FruitPhone: Detecting Sugar Content in Fruits Using Unmodified Smartphones with Spectral Imaging

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Motivation

- Consumers should detect sugar content in fruits to manage health conditions like diabetes or weight control effectively.
- Current solutions asking for **intrusive analysis** or **special equipment** hinders the acceptability for average users.

Consumers have concerns whether the sugar content fit the requirements.

Refractometer

☹ **Invasive**

Spectrometer

☹ **Expensive**

Wireless Signal

☹ **Special Equipment**

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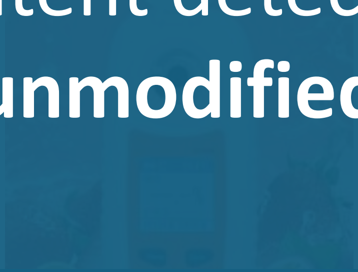
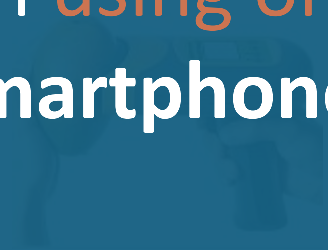


Refractometer

☹ **Invasive**



Spectrometer

☹ **Expensive**

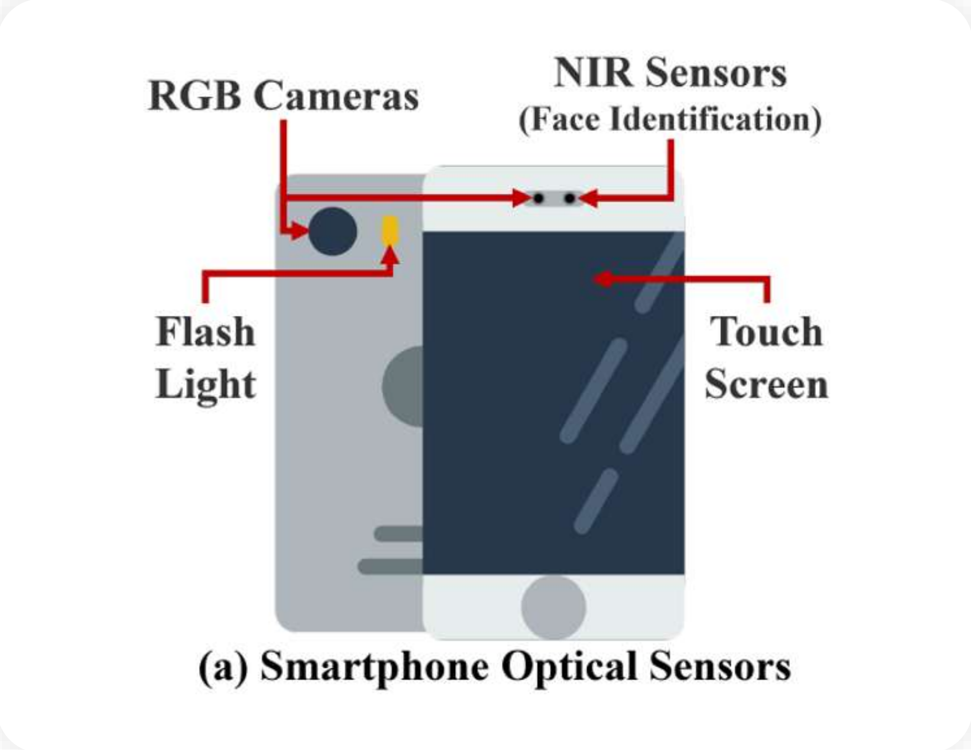
Wireless Signal

☹ **Special Equipment**

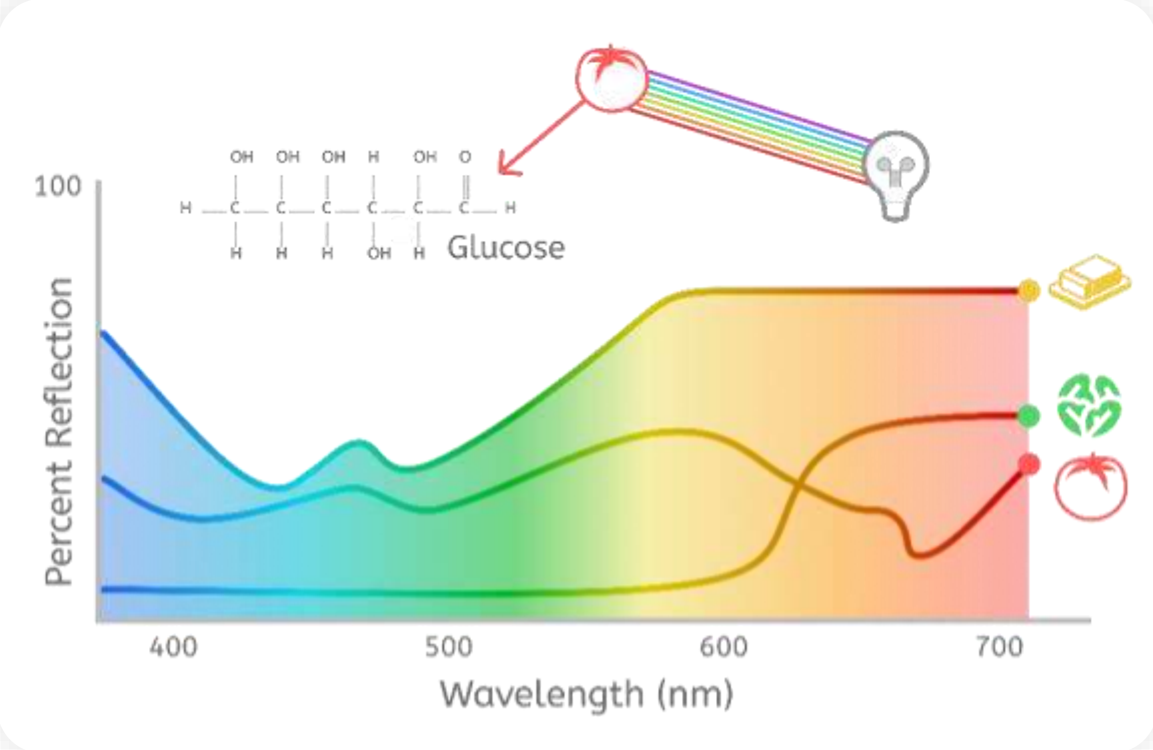
Can we achieve fruit sugar content detection using only the ubiquitous devices (like an **unmodified smartphone**) ?

Background

- Smartphone has many optical sources and sensors that have the potential to be reused as a spectral system.



