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Review

Environmental Factor Detection and Analysis Technologies in Livestock and Poultry Houses: A Review

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Abstract: The environment in livestock and poultry houses plays an important role in the growth and reproduction of livestock and poultry. In order to obtain the environmental conditions of livestock and poultry houses in a timely and reliable manner, and eliminate adverse environmental factors, scholars have been exploring various methods to obtain and predict environmental factors. This paper reviewed the literature from the last 10 years, specifically focusing on technologies for detecting environmental factors in livestock and poultry houses, which can be mainly divided into three categories: research on the environmental monitoring and control of livestock and poultry houses based on detection equipment and wireless sensor technology; research on the distribution and regularity of environmental factors in livestock and poultry houses based on a mathematical model; research on the environmental simulation and detection of livestock and poultry houses based on computer technology. The current testing methods have their advantages and disadvantages. When studying environmental factors, researchers should choose the most appropriate method for data acquisition according to the actual situation. The proposed recommendations for achieving this goal are as follows: (1) The control of environmental factors should be combined with the physiological response of livestock and poultry. The needs of animals should be considered; (2) Novel approaches need to be developed to integrate energy requirements into the environmental regulation of livestock and poultry houses; (3) It is necessary to research and develop control models and strategies that can predict the environment in the houses, and the transient simulation method should be further explored; (4) Improve environmental detection and control accuracy through the coupling of different technologies.

Keywords: animal husbandry; environmental control; detection and analysis technologies; mathematical model; CFD; machine learning

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1. Introduction

A suitable environment of livestock and poultry houses is an essential requirement for the healthy growth of livestock and poultry. In recent years, with the development of intelligent agriculture, the number of large-scale breeding farms is gradually increasing, and the number of breeding personnel is gradually decreasing. Animal husbandry is developing towards intelligent, industrialized, and large-scale efficiency worldwide [1–3]. The No. 1 central document of China in 2023 also emphasized the significance of strengthening the support of agricultural technology and equipment, and promoting the transformation and upgrading of large-scale livestock and poultry farms. This puts forward new requirements for the efficient, real-time, and accurate detection and analysis of environmental factors in livestock and poultry houses.

The livestock and poultry house environment can be categorized into the thermal environment, gas environment, light environment, and water environment [4]. Among them, due to the complexity of the thermal environment and gas environment, it is difficult to predict and directly regulate. Therefore, it is necessary to conduct an effective detection of environmental factors. The thermal environment includes thermal environmental factors related to "temperature—humidity—wind". The concentration of harmful gases such as CO_2, NH_3, H_2S, microorganisms, and particulate matter (PM) is mainly concerned in the gas environment. The thermal environment is the main environmental factor affecting the physiology and growth of livestock and poultry. Too high or too low a temperature, humidity, or wind speed will cause physiological problems for livestock and poultry and have a negative impact on their health and growth [5–8]. CO_2, NH_3, H_2S, other harmful gases, and PM are emitted and produced by manure volatilization during livestock and poultry breeding [9–11]. Once the concentration exceeds hazardous levels, it will have adverse effects on the growth and production of livestock and poultry, and even lead to their death [12–14], endangering the health of breeders [15–17]. In addition, different types and growth stages of livestock and poultry have different requirements for environmental control, and the accuracy requirements for detection and analysis technologies are also different.

The livestock and poultry house environment is critical for health, productivity (e.g., feed efficiency and weight gain), and welfare [7]. In order to adjust the suitable environment of livestock and poultry houses, the distribution of environmental factors should be accurately obtained. Therefore, the detection and control of the environment have always been the major goals of discipline development and research. The research method of environmental factors can help breeders to learn the environmental conditions more clearly. Moreover, it can assist in determining whether the environment is suitable and make reasonable regulations accordingly, which is the key to improving the intelligence and industrialization of livestock and poultry breeding in the future. Therefore, it is necessary to organize, compare, and analyze the detection methods of environmental factors in livestock and poultry houses. On the one hand, the applicability of detection methods can be evaluated to avoid blindness in method selection. On the other hand, by further improving the research progress of relevant detection methods, it can provide references for the further development of detection and analysis technologies.

In order to explore the research status of environmental factor detection and analysis technology of livestock and poultry houses, the authors sorted out the representative review literature published from 2013 to now, as shown in Table 1. It can be found that most of the relevant reviews are aimed at a certain field, without a comprehensive analysis or sorting of detection methods. Due to the wide range of detection methods, the current studies on the environmental factor detection and analysis technology of livestock and poultry houses were mainly divided into three categories: research on the environmental monitoring and control of livestock and poultry houses based on detection equipment and wireless sensor technology; research on the distribution and regularity of environmental factors in livestock and poultry houses based on a mathematical model; research on the environmental simulation and detection of livestock and poultry houses based on computer technology (Figure 1). This article emphatically summarized the scope and application prospects of different detection and analysis methods, discussed the innovative technologies in recent years, and explored the existing problems and development prospects of different technologies.

