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Modeling the 3D shape of a fingernail and pre-distorting an image to be printed on the fingernail to yield the correct appearance*

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Abstract

In this paper, we explore a technique for printing on the curved surface of a human fingernail. We start by reproducing the shape of the fingernail via a 3D model. In our future work, we will apply a distortion to the halftone image to correct the deformation of the printed image.

Introduction

This technique is a solution to the problem presented by a Nail Printer [1][2][3][4] that The Electronic Imaging Systems Laboratory (EISL) at Purdue University developed in partnership with Sunvalleytek International Inc.. This device was created to print images onto human fingernails using a special gel nail polish formulation and a novel inkjet printhead technology. The problem arose because human fingernails have different curvature measurements and that to produce a high quality print, we are looking into fixing the quality issues on the sides of the nail due to inkjet droplets smearing on non-flat surfaces as well as drop spacing problems. Therefore, we are exploring a method to pre-distort the halftone pattern to mitigate these angular errors.

Although there are some industry methods to create high quality prints on non-flat surfaces, due to the limitation of the form-factor and budget in creating the machine, we need to look for a solution that requires very little to no hardware addition.

Nail Printer

The device for which our technique is targeted is a small portable printer. It is in a form of a cube, 210 mm × 210 mm × 210 mm in size, with a screen and a space for a finger to be inserted (Fig. 1). The screen at the top of the device serves as the interface for a user to operate the device from the steps of choosing a desired image to print to positioning their finger inside the printer. Internally, the device has a printhead, camera, and potentially two mirrors on either side of the camera. These mirrors are important for the technique proposed in this paper, to be described later.

Challenges in Printing on Fingernails

Printing on human fingernails risks a lower quality result than printing on flat surfaces due to some factors, such as smearing and distortion. Therefore, our proposed solution is to pre-distort the halftone pattern of the desired image, which takes into account the amount of curvature (z-info on Fig. 2)

Inkjet droplets upon falling on a curved surfaces might create a streak effect instead of settling in the ideal round form. The spacing between the droplets will then be compromised due to the streak, as well as inaccurate due to the slope of the curvature resulting in drops falling closer to each other. These will then cause lower printing quality especially at the edges of the fingernail where the slope is usually steeper than the surfaces that are closer to the top of the nailbed.

The current industry approaches [5] to printing on curved surfaces typically involve either moving the object or moving the printhead such that the ink droplets may be applied perpendicular to the surface tangent to avoid the problems mentioned above. These approaches, which generally need a relatively big space for some type of armature to move printheads/print subjects, are inapplicable in our scenario as the printer we're developing has a form factor limitation. Also, in order to keep costs low for the production of the device, it is not ideal to add more hardware to solve this problem. Therefore, we are opting for a more software-centric approach.

Figure 1: Nail Printer.

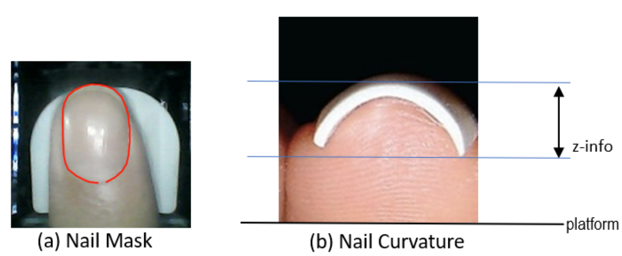

Figure 2: Nail Mask and Nail Curvature.

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Modeling the 3D Shape of a Fingernail

In order to calibrate the amount of distortion needed on the halftone pattern, we need a few pieces of information: nail mask and nail curvature.