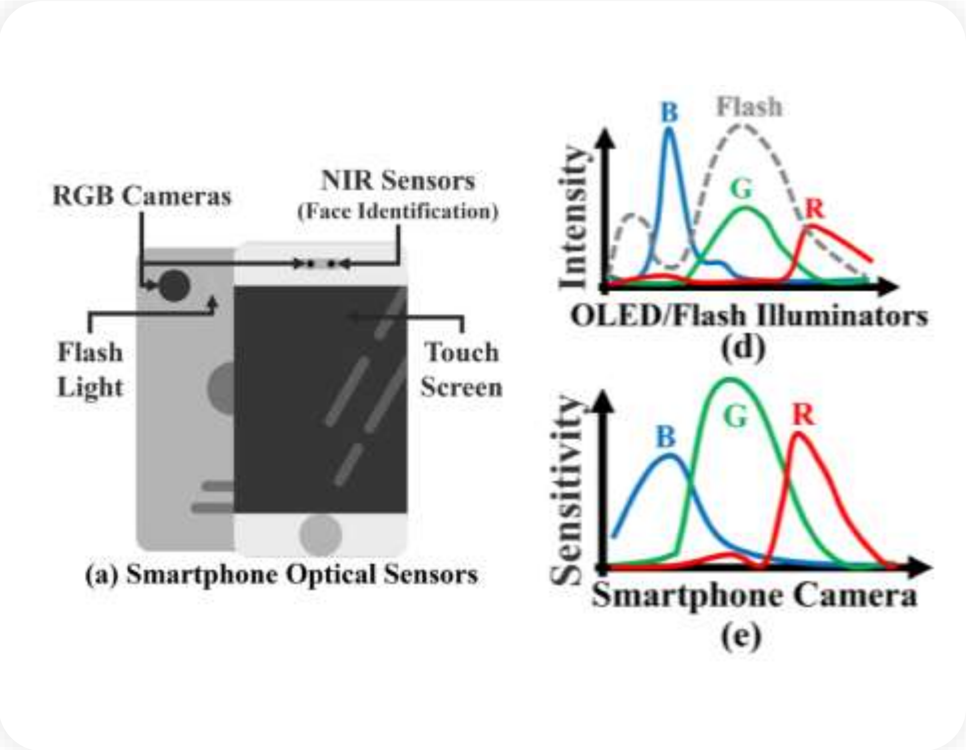
Smartphone Optical Sensors



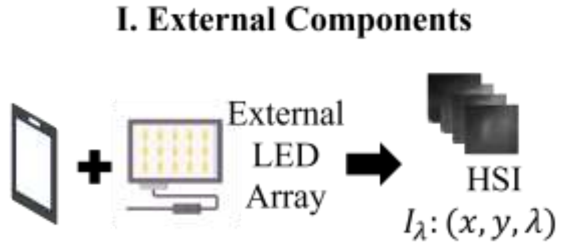
Rationale of Spectroscopy

Background

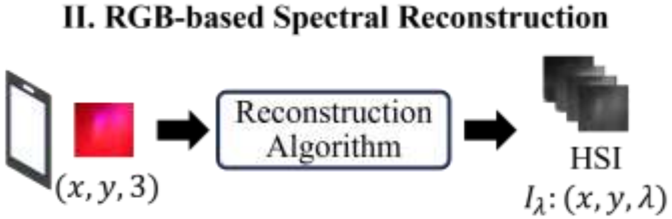
- The smartphone has only three wavelengths of light (RGB), which significantly reduce the performance of spectral analysis.



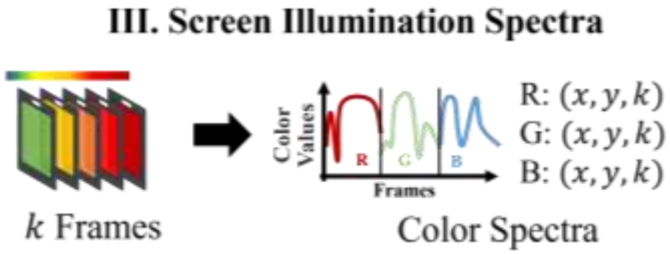
Extend
RGB



☹ **Extra Hardware**
☹ **Poor Usability**



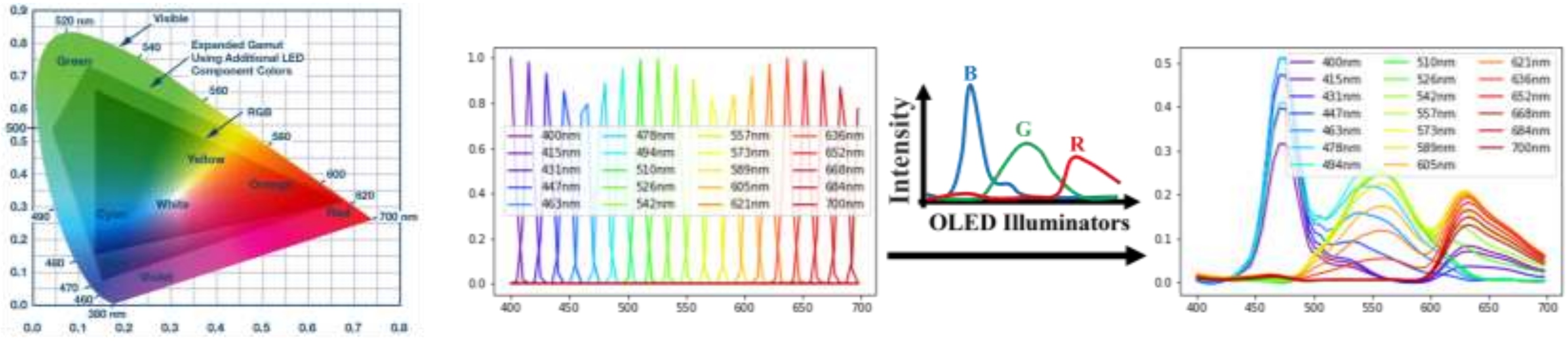
☹ **Metamerism Problem**



☹ **Pseudo-spectrum**
☹ **Qualitative**

Observation

- The screen-simulated monochromatic light can be viewed as a mapping from a real monochromatic wavelength to RGB colors.



