DOI: https://doi.org/10.21323/2414-438X-2022-7-3-150-155

Available online at https://www.meatjournal.ru/jour
Original scientific article
Open Access

Received 19.07.2022
Accepted in revised 05.08.2022
Accepted for publication 10.08.2022

WIRELESS PRESSURE SENSOR SYSTEM FOR FISH QUALITY MONITORING

Boyu Mu[1], Marina A. Nikitina[2], Xinqing Xiao[1]*
[1] China Agricultural University, Beijing, PR China
[2] V. M. Gorbatov Federal Research Center for Food Systems, Moscow, Russia

Keywords: *wireless sensing, pressure sensor, bluetooth communication, fish monitoring, food quality and safety*

Abstract
Food quality monitoring is increasingly important. This paper aims to propose the developed wireless pressure sensor system (WPSS) for fish quality monitoring. WPSS consists of a sensor acquisition module, power supply module, and Bluetooth module. The sensor acquisition module includes a temperature sensor, pressure sensor, and microcontroller unit (MCU). When Bluetooth receives the data collection command from the smartphone, the data of storage temperature and pressure in the food package can be collected by the sensor and transmitted wirelessly to the smartphone through Bluetooth. All data obtained by the system is monitored, stored, processed, and eventually displayed in a smartphone app in real-time to improve temperature, air pressure, and freshness transparency within the food package, ultimately ensuring food quality and safety. The proposed WPSS has potential application in many kinds of food monitoring. It can realize simple and intuitive food quality indications.

For citation: Mu, B., Nikitina, M.A., Xiao, X. (2022). Wireless pressure sensor system for fish quality monitoring. *Theory and Practice of Meat Processing*, 7(3), 150-155. https://doi.org/10.21323/2414-438X-2022-7-3-150-155

Funding:
This research is supported by National Natural Science Foundation of China (No. 61903365), and the No. 2115 talent development program of China Agricultural University.

Introduction

Food corruption is an important topic in food processing and transportation [1–3]. Because of the long transportation distance between food production areas and consumers, food corruption is prone to occur [4]. As an essential food in our daily life, meat is becoming more and more important in terms of quality and safety [5]. Among many characteristics of food, freshness is a key factor in food quality [6]. During storage and transportation, food freshness decreases over time with the resulting changes in meat characteristics such as firmness, tenderness, and flavor that affect the taste of food as well as color [7,8]. Reliable monitoring systems are therefore essential for the food industry to track the breakdown of food during storage and instead of as well as transport to avoid harmful problems caused by spoiled food.

A large number of studies have shown that fish can be affected by microorganisms during storage and transportation leading to decomposition of proteins or amino acids and the production of ammonia, amines, as well as other basic nitrogen-containing organic compounds, such as trimethylamine (TMA) and dimethylamine (DMA) [9,10]. These substances are volatile and are collectively known as total volatile basic nitrogen (TVB-N). This is an important indicator to reflect fish freshness, and also an important research direction to realize non-destructive, accurate, and real-time detection of fish freshness [11,12].

The traditional detection methods of volatile organic compounds mainly include the headspace phase spectrum detection [13,14], gas sensor array of the electronic nose [15–17], etc. Headspace phase spectrometry is one of the most reliable methods to measure volatile organic compounds at present, but this method has the characteristics of complex operation and high cost, so it cannot achieve rapid and accurate dynamic detection [18]. Electronic noses can allow quantitative and qualitative detection and identification by a variety of gas sensor arrays, but at present, the gas sensors are still mainly semiconductor metal oxides and electrochemical. The sensors used in these systems are based on metal oxide semiconductor (MOS) mechanisms and require considerable energy consumption. This greatly limits battery life [19]. It is feasible to measure a change in air pressure in food packaging by a pressure sensor based on an increase in air pressure caused by gas emissions from meat spoilage during storage and transportation. The pressure sensor consumes very low power, thus significantly reducing the power consumption of the entire circuit.

