MEAT FRESHNESS DETECTION SYSTEM FOR HOUSEHOLD REFRIGERATORS
(REFOOD)
ARÇELIK-BEKO

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Abstract. The ReFood Scanner project, developed in collaboration with Arçelik A.Ş., aims to design an innovative system integrated into refrigerators for measuring the ripeness, freshness, and nutritional value of food, with a primary focus on meat products and chicken. This system utilizes gas sensors (e.g., MQ136 and MQ137) to detect spoilage-related gases like hydrogen sulfide and ammonia, as well as a Near-Infrared (NIR) spectrometer for analyzing food composition. Data from these sensors is processed through a feedforward neural network deployed on an STM32F407 microcontroller, which classifies meat as either "Edible" or "Spoiled" with over 85% accuracy. The classification result is transmitted from the STM32 board to an Arduino via UART, and then sent wirelessly to a mobile application using a Bluetooth module. The mobile app provides users with real-time feedback on food freshness in a simple and accessible interface. The project emphasizes low power consumption, high scalability for future integration with other food types, and ease of user interaction. It addresses the global issue of food waste by enabling consumers to monitor food freshness more accurately and make informed consumption decisions. The ReFood Scanner is not only aligned with Arçelik's sustainability goals but also paves the way for the integration of intelligent food quality monitoring systems into everyday appliances.

PROJECT DESCRIPTION

The ReFood Scanner project, developed in collaboration with Arçelik A.Ş., addresses the issue of household food waste by enabling real-time freshness detection of meat products and chicken stored in refrigerators. Food spoilage is a major contributor to global waste, with over 30% of food produced worldwide discarded each year[1]. This project aims to provide a practical and scalable solution to help consumers make informed decisions before consuming perishable items, ultimately supporting healthier lifestyles and reducing unnecessary waste.

The proposed system is designed to classify meat and chicken as either fresh or spoiled based on gas emissions observed during spoilage. It leverages low-cost gas sensors to detect compounds such as ammonia and hydrogen sulfide, which are released as meat and chicken deteriorate. These sensor readings are processed by a lightweight feedforward neural network running on an STM32F407 microcontroller. The classification result is transmitted and displayed in the mobile application.

Several existing solutions, such as FreshDetect, FoodSense, and SmartFoodTech, have been developed for meat freshness assessment. While technically capable, these systems are either built for industrial use or are too large and complex to be embedded directly into consumer refrigerators. Most are not accessible to end users or feasible for everyday household use.

Unlike these existing approaches, the ReFood Scanner is explicitly designed with everyday consumers in mind. It is compact, cost-efficient, and fully embedded—requiring no external computation or connectivity. The model runs entirely offline and integrates seamlessly into Arçelik's refrigerator ecosystem. Thanks to its modular design and energy-efficient operation, it supports future scalability toward monitoring other food categories such as dairy or produce, with minimal hardware changes.

By combining affordability, embedded intelligence, and user-friendly feedback, the ReFood Scanner offers a novel and practical solution for sustainable food management in household appliances.

