Chapter 6
Field Condition Sensing Technology

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Abstract With the rapid development of sensing, digital signal processing, and Internet communication technologies, many novel sensors, as well as essential components to IoT-based monitoring systems, have emerged and are continuing to emerge. Those sensors and networking components could help to achieve high sensitivity, improved adaptability, and enhanced reliability in monitoring field conditions for more efficient and productive agricultural productions. This chapter will introduce some commonly sensing technologies for measuring field environmental parameters, such as temperature, humidity, light, photoelectric, carbon dioxide, and microclimate parameters, such as wind speed and direction, rainfall, evaporation rate, and radiation, for effective field condition monitoring.

Keywords Field condition monitoring · Field environment sensing · Microclimate sensing · IoT-based monitoring system

6.1 Introduction

To achieve precision farming, one essential requirement is to apply the right amount of right resources to the right place at the right time. Doing so often demands knowledge about the field conditions, including environmental and microclimate conditions. This goal can be reached by using IoT-based monitoring system. If the production is conducted in a controlled environment, an IoT-based environment monitor/control system would allow farmers to optimize the environmental parameters, so that needs of crop growth at different stages would be met, thus fostering the optimal growing environment for crops and saving material and

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Y. He et al. (eds.), *Agricultural Internet of Things*, Agriculture Automation
and Control, https://doi.org/10.1007/978-3-030-65702-4_6

manpower at the same time (Tzounis et al. 2017). However, success in achieving such a goal still relies on adequate sensors that are connected to the IoT monitor/control systems (Manyika et al. 2015).

There are many types of agricultural sensors, among which environmental sensors such as temperature sensor, humidity sensor, photoelectric sensor, and carbon dioxide sensors are commonly used. It's important to note that farmland microclimate has a significant impact on agricultural production due to its basic characteristics (including the distribution of light, temperature, humidity, wind, and carbon dioxide in the farmland). At present, with the rapid development of sensor technology, sensors of wind speed, wind direction, rainfall, evaporation, and radiation have emerged for different characteristics of the farmland microclimate. However, agricultural sensors need to work in various harsh environments, so many sensors have poor adaptability, stability, and reliability under agricultural application conditions. For example, an air humidity sensor often works in an environment with a humidity above 95% in a greenhouse, which exceeds the environmental conditions for the normal operation of the sensor itself. How to overcome the adaptability of sensors in agricultural applications is an important breakthrough in agricultural information sensing.

6.2 Definition and Composition of Sensors

According to the Chinese National Standard GB 7665-87, sensor is defined as “A device that can sense a specified measured substance and convert it into a usable output signal conforming to a certain rule.” The basic function of sensors is to detect and convert signals. Ideally, a functioning sensor, in terms of input, should be sensitive on a selective basis, i.e., sensitive only to the specified physical quantity. For example, a temperature sensor should only react to temperature changes and not to any other factor. Similarly, in relation to output, it should produce easily transmittable and processible such electrical or optical signals. With respect to the relationship between input and output, a functioning sensor should maintain a stable input-output relationship and a mathematically describable pattern under all application scenarios, which is to say that both consistent static characteristics and dynamic characteristics should be in place.

As the tools used to acquire the desired information, sensors play a decisive role in acquiring correct and accurate information. To achieve this, sensors are often built in three parts: a sensing element, a signal transforming element, and a signal conditioning circuit. Sometimes an auxiliary power source is also required to provide the energy that is needed, as shown in Fig. 6.1.

The sensing element in this system directly senses the measured value (generally non-electrical quantity) and converts it into certain physical quantities using specially designed selective sensing components. It is then converted, via the conversion element, into electrical parameters that include voltage, current, resistance, inductance, or capacitance. At last, a signal conditioning circuit converts

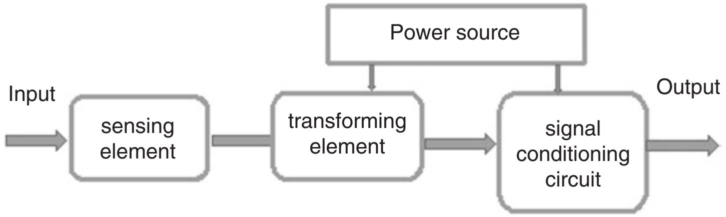

Fig. 6.1 General sensor detection structure

this electrical parameter into a form that can be further transmitted and processed. In a nutshell, sensor is a generic term for a component or device that converts the non-electricity to be measured into a corresponding electrical signal.

Sensors are widely used in the field of automation and artificial intelligence. Similar to the perceptive ability of human being, sensors are the essential elements for acquiring information on the operational scenario in an automated system. To a certain extent, the capability of a sensing unit can greatly influence the capability and/or performance of and automatic control or an artificial intelligence system.

6.3 Farmland Environment Sensors

Various types of sensors can be used in IoT-based farmland environmental parameter monitoring. One parameter often can be measured using different sensors, and similarly sensors working under the same principle can be used to measure different physical parameters. This section will introduce some commonly used sensors for different environmental parameters.

6.3.1 Temperature Sensors

Temperature measurement plays a major role in industrial production and our day-to-day life. In scientific research, environmental protection, and industrial and agricultural production, temperature sensors are mainly used for temperature measurement. As is generally known, temperature sensor refers to a sensor that can sense temperature and convert it into a usable output signal. According to the contact method of the temperature sensor and the measured medium, temperature sensor can be divided into two categories: contact type and non-contact type.

The contact temperature sensor ought to maintain thermal contact with the measured medium, so that the two can conduct sufficient heat exchange to reach the same temperature. This type of sensor mainly includes resistance temperature sensors, PN junction temperature sensors, thermoelectric temperature sensors, etc. The merits of the contact temperature sensor include simple structure, reliable operation, high measurement accuracy, sound stability, and low costs. Its disadvantage is that there is a large hysteresis (due to sufficient heat exchange during temperature measurement), which is inconvenient for movement. Additionally, the temperature field of the measured object is easily affected by the sensor, and the temperature measurement range is determined by the properties of the material used to build the temperature sensing element.

The non-contact temperature sensor, on the other hand, does not have to be in contact with the measured medium: the signal is transmitted to the temperature sensor through the heat radiation or convection of the measured medium. This type of sensor mainly includes infrared temperature sensor, fiber-optic temperature sensor, etc. Non-contact temperature sensors impose no limitation of measurement hysteresis and temperature range. They can be used to measure high temperature; the temperature of corrosive, toxic, and moving objects; and solid and liquid surfaces without affecting the temperature field of the measured object. Notwithstanding the above, non-contact temperature sensors are easily affected by the thermal emissivity of the measured object, their measurement accuracy is low, and the measurement distance and the intermediate medium exert greater impact on results. Many types of temperature sensors are available for application, and many of them fall in the following categories, namely, resistance, infrared, and optical fiber sensors.

6.3.1.1 Electronic Temperature Sensors

Electronic temperature sensors are widely used in many automatic temperature measurement applications and normally fall into two classes: resistive or thermoelectric. Resistive temperature sensors may be either metallic or semiconductor devices, and thermoelectric sensors (i.e., thermocouples) are self-generating transducers; both need having some forms of bridge circuit for signal amplification and conditioning, either built-in the sensor or as an additional signal conditioning device to which the sensor is connected to.

