Modeling of an intelligent management system for smart poultry farms

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Abstract: During the era of digital transformation in Kyrgyzstan, the implementation of innovative solutions based on artificial intelligence technologies and the development of information systems for smart poultry farms can become a key element of sustainable agricultural development and is a pressing issue. This study presents an approach to the conceptual modeling of an intelligent control system for smart poultry farms. This work presents the development of a digital model of the intelligent system of the smart-bird farm, based on which an approach to the integration of Internet of Things (IoT), computer vision and big data processing technologies is implemented. An object-oriented development of an intellectual system using the universal modeling language UML was carried out. The structure of the digital model is presented, the functional components of the system are selected, the objects of the system are considered and the relationship between them, the information flows between the objects and components of the system are described.

1 Introduction

The digitalization of agriculture in Kyrgyzstan is inconceivable without the integration of Internet of Things (IoT) technologies and artificial intelligence (AI) for addressing applied problems such as yield forecasting, plant and animal disease recognition, optimization of water and land resource use, development of digital twins and information systems for smart farms and fields, modeling for optimizing logistics and supply chains, and forecasting prices for agricultural products, among others.

The Concept of Digital Transformation of Kyrgyzstan for 2024–2028 [1] outlines the tasks related to establishing systems for the collection, analysis, and dissemination of agricultural data, including the development of platforms for data exchange and reporting for farmers. Access to accurate and timely information will enable the adoption of evidence-based farming practices, facilitate the planning of future agricultural production, and, more broadly, support the implementation of effective agricultural policies.

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Naturally, this transformation also requires the training of farmers in the use of digital tools and technologies in poultry farming. Such training should include information management and data analysis, the use of digital applications for poultry farm management, and the promotion of agricultural products through digital marketplaces.

In Kyrgyzstan, as in many other countries, the consistently high demand for poultry products as a primary source of protein necessitates innovative technological advancements in poultry farming. The adoption of modern information technologies in this sector will enhance the efficiency of business process management and increase the productivity of poultry farms. Figure 1 presents a simplified schematic of a poultry house, illustrating the main microclimate systems that require intelligent automation.

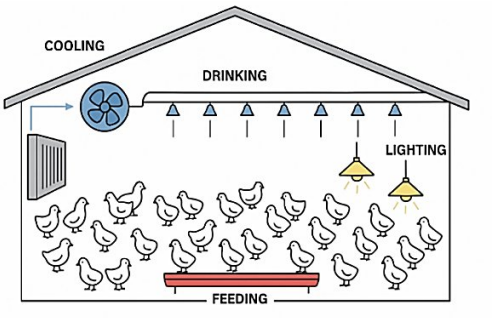

Fig. 1. Diagram of a poultry house

The development of an information system to support decision-making and ensure the optimal management of poultry farms comprises several key components. The first includes sensors—physical electronic devices designed for the intelligent automation of microclimate control, watering, feeding, and monitoring the health and condition of poultry within the farm. Secondly, it includes an artificial intelligence system for real-time disease detection in poultry flocks, as well as a module for recognizing poultry diseases based on feces. Thirdly, it includes an information system interface, a web application, or a mobile app for farmers that integrates all data processing processes across the system components.

Such information systems are necessary for creating an accurate feeding schedule for poultry, which will optimize resource allocation. Thanks to Internet of Things sensors, we constantly collect microclimate monitoring data, which allows us to create favorable conditions for poultry growth and conduct data analysis to optimize microclimate parameters for the productivity of the poultry farm, as shown in Figure 2.

