Developing an Inkjet Printer I: RGB Image to CMY Ink Amounts – Image Preprocessing and Color Management

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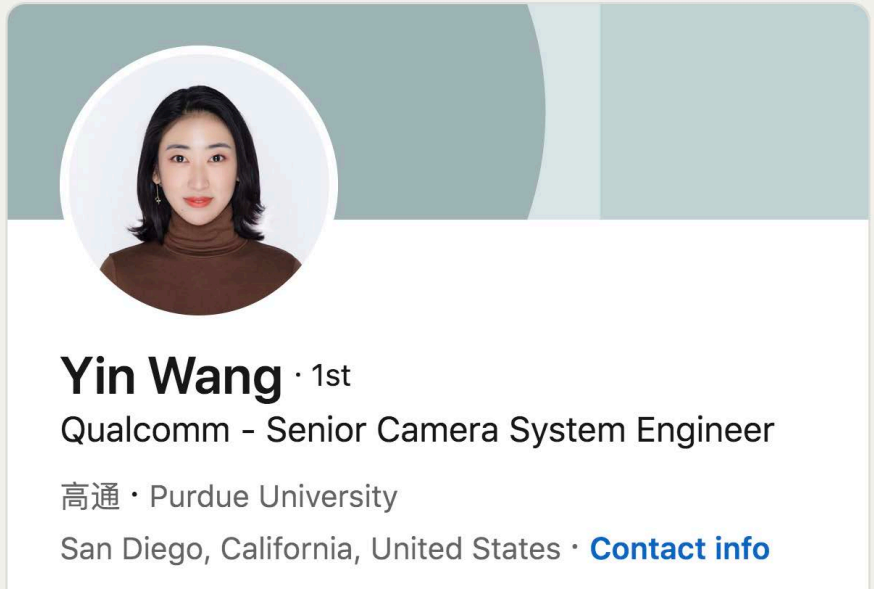

OUTLINE

- Project Overview
  - Goal
  - Challenges
  - Working Process
  - Storyboard
- Image Segmentation
  - Nail mask acquisition
  - Nail edges refinement
- Color Management
  - Pipeline
  - Gamut mapping
  - Results

Y. Wang, B. Choi, D. Kenzhebalin, S. Hu, G. Chiu, Z. Lin, D. He, and J. Allebach, “Developing an inkjet printer I: RGB image to CMY ink amounts – Image preprocessing and color management,” Color Imaging XXV: Displaying, Processing, Hardcopy, and Applications, (Part of IS&T Electronic Imaging 2020), R. Eschbach, G. Marcu, and A. Rizzi, Eds., Burlingame, CA, 26 January - 30 January 2020.

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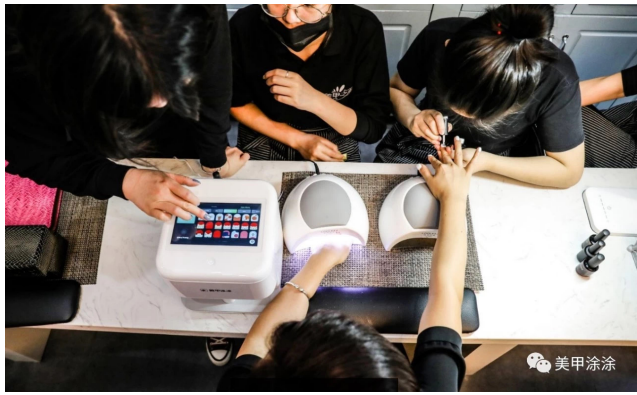
PROJECT OVERVIEW

- Goal:
  - generate a desktop home-using printer that can be used to print any pattern on the finger nail
  - shorten the nail pedicure time to couple of minutes at home instead of hours' labor at nail salon

- Challenges:
  - **find the correct printing zone:** Traditional printer usually print on the flat paper, which has standard size. But our nails usually have various sizes, this will require us to find the printing zone from time to time, in order to define a proper printing zone.
  - **matching the color profile:** We want the input digital image matches the printed color profile. In other words, we want that the printed colors match as much as possible to the original colors in order to improve the printing quality.



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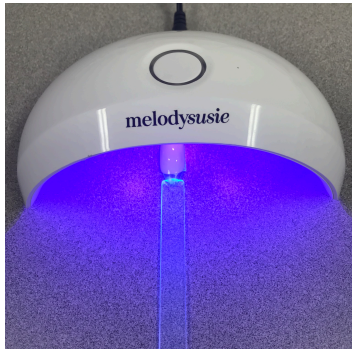
STORYBOARD

Apply base coat on the nail

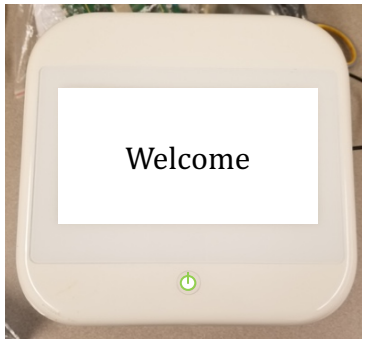


LED cure for 60s

Apply the white gel polish

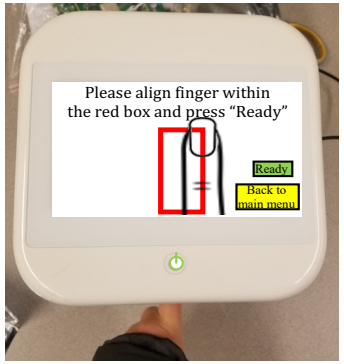
LED cure for 60s

Apply the pre-printing gel

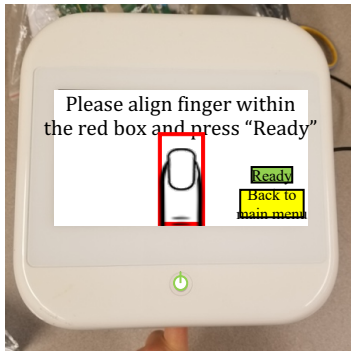


Turn on the printer

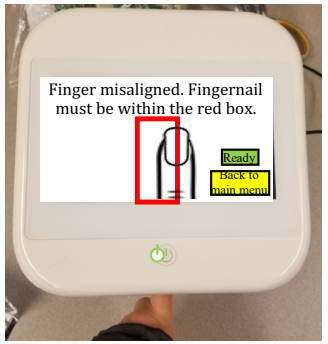
Prompt to get customer to insert finger into the slot for nail capture



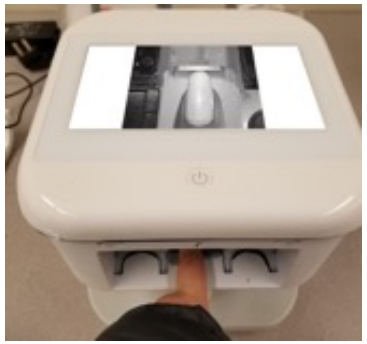
Nail capture starting, turn on camera and wait for customer to align nail in the bounding box (bounding box size 900*600)