Table 1. Representative reviews published since 2013.

Authors (Year)	Title	Keywords	Main Content
Research on the Environmental Monitoring and Control of Livestock and Poultry Houses Based on Detection Equipment and Wireless Sensor Technology			
Xiong, et al. (2015) [18]	Review on application of Internet of Things technology in animal husbandry in China	Data mining; Identification; Monitoring; Tracking; animal husbandry; Internet of Things (IoT); Electronic feeding station; Data application	From the aspects of livestock breeding environment, digital supervision of breeding livestock (breeding pigs, dairy cows) breeding process, and digital network management platform, the application effects and limitations of IoT in animal husbandry were reviewed.
Wang, et al. (2017) [19]	Research progress on pollution and monitoring technology of particulate matter from livestock and poultry farms	Livestock and poultry farms; Particulate matter; Air pollution; Monitoring technology	According to the complex physicochemical and biological characteristics of particulate matter (PM) in livestock and poultry house, the corresponding detection technologies were described.
Ghosh, et al. (2015) [20]	Review of bioaerosols in indoor environment with special reference to sampling, analysis and control mechanisms	Indoor environment; Bioaerosol; Fungi; Air pollution; Bacteria	The sampling and analysis technologies for the different airborne microorganisms in various indoor environments were described.
Jie, et al. (2015) [21]	Advances in methods and instruments for determining concentration of gaseous air pollutants in large-scale livestock farms	Pollution; Gases; Testing; Methods; Instruments; Livestock farm	The research status of field detection methods and analytical instruments for the main pollution gases in large-scale livestock and poultry breeding were reviewed.
Fournel, et al. (2017) [22]	Rethinking environment control strategy of confined animal housing systems through precision livestock farming	Animals; Environment control; Thermal stress; Welfare; Precision livestock farming; Sensors	A critical review of the latest technologies for precise environmental control of livestock buildings.
Wu, et al. (2022) [23]	Information perception in modern poultry farming: A review	Poultry; Intelligent information perception; Unmanned poultry farming system; Precision poultry farming	Studies on information awareness technology in poultry production in 26 countries, including health and environmental monitoring, were reviewed.
Research on the Distribution and Regularity of Environmental Factors in Livestock and Poultry Houses Based on a Mathematical Model			
Rotz (2018) [24]	Symposium review: Modeling greenhouse gas emissions from dairy farms	Greenhouse gas; Model; Dairy; Methane; Carbon footprint	Various greenhouse gas emission models for dairy farms were reviewed, including constant emission factors, variable process-related emission factors, empirical or statistical models, mechanistic process simulations, and life cycle assessment.

Table 1. *Cont.*

Research on the Environmental Monitoring and Control of Livestock and Poultry Houses Based on Detection Equipment and Wireless Sensor Technology			
Authors (Year)	**Title**	**Keywords**	**Main Content**
Research on the Distribution and Regularity of Environmental Factors in Livestock and Poultry Houses Based on a Mathematical Model			
Conti, et al. (2019) [25]	Measurement techniques and models to assess odor annoyance: A review	Odor; Nuisance; Odor measurement; Air dispersion models; Waste; Livestock	Air dispersion models applied for the evaluation of the spatial and temporal distribution of atmospheric pollutants in terms of concentration in air and/or deposition in the studied domain were reviewed.
Ding, et al. (2020) [26]	Mechanism analysis and airflow rate estimation of natural ventilation in livestock buildings	Ventilation; Environmental control; Airflow rate estimation; Livestock buildings; Direct method; Indirect method	The research progress of ventilation theory and ventilation volume estimation of natural ventilated livestock houses was reviewed.
Ye, et al. (2022) [27]	Research progress on application of methane emission monitoring technology in ruminants	Ruminants; Methane; Emission monitoring; accounting method	The sources, accounting methods, and application status of monitoring technologies of CH_4 emissions from ruminants were described.
Research on the Environmental Simulation and Detection of Livestock and Poultry Houses based on Computer Technology			
Pierre-Emmanuel Bournet, et al. (2022) [28]	Advances of computational fluid dynamics (CFD) applications in agricultural building modeling: Research, applications and challenges	Greenhouse; Livestock building; Microclimate; Numerical simulation; Validation	The latest advances in CFD research (over the past 20 years) in the field of greenhouse and livestock construction were reviewed.
Jun Bao, et al. (2022) [29]	Artificial intelligence in animal farming: A systematic literature review	Artificial intelligence; Behavior detection; Sustainable production; Animal welfare; Animal farming	The scientific research progress of artificial-intelligence-related animal breeding was systematically reviewed.
Rasheed O. Ojo, et al. (2022) [30]	Internet of Things and Machine Learning techniques in poultry health and welfare management: A systematic literature review	Behavioral parameters; Environmental parameters; Deep learning; Computer vision; Vocalization	The most advanced AI, IoT, and the latest progress in developing intelligent systems in this field were reviewed systematically. The key applications of identified digital technologies in poultry welfare management were outlined. The challenges and opportunities of artificial intelligence and IoT in the poultry farming industry were discussed.

