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Role of Sensor in The Food Processing Industries

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ABSTRACT

Food processing industry faces various challenges; one of the foremost challenges is monitoring of safety and nutritional quality of the food. The conventional analytical techniques for quality and safety analyses are very tedious, time consuming and require trained personal. Improper handling and storage might cause food poisoning so it is not possible to depend on this system. Therefore there is a need to develop quick, sensitive and reliable techniques for quick monitoring of food quality and safety. This can be overcome by using the sensor automation technique in the food processing industries. Obtaining reliable results depends on selecting the appropriate sensor technology for the application. To accommodate these demands, sensors must be durable, flexible, sensitivity, linearity of response, reproducibility, accuracy, quick response time and recovery time, stability, and reliable, regardless of the environment. Proper selection of the sensors requires careful consideration of the sensor's capabilities, limitations, and suitability for the intended application. Common applications of sensor in the food manufacturing process include process monitoring, shelf-life investigation, freshness evaluation, authenticity assessment and other quality control studies. Because of their versatility and high level of functionality or application different sensor are used in the food processing industries some of them are proximity sensors (inductive, capacitive, and ultrasonic), temperature sensor (resistance temperature detector, infrared sensor, thermistor and thermocouple), humidity sensors (optical, gravimetric, capacitive, resistive, piezoresistive, and magnetoelastic sensors), bio-sensor (amperometric, conductometer, thermometric biosensor and potentiometric biosensor), chemosensor, pressure sensors, E-tongue taste sensors, torque sensors,freshness sensor, pH-sensor and gas sensor are explained in this review paper. Sensors technology play a significant role in the detection and identification of contaminants during the food manufacturing processes and it increase the food quality, safety, production and profitability in the food processing industries.

Key words: *Food quality, temperature sensor, E-tongue taste sensors, biosensor and pressure sensor.*

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INTRODUCTION

In today's industrial environments, most processes rely on monitoring systems to ensure product quality and process efficiency. Obtaining reliable results depends on selecting the appropriate sensor technology for the application. To accommodate these demands, sensors must be durable, flexible, and reliable, regardless of the environment. Proper sensor selection requires careful consideration of the sensor's capabilities, limitations, and suitability for the intended application. Sensors are the vital components of monitoring and control system in food industry to prevent malfunction in the process [1].Sensors are based on physical, chemical, or biological response from the environment.There exists a strong need for rapid and sensitive detection of different components of foods and beverages along with the food borne and water borne pathogens, toxins and pesticide residues with high specificity. Sensors transform real magnitude into usable signals, most often in the form of an electric signal transmitted to human readable display system [2]. Sensors are of two

major types: (i) 'on-line' or 'in-line'sensors means: Instantaneous measurements taken directly in the process line using a probe or sensor (ii) on the other hand, is characterized by manual sampling followed by discontinuous sample preparation, measurement and evaluation.
The following factors are considered while selecting the sensor

- ✓ Sensor Accuracy
- ✓ Calibration – requirements and methods
- ✓ Size of the sensor
- ✓ Cost of the sensor and cost of replacement
- ✓ Output repeatability
- ✓ Circuit complexity
- ✓ Resistance to contamination
- ✓ Reliability of the sensor

Types of sensors used in food processing industries
Because of their versatility and high level of functionality or application different sensor are used in the food processing industries are explained in this review paper.

- ➢ Proximity sensors (inductive, capacitive, and ultrasonic)
- ➢ Temperature sensor (resistance temperature detector, infrared sensor, thermistor and thermocouple)
- ➢ Humidity sensors (optical, gravimetric, capacitive, resistive, piezoresistive, and magnetoelastic sensors)
- ➢ Bio-sensor (amperometric, conductometer, thermometric biosensor and potentiometric biosensor)
- ➢ Chemosensory
- ➢ Pressure sensors
- ➢ E-tongue taste sensors
- ➢ Torque sensors,
- ➢ Freshness sensor
- ➢ PH-sensor and gas sensor

Proximity sensors: this is an electronic-sensor, can able to detect the presence of close by objects without any physical contact. A proximity sensor often emits an EMR (infrared, for instance), and looks for changes in the return signal. Proximity sensors are designed to provide accurate and repeatable operation under high-speed conditions. Performing at speeds as high as 5,000 Hz, these sensors can easily accommodate the demands of many fast-paced industrial applications. The following are the different type of proximity sensors:

1. **Inductive sensors:** These detect metal objects (ferrous or nonferrous). for the ferrous metal it has longer sensing range from 5mm to40mm. Nonferrous metal do not have iron in them, this can reduce the sensing up to 60%. When a ferrous material enter the magnetic field Electrical current known as eddy current are induced on the surface. This eddy current induces a power loss in the surface in the presence of metal surface. Inductive sensors are often because they can operate at higher speeds than mechanical switches. Inductive sensors more reliable and robust
2. **Capacitive sensors:** Capacitive sensors can detect dielectric material (both higher and lower dielectric material) such as liquid, glass, plastic wood and granulated substance. These capacitive sensors can detect the dielectric constant of 1.2 and more. In the capacitive sensors, two plates are located in the sensory form. As the target enters the sensors range the capacitance of the two plate increases thus cause the change in accelerated frequency. This help in identifying the dielectric material in the food.
3. **Ultrasonic sensors:** Ultrasonic sensors can work in smoke, dust, fog, different color, texture and steam. These ultrasonic sensors are widely used. This can detect the object over a long distance. This works great on solid material (plastic, glass and plastic) suies, gar, flour, potato, water, oil and juice. This is also independent of environmental changes like temperature, noise, light etc. this sensor is most commonly found in automated sensors. This sensor most commonly used to measure multiple variables, such as wind speed and direction, tank fullness, and

speed through air or water, and can detect targets in a solid, liquid, granular, or powder state.

Thermo-sensors: It is a device, used for temperature measurement through an electrical signal. This electrical signal will be in the form of electrical voltage and is proportional to the temperature measurement. These thermo sensors have wide range of application in Process control, Food inspection, Freezers, Fermenting units, Baking ovens and Cook- and smoking units. Four different types of temperature sensors are there namely:

1. **Negative Temperature Coefficient (NTC) thermistor**: a thermally sensitive resistor is a thermistor that cans exhibits a large, predictable, and precise change in resistance correlated to variations in temperature. NTC thermistor can effectively operating range is -50 to 250 °C.
2. **Resistance Temperature Detector (RTD).**An RTD, also called as a resistance thermometer. **This RTD can measure temperature by comparing the resistance of the RTD with temperature. RTD can operate at the range of -**200 to 600 °C.
3. **Thermocouple:** This thermocouple consists of two wires of different metals connected at two points. The difference voltage between these two points reflects proportional changes in temperature. **Accuracy of the thermocouple is low ranging from** 0.5 °C to 5 °C. However, they operate across the **widest temperature range**, from -200 °C to 1750 °C.
4. **Semiconductor-based sensors most sensitive temperature sensors.** They also have the slowest responsiveness (5 s to 60 s) across the narrowest temperature range (-70 °C to 150 °C).
5. **Infrared Thermometers:** This device relies on the voltage generated by the junction of two dissimilar metals. The voltage output is proportional to the temperature of the junction.

Biosensors: A biosensor is device, used to measure concentration of analyte. In biosensors, a biological material (enzymes, antibody, whole cell and nucleic acid) is used to interact with the analyte. This interaction produces a physical and a chemical change which is detected by the transducer and converts in to a electric signal. The electric signal is directly proportional to the concentration of the analyte. This signal is interpreted and converted to analyte concentration present in the sample. It is usually constructed from three components: receptor(biological compound), transducer and electronics (fig:1).

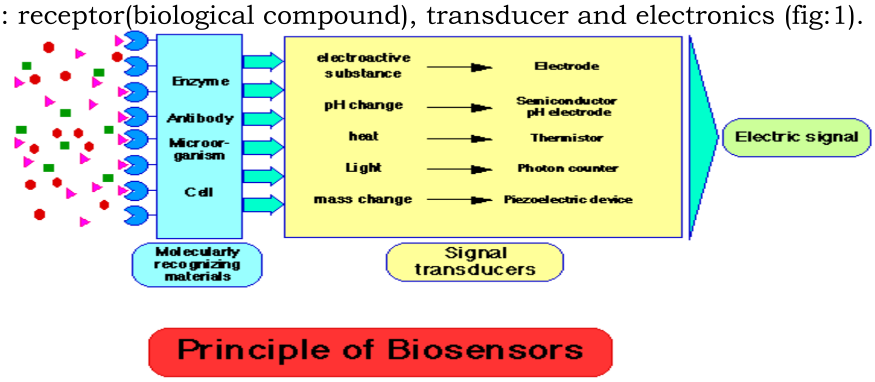

Fig.- (1) :Biosensor block diagram

The following are the different types of biosensors:

1. **Potentiometric biosensors:** Potentiometric biosensors are built on ISFET (ion-sensitive field effect transistors) and ISE (ion-selective electrodes). This sensors measure potential difference arises during redox reaction (oxidation-reduction reaction). A redox reaction is chemical reactions in which the oxidation number of a molecule, atom, or ion changes by obtain or losing an electron. The major outputting signal is possibly due to ions assemble at the ion-selective membrane interface. Current flowing through the electrode is equal to or near zero. The electrode follows the presence of the monitored ion resulting from the enzyme reaction [3].
2. **Amperometric biosensors:** Amperometric biosensors are more preferable for mass production than the potentiometric biosensor [4].Amperometric biosensors are quite sensitive [4]. The amperometric biosensors working electrode is usually a noble metal, the biorecognition component [5]. Carbon paste with an embedded enzyme is

another economic option [6].This amperometric biosensors measure the flow of electrons arises during the reaction.

3. **Thermometric biosensors:** There are many more biological reactions are connected with the absorb (endothermic reaction) or release (exothermic reaction) of heat and it is a basic of thermometric Biosensors [7]. The thermometric biosensors are also known as calorimetric biosensors. In Thermometric biosensor change in the heat directly is directly proportional e the extent of reaction (for catalysis) or structural dynamics of biomolecules in the dissolved state[8]. colorimetric biosensors commonly used in estimation of of food chemical hazard, like synthetic food additives, antibodies, veterinary drugs residue, heavy metals, and other toxic substances
4. **Fiber optic lactate Biosensor:**It measures the change in oxygen concentration, molecules change by the effect of oxygen in fluorescent dye. The following reaction is reduced by the enzyme lactate mono-oxygenate. This is commonly used in detection of food pathogen detection.
5. **Conductometric biosensors:** This device measure change in electrical conductivity arises during a reaction. Most common example is urea biosensors.
6. **Optical biosensors: These** devices measure the light arising from the action of enzyme. The principle used for optical biosensors are florescence, absorbance etc.

Pressure measuring sensors: Pressure sensors are alternatively named as piezometers, pressure transmitters, pressure transducers, pressure indicators, pressure transmitters and manometers, among other names. A pressure measuring sensor, or instrument, is a device for measuring the pressure (physical variable) and transform into an electrical signal. This electrical signal may wary depend on pressure imposed. The pressure of below atmospheric pressure can be measure by Pressure sensors. Pressure sensor can be used to measure other variables suchlike water level, water level, and altitude. There are different types of pressure measuring device such as Absolute pressure sensor, Gauge pressure sensor, Vacuum pressure sensor, differential pressure sensor, and sealed pressure sensor.

- **Vacuum Sensors**: This is one of the major pressure sensing devices. Vacuum sensors usual used to measure the pressure lower than atmospheric pressure. Medium and high Vacuum can be measure by thermal and molecular devices. The sensing element in vacuum sensor is a heating element whose temperature rely on the enclosed pressure. When sub-atmospheric pressure increases directly heating element temperature up rises.

Humidity Sensors:

Humidity is nothing but the amount of water vapour in air that can be a mixture, such as air, or a pure gas, such as nitrogen or argon. It can affect human comfort as well as many manufacturing processes in industries such as electronic, food or pharmaceutical manufacturing, food storage, etc.,. The various physical, chemical and biological parameters are influenced due to the presence of water vapour. In addition, proper humidity levels can be critical to the quality of the product and having the right humidity level can contribute to diminishing energy consumption [1]. Controlling the humidity is necessary in the purification of chemical gas, ovens, dryers, paper and textile production and food processing. Measuring humidity plays an important part for powder production, especially so in the production of hygroscopic substances.
The different types of humidity sensors are (1) capacitive (2) Resistive (3) Thermal (4) gravimetric (5) optical (6) piezoresistive humidity sensor.

