A Perspective-Corrected Stylus Pen for 3D Interaction

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***Abstract*—Compared to traditional flat displays, the three-dimensional (3D) spherical display allows us to see images more naturally from any directions. This display can show not only surface information data, such as digital globes, but also 3D objects. Some user interfaces, such as multi-touch and gesture interfaces, have been implemented on this display. In this study, we propose a novel perspective-corrected stylus pen that can be used for 3D interaction with the display. The stylus pen has six Degrees of Freedom (6DoF) and can be used as pointing and drawing device in the 3D space within the spherical display. Therefore, the user can see the auxiliary line from the pen tip from a different angle. We demonstrated the stylus in terms of accuracy, pointing stability and how users can correctly perceive it in the 3D space. Some applications, such as selecting objects inside a virtual fish tank, were presented to show the usability of the proposed stylus.**

Keywords-VR; 3D stylus; spherical display; virtual reality; perception.

I. Introduction

In recent years, non-planar displays have been actively developed. These displays can display images that are more effective and immersive than flat displays. Non-planar displays can be broadly classified into three types: curved, cylindrical, and spherical. Curved displays have already been put to practical use in mobile devices. They provide excellent visibility even at the edges of the screen. Therefore, some additional information can be put on the edge of the screen. Cylindrical displays are expected to be new digital signages which can effectively display advertisements. Spherical displays, on the other hand, can display images from any angle. These displays can display not only surface information data, such as digital globes, but can also display three-dimensional (3D) objects inside.

Many efforts have been conducted to produce spherical displays. These include a combination of multiple small flat display panels (Geo-Cosmos [1]), synchronized rotating Light-Emitting Diode (LED) strips [2], and a projection mapping system using a Digital Light Processing (DLP) projector [3]. PufferSphere [4], a commercially projector-based spherical display, has a multitouch interface allowing human interaction with the display, such as pointing and rotating.

The spherical display can be enhanced to represent 3D objects [5]. The 3D experiences can be achieved by using monocular (motion parallax) or binocular (stereoscopic) cues. Motion parallax is a type of depth perception cue in which objects that are closer appear to move faster than objects that are further. Stereoscopic vision refers to the sense of depth derived from the two eyes. Fafard et al. [6] indicate that users' performance in various 3D interactions, such as pattern alignment, distance estimation, 3D selection, and 3D manipulation is consistently better when stereo cues are included.

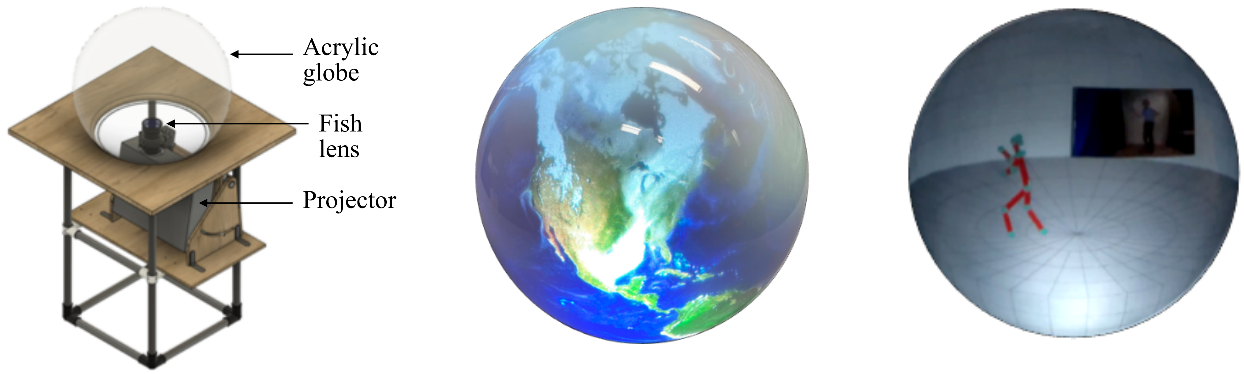
3D interactions with the 3D sphere display need a device that capable to define its 3D location (*x*, *y*, *z*) with respect to the center of the display and its posture information (*pitch*, *yaw*, *roll*). Hereafter, information of 3D location and posture is simply called Six Degrees of Freedom (6DoF).

