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Smart packaging

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***Abstract* — This paper explores and explains how to package food smartly. We are talking about active and smart packaging, about types of sensors for freshness, temperature and storage time. Consumers are looking for high-quality foods that retain their properties and safety. Packaging plays a key role in attracting consumers and ensuring that products stay fresh.**

Keywords— smart packaging, sensors and indicators, microcontrollers, application development.

I. Introduction

In modern business, the emergence of smart packaging represents a revolutionary step for the improvement and preservation of product quality. This is not only aimed at producers and distributors, but also at end consumers. They provide them with better information about the products they consume.

Smart packaging has small sensors inside or on it that monitor parameters like temperature and humidity. These sensors send data wirelessly, like Bluetooth. Using an artificial installation, the system analyzes this data in real time, providing users with information about the state of the product. Color sensors can be used to visually display product quality, changing from green to red if there is a change.

This technology enables personalization of products and provides consumers with transparency.

Intelligent packaging systems monitor the condition of packaged food to provide information on the quality of that food during transport and storage. [1]

II. Smart Packaging

Smart packaging not only improves the preservation of product quality during transport, but directly responds to the challenges faced by consumers. The key importance is:

1. Quality monitoring and preservation
2. Informing consumers
3. Reduction of losses
4. Optimizing the supply chain

A. Significance for the food industry

According to today's lifestyle and consumers, the way of packaging is adjusted. Consumers are increasingly looking for products that can be easily opened, prepared and provide a lot of information about the product. In some cases, it is very difficult to know the condition of the food inside the package just at a glance. Products packed in intelligent packaging show us that the food is fresh and stored appropriately through certain indicators. [2]

B. Sensors

A sensor is defined as a device used to detect, locate and measure energy, thereby providing a signal to measure a physical or chemical property to which the device responds. In order for a device to qualify as a sensor, it must be able to provide continuous signals and must contain two basic parts: a receptor and a transducer. In the receptor, the physical or chemical property is converted into the form of energy that the transducer is able to measure. Furthermore, the converter converts this energy, which carries information about the property of the examined sample, into an analytical signal. [1]

Figure 1. "Keep-it" indicator

The "Keep-it" time and temperature indicator is an indicator of the shelf life of the product, which records the temperature to which the packaged salmon is exposed. When the product is in the cold, the intelligent color in the indicator moves slowly, the dark bar is long, which means that the food is fresh. If the temperature increases the intelligent color moves faster and the strip shortens.

C. Functionality of sensors in smart packaging

In the process of creating smart packaging, key elements are sensors that enable monitoring and measurement of various product parameters.

1. Temperature sensor

This type of sensor measures temperature changes in the

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product's environment. It enables the monitoring of conditions during transport and storage, identifying possible deviations that may affect the integrity of the product. For example, the sensor can detect an elevated temperature that could lead to spoilage or change in chemical composition.

2. Humidity sensors
   Humidity sensors monitor the humidity level in the packaging environment. This is crucial for products that are sensitive to moisture, such as electronics or certain types of food. Monitoring humidity helps prevent condensation inside the packaging, which could otherwise cause product damage.
3. Light sensors
   These sensors will measure product exposure to light throughout the supply chain. Products such as pharmaceutical preparations or certain types of food can be sensitive to light. Light sensors also help identify conditions that could cause changes in product color or composition.
4. Sensors for packaging openness
   Sensors that detect the opening of packaging allow manufacturers and distributors to monitor the moments when the product is exposed to the external environment. This functionality is useful in tracking the actual shelf life of the product after opening.
5. Smell sensors
   Particularly relevant for products such as cosmetics or food products, odor sensors track changes in the product's smell. This can be essential for consumers who rely on smell as an indicator of freshness.

D. Freshness indicator

Freshness indicators provide direct information about the freshness and quality of the product, detecting microbiological growth and chemical changes within the food. Microbiological quality can be determined based on the reaction between the indicator inside the package and the metabolites that are formed as a result of microbiological action. Some indicators can detect certain compounds that arise as a result of chemical changes in foodstuffs. Indicators that can detect ethanol are useful in monitoring the quality of these products. Another indicator of food spoilage is carbon dioxide, which occurs as a side effect of microbiological growth. The exception is packaging meat products in a modified atmosphere, where it is more difficult to monitor such changes because the concentration of carbon dioxide is quite high. The color indicator indicates to consumers, distributors and to packers, the ideal period for product consumption. [3]

Figure 2. Freshness indicator [2]

E. Motivation

Considering all the advantages that smart packaging brings, it is noted that there are some shortcomings in the current version. The existing system does not provide users with full visibility at all times over the state of the product. Freshness sensors can be useful, but they are not always sufficient to provide comprehensive information about the state of the product and are lacking for monitoring other parameters. They may be subject to errors or incorrect readings, which may result in inaccurate information about the product's condition.

