An Inflatable Hemispherical Multi-touch Display

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ABSTRACT
In this paper, we introduce a multi-touch display surface that can be dynamically deformed from a flat circular display to a convex or concave hemispherical display. A rubber latex material is used for the display surface allowing it to inflate or deflate as air is pumped into or out of an airtight container. The elasticity of the display surface also allows users to deform the surface by varying the pressure exerted on it. This deformation may be detected by the device and provides a z-axis input in addition to the typical x,y-axis inputs of flat-screen displays.

Author Keywords
Input devices, Multitouch, Haptic I/O, Organic User Interfaces.

ACM Classification Keywords
H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

General Terms
Human Factors.

INTRODUCTION
When manipulating objects in a computer system it is desirable for the physical properties of the interface medium to resemble the virtual objects being manipulated [10, 19]. With the traditional flat screen display, users have to settle for a geometric projection of a three-dimensional virtual object onto a two-dimensional display surface.

This paper proposes a single display surface that can be flat or domed, and whose curvature can change dynamically and incrementally between those states. This flexibility allows the display surface to mimic a wider variety of objects, in particular spherical and hemispherical objects. More importantly, the user can interact with a surface shape appropriate to the context of the task at hand.

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The Applications section of this paper describes such an example using Google Earth [4], where the display is hemispherical when zoomed out and flat when zoomed in. Other applications include using the device as a musical instrument, especially a drum.

The tactile properties of the rubber latex surface offer a novel way to experience haptic feedback. The firmness of the display surface changes as the air density in the container changes, allowing the surface to mimic the density of different materials. Finally, the Applications section describes how an inflated display can be used to probe and navigate a 3-D brain scan.

BACKGROUND
Different characteristics of the inflatable display have been explored by existing research. Volumetric display interfaces have been considered [1] and built [5] using motion-captured gestures and 3-dimensional displays. Unlike a motion-capture approach, our inflatable display allows interaction with fingertip contact on a surface.

Globe4D [3] and ViBall [11] are examples of a half-sphere and spherical display, respectively. Globe4D excels as an interactive globe, but is not designed to manipulate general spherical objects. Though ViBall's uses can be more varied, it uses external projection causing occlusion when the user is close to the display. Internal projection in the inflatable display eliminates hand shadows and its actuated deformable display surface allows a wider variety of object shapes to be accurately represented.

CrystalDome [14] and DOME [20] have explored projection from underneath a half-sphere onto its interior. DOME additionally uses head tracking to present a customized view to users on opposite sites of the display and requires cooperation between its six projectors to correctly illuminate a point on the display. CrystalDome uses sensors mounted on the table near the display to track hand movements, and supports the translation, scaling, and rotation of images on the display.

Sphere [2] uses a single projector housed internally at the base of its spherical display [7] and has an internal infrared camera used to track hand movement on the surface of the sphere. Both the projector and IR camera share the same optical path, similar to our inflatable display.

In the past, the editing of 3-D objects by direct gestural interaction has been studied for regular planar interfaces [12, 16] and there has been work with motion-captured gestures to edit 3-D objects displayed on a separated flat surface [18] or on a 3-D volumetric Actuality Perspecta display [5]. Sheng et al. [18] examined the use of a physical object, such as a sponge, as a proxy for the user to hold and deform while gestures were detected via motion-capture. Again, the 3-D object being edited was displayed on a separate screen. Our approach is similar because the user deforms a physical object by applying pressure to it, but we detect the deformation of the display surface itself rather than the position of the users hands.

Harrison and Hudson [6] describe a tactile display surface with many similarities to ours. It is also a rear-projection multi-touch display device with a latex surface that can be deformed with pneumatics, but Harrison and Hudson emphasize display surface buttons that can be positively or negatively inflated for tactile feedback. Kim et al. present an inflatable mouse [13] that can sense pressure input from the user and also provide actuated inflation and deflation.

DESIGN CRITERIA

The design philosophy of this project was to unify input and output interfaces as much as possible. We attempted to implement this duality in each interaction property of the inflatable display to help create an organic user experience. We identified two main interaction properties of the inflatable display: the image on the display surface, and the shape of the display surface. For the display surface we chose to use rear projection to avoid hand shadows, requiring the projector to be mounted inside or underneath the flexible display surface. We also wanted the display surface to function as a multi-touch input device to allow the user to interact directly with the shaped data display. Multi-touch detection should occur in both the inflated and deflated states.