(a) CIE-RGB Color Space (b) Translate Monochromatic Light Into OLED Spectra

$$R = Y \cdot \frac{x}{y},$$

$$G = Y \cdot \frac{1 - x - y}{y},$$

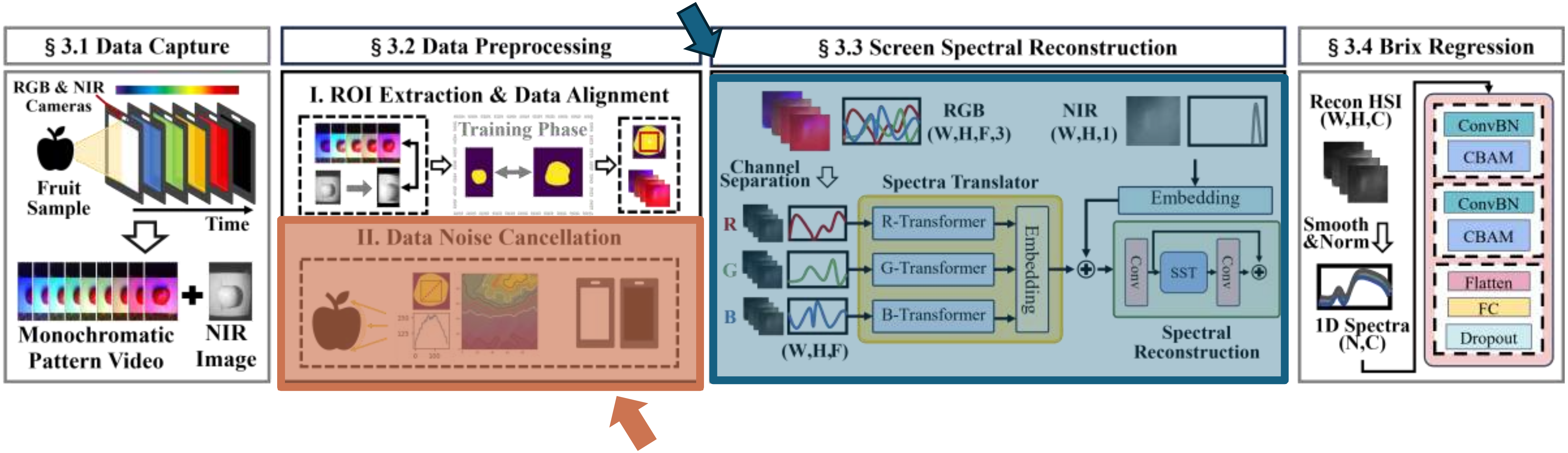
$$B = Y \cdot \frac{(1 - y)}{y}.$$

We have the opportunity to reconstruct the real hyperspectral image from screen-simulated color spectra!

Our System: FruitPhone

- We propose Fruitphone, which reconstructs the color spectra illuminated by smartphone screen light sources into a real hyperspectral image for fruit sugar content prediction.

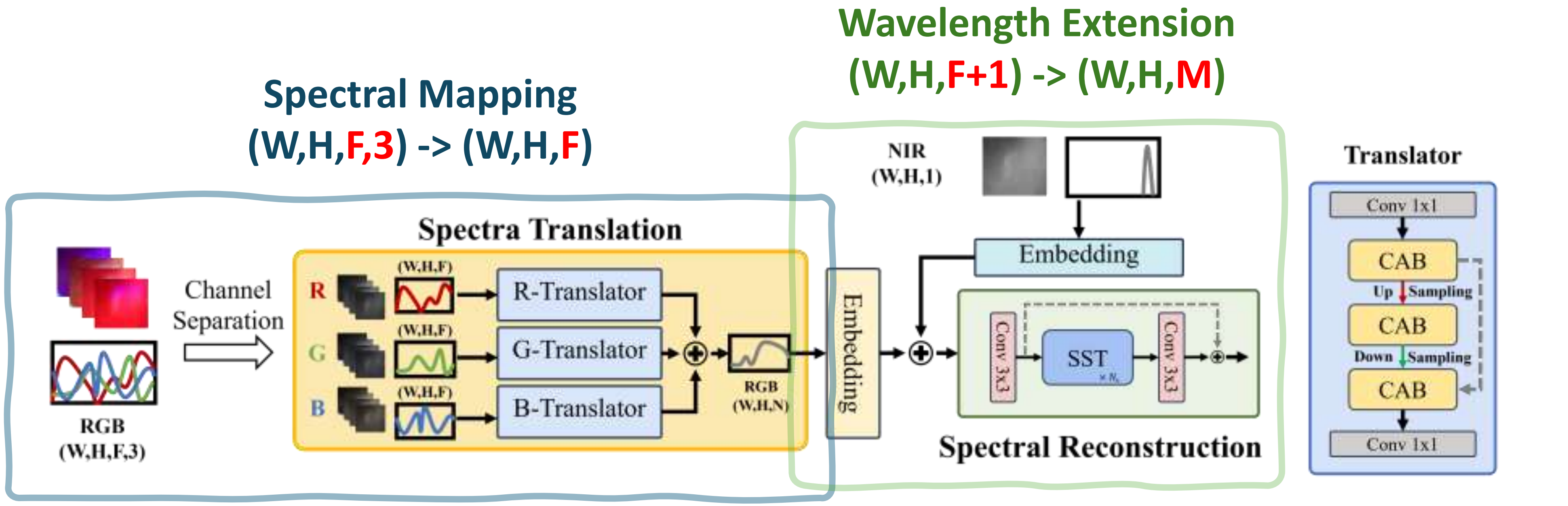
Challenge #1: Reconstruct Screen Spectra



