HS-ENEV-0165: Tackling Food Waste Using Hyperspectral Imaging

WASHINGTON STATE SCIENCE & ENGINEERING, 2021-2022

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Motivation & Background

- Third of the food (~1.3 billion tons/year) globally is lost or wasted annually
- In the US, food wastage by segment
  - Households ~43%
  - Food service industry ~26%
  - Grocery stores ~13%
- UN Goal - By 2030 reduce food waste by **half** at the retail and consumer levels
- Hyperspectral Imaging (HSI) measures reflectance at several wavelength bands resulting in spectrally abundant information to identify unique properties of objects
- Previous studies[1,2] tackling wastage using HSI to measure ripeness of vegetables/fruits have **two** drawbacks –
  - Conducted using expensive hyperspectral cameras (~$26K)
  - Ripeness was a binary metric as ripe or unripe

[Source: blogspot.com]

Reference

1 – Varga, Leon Amadeus, Jan Makowski, and Andreas Zell. "Measuring the Ripeness of Fruit with Hyperspectral Imaging and Deep Learning." *2021 International Joint Conference on Neural Networks (IJCNN)*. IEEE, 2021.

2 - Nashwa El-Bendary, Esraa El Hariri, Aboul Ella Hassanien, Amr Badr, Using machine learning techniques for evaluating tomato ripeness, Expert Systems with Applications, Volume 42, Issue 4, 2015.

Research Objective

Study answers a question and a challenge –

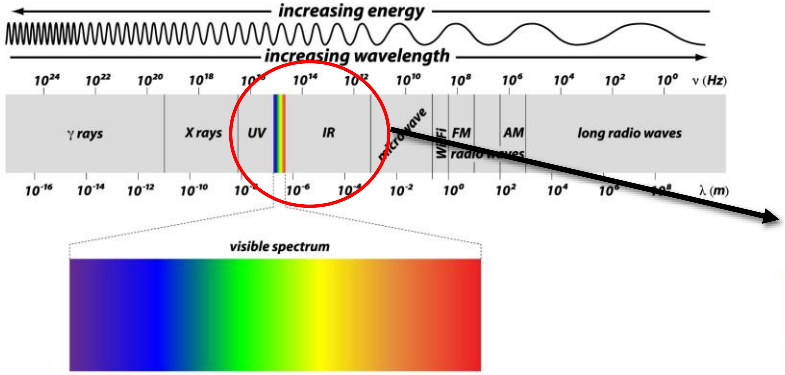
QUESTION: Can spectral imaging be used to predict ripeness of vegetables and fruits on the continuum?

- This study investigates this question using data collected on hyperspectral images and ripeness factor of tomatoes using a penetrometer

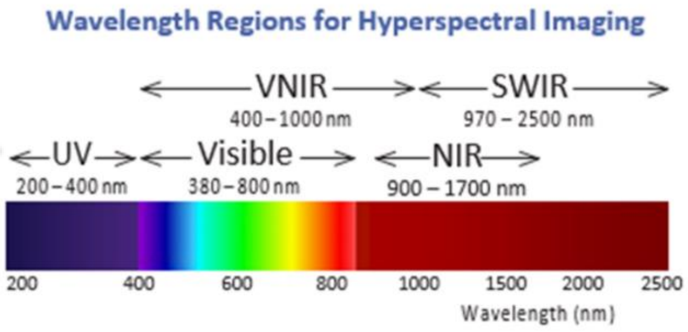
CHALLENGE: Can spectral imaging be made economical?

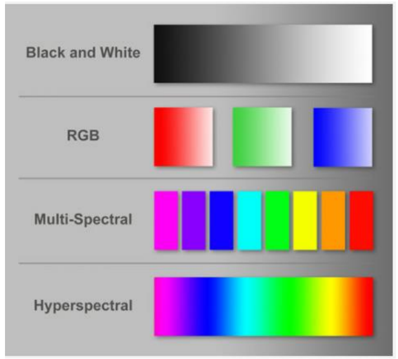
- Can we build an economic version of hyperspectral camera ($500) ?
- Can we use a smartphone camera for this task? (via spectral reconstruction of RGB images)

What is Hyperspectral Imaging (HSI) ?



