DYNAMIC SPHERE: DIRECT MANIPULATION OF 3D VIRTUAL OBJECT ON A HANDHELD SPHERICAL DISPLAY ISSSG 2014

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ABSTRACT: Viewing and manipulating 3D virtual objects are two of the most common tasks for many computer users such as designers and architects. In this paper, we proposed a movable handheld spherical display system known as Dynamic Sphere. It uses a projector to project digital content onto an ordinary Styrofoam sphere surface without any special patterns printed on it, or any connected wires and special sensors attached to it. Users can observe different views of the virtual 3D object by simply rotating the sphere. Such a system can give the user greater freedom of control such as a 360-degree manipulation of the 3D model. It means the user can view and manipulate the virtual 3D object as natural as interacting with a real object. The implementation of the system is based on the combination of computer vision and insect vision model. Experimental results show that our system can allow the user to view and directly manipulate a 3D virtual object on a movable sphere.

INTRODUCTION

Spatial augmented reality uses projector-camera systems to project digital content onto objects directly. It offers the possibility to augment objects without requiring the users to wear any devices (e.g. polaroid spectacles). Usually a person uses a fixed monitor as the display device, or uses a projector to project the display content onto a wall or screen. In these cases, the displays are at fixed positions. Alternatively, a hand-held display device gives users greater freedom of control such as the viewing angle and distance. However, the screens of most hand-held display devices are small. Increasing the size of the screens of these devices will make them heavy and not suitable for a mobile purpose. Though electronic paper is light, it is still not available at low cost. So, an alternative solution is needed.

Many researchers use Head Mounted Displays (HMD) implemented with ARToolkit to provide an interface between the real world and virtual object. However, such implementation is considered intrusive. In addition, HMD based systems are uncomfortable to wear. Other researchers such as Konieczny et al. (2005) and Lee et al. (2008) have explored the use of a projector to project display content onto a movable surface and showed different applications of such movable hand-held displays. However, all these approaches need to attach sensors onto the movable surfaces. So, specially made projection surfaces are required. Computer vision is a more convenient approach to detect and track the movable sphere as we do not need to add sensors onto it. Hence, any ordinary Styrofoam sphere can be used as the movable display. Lee et al. (2009) proposed a movable handheld display system that uses an ordinary cardboard as a display surface. However, when the cardboard is oblique from the view of the user, the viewing angle of the cardboard becomes very narrow. As a result, the viewer can only observe part of the 3D object. In contrast to planar displays that present data on their rectangular surfaces, spherical displays present data on curved

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surfaces that offer a borderless viewing experience. Benko et al. (2008) proposed an improved interactive multi-touch spherical display. However, his display system must be at fixed positions.

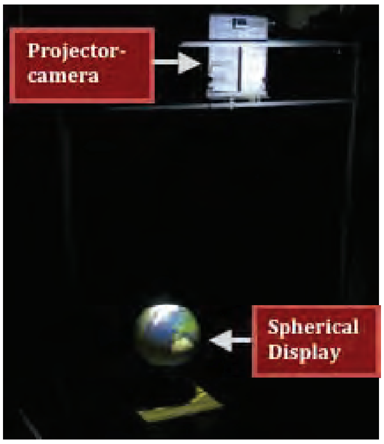

Figure 1. Setting of our spherical display system.

In this paper, we present an implementation of a novel spherical display prototype called Dynamic Sphere, which is a direct projector-based system that projects virtual 3D object onto a mobile spherical surface. The overall goal of our proposed system is to enable viewing and manipulating the virtual 3D object to be as natural as interacting with a real object. The configuration of our system is shown in Figure 1. An ordinary Styrofoam sphere is used as an interface element that provides a very intuitive way to interact with the virtual 3D object. Unlike using a mouse that provides only indirect control, the user can manipulate the virtual 3D object directly by moving the sphere in our system.

Our approach can be divided into two main parts. The first part is the motion estimation of the sphere. We detect the sphere from the camera images and use particle filter to track its subsequent motion. The second part is the 3D virtual object projection. We transform the 3D virtual object according to the rotational motion, and correct the object view with respect to the relative relationship between the user and the holding sphere. Figure 2 shows the overview of our proposed system.