Challenge #2: Calibrate Environment Noises

Challenge #1: Reconstruct Screen Spectra

- We introduce a two-stage spectral reconstruction algorithm:
  - Stage 1: translates the collected pseudo-spectral images into real multi-spectral images
  - Stage 2: derives full spectra from the translated features

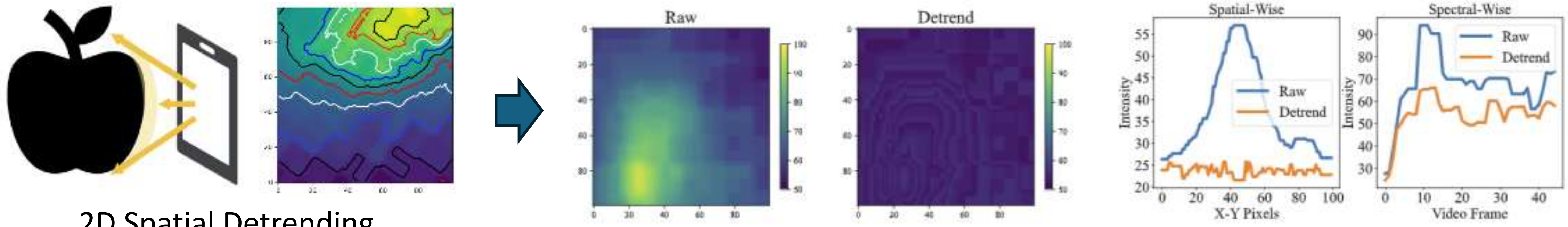


(a) Two-stage Spectral Reconstruction Architecture (b) Translator Backbone

Challenge #2: Calibrate Environment Noises

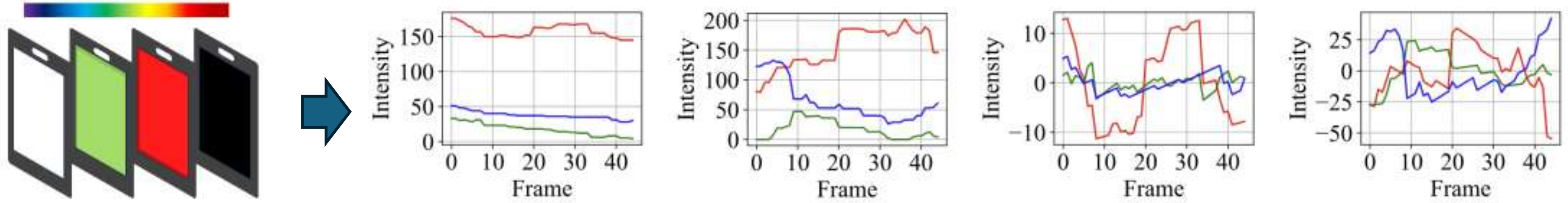
- Distribution: **Spatial unevenness** due to sample shape and screen light distribution
- Fluctuation: **Surrounding interferences** such as ambient light or user jitter may introduce inconsistence of the sample

Distribution



2D Spatial Detrending

Fluctuation



Black-White Frame Calibration

(a) Bright-Raw (b) Normal-Raw (c) Bright-Calibrated (d) Normal-Calibrated

Evaluation: Setup

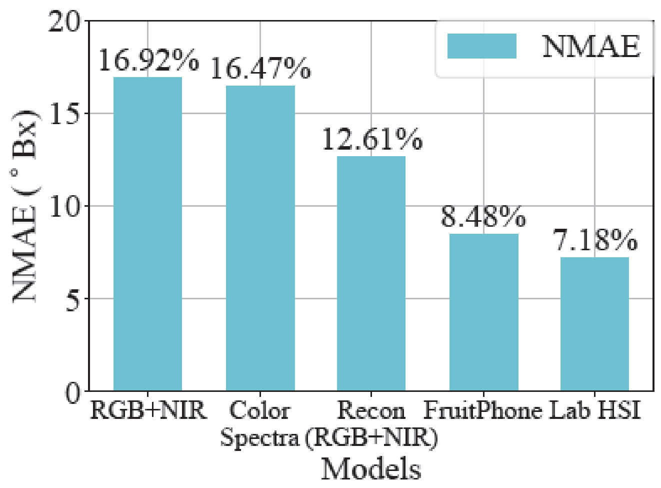
- We evaluate the performance of FruitPhone on **37** types of fruit with **335** fruit samples in total.

