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Optimal Control Analysis of Food Waste Treatment Methods Based on Improved Pressure Sensors

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Abstract: *With the rapid development of the economy and society, people's overall living standard continues to rise, and food waste generated by various industries is becoming a major part of domestic waste, how to dispose of waste in a real-time and resourceful manner is a major test for urban environmental maintenance. This paper focus on the weight perception of solid food waste after pre-treatment and proposes an optimisation strategy for the first time. The core structure of the traditional sensor is improved from three perspectives: temperature, capacitance value and external stress, thus building an improved capacitive pressure sensor to accurately detect the weight of waste and trim the measured data more accurate. Secondly, based on the remote monitoring system, the multi-level control enables the collected food waste to be eliminated in a timely manner, which helps the resource utilization of food waste.*

Keywords: *Food waste, Environmental protection, Capacitive pressure sensors, Remote control, resource recovery*

1. Introduction

With the development of society, the impact of food waste on the city, society and the daily life of the inhabitants are becoming more and more significant. The traditional methods of disposal: direct shredding, incineration and sanitary landfills are prone to secondary pollution and create huge hazards. At the same time, given the size of our population, food waste has the characteristics of "large quantity, wide distribution and difficult to handle", and most of the waste is disposed of in an arbitrary and disorderly manner, which seriously affects the appearance of the city and the quality of the environment. Therefore, the world is now confronted with the problem of how to turn food waste into treasure by making it harmless and resourceful, and there is an urgent need for corresponding measures and methods to address this problem.

Research on food waste disposal is currently in progressing in countries around the world. Each state in the US is under a slightly different policy and approach to food waste disposal, and each state has its own system of waste disposal and recycling for local conditions. In Japan, many new research directions have appeared in recent years, including the production of animal feed from food and the production of biogas from food waste to electricity and heat [1]. To improve the solubility of organic matter in food waste, Liu Yi et al. of Beijing University of Technology and Industry used high-temperature moist heat pretreatment of food waste [2]; Jiangsu Wylie, in conjunction with Tsinghua University, has produced three types of waste-derived fuels using mechanical biochemical treatment of food waste: solid-phase materials from dielectrolysis systems, high calorific value materials from bio-drying and high calorific value plastics and fabrics from mechanical pre-treatment[3]. Compared with developed countries, although China is also developing and applying in the field of food waste treatment and recycling, the level of comprehensive utilization is still low, and the mode of removing food waste in some urban areas is still mixed collection, transportation and treatment [4]. At present, China's food waste disposal equipment for waste weight recognition accuracy is not high enough, the sensor by the ambient temperature and humidity and other influences, can not accurately monitor the weight of the collected waste in order to timely clean up [5].

Therefore, in order to more accurately monitor the weight information of solid waste after pre-treatment in real time, this paper proposes an optimized control method for food waste weight sensing based on an improved pressure sensor: firstly, a basic model of a capacitive pressure sensor is constructed with the help of COMSOL software, and the sensor performance is analysed in terms of operating temperature, model capacitance value and external pressure respectively, followed by a simulation. The simulation results show that the improved pressure sensor proposed in this paper has been upgraded and optimised in terms of accuracy in measuring the weight of waste, and works in conjunction with pyroelectric infrared sensors and temperature and humidity sensors, and finally combined with a remote control system to build a complete food waste treatment system to achieve accurate monitoring and treatment of food waste status.

2. Principle of construction of food waste treatment systems

2.1. Basic principle of modified pressure sensors

Due to the strong development of power electronics, various technical problems of capacitive sensors have been solved and their performance has been improved. They get the advantages of low power consumption, low temperature sensitivity and low background noise, making them widely used in the measurement of a wide range of physical quantities and parameters.

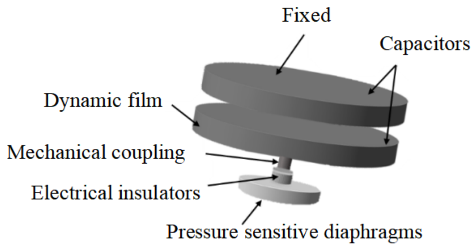

Figure 1: Structure of the capacitive pressure sensor

Capacitive pressure sensor structure as showed in Figure 1, this sensor is mainly composed of three components: pressure-sensitive diaphragm, capacitor and mechanical coupling elements (central column). The basic working principle is: When the pressure-sensitive diaphragm is subject to external pressure, deformation occurs and the deformation at the centre is the largest. The external circuit can measure the change in capacitance ΔC, which is calculated by the formula to obtain the pressure P on the pressure-sensitive diaphragm. Thus realising the function of the sensor to measure pressure.

