Democratizing Produce Waste Reduction Using Hyperspectral Imaging

Dhruv Darbha

Redmond High School, Redmond, WA

dhruv.darbha@outlook.com

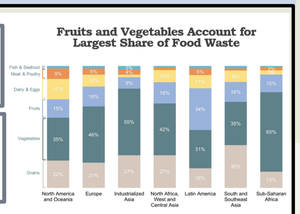
MOTIVATION

1.3 Billion Tons — Food globally wasted every year

15% — Food Waste contributes to Climate Change

2030 — UN goal to reduce food waste by half

43% — Households are responsible for food waste



Previous studies[1] attempted to tackle food/produce waste using hyperspectral imaging (HSI) by measuring ripeness of vegetables and fruits

BACKGROUND

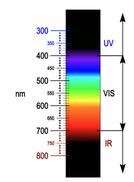
First, demonstrated HSI capability of detecting a "good" vs "bad" tomato (w/ commercial camera)

Overripe Tomato

Just ripe Tomato

What is Hyperspectral Imaging (HSI) ?

Electromagnetic Spectrum:

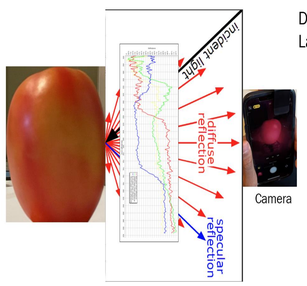


Wavelength regions for Hyperspectral Imaging

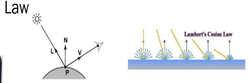
Different modes of imaging

- HSI is the combination of spectroscopy and digital imaging.
- HSI is referred to in the ultraviolet (UV) to near infrared (NIR) range
- Multispectral - several wavelengths are measured
- RGB image from a typical digital camera is a type of multispectral image that uses the light intensity at three specific wavelengths: red, green, and blue, to create an image in the visible region
- Hyperspectral - complete wavelength region, i.e., the whole spectrum, is measured for each spatial point.

Imaging Science



Diffuse Reflection Governed by Lambert's Law



$$R_e = k_d \mathrm{N} \cdot \mathrm{L} R_i$$

image intensity of P $\longrightarrow$ $I = k_d \mathrm{N} \cdot \mathrm{L}$

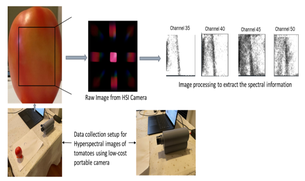
Simplifying assumptions

- $I = R_e$: camera response function f is the identity function:
  - can always achieve this in practice by solving for f and applying f^{-1} to each pixel in the image
- $R_i = 1$: light source intensity is 1
  - can achieve this by dividing each pixel in the image by R_i

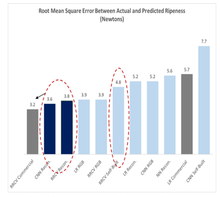
Source: Reflectance Spectroscopy & Colorimetry | PhysicsOpenLab

Prior Arts: Achievement of 2021-2022

2021-2022 Research : SUCCESSFULLY FOUND A WAY



Built own database of Tomato HSI & ripeness (measured 500 tomatoes)



Built ML models to predict ripeness of tomatoes

ISSUE: COST

Hyperspectral Cameras in Market

1. Expensive - ~$25K
2. Used by Labs and Research Institutes

RESEARCH POSTER PRESENTATION DESIGN © 2019

RESEARCH OBJECTIVES

My research last year (Darbha et al, 2022) showed

- Hyperspectral Imaging was an effective method in identifying the ripeness of Tomato.
- However, needed to be **AFFORDABLE and stand-alone optical imaging device**

This study **explored** an economical alternative, iPhone with IR filter.

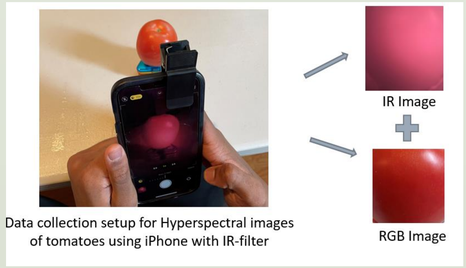
Study answers a question and a challenge –

❑**QUESTION**: Can spectral imaging in the IR wavelength spectrum be combined with RGB imaging to predict ripeness of fruits or vegetables?

❑ **CHALLENGE**: Can an easy-to-use App on an iPhone be developed to predict the firmness of a tomato with a simple click of the iPhone's camera enabling produce waste reduction at the hands of an everyday consumer?