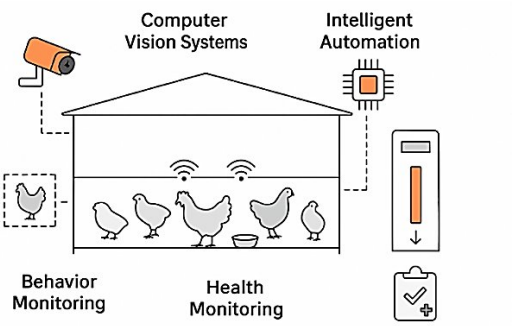

Fig. 2. Poultry house layout with intelligent automation

Artificial intelligence systems based on neural models enable monitoring of entire poultry flocks, tracking bird behavior, and identifying sick birds based on behavior patterns. Artificial intelligence for recognizing poultry diseases based on feces will also enable early diagnosis of diseases using images of bird droppings uploaded by the farmer through a web application. Based on the analysis results of the recognition module, the system provides recommendations for further action, helping farmers make informed decisions. As is known, timely and efficient diagnosis of poultry diseases will help prevent epidemics of viral diseases. Thus, through the interface of a web or mobile application, the farmer interacts with the artificial intelligence system, and the intelligent system becomes a tool for the effective management of the poultry farm.

2 Literature Review

A review of existing scientific studies and applications indicates that the challenges of intelligent automation and the integration of artificial intelligence technologies into the digitalization of agriculture are highly relevant not only in Kyrgyzstan but also globally, as food security in many countries depends on livestock farming. According to projections by the Food and Agriculture Organization of the United Nations [2], global meat protein consumption is expected to rise by 3% by 2033, which is anticipated to contribute to an increase in greenhouse gas emissions. Nevertheless, artificial intelligence (AI) and the Internet of Things (IoT) have the potential to transform livestock farming, enabling farmers to enhance productivity while simultaneously reducing their environmental footprint.

Several studies provide useful insights in this domain. For instance, the work in [3] focuses on the development of a poultry farm management system and an AI-based consultation service for combating poultry diseases. This system is presented as both a mobile application and a web platform, integrating physical electronic devices for intelligent automation while employing a neural model to recognize chicken breeds and detect morbidity in real time, with infection areas mapped via Google Maps to notify national emergency services.

The paper [4] examines the advantages and possibilities of using artificial intelligence (AI) in managing livestock farms and in increasing productivity and economic efficiency. Artificial intelligence has been shown to have the potential to significantly impact animal breeding programs by revolutionizing genetic selection and optimization, making it easier to select superior animals for reproduction, maintain genetic diversity, and create healthier, more productive livestock.

The current demand for poultry products dictates the need for technological progress in the poultry industry, as noted in the work [5]. Along with commercially available solutions, such as poultry management systems such as PoultryCare (https:// www.poultry.care), Poultry Management Systems Inc (PMSI) (https://www.pmsi.cc/) and Amino (https://mtechsystems.io/products/amino/), which focus on different aspects of poultry production, although they are quite complex in terms of data collection, processing and visualization. The authors of [5] propose enhancing such systems with predictive capabilities tailored to precision poultry farming, particularly for application in the Baltic region. Building on a previously developed database architecture for an intelligent poultry farm using multi-sensor data and retrospective analyses of the Aihen platform, an egg production forecasting module was created. This novel approach employs the XGBoost algorithm in combination with SHapley Additive exPlanations (SHAP), which has been incorporated into the Aihen platform as an extension.

The review article [6] further provides a comprehensive overview of the most significant applications of digital technologies for monitoring poultry welfare. It presents a detailed assessment of both the benefits and challenges introduced by AI and IoT in poultry farming. Particular attention is devoted to sensor-based AI applications for analyzing chicken behavior, monitoring health conditions, and developing reliable strategies for tracking the well-being of broilers and preventing disease outbreaks.

Article [7] proposes a solution for the automation of poultry farms using IoT technologies to perform a variety of tasks related to the management of advanced production processes at poultry farms in India. The system described includes a web-based platform for farm management and monitoring, which allows users to track the operational status remotely from anywhere in the world at any time. In addition, the authors propose a solution for generating electricity from methane derived from chicken manure.

Scientific article [8] presents digital solutions designed as modern systems for managing and optimizing technological processes in poultry farming. These solutions provide the information necessary for decision-making, optimize resource consumption, and reduce production costs. Among them are dispatch and management systems for poultry complexes, including a control and data collection system and an automated reporting system based on the Technolog program developed by MicroEl LLC [9], BigFarmNet Manager, and the AMAKS hardware and software complex by Big Dutchman (Germany).

