Fruit Color and Ripeness Detection System with Audio and Display Feedback

Indrani Paul Roy, Aktilek Skakova, Sai Panigrahy

Our Objective

We are developing a smart fruit-sensing system designed to assist color-blind individuals in identifying both the type and ripeness of fruits using color and spectral analysis. The system delivers real-time audio feedback indicating whether a fruit is ripe, unripe, or nearly ripe, while also displaying the fruit's detected color (e.g., "Red," "Green," "Blue," "Yellow") on a clear, high-contrast screen. By combining auditory cues with simple visual feedback, the device enables users to independently and confidently assess fruit ripeness—enhancing accessibility and supporting daily tasks such as grocery shopping and meal preparation.

Limitations of Existing Solutions

Today, most fruit ripeness detection systems rely on gas sensors that monitor ethylene—a gas emitted by fruit as it ripens. These systems are commonly used in large-scale agricultural and transportation settings, where they are effective for managing bulk ripening processes.

However, gas sensors come with key limitations. While generally accurate, they tend to be slower in providing real-time feedback and can be influenced by environmental conditions such as temperature, humidity, and airflow. These factors can reduce reliability, particularly in smaller or more variable environments. Additionally, these systems rarely incorporate color or spectral data, which could offer immediate, visual indicators of ripeness.

In contexts where quick, precise, and localized feedback is essential—such as for individuals with visual impairments—gas-based solutions fall short. A sensor that combines spectral and color data can offer faster, more direct, and environment-independent ripeness assessment, making it a more versatile and user-friendly alternative.

Novelty in our Approach

To accurately detect both fruit ripeness and color, our device integrates two primary sensors—one for visible color (TCS34725) and one for near-infrared spectral data (AS7263).

a) TCS34725 RGB Light Color Sensor **b) NIR spectral sensor AS7263**

Working Principle of the TCS34725 RGB Light Color Sensor:

TCS34725 Sensor is a light-to-digital color converter that contains an integrated infrared (IR) block filter. It operates in visible light reflectance mode. A white LED shines visible light onto a target surface (like a banana), and the sensor detects reflected light across the red, green, and blue parts of the spectrum, as well as clear light (full spectrum).

The top layer is a clear plastic/glass optical window. It allows ambient or LED-reflected light to reach the internal photodiodes. This window often includes an IR-blocking filter to prevent NIR light from distorting RGB readings. Integrated IR Cut Filter ensures that only visible light reaches the photodiodes and improves color accuracy by excluding unwanted infrared.

The TCS34725 includes 4 independent photodiodes, each filtered to sense:

- Red (R): ~615–680 nm
- Green (G): ~515–545 nm
- Blue (B): ~465–485 nm
- Clear (C): Broadband (no filter), measuring total light intensity

Each channel has its own color-specific optical filter (interference-based thin-film coating) that only allows a narrow band of wavelengths to pass. Light filtered by each color channel hits a **dedicated silicon photodiode**, which converts photons into current via the **photoelectric effect**. The sensor integrates **four parallel channels**, measuring intensity simultaneously.

These analog signals are then processed as follows:

- **Programmable Gain Control (PGA)**: Increases the signal strength depending on ambient brightness (e.g., Gain: 1x, 4x, 16x, 60x).
- **Integration Time Control**: Adjustable integration time (~2.4 ms to 700 ms) allows longer exposure under low light.
- **Analog-to-Digital Converter (ADC)**: Converts analog photodiode currents into 16-bit digital values.

SCL (Clock) and SDA (Data) are used for communication and the device can be operated with data rates of up to 400 kHz.

Bananas show visible color transformations during ripening:

- Unripe: more green (chlorophyll)
- Ripe: more yellow (reflects more red and green, less blue)
- Overripe: dark brown spots (drops in overall reflectance)

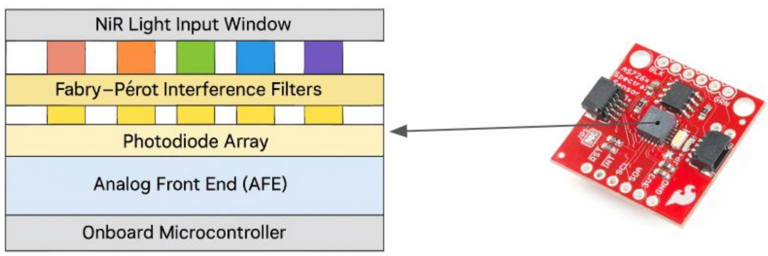
Working Principle of the NIR spectral sensor AS7263:

The AS7263 typically operates in **reflectance mode**, where a **light source** (usually NIR LEDs) shines light onto the target. The light interacts with the material — some of it is **absorbed**, and the rest is **reflected** back toward the sensor. The top of the sensor is a clear window (quartz/glass) that lets reflected NIR light through. This has an anti-reflective coating to reduce losses.