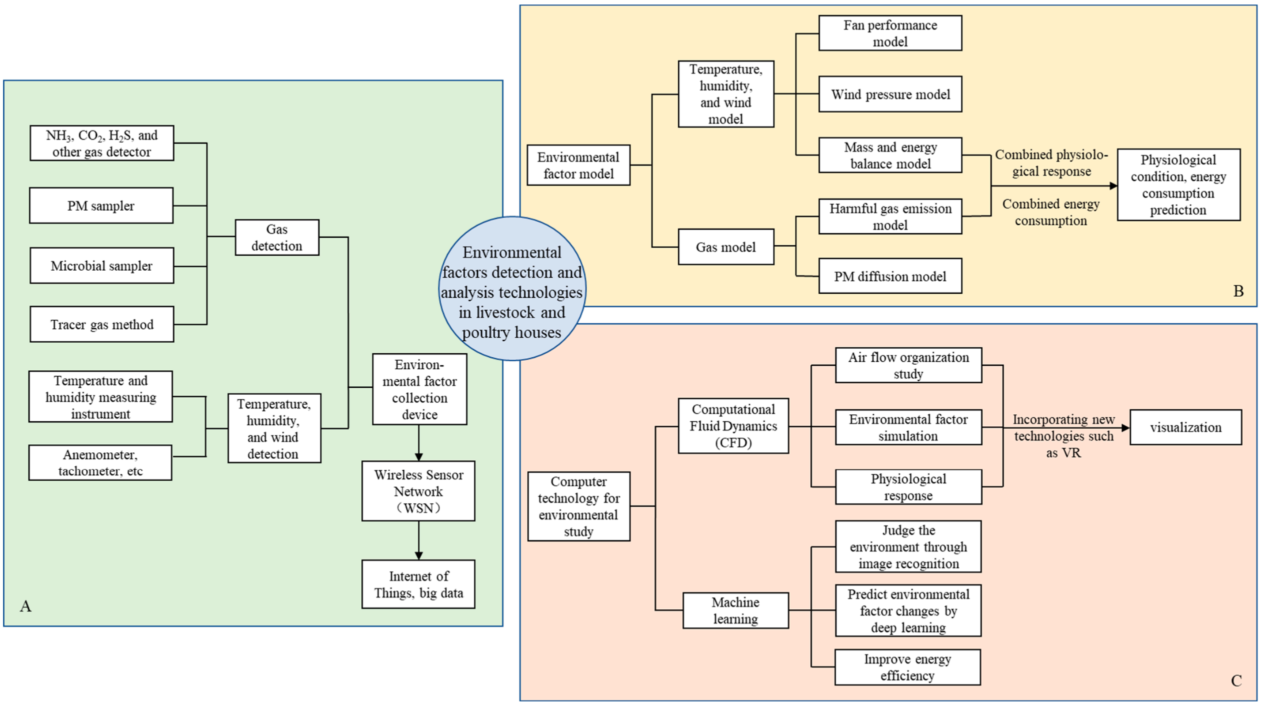

Figure 1. Research areas of different detection and analysis technologies. (**A**): research on the environmental monitoring and control of livestock and poultry houses based on detection equipment and wireless sensor technology; (**B**): research on the distribution and regularity of environmental factors in livestock and poultry houses based on a mathematical model; (**C**): research on the environmental simulation and detection of livestock and poultry houses based on computer technology.

2. Research on the Environmental Monitoring and Control of Livestock and Poultry Houses Based on Detection Equipment and Wireless Sensor Technology

Detection equipment and wireless sensor technology are used to collect the environmental factor data in actual livestock and poultry houses through field measurement. The common tools are the environmental factor acquisition equipment.