Bluetooth communication is an effective method of wireless communication to realize the wireless detection of food quality in packaging [20,21]. At present, Bluetooth is a popular point-to-point or point-to-multipoint communication mechanism for short distances. Among other short-range wireless technologies, Bluetooth has the characteristics of low cost, low power consumption, small size, and

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especially strong anti-interference ability, which makes it a versatile and attractive technology. Because of its robustness to interference, Bluetooth is a wireless solution widely used in industrial applications [22,23].

In this study, a wireless air pressure sensing system (WPSS) is proposed. The wireless air pressure sensor system consists of a sensor acquisition module, power supply module, and Bluetooth module. The sensor acquisition module includes a temperature sensor, pressure sensor, and microcontroller unit (MCU). When Bluetooth receives the data acquisition command from the PC, the data on storage temperature and air pressure in a food package can be collected by the sensor and transmitted to the PC wirelessly through Bluetooth. All data obtained by the system is monitored, stored, processed, and ultimately displayed in a PC-side application in real-time to improve temperature, air pressure, and shelf-life transparency within the food package, ultimately ensuring food quality and safety.

Objects and methods

The materials and methods will be presented in more detail in this section, which include the design and implementation of the wireless pressure sensor system, the freshness evolution and the experimental scheme for the actual fish monitoring.

Wireless pressure sensor system

As shown in Figure 1, the wireless pressure sensor system consists of a sensor acquisition module, power supply module, and Bluetooth module (CC2540, Texas Instruments, USA). The sensor acquisition module includes a temperature sensor, pressure sensor, and MCU (ATmega328P, Microchip Technology / Atmel). As shown in Figure 2, the temperature and pressure sensors are integrated on the BMP180 chip (Bosch Sensortec, Germany). The BMP180 has the characteristics of intelligence, small volume, high precision, wide working range, and can output high precision pressure and temperature measurement data. The temperature sensor ranges from minus 40 °C to 85 °C, with an accuracy of ±2 °C and pressure sensor accuracy of 0.12 hPa/m, requiring calibration calculations before operation. The sensor is equipped with a 3.3 V voltage regulator that can be used in conjunction with Arduino. The BMP180 control unit includes EEPROM and IIC interfaces. The temperature and pressure sensors communicate directly with MCU via the internal integrated circuit (I2C) bus. ATmega328P has 32 8-bit general purpose working registers, high performance, and low power consumption. ATmega328P has more interface functions, among which, ADC6 and ADC7 have independent interfaces with a forward analog voltage of 5 V, and the chip has an external reference voltage input interface, AREF. The chip supply voltage VCC is 5 V. The Bluetooth module has the characteristics of low power and excellent cost performance. The chip integrates the microcontroller, host, and application, and is suitable for many practical application directions such as the Internet of Things. Bluetooth modules can be connected to smartphones or devices. When a data acquisition command is received, the storage temperature and pressure sensing data of the food can be collected by the sensor and transmitted wirelessly to the smartphone via Bluetooth.

