Tangible Synergetic Domes

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Abstract

This paper describes a proof of concept design, development, and implementation for an interactive children's science museum exhibit that uses a TUI (tangible user interface) with a hemispheric surface. The goal of the exhibit is to assist younger students in better understanding the principles of geodesic dome construction developed by R. Buckminster Fuller. Using touch interaction, triangular elements can be selected, moved, and placed to construct geodesic dome patterns. Interacting with these elements on a surface that more closely matches the form of the geodesic dome, children can learn how the proper placement of pieces will lead to the creation a geodesic dome structure without needing to understand the advanced mathematical theories supporting the construction methods.

Keywords

Tangible computing, exhibition design, industrial design, interaction design, geodesic dome, hemispheric surface, touch interaction, learning.

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces---input devices and strategies, interaction styles; J.5 [Arts and Humanities]: Architecture.

Introduction

R. Buckminster Fuller (1895-1983) was a mathematician, scientist, and architect who pioneered a set of theories in the late 1940s and early 1950s, which he named Synergetics. Fuller used idiosyncratic terminology along with metaphors and geometric models to explain his theory of 'universal' structure and energy flow [4, 5, 3]. These discoveries lead to his designs and patents for the construction of geodesic domes [6, 7].

The construction of geodesic domes depends on the selection and configuration of triangular elements consisting of edges (struts) and vertices (hubs). These edges, or triangular sides, must be of an exact measurement fitted together at specific angles to correctly build the structure [6]. Measurements for construction are a result of calculations made based on choices made for three main factors: symmetrical polyhedra (octahedron or icosahedron), the 'breakdown' type (alternate or triacon), and frequency of polyhedra subdivision. Repeating patterns of triangle elements are a feature of any dome design and construction [11].

A 2V frequency alternate division resulting from an icosahedral symmetry (see Figure 1) was chosen for the dome pattern in our implementation of an interactive exhibit about geodesic domes. Triangles of two different measurements are generated from this set of parameters [11]. Rotation angle for each triangle varies depending on its correct placement in the pattern. In our design, the rotation is pre-set for each triangle so that the user needs to move each triangle into the correct location to configure the geodesic dome pattern. A guide is provided to indicate the correct placement for three triangles. This gives the user information for the layout of one fifth of the structure, a section that is then repeated at varying angles.

The exhibit structure is a rectangular closed box base with an acrylic hemisphere surface fitted into the top (see Figure 2). The base houses the working components including a projector and mirror which display a computer projection on the interior of the hemisphere surface which is painted with a semi-transparent material. Users select and move triangle elements with touch interaction. Initially, triangles, composed of red and blue sides, are set in positions which allow for easy selection but are not in the correct location for the a geodesic dome pattern. Selecting one element at a time, users attempt to create a geodesic dome pattern by moving each triangle into its proper place.

figure 1. Geodesic pattern – 2V Frequency Alternate Division based on Icosahedron symmetry [11].

The tangible computing design is an exploration of interaction design for a children's science museum

exhibit, in keeping with exhibit designs at science museums like the Exploratorium in San Francisco and COSI (Center of Science and Industry) in Columbus, Ohio. The following section describes the project background. Then we provide a brief overview of related work and describe the system design, technical implementation, and evaluation. We conclude with a discussion of future work.

figure 2. Exterior – structure with hemisphere surface.

Background

Project Goals: Educational Exhibit Design
The project is designed to be consistent with the goals of exhibition design, specifically exhibit design for children's science museums. Tangible Synergetic Domes is the main component of an exhibit design concept that would include complimentary media (graphics, signage etc.). Design for science museums is meant to educate, engage, and entertain: "The key is to turn complex information into an accessible and immersive experience. Scientific data is often seen as complicated and dry. Designers can introduce artistic, creative, and appropriately whimsical exhibits in order to break this stereotype." [9]

Geodesic domes are visually compelling and appealing because of their symmetrical design and repeating elements, but the mathematical theories supporting their design and construction is complicated and beyond the comprehension of young children. Reading a copy of geodesic math and how to use it [6] is unlikely to be interesting or understandable for kids. Interacting with an exhibit that is game-like, similar to working with puzzles composed of basic, colorful shapes, children can begin to explore and understand geodesic design principles through play.