Currently, several input devices equipped with 6DoF sensors have been developed. The Touch™ Haptic Device [7] is a motorized device that applies force feedback on the user's hand, allowing them to feel virtual objects and producing true-to-life touch sensations as user manipulates on-screen 3D objects. This device acquires the 6DoF information from a sensor attached to the pen tip. The DodecaPen [8] is a stylus pen which obtains its 6DoF with sub-millimeter accuracy using multiple Augmented Reality (AR) markers arranged on a dodecahedron mounted on the stylus. Both styluses [7][8], however, are designed to work on a flat surface where the working area is limited.

A stylus pen for the spherical display must be able to acquire the 6DoF information of the pen tip when touching the surface of the display. The arm for the Touch™ Haptic Device limits its working range, especially when working on the opposite side of the spherical display surface. This problem also applies to DodecaPen because the AR markers of the stylus will be hidden when working on the lower part of the spherical display.

In this study, we propose a stylus pen which is suitable for a spherical display. Measurement of the 6DoF information is done using two sensors. Here, the 3D location (*x*, *y*, *z*) of the pen tip on the display surface is measured by an infrared (IR) camera installed at the bottom of the display. The posture information (*pitch*, *yaw*, *roll*) of the stylus pen is obtained using a gyro sensor. We believe that the new stylus pen's strategy for measuring 6DoF information is effective in capturing this information when the pen tip is touching the display surface.

This paper is organized as follows. Section II describes related works in the development of 3D spherical displays. Section III introduces our approach to implement the perspective-corrected stylus pen. Section IV describes our experiment results in terms of accuracy, stability and visual perception. Finally, Section V presents our conclusions and future works.



(a) Our 3D spherical display (b) Earth (c) 3D human pose

Figure 1. Our 3D spherical display (a) and some contents (b), (c) projected onto the display.

II. Related Work

There are some companies producing spherical displays, such as Global Imagination [3], PufferSphere [4], and ArcScience [9]. These displays were mainly intended to show earth surface data and 360-degree videos. Therefore, there are more like digital globes than displays.

To our knowledge, SnowGlobe is the first published 3D spherical display [10]. This display was implemented by reflecting a projected image off a hemispherical mirror, allowing for a seamless curvilinear display surface. However, it had non-uniform resolution and the mirror caused a blind spot. Spheree is a spherical, multi-projector perspective-corrected display that supports 3D representation using parallax-based 3D depth cues [11]. Uniform resolution is mostly achieved because each projector covers a small area on the display. CoGlobe is a large 3D spherical display for multiple users [12]. It uses a multi-camera OptiTrack system for tracking users' heads and multiplex viewpoints using modified active shutter glasses.

For this study, we have built a 3D spherical display similar to Spheree, but only using a fish-eye lens-equipped single projector (Figure 1). A 4k projector was used to generate a high-resolution image onto the display, comparable with that of Spheree. Our display is capable of supporting monoscopic and stereoscopic displays.

III. Perspective-Corrected Stylus Pen

The proposed stylus pen can find its 6DoF information on any location on the display. As shown in Figure 2, the 3D location (x, y, z) of the pen tip on the display surface is measured with an IR camera. This camera captures the blob (the image of the light reflected from the IR LEDs) of the pen tip. An ellipse is then fitted to the blob, and the center of the ellipse is calculated as the position of the pen tip on the display surface. The posture information (*pitch*, *yaw*, *roll*) of the stylus pen is obtained using a gyro sensor.

In order to simplify the design of the stylus pen, we use a mobile phone with a pen tip attached. The advantage of using a mobile phone is that we can use the built-in gyro information, and send that information to the computer that controls the spherical display. Using this information, the computer calculates the posture of the stylus pen and projects the auxiliary line from the pen tip according to the user's viewpoint. Here, we used VIVE Tracker [13] to track the user's head and define the viewpoint. Users can point out an object inside the spherical display using the auxiliary line from the pen tip, as shown in Figure 3.

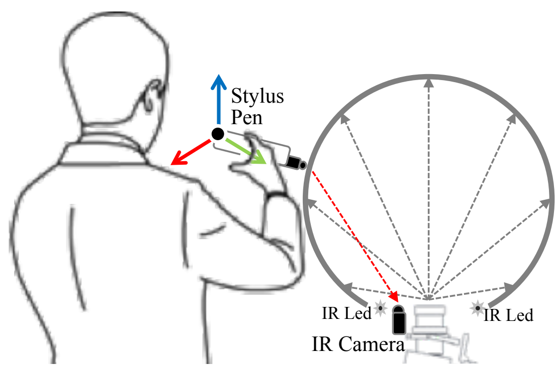


Figure 2. Our proposed stylus pen.