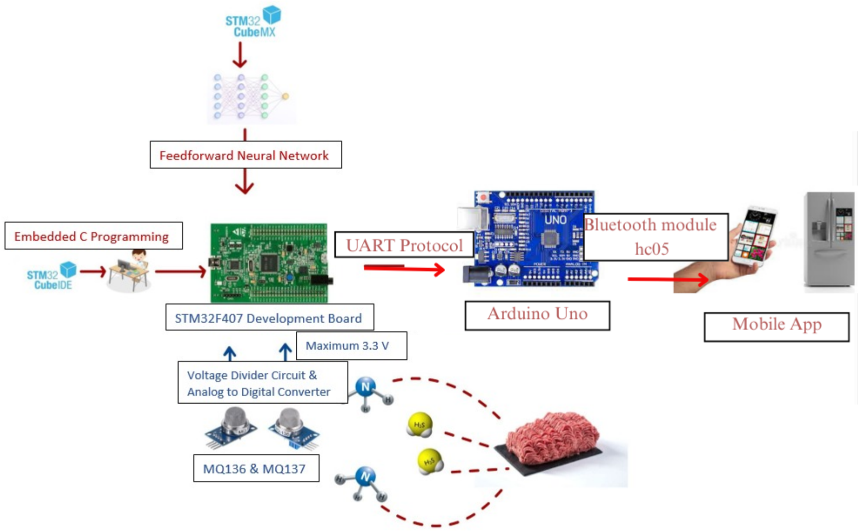

FIGURE 1. Big Picture of the Project

This Big Picture summarizes the overall flow of the ReFood Scanner system: spoilage gases (H2S and NH3) released from meat are detected by MQ136 and MQ137 sensors. The signals are processed by the STM32F407 microcontroller, where a feedforward neural network performs real-time classification. The result is sent to the mobile application.

MILESTONES

- **MS1:** Successful integration of chosen sensors into the STM32 board: This milestone requires MQ series gas sensors' connection and configuration through STM board, which ensures reliable data acquisition and voltage readings under various conditions.

TABLE 1. List of gas sensors used during development

Component	Target Gas	Purpose in Project
MQ136	Hydrogen Sulfide (H2S)	Spoilage gas detection
MQ137	Ammonia (NH3)	Spoilage gas detection
MQ135	NH3, Benzene, CO2	Additional spoilage gas detection
MQ4	Methane (CH4)	Supportive spoilage indication
MQ3	Alcohol	Additional gas presence

- **MS2:** NIR spectrometer initialization: Although not included in the final product, the initialization and usage of the AS7263 NIR spectrometer during development was crucial for validating sensor data. Its integration allowed cross-checking of freshness indicators and served as a ground truth reference during the data collection phase

- **MS3:** System set-up in the refrigerator and data collection: Setting up the sensing system inside a real refrigerator environment enables long-term monitoring of meat samples under realistic conditions. This milestone ensures consistent and context-relevant data acquisition from fresh to spoiled states.
- **MS4:** Obtaining sufficient and clean data to construct our classification model: Constructing a reliable dataset involves labeling sensor readings based on spoilage levels and eliminating outliers and fluctuations. A curated dataset provides the necessary structure for building and testing the model.
- **MS5:** Successfully constructing the classification model: This milestone covers the design of a feedforward neural network that processes gas sensor readings to estimate freshness. The model shall produce a binary output (fresh/spoiled), remain lightweight, and be suitable for deployment on a microcontroller using STM32Cube.AI.
- **MS6:** Successful wireless transmission of classification results to the mobile application: UART communication was established between the STM32 board and an Arduino module, which then relays the classification output via Bluetooth to a mobile application. This setup enables real-time wireless transmission of freshness data and allows users to monitor the condition of their food directly through a user-friendly mobile interface.

DESIGN DESCRIPTION

Sensor Research and Initial System Setup

The project began with a literature review that identified hydrogen sulfide (HS) and ammonia (NH) as reliable spoilage markers [2][3]. MQ136 and MQ137 sensors were selected for these compounds, with MQ135 (air quality) and MQ4 (methane) as supplementary detectors. To validate gas-sensor outputs, an AS7263 NIR spectrometer (600–860 nm) was added as a reference, and the STM32F407 microcontroller was configured as the central processor. Each sensor underwent individual warm-up and voltage-output tests, and raw voltage readings were used in the absence of calibration gas kits. Milestones I–II–III were achieved by successfully integrating all sensors and the spectrometer inside a refrigerator unit.

Dataset Collection and Experimental Infrastructure

A structured dataset was developed by collecting real-time sensor readings from both fresh and spoiled meat samples stored in a controlled refrigerator environment over several days. Voltage outputs from the MQ sensors and reflectance data from the NIR spectrometer were recorded at regular intervals (see Figure 2), and additional data from heat- and air-exposed meat samples were contributed by Arçelik's Eskişehir laboratory to improve diversity. After preprocessing to remove anomalies and inconsistencies, the resulting clean and well-structured dataset marked the completion of Milestone IV and was deemed suitable for machine learning development.