Wait for customer to press "Ready" button after alignment

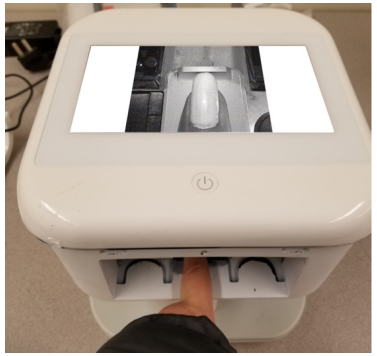


Warning for customer if their finger isn't within the red box



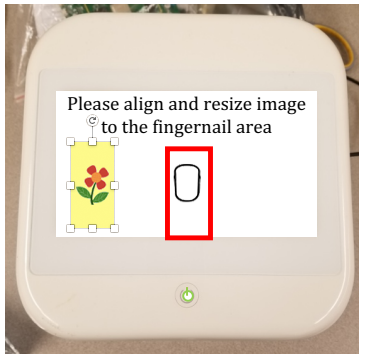
Take picture of the bounding box with fingernail within as PGM,send to Nail Segmentation module

STORYBOARD



Project the structured light pattern onto the nails and capture the nail image as the projecting progress. Send the image to Nail Curvature module

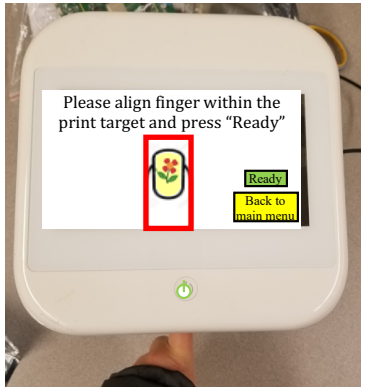
Let customer choose the target pattern that they want to print



Let customer place (resize/zoom, move, rotate) target image to the nail mask (shown in green) info displayed on the screen

Wait for customer to press "Ready" after they've placed the image on the nail

Sunvalley crop the target image to fit the nail mask and send it as 900x600px PPM image to Halftoning module (white = nothing is printed)



Wait for customer to press "Ready"

Call printer driver module and start printing

Printing done

Sample images that printed using the nail printer. (Provided by SunValley Tek)

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About the creator of the story board

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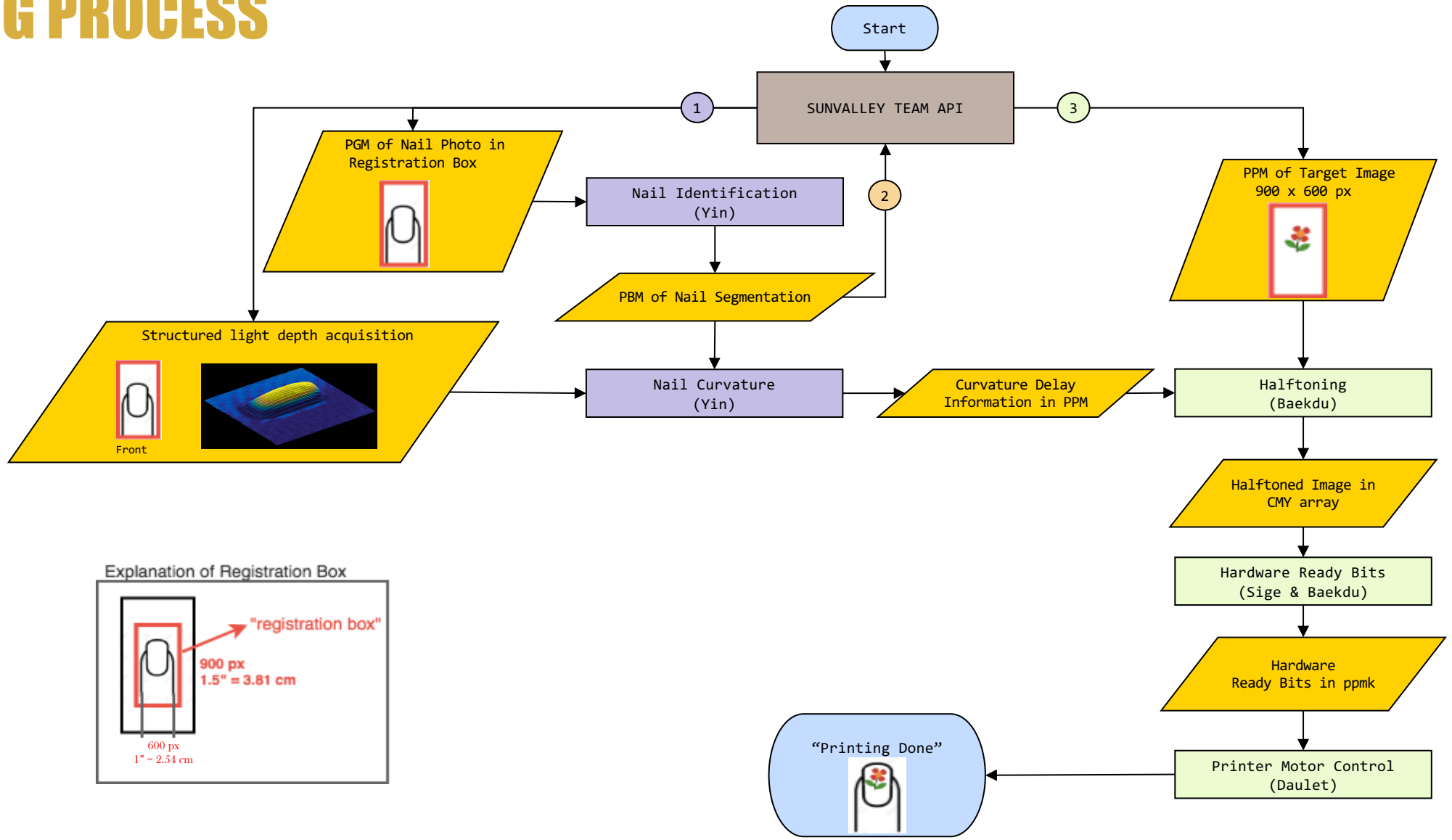
VR/AR Research Engineer at Qualcomm and
MSECE Student at Purdue University