Resistive temperature sensors are probably the most common type in use, with the semiconductor versions being less expensive than the metallic version, and therefore may be more popular in many applications. Resistive-type temperature sensors are also known as the “resistance temperature detector (RTD)”. In general, metallic-type RTDs offer better performance than semiconductor counterparts and may be preferred if high accuracy is required.

Semiconductor type of RTPs are often manufactured as thermistors, made by combining two or more metal oxides, in different shapes of bead, disc, rod, etc. for convenient of using. Thermistors are, in general, very sensitive so they can detect small temperature changes; however, their accuracy is not as good as that of a metallic RTD. Thermistors can be used within the temperature range from −60 °C to +150 °C. The accuracy can be as high as ±0.1%.

Another very commonly used, and probably the most inexpensive, type of resistive temperature sensor is the thermocouples. As a self-generating transducer, it comprises two or more junctions between dissimilar metals, with one junction placed at a known reference temperature and the other junction at the place where the temperature is to be measured. One big advantage of using thermocouples is that their wide temperature can be covered. By selecting different types of thermocouples, it is possible to measure temperatures from −180 °C to +1200 °C. However, their sensitivity is in general not as good as thermistors. Furthermore, the accuracy is heavily dependent on the constancy of the referencing temperature being maintained during the measurement.

6.3.1.2 Infrared Temperature Sensors

In nature, any object with its temperature above absolute zero will constantly emit infrared radiation into the surrounding environment. According to the three major laws of radiation, Kirchhoff's law, Planck's law, and Wien's formula, the amount of infrared radiation energy emitted from an object and its distribution by wavelength are closely related to its surface temperature. Infrared temperature sensor is a sensor designed according to the principle that the radiant energy of an object changes with its temperature. As a long-range and non-contact way of temperature measurement, infrared temperature measurement is particularly suitable for measuring the temperature of high-speed moving objects, charged objects, and high-temperature and high-pressure objects. In addition, this type of sensors does not require thermal equilibrium. It can get the temperature of the object to be measured as long as its infrared radiation can be detected. The reflection time is generally at the millisecond level or even the microsecond level. Furthermore, infrared temperature measurement boasts high sensitivity. Since the radiant energy of an object is proportional to the fourth power of temperature, a small change in the temperature of an object will double the radiant energy, and the infrared sensor can quickly detect it. Its measurement accuracy can reach within 0.1 °C or smaller, and it can measure the temperature range from minus ten degrees Celsius to thousands of degrees Celsius. The temperature range of common infrared radiation thermometers is −30 °C to 3000 °C, and demand-specific specifications can be selected. In addition, the infrared thermometer is also particularly suitable for measuring the temperature of corrosive media and moving objects without destroying the temperature field of the measured object.

6.3.1.3 Optical Fiber Temperature Sensor

Optical fiber temperature sensor, a new type of temperature sensor developed in the mid-1970s, is the product of the rapid development of optical fiber and optical communication technology. This sensor is fundamentally different from electrical-based sensors. Due to the fact that fiber-optic sensors use light as the carrier of sensitive information and optical fibers as media for transmitting sensitive information, these sensors share the characteristics of both optical fiber and optical measurement. Fiber is resistant to corrosion and can be used in water, solutions, and chemical gases. In particular, because fiber is not affected by electromagnetic induction, sparks are not a concern, which is also why it can be measured normally in flammable and explosive environments such as coal mines, oil, and gas storages. Optical fiber temperature sensors have developed rapidly, forming a variety of products, and have been applied to many fields. According to the working principle, the optical fiber temperature sensor can be divided into functional type and transmission types. The functional optical fiber temperature sensor serves as the sensor and the carrier of the optical signal, while the transmission optical fiber temperature sensor only transmits the optical signal. At present, the main optical fiber temperature sensors include distributed optical fiber temperature sensors, fiber grating temperature sensors, and optical fiber fluorescence temperature sensors. Among them, the most widely used is distributed optical fiber temperature sensor. And its measurement distance can reach up to 30 km, the measurement accuracy can reach up to 0.5 °C, the spatial positioning accuracy can reach up to 0.25 m, and the temperature resolution can reach up to about 0.01 °C.

6.3.2 Humidity Sensors

Humidity sensors sense the water vapor content of a gas and convert it into a usable output signal (Farahani et al. 2014). In an agricultural context, because humidity is easily affected by other factors, such as atmospheric pressure and temperature, it is a parameter that is the most difficult to accurately determine. There are a number of traditional methods for measuring humidity, such as thermodynamic methods, coagulation methods, electromagnetic wave methods, moisture absorption methods, and so on. However, such methods fail to meet the development needs of modern technology. In recent years, humidity-sensitive sensors witnessed rapid development, advancing from simple humidity-sensitive elements to integrated, intelligent, and multi-parameter detection.

As the simplest humidity sensor, humidity-sensitive element can be divided into two types: resistance and capacitance. The characteristic of the humidity-sensitive resistor is that the substrate is covered with a film made of a moisture-sensitive material. When water vapor in the air is adsorbed on the moisture-sensitive film, the resistivity and resistance of the element are changed. Though humidity sensors are highly sensitive, they suffer from drawbacks that include poor linearity and poor interchangeability of the product. Humidity-sensitive capacitors are generally made of polymer film capacitors. When the ambient humidity changes, the dielectric constant of the humidity-sensitive capacitor changes accordingly, and so dose its capacitance. Additionally, its capacitance change is proportional to the relative humidity. Humidity-sensitive capacitors boast high sensitivity, sound product interchangeability, fast response speed, small amount of hysteresis, easy manufacturing, and easy miniaturization and integration, yet their accuracy is generally lower than that of humidity-sensitive resistors.

6.3.2.1 Lithium Chloride Resistance Hygrometer

Lithium chloride hygrometers are composed of moisture-sensitive resistors and measuring instruments. Wet-sensitive resistance is an electrode wrapped on an insulated tubular frame, coated with a certain concentration of lithium chloride and polyvinyl alcohol mixture; after drying, a porous wet film is formed. Using the chemical properties of lithium chloride in moisture-sensitive film, which is easy to absorb moisture and release moisture, it can sense the humidity in air. When the partial pressure of water and steam in air is higher than that of water vapor in moisture film, the moisture-sensitive film will absorb water vapor and reduce the resistance value. On the contrary, when the partial pressure of water vapor in air is lower than that of water vapor in moisture-sensitive film, the moisture-sensitive film will release water vapor and make the resistance value rise.

As an ionic electrolyte salt, lithium chloride is highly hygroscopic and dehumidifying. The relative humidity in air is detected through the detection of the change in the resistance value of the moisture-sensitive material containing lithium chloride. The lithium chloride electric humidity sensor based on the principle of resistance-humidity characteristics was first developed by F.W. Dunmore of the American Bureau of Standards (Chen and Yang 1986). This kind of element comes with high precision, simple structure, and low cost.

The measurement range of the lithium chloride element is related to the lithium chloride concentration and other components of the moisture-sensitive layer, and the effective humidity sensing range of a single element is generally within 20% relative humidity (RH). For example, a 0.05% concentration corresponds to a humidity range of about 80–100% RH, a 0.2% concentration corresponds to a range of 60–80% RH, and so on and so forth. It can be seen that when measuring a wide range of humidity, components with different concentrations must be used jointly. The number of hygrometer combinations that can be used for full-scale measurement is generally five, while the measurable range of the lithium chloride hygrometer using the component combination method is usually 15–100% RH.