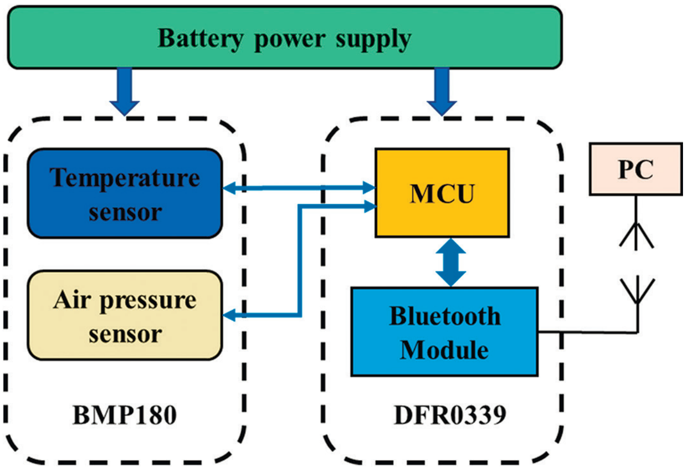

Figure 1. Scheme diagram of the WPSS

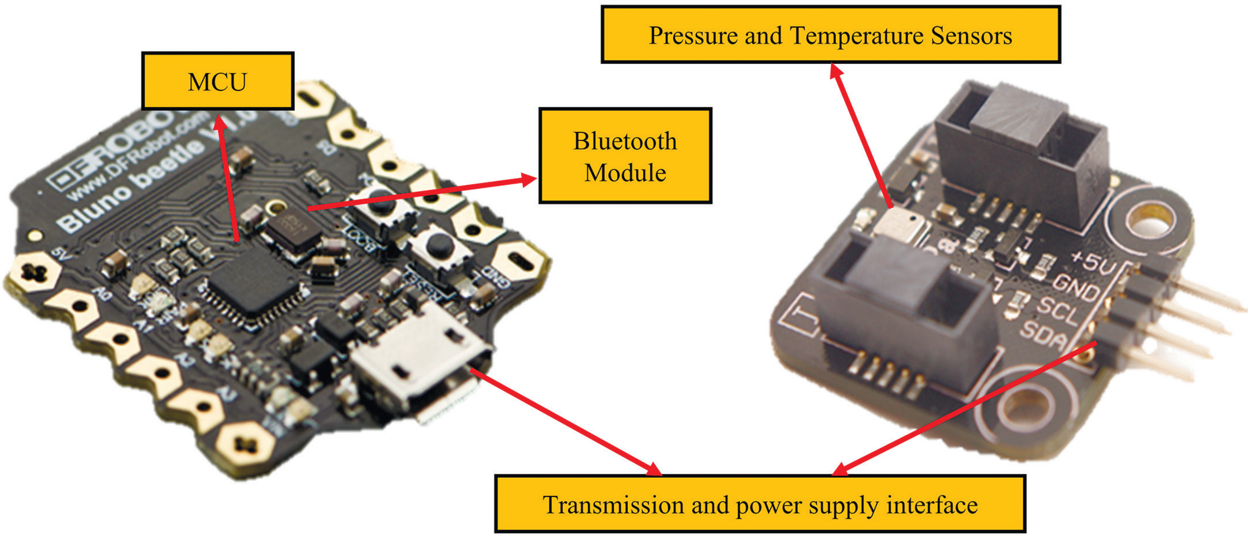

Figure 2. Physical implementation of the wireless pressure sensor

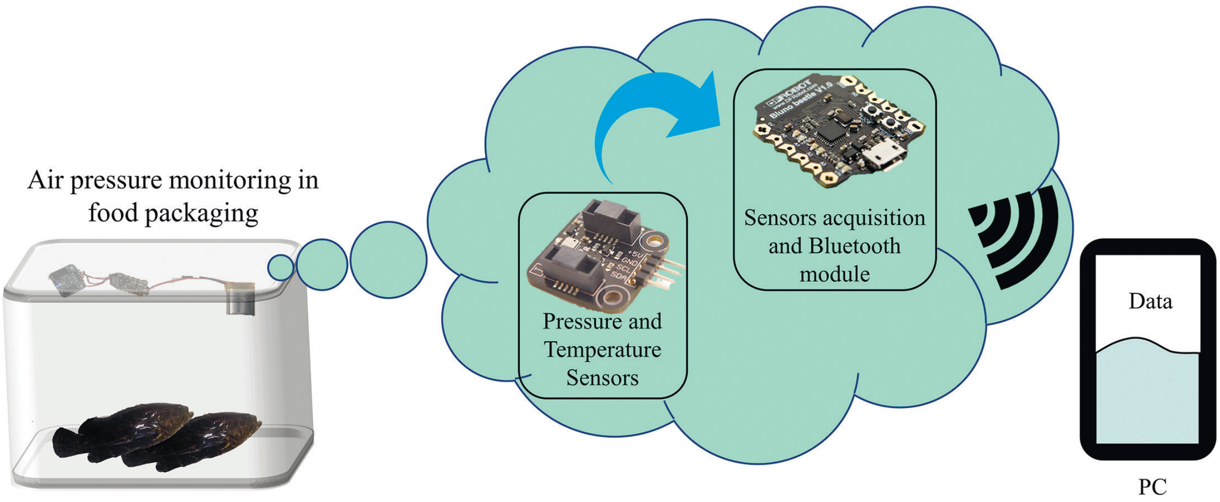

Figure 3. Experimental scheme of the WPSS for fish monitoring

Experimental scheme

Taking gentian grouper meat as an example, the air pressure in the packaging of fish was studied. As shown in Figure 3, the whole monitoring system (development board, sensor, external power supply) is fixed on the wall of the container and does not contact the surface of the chilled fish. The container is sealed with the adhesive tape and plastic film. The container with fish is placed in a constant temperature box, and the temperature is set at 20 °C. The temperature and air pressure in the container measured at intervals of about 3 hours by the sensor are recorded until the fish is completely rotten (there are obvious color and smell changes in the chilled fish, and it is intuitively felt that the chilled fish is rotten). Real-time barometric temperature data can be obtained from sensor data collected on the smartphone.

The same fish samples were tested for the TVB-N content using the Kjeltec 8400 analyzer while the temperature and pressure in the vessel were recorded by the sensors. TVB-N measurement was conducted by the Kjeldahl method identified as Chinese National Standard Method GB5009.228–2016 [24]. The 10.00 g (±0.1 g) homogeneous sample was transferred to the centrifuge tube. The perchloric acid solution was added up to 25 ml and mixed well. Then, the perchloric acid solution was added up to 40 ml. The mixture was filtrated, the supernatant was