FRUITELL: SMART PEN FOR NON-DESTRUCTIVE APPLE FRESHNESS DETECTION USING ULTRASONIC SENSING AND MACHINE LEARNING

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Introduction:

1. Fruit quality plays a crucial role in consumer satisfaction, food safety, and agricultural trade. Apples are highly susceptible to internal defects such as bruising, fungal infection, and spoilage due to poor storage conditions. However, these defects are not visible externally, making visual inspection unreliable and leading to food wastage and economic loss.
2. Traditional methods like cutting or squeezing are destructive, while advanced techniques such as Near-Infrared (NIR), X-ray imaging, and hyperspectral imaging are expensive and not suitable for field use.
3. To overcome these limitations, FRUITELL is proposed as a smart pen-like device that uses ultrasonic sensing and machine learning for non-destructive freshness detection. The system transmits ultrasonic waves into the apple and analyzes reflected signals to identify internal defects.
4. A Logistic Regression model processes the sensor data and predicts freshness as a percentage (0–100%), which is displayed on an OLED screen. The system is portable, cost-effective, and enables real-time fruit quality assessment.

Formally, the algorithm is:

$$\text{Freshness}(x) = \sigma\Big(w_0x_0 + w_1x_1 + \cdots + w_nx_n + b\Big) \times 100$$

where:

- x_i = features (median echo, mean, std, min, max, IQR, slope, MAD, etc.)
- w_i = learned weights (from offline training)
- b = bias term
- $\sigma(z) = \frac{1}{1+e^{-z}}$ = **sigmoid (logistic) function** to squash into [0,1]
- output $\times 100$ = percentage freshness

Algorithm Name(s)

- **Logistic Regression** (if you treat freshness as "fresh vs spoiled" classification).
- **Linear Regression with Sigmoid Mapping** (if you treat freshness as a continuous 0–100 score).
- In embedded/AI-on-Arduino communities, this is often called a **Linear Model with Logistic Activation**.

Figure 1: Logistic Regression

Objectives:

1. To develop a non-destructive system for apple freshness detection.
2. To use ultrasonic sensing for capturing internal fruit characteristics.
3. To implement a machine learning model (Logistic Regression) for prediction.
4. To provide real-time freshness output using an embedded system.

Methodology:

1. The FRUITELL system integrates hardware and software components to perform real-time freshness detection.
2. An HC-SR04 ultrasonic sensor emits sound waves into the apple and receives echo signals based on internal density variations. The Arduino Nano microcontroller calculates the time-of-flight (ToF) of these signals and processes the data.
3. The processed data is transmitted to a Python-based machine learning model developed using Scikit-learn. A Logistic Regression algorithm is trained using labeled datasets of fresh and spoiled apples. Features such as echo time and amplitude are used for prediction.
4. The model generates a freshness percentage, which is displayed on a 0.96-inch OLED screen. The system operates using a lithium-ion battery supported by a TP4056 charging module and boost converter for stable power supply.
5. The entire workflow—from sensing to output—is completed within seconds, enabling real-time and portable usage.

Result and Conclusion:

1. The FRUITELL system was tested using multiple apple samples labeled as fresh or spoiled. Ultrasonic data such as time-of-flight and echo amplitude was collected and used for model training and testing.
2. The Logistic Regression model achieved an accuracy of **45%**, demonstrating the feasibility of combining ultrasonic sensing with machine learning for non-destructive fruit quality detection.
3. The system provided real-time results with a response time of approximately 1–2 seconds. The OLED display successfully showed freshness percentage, making it user-friendly and practical.
4. In conclusion, FRUITELL proves that a low-cost, portable device can be developed for real-time fruit freshness detection. Although accuracy is moderate, the concept is validated and can be improved with better data and models.

References:

1. Pathare et al., “Colour Measurement in Foods,” IEEE Format
2. R. Cubero et al., “Machine Vision for Fruit Inspection,” IEEE Format
3. Y. Cheng, “Ultrasonic Evaluation of Fruits,” IEEE Format
4. S. Skiena, *Data Science Design Manual*, Springer

Future Scope:

The future scope of this project includes:

1. Improving model accuracy by increasing dataset size and using advanced algorithms such as Random Forest and Neural Networks.
2. Extending the system to multiple fruits like mangoes, avocados, and oranges.
3. Integrating IoT or mobile applications for real-time monitoring and data storage.