INTELLIGENT ANIMAL FEEDING SYSTEM BASED ON MULTISOURCE INFORMATION ACQUISITION
/
基于多源信息采集的动物智能饲喂系统

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ABSTRACT

With the increasing refinement of livestock feeding management, conventional manual feeding and record-keeping methods often fail to ensure reliable confirmation of individual animal arrival and accurate identity matching. This may result in ineffective feeding, feed misdelivery, missed feeding, and deviations from the prescribed feed amount. To address these limitations, an intelligent animal feeding system based on multisource information acquisition was developed. The system integrates camera-based monitoring with microphone-array sound-source localization to support target positioning and combines radio-frequency identification (RFID)-based identity verification with weight-based arrival confirmation to enable individualized feeding while minimizing animal–target mismatches. The system also collects body weight and environmental data to generate traceable individual records and supports data transmission and command delivery through an ESP8266 module using the Message Queuing Telemetry Transport (MQTT) protocol. A WeChat mini-program is integrated into the platform to provide remote control, feeding-plan configuration, and data visualization, as well as AI-assisted recognition and question-answering functions. Experimental results demonstrated that the proposed system successfully integrates intelligent feeding with multisource information acquisition. Under the combined audio–visual configuration, the target-positioning success rate reached 92.67%, while the combined RFID–weight configuration achieved a trigger accuracy of 93.33%. These results indicate that the system can support refined feeding management and improve process traceability.

摘要

随着饲喂管理逐步向精细化发展，传统人工饲喂与记录的方式难以保证个体到位确认与身份匹配，易出现无效投喂、误投漏投与饲喂量偏差等问题。为此，本文构建基于多源信息采集的动物智能饲喂系统。系统通过摄像头监测与麦克风阵列声源方位数据辅助定位，并结合 Radio Frequency Identification（RFID）身份确认与称重到位判定，实现个体化饲喂，避免对象错配；系统同步采集体重与环境参数，形成可追溯的个体记录，通过 ESP8266 与 Message Queuing Telemetry Transport（MQTT）实现数据上报与指令下发；微信小程序与平台对接，提供远端控制、方案配置与数据可视化，并集成 AI 辅助识别与问答服务。实验结果表明，本系统能够实现智能饲喂与信息采集的一体化运行，在音频与视频联合配置下，指向成功率为 92.67%；在 RFID 与称重联合配置下，触发准确率为 93.33%。上述结果可为精细化饲喂管理与过程溯源提供参考依据。

INTRODUCTION

Feeding is very important for both feed supply and animal observation. Relevant information is collected during the feeding process, and this information can help adjust feeding plans when the condition of the animals changes *(Kavlak et al., 2023; Gauthier et al., 2022)*. Traditional feeding methods mainly rely on manual operation and record keeping. Prolonged use of such practices may result in inconsistent feed allocation and fragmented records that are difficult to maintain continuously. Poor data continuity also limits timely adjustment of feeding plans and may reduce the effectiveness of long-term management *(Bhaskaran et al., 2024)*. Therefore, intelligent feeding systems generally need to support individualized feeding, continuous acquisition of key state information, and remote cloud-platform management simultaneously (*Leliveld et al., 2024; McCarthy et al., 2023*).

Although sensing and automation modules have been increasingly adopted in animal feeding management, existing solutions are mostly designed independently for single tasks. As a result, process fragmentation and non-uniform interfaces often arise during on-site integration and maintenance, and data and control interactions across modules are difficult to standardize, making it difficult to establish a unified workflow for feeding management *(Nyamuryekung'e et al., 2024)*. Existing intelligent feeding-related devices are typically used for individual functions such as feeding equipment control, RFID-based individual identification, weight acquisition, environmental monitoring, and audio-video behavior recognition. Representative examples include data cleansing for electronic feeding station data *(Garrido-Izard et al., 2022)*, individualized ration supply and precision-feeding strategy validation based on automatic feeders (*Ribas et al., 2024; Spinler et al., 2024; Durand et al., 2023*), behavior-oriented audio-video multimodal recognition *(Yang et al., 2025)*, and association analysis between environmental factors and health/behavior indicators (*Bus et al., 2025*). Furthermore, *Funk et al. (2024)* developed an online monitoring and abnormality warning method for individual feeding behavior based on a low-frequency RFID electronic feeding system, achieving abnormal decline detection in 2,826 finishing pigs, identifying 55.7% of stockperson-diagnosed events, and providing warnings 2.8 days in advance on average. *Decarie et al. (2025*) also proposed and validated a walk-over dynamic weighing system in commercial pig farms, enabling non-invasive automatic body weight estimation while pigs walked through the device and demonstrating the engineering feasibility of a standalone weight-acquisition device. However, because modules are often triggered independently by different hardware and software devices, feeding triggering and execution are easily affected by group-housing behavior, equipment layout, and communication conditions, resulting in missed triggers or record gaps. Data gathered from different sources cannot always be matched reliably, noise and missing data entries are also fairly common, and this raises the amount of work needed for follow-up data cleaning and system maintenance.

In animal feeding, a trigger based on only one signal is easily affected by occlusion, changes in animal posture, and surrounding conditions. These factors can cause false activation and inconsistent data acquisition. When visual information alone is used to control feeding activation, an animal may be detected before reaching the feeding position or before completing the arrival process. Premature detection may therefore lead to invalid triggering *(Scaillierez et al., 2024; Han et al., 2023)*. Weight-only triggering also lacks sufficient reliability. An animal may not stand completely inside the weighing area or may continue moving during measurement. The resulting variation in weight readings can reduce the reliability of the trigger decision *(Zhang et al., 2025)*. Time-based strategies are likewise difficult to align with the actual arrival time of individuals, because the arrival of a preset time point does not necessarily imply arrival at the feeding position, which may lead to empty feeding or repeated triggering *(Bus et al., 2024; Bus et al., 2023; Wallgren et al., 2025; Lagoda et al., 2025)*. Therefore, an organization method based on a controllable on-site process is required to improve the reliability of feeding execution *(Gaillard et al., 2022)* and to provide a stable event entry for multisource information acquisition.

