Multimodal Augmentation of Surfaces Using Conductive 3D Printing

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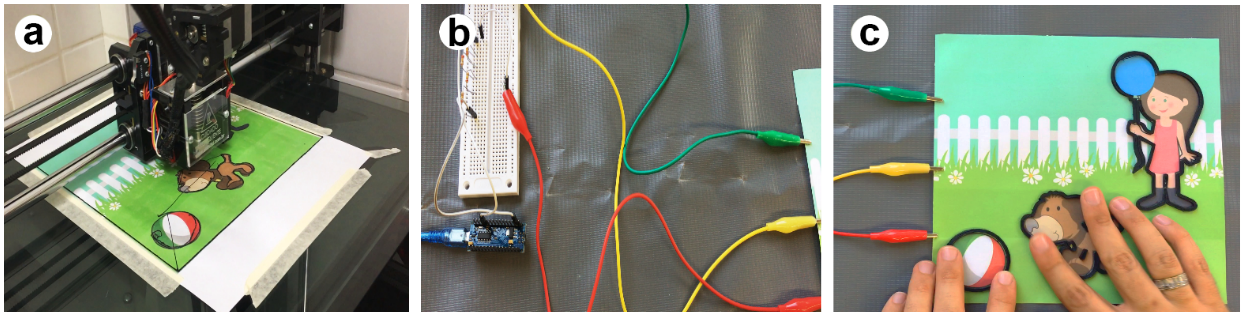

Figure 1: *(a) Registered 3D printing over the drawing placed on printer's bed. (b) Connections between printed content using conductive filaments and circuit board for audio feedback. (c) User sensing the assistive content and triggering the audio associated to the elements being touched.*

Keywords: augmented surfaces; 3D printing; visually impaired touch

Concepts: •**Human-centered computing** → **Accessibility technologies;**

1 Introduction

Accessible tactile pictures (ATPs) consist of tactile representations that convey different kinds of messages and present information through the sense of touch. Traditional approaches use contours and patterns, which create a distinct and recognizable shape and enables separate objects to be identified. The success rate for recognizing pictures by touch is much lower than it would be for vision. Besides that, some pictures are more frequently recognized than others. Finally, there is also some variation from individual to individual: while some blind people recognize many images, others recognize few. Auditory support can improve the points listed before, even eliminating the need for sighted assistance.

[Fusco and Morash 2015] propose a tactile graphics helper mobile system based on visual finger tracking. QR-codes are used as trigger to the content to be read. When users approximate the finger to one of the markers, they can hear a description regarding the visual element. They also revealed that tactile graphics usually take too much time to be produced, due the lack of assistive content processes available.

[Swaminathan et al. 2016] created a solution to help visually impaired users to interact with a complex spatial data and understand the information in there. It is a 140x100cm tactile display system that uses a 3D printer to squeeze liquid PLA plastic onto the board raising tactile lines. Users can feel those lines with their fingers and control the system by voice and by a foot switch.

We propose a pipeline using computer vision techniques for augmenting existing surfaces through touch and sound [Teixeira et al. 2016]. Computer vision is adopted in the content preparation phase, speeding up the assistive content elaboration. Conductive material is deposited over the image and sound feedback is given by mapping printed elements to specific sounds. We show that infant books can be easily transformed into assistive content for visually impaired children using the proposed technology.

2 Our Approach

The proposed pipeline makes use of four distinct components:

- a computer (with at least two USB ports);
- a FFF (Fused Filament Fabrication) 3D printer (RepRap based Sethi3D BB 1.75mm using conductive filament);
- a Microsoft LifeCam Studio webcam;
- a circuit board based on Arduino Nano, used to provide audio response based on what user touches.

The fabrication process starts with the webcam capturing an existing 1080p image placed over the 3D printer's bed and, for simplification reasons, only the 200mm x 200mm central region of the table is considered, as can be visualized in Figure 2. The tool was developed with the OpenCV Library (using C++ language) and receives as input the captured image. In order to calibrate the system, four known points are used in the OpenCVs findHomography function [Bradski 2000]. For that, we have used a G-code that represented a square in the aforementioned dimensions. So, it is only necessary to find on camera image the coordinates for the points (100,100), (300,100), (300,300) and (100,300), all in 3D printer coordinates, as can be seen in Figure 3.

