PRECONDITIONS FOR THE CREATION OF A MEAT FRESHNESS CONTROL AND IDENTIFICATION SYSTEM

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Abstract. The relevance of creating a comprehensive system for meat control and identification to determine its freshness level has been demonstrated in the study. The drawbacks of traditional organoleptic and laboratory methods commonly used for meat inspection were analyzed. The authors presented the advantages and challenges of employing an electronic nose. A design for a meat control and identification system was proposed, which includes an Arduino Uno microcontroller, Raspberry Pi, USB to TTL adapter, gas sensors, color sensor, thermal camera, and image sensor.

The proposed implementation of the electronic nose system on a single-board computer demonstrates its success in controlling and identifying meat freshness. A matrix of semiconductor gas sensors, TGS2602, MQ137, and MQ138, is formed as olfactory sensors, and TCS3200 is used as an RGB vision sensor, enabling the identification of the smell and color of different degrees of meat freshness.

To obtain clear output differences from the gas sensors that react to the freshness level of meat, the baseline method is proposed for use. Therefore, a system enhanced with neural network capabilities will replace traditional devices for identifying meat freshness.

Key words: Meat Freshness Level, Electronic Nose, Gas Sensors, Color Sensors, Thermal Camera, Neural Network, Identification and Control of Meat Freshness.

1. Introduction

One of the most crucial factors that determine meat quality is its level of freshness. Numerous factors influence this aspect. During the storage of meat with temperature and humidity variations, as a result of high moisture and protein content, meat and meat products become a favorable environment for the growth of microorganisms. Products undergo spoilage, leading to changes in color, odor, taste, and appearance. The diversity of microorganisms is extensive, and among them, pathogenic microorganisms can be present as disease-causing agents. Microorganisms that infiltrate the meat release enzymes under the action of which ammonia, carbon dioxide, and hydrogen sulfide are formed. The resulting toxins diminish the nutritional value of the meat and significantly deteriorate sensory characteristics. Sensory and laboratory (chemical and microbiological) methods [1-2] are traditional in determining meat freshness. However, they are time-consuming and labor-intensive. Thus, for rapid and non-destructive assessment of meat freshness, a system is needed that can promptly and accurately evaluate its condition.

In recent years, due to the development of intelligent sensor technologies, electronic sensor equipment, such as electronic tongues and electronic noses, has shown a good degree of application in detection [3-7]. Benefiting from the advantages of rapid and non-destructive detection, electronic noses are widely used in various types of food product evaluation, including beverage identification [8-12] and fruit quality determination [13-16]. An electronic nose can be employed to detect various types of gases emitted by the meat of different freshness levels. Through biochemical analysis methods, numerous food quality indicators can be established, subsequently serving as standards for the electronic nose. Scientists are already working on such projects. For instance, the developers of the Peres device suggest measuring temperature, humidity, and the presence of ammonia compounds, though they do not incorporate color sensors. Researchers from Nanyang Technological University in Singapore, leading an international team, have developed an "electronic nose" that helps identify spoiled products. Instead of receptors, this "electronic nose" employs chitosan (a type of natural sugar) and a set of dyes [17].

2. Drawbacks

Despite numerous research efforts in both electronic nose and computer vision fields, there is still no standardized method available for the rapid determination of meat freshness. Traditional sensory and laboratory methods continue to be used up to this point. Contemporary challenges necessitate the creation of advanced identification systems utilizing artificial intelligence capabilities.

3. Goal

The objective of this article is to study and replace traditional sensory and laboratory methods for monitoring and identifying meat freshness with the utilization of electronic olfaction and imaging technology through the creation of a comprehensive system that combines electronic nose and computer vision capabilities.

4. Determination of meat freshness using sensory and laboratory methods

Determining the degree of meat freshness through sensory attributes involves direct contact with the meat utilizing visual inspection and olfactory assessment carried out by the human nose. Sensory evaluations are conducted using the sensory organs: sight, smell, and touch. The determination of sensory indicators of freshness for beef, pork, and lamb [1] encompasses the assessment of external appearance and meat color, surface condition of the carcass, muscle state in cross-section, texture, odor, fat, and tendon condition, as well as broth quality through boiling (Table 1).

Table 1. Determining the freshness level of meat based on sensory indicators.