Study [10] investigates the Poultry Management System, an IoT-based platform that automates feeding and watering processes. An Android application was developed to enable users to set feeding and watering times. The system includes notifications that alert users when feed and water levels in storage tanks are low. The power supply is supported by a solar panel that charges the battery operating the microcontroller and motors. The proposed management system can be implemented on small poultry farms, which makes it no less relevant.

This review [11] examines the areas of impact of emerging smart sensor technologies on poultry production and describes how sensor technologies are linked to big data analytics and IoT systems and how these technologies can improve productivity in poultry production. As smart sensors collect real-time data on various parameters during poultry operations, large volumes of data will be generated that need to be processed by data analytics tools for decision making.

For research focused on system modeling, [12] demonstrates the modeling of dependencies between feed consumption, water consumption, manure output, ventilation requirements, temperature, and lighting, with respect to broiler live weight gain throughout the production cycle. The modeling was conducted using linear interpolation methods applied to normative, statistical, and experimental data. The resulting models enable the development of a poultry farm process control system that tracks changes in the physiological state of birds and generates appropriate control actions, thereby ensuring real-time adjustment of production processes to increase efficiency and reduce costs.

A review of scientific studies on intelligent automation and the development of information systems for poultry farms demonstrates that multiple approaches can be employed in constructing a Smart Poultry Farm intelligent management system.

2.1 Theoretical framework

The information processes of a smart poultry farm include: microclimate control; monitoring of ammonia and carbon dioxide levels; feeding and ration management; poultry health and biosafety monitoring; productivity and weight control; egg production management; logistics and resource consumption management (including feed, medicines, vaccines, and

electricity); personnel and workflow management; access control to facilities; and reporting on all processes and the overall state of the poultry population. Table 1 presents the distribution of artificial intelligence technologies according to the types of tasks arising in the management of a smart poultry farm.

Table 1. Types of tasks and artificial intelligence technologies applied in smart poultry farm management

Task name	AI Technology
Recognition of bird condition, analysis of droppings, head count.	Computer Vision (CV)
Prediction of diseases, productivity, resource requirements.	Machine Learning (ML)
Collection and analysis of data from sensors (temperature, humidity, gas).	IoT + Big Data
Automatic classification of diseases by photo/video/sound.	Neural Networks (AI)
Predictive maintenance of equipment (e.g. ventilation, heating, cooling, feeders).	Predictive Analytics

The purpose of this study is to develop a model of the Smart Poultry Farm information system specifically designed for mobile poultry houses and small-scale portable poultry farms with a capacity ranging from 300 to 700 chickens.

In Kyrgyzstan, government recommendations encourage private farmers and homeowners to construct mobile chicken coops on wheels. These units are particularly suitable for poultry farmers who lack extensive land resources for keeping chickens. The mobility of such coops allows them to be easily transported from one location to another, thereby ensuring continuous access of the flock to green feed.

An analysis of the current state of poultry farming in Kyrgyzstan revealed that only a limited number of poultry farms are equipped with automated systems and technological lines featuring terminals for setting microclimate parameters. However, these systems generally lack remote control capabilities. In most cases, laying hens are housed in cages, whereas broiler chickens are kept on the floor. Processing of poultry products, including eggs and chicken meat, is predominantly performed manually.

From the perspective of ownership, poultry farms in Kyrgyzstan are primarily operated by private enterprises and household subsidiary farms, Figure 3.

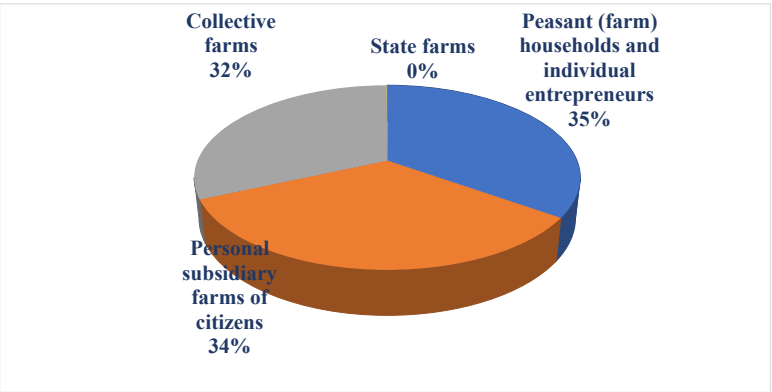

Fig. 3. The structure of poultry stocks by farm category [13]