taken for testing and 20 ml of the supernatant was added to the tube. After adding 3 drops of the phenolphthalein indicator, the digestion tube was placed in the Kjeltec analyzer and the distillation was run on steam (60%) for 6 minutes in 5s delay mode while the boric acid solution absorbed the ammonia from the distillation. The Kjeltec 8400 analyzer analyzed automatically and titrated with standard hydrochloric acid (0.0100 mol/L) to the endpoint grayish blue color.

Data analysis

Matlab R2019a (American Math Works Incorporated) and Microsoft Office Excel 2019 (American Microsoft) were used for processing the temperature sensor data, pressure sensor data, and data on the TVB-N content of fish. The correlation between the pressure in the food package and the TVB-N content of fish was analyzed, and finally, the freshness of fish was judged by the pressure. The WPSS workflow for fish freshness assessment is shown in Figure 4. The smartphone starts scanning the sensor Bluetooth module and then reads the temperature and pressure sensor data after detecting the sensor. The obtained sensor data will be correlated with the TVB-N content of the fish at the same time to further evaluate the freshness. The collected sensor data and food freshness will be monitored, stored, and displayed in real-time in a reader, such as an app on a smartphone.

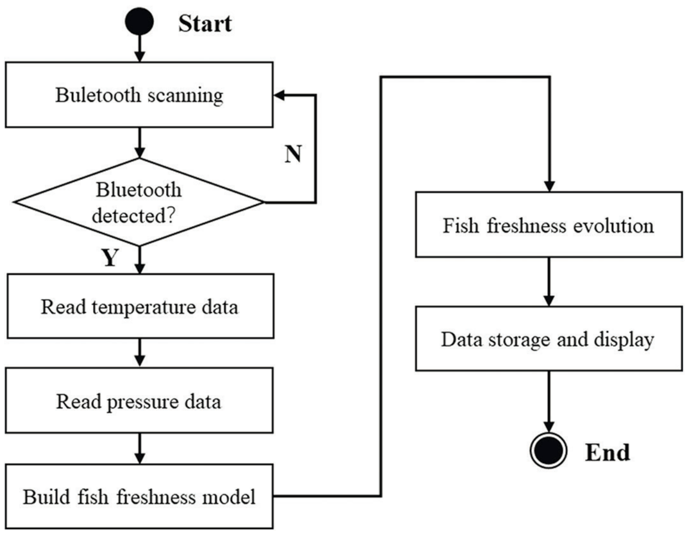

Figure 4. Workflow of the WPSS with freshness evolution of the fish

Results and discussion

The fish freshness evolution and its evaluation using the wireless pressure sensor system will be analyzed and discussed in more detail in this section to explain the application performance of the WPSS.