Electromagnetic Spectrum





Different modes of imaging

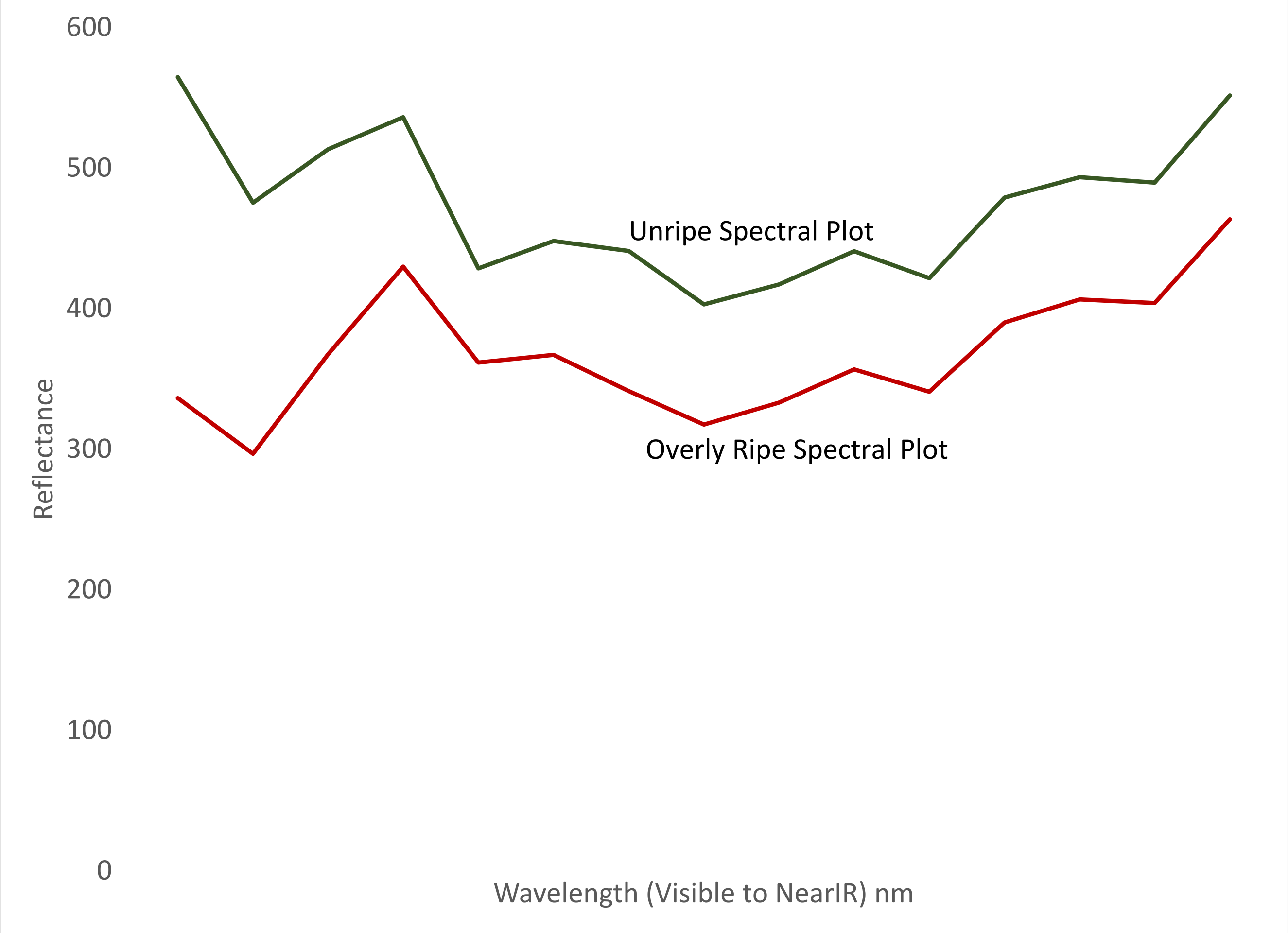
- HSI is the combination of spectroscopy and digital imaging.
- **HSI is referred to in the ultraviolet (UV) to near infrared (NIR) range**
- Visible to near infrared (NIR) spectroscopy has been widely used for quality assurance purposes to analyze solid samples as they require minimal or no sample preparation and achieve a high signal-to-noise ratio

- 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
- **Why Hyperspectral? - Spectrally abundant information to identify and distinguish unique properties of objects**

[Source: middletonspectralvision.com]

