Refrigerator Food Contamination Detection using Electronic Nose

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Introduction

1.1 Objective:

Food poisoning is a serious problem that affects thousands of people every year. Out of approximately 5000 total deaths reported in the United States every year, 1500 are caused by pathogens like Salmonella, Listeria and Toxoplasma. The World Health Organization (WHO) reports that salmonellosis caused by Salmonella spp. is the most frequently reported food borne disease worldwide [2]. Poisoning food must be detected early in order to prevent diseases. A lot of food gets wasted in developing countries or in tropical regions while getting transported from the farmlands to the markets, mainly because of improper intermediary storage techniques. This results in colossal amounts of post-harvest losses that are incurred by the poor farmers or result in raised food prices to make up for the lost food. An early detection system can help prevent the rotting item from affecting the remaining produce. This will imply that food wastage is reduced and the prices associated with these goods don't skyrocket. Even in our households, we often forget about some food item stowed away in our refrigerator drawer hidden under other items, until it turns smelly and moldy, and needs to be disposed. Having a device that detects this would be of great help in reducing such wastage. Not just in a household setting, an early food contamination detection system can find application in industrial refrigerators and storage units that cater to concentration of a single food item in refrigerators and incur losses due to spoilage of one element resulting in contamination of the entire unit.

Contaminated food is usually detected by odor which is composed of molecules of specific sizes and shapes with a corresponding receptor in the human nose. The brain identifies the smell associated with that particular molecule when signaled by the receptor. Electronic nose is an array of sensors that imitates this biological functionality.

Our goal is to build a modular electronic nose that can be fitted inside a refrigerator or any other closed food storage equipment and detect the onset of food spoilage. This early detection can then be notified to the user through an LCD screen, thereby allowing him to consume or dispose the item, depending on its state. Concentration of certain gases and chemicals like CO_2, acetone, ethanol etc. increases because of rotten food and thus can be detected by the array sensors which are the heart of the design. An add-on feature could be a barcode scanner that notes the expiry dates of products and notifies the users, particularly in supermarkets and in households, to consume the product before it gets too late.

1.2 Background:

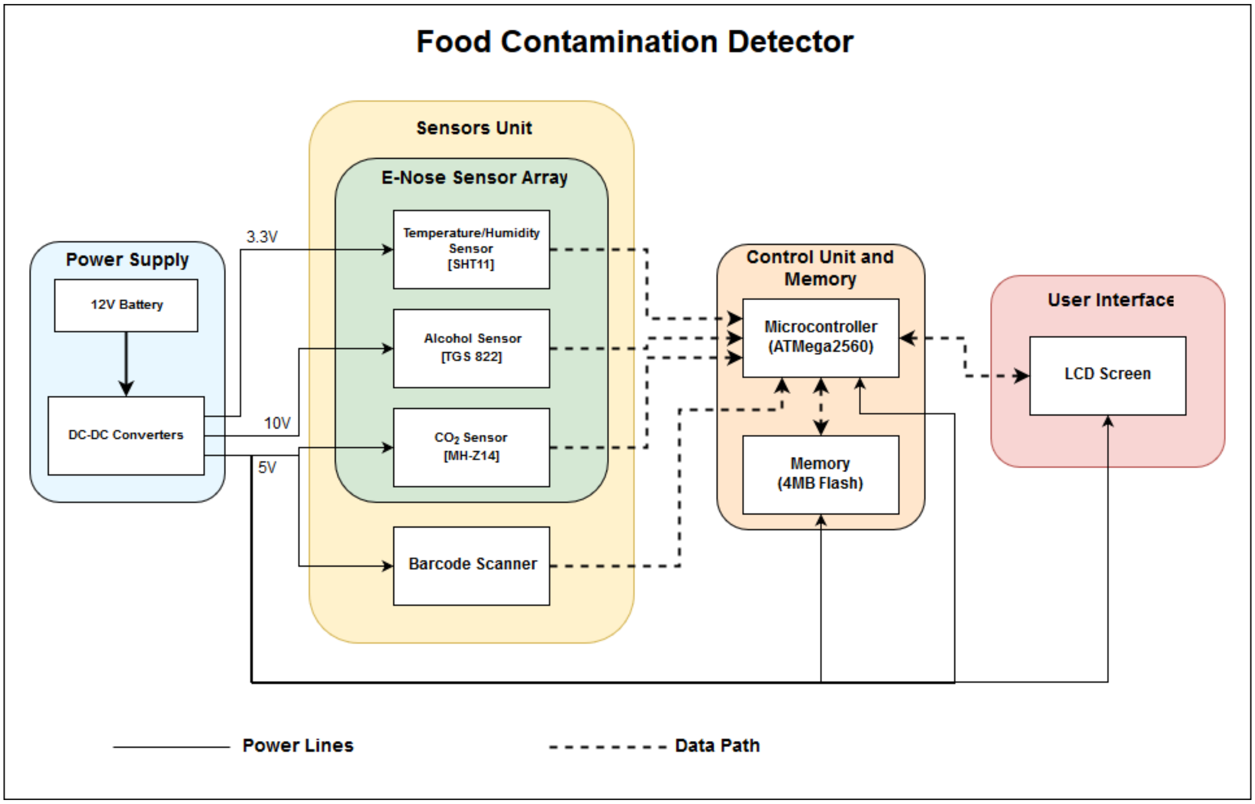
There is a niche market for electronic noses and the current market leader is the French company Alpha Mos which targets the very expensive, very high-performance laboratory equipment market. The relatively cheaper and more portable devices of Scensive Ltd (Bloodhound) and Smiths Detection (Cyranose models) frequently reported in academic literature are both based on conducting polymer arrays. All of the current devices are intended to strictly be used as laboratory instruments analogous to HPLC/GC's and spectrometers. All of these devices need to be individually calibrated for a particular application [6]. The company 'eNose' is working on a technology to build cheaper electronic noses but it is specific to medical industry and disease detection. There has been a lot of research in the industry to build electronic noses for food contamination detection but the white papers have targeted specific food items and the end products are expensive because of the price of the sensors being used in these experiments [5]. We are working on devising a modular, attachable and economical electronic nose system with a smoother user interface that can target the usual consumer markets and not just industries or laboratories.