The next layer is a A **Fabry–Pérot filter, which** is composed of ultra-thin **dielectric layers.** It uses the physics of **constructive and destructive interference** to let only very specific wavelengths of light pass through. There are 6 unique filters, each centered on one of the sensor's fixed NIR bands.

Underneath each filter is a **photodiode**, typically made from **silicon**. Each one converts photons (light) into current via the **photoelectric effect, operating independently for each wavelength.**

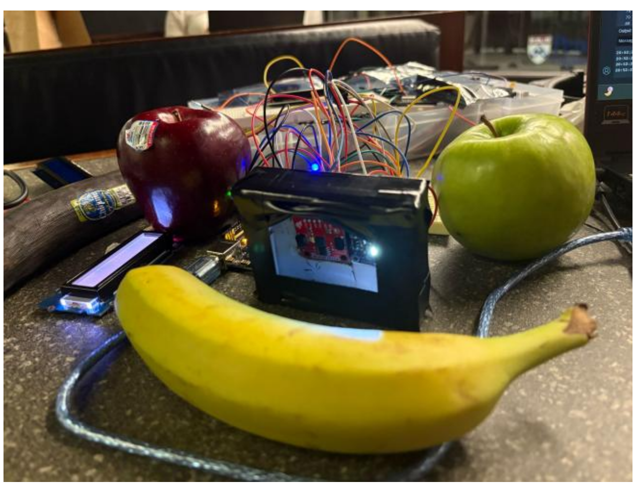
The analog front end includes amplifiers, filters, and an **ADC (Analog-to-Digital Converter)** which Converts the weak analog signals into a digital form. Finally the Embedded logic interprets the sensor data.



Inside the AS7263

We use the **AS7263** to classify banana ripeness based on NIR reflectance, especially because bananas undergo well-known biochemical changes (like sugar accumulation and chlorophyll breakdown) that affect **NIR absorbance**. As the banana **ripens**, **chlorophyll degrades**, and because the structure becomes **less dense and more sugar-rich**, **NIR reflectance often goes up**, especially in the **730–860 nm** range.

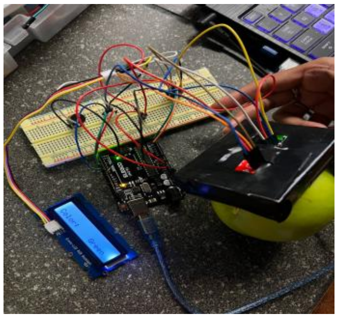
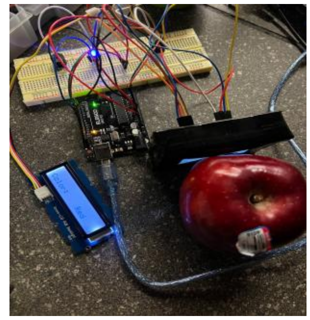
Demonstration of Sensors in Practice:

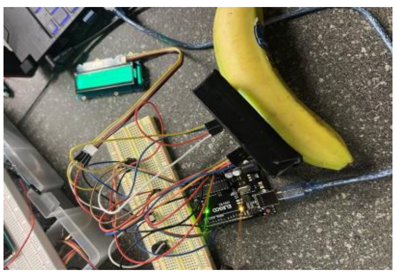
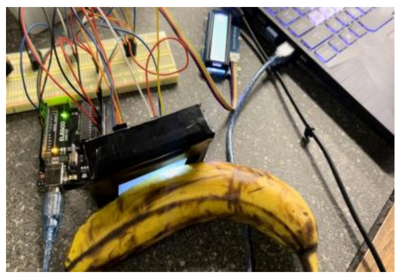