Qualcomm · Purdue University

San Diego, California, United States · **Contact info**

WORKING PROCESS



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PROCESS FLOWCHART

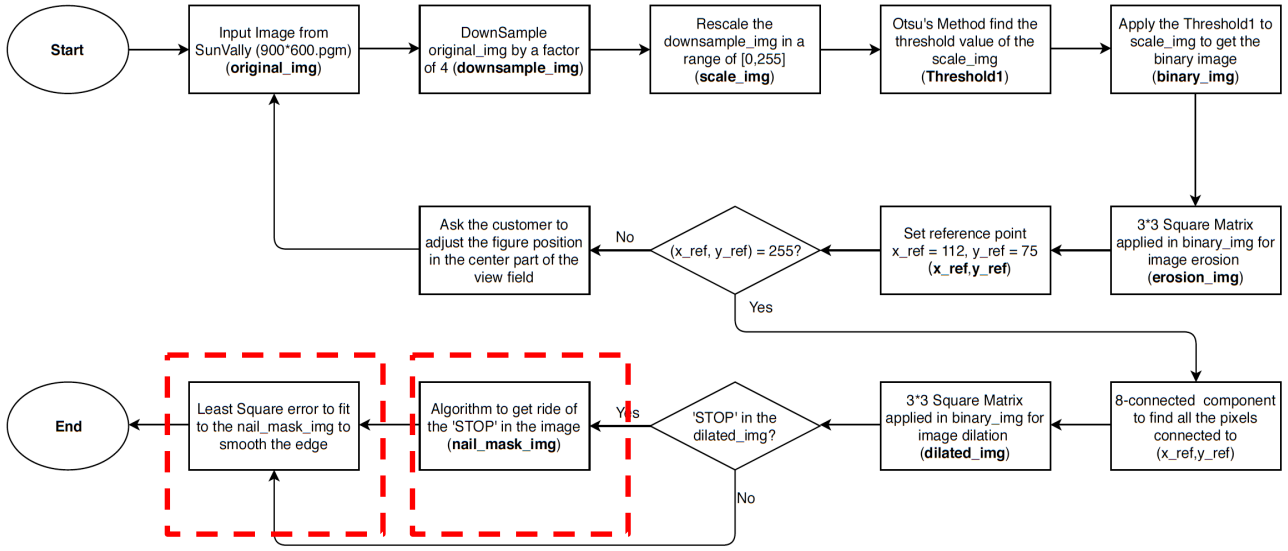


Fig. 1. General flowchart for the image segmentation

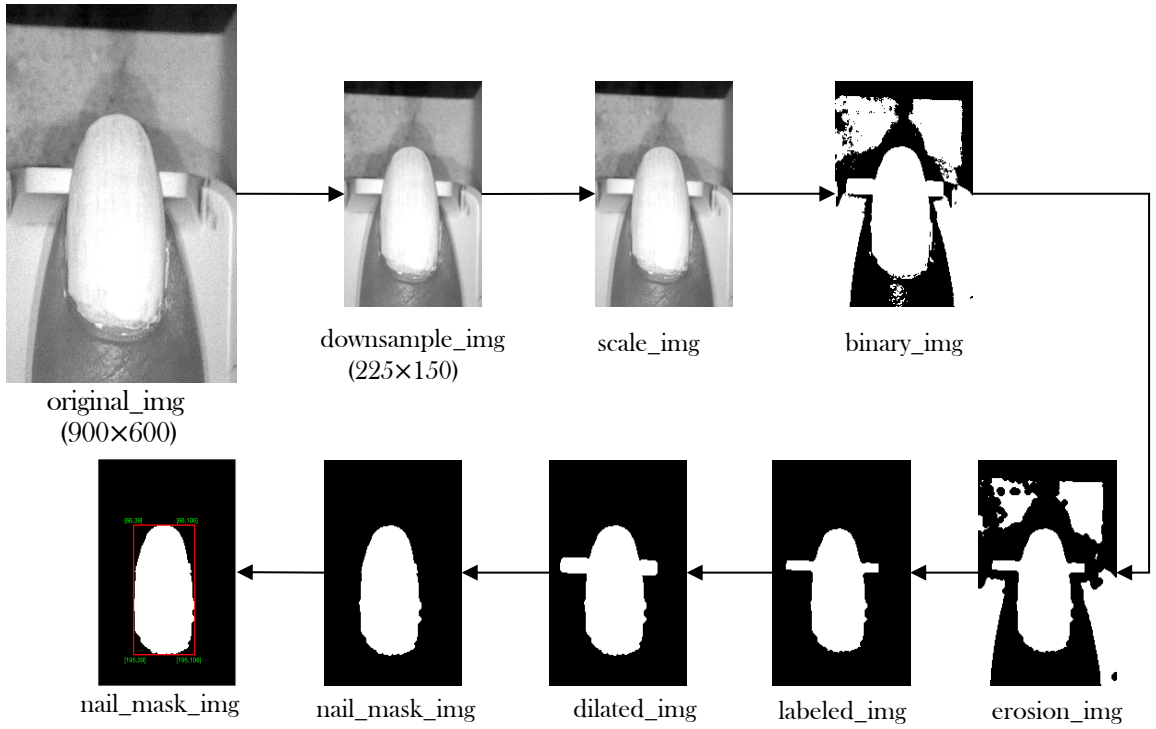
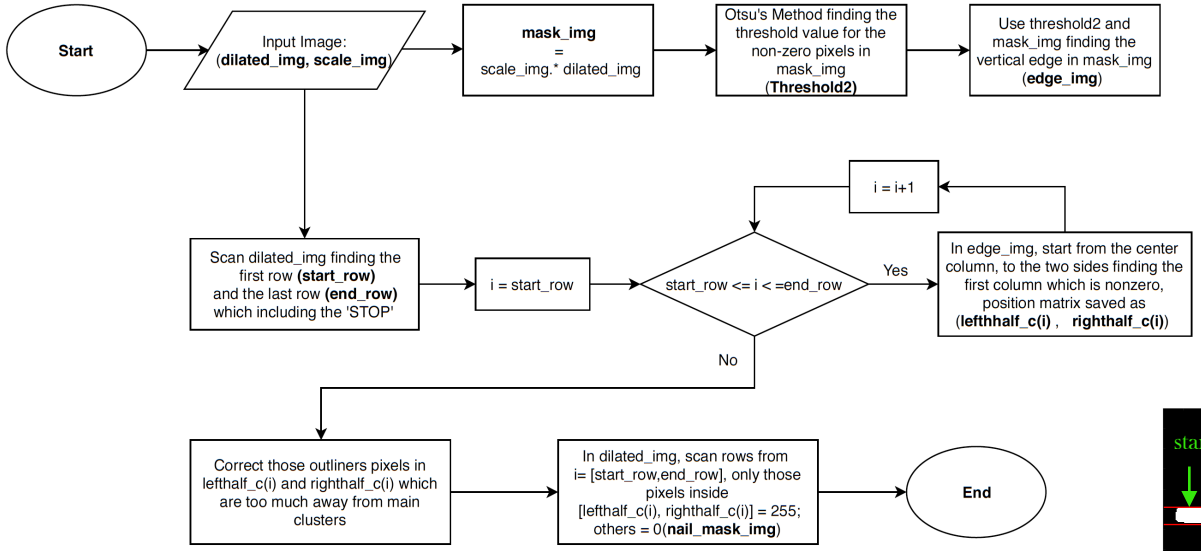
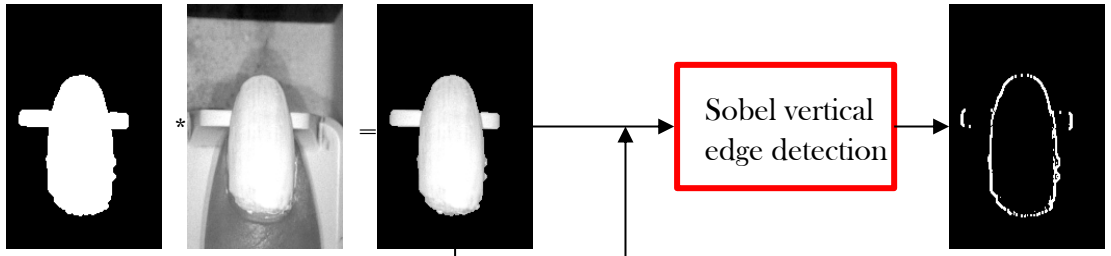
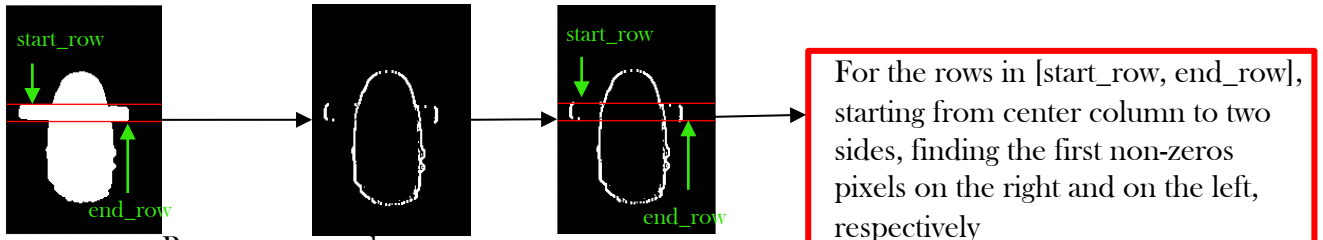