Haptics and Shape of the Display Surface

The inflation and deflation of the display surface should allow the display to automatically reshape itself according to the context of the user task, or for the user to easily customize the shape of the display surface to their liking. For example, if the device is being used as a drum the volume of air in the container and can be adjusted to give the surface a specific pitch when struck. Actuated inflation also provides haptic output in the form of the surface's firmness. As the air density behind the surface increases it feels firmer and offers more resistance to external pressure. When the user pushes on the surface, it is able to push back at varying strengths. The user should able to deform the shape of the display surface by applying pressure with their fingertips or hands. User input through pressure is typically asymmetrical, whereas actuated inflation will always result in a symmetrical deformation of the surface. The inputs and outputs described above should be intimately linked with each other and the user task so when an input is changed, it immediately updates one or more outputs for direct feedback. More concretely, as the user touches and pushes on the surface, the display image and surface shape should also change in a way that is intuitive, logical, and consistent with the application [17].

IMPLEMENTATION

This section describes the hardware used to create our prototype, depicted in Figure 1. Materials were chosen with our design criteria in mind.

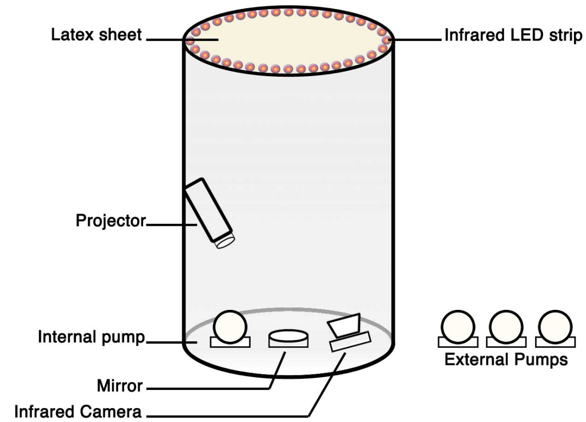

Figure 1. Schematic of the inflatable display canister.

The frame of our device is a plastic cylindrical canister with a height of 35 inches and a diameter of 14.5 inches. Holes were drilled in the side of the canister to run power and data cables for the internal electronic components and for air tubes. A sealant was used around the cables and air tubes to maintain an airtight container. A rubber latex sheet, cut from a 36 inch white balloon, was stretched over the canister's opening to form the display surface and held tightly in place with a metal brace.

An infrared camera placed at the bottom of the canister is used to track multi-touch input on the display surface. This tracking is aided by a strip of infrared emitting lights placed along the external circumference at the top of the canister and directed inward along the plane of the display surface. As a fingertip approaches and touches the surface, infrared light from the light strip reflects off the skin and down through the latex where it is picked up by the infrared camera. The areas of high infrared concentration represent fingertip contact and provide basic multi-touch tracking. As the user presses harder on the surface, the size of the tracked fingertip grows, providing a mechanism to measure z-axis deformation. This fingertip size information is not available in our current prototype’s finger tracking software, but we plan to remedy this in the near future so z-axis values can be captured and used.

A pico projector is placed inside the canister, which projects an image onto the rear of the display surface. To enlarge the display, we positioned the projector along the wall of the canister and directed the projection down towards a mirror placed at the bottom of the canister, which then reflected the image up to the display surface. An alternate way to achieve this effect would be to use a projector with a short throw lens, but we were dissuaded from using one due to its relatively high cost and bulky size.

Four aquarium pumps (three external and one internal) were connected to the air tubes and used to move air into and out of the canister. The current flow rate of these pumps is moderate, and we discuss way to improve inflation speed in our Future Work section. An electronic relay was used to control the activation and deactivation of the individual pumps.

USER INTERACTIONS

The inflatable display has several characteristics that are not usually found in common display screens, and thus offers an opportunity to explore user interactions that are unique to it.

Haptic Experience

A latex rubber material is an uncommon choice for a multi-touch surface and has tactile properties that differ from traditional rigid flat screen displays. Fingertips glide across the rubber surface easily with light pressure, but become more difficult to drag across the surface as the amount of pressure and deformation increases.

Another interesting property of latex rubber is its elasticity, which causes it to return to its original shape immediately after finger pressure is removed. This results in user deformations that are temporary, and any output information that depends on such deformations is quickly lost unless explicitly remembered by the application. The latex rubber therefore lends itself well to tasks using probing actions of the surface where deformation retention is not a high requirement, such as navigating medical scans and other volumetric data [15]. This contrasts with other deformable displays such as Illuminating Clay [9], in which deformations are permanent and the material never returns to its original form.