The external pressure acting on the pressure sensitive diaphragm will cause it to deform, and according to the classical theory of small deflection bending of thin plates [6], the equation of the deflection curve of a thin plate can be obtained as

$$E\delta^3/12\left(1-\mu^2\right)\cdot\nabla^4\omega=q \tag{1}$$

Maximum deformation at the centre of a circular sheet, $r = 0$

$$\omega_{max}=\frac{qa^4}{64D}=\frac{3qr_1^4(1-\mu^2)}{16E\delta^3} \tag{2}$$

The expression for the capacitance of a parallel plate capacitor is

$$C=\frac{\varepsilon_0\varepsilon_r A}{d} \tag{3}$$

Deformation of the pressure sensitive diaphragm, The change in capacitance when moving the plate up a distance wmax is

$$\Delta C=\frac{3r_1^4(1-\mu^2)}{16E\delta^3}\frac{\varepsilon_0\varepsilon_r\pi r_2^2}{d^2}P \tag{4}$$

The sensitivity of the capacitive pressure sensor is calculated as

$$S=\frac{\Delta C}{P}=\frac{3r_1^4(1-\mu^2)}{16E\delta^3}\frac{\varepsilon_0\varepsilon_r\pi r_2^2}{d^2} \tag{5}$$

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where:*d* is the thickness of the diaphragm;***E*** is the modulus of elasticity; *D* is the bending stiffness of the diaphragm;*C* is the electrical capacity;*A* is the area between the poles covering each other;*d* is the distance between the two poles;*e0* is the dielectric constant of the vacuum; *er* is the relative dielectric constant of the medium; *P* is the external pressure; *q* is the standard value of the homogeneous wiring load (kn/m)

2.2. Principle of improved pressure sensors in conjunction with other sensors

This paper relies on the interplay of multiple sensors to build an intelligent system for food waste disposal. When the system starts working, the pyroelectric infrared sensor at the waste outlet continuously scans and detects human dynamic information, and when the human body is close to the waste outlet, the bin automatically opens the lid and monitors the weight change, and the dumped food waste is pre-treated so that the water content of the solid waste in it is greatly reduced and enters the collected waste is pre-treated so that the water content of the solid waste is greatly reduced and enters the collection box. The collection bins have pressure, temperature and humidity sensors that collect information on the weight of the waste and the temperature and humidity in the bins, which are combined with a remote control system to achieve real-time monitoring and timely disposal of the waste. A schematic diagram of the interplay between the various sensors and the remote control is shown in Figure 2

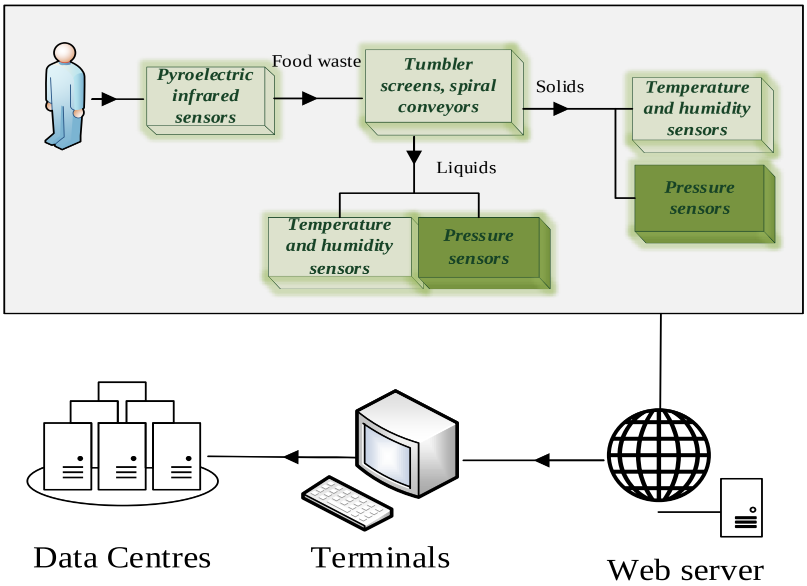

Figure 2: Diagram of sensor interplay

2.2.1. Pyroelectric infrared sensor characteristics

The pyroelectric infrared sensor basically does not emit any type of radiation, it is difficult to be affected by other RF devices, it can adapt to the complex and changing surrounding environment, it only needs to detect the heat generating source in the environment, it has the characteristics of high identification accuracy, strong anti-interference performance and high sensitivity. Infrared radiation is a kind of thermal radiation, from all the material body of the rotation and impact, by its working mode and internal design, can infer that the output signal amplitude and distance are inversely proportional, the farther the distance signal amplitude is lower.