Nail Mask Separation

When we receive the photo of the fingernail from the nail printer, we get a picture of the whole fingernail area. We need to isolate the nail area from the finger in order to model the top view shape of the nail. This is the nail mask, the red outline of a nail as shown in the red outline in Fig. 2a. The two main algorithms used in this experiment are: Yin Wang's Nail Mask Algorithm [6] and the Sunvalleytek Machine Learning method (company proprietary), both with their own pros and cons. The first is faster, but less accurate, while the latter is slower, but more accurate. Towards the latter half of the experiment, we chose Sunvalleytek's method as it is more precise and worked better for detecting the nail mask with different skin tones (Fig. 2a).

Nail Curvature Estimation

The other key piece of information in order to construct a 3D model of the fingernail is the nail curvature (Fig. 2b). To get this information, we attempted a few methods:

- Grey Level
  This is a naive method that plots the variation in grey levels with the idea that the closer the nail surface is to the LED on the side of the camera, the brighter the captured pixel value is (shown in Fig. 3). We then applied some curve fitting to eliminate noise and find a best-fit curve. We have some good results from this method despite its simplicity. More experimentation will be done to determine its robustness.

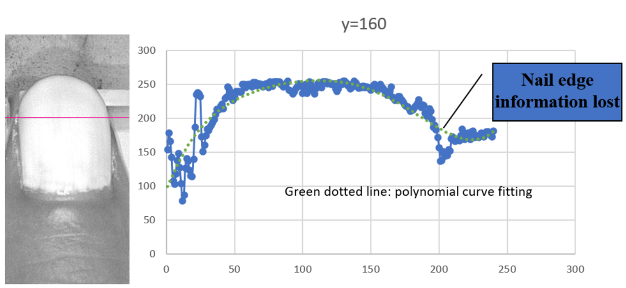

Figure 3: Results from the Grey Level Method.

- Shape from Shading [7]
  In our implementation of this method, the results weren't very accurate relative to ground truth.
- Photometric Stereo [8]
  This method resulted in a promising set of data (Fig. 4). At the time of the experiment, we couldn't use it due to it needing two images to work. Installing two cameras was not an option, but later on we found a possible way to get photos of the same fingernail from multiple angles using the double mirror system [9]. This method is a possibility if the form factor of the device will allow installation of double mirrors.
- Ellipsoidal Model Fitting
  This method is preferred due to it being the simplest and needing no hardware addition. The approach to this is to get a 2D model by fitting the curvature of the nail mask into 4 quadrants (Fig. 5). Wang, *et al* [6] outlined the steps for segmenting the nail mask into 4 different quadrants. Next, each quadrant will be fitted to the equation

$$(\frac{x}{X})^n + (\frac{y}{Y})^n = 1 \quad (1)$$

Then, the 3D model can be obtained similarly using the equation

$$(\frac{x}{X})^n + (\frac{y}{Y})^n + (\frac{z}{Z})^m = 1 \quad (2)$$

Here, n and m are variables that affect the curvature of the ellipsoid, X and Y are number of pixels in the x and y axes, and Z is the height of the ellipsoid The 4 quadrants will have different n and m values to mimic the appearance of the modeled nail.

We would then compare the results to the ground truth collected by a contour gauge, which process is outlined in Fig. 6. An example of data acquired from this process is shown in Fig. 4a.

Pre-distorting the Halftone Pattern

After modeling the 3D shape of the fingernail of interest, we propose to relate the curvature of the model to calculate the distortion needed in the halftone pattern. That way, we can correct image deformations due to droplet distortions. We will investigate