In this context, individual entrepreneurs and farmers willing to adopt innovative practices during Kyrgyzstan's digital transformation are likely to become potential consumers of software solutions and mobile applications for intelligent poultry farm management, such as the Smart Poultry Farm (SPF) system.

3 Research Methodology

Various neural network architectures for recognizing bird diseases were investigated in our work [14]. The prediction accuracy with a result of 98.45% was obtained when predicting salmonella disease. Various CNN variants were built that showed different disease prediction results from 85% to 100% accuracy for individual poultry diseases. An error matrix was built with the results of the largest correctly classified diseases of coccidiosis and salmonella. It was found that the use of Adam and RMSProp optimizers showed the effectiveness of models with an accuracy of 98.33% with a model error of 0.001. The use of a neural network architecture with a training stop or further training with Koras gave us a noticeable increase in the accuracy of the model. The considered data augmentation methods play a key role, allowing for a slight overfitting of the model. Depending on the tasks and the amount of data for training the model, in most cases, the use of different approaches to building models requires different neural network architectures. The choice of epoch and neural network optimizers will have different prediction results each time if there is overfitting. In deep learning, in the presence of overfitting, which is always present, the correct method to stop training the model and depend on the choice of epoch. An important and important step in modeling plays a key role in setting the problem and appropriately choosing and tuning hyperparameters, as well as using already trained models on big data of transfer learning as the main method of deep learning. Thus, the results of this study show that we have successfully developed a poultry disease classification model using transfer learning. The models we trained obtained with an accuracy of 99% can help in early detection of diseases and contribute to effective disease management methods in poultry farming. Further automation of the classification process and use of the trained model to create web systems based on the knowledge base of poultry diseases can save valuable time and resources for farmers, which will lead to increased productivity of the meat industry and a healthier poultry flock.

The further study was carried out using statistical data on the development of agriculture in Kyrgyzstan from open sources, as well as based on the analysis of a number of scientific articles and reports based on general scientific methods of synthesis, evaluation, and comparison. When modeling the information system of a "smart" poultry farm, an object-oriented design methodology was used using the unified modeling language UML. This methodology allows you to formalize the architecture of an intelligent poultry farm management system and describe it in terms of classes, objects, relationships, and interactions. This approach allowed us to consider Smart Poultry Farm from five points of view, as a set of interconnected objects, each of which has certain properties (attributes) and behavior (methods). Using an object-oriented approach ensures modularity, scalability and flexibility of the system, which is especially important for the integration of modern technologies such as IoT, machine learning and computer vision.

3.1. Research design

This study implements the second stage of the project on creating artificial intelligence for diagnostics of poultry diseases. This is the development of a web information system based

on Python/Django Framework to support decision-making of poultry farmers. The system is designed to provide consultations on poultry diseases using a module for automatic recognition of three types of diseases (bacterial, parasitic, viral) based on the analysis of images of bird droppings. The system provides a preliminary diagnosis, recommendations, and also supports interaction between farmers, veterinarians and analysts through personal accounts.

3.2. Participants

The study analyzed the poultry market in Kyrgyzstan based on information from statistical reports of the National Statistical Committee, information from the media on the work of the Ministry of Agriculture on the development of the poultry industry of agriculture in Kyrgyzstan. On-site visits and consultations were also conducted with representatives of five large poultry processing enterprises in Kyrgyzstan located near Bishkek. It was found that only large poultry farms are equipped with the necessary equipment, and manual labor is mainly used. A survey of poultry farm managers is being conducted on the issue of introducing innovations and artificial intelligence technologies into their work.