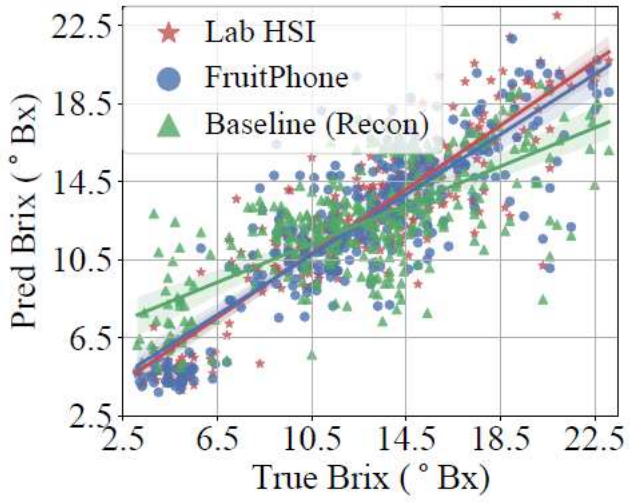
Category	Fruit Type (Number of Varieties)	Sample	Brix Range ($^\circ Bx$)
Berry	Grapes (6), Tomato (2), Strawberry (1), Blueberry (1), Mulberry (1), Guvav (1), Kiwi (1), Passion Fruit (1), Pepino (1)	180	3.1-23.1
Drupe and Kernel	Apples (4), Pear (2), Peach (1), Jujube (1), Loquat (1), Mango (1), Cheery (1), Persimmon (1)	75	8.9-20
Citrus	Mandarin (3), Orange (2), Lemon (2), Kumquat (1), Grapefruit (1)	75	4.6-21.5
Cucurbits	Longan (1)	5	11.4-16.3

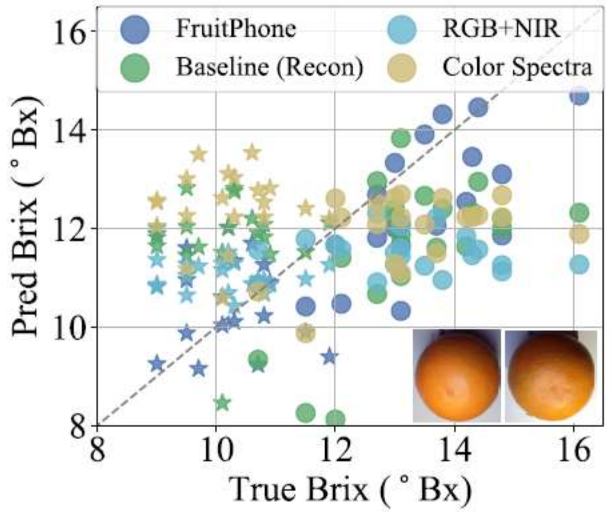
(a) Partial Fruit Samples in Training Dataset (b) FruitPhone Setups (c) Brix Ground Truth

Evaluation: Results

- FruitPhone achieves a normalized mean-absolute error (NMAE) of **8.48%**, which is **only 1.3% higher** than that of an expensive laboratory hyperspectral spectrometer (priced over $10,000).