1.3 High-Level Requirements:

- The e-nose detects the onset of food spoilage beyond a certain concentration of gases. We devise a threshold for this gas concentration based on experiments that we will conduct in the course of the build.
- The system should work under refrigerator temperature conditions (0°C - 10°C) as well as room temperature conditions (20°C - 25°C).
- The micro-controller performs the data-analysis and successfully displays a user-friendly infographic on an LCD screen and warns the user about the rotting food.

Design

2.1 Block Diagram:



Our design consists of 6 main components. There is a power supply that is composed of a 12V battery to power all the circuitry and a DC-DC converter to provide each of the units with the required voltages. The sensor array unit consists of a CO2 sensor, Alcohol/Organic Solvent sensor and Temperature Humidity sensor - all working together to provide the values on detection of the chemicals at the particular temperature and humidity setting to contribute to accurate readings. The inputs from this unit are fed to the microcontroller which interprets the readings and passes a signal to the UI unit that in turn notifies the user of potential food contamination. The barcode scanner is an additional feature present in the sensor unit that enables the user to feed in data pertaining to packaged foods. The details are stored in memory and the user is notified if any of the products approach their respective expiry dates. The microcontroller will be programmed to work with this data while the UI will be used to output the signals to the beneficiary.

Functional Overview:

Power:

- The power supply will get the whole system working.
- The main components of the power supply will include a 12V battery. The voltage requirements of each of the individual units are different and lesser than 12V. The DC-DC converter will be used to make sure that each of the units get the required voltage.
- The 12V supply will be converted to 10V using a voltage divider instead of a regulator or DC-DC converter since the options are limited in the market and they are expensive adding significantly to the overall cost
- Further conversions to 5V and 3.3V will be done using DC-DC converters to provide a higher efficiency in conversion.

Requirements: We will power the board using a 12V battery. The 12V source will then be converted to other required voltages i.e. 5V and 3.3V using DC-DC converters.

E-Nose Sensor Array:

- The sensor array contains 3 sensors to measure CO_2 concentration, alcohol/organic solvents concentration and temperature and humidity
- The gas sensors are used to detect the activity of bacteria that causes contamination of the food. The alcohol sensor TGS 822 gives out an analog output while the CO_2 sensor MH-Z14 communicates using UART serial protocol
- The humidity and temperature sensor will keep track of the local conditions of the system which can be used to calibrate the change in sensor output due to changes in RH and temperature. Humidity and temperature sensor SHT11 communicates using a serial interface similar to I^2C protocol

Requirements:

Sensor	**Element to be sensed**	**Typical Supply Voltage**	**Operating Condition**
TGS 822	Alcohol/Organic Solvent	10±0.1V	-10°C - 40°C
MH-Z14	CO_2	5V	0°C - 50°C
SHT 11	Humidity & Temperature	3.3V	-40°C - 123.8°C

Micro-Controller:

- The microcontroller will be the main control unit of the entire system.
- The MCU will communicate with the different blocks of the product to execute the seamless functional design of the contamination detector.
- It should have at least one UART to communicate with the CO_2 sensor.
- It should have at least 2 pins for communicating with the other sensors.
- It should have serial interface to communicate with the SHT 11 sensor.
- The MCU should be able to communicate with the memory using SPI.