Comparison of Reflectance using Commercially Available Hyperspectral Camera

Overly Ripe Tomato

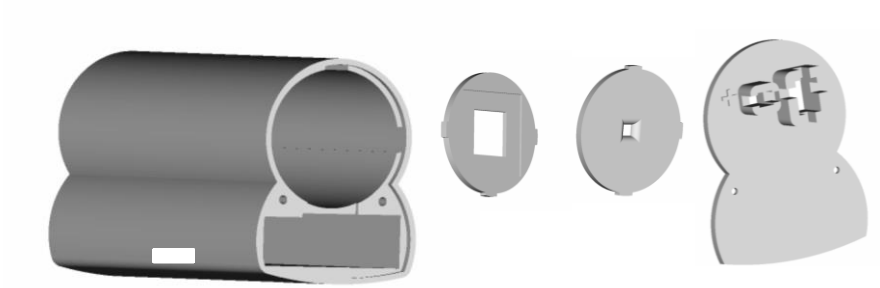


Significant Difference in Spectral Signatures between ‘Overly Ripe’ and ‘Unripe’ Tomato across Visible to Infrared Spectrum

Unripe Tomato

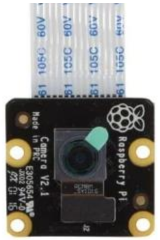
Self-Built Low-Cost Portable Hyperspectral Camera[3]

- Self-built camera including soldering all the key cables from Raspberry MB, to power cable and on/off switch with the help of the procedure outlined in Salazar-Vazquez's paper



CAD Model & 3D Printing of Enclosure & Lens/grating, On/off switch holders

Raspberry Pi 3 B+ Board



NoIR Camera

35mm FL Lens

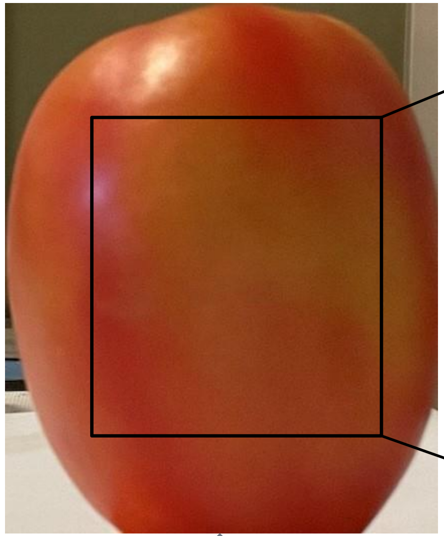
Electronic & Optic components sourced from Amazon.com / Edmund optics

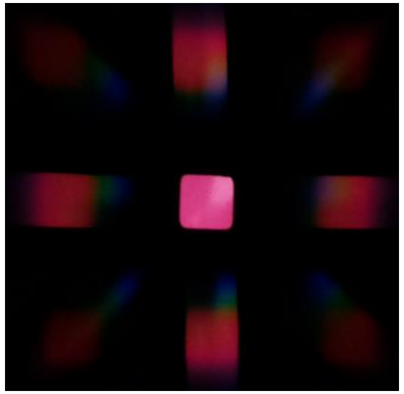
- Some relevant specs of the Self-built Camera include:
  - Visible/Near Infrared spectra over 300nm-700nm range of the electromagnetic spectrum
  - 50 spectral bands
  - Camera 8 Megapixels
  - HSI processing was completed with mentorship from SUNY Binghamton

Reference

3 - Invented by Salazar-Vazquez, Jairo, and Andres Mendez-Vazquez and referenced in their paper on "A Plug-and-Play Hyperspectral Imaging Sensor Using Low-Cost Equipment." HardwareX, Elsevier, 22 Nov. 2019.