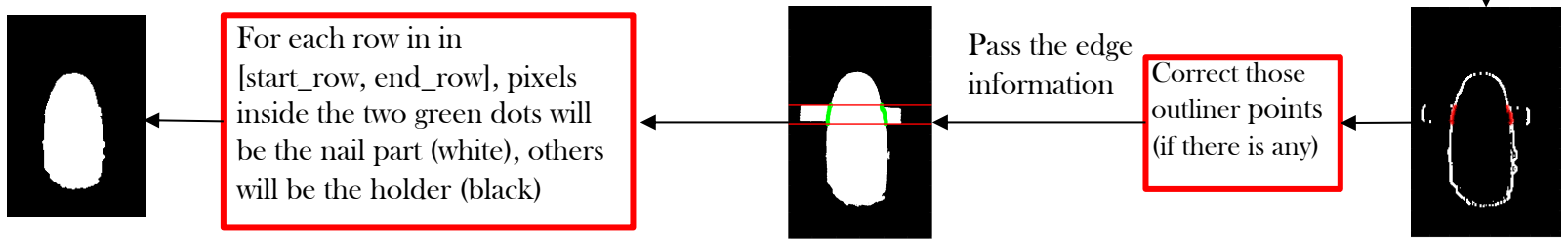
Fig. 2. Image segmentation and intermediate procedure result

'STOP' ELIMINATION ALGORITHM









Sobel Edge Detection:

- $G_x = \begin{bmatrix} 1.5 & 0 & -1.5 \\ 3 & 0 & -3 \\ 1 & 0 & -1 \end{bmatrix} * Image,\ G_y = G_x$
- $G(i,j) = \sqrt{{G_x}^2(i,j) + {G_y}^2(i,j)}$
- $sobelimage(i,j) = \max(G(i,j), threshold)$
- $sobelimage(sobelimage == threshold) = 0$
- ***Notice: '*' represent 2D convolution***

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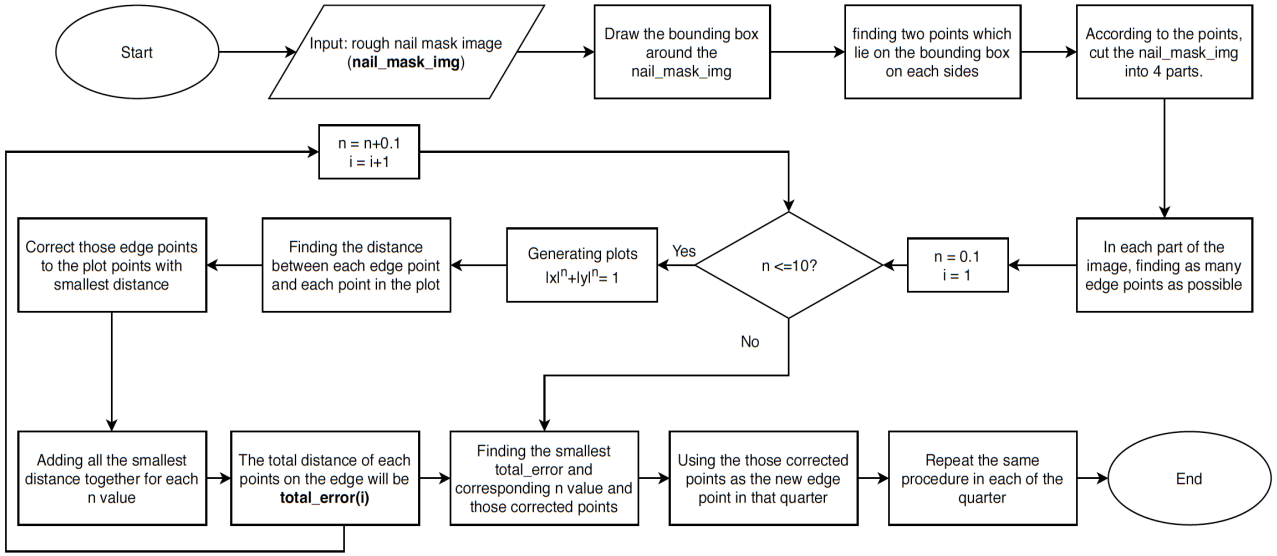
EDGE REFINEMENT ALGORITHM

- The result from the segmentation and the 'STOP' elimination does not have a smooth edges. But we want a smooth edges in order to conduct the further experiment, s.t. 3D reconstruction. So we propose a best line fitting algorithm to smooth the nail edges.
- Equations:
  - $c(x,y) = (|x|^n + |y|^n)^{\frac{1}{n}} = 1 \Rightarrow (|x|^n + |y|^n) = 1$
  - $where\ x \in [0,1], y \in [0,1], n \in [0,\infty]$
- Flowchart:



