Integration of IoT and Sensors to Monitor Storage Condition of Fruits and Vegetables

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Abstract

Approximately half of the global production of fruits and vegetables is wasted or lost during the supply chain, resulting in the squandering of valuable resources and economic setbacks. The quality and shelf life of fresh produce are significantly influenced by ambient factors. To address this issue, the utilization of Internet of Things (IoT)-enabled sensors and communication technology in supply chains can play a crucial role in optimizing product quality and minimizing rejections and losses. While there are various technical solutions available, the unique characteristics of fresh plant-based produce pose challenges in implementing effective applications. Therefore, the objective of this review is to provide an overview of IoT-enabled sensor and communication technology specifically tailored to the quality and spoilage characteristics of fresh fruits and vegetables. Ambient parameters such as temperature, relative humidity (RH), O2, CO2, and vibration/shock offer substantial value in terms of product quality optimization and can be effectively monitored using existing IoT-enabled sensor technology. Additionally, there are several wireless communication technologies that facilitate real-time data exchange, subsequent data processing, and utilization. Despite numerous studies exploring the feasibility of monitoring systems using IoT-enabled technology, the widespread implementation in fresh fruit and vegetable supply chains is still impeded by unresolved challenges.

Keywords: Internet of Things (IoT), sensor, supply chain, monitoring system

Introduction

The Internet of Things is an interconnected system of computing devices, both mechanical and digital, that uses sensors applied to machines, animals and people to create unprecedented amounts of important and detailed data about systems in order to improve them. From a supply chain management perspective, the Internet of Things can enable machines to undertake the decision-making process with little or no human intervention through autonomous coordination between “things” as they are transported between different entities in the supply chain. In particular, the concept of the Internet of Things (IoT) enables visualization of supply chain operational processes, information gathering, and control of business development in real time. As far as the food industry is concerned, IoT helps to maintain safety standards, limit food waste, manage unpredictable variations, track and monitor the quality of foodstuffs. The solutions proposed by IoT are expected to not only influence the way food is produced, but also to assess social, environmental, and economic concerns. (Barbara Bigliardi et.al). The main results obtained by adopting IoT in the food industry are:

a) Improved food security and control

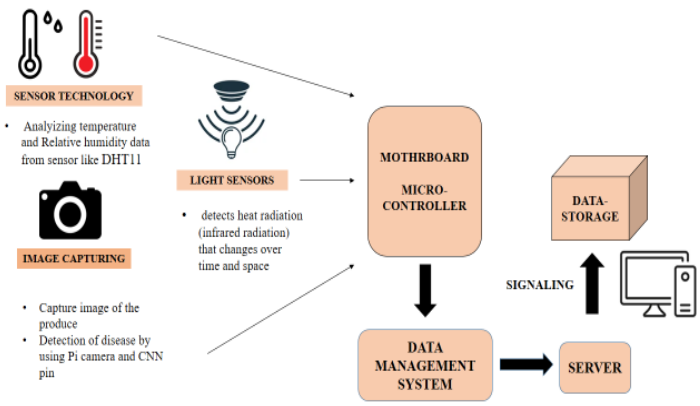
b) Improved traceability and transparency in the supply chain

c) Improving sustainability and reducing waste

d) Optimizing transport

IoT working principle

A food monitoring system using IoT consists of a wireless sensor unit that monitors critical environmental parameters such as temperature, humidity and food-borne gas. Sensor like DHT11, hygrometer, thermistor detects the temperature and humidity of the product storage environment. It detects the environmental value and sends the data to a machine learning algorithm that converts this analog value into a digital value that is compared to a threshold value mentioned for each food sample. If the algorithm detects a disease, the system stops and warns the user. If no disease is found, the system continues to predict the shelf life of stored products using the same machine learning algorithm. The estimated storage is then shown to the user who can use this information to manage fruit and vegetable storage and distribution. Finally, the system stops and the process ends. Overall, this IoT-based storage monitoring system helps ensure the quality and freshness of stored products by detecting diseases and predicting shelf life, which can help reduce waste and improve profitability for manufacturers and retailers.