2.1. Environmental Factor Acquisition Equipment

The environmental factor acquisition equipment of livestock and poultry houses is used to detect various environmental parameters inside and outside the house, which is widely used to collect field data in experimental research. According to the use path, environmental factor acquisition equipment includes temperature and humidity measurement, ventilation measurement, harmful gas measurement, microbial measurement, PM measurement, tracer, etc. [31–35]. With the development of detection technology and environmental research of livestock and poultry houses, the precision and accuracy of environmental factor acquisition equipment can meet the needs of production and life.

Due to the limitations of the field test, recent studies mainly focus on improving the portability and stability of equipment. Mendes et al. [36] evaluated the performance of a low-cost non-dispersive infrared (NDIR) sensor for the intensive spatial field monitoring of CO_2 concentrations in a naturally ventilated dairy cow house. Habib et al. [37] used a cheaper handheld sampler, which has a potential function in the rapid and relatively immediate measurement of PM emissions. Tan et al. [38] established an NH_3 concentration monitoring system for livestock and poultry houses based on tunable diode laser absorption spectroscopy (TDLAS). Performance tests were performed on the system under the optimal system parameters. The results showed that the monitoring system indicated a comprehensive linear error of 1.00%, and a quantitative comprehensive repeated error of 0.51%, which could meet the demand for long-term continuous monitoring of NH_3 concentration in livestock and poultry houses. The primary objective of the convenience requirement is to reduce the difficulty of measurement and the input of material and manpower based on maintaining the measurement accuracy, so as to realize unmanned automatic monitoring. The main method to realize this goal is wireless sensor technology.

2.2. Wireless Sensor Networks

The advanced livestock and poultry house management system can collect a large quantity of data about the environment and operation, and record the environmental changes in the house in real time through a mass of detection points. In this regard, technologies such as pervasive computing, the wireless self-organizing and sensor network, radio frequency identifiers (RFIDs), cloud computing, and satellite monitoring are becoming increasingly popular [39,40]. Among them, based on the development of different types of sensors for environmental detection, wireless sensor networks (WSNs) have found extensive application in the agricultural field [41].

The wireless data transmission technologies commonly used by wireless sensors include ZigBee, GPRS/4G, WI-FI, 433MHz, NB-IoT, and LoRa, which are currently receiving significant attention in the field of environmental factor acquisition equipment. Yasmeen et al. [42] used low-cost sensors to exploratively monitor PM and gas concentrations in controlled-environment facilities. Ali et al. [43] developed a suite of inexpensive, open-source devices based on the Arduino platform, which were used to measure and record long-term indoor environmental and building operational data, including air velocity, ground temperature, air relative humidity, human living conditions, light intensity, CO_2 concentration, etc. It showed good performance on the basis of cost reduction. Based on the system for monitoring various air pollutants developed in 2009, Gray et al. [44] explored software that could be used to organize and store recorded real-time environmental data from multiple farms, which provided a template for improving environmental monitoring systems and analyzing environmental detection data. Ramirez et al. [45] developed separate Thermal Environment Sensor Arrays (TESAs) to record the temperature, humidity, and wind conditions of livestock and poultry houses. The recorded data were connected to a notebook computer through the serial communication network to monitor environmental conditions in real time. The results showed that TESAs can be used to measure and record the environmental conditions of pig houses and as a design tool to explore different ventilation and cooling strategies. Chen et al. [46] developed an environmental monitoring system for air quality parameters in animal husbandry based on a WSN. It was found that compared with the data from an air quality analyzer, the measurement accuracy of temperature, relative humidity, NH_3, and CO_2 of the WSN system was higher. In addition, the control precision of temperature and humidity was higher. Zeng et al. [47] adopted the ZigBee mesh topology for wireless distributed networking, and the node devices achieved multi-point monitoring in the form of "one master, multiple slaves". Long et al. [48] took the STM32 microcontroller as the master control unit, set a mobile intelligent monitoring platform outside the fixed-point sensor, and monitored the environment of a livestock and poultry farm through an ultra-wide band (UWB) wireless system and integrated sensor system.

2.3. Combined with IoT and Big Data for Application

The development of environmental detection technology for livestock and poultry houses is becoming more and more important to the requirements of automation and intelligent decision making. Combining with the IoT, the WSN builds the data foundation for improving livestock and poultry environment. Therefore, agricultural environmental data collection gradually develops in the direction of remote, big data, and cloud storage. Duan et al. [49] proposed a livestock breeding IoT data fusion model to effectively improve the accuracy of data fusion and meet the requirements of livestock breeding IoT data analysis. Popa et al. [50] monitored key air pollutant parameters (such as CO, NH_3, PM1, PM2.5, and PM10) in a stable environment through IoT devices. Faverjon et al. [51] gave an overview of the research project named "Pig Data", describing the use of a transdisciplinary approach in a big data research project in the Swiss pig industry. Combined with the strong data processing and analysis ability of the IoT and big data, it can effectively integrate the changes and interactions of environmental factors, providing the data basis for the accurate regulation and control of livestock and poultry houses.