Capacity Humidity Sensor:

These sensors are one of the basic types of humidity sensors and these works on the bases of capacitive effect. They are often used in applications where factors like cost, rigidity and size are s of concern. In Capacitive Relative Humidity (RH) Sensors, the electrical permittivity of the dielectric material changes with change in humidity. The small amount of capacitance is developed in between the pair of electrodes and dielectric material. Normally the diectric material used in the most of the capacitive sensor is Plastic or polymers and these dielectric constant ranging from 2 to 15.the capacitance value is calculated in absence of moisture by determining the dielectric constant and sensor geometry.at room temperature the dielectric constant of water vapours is about 80 and this value is more than that of the dielectric constant of the sensor. As a result the values of capacitance sensor get increases when it absorbs the water vapour.

Working of Capacitive Sensors

These sensors consisting anair filled capacitor as the moisture in the atmosphere change its permittivity. Since air is a dielectric so not feasible for practical applications Therefore, the space between the capacitor plates is generally filled with an appropriate dielectric material (isolator), whose dielectric constant varies when it is subjected to change in humidity. The common method of constructing a capacitive RH sensor is to use a hygroscopic polymer film as dielectric and depositing two layers of electrodes on the either side.

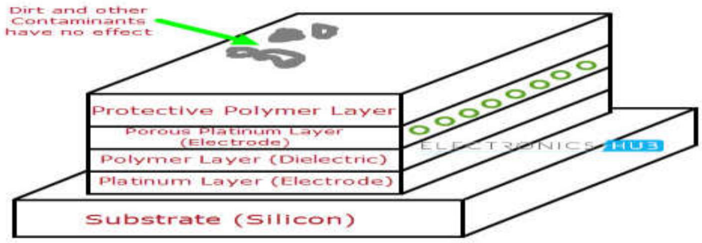

Fig.- (2) :Working principle of a capacitive sensor

The change in the frequency of test sample is determined by using the this sensor during the process the sample is placed in-between the capacitor place and oscillator is constructed using the capacitance with RH sensitive test subjected as dielectric. This arrangement normally used in the pharmaceutical industries. The test samples like medical tablets are placed between two plates in order to form a capacitor in the LC Oscillator circuit. According to the surrounding humidity of a test sample the frequency of an oscillator get changed.

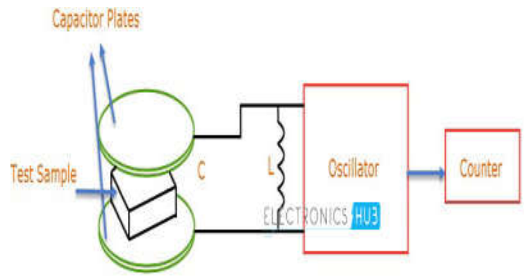

Fig.- (3) :capacitive sensor using LC oscillator

Advantages of Capacitive Humidity Sensors

- The variation of the output is nearly linear in nature
- They provide stable results over long usage.
- Can be operate in the wide range of relative humidity

Disadvantages of Capacitive Humidity Sensors

- It operate in a shorter distance between the sensor and signalling circuit

Applications of Capacitive Humidity Sensors

These are used in a wide range of applications some of them are

- High Voltage AC Systems in order to absorb the moisture from the system.
- Used in the Printers and Fax Machines
- Weather Stations
- Automobiles
- Food Processing
- Refrigerators, Ovens and Dryers

Resistive Humidity Sensors (Electrical Conductivity Sensors):
Resistive type humidity sensors which identify the changes in the resistance value of the sensor element with respect to change in the humidity. The basic principle behind these is the fact that the conductivity in non – metallic conductors is reliant on their water content.

Working of Resistive Humidity Sensors
These sensors are made up of relatively low resistive material. As the humidity changes correspondingly the resistivity of the material get changed. The response between resistance and humidity is inverse exponential in nature. On the top of the two electrodes the low resistivity material is deposited and these electrodes are placed in interdigitized pattern in order to increase the contact area. Once the top layer absorbs the water the resistivity between the electrodes gets changed and this change can be measured in terms of a simple electric circuit. Modern Sensors are protected with ceramic substance to provide an extra protection. The electrodes in the sensor are usually made of noble metals like gold, silver or platinum.

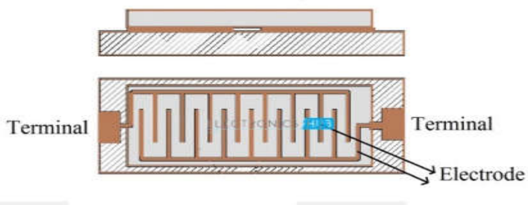

Fig.- (4) :Resistive type humidity sensors

Benefits of Resistive Humidity Sensors

- Cost is low
- Compact in Size
- The distance between the sensor and signal circuit can be large (suitable for remote operations).
- As there are no calibration standards so these are highly interchangeable.