Indicator	Characteristics of meat		
	fresh	of questionable freshness	stale
External appearance, carcass surface color	Cured (dried) rind is pale pink or pale red; in thawed carcasses, it is red. The fat is soft and partially stained in bright red color.	The rind is moist in places, slightly sticky, and has darkened.	The rind is heavily dried, and covered with a grayish-brown slime or mold.
Muscles in cross-section	Slightly moist, does not leave a wet mark on filter paper; color characteristic of the respective meat type: for beef, from light red to dark red; for pork, from light pink to red; for lamb, from red to cherry red; for mutton, pink.	Moist; leaves a wet mark on filter paper, slightly sticky, dark red. In thawed meat, a slightly cloudy meat juice drips from the cross-section surface.	Moist; leaves a wet mark on filter paper, slightly sticky, dark red. In thawed meat, a slightly cloudy meat juice drips from the cross-section surface.
Consistency	In cross-section, the meat is dense and elastic; the dimple formed when pressed with a finger quickly levels out.	In cross-section, the meat is less dense and less elastic; the dimple formed when pressed with a finger levels out slowly (within 1 minute); the fat is soft, and in thawed meat, it is slightly granulated.	In cross-section, the meat is flaccid; the dimple formed when pressed with a finger does not level out; the fat is soft, and in thawed meat, it is swollen with signs of exudation.
Odor	Characteristic, specific to each type of fresh meat.	Slightly acidic or with a hint of staleness.	Sour, musty, or slightly rotten.
Fat condition	For beef - white, yellowish, or yellow fat with a firm consistency. It crumbles upon compression. For pork - white or pale pink fat, soft and elastic. For lamb - white fat with a dense consistency. The fat should not have a rancid or sour smell.	A slightly matte grayish hue, slightly sticky to the touch, may have a faint odor of rancidity.	Has a grayish-matte hue, and becomes smeared due to compression. Pork fat may be covered with a small amount of mold, with a smell of sourness.
Tendon condition	Tendons are elastic and dense; joint surfaces are smooth and shiny. In thawed meat, they are soft, swollen, and brightly red-colored.	Tendons are less dense, with a matte-white color. Joint surfaces are slightly covered with mucus.	Tendons are softened and grayish. Joint surfaces are covered with mucus.
Bone marrow	Fills the entire cavity of long bones, solid, yellow, and has a porcelain-like sheen.	Fills the entire cavity of long bones, solid, yellow, and dull in appearance.	Doesn't fill the space of the bone cavity, soft consistency, dirty gray, or dark in color.
Clarity and aroma of the fat.	Clear, aromatic. Fat on the surface is in the form of large droplets.	Clear or cloudy, with an odor not characteristic of fresh broth. Small droplets of fat on the surface.	Cloudy, with a large amount of sediment and a strong, unpleasant odor. Fat droplets are almost absent.

Assessing the freshness of meat using sensory organs in the food industry is not sufficiently accurate, prone to errors, and costly for standard application. If there are discrepancies in the results during organoleptic assessments, laboratory tests are conducted. For meat freshness analysis, microscopic and chemical analysis methods are employed. According to the Rules of Veterinary and Sanitary Examination of Meat and Meat Products, the quantity of volatile fatty acids, meat pH, and microscopic examination of smear imprints can be determined. In cases of result discrepancies, histological and microbiological methods are used. However, these processes require lengthy analysis and are destructive since meat becomes unfit for consumption after chemical testing.

5. Electronic Nose System Development

During the creation and implementation of the system, it is important to consider the benefits and challenges of using an electronic nose (Table 2).

For the implementation of a meat freshness identification system using an electronic nose, it is proposed to utilize a sensor array consisting of MQ-135, MQ-136, MQ-137, MQ-138, and TGS2602 sensors for odor analysis, a thermocamera for temperature measurement, and a color sensor TCS3200. This combination of sensors allows for a more reliable assessment of the meat's condition. MQ-135, MQ-136, MQ-137, and MQ-138 sensors can detect characteristic components associated with various stages of meat decomposition. The TGS2602 sensor provides additional information about the presence of hazardous substances. The thermocamera monitors temperature changes, which are also indicators of freshness compromise. Furthermore, the TCS3200 color sensor enables detailed tracking of color changes during meat degradation.

5.1. Gas and color sensors

Among the advantages of using gas and color sensors to identify the freshness of meat, the following should be highlighted:

Accuracy and Reliability: Gas and color sensors can provide an objective assessment of meat quality, leading to reduced errors and variations in freshness determination. However, to ensure high accuracy and reliability, these sensors need to be carefully calibrated and maintained.

Speed and Efficiency: Gas and color sensors enable a rapid assessment of meat quality without the need for lengthy and complex procedures. This is crucial for the food industry where time is a valuable resource.

Objectivity: A sensor-based system provides a more objective and consistent assessment of meat freshness compared to subjective methods that can be influenced by personal perception.