IV. Experimental Results

We evaluate the proposed stylus pen in terms of accuracy, pointing stability, and user experience. For the experiments, we built a spherical display with a diameter of 51 cm. The coordinate systems of the display, stylus pen and user's viewpoint are calibrated using the VIVE tracker. The display system runs on a desktop computer with a 3.6 GHz CPU, 32 GB RAM, and a GTX980Ti graphics card. An iPhone 7 (iOS 13) is used to get the posture information for the stylus pen.

A. Accuracy

Twelve arbitrary locations on the display surface were selected and the stylus pen was used to point to the center of the display from each location. The resulting 6DoF information of the stylus pen on each location was validated against the true 6DoF information (ground truth) as the vector

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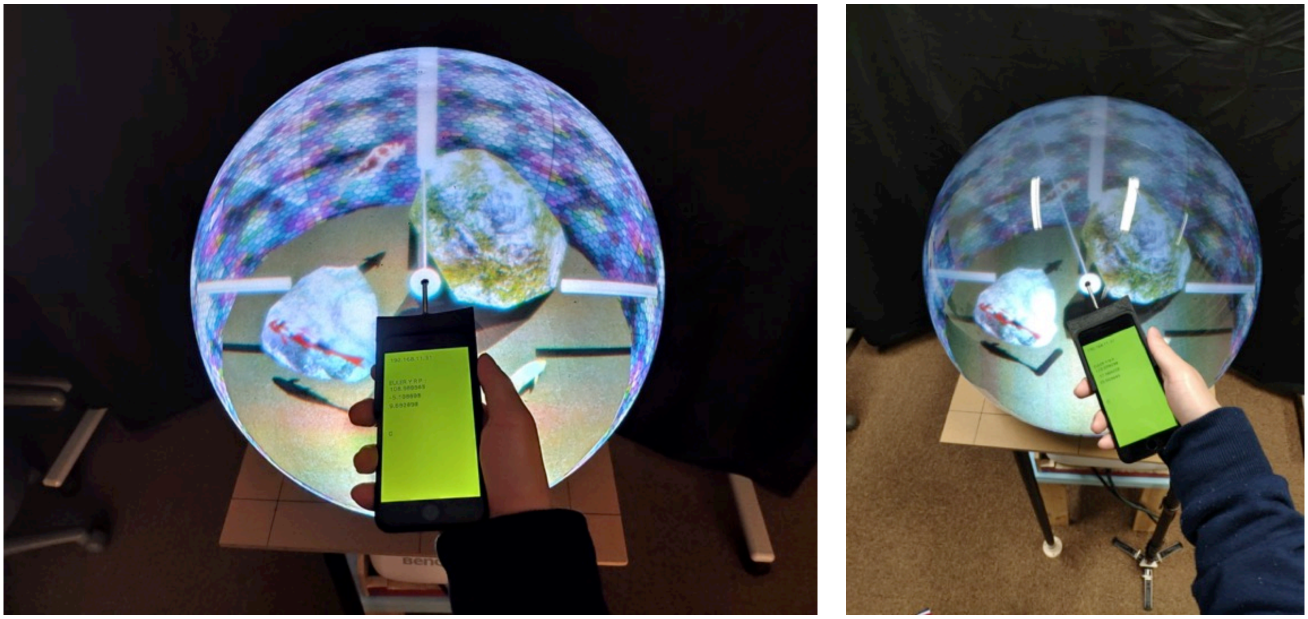

Figure 3. Our working perspective-corrected stylus pen.

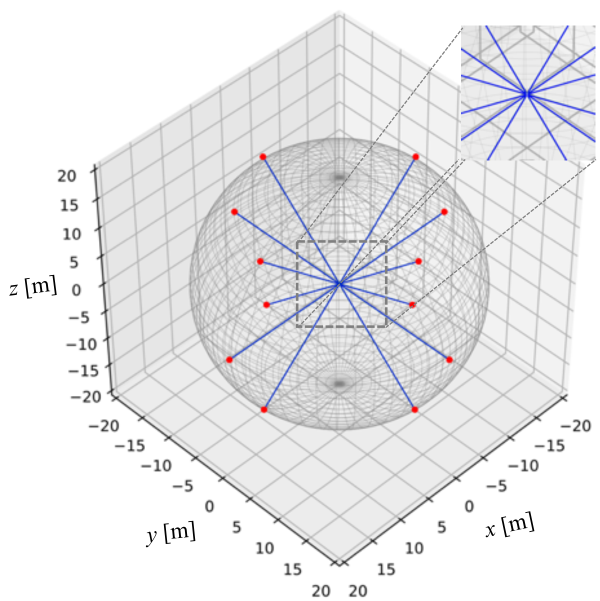

Figure 4. The resulting auxiliary lines from the pen tip and their corresponding ground truths.