EXPERIMENTAL PROCEDURE

1. Built own database of spectral images with RGB and IR over 200 tomatoes



Data collection setup for Hyperspectral images of tomatoes using iPhone with IR-filter

2. IR Image Using Smartphone and 5 IR pass-through filters - Only 720nm filter provided a sharp image while the other 4 filters (760nm-1000nm) had low fidelity images and hence was not pursued further in the study

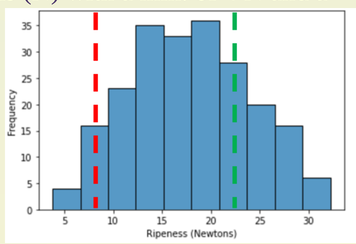
IR Filter	Image Quality	Comments
720nm		Image is sharp and results used in ML model development
760nm		Image slightly blurry and discontinued using filter
850nm		Image not visible. Discontinued using this IR filter
950nm		Image not visible. Discontinued using this IR filter
1000nm		Image not visible. Discontinued using this IR filter

Flesh firmness (in N/cm2) using a penetrometer

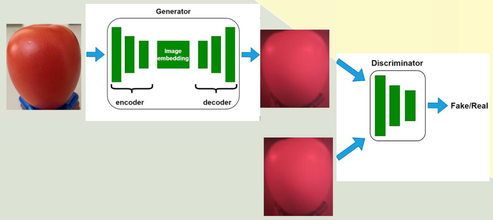
RESULTS

1. Average ripeness, collected with penetrometer, was around 17.1 Newtons (N) with a min. of 4 N and a max of 32 N.

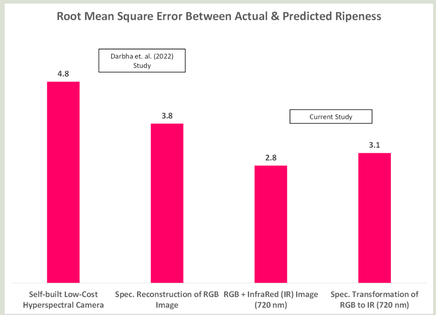
< 8 N as overripe (red line)
> 8 N and < 22 N as ripe
> 22 N as unripe (green line)



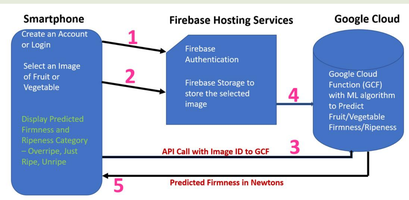
2. Selected 2 of 16 machine learning (ML) models developed to predict ripeness factor.
   - Average pixel intensities for Near IR and RGB wavelengths as features
   - A second model built using Pix2Pix architecture to spectrally reconstruct IR images from the RGB images. Pix2Pix is a deep learning model that can learn a mapping function from an input image to an output image. The input and output images can be related in some way, such as an image of a hand-drawn sketch and the corresponding realistic image. The architecture uses a conditional generative adversarial network (cGAN). Pix2Pix architecture is a powerful tool for image-to-image translation tasks



3. ML models achieve root mean squared errors (RMSE) between the predicted and actual ripeness metric ranging from 2.8N to 3.1N.



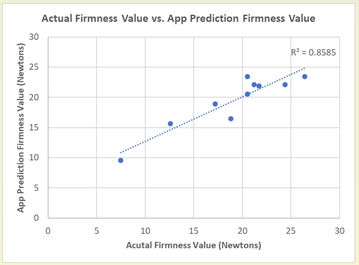
CHALLENGE: APP DEVELOPMENT



- Easy-to-use App to predict firmness of tomato with a simple click of the iPhone's camera
- Democratizes produce waste at the hands of an everyday consumer

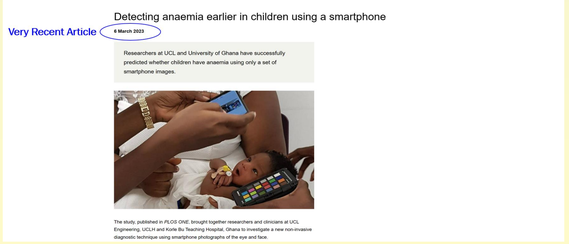
RESULTS

Excellent correlation in ripeness between actual & predictions from App.



CONCLUSIONS & FUTURE WORK

Not alone……Other examples of using Smartphone based imaging



In summary, research provides two economical approaches to predict ripeness using HSI –

- ➢ Predictive ML models based on spectral generated Near IR image from a RGB image taken using a smartphone camera
- ➢ Easy-to-use App on iPhone to predict the ripeness of tomato with simple click of iPhone camera

Demonstrated non-destructive, affordable, and easy to use solutions by any consumer/grocery store to reduce produce waste

Next Steps include:

- Test with other most wasted vegetables and fruits (Avocadoes, Watermelon)
- Explore other alternatives like IR Thermal Imaging if accuracy of ripeness predictions can be further improved.

ACKNOWLEDGEMENTS

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