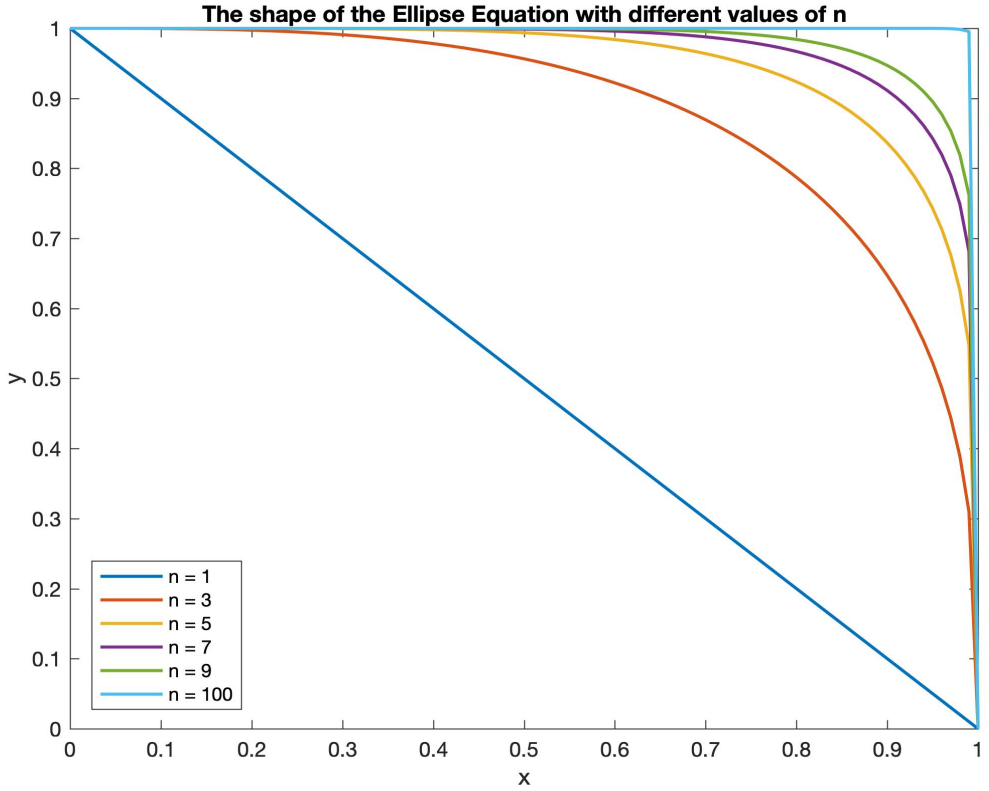
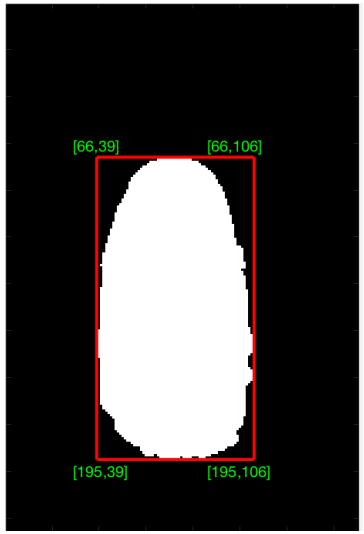
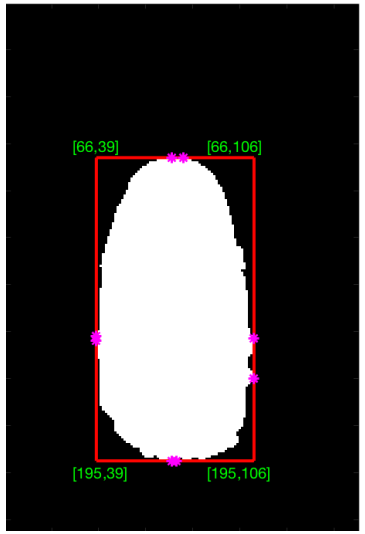


Fig. 1. General shape of the equation with different values of n

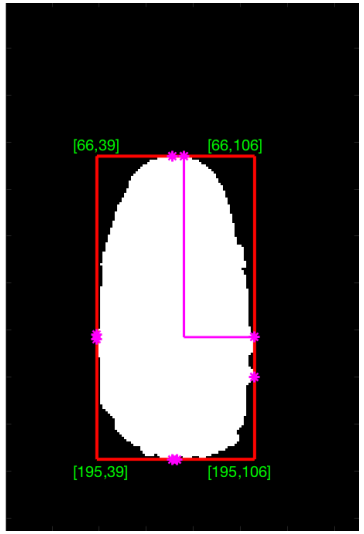
EDGE REFINEMENT ALGORITHM DETAILS



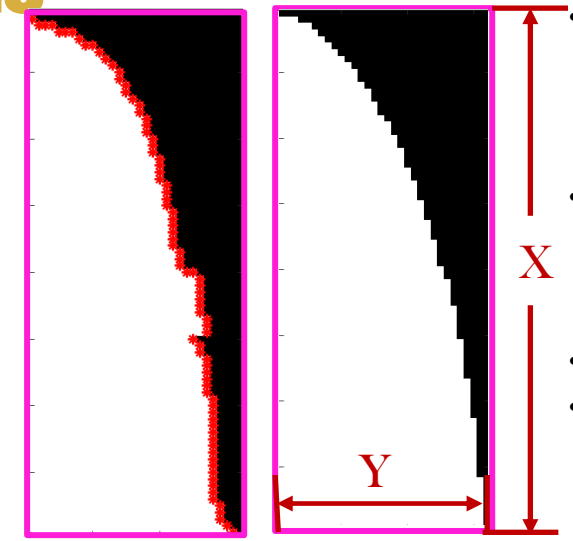
Input Image



Images with cutter points

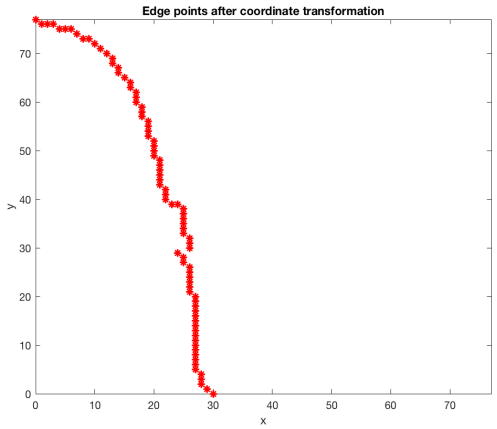


Magenta is the first quarter cutting boundary

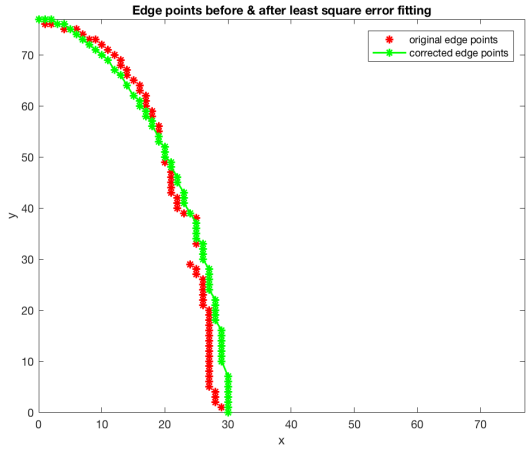


before after

First quarter part with edge points



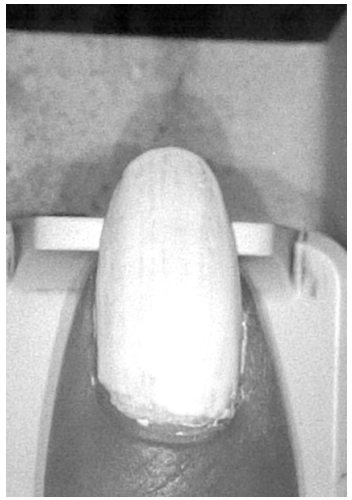
original edge points plot



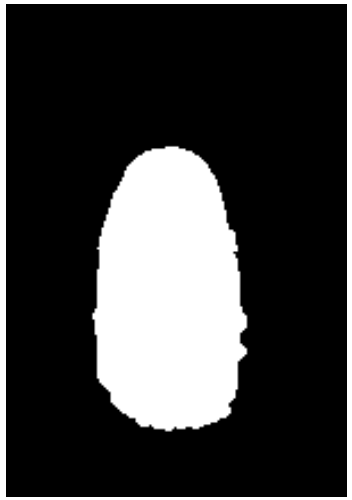
original edge points vs. corrected edge points

- For different n values, generating different shape of curves of the equation: $(\frac{x}{X})^n+(\frac{y}{Y})^n= 1$. Where $X = 77, Y = 30$.
- Searching all the points in the edge points plot, finding the points with the smallest distance value.
- Where the distance was calculated as:
- $D_{min} = \sqrt{(x_1 - x_2)^2+(y_1 - y_2)^2}$, (x_1, y_1) are the points on our edge points plot, (x_2, y_2) are the points on the best fitting plot.
- After finding D_{min}, we shift the point (x_1, y_1) to the point (x_2, y_2) .
- Calculate the total error by adding all D_{min} together, label as total_error(n)
- The we can find the minimum total_error(n) and it's corresponding n values. Where we change the n values in a range of (0,10] with step size 0.1.