To address these issues, this study designed and implemented an intelligent animal feeding system based on multisource information acquisition. The system uses a single feeding event as the basic operational unit and integrates audio-visual-assisted monitoring, RFID-based individual identification, weight-based arrival confirmation, feeding execution, environmental parameter acquisition, and remote data interaction into a unified workflow. This design establishes continuous associations among target confirmation, trigger decision-making, execution control, and process recording. The camera and microphone array provide visual positional feedback and acoustic directional assistance, respectively. RFID and weight information are jointly used for individual identity verification and arrival confirmation. The acquired body weight, environmental parameters, and device operating status are synchronously uploaded to a mini-program for record retrieval, trend visualization, feeding-plan configuration, and remote management. The system uses OpenMV and a K210 microphone array to support low-cost on-site deployment, local real-time processing, and direct integration with the pan-tilt control system. A DHT11 sensor records the basic temperature and humidity conditions associated with feeding events and provides the environmental information required for functional validation of the prototype rather than high-precision environmental regulation.

On this basis, the study evaluates whether the proposed multisource information coordination mechanism can improve the reliability of target pointing and feeding triggering while supporting continuous process recording and traceability. Based on the complementary roles of different information sources in the feeding workflow, acoustic directional information is expected to assist target reorientation when visual tracking becomes temporarily unstable or is lost. Visual information is expected to provide more accurate positional feedback once the target enters the field of view. Their coordinated use is therefore expected to improve the continuity and stability of target pointing. When RFID identity confirmation is combined with weight measurement to confirm arrival, this method is likely to make the activation of feeding more reliable, but the system needs to wait until the weight reading is stable, and this may make the trigger time longer.

MATERIALS AND METHODS

Overall System Architecture

To achieve multisource information acquisition, this study develops an intelligent animal feeding system, which is mainly composed of two components: a feeding device and a WeChat mini-program. The STM32F103ZET6 microcontroller is employed to implement system control and task scheduling, and coordinate the operation of modules including audio-video assisted target monitoring, animal identity recognition, automatic feeding, and IoT-based environmental data acquisition. Information on animal identity, arrival status, body weight, environmental conditions and feeding execution status is correlated within the system and stored in a structured form. The ESP8266 module is adopted for wireless communication, MQTT supports bidirectional transmission of data and control commands, and the cloud server undertakes storage and forwarding of the relevant data. The WeChat mini-program allows users to view historical records and collected data, set feeding plans, and perform remote control of the system. Additionally, the platform supports centralized storage, remote access, and system maintenance. Figure 1 presents the overall architecture of the system.

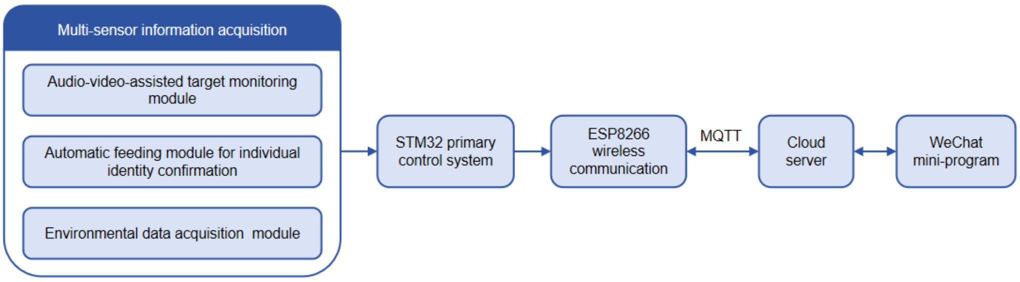


Fig. 1 - Structure diagram of system

Experimental Protocol

The prototype was tested in an indoor nursery pig house. Three weaned piglets were chosen for this experiment. Each piglet was equipped with an RFID ear tag. Their ages were between 21 and 28 days, and their body weight was around 6 to 8 kg. The whole test lasted for three straight days. During the test with combined audio and video for target pointing, a blue visual marker assisted the OpenMV camera with target tracking work, and it also provided support for the control of pan and tilt. Throughout the whole test process, the surrounding temperature stayed between 26 and 30℃, and the relative humidity was within the range of 50% to 65%. The feeding device, RFID reader, weighing platform, OpenMV camera, and K210 microphone array were installed around the feeding port. All devices were calibrated before formal testing.

A complete system operation was defined as a single event-level trial. Consecutive video frames and individual sensor readings were not treated as independent replicates. The audio–visual pointing test comprised a visual-only group, an acoustic-only group, and a combined audio–visual group. The feeding-trigger test comprised an RFID-only group, a weight-only group, and a combined RFID–weight group. Each group included 300 event-level trials, and cases of target loss, feed misdelivery, and missed feeding were included in the statistical analysis. The three piglets were used primarily to establish a representative on-site feeding scenario. Accordingly, the repetitions represented system-event-level replicates rather than animal-level biological replicates. The results were used solely to evaluate the feasibility and operational reliability of the prototype system and were not intended to support inferences regarding population-level production performance or behavioral patterns.

Hardware Design of the Animal Feeding Device

Primary control system

The system adopts STM32F103ZET6 as the main control chip, which is a 32-bit microcontroller manufactured by STMicroelectronics. Under the control and scheduling of the main control system, each subsystem cooperates closely to acquire parameter information from surrounding sensors and connect to the STM32 through GPIO and other interfaces, where local data encapsulation and state management are completed. Subsequently, data are uploaded to the cloud server through the WLAN subsystem, where storage and forwarding are performed and synchronized to the mini-program platform, facilitating real-time access to breeding information and remote management.

The process of the main control system based on STM32F103ZET6 is shown in Figure 2.

