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Long-range-based Intelligent Farming Management System

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Agriculture and animal husbandry form the backbone of a country, and the global shortage of food and meat products has intensified efforts to increase agricultural production and livestock farming for self-sufficiency. Taiwan is importing most farm produce and livestock products, which makes it urgent to enhance agricultural and animal husbandry production capacity. All industries, including agriculture and animal husbandry, are experiencing a severe labor shortage, exacerbated by an aging workforce. To solve the labor shortage, industrial innovation in agriculture and animal husbandry is also necessary to increase the quality and quantity of the products with limited labor availability. Therefore, we developed a farming management system using intelligent automation technologies. We adopted a long-range (LoRa)-based monitoring system for the real-time monitoring and control of agriculture and animal husbandry. The system was equipped with sensors to detect and control environmental parameters, including temperature and humidity, to ensure the stable growth and high survival rate of livestock. To ensure sufficient space and water sources for livestock, ponds were integrated into the system enabling aquaculture and agriculture by using plankton generated from the livestock's organically processed manure. The developed farming management system increases the amount of farm produce and livestock yield through a symbiosis approach.

1. Introduction

Organic farming was first advocated by Steiner in 1924.(1) Then, a major purpose was to increase crop production via the industrialization and commercialization of agriculture with organic farming mainly ignored. After World War II, synthetic materials such as chemical

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fertilizers, synthetic pesticides, and agricultural machinery were introduced into agriculture to enhance productivity. However, natural resources have been over exploited, which has depleted the resources and harmed the environment.(1) Since the 1970s, the global society has paid considerable attention to maintaining environmental quality and living standards, ensuring sustainable development for future generations, and minimizing the energy crisis.(2)

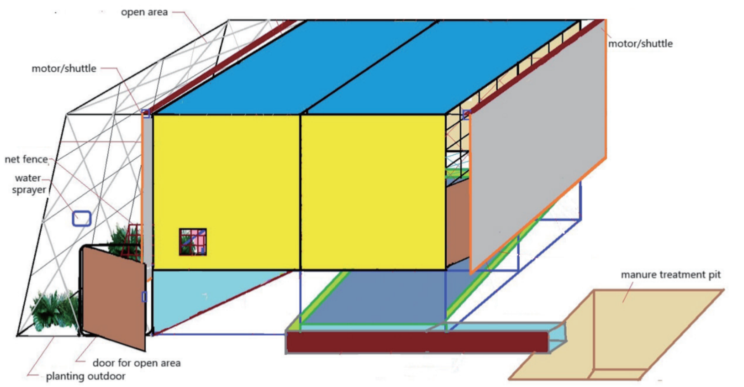
In farming, environmental parameters including air temperature, humidity, illuminance, and soil moisture are critical factors in growing plants and livestock.(3–5) Various technologies to control such parameters have been implemented. For example, temperature is controlled using cooling fans and solar equipment in farming.(6,7) Recently, to enhance the productivity of agricultural products, online remote network systems have been introduced.(8–12) For example, poultry growth was optimized by regulating dietary diversity and adjusting the height of growth platforms.(13) Since environmental changes significantly affect hydrology and water resources considerably,(14–16) effective water management is essential to solve groundwater scarcity.(17) In mountainous areas with high evaporation rates, only 10–14% of precipitation is preserved in the surface water.(18,19) In inland farms, the overuse of groundwater leads to the subsidence of landmass.(20) In Taiwan, 10% of the agricultural land was subsided in the Yilan, Changhua, Yunlin, Chiayi, and Pingtung areas.(21) Although precipitation is large in Taiwan, water storage is poorly managed owing to a lack of and inefficient water conservation management.

