Magic Touch: Interacting with 3D Printed Graphics

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ABSTRACT

Graphics like maps and models are important learning materials. With recently developed projects [2,3,5], we can use 3D printers to make tactile graphics that are more accessible to blind people. However, current 3D printed graphics can only convey limited information through their shapes and textures. We present *Magic Touch*, a computer vision-based system that augments printed graphics with audio files associated with specific locations, or *hotspots*, on the model. A user can access an audio file associated with a hotspot by touching it with a pointing gesture. The system detects the user's gesture and determines the hotspot location with computer vision algorithms by comparing a video feed of the user's interaction with the digital representation of the model and its hotspots. To enable MT, a model designer must add a single tracker with fiducial tags to a model. After the tracker is added, MT only requires an RGB camera, so it can be easily deployed on many devices such as mobile phones, laptops and smart glasses.

CCS Concepts

• **Human-centered computing~Accessibility systems and tools**   • *Human-centered computing~Interactive systems and tools*

Keywords

Computer vision; 3D printing; visual impairments

1. INTRODUCTION

Graphics are important tools in our daily life. With 3D printing, we can use different shapes and textures to make visual information accessible to blind people. Researchers have proposed several ways to enable blind people to make and use tactile graphics with 3D printing. Brown *et al*. [2] developed 3D printing software that could automatically generate tactile line graphs. Kane *et al*. [3] used 3D printing technology to help blind students understand their Twitter visualizations. McDonald *et al*. [5] used a laser cutter and 3D printer to teach graphic design theory to visually impaired students.

While 3D printing is a powerful accessibility tool, 3D printed graphics can only convey limited information through their shapes and textures. Text, like annotations and legends, is hard to represent on these graphics due to limited printing and perceptual resolution and the complex topography of many graphics. For example, when designing an accessible world map using a 3D printer, model designers have to cut down some text to leave
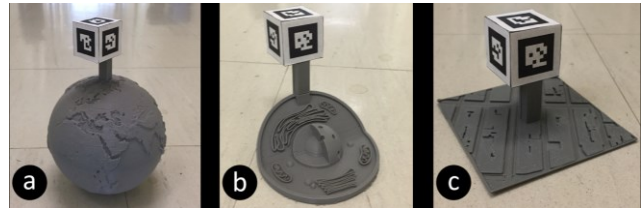
Figure 1. We made three interactive graphics with our trackers: (a) a globe, (b) a cell model and (c) a tactile map.

space for the graphic information. Blind people, especially those who don't know Braille, will still rely on sighted people to understand these 3D printed graphics. The accessibility community has explored several accessible labeling methods for 3D printed graphics. Shi *et al*. [7,8] used acoustic sensing technologies to add accessible labels on 3D printed models. CamIO used bullseye fiducials to track hotspots of annotations on fixed models [6]. However, these systems required a relatively quiet environment or specific settings like mounting a depth camera in a room.

We present Magic Touch (MT), a system that can significantly enhance 3D printed graphics by providing an additional interaction modality, audition. Besides the tactile information from printed graphics, users can access audio information about pre-defined hotspots when they explore the graphics with our system. For example, when a user points to a continent (*i.e.*, one hotspot) on a globe using her index finger, MT will speak relevant information about that continent. MT only requires an attached 3D tracker to track a printed graphic. The system tracks the printed graphics and identifies gestures using the tracker and computer vision algorithms. It takes a video feed as input and outputs audio, so it can be deployed on a variety of devices including smart glasses, mobile phones, and personal laptops.

In this demonstration, we describe the design and implementation of MT. We made three interactive graphics with our trackers (as shown in Figure 1), and implemented our current system on a laptop. Our current system will speak out information corresponding to the hotspot a finger points to. In the future, MT will provide varied output information when users interact printed graphics with different gestures.