3. Research on the Distribution and Regularity of Environmental Factors in Livestock and Poultry Houses Based on a Mathematical Model

The research on the distribution and regularity of environmental factors based on mathematical models is to construct theoretical models of the release, distribution, and movement law of different environmental factors. This approach aims to provide a theoretical analysis to show the existence of environmental factors in livestock and poultry houses more clearly.

3.1. Temperature–Humidity–Wind Correlation Model

The law of conservation of matter can be used to predict the environment of the house and calculate the ventilation volume, which has been verified very early [52–54]. However, its widespread application has been hindered because of its complex calculation. In recent years, with the widespread use of computers, a large amount of data processing becomes possible, so many scholars use the conservation of matter to study the environmental factors in livestock and poultry houses. Blanes et al. [55] calculated the ventilation flow of the pig house by using CO_2, moisture, and heat balance equations. On average, the calculated ventilation by the CO_2 balance was 8% lower than the measured ventilation, and the calculated ventilation flow by the humidity and heat balance was 9% lower. Therefore, the CO_2 balance method is the most widely used to estimate ventilation volume in practice. Qi et al. [56] calculated the application capacity and effect of cooling pads in different regions of China by researching the summer ventilation conditions in different climatic regions. Rosa et al. [57] used the direct hot wire anemometer (HWA) and fan rotational speed methods, and the indirect CO_2 mass balance method, respectively, to evaluate the ventilation volume of poultry houses. The calculation of ventilation volume through the conservation of matter is performed to reverse the appropriate ventilation volume based on the environmental requirements of the house. The actual ventilation volume can also be calculated according to the opening condition of the fan through the fan performance model. Based on this, Chen et al. [58] analyzed the actual ventilation rate and the uncertainty of the ventilation rate in a pig house. It is believed that the more fans in operation, the lower the relative uncertainty of the ventilation rate of a pig house. The uncertainty of the estimates can be reduced by proper and frequent field fan calibration. These studies provide theoretical bases for the prediction and determination of ventilation in livestock and poultry houses.

3.2. Gas Diffusion Model

A mathematical model of environmental factors in livestock and poultry houses can fit the emission characteristics of harmful gases well. As a result, it is frequently applied for the purpose of forecasting gas diffusion. Especially as breeders have been paying more attention to the emission of harmful gases from livestock and poultry breeding, studies on the diffusion mechanism of harmful gases such as NH_3, H_2S, and CH_4 are gradually increasing. Gas diffusion models mainly include Gaussian plume models, Puff models, Fluctuating models, and other models that have been used in livestock odor dispersion modeling [59]. Li et al. [60] applied the equilibrium model ISORROPIA II to predict the behavior of inorganic aerosols in response to precursor gas concentrations and environmental parameters. Schauberger et al. [61] established the emission model that took into account a time series of the odor emission rate, which can more truly describe the odor emission characteristics than an annual mean value. Hadlocon et al. [62] used AERMOD, an atmospheric diffusion model, to predict the dispersion of PM in poultry facilities. Schrade et al. [33] and Hempel et al. [63] analyzed the temperature dependence of NH_3

and CH_4 emissions. It was considered that the relationship between NH_3 and temperature is approximately an exponential function, and CH_4 shows a non-monotonic dependence on temperature, which can be expressed by a parabolic approximation. Zou et al. [64] analyzed the emissions of harmful gases based on the carbon dioxide balance method. Li et al. [65] systematically determined the concentration, size, and distribution of PM and airborne bacteria in laying hen houses, and established the quantitative relationship between PM and airborne bacteria. The construction of these models is conducive to the prediction of gas diffusion in livestock and poultry houses, and thus plays a significant role in source emission reduction and concentration control.