III. INNOVATIVE SMART PACKAGING

In order to improve, I plan to improve the system so that users can have insight into product information at any time. In this way, I want to ensure that users are always informed about the state of the food they consume, by adding sensors that will enable monitoring of temperature, humidity and other parameters, thus ensuring even more precise and comprehensive information about the state of food to users.

The packaging will be equipped with high-precision sensors, each of them specialized in monitoring certain parameters to ensure maximum food safety and quality. These sensors will be placed inside the packaging, allowing them to continuously monitor key factors such as temperature, humidity and the hermetic closure of the package. Their precision and sensitivity will be calibrated so that they can detect even the smallest changes in the food's environment.

When the sensors collect data, they will transfer it to the microcontroller or microprocessor that will be the heart of this system. This microcontroller will be specially designed to process, analyze and interpret the collected data in real time. Its role will be multiple, including checking compliance with set security standards, as well as activating appropriate measures if any irregularities occur. Communication between the microcontroller and the user application on smartphones or other devices will be extremely simple. The system will support multiple communication protocols such as Bluetooth, WiFi or NFC, allowing users to connect to the packaging in a way that is most suitable for their situation and the devices they use.

When the user scans the packaging using the app, it will provide them with a detailed view of all the relative information about the product. This includes the current temperature and humidity inside the package, the recommended shelf life in real time, detailed nutritional values, information on possible allergens or additives, as well as advice on optimal storage and consumption of the product.

Additionally, the application will automatically generate warnings and notifications to users in case the sensors detect any changes that could affect the quality of the food.

Such a system provides users with complete control and security over the food they consume, allowing them to make the right decision about purchase and use, while reducing the risk of food loss or spoilage.

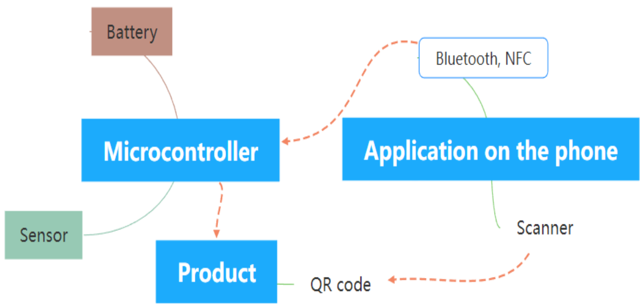

Figure 3. Block diagram

The working principle:

Smart packaging uses an ESP32-WROOM-32 microcontroller in combination with a DHT11 temperature and humidity sensor to continuously monitor the food environment. This system is powered by a CR2032 battery that allows use without the need for constant power from the mains.

Once the sensor collects temperature and humidity data, the microcontroller processes them and sends them via communication protocols such as Bluetooth or NFC to the application on the smartphone.

When users scan the packaging using the application on their smartphone, they receive information about the production date, the presence of allergens, recommended guidelines for storage and consumption, as well as the current state of temperature and humidity inside the packaging.

A. *Microcontroller Programming*

Microcontroller programming is a key aspect in the development of intelligent systems, especially those that rely on sensors to monitor the environment, such as temperature, humidity and other parameters. This process enables precise sensor management and efficient data collection, which is key to ensuring optimal system functioning. The first step in microcontroller programming is detailed planning of the software architecture. It includes defining the communication of the microcontroller with the sensors, the strategy data collection and processing, as well as methods for further interpretation and distribution of data.

After defining the architecture, the implementation of algorithms for precise measurement and monitoring of parameters follows. It is especially important to define everything because of microcontrollers that use low-power batteries.

Various tools and technologies can be used for microcontroller programming and application development. Programming the microcontroller will be done using a tool like Arduino IDE, which supports models like Arduino Nano.

The ESP32-WROOM-32 module provides 4MB of flash memory, while the ESP32-WROWER module provides that same capacity plus an additional 4MB of PSRAM memory for more advanced and more complex projects. Dimensions ESP32-WROOM-32 and ESP32-WROVER are 25mm x 18mm.

