired students using manipulatives. The form and outer shape of TIMM is also meant to be adaptable and to serve as a generic platform for TUI-based interaction with graphical structures. As a generic platform, the system provides a novel notion of active position, proximity and orientation tracking of all objects. With this information we create a tangible user environment that reasons with user intent and validate their manipulation. Thus, provide continuous feedback to the user while guiding and instructing him/her to complete their task without the need of a 3rd person.

Consequently, the system also provides active tracking of TIMM against components of interest (e.g., diagram relation markers, entities, or graphs). If the orientation and position of a TIMM matches a component, then a user is allowed to modify that component by moving the TIMM (Fig. 4). Conversely, if a TIMM does not match the orientation or it is far from a component, audio feedback will be activated to direct and help the user to reach that component. A user may also use his fingers to quickly touch and browse the surface while listening for audio feedback. If a component is found, a user may put a TIMM on that position. This notion is called "bread crumbs", which allows the user to leave several TIMMs behind to form a tactile presentation and meaning that is configurable. As summarized in Fig. 4, multitouch can be used to detect or create links among entities (e.g., connect two nodes in a graph), manipulate graphical structures or construct expressions and equations. Thus, there are two general modes of interaction:

- Construction Mode:
  - Graphing: During construction of a graph (e.g., linear equation) a blind or visually impaired student typically locates two points (i.e. point A & point B) on a corkboard then inserting a pin on each point, and then wraps a rubber band around them to construct a tactile line. Using TIMM, a user will also locate two points through moving a TIMM and verifying the point of interest by reasoning with feedback (e.g., music, speech). Once points are located, a user can tie a piece of yarn or wikki-stix to form a tactile line between both TIMM points as shown in fig 3.
  - Diagram: Pins and rubber bands on a corkboard are also used to form an outline of a geometric shape. Similarly, TIMM graph construction method can be used to form outlines of shapes. However, when constructing more complex representations (e.g., UML, flow chart, compounds), a user must place several TIMMs to form a representation, and can link each object with a relation object. Once placing a TIMM, a user is then asked to describe or provide a description using a standard or a braille keyboard.

- Browsing Mode: (this mode is activated once a user finishes construction, loads a diagram representation from file, or inputs a function to graph).
  - Graphing: If a user enters a function, then he will be asked to place a TIMM to locate a point (e.g., x-intercept, y-intercept, vertex, center of circle, etc…) while listening to directions (e.g., "go upper left", "go lower left", "go up", "go down", "you are on the line", "you are on x-intercept", etc…). The system will continue to ask to user to locate the least amount of point to construct a tactile representation of the graphed function. Once all TIMMs are in place, the user can then manipulate the function by moving any TIMM. With every new move, audio feedback will be given to describe the change in the graph (e.g., "negative slope", "positive slope", "area of circle", etc…) as seen in scenario 1 of fig 5.

Alternatively, a user may use the “Guide” TIMM to quickly represent a function after locating only a single point. Then, the user can manipulate the graph either by moving the TIMM or rotating the “Guide” tactile representation as seen in scenario 2 of fig 5.

- Diagram: Similarly with TIMM graph manipulation, the user will also receive directions to place a TIMM to match a loaded diagram. Once all TIMM objects are in place, the user is free to manipulate the diagram, add to it, or remove links and relationships. User is also able to change the description of each object and rotate to change orientation.

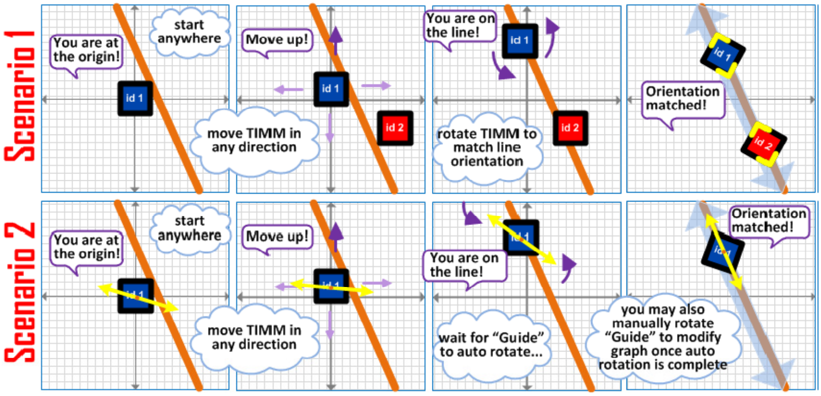

Fig. 5. Graph browsing and manipulation example

3.1 Hardware and Software Implementation

TIMM has been developed from scratch, using affordable off-the-shelf hardware components. The system allows for natural interaction using TIMM on a multi-touch surface. The current surface is controlled through a single infrared camera for TIMM movement and orientation tracking. Through the open-source Community Core Vision 1.5 (CCV) platform [3] we are extending our initial design to support multiple cameras for higher precision tracking of markers (Fig 6). Through CCV we can configure camera video stream and select tracking data to publish as UDP packets.