Detection of Decomposition and Microorganisms: Gas sensors can detect chemical changes associated with meat decomposition or the presence of harmful microorganisms, helping to identify products that may be unsafe for consumption.

Table 2. Advantages and challenges of creating and implementing an electronic nose

Advantages:	Challenges:
Calibration: The electronic nose requires continuous calibration and maintenance to ensure its accuracy and reliability. This may require additional time, resources, and expertise.	**Rapid Freshness Assessment of Meat:** The electronic nose is designed for the swift determination of meat freshness by analyzing its odor. It can recognize distinctive odor characteristics that change due to decomposition processes and freshness deterioration.
Sensitivity to Environmental Conditions: The electronic nose can be sensitive to external factors such as temperature, humidity, and other chemical substances. This can influence its ability to accurately perceive and recognize odors.	**Objective Control:** The electronic nose can provide a more objective and consistent assessment of meat quality compared to subjective methods that rely on human perception. This helps reduce errors and variability in quality assessments.
Environmental Sensitivity: The electronic nose can be sensitive to environmental conditions, such as temperature, humidity, and other chemical substances. This sensitivity can affect its ability to accurately perceive and recognize odors.	**Ensuring Food Safety:** The electronic nose can detect odors associated with meat decomposition or the presence of harmful microorganisms. This allows for timely detection of potentially unsafe food products for consumption.
Interference Effects: The electronic nose can be susceptible to interferences that may arise in food production or other industrial environments. For instance, the presence of other odors or chemical substances can hinder the accurate identification of meat odors.	**Interference Effects:** The electronic nose can be susceptible to interferences that may arise in food production or other industrial environments. For instance, the presence of other odors or chemical substances can hinder the accurate identification of meat odors.

Wide Range of Odors and Colors: The use of gas and color sensors allows for the detection of various chemical compounds and colors that change during the processes of meat decomposition and freshness loss.

Automation and Integration: Gas and color sensors can be integrated into production lines and automated quality control systems, facilitating rapid and efficient determination of meat freshness.

The aforementioned aspects demonstrate the high potential of cutting-edge technologies for improving the process of meat quality assessment and ensuring food safety.

Each of the sensors selected for creating a comprehensive meat control and identification system has its unique capabilities and functions, namely:

- **MQ-135:** This gas sensor specializes in detecting a wide range of gases, such as ammonia, carbon dioxide, hydrogen sulfide, and others. It is capable of responding to specific gases emitted during meat decomposition and providing information about changes in their concentration.
- **MQ-136:** This gas sensor specializes in detecting ozone gas. Ozone can form as a result of the interaction between oxygen and pollutants that are known to be present during meat decomposition. This sensor can detect changes in ozone concentration, which may indicate decomposition processes.
- **MQ-137**: This sensor is designed to detect ammonia, which can be released from meat during decomposition. Changes in ammonia concentration can serve as indicators of changes in the meat's condition.
- **MQ-138:** This gas sensor is designed to detect sulfur dioxide, which can also be released during the decomposition of meat. Changes in sulfur dioxide concentration can indicate processes of freshness deterioration.
- **TGS2602:** This sensor also specializes in detecting various gases, including volatile organic compounds that can be released from meat during its decomposition. It can complement the information gathered by other gas sensors and provide a more comprehensive analysis.
- **TCS3200:** The TCS3200 color sensor detects the color properties of meat, which can vary depending on its condition. It will help conduct a more detailed analysis of color changes that may indicate alterations in the physical and chemical properties of meat during its decomposition.

5.2. Hardware realization

To implement a comprehensive system for meat control and identification, the use of two platforms, Arduino and Raspberry Pi, is proposed. This will enable achieving high accuracy and reliability in measurements while leveraging their respective strengths for optimal system implementation. The combination of Arduino and Raspberry Pi platforms is advantageous for the following reasons:

- **Efficient Resource Utilization:** Arduino features a simple and efficient microcontroller responsible for data collection from gas sensors and the thermal camera. Simultaneously, Raspberry Pi is utilized for performing complex computations, data analysis, and user interaction.
- **Computational Power:** Raspberry Pi provides greater computational power and RAM, enabling the use of complex data processing algorithms and the implementation of neural networks for more accurate odor and color identification.
- **Network Connectivity and User Interface:** Raspberry Pi features a built-in Ethernet port and the capability to connect to Wi-Fi, enabling network communication. It's suggested to create a user interface accessible via a web browser for tracking and managing our system.
- **Data Synchronization and Storage**: Raspberry Pi can utilize a larger memory capacity to store data from the sensors, which can then be processed and analyzed. This allows for keeping a history of data and generating reports.
- **Capability Expansion:** Raspberry Pi can connect various additional devices and sensors, which can diversify and expand the range of investigated characteristics during meat identification, for instance, the TCS3200 color sensor.
- **Further Development:** One of the advantages of the proposed approach is the potential for system optimization in the future. This includes updating the software and adding new features without significant changes to the hardware.