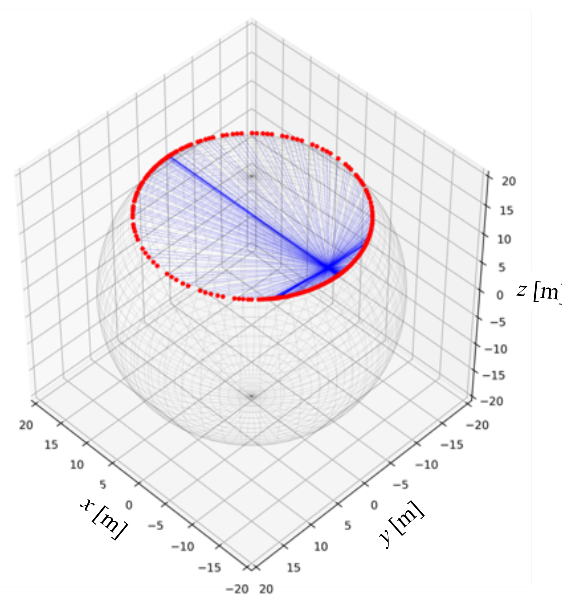

Figure 5. Intersection points of the auxiliary lines from the pen tip and the display surface.

connecting the display center to that location. Overall, the accuracy was achieved with an average of 1.08 degrees. The ground truth vectors (red lines) and auxiliary lines from the pen tip (blue lines) are shown in Figure 4. We considered that our stylus pen is accurate to do 3D interactions within the spherical display. In practical use, most users are not aware of the differences within this range.

B. *Pointing Stability*

The stylus pen was rotated horizontally from 0 to 180 degrees at a location toward the display. For each angle, the intersection (red dot) of the auxiliary line (blue line) from the pen tip with the display surface was calculated. The resulting points were observed to be horizontally distributed (Figure 5), indicating the pointing stability of the stylus pen. The error distribution is shown in Figure 6.

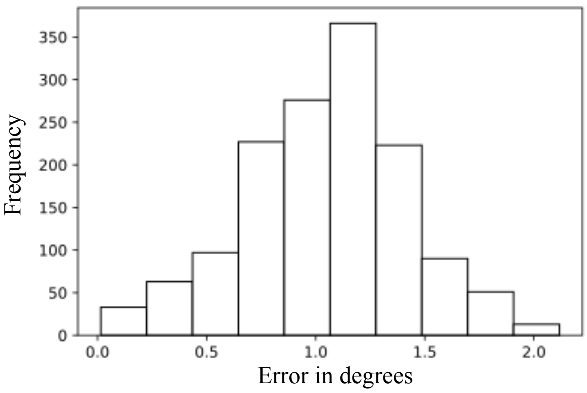

Figure 6. Histogram of the error distribution during the pointing stability test.

Figure 7. The virtual fish tank used for the visual perception evaluation.

C. Visual Perception

In order to perform a visual evaluation, an experiment was performed in which a virtual fish tank was drawn on a spherical display and the subject was instructed to use a stylus pen to touch the fish from multiple directions (Figure 7). Three users participated in the experiment. All of them managed to touch all fishes in the spherical display. This result shows that the proposed stylus pen can be perceived in the same way as the real one.

V. CONCLUSION

In this study, we have proposed a novel perspective-corrected stylus pen that can be used to interact with a 3D spherical display. A mobile phone with a pen tip attachment is used to build the stylus pen. The use of a mobile phone does not only make it easier to obtain posture information from the built-in gyro, but also has advantages, such as simplifying the design. The location where the stylus pen touches is detected by the IR camera installed in the spherical display. Our experiments have confirmed the high accuracy of the proposed stylus and show that it can be used to perform natural 3D interactions. We are working on putting a pressure sensor inside the stylus pen to enable the user to control the length of the auxiliary line from the pen tip by applying varying levels of pressure to the screen surface. In the future, the proposed stylus pen will be extended for use in virtual surgical training on a spherical display.

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