Figure 4. ESP32-WROOM-32 [8]

LiPo batteries or CR2032 batteries are used to power the microcontroller. The dimensions of LiPo batteries vary depending on capacity and shape, but the miniature LiPo batteries often used in small devices have common dimensions of approximately 20 mm x 30 mm x 3 mm. Standard CR2032 battery dimensions are approximately 20mm and approximately 3.2mm thick.

Figure 5. LiPo battery [4]

Figure 6. CR2032 battery [5]

Sensor for measuring temperature and humidity DHT11 or DHT22 dimensions are 15 mm x 12 mm x 5 mm. DTH11 is simple, cheap and has limited accuracy, the DHT22 is more expensive and has more accurate environmental measurements.

Figure 7. Temperature and humidity sensor [6]

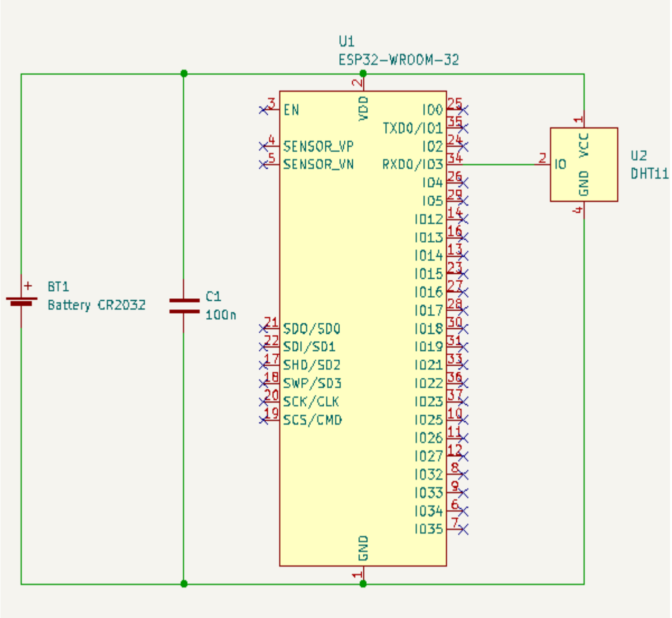

Figure 8. Microcontroller and sensor scheme

B. *Application development*

Development environments such as Android Studio for Android or Xcode for iOS applications can be used to develop smartphone applications, which provide tools and resources for building highly functional and aesthetically appealing mobile applications.

The app's home screen can display a list of products or allow users to scan a QR code on the packaging to access information about a specific product.

When the user selects a product, the application will display detailed information such as temperature, humidity, shelf life and etc. In this way, users will be informed about each product before they buy or consume it.

Various settings, such as notifications or user account management, will be available to users. The application will allow users to add products to their wish list or rate them and leave reviews so that other users can be more informed and make a decision more easily.

The application will be easy to use, providing users with all the information they need in a simple and reviewed way.

Figure 9. QR code scanning [7]

Figure 10. Appearance of the application

For smart packaging like this, there may be some potential problem or challenges to consider:

1. Power supply: CR2032 battery has limited capacity and service life, which is several months, due to frequent sensor readings,
2. Connectivity: it can sometimes be challenging to maintain a stable connection with user devices, especially if they are in an environment with many electronic signals,
3. Sensor accuracy: although the sensors are highly accurate, it is possible that a problem with the calibration or accuracy of the sensor may occur over time,
4. Dimensions of the components: it can be a problem to fit the components inside the small packaging.

C. *Product price*

This product represents a conceptual idea that is currently in the development phase and does not yet have a finished prototype, which is the next step in development. Prototyping costs are calculated based on the prices of the components, and these costs refer only to the prototype and not to the finished product. The cost of packaging would be high initially, so this concept would pay off first for more expensive products. However, as the concept was used more, the price would gradually decrease. Also, recyclable packaging could further reduce the price in the long run.

Component	Price $
Sensor DHT11	0.40
Battery CR20322	0.01
ESP-WROOM-32	0.56
Capacitor 100nF	0.35
	1.32

IV. CONCLUSION

With the growing interest in smart packaging, my innovative idea of smart packaging represents a step forward in the advancement of the food industry. By providing precise information about temperature, humidity and other key factors that affect the quality of the product, my packaging allows users to be sure of the freshness and safety of the products they consume.

The development of new technologies for food quality control is becoming a key factor for the improvement of smart packaging. Investing in these advanced technologies becomes crucial for companies that want to remain competitive and meet the increasing demands of consumers.

The new packaging enables better storage and transportation of food, which contributes to reducing losses and ensures product freshness.

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