Ambient parameter monitoring and sensor technology

Ambient parameters like temperature, relative humidity, ethylene concentration, CO_2, O_2 strongly influence the quality and shelf life of fruit and vegetables. It is essential to conduct regular and consistent monitoring in order to ensure the safety, freshness, and nutritional quality of products. The conventional method of monitoring environmental conditions in fruit and vegetable supply chains often involves outdated and non-digitalized practices. The insufficiency of real-time data poses a specific challenge that innovative solutions are working to address in order to enhance food safety and minimize waste. Additionally, having access to real-time data on ambient conditions is a critical necessity for accurate predictive shelf-life calculations. One approach to provide this data is through the utilization of IoT-based sensors with wireless communication technologies.

Temperature

Temperature is the most important ambient parameter in the context of quality retention and shelf life because it strongly influences all spoilage mechanisms of fresh fruit and vegetables. For products that are sensitive to chilling injury, such as mangoes, avocados, bananas, papayas and pineapples, not only a temperature increase, but also a lower than optimum temperature can negatively impact their quality. Temperature sensors are widely available and account for up to 80% of the global sensor market. Although traditionally thermocouples were common, in most IoT temperature sensors resistive temperature devices or thermistors are used. Both types are inexpensive and measure the temperature accurately over a wide range. Given the availability of cost-efficient IoT temperature devices, an application for optimized product quality and shelf life can be profitable for all fruit and vegetables.

Relative Humidity

During the storage and distribution processes, it is crucial to determine the optimal relative humidity (RH) level that minimizes moisture loss while simultaneously preventing the growth of microorganisms. RH has a significant impact on reducing the transpiration rate, but it can also facilitate the growth of certain microorganisms when it is too high. Therefore, it is of utmost importance to continuously monitor and control the RH in real-time, particularly for fresh fruits and vegetables that are susceptible to water loss or microbial decay, such as berries and citrus fruits. In addition to moisture loss, RH can also negatively affect other quality characteristics. The integration of IoT technology with RH monitoring can offer numerous benefits for various fruit and vegetable supply chains. There are different sensor technologies available for this purpose, including optical, gravimetric, capacitive, resistive, piezo-resistive, and magnetoelastic sensors. However, when it comes to IoT devices, capacitive and resistive sensors are predominantly used due to their durability, compact size, and low power consumption. IoT solutions for measuring RH are readily accessible and often incorporate temperature sensors as well.

Ethylene

The gaseous plant hormone ethylene plays a crucial role in enhancing metabolic processes in various fruits and vegetables. However, its impact is particularly significant in stimulating the ripening process of climacteric fruits. Even at extremely low concentrations, ethylene can have adverse effects on sensitive products. This becomes a concern when different commodities are stored together, as the presence of ethylene-producing items can lead to a decline in quality for the more sensitive ones. Even in cases where ethylene is intentionally added to facilitate controlled ripening and de-greening, it is essential to carefully monitor and control the concentrations. Therefore, the ability to monitor ethylene concentrations in real-time would be immensely valuable during the transportation and storage of climacteric fruits and other ethylene-sensitive products. While ethylene sensors with sufficient accuracy are currently too expensive for integration into IoT devices, there have been promising advancements

in the development of Chemi resistors, Chemi capacitors, and NDIR spectroscopy techniques.

Conclusion

In conclusion, the IoT-based system for monitoring fruits and vegetables storage, along with machine learning for shelf-life and disease detection, shows great potential in maintaining the quality and freshness of stored produce. By utilizing sensors, cameras, and machine learning algorithms, the system accurately identifies diseases and predicts the remaining shelf-life of the produce. Additionally, the web dashboard offers real-time updates on the status of the fruits and vegetables. However, further improvements can be made by incorporating wireless sensor networks, predictive maintenance, cloud-based data analytics, and mobile application integration. These enhancements have the potential to enhance the accuracy and reliability of data, increase transparency, reduce maintenance costs and downtime, and provide a more user-friendly interface for consumers and retailers. Therefore, future research should focus on exploring these areas to enhance the efficiency and effectiveness of the system in ensuring high-quality produce for all stakeholders and retailers.

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