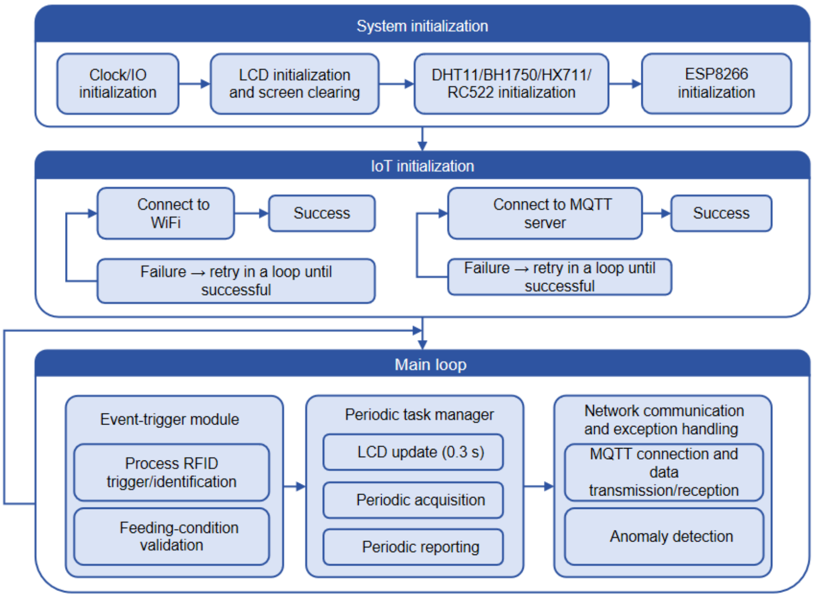


Fig. 2 - Flowchart of the Main Controller

Audio-Visual Assisted Target Monitoring Module

The target monitoring module combines an OpenMV camera with a K210 microphone array to continuously monitor animal targets in the feeding area and provide directional guidance. Visual and acoustic information is collected in parallel. When illumination is weak, the target is occluded, or image quality becomes unstable, the estimated sound direction provides an additional reference for target orientation. The combined sensing approach improves monitoring stability and increases the adaptability of the system under complex environmental conditions.

<u>Target Tracking Based on Image Information</u>

The image-based tracking unit uses an OpenMV module equipped with an OV7725 camera. An animal that enters the feeding range and carries a blue marker is regarded as the current target. OpenMV reads the video stream frame by frame and segments the blue region in the LAB color space using a preset threshold. The centroid offset relative to the image center is then calculated. A PID controller converts the offset into servo control signals and adjusts the pan and tilt angles. During the control process, the target is slowly moved back toward the center of the visual field. Real-time tracking state is maintained all the time. Meanwhile, the identity information of the animal is collected by the RFID reader and writer module. The main controller connects the RFID number with the target position sent back by the camera. The connected information is then used to make feeding records. It also offers support for data tracing work. The functional introduction of the OpenMV module is shown in Table 1.

Table 1

Functional Description of the OpenMV Module

Module Pin	Main Controller Pin	Specific Function
GND	GND	Ground
VIN(3.6-5)	VIN	Power input
UART1_RX	P0	UART receive
UART1_TX	P1	UART transmit

Module Pin	Main Controller Pin	Specific Function
CAN2_TX	P2	CAN bus transmit
CAN2_RX	P3	CAN bus receive
UART3_TX	P4	UART transmit
UART3_RX	P5	UART receive
P6	P6	Reserved analog output or general-purpose I/O
P7	P7	Servo control signal output (pan / horizontal)
P8	P8	Servo control signal output (tilt / pitch)
P9	P9	Reserved general-purpose I/O pin
BOOT0	BOOT	Boot mode selection
FRAMESYNC	SYN	Frame synchronization signal interface
3V3_OUT	3.3V	3.3 V power output
RESET	RST	Reset signal input

OpenMV initializes the camera and acquires image frames through the sensor module. Camera initialization includes sensor reset and configuration of the pixel format and image size. Automatic white balance is disabled to reduce the effect of color drift on detection based on preset thresholds. After initialization, OpenMV continuously captures frames in the main loop. Color blob detection and servo angle updates are performed on each frame to achieve pan and tilt tracking control. Table 2 lists the pixel format, image resolution, and frame skipping setting used during the warm-up stage of image acquisition.

Table 2

Image Acquisition and Operating Parameters

Parameter	Setting Value
Pixel format	RGB565
Image size	QQVGA 160 × 120
Frame-skipping warm-up	10frames
Automatic white balance	Disabled

Color blob detection is carried out on every single frame by the system after a steady image stream is acquired, and the pre-set LAB color threshold is applied in this process. Pixels are screened by the find_blobs() function based on the given threshold, connected regions that meet the detection condition are sorted into different groups. A group of candidate blobs is formed by the obtained regions. Candidate blobs are represented by bounding rectangles, and their centroid coordinates are output as position observations; the pixel discrimination rule is expressed in Equation (1).

To reduce target drift when multiple candidates are present, the system determines the primary target blob using the maximum bounding-rectangle area criterion, as shown in Equation (2), where w_k and h_k denote the width and height of the bounding rectangle of the k-th candidate blob, respectively.

$$M(x,y) = \begin{cases} 1, t_1 \le L(x,y) \le t_2, t_3 \le a(x,y) \le t_4, t_5 \le b(x,y) \le t_6 \\ 0, otherwise \end{cases} \quad (1)$$

Let $L(x,y)$, $a(x,y)$, and $b(x,y)$ denote the values of the three LAB color channels at pixel (x,y). The intervals (t_1,t_2), (t_3,t_4), and (t_5,t_6) represent the calibrated threshold ranges for the L, a, and b channels, respectively.

$$k^* = \underset{k}{\operatorname{argmax}} S_k, S_k = w_k \cdot h_k \quad (2)$$

After the individual target is determined, the system outputs the bounding rectangle and centroid coordinates as tracking results. The bounding rectangle is represented by the four-tuple (x,y,w,h), and conversion between the top-left and bottom-right coordinates is given in Equation (3). The centroid coordinates are obtained from color blob object processing and are used to characterize the target position in the current frame.

$$(x_1,y_1) = (x,y), (x_2,y_2) = (x+w, y+h) \quad (3)$$

To keep the target animal near the center of the field of view, the centroid deviation is calculated with the image center as the reference point. The control signal is then obtained through PID computation. The pitch error is defined as positive upward. The control signal is used to update the pan and tilt servo angles, thereby driving the pan-tilt unit to adjust and gradually return the target to the image center region, as defined in Equation (4). Here, c_x and c_y denote the centroid coordinates of the target, W and H are the image width and height, and w and h represent the width and height of the target bounding rectangle.

$$e_{pan} = c_x - \frac{W}{2}, e_{tilt} = c_y - \frac{H}{2} \quad (4)$$

In the single-target tracking scenario, the system selects the connected region with the largest area among the candidate blobs in each frame as the target marker and outputs its bounding rectangle and centroid coordinates. For visualization and debugging, the circular marker is enclosed by a bounding rectangle in each frame, and a cross marker is drawn at the centroid position to visualize detection and tracking status. The detection and annotation effects are shown in Figure 3.