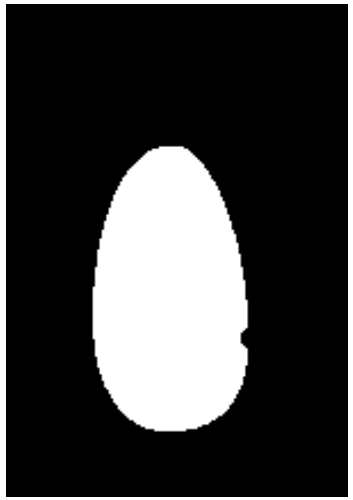
FINAL RESULTS



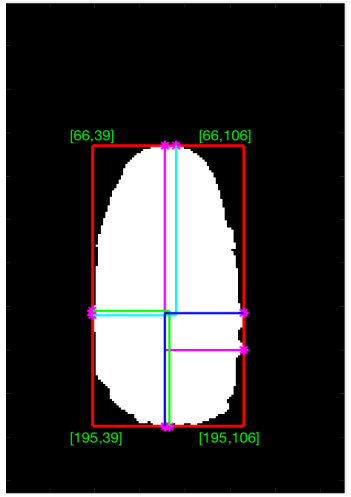
(a). original image



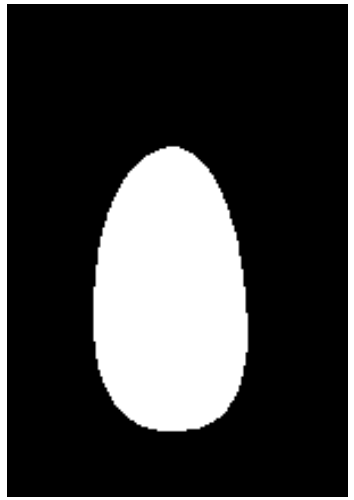
(b). mask before line fitting



(c). make after line fitting

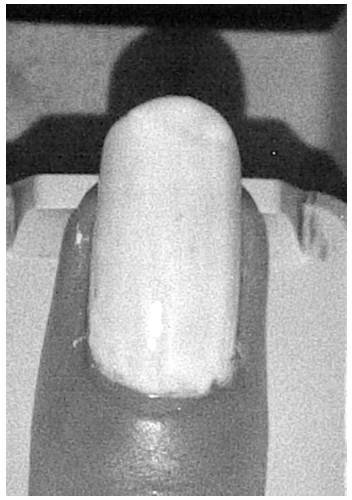


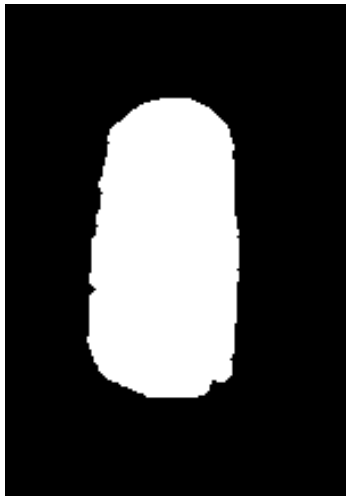
(d). intersecting four quarters

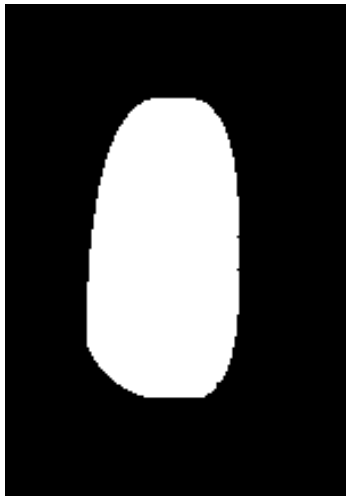


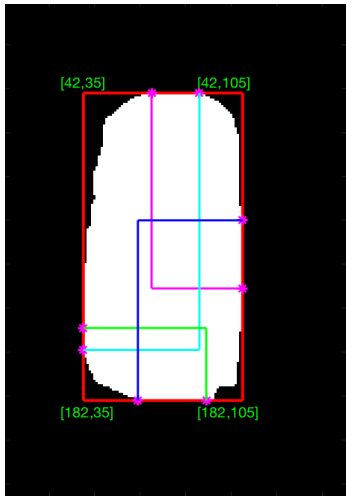
(e). final mask

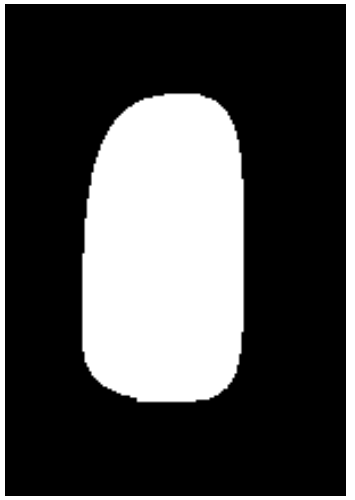
(f). compare with the original image

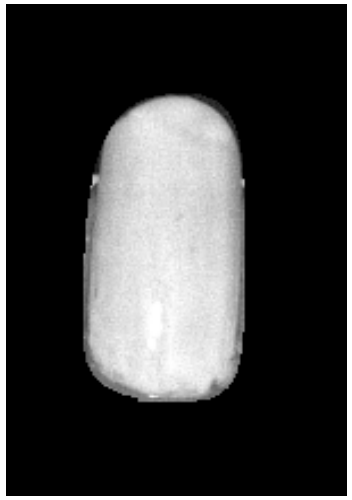












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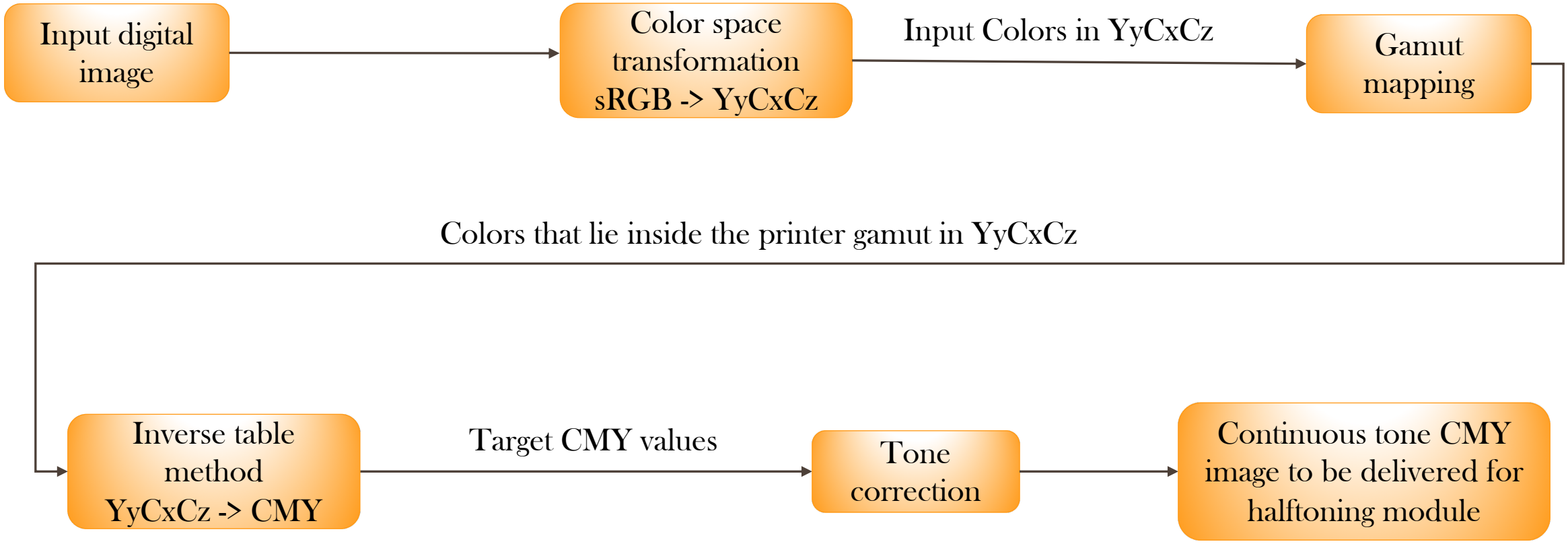