6.3.2.2 Lithium Chloride Dew Point Hygrometer

The lithium chloride dew point hygrometer was first developed by Foxboro Corporation, a US-based company. This type of hygrometer is similar to the abovementioned lithium chloride resistance hygrometer, yet its working principle is completely different. In a nutshell, this hygrometer functions using the saturated water vapor pressure of a saturated aqueous solution of lithium chloride as a function of temperature. Determine the dew point temperature of the air to be measured by measuring the temperature of the salt solution when the saturated water vapor pressure of the saturated lithium cyanide solution is equal to the water vapor pressure of the measured air. Then calculate the relative humidity of the air according to the dry bulb temperature and dew point temperature of the air.

The measurement range of the lithium chloride dew point humidity sensor can be from −45 °C to +60 °C dew point. When the air dew point temperature does not exceed +60 °C, the probe can be used in temperatures ranging from 100 °C to higher. When measured at 0 °C to +60 °C at room temperature, relative humidity ranges from 12% to 100%.

6.3.2.3 Carbon Humidity Sensor

Moisture-sensitive component is referred to as moisture-sensitive device, which refers to a class of electronic components easily affected by environmental temperature, humidity, and static electricity.

Advantages of the carbon humidity sensor, first proposed by Carver and Breasefield in the United States in 1942, include fast response, sound repeatability, zero erosion effect, and narrow hysteresis loop (Xu 2006). Carbon humidity sensors work by soaking plastic sheets in a mixture of chemicals such as carbon particles, Then dry it as a moisture sensitive film. When the relative humidity in the atmosphere increases, the moisture absorption of the membrane increases causing the volume expansion of membrane. The volume expansion makes the contact probability of the conductive carbon black particles decrease, which leads to the resistance of elements increases; On the contrary, the relative humidity decreases and the moisture sensitive film dehydrates, resulting in the shrinkage of the film volume, which increases the probability of the conductive carbon black particles contacting each other, leading to the reduction of the resistance value of the element.

China's meteorological department started with the development of carbon humidity sensors in the early 1970s and achieved positive results. More specifically, the measurement uncertainty does not exceed ±5% RH, the time constant is 2–3 s at positive temperature, and the hysteresis is generally between about 7%.

6.3.2.4 Alumina Hygrometer

Alumina hygrometers are generally composed of a sensor, a sensing element, an electrical parameter measuring unit, and a display. The aluminum oxide sensor is actually a flat plate capacitor with aluminum substrate and gold film as the poles and porous aluminum oxide layer as the medium by chemical anodic oxidation. The porous alumina tube structure and the gold film which can permeate water molecules lay a good foundation for the moisture measurement. It has been proved that the moisture measurement of alumina moisture sensor is based on physical adsorption. It works by placing components in the gas path being measured. Water molecules will quickly through the whole film, and is adsorbed in the pore wall of alumina. It reaches a dynamic adsorption equilibrium with the water pressure in the space around the electronic component, and then causes changes in the dielectric constant, capacitance and resistance of the component. The changes in these electrical parameters of the component can be used to determine the water content in the gas.

Alumina sensors feature advantages that include small size (such as 90 μm thick and 12 mg weight for humidity sensors used in radiosondes), high sensitivity (lower measurement limit of −110 °C dew point), and fast response speed (typically 0.3–3 s). The measurement signal is directly produced in the form of electrical parameters, significantly simplifying the data processing program. In addition, alumina hygrometers can also be used to measure moisture in liquids. The above characteristics are exactly what certain measurement fields in industry and meteorology require and are the reason why people show great interests for the method. Therefore, alumina hygrometers are considered as one of the applicable sensors for high-altitude atmospheric detection.

6.3.3 Light Sensors

Light sensor is used to measure light intensity, "illumination" for short. The number of lumens (lm) per square meter is referred to as illuminance, which is a unit that reflects the intensity of light. Its physical meaning is the luminous flux that shines onto a unit area.

Photoelectric sensor technology mainly uses the optical effect of the measured object. It collects the optical signal of the measured object and converts the optical signal into electrical signal for signal transmission and analysis. The technology is widely used and has a good prospect in agriculture. Current agricultural greenhouse automation degree is not high and needs a lot of manpower money to monitor and maintain the crops, and the cost is high. With optical fiber transmission and embedded control, the photoelectric sensor can intelligently control the illumination, humidity, and carbon dioxide concentration in the greenhouse, which not only saves the labor cost but also makes the growth of crops in the greenhouse under the optimal environment all the time through scientific methods.

Photoelectric sensor is a sensor that uses a photoelectric element as a detection element and converts luminous flux into electricity. The basis for such sensors is the photoelectric effect of the photoelectric conversion element. The measured change is first converted into a change in the optical signal, and the optical signal is then further converted into an electrical signal by means of a photoelectric element. Photoelectric sensors, generally composed of three parts, light source, optical path, and photoelectric element, are non-contact, and they feature high precision, high resolution, high reliability, and fast response. Thanks to these characteristics, photoelectric sensors are widely used in the field of detection and control (Dutta 2019; Hou and Yao 2020; Jin et al. 2018).

Generally speaking, photoelectric sensors work in four ways: absorption, reflection, shading, and radiation. With respect to the absorption method, the measured object is located between the constant light source and the photoelectric element. The measured parameter is determined by the degree of light absorption of the measured object or the selection of its spectral line, such as the transparency measurement of liquids and gases. In terms of the reflection method, the light emitted by a constant light source is projected onto the measured object, which reflects part of the light flux onto the photoelectric element, and the surface state and property of the measured object are determined according to the reflected light flux. For example, the reflection method can be used to measure the surface roughness, surface defects, and surface displacement of parts (Li 2004). Regarding the light-shielding method, the measured object is located between the constant light source and the photoelectric element. A part of the light flux emitted by the light source is blocked by the measured object, so that the luminous flux acting on the photoelectric element is weakened, and the degree of attenuation is the same as that of the measured object in the optical path that is related to location. This principle can be used to measure length, thickness, linear displacement, angular displacement, vibration, etc. Radiation means that the measured object itself is a radiation source, which can be directly irradiated on the photoelectric element, or it can act on the photoelectric element after a certain optical path. Photoelectric pyrometers, colorimetric pyrometers, infrared detection, and infrared remote sensing all fall into this category. This method can also be used for fire alarms and photometers.

6.3.4 Carbon Dioxide Sensors

Carbon dioxide is one of the raw materials for photosynthesis, which produces 95% of the dry weight of crops. Therefore, the adoption of carbon dioxide sensors for controlling concentration has become an important factor affecting crop yield. Plastic greenhouse cultivation keeps crops in a relatively closed place for a long time. The carbon dioxide concentration in sheds, changing drastically within the period of 1 day, reaches a maximum of 1000–1200 ppm before sunrise and drops to about 100 ppm, approximately equivalent to 30% of the atmospheric concentration, 2.5–3 hours after sunrise. Carbon dioxide concentration did not rise until 2 pm and did not return to atmospheric levels until around 4 pm. The carbon dioxide concentration required for vegetables is generally 1000–1500 ppm; therefore, carbon dioxide deficiency in the plastic greenhouse is quite severe. It is a problem that has become an important factor affecting the yield of vegetables in the plastic greenhouse. Installing a carbon dioxide sensor in a plastic greenhouse can ensure prompt alarm in the event of insufficient carbon dioxide concentration, so that gas fertilizers can be used to ensure the market availability of vegetables, edible fungi, flowers, and so on while ensuring quality and yield.