Therefore, in the proposed meat control and identification system, Arduino is responsible for data collection from gas sensors (MQ-135, MQ-136, MQ-137, MQ-138, TGS2602) and a thermal camera. Raspberry Pi, with its greater computational power and the capability to install operating systems, is used for data processing, user interface creation, data analysis, and the implementation of a neural network for making decisions regarding meat freshness. Arduino performs real-time data collection, while Raspberry Pi handles more complex computational tasks and ensures interactivity. Of course, when choosing this approach, it is important to ensure proper communication between Arduino and Raspberry Pi. Various data transmission protocols exist for communication between the Arduino and Raspberry Pi platforms, namely:

Serial Communication (UART/USART): a basic data transmission protocol between devices using TX (transmit) and RX (receive) pins. One device sends data via TX, and the other receives it via RX. This protocol is relatively simple to implement but requires dedicated physical connections for data transmission

I2C (Inter-Integrated Circuit): a two-wire protocol that enables multiple devices to share the same wires for data transmission. This allows for connecting more sensors to the system if the need arises.

SPI (Serial Peripheral Interface): Synchronous data transmission protocol that allows fast exchange of information between devices. It can be used when high data transmission speed is required, for instance, for real-time processing.

UART by USB: For using Raspberry Pi with USB support, a USB-to-Serial adapter can be used to connect to the TX/RX pins on Arduino. This is convenient as USB ports are a common practice for many computer devices.

Ethernet or Wi-Fi: To provide wireless access, network protocols such as Ethernet or Wi-Fi can be used.

For the proposed system, a combination of UART and USB is suggested for communication between Arduino and Raspberry Pi. This combination will ensure a reliable and straightforward connection between the platforms, allowing the transmission of data about meat odors and colors for further processing and analysis on the Raspberry Pi.

Therefore, the hardware components of the system (Figure 1) include the following elements (Figure 2): Arduino Uno microcontroller, Raspberry Pi, USB to TTL, gas sensors, color sensors, thermal camera, and sensory camera.