COLOR MANAGEMENT PIPELINE



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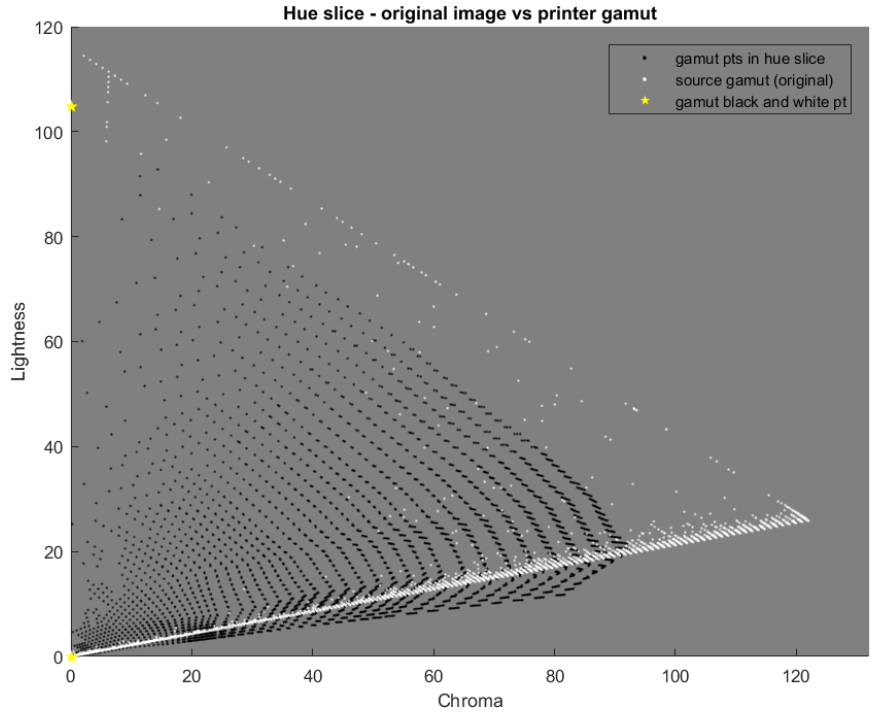
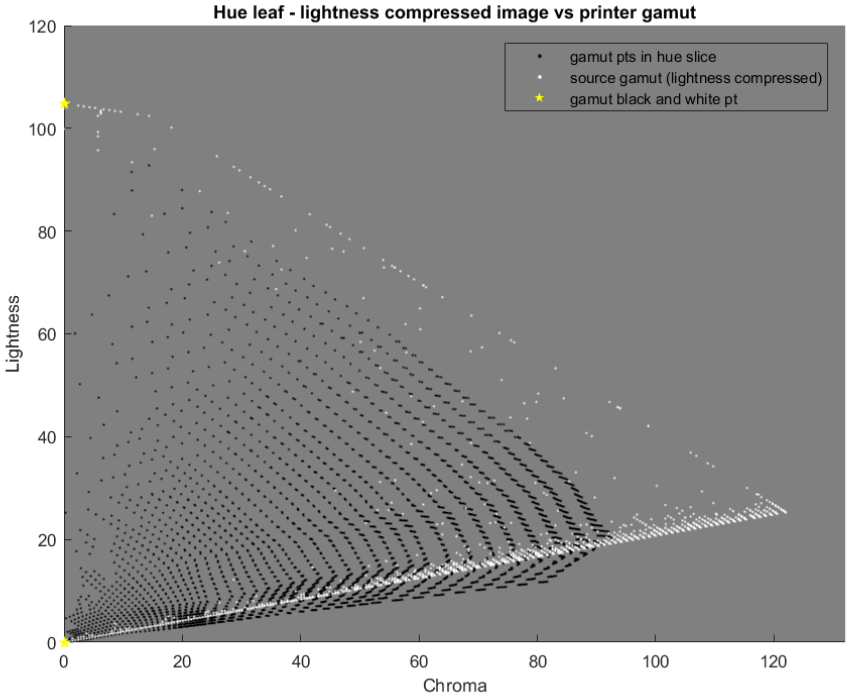
GAMUT MAPPING

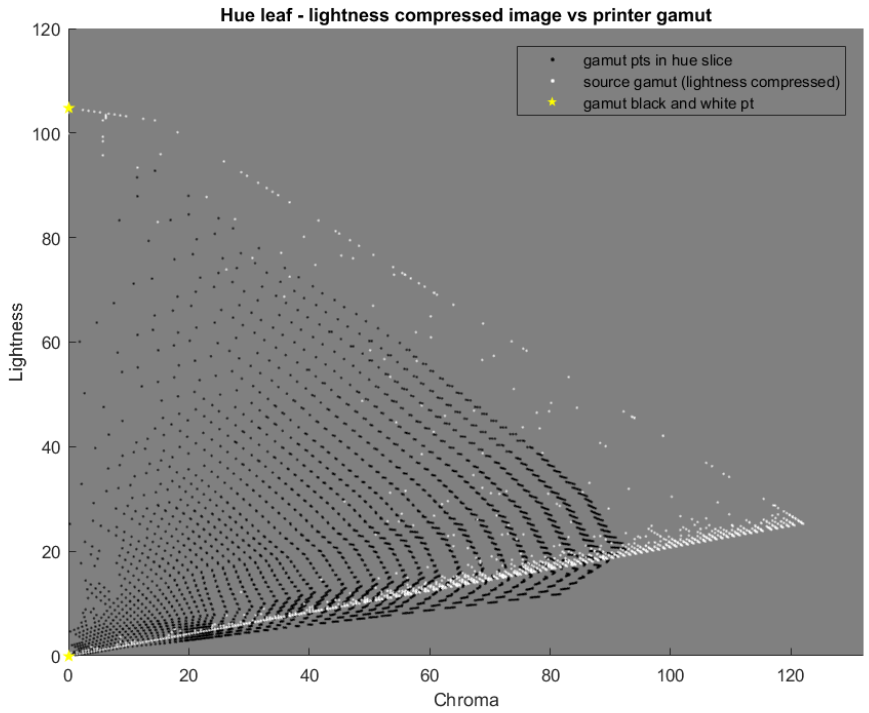
- We perform gamut mapping in YyCxCz color space, which is a *linearized* version of CIE L*a*b* color space [1]
- The first step of the gamut mapping is to align the neutral axes of source and printer gamut
- Then we perform lightness compression for the source gamut, which results in all source gamut points' lightness (Yy) being inside the lightness range of the printer gamut