6.3.4.1 Carbon Dioxide Semiconductor Sensors

Carbon dioxide semiconductor sensors are mainly composed of metal oxide semiconductor materials. At certain temperatures, this type of semiconductor sensing equipment changes, to a certain extent, as the composition of the ambient gas changes. Related parameters of carbon dioxide in the air are then detected by the fluctuation of the resistance current in the sensing core. Based on semiconductor ceramic technology doped with CeO-AgNO3, Xiu et al. (2007) created a functional material that is sensitive to carbon dioxide gas and measured the temperature and humidity characteristics of the device. Kim et al. (2017) also built a semiconductor-type carbon dioxide sensor using cobalt oxide containing barium carbonate.

6.3.4.2 Carbon Dioxide Catalyst Sensor

Carbon dioxide catalyst sensors typically relied on a catalyst coating on the surface of a platinum resistor. At a certain temperature, the flammable gas catalyzes combustion on its surface, the platinum resistance temperature rises, and the resistance changes according to the function of the flammable gas concentration. Carbon dioxide catalytic combustion sensors detect flammable gases on a selective basis: anything flammable can be detected. The sensors do not respond to anything that are not flammable, which is why this kind of sensor is mostly used in metal smelting industry.

6.3.4.3 Carbon Dioxide Thermal Conductivity Sensors

Thermal conductivity sensor is a kind of thermal effect sensor. In the test process, no chemical reaction occurs with the gas to be measured, which avoids the material change caused by chemical reaction. Therefore, its output is stable and its drift is small.

The principle of a carbon dioxide thermal conductivity cell sensor is to make use of the unique thermal conductivity of each carbon dioxide gas. When the thermal conductivity of two or more gases significantly differs, the thermal conductivity element is used to distinguish the content of one of the components. Though widely used for the detection of hydrogen, carbon dioxide, and high-concentration methane, such sensors are limited by their narrow scope of application and many other factors. Additionally, carbon dioxide thermal conductivity cell sensors are old-fashioned products with manufacturers all over the world. In order to overcome the shortcomings of traditional thermal conductivity gas sensors, Febrina et al. (2019) developed a simple CO_2 sensor based on the thermal conductivity, which consists of a modified IR thermopile sensor without an IR window. The thermopile can simultaneously serve as a heater and temperature sensor and was used for measuring the CO_2 concentration.

6.3.4.4 Carbon Dioxide Electrochemical Sensors

Carbon dioxide electrochemical sensor is a kind of chemical sensor that converts the concentration (or partial pressure) of carbon dioxide into electrical signals through electrochemical reaction. It can realize continuous on-site monitoring and has the advantages of low price, compact structure and easy to carry, etc. It mainly includes potential type, current type, and electric quantity type.

A large number of the flammable, toxic, and harmful gases are electrochemically active, and the relevant parameters of carbon dioxide in the atmosphere can be distinguished by electrochemical oxidation or reduction, that is, by using these reactions of carbon dioxide gas and sensor sensing components. Such sensors usually have many functions, and sometimes they can be used to distinguish some gases other than carbon dioxide (Rowiński and Bilewicz 2001).

6.3.4.5 Carbon Dioxide Infrared Sensors

Carbon dioxide infrared sensors use the special characteristics of carbon dioxide in the infrared to detect the absorption of carbon dioxide by infrared to determine the concentration of a given gas (Zhang 2002). This kind of sensors used to be large analytical instruments, but in recent years, due to the development of the sensor industry based on MEMS technology, the volume of this sensor has been reduced from 10 L to about 2 ml (thumb size). The use of an infrared detector without a modulated light source makes the instrument completely free of mechanical moving parts and hence maintenance-free. Zhang (2002) proposed a new spatial dual-beam measurement structure and established a mathematical model of the sensor based on the RBF neural network. They designed a dynamic compensation filter and successfully developed a new type of high-performance infrared carbon dioxide sensor. Wang et al. (2016) proposed a carbon dioxide sensor based on mid-infrared absorption spectrum for greenhouse agriculture and deployed a sensor network. Zhang et al. (2010) developed a miniature sensor for measuring the concentration of carbon dioxide gas. In Zhang's research, a new type of space dual-beam optical detector was designed. The detector consisted of an infrared light source, an air chamber, an infrared receiving device, and two windows. The experiments demonstrate that the infrared sensor markedly improved the signal-to-noise ratio of the sensor (Zhang et al. 2010).

Taking as an example the application of carbon dioxide sensors in the production and cultivation of edible fungi, the following section seeks to provide the reader with a clear understanding of the important role played by carbon dioxide sensors in production. China's edible fungus production currently accounts for 65% of the world's total output, ranking first globally. However, the production of edible fungi in China is scattered among thousands of households. The small scale, poor conditions, and lack of technology have hindered further growth of the edible fungus industry. Control of production process is based on experience only, and monitoring facilities are extremely scarce, making the quality and safety of edible fungus products a major issue. In the production of edible fungi, air temperature, humidity, illuminance, and carbon dioxide and oxygen concentrations are the key factors that influence growth. Operation based on the individual experience of farmers alone will result in poor quality and low yield of edible fungi. Therefore, monitoring carbon dioxide, oxygen, temperature, and humidity in the context of edible fungus is essential for standardized management of edible fungus production. In this respect, using carbon dioxide sensors and oxygen sensors to monitor the environment is required. All edible fungi are aerobic fungi, and the oxygen supply and carbon dioxide concentration in the ambient air exert major influence on the growth of edible fungi. Generally, the aerobicity of mycelial growth is low, and a slightly higher concentration of carbon dioxide is conducive to primordium differentiation; however, in the growth stage of fruiting bodies, a large amount of oxygen supply is needed. The carbon dioxide concentration should be controlled below 0.1%, and if the concentration of carbon dioxide is excessive, the stem cap would be small, and the cap would even be undifferentiated and deformed. Therefore, carbon dioxide sensors can be used to accurately reflect the concentration of carbon dioxide in the environment, which is convenient for timely adjustment. Carbon dioxide-sensitive fungi include black fungus, *Ganoderma lucidum*, *Agaricus bisporus*, and mushrooms, while *Flammulina velutipes* and *Pleurotus ostreatus* are more resistant to carbon dioxide. In particular, when the carbon dioxide concentration is 0.06–0.49%, as the carbon dioxide concentration increases, the diameter of the lid decreases. Moreover, under such circumstances, the opening of the lid is suppressed, the extension of the mushroom stem is promoted, and the commercial value of the mushroom is improved.

6.4 Farmland Microclimate Sensors

As an important factor of affecting crop growth and yield, farmland microclimate refers to the small-scale climatic conditions formed within a particular land. It is generally expressed using wind, rainfalls, evaporations from soil and crop, and radiation. It is often an important piece of information for precision management of crop production, including predicting and preventing pests and diseases and preventing weather/climate-related crop damages or even disasters.

The physical basis for the formation of microclimates in farmland mainly consists of active surfaces and layers. The moving surface is the surface of the object with the most apparent heat and moisture exchange. A major role is played by the transport of material and the conversion of energy among farmland soil, plants, and the various components of the atmosphere in the formation of microclimates. In addition, the active surface is not the only layer that facilitate the basic physical functions of microclimate formation; layers with a certain thickness also contribute to this process. Such layers are referred to as the active layer or contributing layer.