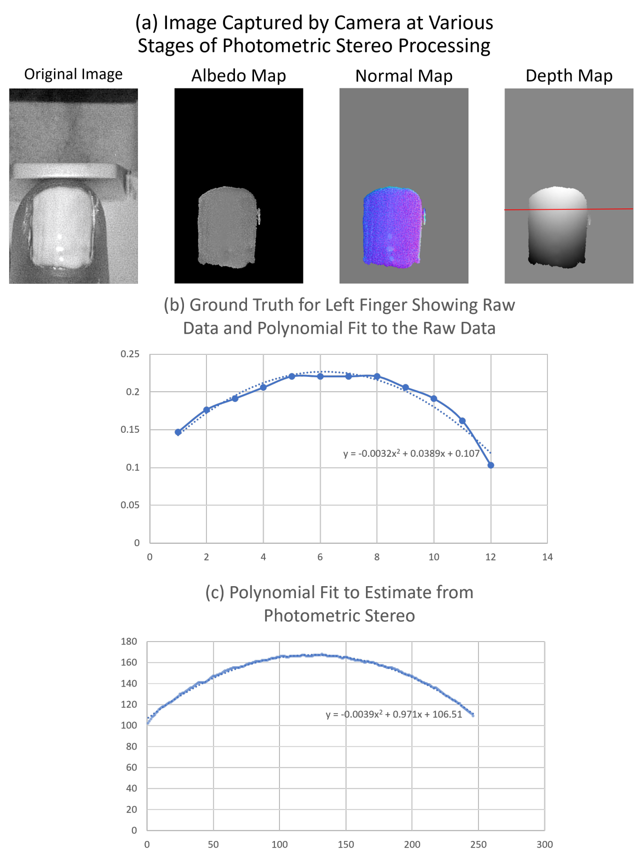

Figure 4: Results from Photometric Stereo. Topmost picture (Fig. 4a) shows the original left ring fingernail picture from the device's camera followed by the albedo, normal and depth maps. Figure 4b shows the graph of the ground truth acquired from the contour gauge (Fig. 7); and Figure 4c shows the data from Photometric Stereo, with relatively similar results to the ground truth data.

the deviation of the drops shape and spacing on curved surfaces so we can calculate the spatially varying distortion needed in the halftone pattern to produce more accurate prints.

Limitations

One limitation that we can expect is that image might look incorrect from different angles (anamorphosis [10]). However, considering that the human fingernail is relatively small, we hope that the distortion created by this effect will outweigh lower print qualities as result of the distortion from printing on curved surfaces.

Conclusion

In this paper, we discussed how printing on curved surfaces requires some problem solving as compared to printing on flat surfaces due to droplets smearing and settling closer together/further apart from one another. The result of ignoring these distortions would be lower quality images, especially on areas where the curvature of the nail is more extreme. To solve this problem, we propose a method that includes a few steps: nail mask separation as well as nail curvature estimation to create the 3D model of the nail, followed by the pre-distortion of halftone pattern, which would then account for and correct the distortions. Although the method has a concern of anamorphosis, we hope that due to the small form factor of a fingernail, the distortion caused by anamorphosis is less than the distortion resulting from the lower print quality due to printing on curved surfaces. The pre-distortion portion of the method is still in progress. But once we are able to find the formula that relates the curvature of the nail to the amount of distortion needed in the halftone pattern, hopefully this can be a compact solution to getting our nail printer to produce high quality images.

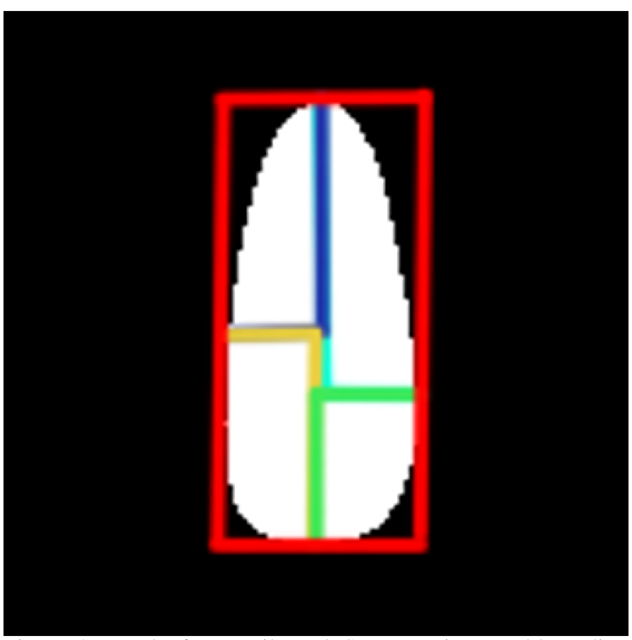

Figure 5: Results from Nail Mask Segmentation. Red bounding box gives an outline of the whole nail mask. The first, second, third and fourth quadrant are the areas bounded by the different color lines.