Representative Hyperspectral Images from Self-Built Camera for a Specific Tomato





Raw Image from HSI Camera

Channel 35 Channel 40 Channel 45 Channel 50

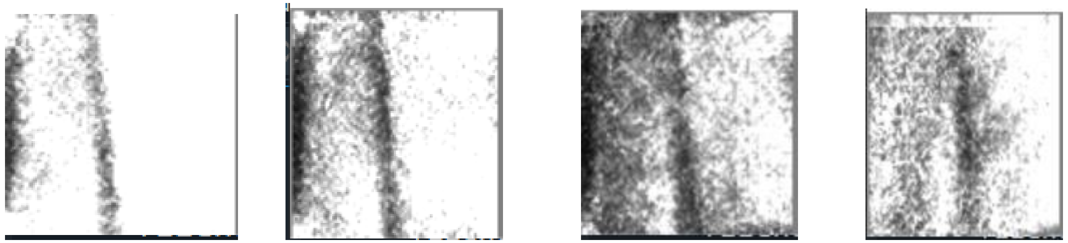
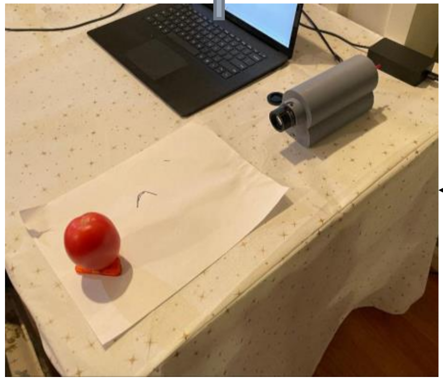
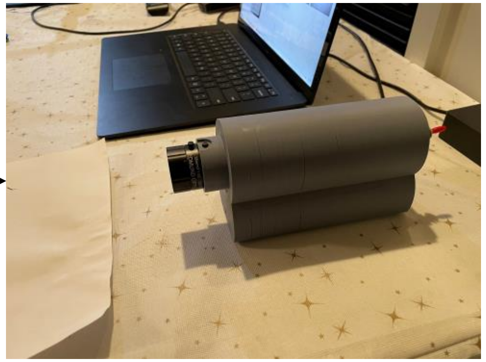


Image processing to extract the spectral information

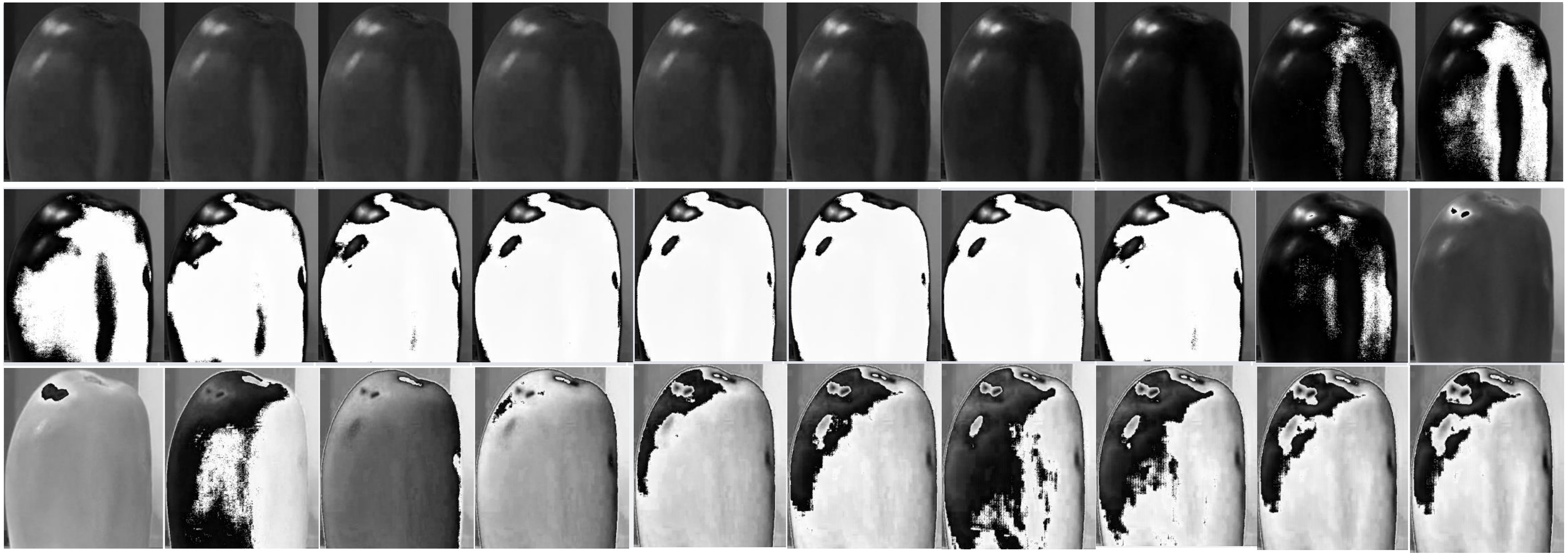


Data collection setup for Hyperspectral images of tomatoes using low-cost portable camera