The calibration process results in a transformation matrix H (Homography) which is capable of transforming a point C_i from the

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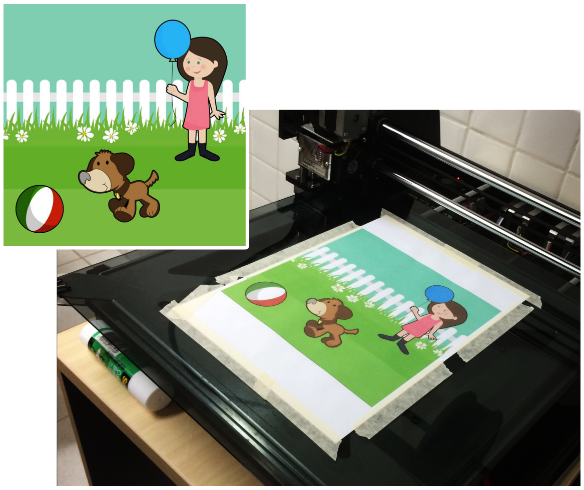

Figure 2: *Image placed over the 3D printer's bed.*

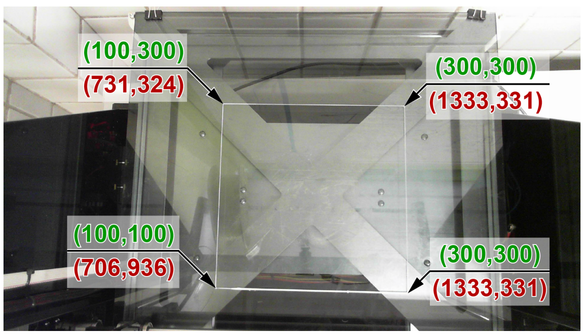

Figure 3: *Correspondences between camera and 3D printer reference points for calibration. Coordinates in red (below) are relative to the webcam's coordinate system, while those in green (above) relative to the 3D printer's coordinate system.*

camera coordinate system to a point P_i in the 3D printer coordinate system using equation (1). As the paper is placed over the 3D printer's bed, the z coordinate the of the point in 3D Printer's coordinate system is always 0 (zero), so a homography is enough to represent the mapping between two planes. With camera-printer system calibrated, the tool establishes a correspondence between both coordinate systems.

$$C_i = H * P_i \tag{1}$$

The image is then rectified, segmented and it has its contours detected. Each contour defines an interaction zone and maps the touch to a specific sound. In order to optimize the G-code generation, contours are simplified using a polygonal approximation algorithm. Both image segmentation and polygonal approximation can be manually adjusted using the sliders present on the tool developed, as can be seen in Figure 4. The generated G-code solely uses G0 and G1 instructions which corresponds to extruder movement and extruder movement with material deposition, respectively. After sent to the 3D printer, the instructions allow the printing process to be registered with the drawing still placed on the printer (Figure 1.a). After printed, each contour is connected to an end point in the circuit board using conductive wires and are then associated to a given sound (Figures 1.b and 1.c). The wires are connected to the analog ports of Arduino Nano and it filters any noise generated when the user touches the conductive filament.

Figure 4: *Tool developed to define contours and polygonal approximation.*

The proposed solution[1] precision corresponds to the precision of the 3D printer used, which in this case is 0.1 mm (0.039 inches) and a total of 5 layers in order to print with the conductive filament and make it work accordingly. The number of different contours to be printed is limited only by the sense of touch (too many contours may confuse the user) and circuit board (a maximum of eight different contours is supported by the current board). We are currently testing the system with visually impaired users in order to verify its potential. By printing on both sides of the surface, we will also be able to automatically construct the conductive channel from the contour to the circuit board connector on the backside of the paper.

Each filament type has its own properties such as work temperature, adherence, diameter. We have found some difficulties regarding the conductive filament brand used in the tests and a deep analysis regarding its adherence is needed. We also plan to test different base materials including Paper, Nonwoven, Acetate, Nylon and PVC so we can know which existing content can be adapted by the proposed pipeline. An analysis regarding the conductibility performance of different materials, such as conductive Graphine and ABS, will be performed as well.

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[1] More details can be found at http://www.cin.ufpe.br/~jmxnt/augmentedprinting