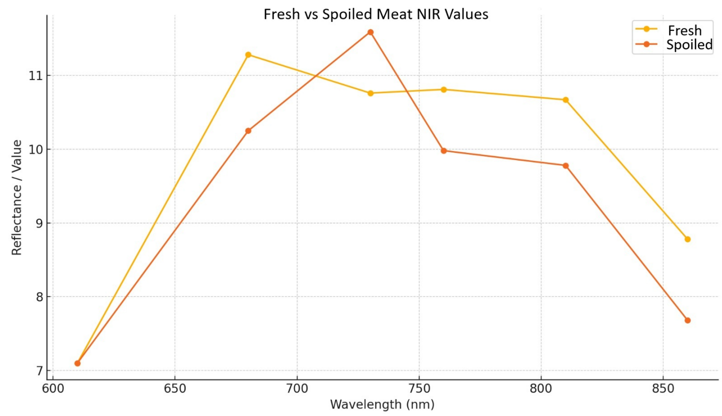

FIGURE 2. Fresh vs. spoiled meat reflectance values through wavelengths

Classification Model Development and Deployment

After preparing the dataset, a classification model was built to determine whether meat was fresh or spoiled. A simple feedforward neural network (FNN) with one hidden layer was chosen due to its suitability for embedded platforms. The input layer received four features—voltage values from MQ136, MQ137, MQ135, and MQ4—while the output layer provided a binary result.

The model was trained using the collected dataset and fine-tuned through hyperparameter optimization. Once a satisfactory accuracy level was achieved, it was converted to TensorFlow Lite format and deployed on the STM32F407 using STM32Cube.AI. Real-time classification was successfully performed directly on the embedded hardware without external computation, marking the completion of Milestone V.

Communication with Mobile Application and User Interface

To deliver real-time classification results to users, a wireless communication system was implemented using UART and Bluetooth. The STM32 board sends the classification result—either "Fresh" or "Spoiled"—to an Arduino via UART, which then transmits it to a mobile app through an HC-05 Bluetooth module. The result is displayed on the mobile interface within 60 seconds. This setup ensures portability, flexibility, and independence from the refrigerator's internal systems. With this, Milestone VI was successfully completed.

Extension to Other Food Groups and Final Integration

The system was then expanded to support additional meat types, including chicken breast and beef tenderloin. New datasets were collected, and sensor outputs were analyzed to detect spoilage patterns specific to each type. To differentiate red meat from poultry, a TCS34725 color sensor was added, enabling classification based on surface color. This allowed the model to apply meat-specific thresholds and logic. Feature extraction techniques enhanced model sensitivity, and spoilage thresholds were recalibrated for each meat category. Finally, all hardware components were integrated into a compact 3D-printed enclosure that supported airflow and was durable enough for refrigerator use.

RESULTS AND PERFORMANCE EVALUATION

Following the successful integration of the sensor system and microcontroller, the classification model was trained using a curated dataset composed of voltage readings from four sensors: MQ136, MQ137, MQ135, and MQ4. The sensor data reflects various spoilage levels of meat samples collected under real-life conditions. The model was developed as a feedforward neural network with a single hidden layer and a sigmoid output for binary classification. The training process involved standard backpropagation and optimization techniques, and the model was then deployed on the STM32F407 microcontroller using STM32Cube.AI.

To evaluate the performance of the trained model, both training and test datasets were analyzed. The best-performing threshold values for each sensor were identified, as shown in **Figure 3**, which also highlights classification accuracy in both training and test phases. These thresholds provided insight into the contribution of each sensor to the binary decision process (fresh/spoiled)[4].

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Single-Feature Best Thresholds (Train Set):
  MQ4: threshold=0.6600, accuracy=0.9085
  MQ135: threshold=1.2758, accuracy=0.9868
  MQ136: threshold=1.9829, accuracy=0.9795
  MQ137: threshold=1.9100, accuracy=0.9639