3.2.1. Instruments

Following object-oriented analysis and conceptual modeling of the poultry farm management information system, the key objects and entities of the system were identified. The primary actors, i.e., the users of the system, include three categories of participants: the farmer, the system administrator/analyst, and the veterinarian, as illustrated in the use case diagram (Figure 4).

The use case diagram demonstrates the ways in which external actors interact with the system. For instance, the farmer is responsible for managing the poultry farm and monitoring operational data; the veterinarian supervises reports concerning the health status of the flock and receives automated alerts; while the system administrator ensures system maintenance and carries out analytical calculations.

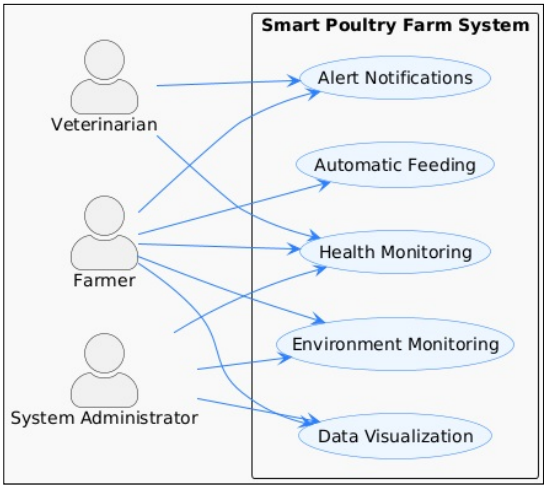

Fig. 4. Use case diagram of the SPF system

The Smart Poultry Farm system manages sensor networks that enable continuous monitoring of key parameters, including microclimate, feeding, watering, poultry health, and productivity. The collected data are processed and transmitted to the corresponding system modules, which in turn generate relevant notifications and recommendations for users, as illustrated in Figure 5.

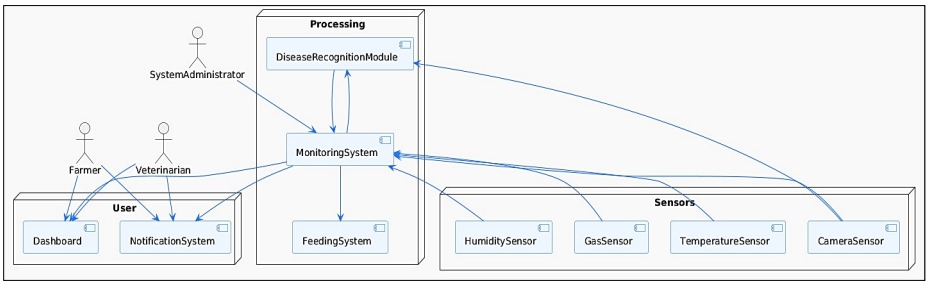

Fig. 5. Component diagram of the SPF system

The processes implemented within the Smart Poultry Farm system include automatic feed delivery; environmental monitoring (temperature, humidity, and concentrations of carbon dioxide and ammonia); flock condition monitoring (detection of sick or dead chickens using cameras and sensors); data visualization through the control panel and mobile application; and automated anomaly notifications directed to the farmer and veterinarian.

Object-oriented analysis further makes it possible to identify the core objects of the smart poultry farm information system, as illustrated in Figure 6.