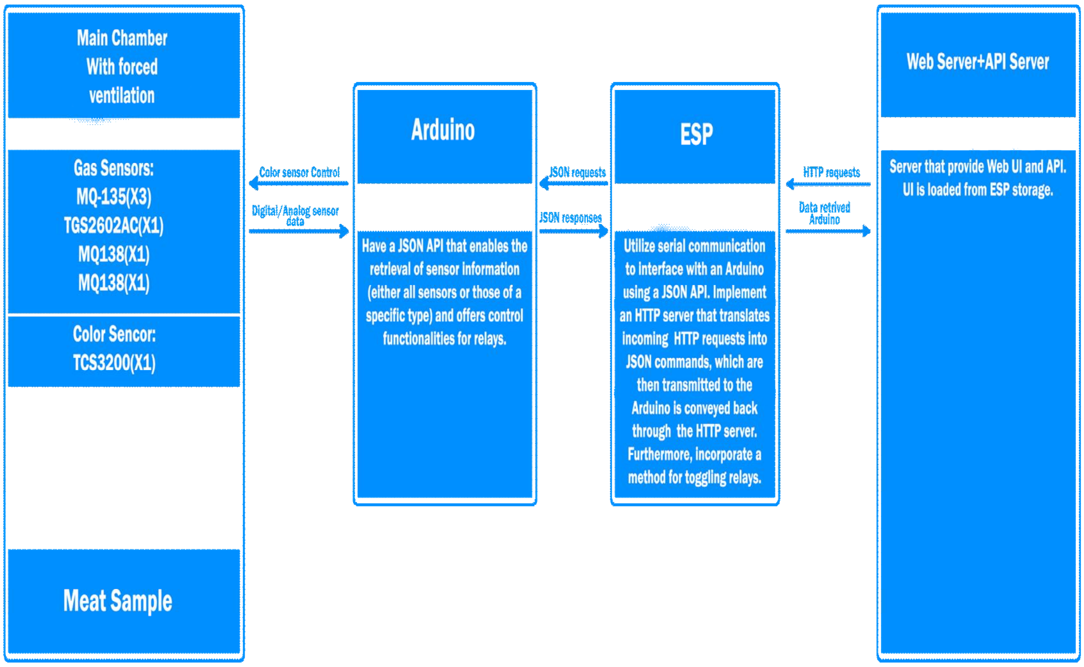

Fig.1 Block scheme of the meat control and identification system

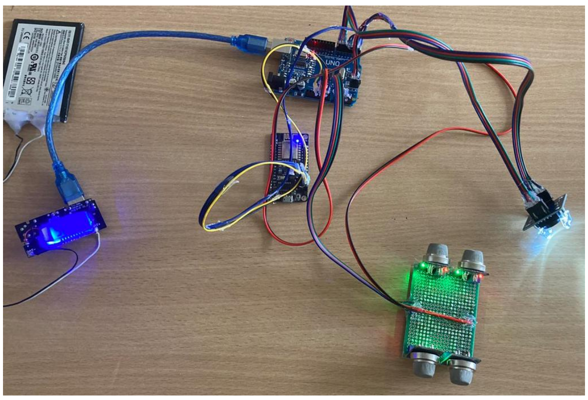

Fig.2 Components of the meat control and identification system

5.3. Software

The process of developing software for the meat freshness control and identification system involves programming the Arduino microcontroller to process data from gas sensors, developing a graphical user interface for the Raspberry Pi, and utilizing a neural network for making decisions about meat freshness determination.

Programming the Arduino Microcontroller

Starting with the initialization of gas and color sensors, the software code is written in the C/C++ programming language, which reads data from the sensors and processes them. For the gas sensors MQ135, TGS2602, MQ138, and MQ137, analog input/output is used to obtain gas level values in the surrounding air. The color sensor TCS3200 is connected to digital inputs and reads color data from objects.

Development of the Graphical User Interface

For convenient control and monitoring of the system, a Graphical User Interface (GUI) is developed on Raspberry Pi. In this process, Lazarus software is used to create the interface, which operates under the Raspbian operating system. The GUI consists of two parts:

Training Section: This part of the interface enables the configuration of parameters for the neural network training process, such as learning rate and error parameters. Once configured, the training can be initiated. The progress of the training and error graph will be displayed on the screen.

Freshness Determination Section: This part of the interface displays the results of meat freshness determination using the neural network. It showcases the values from the gas sensors and the RGB sensor, which are transmitted from the Arduino microcontroller. Once a connection is established between the Arduino and Raspberry Pi, the data is read and employed to ascertain the level of meat freshness.

Data Storage and Display:

The collected data, neural network training results, and meat freshness determination outcomes can be saved as text files in designated folders on the Raspberry Pi. This enables the analysis of data and tracking changes in the investigated product over time.

Pin Arduino:

1. **SCL (Serial Clock Line) and SDA (Serial Data Line):** These pins are used to establish communication with I2C sensors and other devices.
2. **Analog pins (A00-A05):** They are intended for connecting gas sensors MQ135, TGS2602, MQ138, and MQ137. For each sensor, the correct connection and orientation of the connected wires are crucial.
3. **Digital pins D00-D13:** These pins are used for connecting various devices, including the color sensor module, relays, and LED indicators.
4. **3.3V and 5V:** These pins provide power to devices that operate at voltage levels of 3.3V and 5V, respectively.
5. **Ground**: These pins are intended for grounding the system.

In summary, the development and implementation of the meat freshness identification system based on an electronic nose have successfully integrated various technological components to achieve the main goal - reliable and accurate identification of meat freshness levels. The utilization of gas and color sensors such as MQ-135, MQ-136, MQ-137, MQ-138, TGS2602, and TCS3200, in conjunction with the Arduino microcontroller and the Raspberry Pi single-board computer, has created a powerful system capable of analyzing meat based on its odor and color. The neural network embedded in the system's software aims to provide a new level of data processing, enabling precise product identification. The process of data acquisition from sensors, their communication between platforms, and computation through the neural network will establish a robust functional framework.

6. Conclusions

As a result of current consideration, for meat inspection, the authors have studied the advantages and challenges of employing an electronic nose. A design for a meat control and identification system was proposed, which includes an Arduino Uno microcontroller, Raspberry Pi, USB to TTL adapter, gas sensors, color sensor, thermal camera, and image sensor. Recommendations for software implementation of the proposed system were outlined, involving programming the Arduino microcontroller to process data from gas sensors, developing a graphical user interface for the Raspberry Pi, and employing a neural network for decision-making regarding meat freshness determination.

This issue paves the way for the application of nowadays technologies in the food industry, contributing to ensuring consumers quality and safe products.

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8. Conflict of interest

The authors declare that there is no financial or other potential conflict related to this work.

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