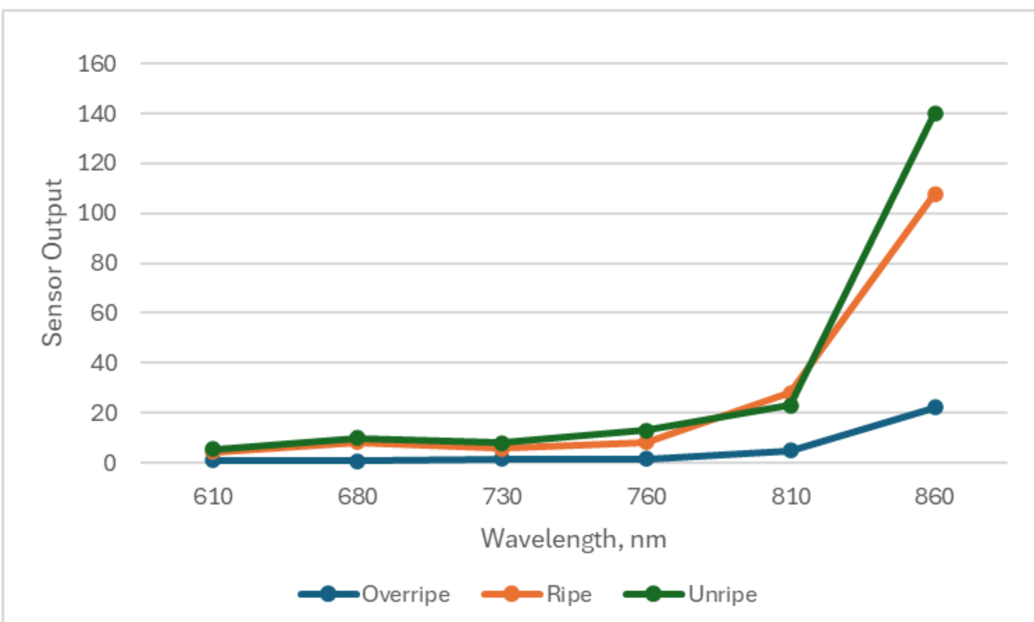
The colour sensor and the NIR spectral sensor are housed in a box structure to minimise environmental noise (Housing a RGB sensor + Spectral Reflectance Sensor). Grove LCD is used to read the output from the sensor and display the colour of the fruit for the user. An active piezo buzzer that alerts the user to the ripeness level.

Device Setup

Color Detection with Display Feedback

 (Display shows “Green”)	 (Display shows “Red”)

Ripeness Detection with Audio Feedback		
		
1 beep	1 long beep	3 beeps



Transfer function of sensor (Change in wavelength based on fruit ripeness)

Potential Impact on Target Audience

Our device is especially valuable for individuals with color vision deficiencies—particularly those with red-green color blindness—who often struggle to judge the ripeness and color of fruit. For individuals who are color-blind, identifying fruit type and ripeness is a constant challenge, especially in environments like grocery stores or kitchens where fast, independent decisions are needed.

If successful, this device empowers target users to independently and confidently select ripe fruit, improving their nutrition, autonomy, and quality of life. It also has potential uses in small-scale retail, food services, and even home automation—anywhere quick, accurate, and non-invasive fruit quality assessment is useful.

Potential Risks associated with the device

1. **Sensor Accuracy:** The performance of spectral and color sensors can be affected by varying lighting conditions or by the subtle color differences between certain fruits, potentially causing misclassification.

   <u>Mitigation Solution</u>: Regular calibration and algorithmic tuning will be implemented to account for lighting variations and improve classification accuracy across different fruit types.

2. **User Experience:** Delivering audio feedback through a buzzer may present challenges, especially when distinguishing between multiple ripeness stages or fruit types.

   <u>Mitigation Solution</u>: User testing and iterative feedback from the target demographic—particularly color-blind individuals—will guide improvements in feedback design. Additionally, replacing simple buzzers with recorded voice messages will enhance clarity and usability.

3. **Integration with Environment:** The system's performance may degrade in environments with inconsistent lighting or high background noise.

   <u>Mitigation Solution</u>: The integration of ambient light sensors and adaptive sound controls will help ensure the system remains responsive and effective across a variety of environmental conditions.

Bibliography

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