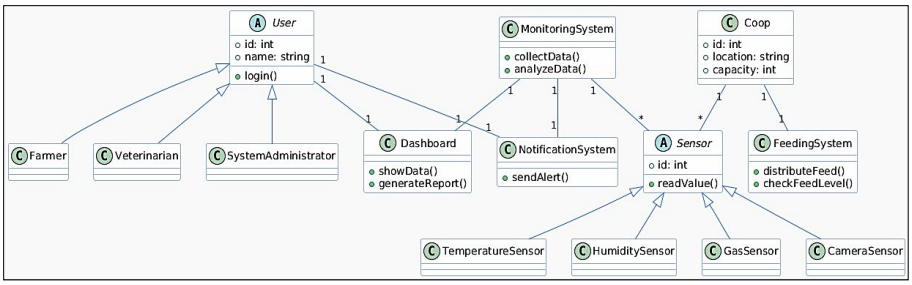

Fig. 6. Class diagram of the SPF system

The class diagram illustrates the key classes within the Smart Poultry Farm system. The sensor classes—temperature sensor, humidity sensor, gas sensor, and camera sensor—are derived from the abstract Sensor class. Additional classes include Poultry House, Feeding System, Monitoring System, Notification System, and Control Panel. The user-related classes—Veterinarian, Farmer, and System Administrator are derived from the abstract User class. The diagram also depicts the relationships between classes. Users interact with the system through the control panel and receive notifications. Sensors are installed in each poultry house. The monitoring system collects data from these sensors, performs analysis, and generates alerts, while the feeding system provides automated feeding of poultry.

The sequence diagram presented in Figure 7 illustrates the automatic feeding process within a smart poultry farm.

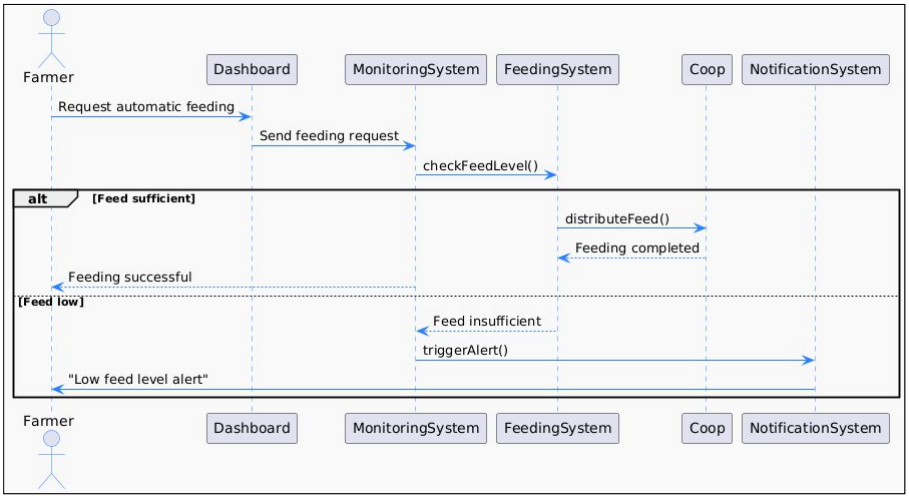

Fig. 7. Sequence diagram of the automatic feeding process

The sequence and activity diagrams presented in Figures 8–9 illustrate the process of poultry disease recognition. In this process, the camera sensor captures an image of the bird's droppings, which is then transmitted to the monitoring system. The monitoring system employs an AI-based disease recognition module to analyze the image. If a potential disease is detected, the notification system sends an alert to both the farmer and the veterinarian. If no disease is detected, the control panel is updated and the analysis results are recorded in the system log.