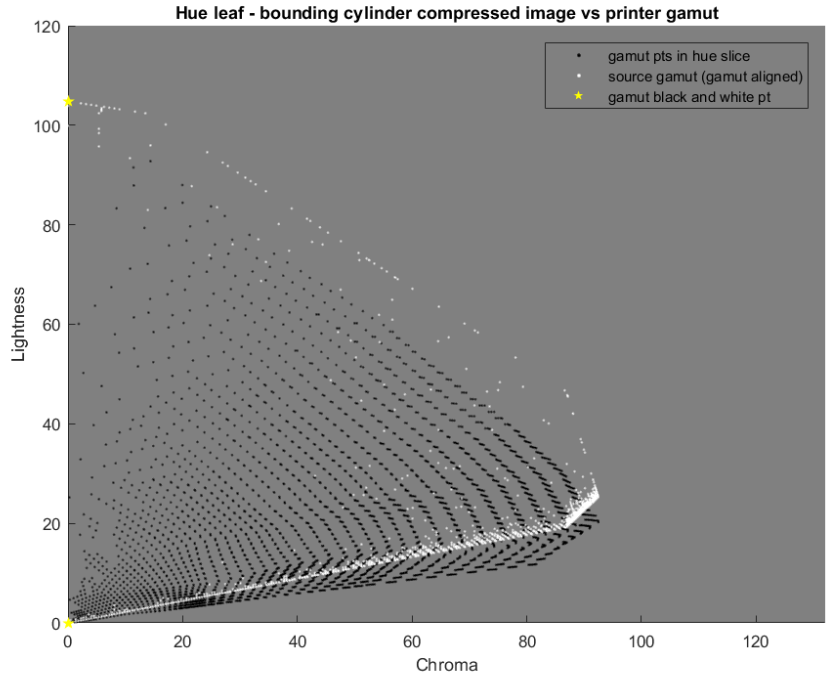




GAMUT MAPPING

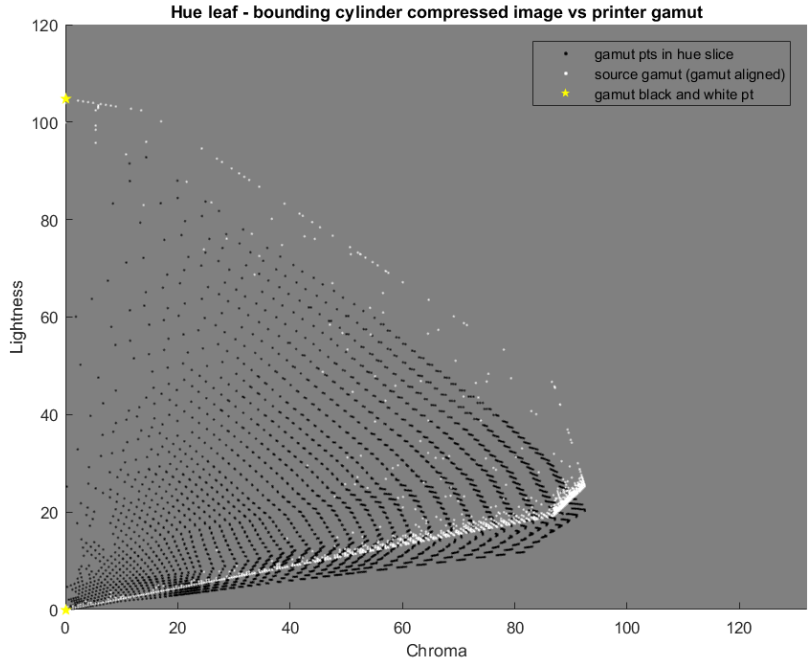
- Then we perform bounding cylinder compression
- This step compresses the chroma ($\sqrt{Cx^2 + Cz^2}$) component of the source gamut so that all the source gamut points have chroma component not exceeding the maximum chroma component of the printer gamut in the hue slice

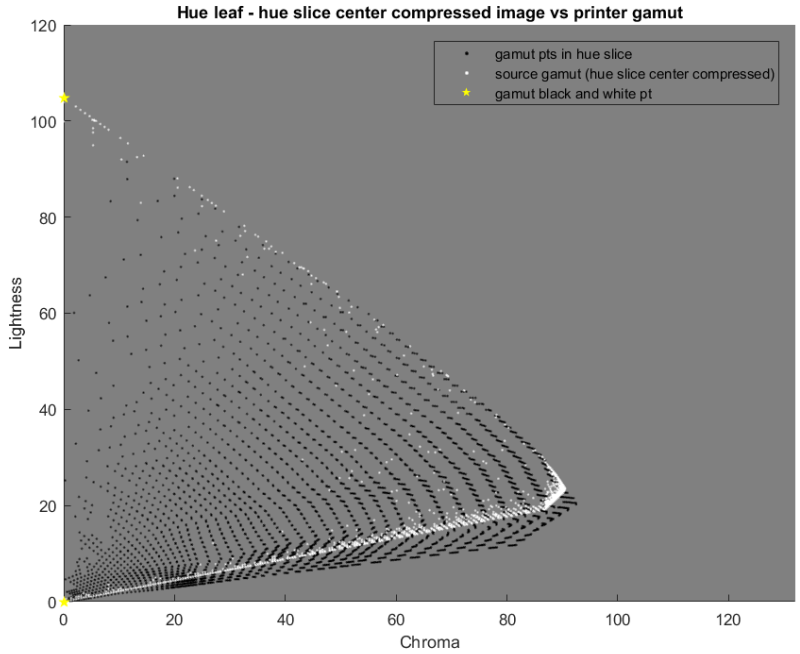




GAMUT MAPPING

- The last step of gamut mapping is the hue slice center compression
- In this step, we compress all the source gamut points towards the hue slice center
- Hue slice center is defined as $(0, Yy_{mid})$, where $Yy_{mid} = \frac{Yy_{white,shifted}}{2}$
- After that, the source gamut points need to be rotated and shifted back in the way that the printer gamut is rotated and shifted back to its original shape





OUTLINE

- Project Overview
  - Goal
  - Challenges
  - Working Process
  - Storyboard
- Image Segmentation
  - Nail mask acquisition
  - Nail edges refinement
- Color Management
  - Pipeline
  - Gamut mapping
  - Results

RESULT

- Left : original image, right : gamut-mapped image

SUMMARY

- Developed a storyboard of the overall nail printing process to facilitate accurate communication regarding the printer between team members.
- Developed an algorithm for segmenting the nail region from the captured image, and fitting parameterized smooth curves to each of the four quadrants of the nail outline.
- Used color management pipeline to keep the color profile as much as possible

THANK YOU !