Disadvantages of Resistive Humidity Sensors

- these are very sensitive to the chemical vapours and other contaminants
- The output readings may change if used with water soluble products.

Thermal Conductivity Humidity Sensors
These sensor measures the absolute humidity so these sensors are also called as Absolute Humidity (AH) Sensors. These sensor measures the thermal conductivity of both dry air as well as air with water vapour.
Working of Thermal Conductivity Humidity Sensors
Thermistor is the best component to get the thermal conductivity based humidity sensor. Therefore, two small thermistors with negative temperature coefficient are used in the form of bridge circuit. Out of this one thermistor is kept in open environment from a small venting hole and another one is hermetically sealed in a dry nitrogen chamber. The supply is given to the circuit and resistance of the two thermistors are noted down. The difference between the resistances of the thermistor is directly proportional to the Absolute Humidity (AH).

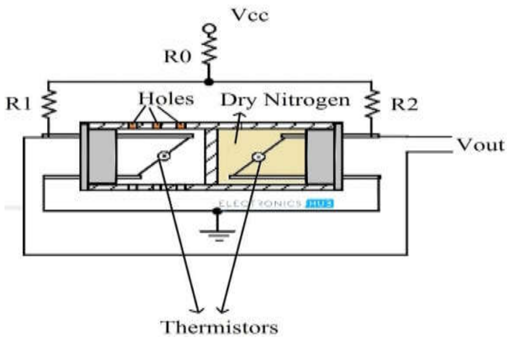

Fig.- (5) :Thermal Conductivity Humidity Sensors

Benefits of Thermal Conductivity Humidity Sensors

- ❖ High corrosive and high temperature environments conditions these sensors are suitable
- ❖ Very robust
- ❖ Higher resolution compared to other types

Disadvantage of Thermal Conductivity Humidity Sensors

- ❖ Exposure to any gas with thermal properties different than Nitrogen might affect reading measurement.

Applications of Thermal Conductivity Humidity Sensors are:

- ❖ Drying kilns
- ❖ Pharmaceutical plants
- ❖ Owens
- ❖ Clothes dryers and drying machines
- ❖ Food dehydration

Optical fiber humidity sensors (OFHSs): it offers several advantages over electronic humidity sensors for example small design, toughness, can work in combustible environments and at higher temperature and pressure ranges, and, most important, their electromagnetic immunity. Accordingly, they can withstand the sort of unforgiving and requesting conditions found in processing procedures. .

Other Humidity Sensing Mechanisms:

1. Coulometric

An electrolyte is made by concentration of water and the current level obtained is proportional to the moisture content.

2. Gravimetric

A volume of moist air is exposed to a drying agent and subsequently weighed. The weight parallels to the moisture.

3. Microwave/Infrared:

As the amount of water content increases the attenuation of the transmitted signal varies and it corresponds the moisture content in the medium.

4. Dry-and Wet globule temperature

Psychrometer gives relative humidity estimates based on Dry-and Wet bulb temperature measurement

5. Dew Point

Dew Point hygrometers measure dew-point temperature by detecting dew formation on a cooler base.

Electronic nose: these are the instruments that identify the smell more effective than the human nose. This device is a more accurate and precise, used to detect smell based on mechanism for chemical action. This can detect poisonous and harmful odor which human nose cannot detect. These sensors are very commonly used in agriculture, food processing sector, public security, cosmetics, biochemical and other scientific research field.

There are five compounds to identify the aromatic compound in food are

1. An aroma delivery system, (convey volatile aromatic molecules from the food compound to the sensor array.
2. A chamber where sensors are housed: this has usually fixed temperature and humidity chamber were maintained in chambers of sensors.
3. An electronic transistor which converts the chemical signal into an electrical signal, amplifies and conditions it
4. a digital converter(transform the electrical signal to digital)
5. A computer microprocessor.