The basic characteristics of farmland microclimates include the distribution of light, temperature, humidity, wind, and carbon dioxide in farmland. When solar radiation reaches the upper surface of farmland vegetation, part of it is reflected by the foliage, part of it is absorbed by the foliage, and part of it passes through the plant gap or penetrates through the foliage to the lower layers of ground. Different crops or the same crop at different growth periods differs in terms of their ability to reflect, absorb, and transmit solar radiation. The vertical distributions of total radiation intensity, direct radiation intensity, and scattering intensity in farmland are similar, all of which decrease progressively from the top of the plant. At the beginning, the speed of decrease is relatively slow, it then weakens rapidly in the middle layer, and then it resumes the same slow speed. Therefore, over-planted farmland is not conducive to light transmission in the lower layer, and cultivating appropriate plant types holds the key to the effective use of solar energy. The temperature distribution in the farmland hinges on the farmland radiation difference and farmland turbulence. The temperature distribution differs according to different crops, different growth periods, and cultivation measures; and the humidity distribution and change in farmland are determined by changes in temperature, farmland evaporation, and turbulent water vapor exchange intensity. The air turbulence in the daytime causes water vapor to evaporate upward, and at night the water vapor flows to the crop layer and condenses into dew or frost. Regarding the distribution of wind, judging from the horizontal distribution of wind speed, the wind speed continuously decreases from the side of the farmland to the middle of the farmland. The decrease is fast at the beginning, and it then slows down and stabilizes after reaching a certain distance. Seen from the vertical direction, wind speed is significantly weakened in the dense part of the leaves in the crop layer; at the place where the top and lower stems and leaves are scarce, the wind speed is high; and in the lower part of the crop layer farther from the side, it is low.

Due to effects of the adoption of different agricultural practices, different crops, and dynamic changes of crop groups in places of production that include farmland, greenhouses, and pastures, the conditions and various physical characteristics of the active surface of the farmland are constantly changing, resulting in changes of local radiation balance and heat balance, which in turn form various types of farmland microclimate characteristics. After the formation of a certain farmland microclimate, the environmental conditions for crop growth will directly affect the growth, development process, and yield of crops. The significance of studying farmland microclimate is to analyze the distribution and changing characteristics of farmland microclimate elements and to look for measures to improve crop growth environmental conditions (i.e., farmland microclimate conditions), so that these microclimate conditions would be conducive to crop growth and development and improve crops' yield and quality. At present, with the rapid development of sensor technology, various sensors, targeting different characteristics of farmland microclimate, have been developed for the continuous monitoring of environmental parameters closely related to vegetation and crop growth.

6.4.1 Wind Sensors

The wind, a natural phenomenon caused by the movement of air, is a product of solar radiation heat. From meteorology perspective, the wind often refers to the horizontal motion components of the air, including direction and magnitude, i.e., wind direction and wind speed; and it is also one of the environmental factors of production. As such, the measurement of wind speed and direction plays a major role in monitoring farmland microclimate. Sensors for wind speed and direction measurement are already available on the market.

6.4.1.1 Wind Speed Sensors

Wind speed sensor is a common sensor that can be used to continuously measure wind speed and wind volume (air volume = wind speed × cross-sectional area). Wind speed sensors are roughly divided into mechanical (mainly propeller type, wind cup type) wind speed sensors, hot wind specific speed sensor, and ultrasonic wind speed sensor based on acoustic principles.

Propeller Wind Speed Sensor

As shown in Fig. 6.2, the electric fan, driven by a motor to rotate the fan blades, creates a pressure difference between the front and rear of the blades to promote airflow. The working principle of the propeller anemometer is exactly the opposite of this. Aligned with the airflow is affected by wind pressure, the blade system generates a certain torsional moment, causing the blade system to rotate. Generally, a propeller-type speed sensor measures wind speed by rotating a set of three- or four-blade propellers around a horizontal axis. The propeller, whose speed is proportional to the wind speed, is usually installed at the front of a weather vane so that its rotation plane always faces the direction of the wind.

Fig. 6.2 Propeller wind speed sensor

Fig. 6.3 Wind cup-type wind speed sensor

Fig. 6.4 Thermal wind speed sensor

Wind Cup-Type Wind Speed Sensor

Wind cup-type wind speed sensor, a commonly used wind speed sensor, was first invented by Rubin Sun of the United Kingdom. As shown in Fig. 6.3, the sensing part consists of three or four conical or hemispherical empty cups, while the hollow cup shell is fixed on a three-pointed star bracket at a 120° angle or a cross-shaped bracket at a 90° angle. The concave surfaces of the cup are aligned in one direction, and the entire cross arm is fixed on a vertical rotation axis. When the wind cup rotates, the coaxial multi-tooth disc or magnetic rod is driven to rotate, and a pulse signal proportional to the speed of the wind cup is acquired through the circuit. The pulse signal is counted by a counter, and the actual wind speed value can be obtained after conversion. At present, the new rotating cup anemometer uses three cups, and the conical cup outperforms the hemisphere. When the wind speed increases, the rotating cup can quickly accelerate to adapt to the airflow speed. When the wind speed decreases, due to the influence of inertia, the speed drops likewise; however, the speed may not drop immediately. The wind speed indicated by the rotary anemometer in the gust wind is generally high, a phenomenon referred to as the excessive effect (the average error produced is about 10%).

Thermal Wind Speed Sensor

As shown in Fig. 6.4, thermal wind speed sensor adopts hot wire (tungsten wire or platinum wire) or hot film (film made of platinum or chromium) as probe. The sensor is exposed in the measured air and is connected to the Wheatstone bridge. By measuring the balance relationship of its resistance or current, the air flow rate of the measured section can be detected. Coated with an extremely thin quartz film insulation layer to insulate the fluid and prevent pollution, the thermal film of the thermal film-type wind speed sensor can work in air flow with particles, and its strength is higher than that of metal hot wire. The resistance, varying with temperature, and the temperature of the hot wire are in a normal temperature range (0–300 °C). The two illustrate a linear relationship. The heat dissipation coefficient is related to the airflow speed: the higher the flow velocity, the larger the corresponding heat dissipation coefficient, which means fast heat dissipation; and the slower the flow velocity, the slower the heat dissipation.

Hot wire wind speed sensor is equipped with two design circuits, constant current and constant temperature, the latter of which are more commonly used. The principle of the constant temperature method is to keep constant the temperature of the hot wire during the measurement process to balance the electric bridge. At this time, the resistance of the hot wire remains unchanged, and air velocity is only a single value function of the current. According to the relationship between the known air velocity and the current, velocity of the airflow at the end of the devise can be determined. The constant current hot wire wind speed sensor keeps the current value flowing through the hot wire from any changes during the measurement. When the current value is constant, the airflow speed is only related to the resistance of the hot wire. According to the known relationship between the airflow speed and the resistance of the hot wire, velocity of the airflow that travels through the wind speed sensor can be obtained. Additionally, pulsating wind speed is measured by the hot wire wind speed sensor. The constant-type wind speed sensor has a large thermal inertia, and the constant temperature-type wind speed sensor has a relatively small thermal inertia as well as a high-speed response. The measurement accuracy of the hot wire wind speed sensor is not high; thus, users should pay attention to temperature compensation when using the device.