Spectral Reconstruction of RGB Image[4]

Images of 31 channels for a particular tomato



Reference:

4. Zhao, Yuzhi, et al. “Hierarchical Regression Network for Spectral Reconstruction from RGB Images.” ArXiv.org, 10 May 2020

Data Collection

Collected following data on 500 Roma Tomatoes -

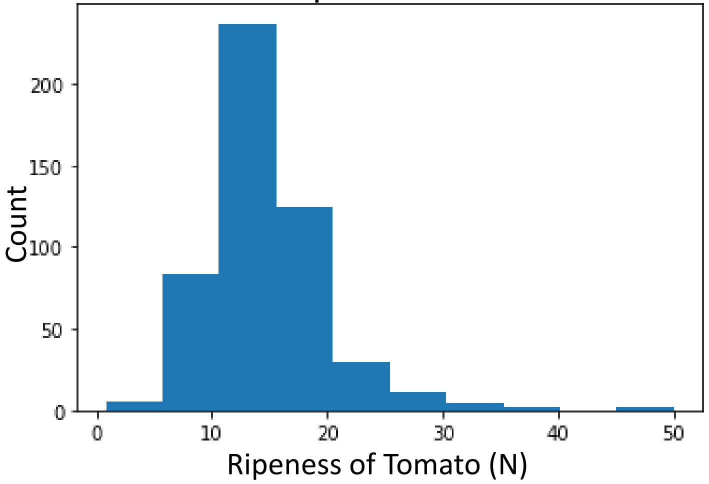
- ❑RGB using Smartphone
- ❑HSI using self-built camera
- ❑HSI reconstructed from RGB image
- ❑HSI using a commercial camera

- ❑Ripeness metric on the continuum
  - ➢ Average Ripeness around 14.4 Newtons (N) with a minimum of 0.8 N and a maximum of 50 N

500 Roma Tomatoes

Measuring Ripeness
w/ Penetrometer

Distribution of Ripeness across 500 Tomatoes



Methodology

ML MODEL	RGB	Self-Built HSI	Reconstructed HSI	Commercial HSI
Linear Regression (LR)	✓	✓	✓	✓
Ridge Regression (RR)	✓	✓	✓	✓
Neural Network (NN)	✓	✓	✓	
Convolutional Neural Network (CNN)	✓	✓	✓	

- ❑ Implemented 14 Machine Learning (ML) Models to Predict Ripeness –
  - ➢ Linear Reg. & Ridge Reg. use aggregate metrics (mean, std. dev., min. and max. values of image pixel intensities by channel = 4 metrics per channel)
    - ➢ RGB = 12 features or independent (X) variables
    - ➢ Self-built HSI = 200 features
    - ➢ Reconstructed HSI = 124 features
- ❑ Neural Network & CNN use individual pixel intensities