2.2.2. Temperature and humidity sensor characteristics

This system equipment uses a DHT11 digital temperature and humidity sensor for data detection, consisting of a resistive humidity sensing measuring element and an NTC temperature measuring element with calibrated digital signal output, and applies special digital module detection technology and temperature and humidity sensor technology to ensure extremely high quality and reliability and long-term stability. The main principle of the work is that when the programmed operating range is exceeded, a temporary drift signal of 3% RH is likely to occur, and after returning to normal operation, the sensor will return to its calibrated state, which will accelerate the ageing of the product under non-normal operating conditions.

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2.2.3. The principle of remote control systems

The PLC remote monitoring system mainly makes use of the cloud platform for the integration of diverse data, which in practice fully reflect the convenience and speed of the function. By deploying all the devices in a local area network and connecting them via a switch, the entire control system can be built into the PLC with the touch screen and the remote control module by virtue of the cloud server. In the process of transferring information, the remote control module needs to be connected to the network and eventually the cloud platform. When in use, it is only possible to operate remotely by connecting to a dedicated address to access the equipment network through a parallel network with the Internet, and technicians can do program rearrangement of the PLC at any time, ensuring remote programming, program monitoring and screen group interface modification.

3. Example analysis of a food waste treatment system

3.1. Analysis of the internal structure of capacitive pressure sensors

While ordinary pressure sensors are inaccurate in winter and summer, day and night operation, where the measured values are influenced by temperature, this paper constructs a model of a capacitive pressure sensor by means of COMSOL software to analyse the performance of the capacitive pressure sensor in three comprehensive aspects: temperature, capacitance value and external pressure. The geometry of the constructed model is symmetrical and therefore only a quarter of the geometry has to be analysed. The quarter model structure is shown in Figure 3. A cross-sectional view of the device function is shown in Figure 4, where the diaphragm is maintained at a fixed potential of 1V and is isolated from a sealed ground plane under high vacuum.