Ultrasonic Wind Speed Sensor

The working principle of the ultrasonic wind speed sensor is to measure the wind speed using the ultrasonic time difference method. Due to the speed of sound in the air, it will be superimposed on the velocity of the wind. If the ultrasonic wave travels in the same direction as the wind, then its speed will increase; conversely, if the ultrasonic wave travels in the opposite direction to the wind, its speed will become slower. Therefore, under fixed conditions, the speed of ultrasonic wave propagation in the air corresponds to the wind speed function. One can acquire accurate wind speed and direction through calculation. As sound waves travel through the air, its speed is subject to temperature. The wind speed sensor detects two opposite directions on two channels, thus making the effect of temperature on the speed of sound waves negligible.

Fig. 6.5 Ultrasonic wind speed sensor

The ultrasonic wind speed sensor features light weight, zero moving parts, and ruggedness. Plus, the device does not require maintenance and on-site calibration, and it can produce wind speed and direction simultaneously. Customers can choose the wind speed unit, output frequency, and output format according to their own needs. One can also choose a heating device (recommended for use in cold environments) or analog output according to the specific needs. The sensor can be used together with computers, data collectors, or other acquisition equipment with RS485 or analog output. If necessary, multiple units can also be used in a network. Ultrasonic wind speed and wind direction instrument is a relatively advanced instrument for measuring wind speed and direction, and because the instrument overcomes the inherent shortcomings of the mechanical wind speed and direction indicator, it can work normally all day and for a long period and is used increasingly widely. The instrument can be a powerful alternative to mechanical anemometers (Fig. 6.5).

6.4.1.2 Wind Direction Sensor

The wind direction sensor is a physical device that detects the external wind direction information through the rotation of the wind direction arrow. The information is then transmitted to the coaxial code disc; at the same time, the corresponding value of the wind direction is produced. It is generally the case that the main body of the wind direction sensor adopts the mechanical structure of the wind vane. When the wind blows toward the tail fin of the wind vane, the arrow of the wind vane will point in the direction of the wind. In order to remain sensitive to direction, different internal mechanisms are also used to distinguish the direction for the wind speed sensor (Fig. 6.6).

Electromagnetic Wind Direction Sensor

Although the design of this device is based on the electromagnetic principle, its structure differs due to the adoption of many types of principles. At present, some of these sensors started to use gyro chips or electronic compasses as basic components, and the accuracy of measurement has been further improved.

Fig. 6.6 Wind direction sensor

Photoelectric Wind Direction Sensor

This wind direction sensor, adopting absolute Gray code disc as the basic element, uses a special customized coding. Based on the principle of photoelectric signal conversion, it produces accurate information of the corresponding wind direction.

Resistive Wind Direction Sensor

The structure used is similar to sliding rheostat, and the maximum and minimum resistance values are marked as 360° and 0°, respectively. When the wind vane rotates, the slider of the sliding rheostat will follow the wind vane on the top Rotate, and different voltage changes can be counted on for the calculation of the angle or direction of the wind direction.

In agricultural production, moderate wind speed holds the key to improving farmland conditions. Near-surface heat exchange, farmland evapotranspiration, and transportation of carbon dioxide and oxygen in the air are accelerated or strengthened in line with the increase of wind speed. In addition, wind can spread plant pollen and seeds to facilitate plant pollination and reproduction. However, wind also exerts negative effects on agriculture. For instance, wind spreads pathogens and plant diseases. Strong levels of wind cause mechanical abrasion of leaves, crop lodging, broken trees, flowers and fruits, reduced yield, wind erosion, sand dune movement, and farmland destruction. Blind reclamation in arid areas would lead to desertification. Moreover, strong winds and blizzards in pastoral areas can blow away herds and aggravate freezing damage. Some special characteristics of local winds often lead to wind-related damage. The tidal wind with high salinity from the sea and the high-temperature and low-temperature foehn wind and dry hot wind all pose critical threats to the flowering of fruit trees, fruit filling, and grain filling of cereal crops. Normal wind, on the other hand, is beneficial to agricultural production; thus, it is of great benefit to measure wind speed and direction. Timely monitoring of agricultural meteorology and the environment is therefore needed. One can use wind speed sensor for the monitoring of the wind speed and volume in real time and connect it with the data acquisition control module to acquire relevant data, which would be transmitted to the meteorological data analysis software through the wireless module for analysis and display, thus facilitating safe production.

6.4.2 Rainfall Sensors

Figure 6.7 is an illustration of a rainfall sensor, which is mainly composed of a water receiver, a filter funnel, a dump bucket, a reed switch, a base, and a special measuring cup. As a physical quantity that measures the magnitude of rainfall, precipitation measurement also represents a major element in meteorological observations, providing accurate and reliable data for weather forecasting, hydrology, scientific research, agriculture, forestry production, disaster prevention, and disaster reduction. After years of improvement and application, rainfall sensors have become increasingly advanced and accurate. Rainfall sensors that have been put into practical use include siphon, tipping, water-conducting and double valve capacity grid, etc. Among these, the first two types of sensors are the most widely used ones in China (Jiang et al. 2019). Thanks to continuous research and optimization, the tipping bucket rain sensor has become more and more advanced. This kind of rain sensor features small size, high sensitivity, intelligence, sound stability, and easy maintenance. Rainfall sensors can be adopted in such departments as meteorological stations, hydrological stations, agriculture and forestry, national defense, field observation and reporting stations, and so on, so that raw data can be provided for flood prevention, water supply dispatching, and water management in power stations and reservoirs.

Figure 6.8 illustrates a dump bucket rain sensor, which is mainly composed of a rain receiving bucket, a metering bucket, a counting bucket, a throttle tube, a pulse generating circuit, a base, a magnetic steel, a reed pipe, and a casing. The tipping bucket rainfall sensor is used in meteorological stations, hydrological stations, agriculture, forestry, national defense, and other related departments for the measurement of liquid precipitation, precipitation intensity, and time of precipitation.

Fig. 6.7 Rainfall sensor

Fig. 6.8 The dump bucket rain sensor

Meanwhile, it can also be used to provide raw data for flood control, water supply dispatching, and water management of power stations and reservoirs.

The rainwater, collected by the water inlet of the bucket rainfall sensor, passes through the upper cylinder filter screen and is then injected into the metering bucket (Jiang et al. 2019). Injection-molded with engineering plastic, the bucket is divided into two equal-volume triangular buckets with an intermediate partition. Such a structure is mechanically bi-stable – one bucket receives water, while the other bucket waits. When the volume of rainwater received reaches a predetermined value, it falls over due to gravity and starts to wait, and the other bucket chamber starts to function. When the predetermined value is again reached, it too overturns and starts to wait. A magnetic steel, installed on the side wall of the dump bucket, scans from the side of the dry reed pipe as the bucket turns, so as to turn the dry reed pipe either on or off, which is to say that each time the tipping bucket is turned over, the dry reed switch is turned on and a switch signal is sent out. In this way, the number of times the tipping bucket is turned on and off is recorded by the pulse signal sent out by dry reed pipe, which is scanned via the magnetic steel. Each pulse signal recorded represents a certain amount of precipitation, thus achieving the purpose of remote precipitation detection. Refer to Fig. 6.9 for the structural schematic diagram of dump bucket rain sensor.