Fig. 3 - Example of color blob detection with centroid visualization

Target Tracking Based on Audio Information

The system uses a K210 microphone array module as the acoustic sensing unit. The module receives audio information from the feeding area and the surrounding space and determines the direction of the sound source. The main controller is connected to the microphone array through the I^2S digital audio interface. A multichannel synchronous sampling path is built through this connection. Audio signals from different spatial positions can be received at the same time in this way. Multichannel synchronous sampling also provides basic support for sound source direction judgment. The directional information obtained from this process helps realize stable rough target positioning. It works under the conditions of weak light, blocked targets, or incomplete field of view information.

Two main functions are fulfilled by the K210 microphone array in this system. Multi-channel audio signals are collected by this module. The sound source direction of the target animal is calculated based on these signals. This direction information can reflect the position changes of the target's activity area. It provides early direction reference for the rotation of the camera and pan-tilt. The cost of video data collection is reduced in this way. The continuity of monitoring work is improved at the same time. Sound events can also reflect the activity state of the target animal. These events mainly include animal calls and collision noises generated during the feeding process. All kinds of related data are recorded by the system within the same feeding window. These data cover audio direction data, individual identity, body weight and environmental parameters. These records enrich the description of the animal's feeding state. They also provide reference for research on feeding quantity adjustment and related management applications.

The reproducibility of system integration needs to be guaranteed. For this purpose, the interface connections between the K210 microphone array module and the main controller are listed in Table 3. In addition to the I^2S audio signal lines, the module contains LED data and clock lines for directional display and on-site debugging.

Table 3

Pin Connections of the K210 Microphone Array Module

Module Pin	K210 Pin	Function Description
GND	GND	Ground
5V	5V	5 V power supply
BCLK	MIC_CK	I^2S bit clock
WS	MIC_WS	I^2S word select / frame sync
D0	MIC_D0	I^2S serial data output (Channels 0 and 1)
D1	MIC_D1	I^2S serial data output (Channels 2 and 3)
D2	MIC_D2	I^2S serial data output (Channels 4 and 5)
D3	MIC_D3	I^2S serial data output (center microphone channel)
LED_DA	LED_DA	LED data line
LED_CK	LED_CK	LED clock line

To obtain directional information from target animal sounds near the feeding area, the system calls the MIC_ARRAY function of the microphone array for multichannel audio acquisition. Real-time calculations are then performed on the K210. During operation, the system first obtains response intensities from different directions. The dominant direction of the sound source is displayed by the ring LED. Angle and operating status information are also displayed for on-site debugging and parameter calibration. Acoustic processing runs simultaneously with video acquisition, which allows sound and image information to be collected in parallel.

The sound source direction is calculated at fixed angular intervals of 30°. A threshold is first applied to the directional response intensities to remove directions with weak responses and reduce the effect of background noise. The reserved directional components are weighted and combined first. The main azimuth of the sound source is obtained through this step. Smoothing processing is performed afterwards. This step helps improve the stability of the output. Jitter during intermediate calculations is suppressed by recursive filtering. A moving average is used to process the final angle sequence. These two filtering operations prevent the output angle from changing frequently. These changes are caused by intermittent vocalizations or impulsive noise. The real-time response intensity in each angle range is used as the reference. The ring LED indicates the direction based on this reference. Continuous pointing toward the sound source is maintained. The smoothed azimuth angle is adopted as the servo steering input for this purpose. Approximate estimation of the sound source distance is required when distance reference information is needed. This work is completed with the installation calibration constant OneD_Distance. Relative changes of distance are reflected by the estimated distance. This estimated value is applied to reference display and steering control. This distance estimation is not suitable for high-precision ranging.

Servo Control

Some difficulties are caused by insufficient light or unstable target capture by the camera. To deal with these difficulties, the system applies the K210 microphone array to calculate the sound source direction. The calculated result is taken as the control input of the pan-tilt servo. The K210 acquires array audio signals through the I^2S interface and calculates the directional vector of the sound source in the horizontal plane based on directional energy distribution, thereby obtaining the azimuth angle. In addition, to suppress directional jitter caused by noise, recursive smoothing is applied to the directional vector components, and window averaging is applied to the output angle sequence to improve the stability of control inputs.

At the execution level, two servo control signals are configured as PWM outputs. The K210 timer generates control pulses on GPIO pins to drive the two degrees of freedom (pan and tilt) of the gimbal, enabling real-time pointing and maintenance toward the sound source direction. The system simultaneously outputs current directional information on the display and supports operating-mode switching via buttons. The servo PWM control flow is shown in Figure 4.

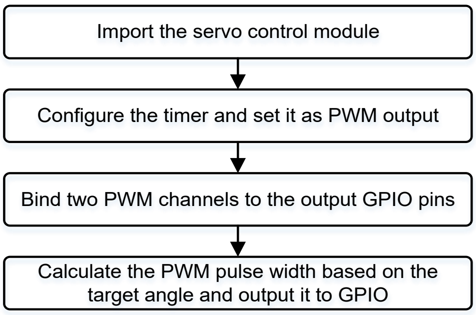


Fig. 4 - Servo control flow based on PWM

Automatic Feeding Module for Individual Identification

The intelligent feeding system is designed for large-scale captive breeding scenarios. Through a closed-loop process including individual identity confirmation, weight and status acquisition, feeding execution, and record uploading, the system realizes scheduled feeding at the individual level. Compared with manual feeding, this scheme can reduce human intervention and feeding errors and provide data support for subsequent growth assessment and traceable management.