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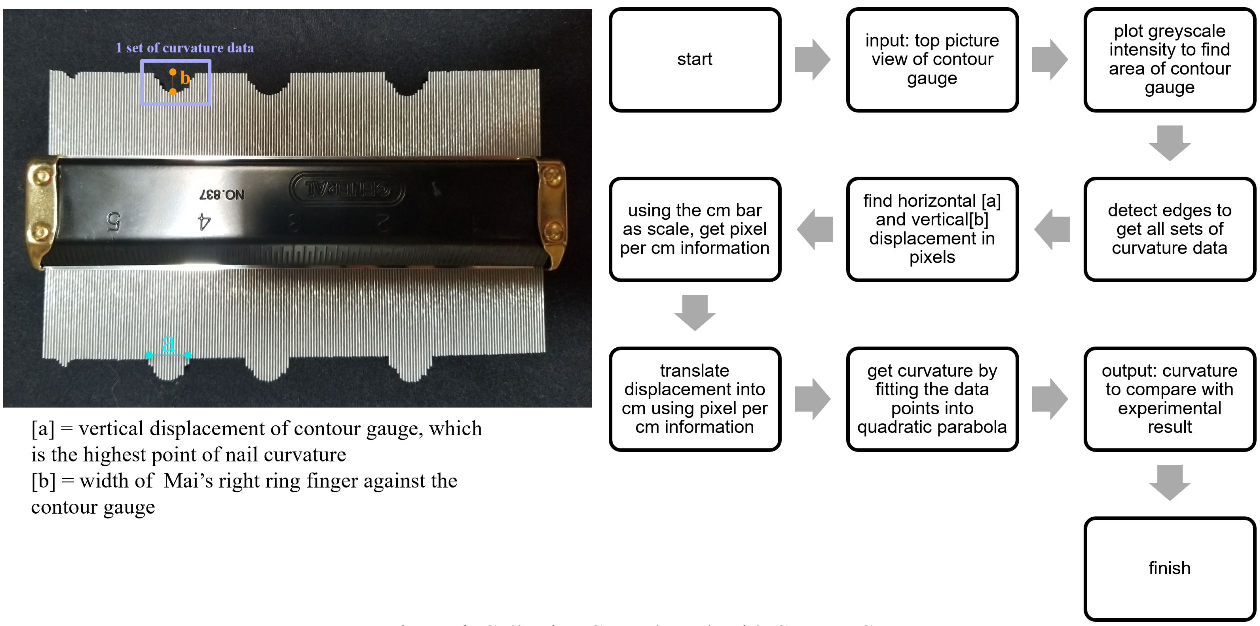
Author Biography

Marshia, best known as Mai, majored in Computer Science at Purdue University tracking in Machine Learning with a minor in Electrical Engineering. Mai’s passion lies in the image processing/machine learning field. Currently, Mai is working full-time as a research engineer at Qualcomm in the Graphics Research VR/AR Hardware Architecture team while continuing her education as a part-time distant student at Purdue University for a Master’s in Electrical and Computer Engineering. She is pursuing the Master’s thesis track under Professor Jan P. Allebach, continuing her previous research in college, working on an image processing methodology for printing on 3D surfaces.



[a] = vertical displacement of contour gauge, which is the highest point of nail curvature
[b] = width of Mai's right ring finger against the contour gauge

Figure 6: Collecting Ground Truth with Contour Gauge.