Existing Tools for Exploring Geodesic Domes
Early in the design process for this project, geodesic dome models of varying breakdown patterns and frequencies were constructed using paper models and plastic construction kits. Generating physical models is a more traditional method for understanding Fuller's theories on the subject; he used models of this kind in lectures. These types of models are good because they are, like the geodesic dome architecture itself, tangible,

physical objects that can be examined in three-dimensional space. But, they have several limitations that are not present in our project. First, physical models take more time and effort to construct. Once built, models are fixed in place. For a kit like Zome Tools (www.zometool.com), geodesic models can be constructed from a set selection of parts. This kind of tool allows the user to create a structure that is three-dimensional and demonstrates geodesic design principles, but is not flexible or easily altered.

Related Work

The hemisphere surface described in this paper incorporates similar technologies to those used in other projects with spherical and hemispherical displays: IR camera and lights, projectors and mirrors with rear-projection to create interactive displays on curved surfaces [1, 2, 10]. The research in these projects is focused on the implementation of the technology and examines its uses. For Tangible Synergetic Domes, the inclusion of a hemisphere form factor as the surface for the TUI is a result of design choices made to complement the subject matter. The Microsoft spherical surface [1] and the inflatable hemispherical multi-touch display from the Human Media Lab [10] are examples of research in user interaction with these surfaces, and provide considerations for best uses of spherical and hemispherical displays. The project discussed in this paper differs because the hemisphere surface is used in a specific context and is not intended as a design for many potential uses. The surface in this project is part of a design concept for one interactive exhibit. The placement and presentation of the surface is a result of considerations that included the stature and movement of the users, younger children, who can move around the display, approaching it from any angle. The design

of the box structure and hemisphere surface is symmetrical to best present geodesic dome structures. In their research, Bolton et al. point out that a hemispherical display obscures part of the surface from the view of the user [2]. In the implementation for our project, this is not a problem because, like building a physical dome model, the virtual construction is a three-dimensional puzzle that must be worked with from all angles. This goal necessitates movement around the exhibit and use of the surface from many angles. Although the current implementation creates a projection that only covers the hemisphere surface in part, an eventual design goal is to have full hemisphere projection coverage.

System Design

Research
To understand Fuller's theories and explore tangible interaction techniques, geodesic dome models of varying breakdown patterns and frequencies were constructed using paper models and plastic construction kits (see Figure 3).

Interaction Design
We initially focused on the ability to alter measurements within a geodesic dome construction in a flexible manner. By altering one measurement in a pattern, the resulting change could be seen across the structure as a whole, and the relationship of the elements in the structure would be clearly understood. The adjusting of interconnected parameters was simplified into the ability to manipulate individual triangle sections that would be displayed on a hemispherical surface in the correct orientation. By restricting the transformation of selected elements to movement on the x and y axes, the relationship of

triangles and angles between triangles in a geodesic pattern are emphasized. The choice of triangle orientation and placement is important. Selecting and placing the triangles correctly is a process for identifying the geodesic dome pattern and learning the construction method.
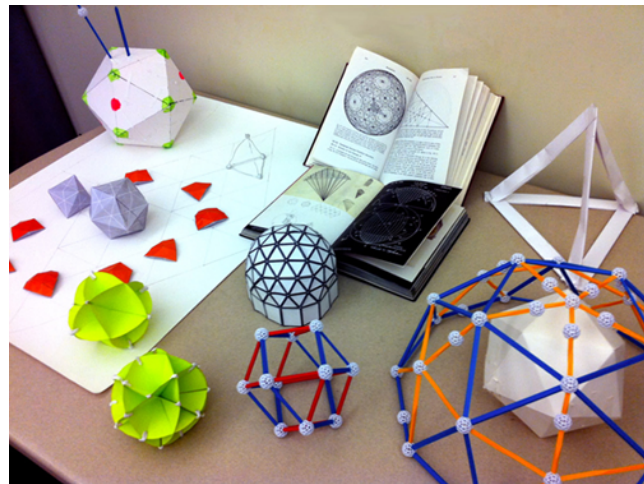

figure 3. Research – paper, plastic models, books [5, 8].