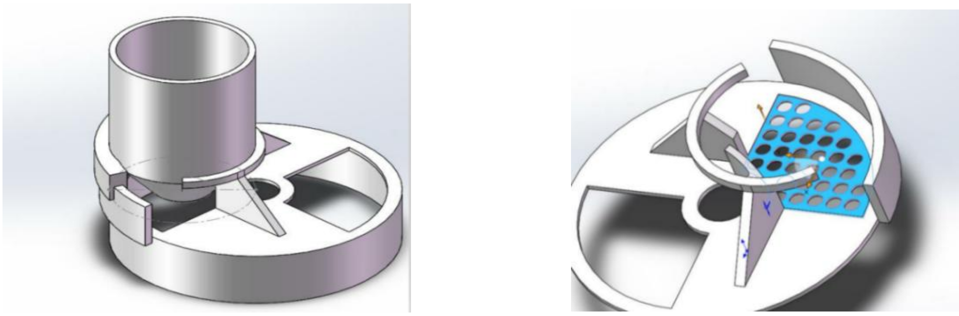
Individual Information Acquisition Module

An RFID reader/writer module is installed near the feeding port to trigger identity recognition when an animal enters the feeding area. After obtaining the unique ear-tag number, the reader/writer uses it as an individual index and binds it with acquired body weight, feeding status, and other information. These data are sent to the main controller or server through the wireless network, and feeding records as well as traceability data for multiple individuals are formed in the end.

Body Weight Information Acquisition Module

Body weight collection work is finished by the weighing module, and this module makes use of a load cell and a 24-bit A/D conversion chip (HX711) in the process. The load cell typically outputs a weak differential signal in the form of a Wheatstone bridge, while the HX711 performs high-gain amplification and high-resolution sampling and outputs digital values. During operation, the main controller reads sampled results at a fixed interval. To eliminate the dead weight of the scale body and installation bias, a tare operation is performed during initialization to record the no-load baseline value. During operation, the real-time sample value is differenced from the no-load baseline, and linear conversion is completed using a pre-calibrated proportional coefficient to obtain the current body weight. The final body weight result is bound to the RFID number read at the same moment and uploaded via the wireless network to the main controller or server for growth recording and feeding control.

Intelligent Feeder Module



(a) Structural diagram of the feeding device *(b) Detail view of the trough structure*

Fig. 5 - Structural diagram of the feeding device and trough

The feeding device and trough are illustrated in Figure 5. The device includes a storage hopper, a feed drop channel, a valve plate assembly, and a trough. An actuator rotates the valve plate so that the valve opening aligns with the feed outlet and the trough inlet at different operating stages. The position alignment controls the switching between feed discharge and closure. The valve changes the way of continuous manual material adding. The process becomes a set of adjustable opening and closing movements. The system uses identity checking and weighing results. It changes feeding ways for different individual situations.

For every single feeding event, the feeding parameters are figured out by the main controller based on the identified individual number and current body weight, and the computed result is changed into a valve plate angle command or an equivalent opening duration. The valve plate is adjusted and reset by the actuator as required by the control instruction. The controlled positioning process makes the feeding amount and feeding time repeatable. The valve plate is rotated in separate stages by the drive motor, and this action adjusts the feed output and pushes the whole feeding process forward. The angle control of the valve plate follows the alignment restrictions between the valve plate and the openings.

Environmental Data Acquisition Module

Light, temperature and humidity in the feeding region can affect animal activity and feeding status. Sensors for light, temperature and humidity are installed around the feeding place. These sensors are used to keep records of these environmental conditions. These sensors test light intensity, air temperature and air humidity at fixed time intervals. After the system begins to work, the main control device gets the sensors ready. It collects data from these sensors at regular periods. The system checks and changes the gathered data first. Then the data are shown on local equipment or sent through the communication device.

Light intensity is measured by the system using a BH1750 digital light sensor, and the collected data are sent through the I^2C bus. During initialization, the system configures the I^2C pins and the operating mode of the sensor. During data acquisition, the main controller first checks the device acknowledgment to confirm normal bus communication. The measurement result is then read and converted into a light intensity value that represents the illumination condition of the feeding area. The DHT11 sensor is used to collect temperature and humidity data, and the whole collection process follows a single-wire timing protocol. During sampling, the main controller first sends a start signal. The data frame is then read according to the specified timing and checked for validity. When verification is successful, the temperature and humidity values are parsed. The sensor should be installed away from heating elements to reduce the effects of local heat sources and structural heat dissipation. Adequate air circulation should also be maintained around the sensor. The installation arrangement improves the stability and representativeness of the measurements. Figure 6 shows the flowchart of the light acquisition module, while Figure 7 shows the flowchart of the temperature and humidity acquisition module.