2. SYSTEM DESIGN

MT tracks hotspots on a printed graphic with the help of a 3D tracker. The tracker is a cube covered with fiducial tags, which provides spatial coordinates to our system. Hotspots are locations on a graphic that are associated with audio information. MT will record the coordinates of hotspots in a relative Cartesian coordinate system, whose origin is at a corner of the tracker. To make a printed graphic work with MT, a model designer needs to add one 3D tracker and hotspots onto the graphic. To add a hotspot, the designer needs to provide the Cartesian coordinate of the hotspot to our system, as well as the audio information of the
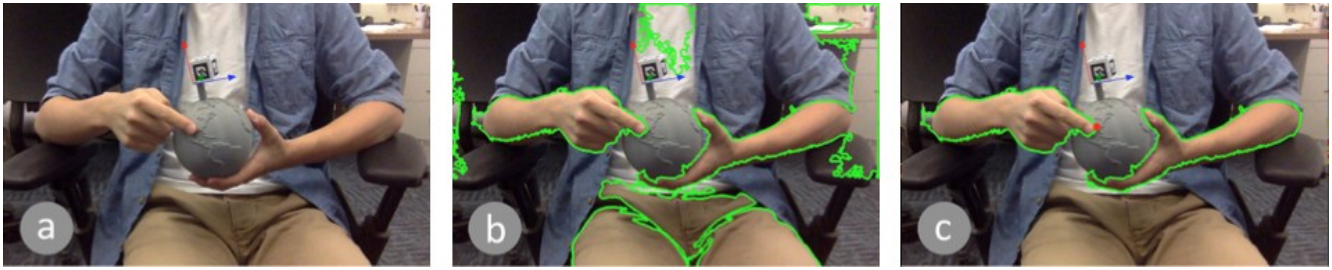
Figure 2. (a) First, our system finds the position of the model based on the tracker. Then, (b) it applies a detector to find all contours that contain skin color. (c) The system identifies gestures in contours that's close to the model, and speaks out information related to a nearby hotspot (marked in red dot).

hotspot. Blind users can run our system using cameras from laptops or smart glasses. When users perform gestures over a hotspot, our system speaks the associated audio information.

2.1 The Tracker

We designed a 3D tracker (as shown in Figure 1) with five fiducial tags, which can be tracked by RGB cameras. The tracker is a 2×2×2 cm^3 cube. We used tags from Chilitags [1], and added one tag on each face of the tracker except its bottom face. With this tracker, a camera will be able to capture at least one tag when users hold models in different directions. The tracker and tags can be printed together in dual-extruder printers. Users can also easily glue paper tags to a tracker whenever dual-extruder printers are not available. The current tracker can be bulky when used with certain models, and we plan to explore less obtrusive tracker designs in our future work.

2.2 The Algorithms of MT

MT has three main functions: it (1) determines the orientation and location of a model in video stream, (2) identifies gestures on the model based on the locations of fingertips, and (3) plays audio files based on the position of the gestures and the hotspot locations.

The system calculates the position of a model by tracking the coordinates of the tags on the tracker. We used the Chillitags C++ library to compute the coordinates of the tags. Based on these coordinates, the system builds a relative Cartesian coordinate system with an origin at a corner of the tracker, and maps the 3D coordinates of hotspots into the current 2D video stream.

Our system uses a color-based skin detector [4] to identify hands. The algorithm finds all contours that contain skin color in the frame and then disregards contours that has no overlap with the model, as shown in Figure 2. For the remaining contours, the system identifies fingertips using a convex-hull algorithm, and recognizes hand gestures based on the locations of identified fingertips.

MT provides audio information about hotspots based on recognized hand gestures. Our current prototype only supports pointing gestures using one finger. The system finds the closest hotspot to the fingertip of the finger, and speaks out information corresponding to that hotspot.

3. PROTOTYPE AND SAMPLE MODELS

We implemented our current prototype in Python, and used the webcam of a Macbook. In the future, we plan to implement our prototype on other devices like tablets and smart glasses, which will provide different user experiences.

We printed three models using a Makerbot 5th generation printer and modified them by adding a bar that can host a tracker to each of the models, as shown in Figure 1. We printed the trackers

separately and stuck paper tags on them. A researcher hardcoded the position and audio information of hotspots in Python scripts. We printed the following three models:

1. A globe model: we added a hotspot for each continent.
2. A cell model: we added a hotspot for each major component.
3. A tactile map: we added a hotspot for each building.

4. FUTURE WORK

In the future, we will design more gestures and make tactile graphics more powerful. Currently, MT allows blind users to inquire about specific elements on a graphic (*e.g.*, the name of each building in a tactile map). We plan on combining multiple gestures and non-speech audio to help users explore such information. For example, a user can perform a zoom-in gesture to browse the names of companies in a building, or uses a series of swipe gestures to select a certain store and read its description. With these new interaction techniques, for example, blind people can use our system to navigate with talking tactile maps when on the go. We will also develop tools to assist designers to add hotspots on 3D models.

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