MOTION ESTIMATION

The rotational measurement of the sphere is one of the challenges in this work. Basically, the rotation of the sphere can be measured internally by installing inertial or magnetic sensors inside the sphere. However, it raises the power supply issue. The power cable will limit the rotation of the sphere. If a battery is installed, it needs to be recharged periodically.

To measure the rotation externally, a vision-based method by measuring the optical flow is proposed. However, the sphere requires a plain surface for image projection. The tracking of a surface without visible features is a challenging task. To solve this problem, an IR laser beam is shine on the ball surface to generate a speckle pattern. Speckle pattern is an intensity pattern due to the interference of the reflected wave front from the surface (Fig. 3a). As the ball surface is not perfectly smooth, the beams are reflected from the surface and interfere with each other. When the surface is rough enough with path-length difference more than one wavelength, the point with constructive interference results in bright spot while destructive interference results in dark spot. It can only be observed under laser lamination due to its coherence properties. Other light source with low coherence will generate different speckle pattern with different wavelength which usually average out the pattern.

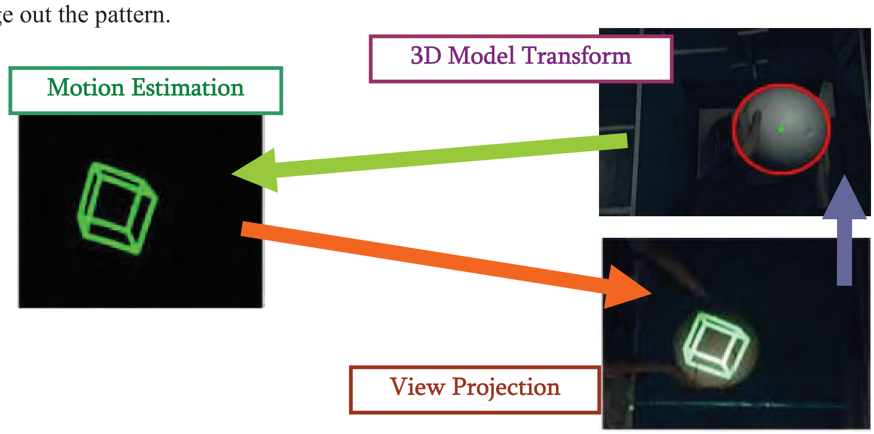

Figure 2. Overview of our methodology.

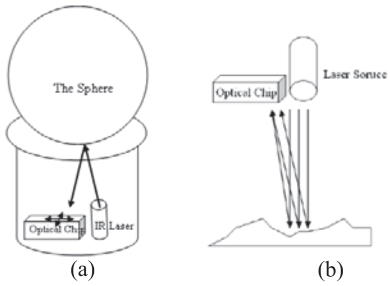

Figure 3. (a) Configuration of laser source and optical sensor. (b) Showing how the beam reflected from a rough surface.

By setting the optical flow sensor and laser source as shown in Fig. 3b, the rotation can be measured by tracking the speckle pattern reflected from the surface of the sphere. When the sphere is rotated by the user, the pattern moves progressively. In this implementation, an optical chip (ADNS2620) that is commonly found in optical mouse is used. The chip returns the delta changes of pattern s_x and s_y in horizontal and vertical dimension respectively. The calibrated constants c_x and c_y are used to convert the delta changes to the horizontal rotation r_x and vertical rotation r_y respectively.

$$r_x = c_x s_x \quad (1)$$

$$r_y = c_y s_y \quad (2)$$

PROJECTION ONTO THE SPHERE

In order to project digital content onto the movable sphere surface, we have to know the relationship G_p between the 2D projection image point I_p and its corresponding 3D point P_c on the sphere surface. G_p is a 3*4 matrix which can be found using the method by Leung et al. (2009).

$$I_p \propto G_p P_c \quad (3)$$

A webcam is used to detect the location of the sphere. A 3*3 matrix A_c describing the relationship between the 2D camera image point I_c and its corresponding 3D point P_c on the sphere surface is calibrated by OpenCV calibration functions.

$$I_c \propto A_c P_c \quad (4)$$

To show the correct projection of the virtual object, we have to transform the projection image so that user can observe the correct view of the model on the curved sphere surface. Since we know the correct view observed by the user, we only need to match the color of each pixel in the user's view to its corresponding pixel in the projection image. The 3D location of the sphere center is found to assist the matching of the pixels between the two images. The sphere's center can be located based on its image from the camera. The image of a sphere is a conic section under the pinhole perspective camera model. Since the depth is lost in perspective projection, the conic section could be created by a family of co-centric spheres. Only given the conic section, we cannot uniquely recognize the true sphere out of the family. Once the physical radius of the sphere is given, we can uniquely locate the sphere. The projection image is then mapped to the corresponding 3D point P_s on the virtual sphere with virtual 3D sphere center at translation T.