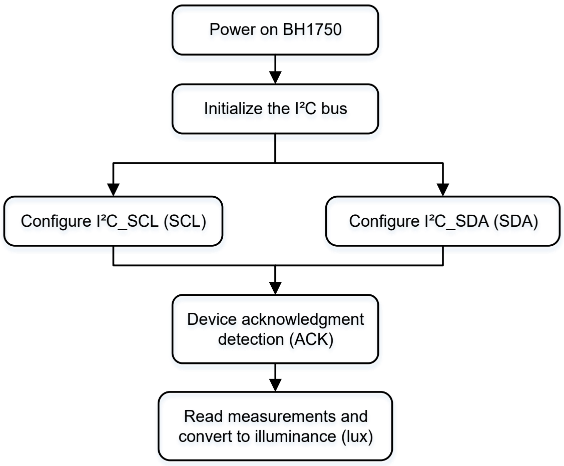


Fig.6 - Flowchart of the Light Control Module

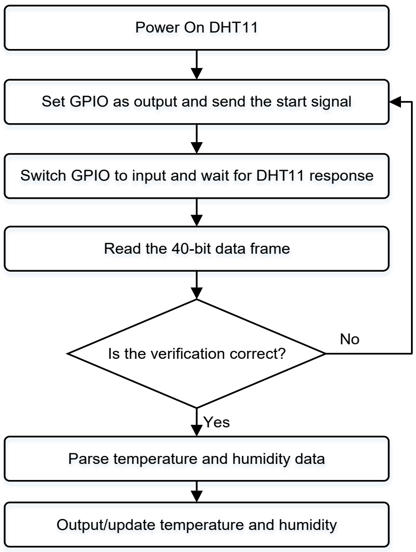


Fig. 7 - Temperature-Humidity Sensor Module Flowchart

Remote monitoring and control of the feeding device are implemented through an ESP8266 wireless communication module. The ESP8266 connects to the main control board through a serial interface and accesses the local area network in the feeding area. After startup, the module completes network access and establishes an MQTT connection with the IoT platform through the TCP-based MQTT protocol. The system publishes environmental parameters and other operating data to upstream topics at fixed intervals. The platform receives the published data for storage and interface display. The device also subscribes to downstream topics and receives control commands from the mini-program. The received commands support remote control and parameter configuration. Uploaded data are organized into structured fields. The fields include key environmental parameters such as temperature, humidity, and illumination. Device operating status fields may also be included. The structured format facilitates data parsing, storage, and trend visualization on the platform. The mini-program sends control messages to the device through the platform. After receiving a message, the device parses the command and performs the corresponding action or parameter update. Basic exception handling is included to support stable field operation. The communication module retries the connection after a connection failure and reconnects after a disconnection. The retry and reconnection mechanisms maintain the availability of data reporting and control links during network fluctuations.

Software Design of the Feeding System

The WeChat mini-program is taken as the interface for information aggregation and user interaction in this system. This platform offers centralized data display and remote control for livestock breeding, and it supports the combined workflow of production and marketing. For the hardware part, data from multiple sensors are collected by the STM32, and the operation of devices is also controlled by it. Wireless network connection and data transmission are supported by the ESP8266. The collected data are shown on the WeChat mini-program, and related control functions are also provided on it. Feeding information, body weight data, images and environmental data collected in the feeding area are sent to the mini-program at the same time. The information can be viewed and managed by users in real time. This integrated data flow helps realize precise feeding, and it also cuts down the waste of feed.

The device connects to a router or mobile hotspot through the ESP8266 and establishes an MQTT connection over TCP. The hardware publishes sensor data and device status to the pcTopic topic. The cloud server mqtt1tbtb.xyz forwards the published messages. The WeChat mini-program subscribes to pcTopic to receive and display the data. The mini-program also sends MQTT control commands for the remote operation of devices such as buzzers and lighting LEDs.

Client Side

The client interface is available to users and provides a unified entry point for product selection, intelligent services, and reservation services. The mini-program contains five pages, namely Home, Category, Recognition, Reservation, and Personal Center. The Home page brings together the main functions of the platform, including the animal encyclopedia, animal feeding, video monitoring, AI animal recognition, and AI-powered question answering. Users can quickly access remote feeding, status viewing, image recognition, and health service functions from the Home page. The Category page uses a layout with categories on the left and item lists on the right to display animals and related supplies. Users can add items to the shopping cart and complete checkout, forming a complete process from product browsing to order placement. The Recognition page allows users to upload an image by taking a photograph or selecting one from the album. The page then returns the pet recognition result and corresponding basic information. The Reservation page provides access to medical consultation and home service appointments. Users can complete and submit reservation information and review previous reservation records. The Personal Center provides the login entry and includes order viewing, About Us, online customer service, and sharing functions. Figure 8 presents the functional structure of the client interface.

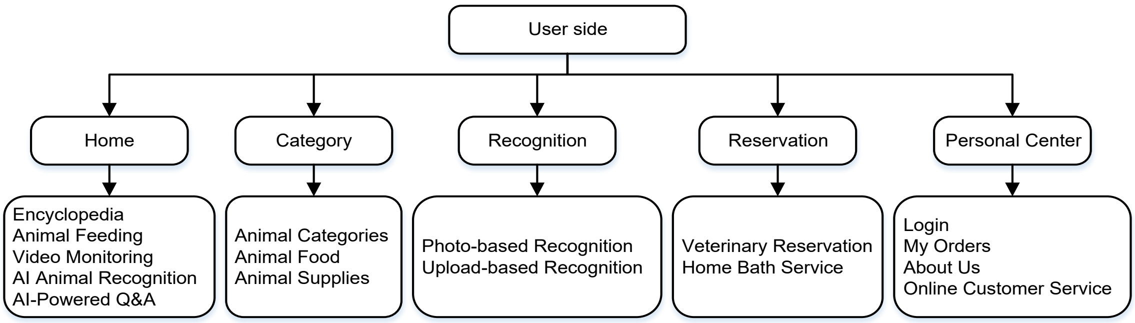


Fig. 8 - Functions of the client-side app

Deployment Side

This module serves to monitor and manage feeding work and surrounding environment in large-scale breeding sites in a unified way. A variety of sensing devices and video shooting devices are set up around feeding zones. These devices can work nonstop to gather various data. The collected information includes temperature, moisture, light intensity, animal weight and other related breeding indicators. Individual data and environmental data for each animal are aggregated using individual identifiers as indices, enabling feeding personnel to grasp group status in real time and providing a basis for subsequent intelligent feeding decisions and data analysis.

After data association is established between the mini-program and field devices, device acquisition results are synchronously transmitted to the mini-program for display. Uploaded data mainly include feeding information, body weight information, environmental information, and image information captured by the camera. Users can centrally view and compare state changes on the page, thereby assisting in feeding amount adjustment and management strategy optimization, reducing feed waste, and improving management efficiency. The deployment-side data acquisition and classification architecture is shown in Figure 9.