Tangible Interaction
We constructed a box-like structure incorporating the hemispherical rear-projection surface and explored different methods of interaction with the projected triangle sections. Our first approach used two tangible controls for selecting, moving, and dropping the triangles. We initially used golf balls as the tangible controls. The golf balls were fitted with magnets and held to the surface by magnets of opposite polarity on the interior of the dome. Fiducial markers attached to the magnets inside the dome allowed their position to be tracked. The golf balls were later replaced with

plastic handles that more easily afforded hand-held use (see Figure 4). One challenge with this design is that if a user pulls hard on one of the handles, it becomes detached from the interior magnet, which falls down in the containing structure and needs to be manually re-attached.
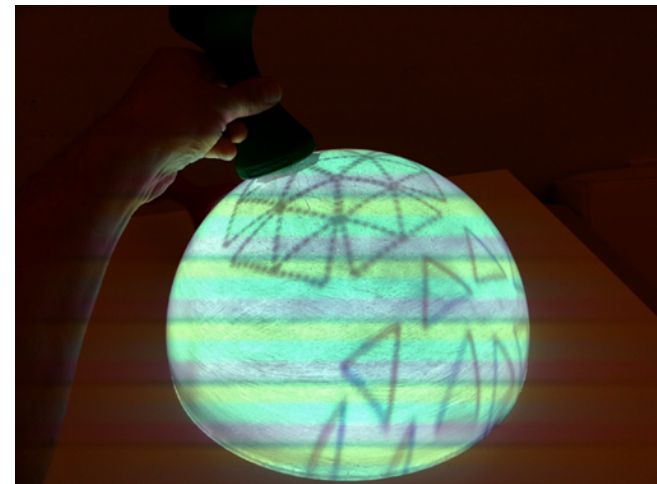

figure 4. Initial design with tangibles.

The tangibles were red and green to clearly signify opposite purposes: green for selecting and moving, red for dropping. By moving the green tangible into proximity with a triangle, the triangle element would become attached to the tangible and could then be moved around. Moving the red tangible into proximity with the green would to cause the detachment of the triangle, thereby placing it on the surface.

Touch Interaction
The interaction using tangible handles was later replaced with finger-touch interaction, allowing for a

more straightforward user interaction. With touch interaction, a triangle can be selected and moved with a one-finger touch and slide (see Figure 5). Lifting the finger from the surface drops the triangle into place on the surface. Triangles can be moved again with the same interaction technique.

figure 5. Final design with touch interaction.

Technical Implementation

We used pre-made materials that were modified and combined to create a box structure with a hemisphere acrylic dome as the projection/interaction surface. Side panels are acrylic with laser-cut shapes matching geodesic dome pieces. The interior of the structure contains an InFocus LP70 projector, mirror, three Infrared (IR) light sources, iSight camera modified to allow IR light, and Mac Mini computer with reacTIVision 1.4 and Processing 1.5.1 software. The interior of the acrylic dome is painted with a transparent acrylic medium creating a surface that can display the

projected image while remaining semi-transparent in order to detect finger touches. Figures 6 and 7 show the arrangement of system components inside the box from side and top views.
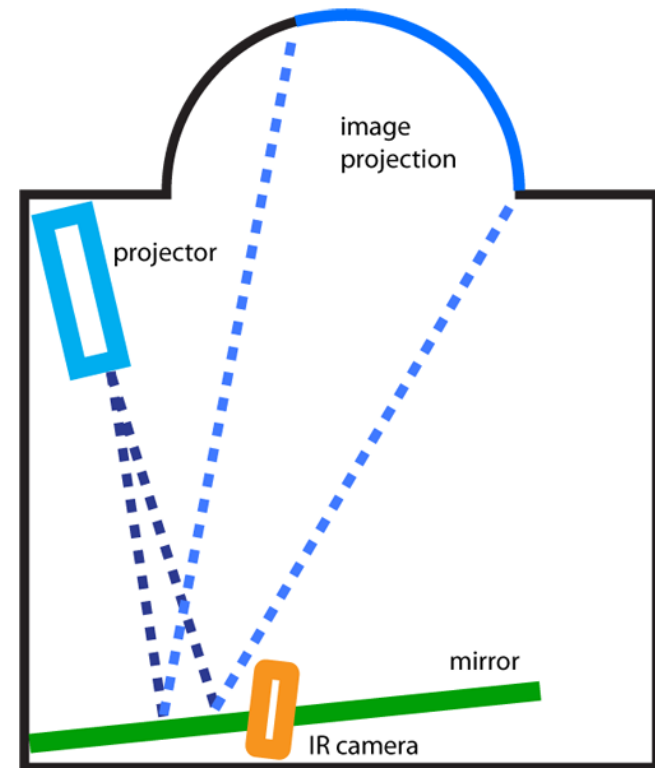