TRAIN	TEST

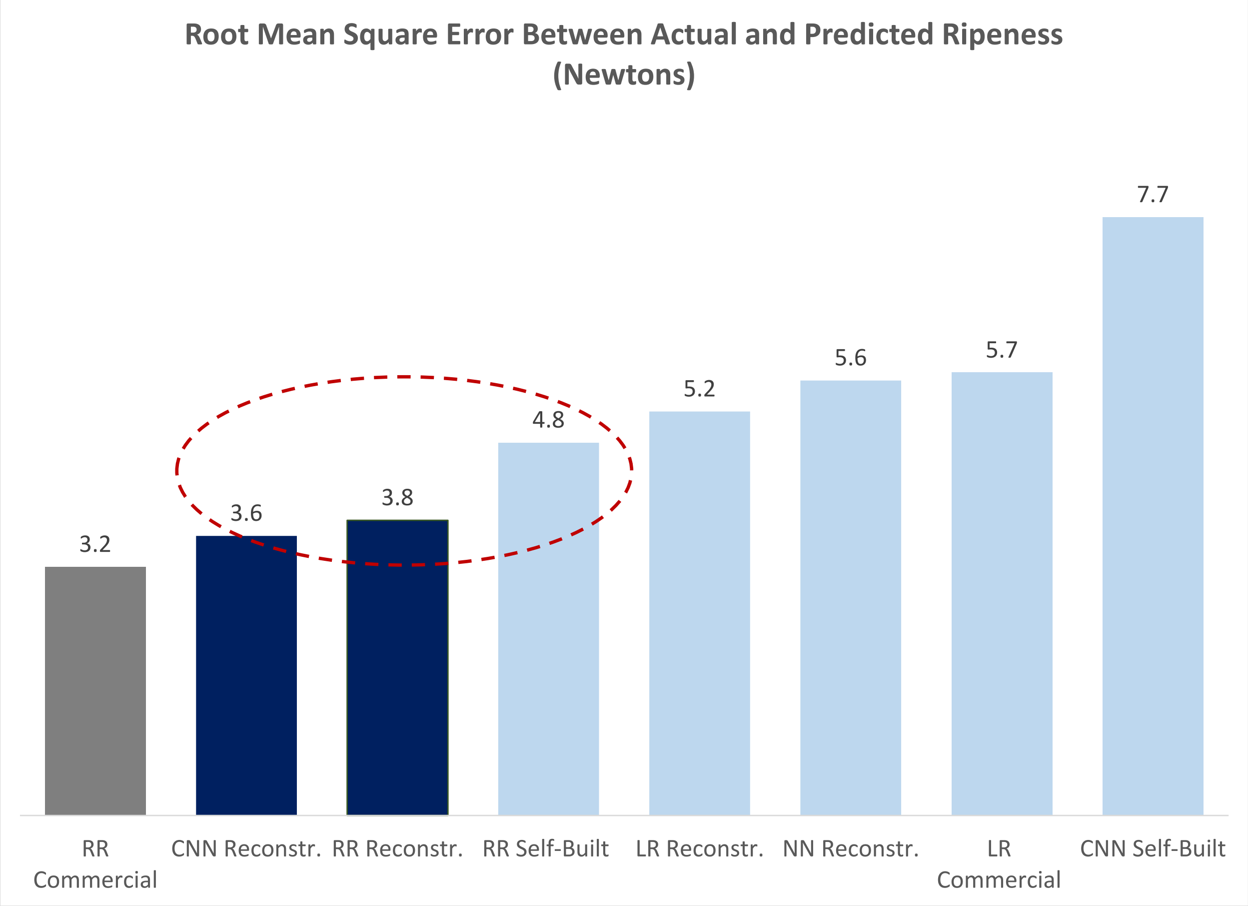
- ❑ For each model, the root mean square error (RMSE) was computed – this metric gives us the average difference between the actual and the predicted ripeness factor on a continuum -

$$RMSE = \sqrt{\frac{\sum(Actual\ Ripeness - Predicted\ Ripeness)^2}{N}}$$

→ **Lower the RMSE, Better the Model Likely to Predict Ripeness**

Results & Conclusions

- Graph to the right shows the RMSE for the ML Models –
  - RMSE across all ML Models have accuracy comparable to commercial camera
  - Predicted ripeness of 10 random tomatoes and obtained excellent predictions (~3N in RMSE) using both economical approaches of spectral imaging when compared to actual measurement
- Research demonstrates two economical approaches for collecting HSI –
  - Self-built low-cost portable HSI camera
  - Spectral Reconstruction from a RGB image
- Democratize reduction of produce waste at the consumer, retail, and supplier levels by providing
  - Non-Destructive
  - Affordable
  - Interactive solutions to predict ripeness of vegetables & fruits on the continuum and hence consume them within the right time period



Next Steps

- Started to build an easy-to-use application for any user to download on their phone and use the phone camera to assess ripeness of fruits and vegetables they intend to consume [Completion by June 2022]
- Refinement of App to provide a 'best until use' date for a particular vegetable or fruit based on its current state as opposed to a generic date [Completion by July 2022]
- Test with other most wasted vegetables and fruits (most common being bananas, apples, lettuce, sweet peppers, pears, and grapes)[5] [Completion by Aug 2022]
- Optimize hardware configuration to focus HSI in near infrared region (600-800nm) to investigate whether RMSE can be lowered [Completion by Dec 2022]

Reference: 5. Lisa Mattsson, Helén Williams, Jonas Berghel, "Waste of fresh fruit and vegetables at retailers in Sweden – Measuring and calculation of mass, economic cost and climate impact", Resources, Conservation and Recycling, Volume 130, 2018 (https://doi.org/10.1016/j.resconrec.2017.10.037)