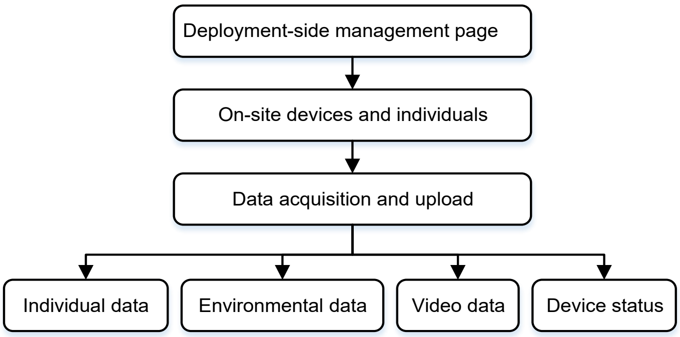


Fig. 9 - Deployment-Side Data Acquisition and Classification Architecture

On the deployment-side interface, users can centrally view individual and environmental data and remotely control lower-level actuators. The system establishes a wireless network connection through ESP8266, allowing the lower-level device to access the cloud message service as an MQTT client. The device uploads collected temperature, humidity, illumination, body weight, and device operational status to the cloud at the configured interval, and the cloud forwards the data through fixed data channels. After the mini-program connects to the cloud, it continuously listens to the data channel and receives new data in real time to refresh the page display.

For the control link, operations such as turning on the buzzer and turning off lighting are sent by the mini-program to the cloud control channel. The lower-level device continuously listens to the control channel and, after receiving control content, determines the required action according to predefined control fields, then drives actuators such as the buzzer and LED to respond. After execution, the lower-level device can upload the latest status again for synchronization on the mini-program interface. The mini-program control flow for the lower-level device is shown in Figure 10.

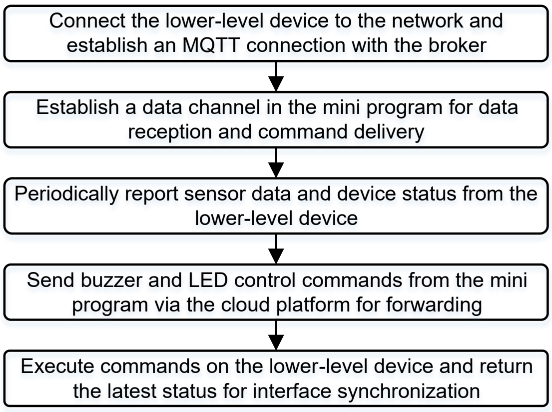


Fig. 10 - Mini-Program Control Flowchart for the Device Side

RESULTS

Test Results and Analysis

To verify the availability and trigger reliability of the system in practical feeding scenarios, comparative tests were conducted for (i) audio-video pointing and observation performance and (ii) feeding target confirmation and triggering performance. For the audio-video comparison, three experimental groups were set: video, audio, and audio and video. For the feeding trigger comparison, three experimental groups were set: RFID, weight, and RFID and weight. Each experimental group included 300 event-level trials. The final results were sorted and summed up based on the indexes shown in Table 4 and Table 5.

Table 4

Comparison Results of Audio-Video Pointing

Group	Configuration	Pointing Success Rate (%)	Loss Rate (%)	Mean Re-stabilization Time (ms)
A	Video	78.33	21.67	230
B	Audio	66.00	34.00	310
C	Audio and Video	92.67	7.33	145

The share of test runs with stable pointing is called pointing success rate. The stable state is kept during the whole fixed observation period. The loss rate describes the percentage of test cases. These cases include target loss or obvious direction error in pointing. The mean re-stabilization time refers to the average time required to restore stable pointing after target loss. It is used to rebuild stable pointing after the target is lost. Three hundred event-level test runs were arranged in each experimental group.

Three key indexes of the three test schemes are shown in Table 4. They are pointing success rate, loss rate and average re-stabilization time. For the video test group, the pointing success rate reached 78.33%. The loss rate of this group was 21.67%. The average re-stabilization time was 230 ms. For the audio test group, the pointing success rate was 66.00%. This rate was lower than the video group. The loss rate of the audio group reached 34.00%. This rate was higher than the video group. The average re-stabilization time was 310 ms. It was also longer than the video group. The test result of the audio group shows that only sound direction cues cannot offer enough stability. They cannot support stable pointing and continuous observation well. The test group using both audio and video got the best test effect. Its pointing success rate rose to 92.67%. The loss rate fell to 7.33%. The average re-stabilization time was reduced to 145 ms. When the target cannot be seen for a short time, or the pointing direction goes wrong, audio information can offer direction guidance. It helps to make the re-stabilization time shorter. After the target comes into the view range, video information provides clearer position feedback. It helps to keep pointing more stable. Using audio and video together obviously reduces the loss rate. It also increases the proportion of stable pointing. This improved performance makes on-site observation and debugging more continuous.

Table 5

Comparison Results of Feeding Target Confirmation and Triggering

Group	Decision Method	Trigger Accuracy（%）	Misdelivery Rate（%）	Missed-feeding rate（%）	Mean Trigger Delay（ms）
A	RFID	92.00	2.00	6.00	300
B	Weight	82.33	6.67	11.00	2500
C	RFID and Weight	93.33	2.00	4.67	2200

Trigger accuracy is defined as the proportion of cases in which the system successfully executes feeding when the target animal has arrived and the RFID identity matches. The misdelivery rate is defined as the proportion of cases in which feeding is still executed when the target has not arrived or the RFID identity does not match. The missed-feeding rate is defined as the proportion of cases in which the target animal has arrived and the identity matches, but the system does not execute feeding. Trigger delay is defined as the average time from the moment the animal arrives and is successfully recognized to the start of feeding execution. For the weight group, the trigger condition was that the weight reading exceeded a threshold and satisfied a stability-window condition. Identity matching was used only for statistical evaluation, with RFID used as the ground-truth label, and RFID did not participate in trigger decision-making for the weight group. Each experimental group included 300 event-level trials.