6.4.3 Evaporation Sensors

The purpose of water surface evaporation observation is to explore the distribution law of water surface evaporation in different regions and at different time points, so that the basis for hydrological calculation and scientific research can be provided.

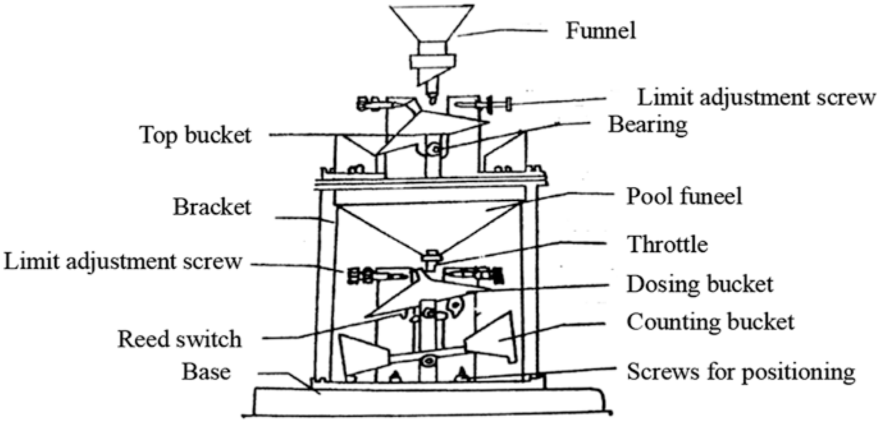

Fig. 6.9 Schematic diagram of dump bucket rain sensor

As information technology matures, the manual observation evaporators are replaced by digital and ultrasonic water surface evaporators, which can achieve automatic overflow, automatic water replenishment, automatic rainfall deduction, and automatic error correction, making the evaporation data more accurate, objective, and real-time.

6.4.3.1 Digital Evaporation Sensors

FFZ-01 digital water surface evaporation sensor, an instrument used to observe the change of water surface evaporation at different time periods, is manufactured in accordance with the requirements of the Ministry of Water Resources and Electric Power Standard *Water Surface Evaporation Observation Code* SD265-88, as shown in Fig. 6.10. The instrument can be directly applied, together with a Φ618mm evaporation bucket or with a 20 m^2 standard evaporation pond, to monitor the evaporation of water. Additionally, the instrument can be combined with evaporation data recorder to form a digital recording evaporator, which can automatically record the evaporation process. It can also be matched with JFZ-01 digital rain gauge and digital flow meter of overflow to form a fully automatic evaporation rain measurement station that is equipped with a basic evaporation network for automatic observation, recording, and remote transmission of evaporation and rainfall processes. The measurement accuracy and stability of the instrument are far superior to ultrasonic and other types of surface evaporation sensors. Moreover, it allows real-time remote transmission and is applicable to evaporation stations and weather stations across regions and types. Its primary features include:

- Free from drifts of temperature and time and stable over the long term.
- High resolution and high accuracy.

Fig. 6.10 The digital evaporation sensor

- Able to be observed normally under wind, wave, and rainfall climate conditions without loss of accuracy.
- Anti-electromagnetic interference – the data produced would remain correct even if the power is turned off and then on again.
- Able to be used in combination with evaporation bucket, hydrosphere, automatic water adding device, and recording device for the automatic monitoring of evaporation process.

Its scope of application is as follows:

- Real-time detection of evaporation data. Taking Yuan'an Station as an example, the computer transmits data from time to time every day, so that the automatic evaporation data is stored in the computer's local database. The evaporation transmission serial port is connected to the computer serial port via a converter, which allows the use of automatic evaporation monitoring software for low-level real-time information monitoring. The software displays the evaporation data of the day, the previous day, and the day before that, as well as the day's evaporation situation, evaporation water level, overflow water level, and other information.
- Evaporation data storage management. Click Evaporation Data Management in the abovementioned software, and the evaporation data is then automatically stored in the database set by the machine. The function of data management is to analyze and process the evaporation data and generate various reports as required.

6.4.3.2 Ultrasonic Evaporation Sensors

The ultrasonic evaporation sensor, adopting a top-loading structure, reduces the number of connection bolts of the valve body under conditions of high pressure and large diameter, thus enhancing the reliability of the valve and eliminating the influence of the system's own weight on the normal operation of the valve. In order to achieve automatic observation of evaporation, the meteorological department began to adopt the AG1.0 evaporation sensor based on E601B evaporator at the reference climate station from January 2003. Apart from their relative accuracy and stability, the sensors have also demonstrated low failure rate since they were put into operation. However, they are prone to wild values under severe weather conditions, such as strong wind and rain. In order to minimize the environmental impact on the measurement results, Zhonghuan Tianyi (Tianjin) Meteorological Instrument Co., Ltd. has developed the AG2.0 evaporation sensor, which modifies the installation method of the original AG1.0 sensor and improves the measurement accuracy by optimizing the application environment. The AG1.0 and AG2.0 ultrasonic evaporation sensors, operating at a frequency of 40 kHz, consist of an ultrasonic generator and a stainless steel cylinder. Including a transmitting probe and a receiving probe, the ultrasonic generator generates ultrasonic waves and automatically receives echoes. The transmitting probe converts high-frequency electrical vibration into high-frequency mechanical vibration to generate ultrasonic waves, while the receiving probe converts ultrasonic vibration waves into electrical signals. The signal detection system calculates the distance between the emission point and the water surface by measuring the time interval between the ultrasonic emission and the reflection after the water surface reflection. To determine the amount of evaporation, a relative quantity, during a given period, data on the water surface height only need to be acquired twice within that time for arithmetic calculations.

With respect to the application of ultrasonic evaporation sensor, the measurement accuracy of the sensor is subject to the measurement environment. When using the AG1.0 evaporation sensor directly above the E601B evaporator, the water surface humidity and air temperature significantly fluctuate, thus reducing the measurement accuracy. At the same time, the casing of the ultrasonic generator is easily deformed owing to long-term exposure to sunlight, resulting in zero offset. Under this installation method, the water surface is prone to fluctuations, and abnormal values tend to occur under severe weather conditions. AG2.0 ultrasonic evaporation sensor changes the original installation method (Wang et al. 2019). As shown in

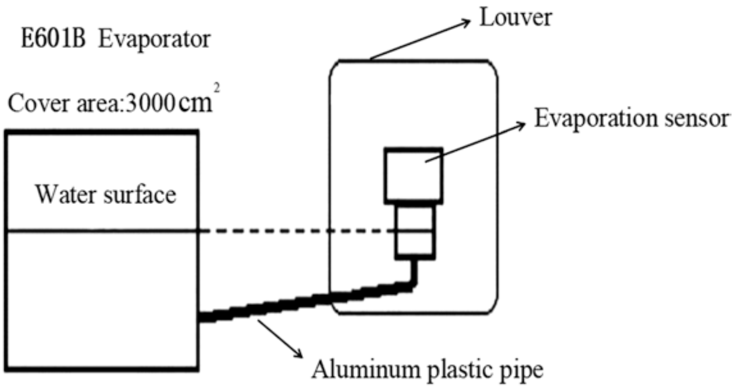

Fig. 6.11 Schematic diagram of AG2.0 ultrasonic evaporation sensor installation

Fig. 6.11, the ultrasonic evaporation sensor is installed outside the E601B evaporator and fixed in the louver. This reduces the influence of temperature and humidity on the accuracy of the measurement and also avoids abnormal values of liquid-level fluctuations under severe weather conditions. The evaporation sensor is connected to the evaporator through an aluminum-plastic tube. Under the effect of pressure balance, the height of the stainless steel cylinder of the evaporation sensor is the same as the water level of the evaporator.