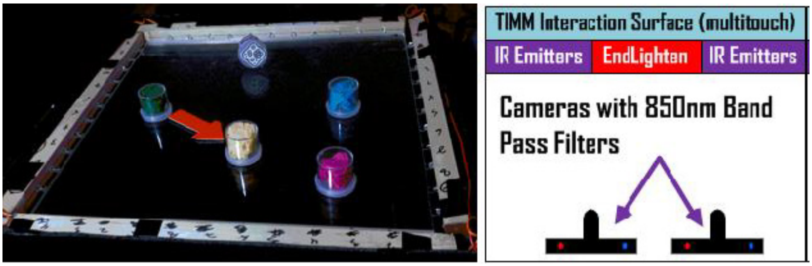

Fig. 6. Side view layers (right) and current design (left)

Current software implementation is a custom C# application which extends the open source reacTIVision TUIO framework [6]. New TIMM API provides active proximity and orientation of TIMM against components of interest. API for direction feedback, "Guide" control and "Roll" ability are also provided. The software subscribes to the CCV UDP packets, then plots position and orientation of each TIMM. Depending on the current application of TIMM that the user selected (e.g. graph, diagram), the software provides a graphical representation of the table-top surface. This representation can be saved and printed. The software also keeps track of overall time taken to complete each task, correction or incorrect movement of each TIMM, and time taken to move a single object, to later be used for evaluation and usability testing.

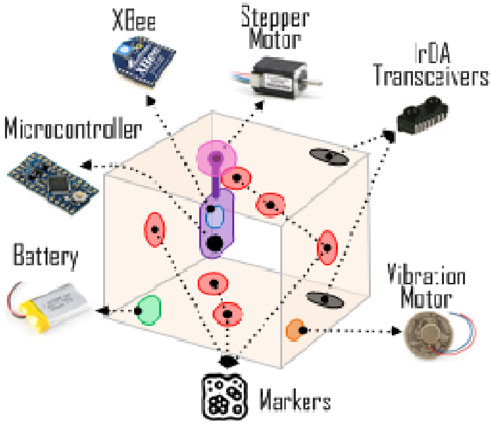

Fig. 7. Hardware design of TIMM

Since our system is to serve as a generic platform, there is no limit on the look and feel of TIMM objects. The intent is to make use of everyday manipulatives found in classrooms, and convert them to trackable objects. This can easily be done by placing a fiducial marker underneath any object. Software must then be configured to understand new objects on the surface and correctly predict user intention of manipulation, since current software only supports graph and diagram construction. Figure 7 describes associated hardware with interactions possible with TIMM currently developed: "Guide": using a stepper motor and volume knob to provide rotation feedback and input; "Roll": six markers placed on each side of a TIMM are used to determine the current side facing the surface; and "Stack": two IrDA transceivers are used to sense any stackable TIMMs. Generally, each TIMM sends wireless data to our interaction software and receives instructions (e.g. stepper motor movement, vibration feedback, etc…). Currently we are adding a speech/audio player component to provide speech and audio feedback. Each TIMM is programmable using the Arduino open-source prototyping platform [1].

4 Current Status

A number of formal evaluation activities are currently underway, including NASA TLX (Task Load Index) workload assessment and Neurosky's MindWave attention and meditation data. Current participants include students from the Alamogordo New Mexico School for the Blind and Visually Impaired. Participants will be tasked to browse, modify and construct a graph (on a Cartesian plot) and a diagram. Completion times and errors will be recorded and analyzed.

Acknowledgments. Many thanks to the NUI (Natural User Interface) Group Community forums for answering questions during the system building process.

References

1. Arduino, `http://www.arduino.cc`
2. Braille Math Blocks, `http://www.unclegoose.com/products/braille-math-blocks`
3. Community Core Vision Information, `http://nuicode.com`
4. Definition of Manipulatives, `http://mw3.merriam-webster.com/dictionary/manipulatives`
5. Ishii, H., Ullmer, B.: Tangible bits: towards seamless interfaces between people, bits, and atoms. In: Proc. CHI 1997: Conference on Human Factors in Computing Systems, Atlanta, GA, USA (1997)
6. Kaltenbrunner, M.: reacTIVision and TUIO: a tangible tabletop toolkit. In: Proc. ITS 2009: Conference on Interactive Tabletops and Surfaces, Banff, Canada (2009)
7. Manshad, M.S., Pontelli, E., Manshad, S.J.: MICOO (multimodal interactive cubes for object orientation): a tangible user interface for the blind and visually impaired. In: Proc. ASSETS 2011: Conference on Accessibility and Computers, Dundee, Scotland (2011)
8. Manshad, M.S., Manshad, A.S.: Multimodal vision glove for touchscreens. In: Proc. ASSETS 2009: Conference on Accessibility and Computers, Nova Scotia, Canada (2009)
9. Mcgookin, D.K., Robertson, E., Brewster, S.A.: Clutching at straws: using tangible interaction to provide non-visual access to graphs. In: Proc. CHI 2010: Conference on Human Factors in Computing Systems, Atlanta, GA, USA (2010)
10. Reading Braille, `http://www.aph.org/devel/donoresp.htm`
11. Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., Silverman, B.: Digital manipulatives: New toys to think with. In: CHI 1998: Proc. of the ACM Conference on Human Factors in Computing Systems, Los Angeles, CA, USA (1998)
12. Shaer, O., Hornecker, E.: Tangible User Interfaces: Past, Present, and Future Directions. In: Foundations and Trends in HCI vol. 3(1-2), pp. 1–137
13. Texas School for the Blind and Visually Impaired, `http://www.tsbvi.edu/presentations`
14. Wikki-Stix, `http://www.wikkistix.com`