3.3. Innovation Models Combining the Livestock and Poultry's Demand and Energy

The modern mathematical model of livestock and poultry houses is not only limited to the changes in environmental factors in the house but also begins to couple the needs of livestock and poultry. Ramirez et al. [66] established a mechanical heat balance model, using body weight, dry-bulb temperature, relative humidity, and air to evaluate the somatosensory temperature of pigs, so as to estimate the heat loss and thermal stress index of pigs. Mylostyvyi et al. [67] made several periodic measurements of the air temperature and relative humidity outside and inside the barns, and established a linear regression (LR) model for predicting the temperature–humidity index (THI) with an accuracy of 93~96%. With the demand for energy conservation and emission reduction, there is more research combining mathematical models and energy consumption prediction. Costantino et al. [68] proposed a simulation model (based on a customization of the hourly model of ISO 13790) to estimate the energy consumption of broiler houses and the thermal model of indoor environmental conditions. Xie et al. [69] analyzed the ventilation and energy consumption of pig houses through the simulation and verification of the microclimate environment in closed pig houses based on the energy–mass balance. Qi et al. [70] estimated the heating energy consumption in winter and the cooling energy consumption in summer through the energy–mass balance model. These mathematical models combined the theory of environmental factors with the key issues of livestock and poultry farming—animal welfare and energy—to provide theoretical bases for environmental factor control.

4. Research on the Environmental Simulation and Detection of Livestock and Poultry Houses Based on Computer Technology

Due to the lack of the ability to predict the environment by traditional detection methods and the difficulty of reflecting the multi-factor interaction of mathematical models, the research of environmental detection of livestock and poultry houses by computer analysis software simulation came into being. This method often combines the actual environmental indicators and the theoretical model of the change in factors, which has a certain reliability and predictability. Therefore, relevant computer technologies such as computational fluid dynamics (CFD) and machine learning have been widely used in the field of the environmental detection and control of livestock and poultry houses.

4.1. Applications of CFD

CFD uses computers and applied mathematics to model fluid flow situations for the prediction of heat, mass, and momentum transfer and optimal design in industrial processes [71]. In the initial CFD studies, livestock house structures were mainly regarded as two-dimensional or simplified three-dimensional domains, and complex configurations including animals were ignored in the simulation model [72]. However, the presence of animals inside the house can also significantly affect airflow patterns and internal environmental conditions. With the improvement of computer performance and the increasing requirement of simulation accuracy, the research on animal simulation, full-size and precise simulation has gradually increased [73,74]. The utilization of CFD has become prevalent in a variety of research on the environment of livestock and poultry houses.

(1) Study of airflow organization: With the development of the simulation, CFD is applied more and more in the airflow simulation of livestock and poultry houses. Bianchi et al. [75] used the software Comsol multiphysics to study the efficiency of a semi-transversal ventilation system and a purely transversal one. Rojano et al. [76] researched the air discharges caused by natural ventilation of a poultry house and predicted the air renewal rate (ARR). It is useful to know how the gases contained in air will likely spread downstream from the building in order to define regions of potentially high gas concentration that could endanger neighboring habitable facilities. Yeo et al. [77], by changing the conditions of the pig house air inlets and outlets (air buffer space, inlet duct, and exhaust fan), found that when an air buffer space was installed just before the location of the inlet on the sidewall, the air temperature flowing through the air buffer space increased, so that more than twice the external air could be supplied to the pig house. These studies enable the visualization of airflow in livestock and poultry houses, which is convenient for researchers to systematically understand and control the environment inside the house. With a wide range of applications, not only can existing buildings be simulated, but also the ventilation performance of imaginary buildings under any wind conditions for design purposes [78,79].

(2) Simulation of environmental factors: CFD can be used to simulate indoor temperature, humidity, gas emissions, and concentrations. Kyeong et al. [80] evaluated the identification of key factors of dust reduction and the effect of dust reduction in nursery pig houses based on CFD technology. Yeo et al. [77,81] used CFD to evaluate the key factors of odor dispersion (wind speed, wind direction, atmospheric stability, terrain condition, ventilation type, and so on). Kim et al. [82] simulated the temperature and ammonia concentration distribution inside a nursery pig house by CFD, which was able to systematically quantify and analyze the distribution and change in environmental factors.

(3) The multi-factor coupling simulation of CFD was used to study the physiological response of livestock and poultry. Li et al. [83,84] studied a CFD simulation including a pig model, and believe that the skin layer modeling should still be considered when studying the skin surface temperature in correlation to the deep body temperature. The orientation and turbulence intensity significantly affect the convective heat transfer coefficient of pigs. They also compared two wall inlet styles (a conventional inlet with an upward guiding plate and a modified inlet that supplied downward airflow directly onto the pigs) to estimate the effect of the ventilation system on the convective heat loss of pigs. Gebremedhin et al. [85] used CFD to develop a three-dimensional conduction model that simulated cooling thermally-stressed dairy cows. Bjerg et al. [86] estimated the effective temperature (ET) of the lying area in pig houses through a CFD simulation. Zhang et al. [87] evaluated the effects of different inlet diameters, air speeds, and temperatures on the airflow and temperature field around lactating sows, as well as the heat dissipation of lactating sows under the fixed-point air supply cooling system using a CFD numerical simulation. Many scholars have realized that the simple environmental control of livestock and poultry houses does not represent the actual state of animals. Environmental control technology combined with physiology has become a development trend.