Requirements: We'll be using ATMega-2560 MCU for the project as it satisfies the above requirements and the choice will be helpful in prototyping as well since Arduino uses the same AVR Microcontroller

<u>User Interface:</u>
For the prototyping phase, we plan to get started with using LEDs that would be an indication of whether the sensors provide adequate data for the ranges fed into the microcontroller to provide a message to the user. For the final product, we aim to integrate the circuitry with an LCD display that can warn the user of potential food contamination detection or of product expiry.
Requirements: A 16x2 LCD screen capable of displaying two lines of text in English. It should have RGB backlight. The working voltage should be 5 V as that meets the power supply limits and operating current should be <100mA. It should use I2C communication to interface with the microcontroller.

Additional Features - The following features are additional based on cost and time constraints:

<u>Barcode Scanner:</u>

- The Barcode scanner will provide an additional feature to the device by giving an additional layer of protection especially for packaged foods whose state cannot be detected by the e-nose.
- Once a product is scanned, the expiry date of the food product is stored in the memory to remind the user at the right time before the food goes bad.

Requirements: A normal barcode scanner that can be interfaced with the microcontroller and on-chip Flash memory. This is important because the data would get stored and retrieved from memory but will be processed by the microcontroller.
Certain requirements that we are aiming to include, but are not limited to the following are:
Scan depth of field: 230mm@20mil/0.5mm, PCS90%
Resolution: 5mil/0.127mm@PCS90%
Ambient light immunity: 5000 Lux Max
Voltage: DC + 5V ± 5%
Scan speed: 100 scans / sec ± 10%
Operating temperature:0°C to 50°C

Memory:
We plan to use a 4MB on-chip Flash memory. This is because it is non-volatile and we want these contents to be preserved even in case of a power outage to this unit. Additionally, the memory should be capable of handling enough reads and writes. This will aid quick storage of the data read by the barcode scanner. The memory chip should be able to interface with the microcontroller as well.
Requirements: The voltage can be in the range 2 to 4 V and the operating temperatures should be >= 0°C and operates at 80MHz. The interface type to communicate with the microcontroller would be through SPI (Serial Peripheral Interface).

Physical Design:

The system will consist of the sensor unit + microcontroller placed inside the fridge as an attachable entity. Wires will be used to connect this system to the LCD screen that will be attached outside the enclosure or the fridge. The entire system which includes the screen and the electronic nose will be portable.

Risk Analysis:.

The e-nose sensor array is at the heart of this project and poses the greatest risk to successful completion. Since we are dealing with gases which have complex fluid dynamics, the ability of the sensors to accurately and consistently detect the concentration of gases would determine the correctness of the outcome. Moreover the biochemistry of food is quite intricate and dynamic. The concentration of gases released by spoiling food is a function of many different variables. Not only does it vary depending on the type of food but also changes based on the environmental conditions - temperature, humidity, presence of other gases. Hence devising a threshold for the concentration of a particular gas after which an item can safely be declared as spoilt, is a fairly challenging task.

Ethics and Safety:

Potential applications of this device could be by businesses using it to monitor the quality of their produce or food items they are selling. This device could be tampered to show wrong results and deceive the consumers. Since the device is not connected to the network, hacking into it remotely would not be possible. However someone could reverse engineer and change the threshold of contamination detected by the sensors thereby declaring something as fresh to consume, despite being of inferior quality. This is in direct violation to #3 of the IEEE Code of Ethics which is “to be honest and realistic in stating claims or estimates based on available data”.

Our project doesn't have serious potential hazards as such. One particular potential hazard could be the short circuit of the sensors. Since the sensor array is placed inside the refrigerator, a potential liquid spill could damage the e-nose sensors and cause a short-circuit. Since it is composed of gas sensors, complete waterproofing of the sensor array is not possible. The casing would adhere only IP61 guidelines, which protects it from condensation.

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