The performance of the wireless pressure sensor system

Through the actual test of the wireless pressure sensor system for chilled fish, the data on pressure and pressure change in a vessel during storage of chilled fish are obtained, which can be further analyzed and summarized. As shown in the Figure 5, during the system test, the temperature in the food packaging basically remained at 20 °C with little fluctuation. During the preservation of chilled fish at 20 °C, within 0–15 hours, the change in air pressure caused by microbial activities in the container was only about 100 Pa. Then, during 15–24 hours, the pressure in the container increased rapidly, and the pressure changed to about 200 Pa. After 24 hours, the freshness of chilled fish at this stage could be judged to be poor by artificial senses, and the chilled fish at this stage had no edible value. The pressure increased slowly, by about 100 Pa. The experimental results show that it is feasible to monitor food freshness in packaging by pressure. Compared with other related studies [25,26], although the initial air pressure is different due to the different external environment, the change principle and trend of air pressure in food packaging are the same.

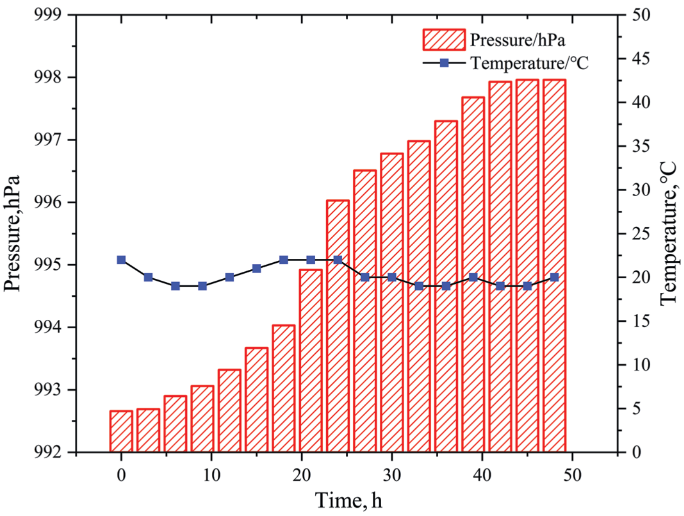

Figure 5. Data on a package pressure increase in the experiments with fish

Fish freshness evolution

The content of volatile base nitrogen (TVB-N) is an important indicator of fish freshness. We further classified foods into different freshness levels according to the TVB-N content of fish. Gentian grouper meat was used to study the availability of this classification. As shown in Figure 6, at a constant temperature of 20 °C, the TVB-N value of fish increased slowly from 9.91 mg/100 g to 15.31 mg/100 g during the period of 0–18 h at the beginning of the experiment. At this stage, the fish was of good quality. After 18–36 h, the content of TVBN in fish began to increase rapidly, from 15.31 mg/100 g to 25.31 mg/100 g. In this case, the freshness of the fish was mediocre, and the use value of the fish decreased and eventually reached the warning status. After 36 hours, the TVB-N content of fish continued to rise for a while until it was completely rotten. At this stage, the fish was completely inedible. The TVB-N of the fish and the pressure in the vessel is monitored simultaneously throughout storage. During this process, the TVB-N content of the fish was compared to the pressure value in the container at the same time to find the internal pressure value of the fish as it changed from one level of freshness to another. The pressure values at these points are called thresholds. Based on the results, the fish is good for the first 18 hours, then classified as normal for the next 18 hours, and the fish freshness warning appeared until the fish was not edible. The thresholds were then used to develop a food classification mobile application.