(4) Combine with new technologies: By combining with other technologies, CFD is more advanced, intelligent, and visual. Kim et al. [88] applied the results of CFD calculations, such as internal airflow, air temperature, humidity, and gas, to a VR simulator.

4.2. Applications of Machine Learning

Machine learning uses computers to simulate or realize human learning behaviors and reorganize existing knowledge structures. It can use computers to imitate the working mode of humans to process, classify, and identify the huge amount of information in the livestock and poultry house, and explore the law of the existence of environmental factors in the house and the direction of change and development.

(1) Image recognition: Combined with image recognition technology, it can timely and accurately understand the status of each individual through video and monitoring, so

as to indirectly learn environmental information. Shao et al. [89] investigated a real-time monitoring system based on image processing technology. It could skillfully use the group behavior of pigs in hot and cold conditions, judge the temperature in the house by the behavior of pigs in the image, and take corresponding control measures.

(2) Predict the change in environmental factors in livestock and poultry houses: In contrast to the mathematical model, the former is to explore the theoretical emission law through the gas emission mechanism or reversely fit the emission model through actual production data, etc., while the latter is to predict the emission results based on a large quantity of test data through deep learning. Xie et al. [90,91] used five kinds of membership functions to establish a well-fitted ANFIS prediction model and established an NH_3 emission prediction model based on the NH_3 concentration of finishing pigs. A hybrid deep-learning-driven sequential Concentration Transport Emission Model (DL-CTEM) was also proposed to estimate the emissions of NH_3, CO_2, and H_2S from a pig building. Gautam et al. [92] developed an offline prediction model to estimate future thermal conditions from building data collected in operation. Basak et al. [93,94] used statistical and machine-learning methods to model CH_4 and CO_2 emissions from pig manure. Rodriguez et al. [95] developed a CO_2 emission prediction model using neural networks. In recent years, Chinese scholars have also conducted much research on the prediction model of environmental factors of animal houses based on machine learning. The results of the model have shown good agreements, which provide references for the advanced prediction and control of the environment of livestock and poultry houses in the future [96–99].

(3) Take energy consumption into account in the calculation: Moon et al. [100] used artificial neural networks (ANNs) to develop thermal management algorithms to improve the thermal comfort and energy efficiency of buildings. For this, two ANN-based predictive and adaptive models were developed and employed in the algorithm. Shin et al. [101] analyzed indoor environmental changes and energy consumption based on ventilation system control applications by EnergyPlus, while predicting indoor temperature and CO_2 concentration.

5. Problems and Research Prospects of Environmental Factor Detection and Analysis in Livestock and Poultry Houses

The development of research on environmental factors of livestock and poultry houses affects the research on animal environment. At present, the research on the environmental monitoring and control of livestock and poultry houses based on detection equipment and wireless sensor technology, research on the distribution and regularity of environmental factors in livestock and poultry houses based on a mathematical model, and research on the environmental simulation and detection of livestock and poultry houses based on computer technology still have contents that need to be improved and developed (Table 2).

In general, the development of environmental detection and analysis technology has a significant trend of intelligence. Technology combined with computers has developed rapidly in recent years, leading to a substantial increase in the corresponding research literature. The use of computers has greatly improved the ability of calculation and analysis and has provided a powerful tool for the calculation of the diffusion, distribution, and prediction of environmental factors in the house. Another significant feature is the gradual fitting of detection and analysis technology with actual needs, and the combination of research hotspots such as animal welfare and energy utilization [102–104], which is no longer limited to the monitoring of environmental factors.

Optimal control strategies are essential for the environmental control system and livestock and poultry house research. These strategies must be developed for specific applications to achieve timely and effective control, eventually creating a favorable environment for animal growth. At present, the control strategy of most environmental control systems only determines the running state of the control equipment based on the data collected by the field sensor or the simulation result of CFD, ignoring the prediction of the environmental change in the house. Additionally, it is not clear how the measurement accuracy will affect the accuracy of the environmental control system. Therefore, the author's suggestions for the future development direction of environmental factor detection and analysis technology are as follows: (1) Multi-factor environmental control and detection methods should be established, combined with the physiological response of livestock and poultry. (2) Novel methods need to be developed to integrate energy requirements into the environmental regulation of livestock and poultry houses. Moreover, the "building—environment—physiology" needs to be unified gradually and the comprehensive benefits also should be considered. (3) Control models and strategies that can predict the internal environment need to be researched and developed, and transient simulation methods have to be further explored. (4) Through the coupling of different technologies, the mutual verification of environmental factors in the house can be achieved, which will improve the detection and control accuracy.