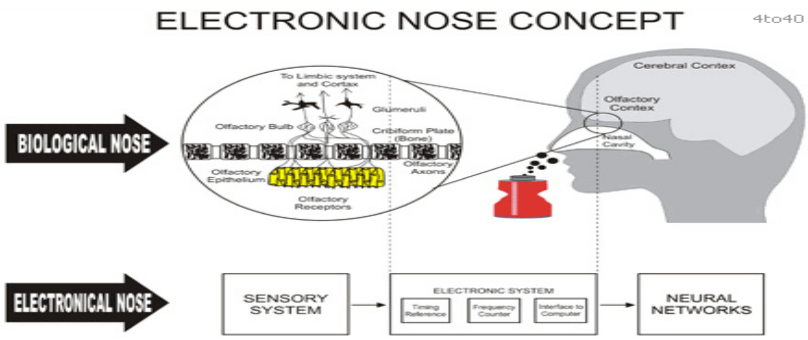

Fig.- (6) :Electronic nose concept

Table 1: Types of E-nose: Based on the sensors type different sensors are there,

Sensitive material	**Sensor type**	**Detection principle**
catalytic metals	Catalytic field-effect sensors (MOSFET)	electric field change
organic dyes	Colorimetric sensors	color changes, absorbance
modified conducting polymers	Conducting polymer sensors	resistance change
solid or liquid electrolytes	Electrochemical sensors	current or voltage change
Fluorescence-sensitive detector	Fluorescence sensors	fluorescent-light emissions
IR-sensitive detector	Infrared sensors	Infrared-radiation absorption
doped semi-conducting metal oxides (SnO_2, GaO)	Metal oxides semi-conducting (MOS, Taguchi)	resistance change

Table 2: Comparison between electronic nose and bio nose

BIO NOSE	**ELECTRONIC NOSE**
Lings is used to bring odor to epithelium layer	Pump is used to smell the odor
Hair , mucus and membrane act as a filter	Filtration is provide by the inlet sampling system
Millions of sensing cells are present in the olfactory epithelium, that interact with odorants in unique	Electronic nose has a variety of sensors that interact differently with a group of odorous molecules
The human receptors convert the chemical response to electronic nerve impulses whose unique patterns are propagated by neurons through a complex network before reaching the higher brain for interpretation	the chemical sensors in the electronic nose react with the sample and produce Electrical signals. A computer reads the unique pattern of signals and interprets them with some form of intelligent pattern classification algorithms

E-Tongue:

Electronic tongue mimics the gustatory system of human beings. It artificially reproduces the taste sensation. It can sense sourness, astringency, bitterness, saltiness, and umami.. E-tounge can be used for both qualitative and quantitative purpose. This instrument contains sensor array, electrochemical cells like conductimetric, amperometeric, potentiometric, impedimeteric and voltammetric and appropriate pattern recognition system, can easily recognize the sample (simple or complex nonvolatile soluble molecules) (10,11,12). These sensors are most application in all food processing industry like beer, wine, coffee, tea, chesses, fish, synthetic beverage, meat, grains, fruits and vegetable industry (13, 14, and 15). It can also be used for environment monitoring (toxic heavy metal analysis, water quality analysis and plant sample).

Working of the E-Tongue

The electronic tongue contains a light source, a sensor array and a detector. The light source shines onto chemically adapted polymer beads arranged on a small silicon wafer, which is known as a sensor chip. These beads change colour on the basis of the presence and quantity of specific chemicals. The change in colour is captured by a digital camera and the resulting signal Converts into data using a video capture board and a computer.

CONCLUSION

The conventional analytical techniques for quality and safety analyses are very tedious, time consuming and require trained personal. Improper handling and storage might cause food poisoning so it is not possible to depend on this system. This can be overcome by using the sensor automation technique in the food processing industries. Proper selection of the sensors requires careful consideration of the sensor's capabilities, limitations, and suitability for the intended application. Common applications of sensor in the food manufacturing process include process monitoring, shelf-life investigation, freshness evaluation, authenticity assessment and other quality control studies.Advantages of food sensors include real-time analysis, high sensitivity, reproducibility, selectivity and mobility, low cost-of-ownership and gradual replacement and/or parallel use to complex and cumbersome analytical laboratory instruments. The potential result is low-power consumption, humidity-resistant and cost-effective portable detection devices and/or a network of sensor arrays providing rapid screening, monitoring and reporting. Sensors technology play a significant role in the detection and identification of contaminants during the food manufacturing processes and it increase the food quality, safety, production and profitability in the food processing industries.

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