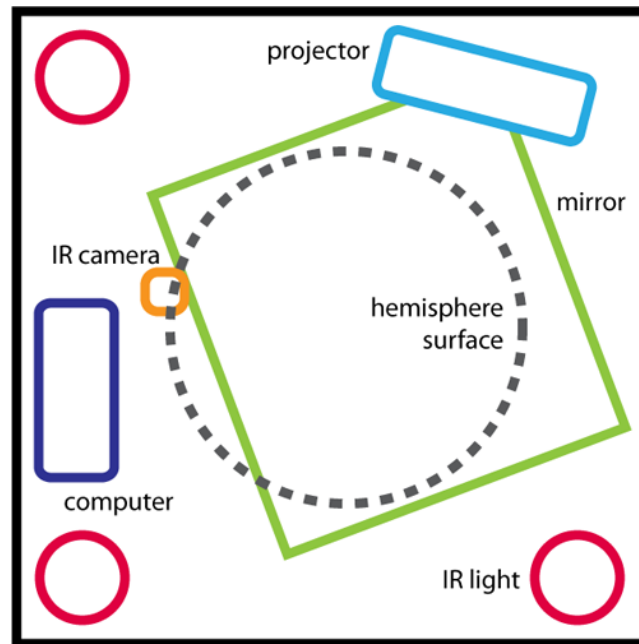**figure 6.** Diagram – side view – projection components.

figure 7. Diagram – top view – system components.

Evaluation and Discussion

During project development, user testing was conducted to evaluate technical components and usability. We invited visitors to interact with the piece at varying stages of progress during several demo showcases in our research center. Design iterations based on these tests resulted in our decision to base the interaction on the arrangement of triangles (rather than altering measurements) and in the use of touch interaction. Earlier designs included the use of tangibles, which had both technical and interaction challenges. The height (20") affords the reach of young children (approx. age 6-7). The structure can be placed on a platform to raise its height. In the overall exhibit design, this structure is the main component. Other design elements can compliment this piece, including media to introduce the subject and provide overall context.

There are a number of technical improvements to the project that would bring it closer to the intended design. Currently, the image projection covers roughly one-half to three-quarters of the hemisphere. The dimensions of the box structure can be increased vertically to allow for more distance in the projection from the mirror, thereby creating an image that covers the hemisphere completely. The projected image on the hemisphere results in a distorted image that is more pronounced closer to the base or equator. To have a true representation of the projected shapes, this distortion needs to be corrected and compensated for in the software. The touch interface can be changed to allow for multi-touch interaction, which would allow for multiple users. Several types of geodesic dome pieces can be generated to allow for building structures with a variety of patterns based on frequencies and division types. Implementing a version of the interaction design that allows the user to manipulate the position of vertices (hubs) to visualize the resulting change to the overall geodesic pattern could be implemented. This would be closer to the original concept of allowing the user to change specific parameters in an existing structure and view the resulting effect on the overall structure.

Conclusions and Future Work

The project allowed for an exploration of interaction design, exhibit design, and tangible user interface design. The use of the hemisphere surface was an experiment and design choice driven by the goal of

developing a unique user experience that would translate the complicated theories of geodesic dome construction into a simplified, accurate interaction. Incorporating the technologies and industrial design considerations, with the goals of fitting conceptually within the framework of a science museum exhibit design for children, the project was successful. Further development of an overall exhibition design could place this project in context. Adding media to provide further information for users would make the project a stand-alone piece. User testing with children in an exhibition setting would provide useful feedback for further design iterations.

Acknowledgments

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