Table 2. Comparison of detection and analysis technologies of different environmental factors.

Detection and Analysis Technology in Livestock and Poultry Houses	Advantages	Disadvantages	Development Direction
Research on environmental monitoring and control of livestock and poultry houses based on detection equipment and wireless sensor technology	(1) The stability and accuracy can meet the needs of production and life, with reliability. (2) The actual value of a certain point can be obtained accurately. (3) Based on the analysis of different environmental factors in livestock and poultry houses, correlation results conducive to environmental regulation can be obtained. (4) The requirements for the technical level of measurement personnel are low. (5) The requirements for livestock and poultry houses are relatively high.	(1) The amount of information required to fully quantify environmental variables depends not only on the physical principles involved, but also on the level of accuracy associated with the analysis tool, which is difficult to avoid errors. (2) Comprehensive analysis of test data not only requires expensive equipment, but also requires a lot of time, manpower, and material resources. (3) The number of measurement points in the test is limited. Therefore, the actual measured results may not represent the whole livestock and poultry house. The measurement fluctuation is large, which made its accuracy cannot be guaranteed [105]. (4) Field measurement may affect animal life. (5) The environment of the livestock and poultry house will affect the reliability of the detection data and reduce the service life of the sensors.	(1) Reduce costs and energy consumption; (2) explore ways to increase accuracy and improve the convenience of detection; (3) enhance interoperability. Several current trends (cloud computing, big data, IoT) should be included in the research of sensor technology.
Research on distribution and regularity of environmental factors in livestock and poultry houses based on a mathematical model	(1) The most essential emission law and material exchange of factors were considered. (2) The change in a single environmental factor can be predicted clearly, which is conducive to analyzing the change law of different environmental factors.	(1) A mathematical model is highly theoretical, and due to uncertainties in actual production, the accuracy of the model will have a certain gap. (2) The structure of the model is simple, making it difficult to realize the influence and change in the multi-factor interaction. (3) It is difficult to apply and promote in actual production.	(1) Consider the interaction of multi-factor environment; (2) complete the model construction and calculation with computer technology; (3) on the basis of theory, try to consider the actual demand and increase the variables.
Research on environmental simulation and detection of livestock and poultry houses based on computer technology	(1) Due to its ability to control experimental conditions artificially and modify structural configuration easily, it is widely used to overcome the limitations of field experiments [106]. (2) The survey setup cost is lower, and the control of research parameters is easier. (3) The accuracy of simulation predictions was improved, which made it showed excellent potential for analyzing environments of complex animal house.	For CFD simulation: (1) It is impossible to perform continuous simulation and connect real-time data collection. (2) There is no standard or benchmark for verifying CFD model currently [107]. (3) The simplified model will ignore variables that are difficult to control, resulting in inaccurate simulation results, which cannot fully take into account the changeable characteristics of the actual environment.	(1) Improve the reliability and stability of the simulation; (2) enhance the capabilities of real-time and continuous detection in simulation; (3) pay attention to the combination of different detection methods, and verify the reliability of the model with field tests.

6. Conclusions

The internal environment of the livestock and poultry house is crucial to the health, productivity, and welfare of the animals. Therefore, it is necessary to effectively detect and regulate the environmental factors in the house. This paper presents a systematic overview of the current research status of technologies for detecting and analyzing environmental factors in livestock and poultry houses. The scope, application, and development status of these technologies are comprehensively summarized, and the advantages, disadvantages, and prospects of different technologies are analyzed. In general, environmental factor detection and analysis technology can be categorized into three areas: (1) the environmental monitoring and control of livestock and poultry houses based on detection equipment and wireless sensor technology; (2) the distribution and regularity of environmental factors in livestock and poultry houses based on a mathematical model; (3) the environmental simulation and detection of livestock and poultry houses based on computer technology. With the advancement of the main theme of intelligence, different detection and analysis technologies are developing in the direction of being unmanned, convenient, and automated. In terms of application, each has its advantages and disadvantages; thus, it is necessary to select detection and analysis technology according to the actual demand and corresponding numerical parameters. The future development of environmental detection and analysis technology of livestock and poultry houses should be combined with the physiological response of livestock and poultry. Novel methods need to be developed to integrate the prediction of material exchange and change, as well as energy requirements, into the environmental control strategy. Through the coupling of different technologies, the detection and control accuracy can be improved.

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