6.4.4 Irradiation (Radiation) Sensors

Radiation sensors are divided into infrared sensors and nuclear radiation sensors. Nuclear radiation sensors are based on the absorption, backscattering of the measured substance, or the ionization excitation effect of the measured substance; hence, they are also referred to as radioisotope sensors. As a kind of sensor that uses infrared to process data, infrared sensors boast high sensitivity and can be used to control the operation of the driving device.

6.4.4.1 Infrared Sensor

Adopting the physical properties of infrared for measurement, infrared sensors share the same properties with visible light in terms of reflection, refraction, interference diffraction, and absorption. In the field of engineering, the areas occupied by infrared spectrum are divided into four regions: near-infrared region, mid-infrared region, far-infrared region, and extreme far-infrared region. Research in this regard found that the thermal effect of various monochromatic light in the solar spectrum gradually increases from purple to red and the maximum thermal effect should appear in the frequency range of infrared radiation.

Infrared sensors tap into the generation of infrared radiation by objects for automatic detection and include three parts: optical system, detection element, and conversion circuit. When infrared sensors are used for measurement, fast measurement speed and high sensitivity can be achieved. Additionally, infrared sensors engage in measurement without directly contacting the measured object. Infrared sensors can be divided into five categories depending on functions (Bai 2017), including:

- Radiometers for radiation and spectrum measurement
- A search and tracking system for exploring and tracking infrared targets that determines their spatial location and tracks their movements
- A thermal imaging system that produces an image of the entire target's infrared radiation distribution
- Infrared ranging and communication system
- Thermal imaging system with two or more combinations of various systems
- The application scope of infrared sensors:

- Night vision technology. The camera is equipped with an infrared sensor to achieve night vision, i.e., under night vision, the digital video camera will emit infrared light, invisible to the naked eye, to illuminate the object being shot. Turn off the infrared filter; and the infrared rays would no longer be blocked from entering the CCD and would be reflected by the object and enter the lens for imaging.
- Infrared detector. The core of the infrared system is an infrared detector, which can be divided into two categories according to the detection mechanism: thermal detectors and photon detectors.
- Non-destructive infrared. Non-destructive infrared flaw detectors can be used to inspect the internal defects of the component and any damage to the component structure.
- Infrared gas analyzer – using infrared gas for gas analysis. A signal of electrical detector is generated based on the different concentrations of the component, the different absorbed radiant energies, the different rises of temperature in the detector for the remaining radiant energy, and the different pressures borne by the two sides of the east thin membrane. In this way, the concentration of the component to be analyzed can be measured indirectly.

6.4.4.2 Nuclear Radiation Sensors

Nuclear radiation sensors include a radiation source, a detector, and a signal conversion circuit. The radiation source is generally disc-shaped (β-radiation source) or filament-shaped, cylindrical, or disc-shaped (γ-radiation source). For example, TI204 is plated on a copper sheet, covered with a mica sheet, then packed in an aluminum or stainless steel case, and finally sealed with epoxy resin, which becomes a radiation source. Detectors, also called receivers, are devices that detect the presence and strength of rays through the interaction of rays and matter. The functioning of detectors are generally based on the emission of certain substances under the influence of nuclear radiation or the effect of gas ionization. Commonly used detectors include current ionization chamber, Geiger counting tube, and scintillation counting tube. In terms of the working principle of nuclear radiation sensors, the functioning of these sensors is based on the absorption, backscattering of the measured substance, or the ionization excitation of the measured substance by the radiation. Nuclear radiation measurement is mainly used in tomography (industrial CT, medical CT), non-destructive testing, pre-furnace analysis, on-site element analysis, online monitoring, environmental monitoring, flaw detection, and so on. Zero radioisotopes emit particles (rays) with a certain energy during the decay process, including alpha particles, beta particles, gamma rays, and neutron rays. Using alpha particles to ionize a gas is much stronger than using other radiation, which is why alpha particles are frequently used for gas composition analysis to measure the pressure, flow, or other parameters of a gas. Beta particles have a range of up to 20 meters in the gas. According to the material's absorption of beta radiation, the thickness and density of the material can be measured; the thickness of the cover layer can be judged by looking at the reflection of the beta radiation; and the gas flow rate can be determined using ionizing capacity of the beta particles. As a kind of electromagnetic radiation, γ-ray has a strong penetrating capability in matter and a range of hundreds of meters in gas. It is noteworthy that γ-ray can penetrate tens of centimeters into solid matter. This is the reason why γ-ray is widely used in metal inspection and thickness measurement, as well as the measurement of flow rate, level, and density. Neutron rays are often used to measure humidity, level, or composition of hydrogen-containing media. The scope of application of nuclear radiation sensors is as follows:

- Detection of parameters that include thickness, liquid level, material level, speed, material density, weight, gas pressure, flow rate, temperature, and humidity.
- Flaw detection of metal materials.
- Extensive application in pharmaceutical factories, laboratories, power plants, quarries, emergency rescue stations, metal processing plants, underground oil fields and oil pipeline equipment, environmental protection, and other departments. In the abovementioned scenarios, nuclear radiation sensors are used to check local radiation leakage and nuclear radiation pollution, the radon radiation cesium pollution of the surrounding environment, the cobalt 60 radiation pollution, the radioactivity of building materials such as stone, and the landfills and dumps where there is a danger of nuclear radiation. They are also adopted to test X-ray instruments for medical and industrial X-ray radiation intensity, radium pollution of groundwater, radioactivity monitoring of underground drill pipes and equipment used to measure air and water pollution around nuclear reactors, harmful radiation of personal valuables and jewelry, and radioactivity of porcelain tableware glass.

In order to make comprehensive agricultural bases more information-based and more intelligent, and to improve farming productivity and efficiency, a team designed the software and hardware structure of the front-end information collection system and back-end intelligent control system for agricultural IoT and developed the IoT information collection equipment and smart controlling equipment. The front-end information collection is combined with sensor nodes, wireless transmission network, and sensor configuration for information collection, while the back-end intelligent control system is combined with expert-linked systems, agricultural intelligent variable frequency irrigation systems, automatic greenhouse control systems, and so on to achieve smart control. The systems and instruments that were developed have yielded sound results in practical application and brought economic and ecological benefits and are key to the intelligent and information-based development of modern agriculture (Fig. 6.12).

Fig. 6.12 Effect of intelligent greenhouse control system

6.5 Summary

In this chapter, sensors of farmland conditions were introduced to analyze their working principle and application method in detail. The temperature and humidity of the soil and the composition of fertilizers ought to adapt to the needs of crop growth, and in order to facilitate such adjustments, sensors are needed for the detection and data processing of temperature, humidity, light intensity, carbon dioxide concentration, and other parameters in the environment. Thanks to these sensors with different functions, the efficient acquisition of farmland environmental information is made possible in agricultural IoT, thus facilitating the full use of farmland information in promoting agricultural development.

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