Table 5 reports the trigger accuracy, misdelivery rate, missed-feeding rate, and mean trigger delay for the three decision methods. For the RFID test group, the correct trigger rate was 92.00%. The wrong feeding rate was 2.00%. The missed feeding rate was 6.00%. The average trigger delay time was 300 ms. These test data show that RFID can finish target confirmation quickly. However, missed feeding may still occur. This situation appears when the animal does not stay in a stable position. It also happens when RFID signal reading conditions are influenced. For the weight test group, the correct trigger rate was 82.33%. The wrong feeding rate reached 6.67%. The missed feeding rate was 11.00%. The average trigger delay time was 2500 ms. The trigger delay time increased obviously. Both the wrong feeding rate and the missed feeding rate remained at relatively high levels. The unstable body posture of animals causes fluctuations in weight reading values. For this reason, the judgment method that only uses weight threshold has clear shortcomings. It has difficulty balancing trigger speed and trigger correctness. For the test group using both RFID and weight detection, the correct trigger rate rose to 93.33%. The wrong feeding rate fell to 2.00%. The missed feeding rate dropped to 4.67%. The average trigger delay time was 2200 ms. The results of the combined test show that RFID confirmation works effectively. It can reduce the risk of wrong feeding caused by target matching errors. Weight information improves the reliability of arrival determination. Although the joint decision sacrifices some triggering speed, it significantly improves trigger accuracy and feeding reliability and is therefore more suitable for long-term field operation.

Taken together, the two sets of comparative results indicate that the combined audio and video configuration improves the continuity of pointing and observation, reduces loss, and shortens re-stabilization time, whereas the combined RFID and weight decision improves feeding trigger accuracy and reduces misdelivery and missed delivery. These findings demonstrate that the system has good engineering usability under field conditions and can support target confirmation, information acquisition, and feeding execution during the feeding process.

Each of the 300 tests in every group was treated as one complete system event. After each event, the current decision state was cleared to minimize carryover between successive tests. Therefore, the results represent repeated observations at the system event level. The higher pointing success rate and shorter re-stabilization time obtained with the combined audio and video configuration may be explained by the complementary roles of the two information sources under different observation conditions. Visual information provides relatively accurate positional feedback when the target is clearly visible. Acoustic information is not used for precise localization. Instead, it provides a directional reference for pan-tilt reorientation when visual tracking is temporarily degraded or the target is lost. Previous studies have shown that variations in illumination, animal posture, and environmental conditions can affect the stability and generalization of visual monitoring systems in pigs *(Scaillierez et al., 2024; Han et al., 2023)*. The present results further show that acoustic directional information can provide supplementary cues when visual observations are limited, thereby improving monitoring continuity. This finding is consistent with previous studies on the complementary use of audio and visual information in animal monitoring *(Yang et al., 2025)*. In the feeding trigger process, RFID and weight information correspond to identity verification and arrival confirmation, respectively. Previous studies have commonly used RFID-based systems for individual identification and feeding behavior recording *(Funk et al., 2024)* or weighing devices to acquire body weight information *(Decarie et al., 2025)*. In the present system, both signals are incorporated into the same trigger decision. Feeding execution is therefore constrained by both individual identity and physical arrival at the feeding position. This approach was associated with improved trigger reliability in the present tests, although the stability check for the weight signal also increased trigger delay. Overall, the results indicate that the multisource information coordination mechanism improved monitoring continuity and feeding trigger reliability, thereby supporting the feasibility and operational reliability of the prototype system.

CONCLUSIONS

To meet the requirements of refined feeding and traceable management, this study designed and implemented an intelligent animal feeding system based on multisource information acquisition. The system uses STM32F103ZET6 as the control core, incorporates visual and audio sensing units, and integrates RFID-based identity recognition, weighing, and environmental parameter acquisition modules. When an animal enters the feeding area, the system can perform target monitoring and localization, individual identity confirmation, and acquisition of body weight and environmental parameters, and can upload the acquired results together with feeding execution status to form multi-target feeding records and a remote management link, thereby providing a feasible data basis for subsequent physiological assessment and traceability applications.

(1) The system uses an OpenMV camera to detect color blobs with preset color thresholds and to control pan and tilt tracking. A K210 microphone array provides directional information about the sound source. The acoustic direction is used to maintain target pointing when illumination is weak or camera observations are unstable. The combined sensing method improves continuous monitoring under complex lighting and occlusion conditions. Under the combined audio and video configuration, the pointing success rate was 92.67%, the loss rate was 7.33%, and the mean re-stabilization time was 145 ms.

(2) In multi-target feeding scenarios, an RFID reader and writer module at the feeding port obtains each animal's unique ear tag number, while an HX711-based weighing unit collects body weight information. Identity and body weight are then synchronously associated as key variables for each feeding event. The system also controls the feeding mechanism for individualized feeding. This changes feeding from a manual, experience-based process into one that is controllable, recordable, and reproducible. The workflow provides an implementation path for individualized and differentiated feeding. Under the combined RFID and weight configuration, the trigger accuracy was 93.33%, the misdelivery rate was 2.00%, the missed-feeding rate was 4.67%, and the mean trigger delay was 2200 ms.

(3) Different kinds of environmental data like temperature, humidity and light are collected by this system. Network connections are built through the ESP8266 device. MQTT is used to finish uploading data and sending commands. The WeChat mini-program serves as the information aggregation and interaction interface, enabling visualization of feeding records and body weight/environment trends, and supporting remote control and parameter configuration. Through multisource data acquisition and interaction, the system enables end-to-end monitoring and management.

Future work may introduce target tracking and re-identification algorithms to maintain continuous individual tracking in multi-target scenarios, reduce identity interruption caused by occlusion and interaction, and preserve individual identity as much as possible during unstable card reading or short-term occlusion. To enrich animal state information, non-contact sensors such as infrared and radar can be added to the existing device and aligned/fused with existing video and audio data to form more complete multi-target datasets. Based on continuously accumulated multisource data, animal health status can be predicted, health anomaly detection and risk alerts can be performed, and feeding adjustment recommendations can be generated, thereby further improving the level of refined management.

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