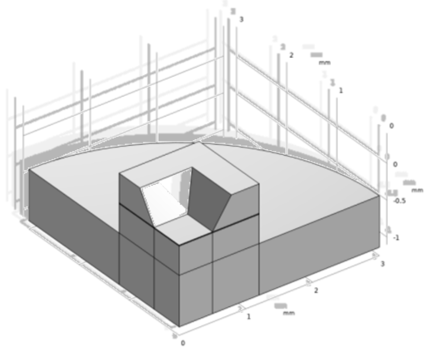

Figure 3: Geometry of the quarters

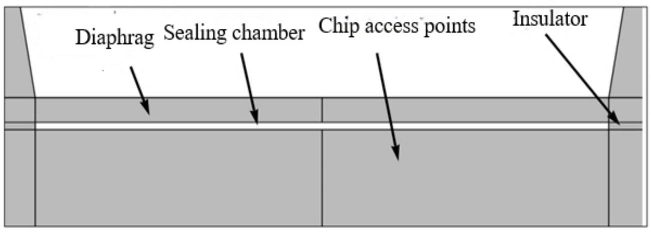

Figure 4: Cross-sectional views of the device

When the pressure outside the sealing chamber changes, the diaphragm is deflected, resulting in a change in the thickness of the sealing chamber across the diaphragm and therefore the capacitance to ground, which can then be monitored using a circuit interface [7]. Due to the mismatch in thermal conductivity between the silicon chip and the metal plate, and the high-temperature of the bonding process, thermal stresses are generated in the structure, these stresses change the deformation of the diaphragm in response to the applied pressure and alter the response of the sensor, the stresses are temperature dependent and also introduce unwanted temperature dependence in the device output. In this paper, the response of the device at a fixed temperature is calculated taking into account the encapsulation stresses. The variation of capacitance with temperature is observed at an applied pressure of 20 kPa and the response of the device is illustrated in figure 5. The temperature sensitivity of the model response is given by the gradient of the curve in the figure and is approximately3.5 ·10-3 pF/Pa and 14 ·10-3 pF/Pa on the entire device. Variation of diaphragm capacitance with applied pressure is simulated in the COMSOL software and is shown in Figure 6, external pressure increases non-linearly, where the gradient of the curve is a measure of the sensor sensitivity. The sensitivity of the quarter sensor is 7.3 ·10-6 pF/Pa, thus the device sensitivity is 29 ·10-6 pF/Pa, the value calculated in reference [7] is 26 ·10-6 pF/Pa, when different pressures are applied to the membrane, the membrane sheet deforms, resulting in a non-uniform potential in the sealing chamber,the results obtained through the COMSOL software simulation are shown in Figure 7, Figure 8 and Figure 9, which show the potential distribution between the two plates when the pressure is 0 kPa, 10 kPa and 25 kPa respectively. It can be seen that the sensitivity of the pressure sensor constructed in this paper has been improved and can adapt to complex environmental changes, and the measured data are more accurate in practical applications.

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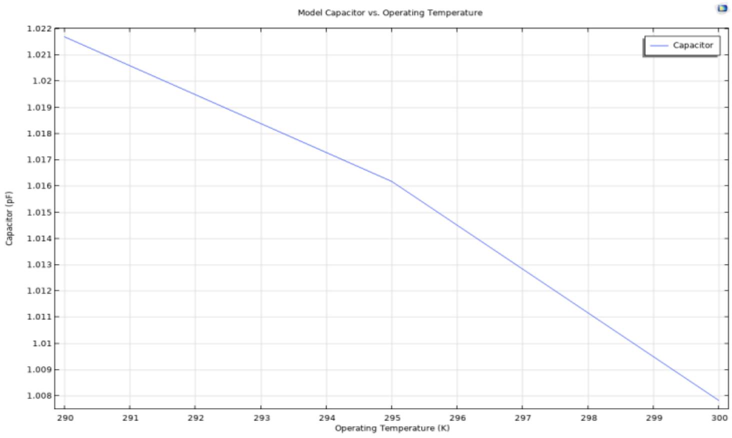