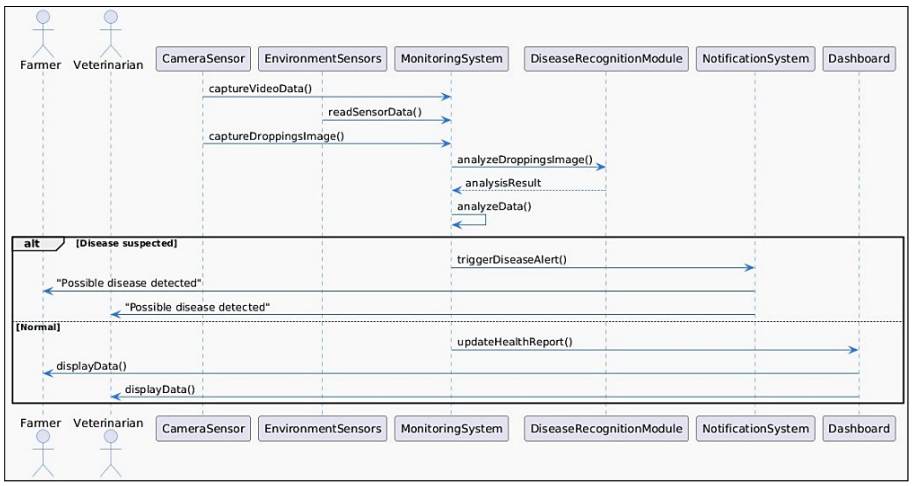

Fig. 8. Sequence diagram of the process disease suspected

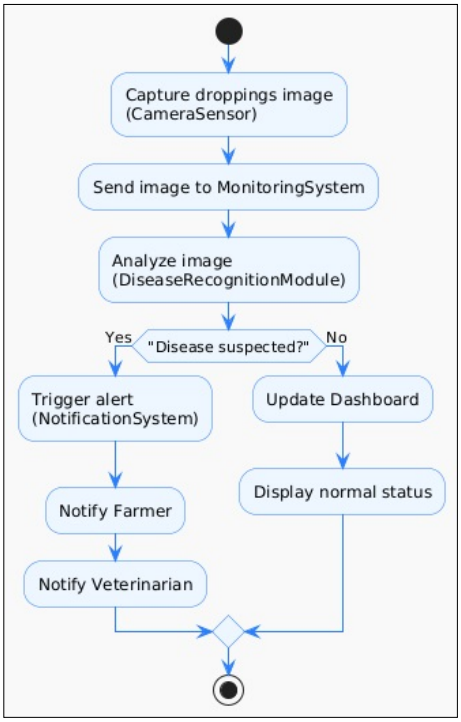

Fig. 9. Activity diagram of the suspected disease process

The operation of the bird disease recognition module, based on artificial intelligence (AI) technologies, was described in detail in our previous work [14]. Neural network models for recognizing poultry diseases using deep learning have been developed, covering diseases such as coccidiosis, salmonellosis, and Newcastle disease, which are common in poultry farming.

Convolutional neural networks (CNNs) and deep learning models were constructed to diagnose poultry diseases by classifying fecal images into four categories (healthy and three types of diseased samples). Initial test accuracy without fine-tuning was 85,06% for the baseline CNN and 87,85% for the updated neural network. Fine-tuning, including batch normalization layer freezing, improved model accuracy to 95,01%, with F1 scores above 83% for all four classes. Given its smaller model size and superior generalization capability, this CNN model is recommended for early detection of poultry diseases at the farm level.

The trained models achieve up to 99% accuracy and can be applied for early disease detection, contributing to effective disease management in poultry farming. The development of farmer-facing applications and further automation of the classification process, based on these trained neural models, will save time and resources, ultimately increasing meat industry productivity and maintaining healthy poultry stocks.

To implement such a system, there are currently many technology stacks for designing information systems. For example, let's consider a set of technologies: the Django framework, a free, high-level, open-source framework for creating applications in Python, was chosen to develop the server part of the system. The React tool, JavaScript, an open-source library for developing user interfaces, was selected for developing the client part of the system. The PostgreSQL database management system was selected for developing the

database, and TimescaleDB was selected for collecting sensor readings, as well as libraries with machine learning (ML) and big data (BigData) models for analytics and forecasting.

4 Conclusion

The integration of innovations and artificial intelligence technologies into the digitalization of agriculture enables the intelligent automation of all production processes within Kyrgyzstan's agricultural sector. This marks the beginning of the construction of a productive, efficient, and sustainable food production system.

A prerequisite for the successful implementation of Smart Poultry Farm management systems is reliable access to data infrastructure and internet connectivity for all farmers, particularly in rural areas. Adequate access to cloud services and other affordable digital solutions is essential. Additionally, small- and medium-sized farmers require support to invest in the necessary technologies and to receive training in the effective use of artificial intelligence for poultry farm management.

5 Recommendations

The finding revealed that poultry farmers are very interested in the implementation of innovations, artificial intelligence in poultry management, but there are problems in terms of technical difficulties with infrastructure and Internet networks in rural areas and mountainous areas. Also, many agricultural producers do not have information technology, which, of course, complicates the process of implementing smart poultry farm systems. Therefore, it is recommended to conduct training for farmers on information technology and the use of web and mobile applications in poultry farming.

Acknowledgements

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