EXPERIMENTAL RESULTS

Our prototype system consists of a projector, a camera, a motion tracking module and a plastic sphere with diameter of 300mm. The projector used in this experiment has resolution of 1280 x 1024 and the camera is a typical low-cost webcam with resolution of 320 x 240. The motion-tracking module is made from a low-cost optical mouse. The projector-camera pair is calibrated using the method described in section 3. All the following experiments were done on a normal PC with 2.13 GHz CPU and 2GB RAM running Microsoft Windows XP.

The first experiment is to test the tracking ability of the motion tracking module. An arrow is projected on the plastic sphere to indicate current movement of the display. The rotational movement of the plastic sphere along the x-axis and y-axis are decomposed into the x and y-component of the arrow respectively. The experiment result shows that the motion tracking module is very sensitive and it can detect even unnoticeable small changes. Figure 4 shows two frames captured during the experiment. We have also tested the performance of our system on rotating a colorful balloon as well as an Earth model. The results show that our approach provides a direct and intuitive method for displaying and controlling such objects. Some demonstration results are shown in Figure 5.

We conducted a user test experiment to compare the performance of our device and mouse. 11 users were asked to rotate a projected globe to a target orientation and hold that orientation for 5 seconds. Figure 6 shows the time recorded for completing the task by using either our system or a mouse. Figure 7 shows the comparison result of the user test. Although most of the invited users have used mouse for a long time, the experiment result shows that the users performed better with the proposed system.

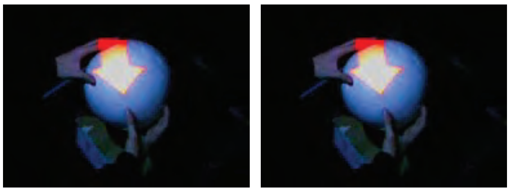

Figure 4. The motion tracking experiment.

Figure 5. System demonstration with different projected content.

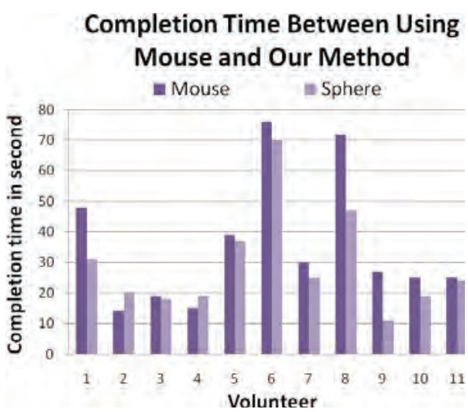

Figure 6. Completion time of the proposed system and conventional 2D mouse.

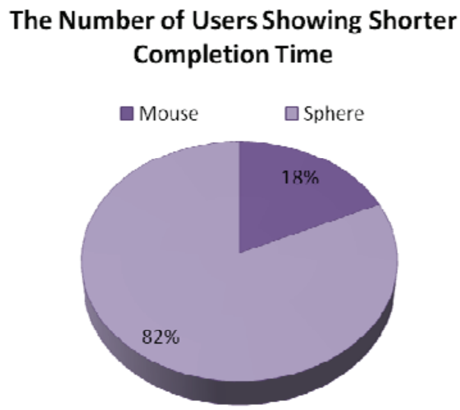

Figure 7. User test comparison result.

CONCLUSION

In this paper, we have proposed a handheld spherical display system based on the combination of computer vision and insect vision model. Our system is easy to build, robust and effective. It is appropriate for various daily applications. However, the sensor for detecting the rotation motion of the sphere is placed underneath the display device. Therefore, tracking of the translation motion is limited to one-dimension only. This can be solved by applying more motion sensors. In the future, we will continue to work on this to improve its accuracy and overcome those restrictions, making it more convenient for practical situations

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