Figure 5: Variation of capacitance with temperature

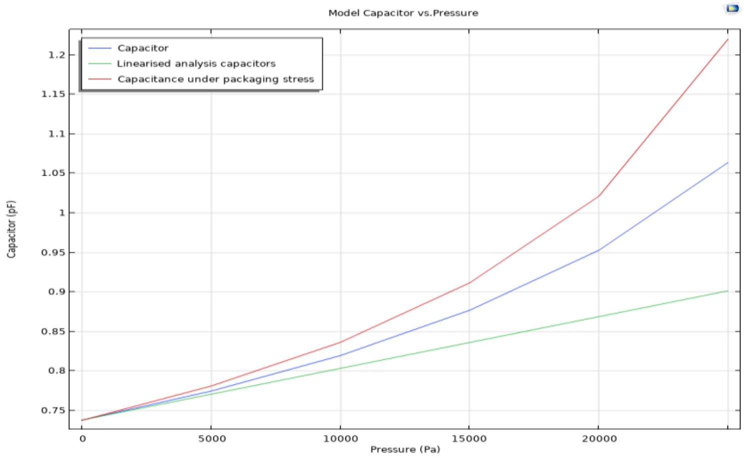

Figure 6: Variation of diaphragm capacitance with applied pressure

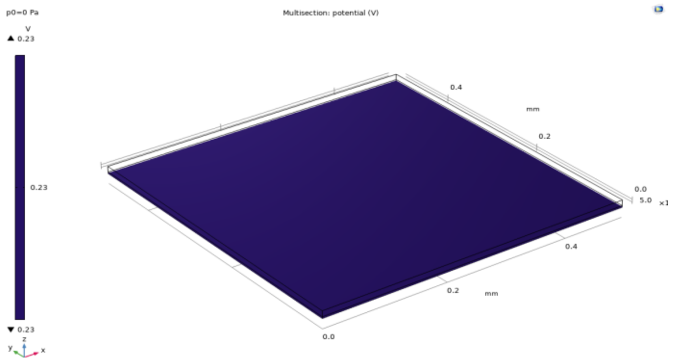

Figure 7: Distribution of potential in the sealing chamber at a pressure of 0

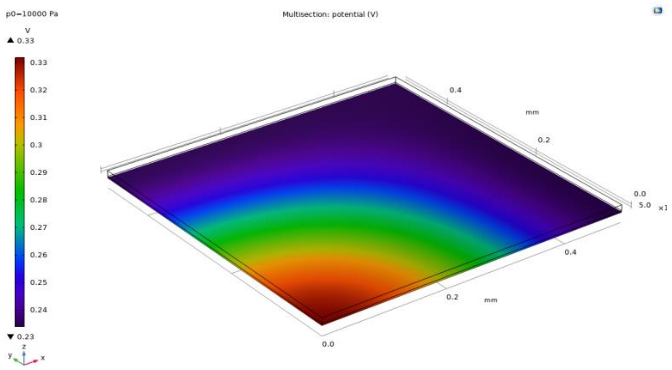

Figure 8: Distribution of potential in the sealing chamber at a pressure of 10 kPa

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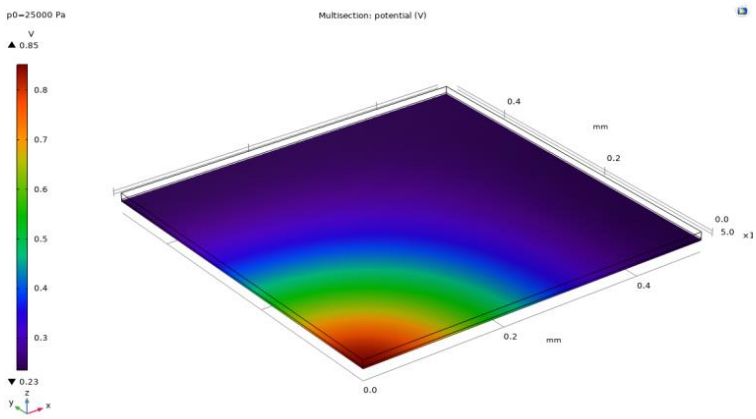

Figure 9: Distribution of potential in the sealing chamber at a pressure of 25 kPa

3.2. Remote control systems

The food waste pre-processing equipment consists of pyroelectric infrared sensors, capacitive pressure sensors and temperature and humidity sensors that work together in order to achieve remote dispatch and build a remote control management system. The entire management system consists of three levels: in-situ treatment, local control and remote control. The terminal not only receives information about the waste in time but also monitors the status of the equipment so that it can be controlled and maintained in time. The overall control system is illustrated in figure 10.

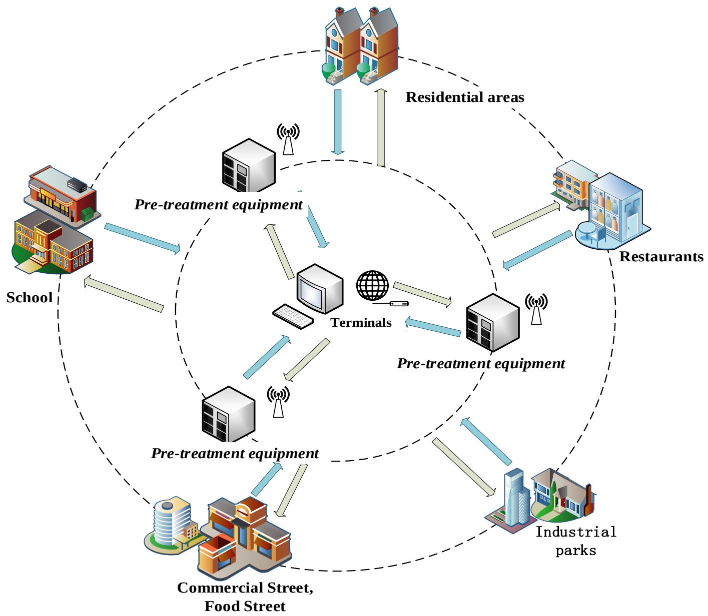

Figure 10: Overall control system

4. Conclusion

Under the wave of waste classification, food waste has been separately classified, there is also a more complete treatment system, but there continue to be shortcomings in the process of processing and monitoring waste. On the basis of ordinary pressure sensors, the capacitive pressure sensor model analyzed and constructed in this paper from three aspects: temperature, capacitance value and external pressure can well overcome the shortcomings of food waste treatment equipment such as inaccurate detection of waste weight and large impact by the environment, and then combined with remote control technology to constitute a scientific and complete food waste treatment system with stable overall system performance, accurate detection and reliable communication, which helps to promote the orderly treatment of food waste in China.

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