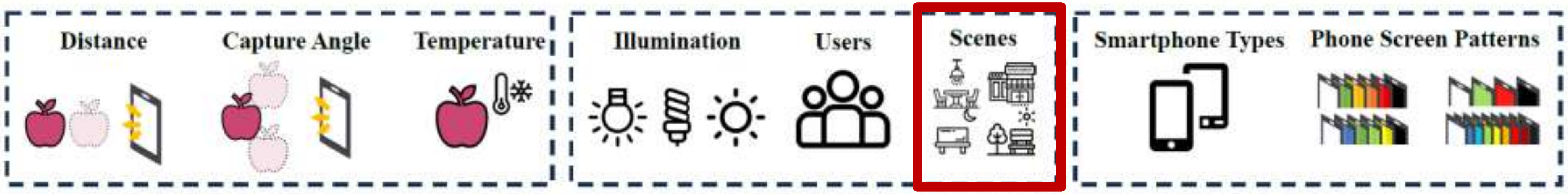


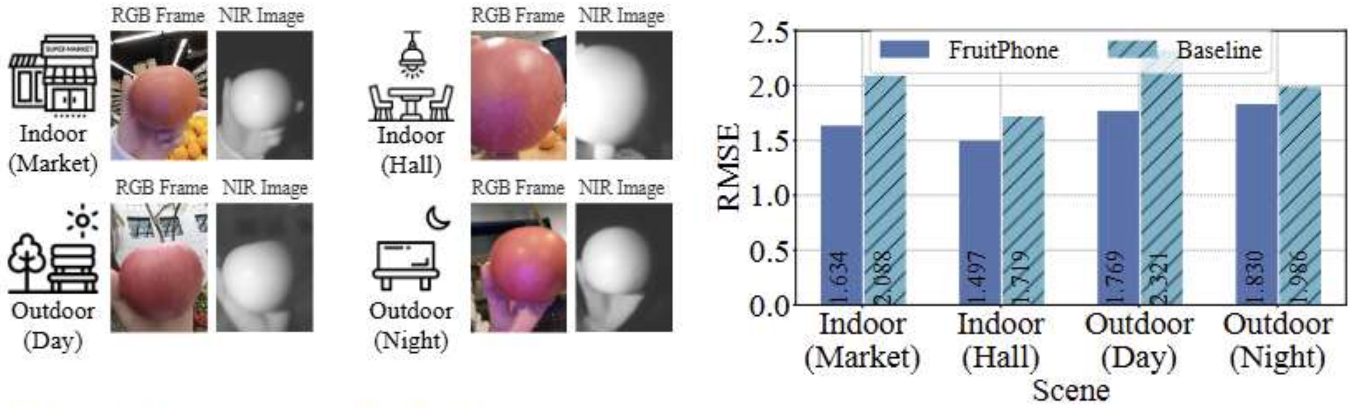


FruitPhone shows great improvement than baselines on metameric samples.

Evaluation: Robustness

- FruitPhone demonstrates remarkable robustness across various setups, including **diverse fruit placements**, **user configurations**, and **smartphone models**.

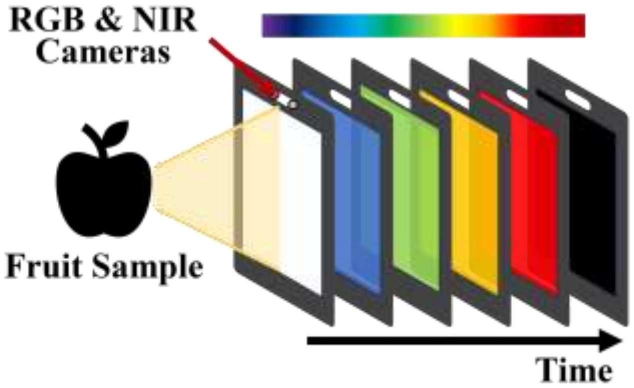




(a) The same fruit sample captured under various scenes with diverse compounding factors.

Conclusion

- Enabling **quantitative fruit sugar measurement** using only a smartphone.
- Overcoming hardware limitations via screen-based illumination and a two-stage spectral algorithm.
- Opening our dataset (with **335 hyperspectral images, RGB color spectra, near-infrared reference, and ground true brix values**) to involve more investigations in this area.



Scan QR Code to access our dataset

THE DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING 計算機科學及工程學系

UBICOMP ISWC2025

Thank you!