Checking these same thresholds on the TEST set:
  MQ4 (threshold=0.6600): test accuracy=0.9327
  MQ135 (threshold=1.2758): test accuracy=1.0000
  MQ136 (threshold=1.9829): test accuracy=0.9856
  MQ137 (threshold=1.9100): test accuracy=0.9904
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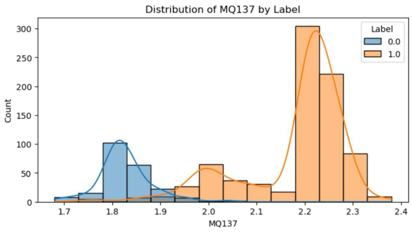
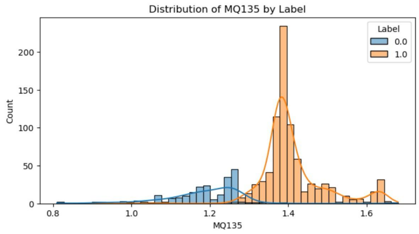
FIGURE 3. Threshold values and corresponding accuracy levels of the classification model.

Analysis of the label-based voltage distributions (Fig. 4) for MQ137, MQ135, MQ4, and MQ136 showed clear separation between "fresh" and "spoiled" samples, validating our sensor choices and the classifier's reliability. In real-time refrigerator tests, the model achieved over 85 percent accuracy and completed detection in under 60 seconds, meeting both performance and timing requirements. The embedded system also ran stably across –2 °C to +8 °C, in line with standard refrigeration conditions.

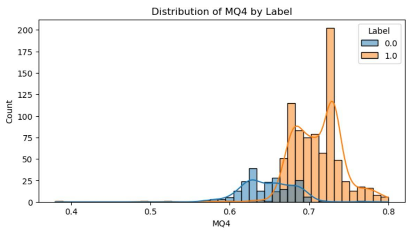
In addition to overall accuracy, robustness and power efficiency were considered. The embedded inference process introduced negligible delay and consumed low computational resources, enabling long-term use within energy-constrained appliances[5].Rather than integrating with the refrigerator's internal motherboard, the system was redesigned to communicate results via Bluetooth. The STM32 board transmits classification results to an Arduino over UART, which then sends the data wirelessly to a mobile application. This wireless architecture improves flexibility and allows the system to be easily tested and used without direct access to the refrigerator's hardware. The mobile app provides a lightweight and user-friendly interface that displays freshness results in real time. While initial results are promising, future improvements include testing the system on additional food types and evaluating the contribution of each sensor to optimize the model. These directions are expected to increase scalability and reduce system complexity in future iterations.



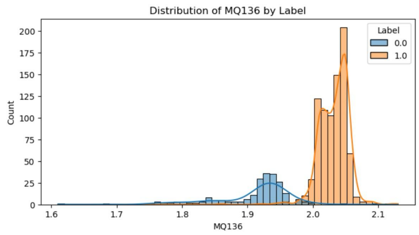
(A) Distribution of MQ137 by Label



(B) Distribution of MQ135 by Label



(C) Distribution MQ4 by Label



(D) Distribution of MQ136 by Label

FIGURE 4. Voltage distribution of gas sensors based on freshness labels where blue indicates fresh and orange indicates spoiled.

While most studies focus on high-precision freshness detection using optical systems or gas chromatography, such methods are not suitable for consumer-level integration due to their complexity and cost. This work, instead, aims for an embedded and low-cost solution compatible with household appliances.

CONCLUSIONS AND FUTURE DIRECTIONS

The ReFood Scanner project demonstrated a low-cost, modular embedded system for detecting meat and chicken freshness in household refrigerators. By using multiple gas sensors and a feed forward neural network on an STM32 microcontroller, the system performs real-time binary classification of meat as “Fresh” or “Spoiled.” Also, a TCS34725 color sensor has been used to distinguish between meat types, such as red meat and poultry, based on color. The classification results are transmitted from the STM32 board to an Arduino via UART and then sent wirelessly to a mobile application using a Bluetooth module.

Future work may include extending classification to other food types such as poultry, dairy, or produce, and optimizing sensor use through contribution analysis to reduce complexity and cost. One key future direction is the full integration of the system into the refrigerator’s internal display panel. Although this was not possible in the current version due to Beko’s internal access restrictions and security protocols, such integration would allow results to be shown directly on the display screen of the refrigerator. This would enable a seamless user experience and tighter coupling with the appliance ecosystem.

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BEHIND THE SCENES