Multi-touch Gestures and Z-axis Deformation

Multi-touch gestures for flat screen displays have coalesced around several basic and commonly used gestures for virtual object manipulation: one-touch gestures for object selection and translation; and two-touch gestures for object rotation and scaling (pinch zoom). The z-axis deformability of our rubber display material provides another dimension for meaningful gestures.

For example, when organizing a jumbled pile of images you could send the top image to the bottom of the pile with a gesture pressing it into the display surface. For even greater control, the degree of z-axis deformation could determine the depth of the object in the pile or stack.

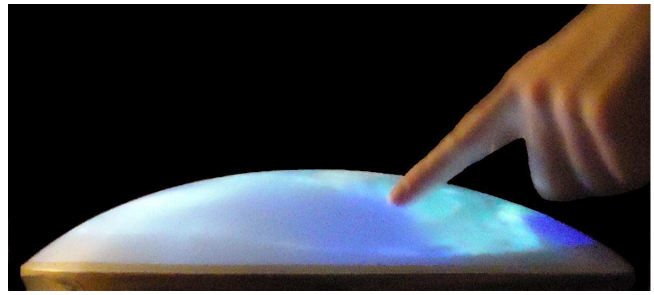

Figure 2. A partially inflated display of the Earth.

Another possibility is using a pinch-and-lift gesture to remove a virtual object from the display surface. The rubber material allows the user to literally pinch the display surface, unlike with a flat screen display. The removed object could be "held" above the screen and when the user touches another part of the screen it could reappear there. This lift-and-drop operation could be used in unison with a drag-and-drop operation to intuitively move multiple objects around a workspace with ease.

Z-axis deformations used in conjunction with multi-touch lends itself well to artistic applications. Consider a multi-touch paint application, where the z-axis could be mapped to the lightness of a colour. Pressing harder on the surface could produce a darker paint tone. Multi-touch music applications could also be influenced, for instance, by mapping the z-axis to the pitch of a note.

APPLICATIONS

Current spherical displays do not allow for consistent interactions with earth data on different levels of zoom [2, 3, 6, 10]. We therefore used Google Earth as a proof-of-concept application to test the inflatable display, as shown in Figure 2. Since the Earth appears flat when close to its surface and round when far from its surface it is an ideal object to manipulate in our inflatable display.

When zoomed out, the display becomes fully inflated and the Earth can be viewed as a globe. Zooming in will incrementally deflate the display surface until it becomes flat and can be viewed as a two-dimensional map. This context switch is continuous and unobtrusive to the user's task, and allows different geographical viewpoints to be presented in the way most naturally suited for them.

Another application is a steel pan drum simulator, used to demonstrate negative inflation (a concave display surface). An image of a steel pan surface is displayed on the concave display screen, and striking the various notes with a finger will produce the correct sound. While this example does not use dynamic screen inflation or deflation, it does demonstrate the versatility of a deformable display surface.

McGuffin et al. describe the advantages of using deformations to browse volumetric data such as medical scans [13]. The inflatable display is well suited to this form of browsing, and in particular navigating 3-D brain scans.

The fully inflated display can represent the hemispherical surface of the brain, and pressing on the display can reveal the interior layers of the brain in that area of the scan. By pressing harder on the surface, the user can see deeper into the 3-D brain model.

FUTURE WORK

In the future we wish to improve our inflatable display prototype by augmenting its hardware and software, and exploring new interaction techniques. Z-axis information can be captured by using finger tracking software that provides the fingertip blob sizes in addition to the x,y screen coordinates. We also hope to make finger tracking more consistent during inflation. Currently, fingertips placed on the surface near the circumference appear different than those placed in the middle while the screen is inflated. A diffusion layer for the infrared light strip would help remedy this by providing a more uniform infrared light source. The airflow rate can be improved with a single more powerful pump or a pneumatic plunger that pushes a volume of air into the canister quickly. This provides a prompt inflation response to user input when necessary.

CONCLUSIONS

In this paper, we introduced a multi-touch display surface that can be dynamically deformed from a flat circular display to a convex or concave hemispherical display. We used a latex material for the display surface, which allows it to inflate or deflate as air is pumped into or out of an airtight container. The elasticity of the display surface also allows users to deform the surface by varying the pressure exerted on it. Applications include earth browsing with support for flat zooms as well as convex overview, and for medical or 3D image data manipulation.

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