Homepage: https://hyanhu.github.io/

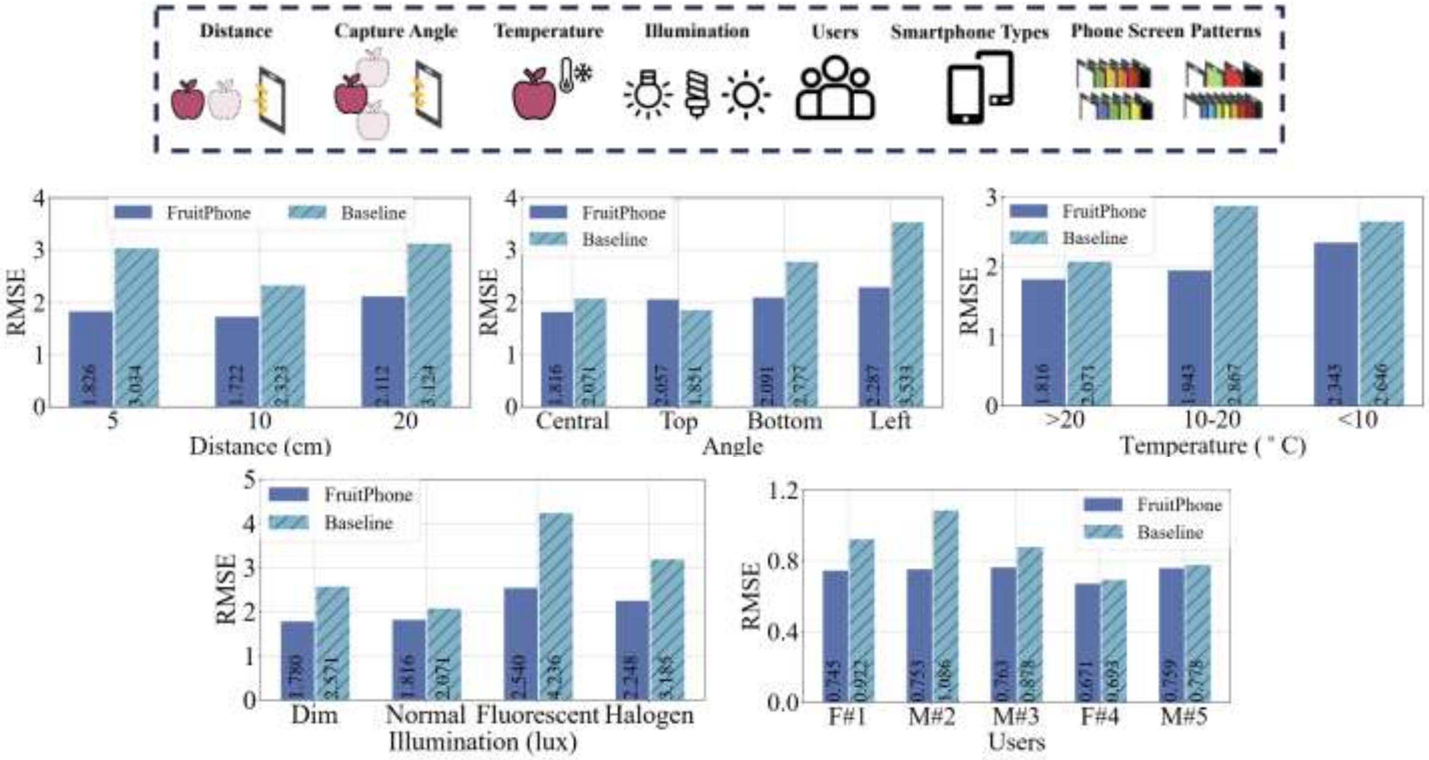
October 15, 2025

Espoo, Finland

Evaluation: robustness

- Compared to the state-of-the-art smartphone-based spectral system baseline, our solution reduces reconstruction errors by **19.98%.**
- A single run of the app on Google Pixel 4 XL consumes 2.945 mAh (0.079% of the battery capacity).

	FruitPhone	Baseline
MRAE	0.1803	0.2643
RMSE	0.0981	0.1226
PSNR	23.81	20.19
Flops (G)	230.6	221.7
Params (M)	31.44	31.26



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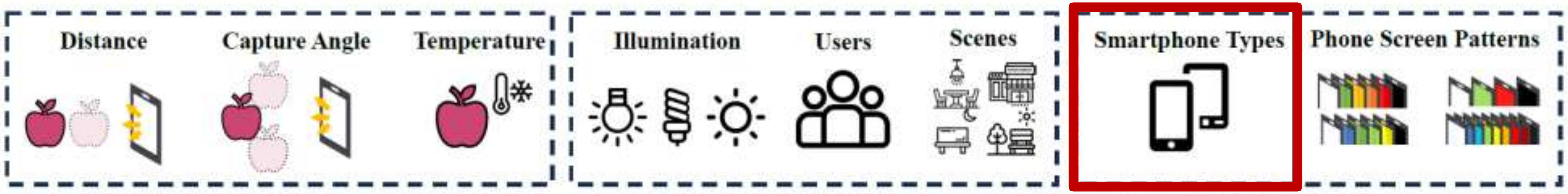

Table 5. Comparing the parameters across three smartphones and FruitPhone's performance on them after fine-tune.

	Screen Type	Screen Resolution	Refresh Rate	Camera Resolution	HDR Support	MRAE	RMSE	R2	NMAE
Google Pixel 4XL	OLED	3040×1440	90Hz	8MP	HDR10	0.1954	0.1032	23.15	8.90%
OnePlus 8 Pro	Fluid AMOLED	3168×1440	120HZ	16MP	HDR10+	0.2120	0.1476	20.26	9.97%
IQOO Z9X	LCD	2400×1080	120HZ	16MP	HDR10	0.2068	0.1353	20.79	9.25%