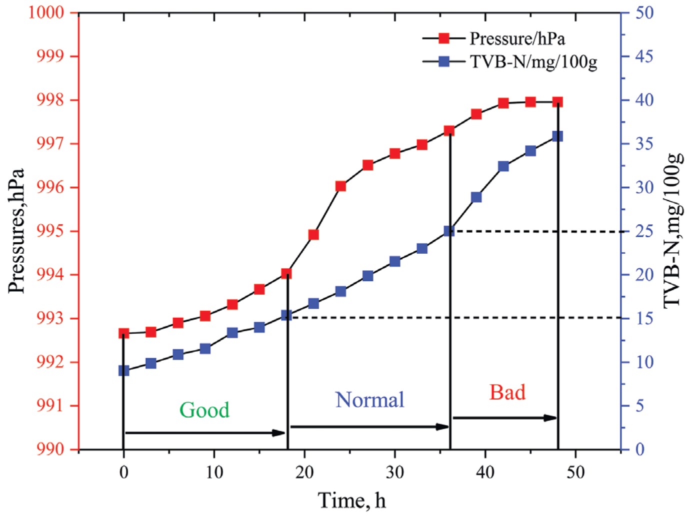

Figure 6. Correlation analysis of pressure and TVB-N of fish

Evaluation of WPSS

WPSS deployment and improved performance were evaluated and discussed (as shown in Table 1 and Table 2). This performance is helpful to improve the efficiency of the system in the practical application of food monitoring and improve the performance of freshness evaluation.

Recommendations to change the WPSS were made by inviting about 10 customers to try out the deployed WPSS. They provided constructive suggestions for WPSS. Table 1 summarizes the improved performance of WPSS.

WPSS can obtain the temperature and pressure sensor data in food packaging to effectively monitor the food environment, and through the pressure in food, packaging to judge food freshness. All data obtained by WPSS is monitored, stored, processed, and ultimately displayed in a smartphone app in real-time to improve the transparency of food temperature, and freshness and ultimately ensure food quality and safety.

Table 1. Deployment performance of the WPSS

ID	Content	Before implementation	After implementation
1	Pressure sensor system	Null	Monitoring in need
2	Freshness evaluation	Null	Predicting in need
3	Sensor deployment	Null	Easy to deployment
4	Monitoring efficiency	Low	Improving with freshness evaluation

Table 2. Improvement suggestions for the WPSS

ID	Suggestion	Suggestion type
1	Improve the stability of WPSS in further	WPSS
2	Reduce the cost and size of WPSS in further	WPSS
3	Improve the flexible deployment possibly in further	WPSS
4	Improve the accuracy of shelf-life prediction model in further	Freshness evaluation
5	Increase the applicability for more fruits or other foods	Food monitoring

Conclusion

The developed wireless pressure sensor system for fish spoilage monitoring is proposed in this paper. The WPSS consists of the sensor module, power supply module, and Bluetooth module. WPSS sensor module includes sensor acquisition module and MCU. Data from temperature and pressure sensors stored in food packaging is sent to Bluetooth module through the MCU. When receiving the data acquisition command of the smartphone, the signal is transmitted to the smartphone wirelessly through Bluetooth. The system takes temperature and pressure sensing data to effectively monitor the pressure inside the food package and judge the freshness of fish by pressure. All data obtained by WPSS will be monitored, stored, and processed in real-time, and finally displayed in the APP on the smartphone to improve the transparency of fish temperature and freshness, and ultimately ensure the quality and safety of fish. This method can display food quality simply and intuitively and has the potential application value in various food monitoring.

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AUTHOR INFORMATION

Boyu Mu, Master, Beijing Laboratory of Food Quality and Safety, College of Engineering, China Agricultural University, Beijing 100083, PR China. Tel.: +86–188–6058–7671, E-mail: mby0527@cau.edu.cn
ORCID: https://orcid.org/ 0000–0002–2635–7206

Marina A. Nikitina, Doctor of technical sciences, docent, leading scientific worker, the Head of the Direction of Information Technologies of the Center of Economic and Analytical Research and Information Technologies, V. M. Gorbatov Federal Research Center for Food Systems. 26, Talalikhina str., 109316, Moscow, Russia. Tel: +7–495–676–95–11 extension 297, E-mail: m.nikitina@fncps.ru
ORCID: https://orcid.org/0000–0002–8313–4105

Xinqing Xiao, Doctor of Engineering, Associate Professor, Beijing Laboratory of Food Quality and Safety, College of Engineering, China Agricultural University, Beijing 100083, PR China. Tel.: +86–158–0122–7781, E-mail: xxqjd@cau.edu.cn
ORCID: https://orcid.org/ 0000–0002–9512–4000
* corresponding author

All authors bear responsibility for the work and presented data.

All authors made an equal contribution to the work.

The authors were equally involved in writing the manuscript and bear the equal responsibility for plagiarism.

The authors declare no conflict of interest.