Sung and Hsiao applied LoRa technology in implementing a secure long-range wireless sensor network that collects and fuses multisensor localization data, and transmits the results to a central monitoring system for applications such as energy, environmental, and security management.(22) Bonilla *et al.* presented a Long Range Wide Area Network (LoRaWAN), which is a low-power, long-range communication protocol widely used in IoT applications such as environmental monitoring, agriculture, health, and mobility.(23) In this study, we review LoRaWAN applications, commonly used devices, and research efforts on performance and security, highlighting its broad applicability and optimization potential. Chen *et al.* proposed a self-sustaining greenhouse using renewable energy, rainwater harvesting, and sensor-based automated control to support sustainable agriculture.(24) Long-range communication enables remote monitoring and operation without relying on Internet connectivity, making the system suitable for remote areas. In this study, we developed a long-range (LoRa)-based management system to enhance livestock and poultry growth to increase related production. To enhance poultry production, a large activity space is required for poultry's sufficient movement. In addition, to ensure a comfortable habitat environment, we deployed temperature and humidity sensors in conjunction with a microcontroller and actuators (cooling fan, mist sprayer, and heating device) to regulate environmental conditions within the habitat area. For poultry growth, indoor and outdoor activity spaces are required, and we implemented an elevated platform in the indoor space. For efficient feed management, an organic planting area was integrated into the outdoor area. The developed system facilitates organic vegetable farming to sustain livestock and poultry and meet consumer needs. To ensure sufficient moisture in the soil, sensors were installed with a sprinkler system. We developed an organic processing module for the manure on the installed slope plate using a water pump for efficient processing. To save water, an ecological pond was added to utilize rainwater. The level of water in the pond was regulated using water level sensors and a water pump. We introduced a hybrid method to process the manure and use it as organic fertilizer for farming.[11] The grown organic plants and fish in the system were fed to poultry and livestock. A farm is usually located remotely, which necessitates a stable and self-sufficient energy resource and a protection method from wild animals. Therefore, we integrated a wind turbine (a three-blade wind turbine rated at 12 V DC and 30 W) and a solar power generation module (rated at 12 V DC and 30 W) and a far-infrared sensing module with warning and alarm systems. The generated electricity is routed to a control unit that manages battery charging and prevents overcharging and reverse charging. To address a lack of online networks, a network-free LoRa network was utilized to monitor and control the system.[25]

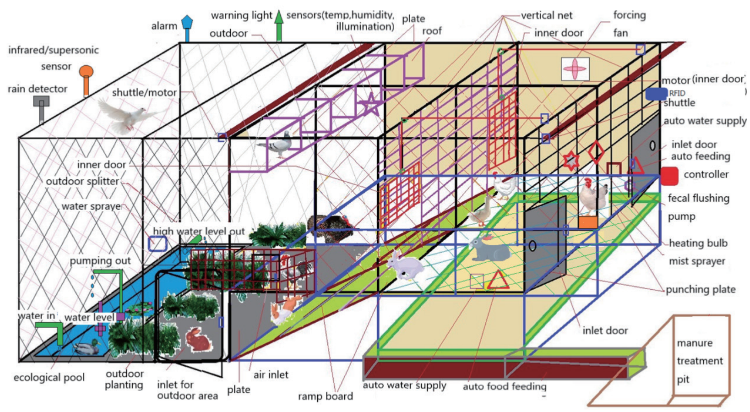
2. Methodology

2.1 System development

To grow poultry and livestock such as chickens, ducks, birds, and rabbits, we designed the whole system as shown in Fig. 1. The system integrates fish ponds, a planting area, and dedicated



(a)



(b)

Fig. 1. (Color online) Developed system to grow chickens, ducks, birds, and rabbits. (a) Three-dimensional diagram of developed system. (b) Detailed illustration of developed system.

livestock spaces to ensure efficient resource utilization. The fish pond is located close to the planting area for filtering water. To control the water level, we installed drainage pipes and water level sensors to discharge excessive water to the planting area and supplement water using a water pump (a 110 V AC submersible pump). Fruit trees and leafy vegetables are planted as such mixed planting reduces pests and diseases. Leafy vegetables are separated from fruit trees using a movable purse seine for efficient organization and management, and feeding the poultry. In the planting areas, a soil moisture sensor (YL-69) is installed to detect the soil humidity and supply water via a water sprinkler (composed of a 110 V AC submersible pump with sprinkler nozzles) automatically when the soil moisture becomes low. The indoor area can be separated with movable net doors for the livestock to breed and control its entry and exit. Rain sensors (FC-37 sensors with a large surface area of 5.0×4.0 cm^2, nickel-plated for oxidation resistance and enhanced conductivity) together with an illuminance sensor GY-30 (BH1750FVI) and RFID (UHF-R200 module, UHF reader–writer and radio-frequency identification module) are implemented to open or close the roof and gates, and count the number of livestock to control the movement of the livestock. A pull-out wind curtain is installed outside the gate to shield the system inside from strong wind and rain. At the bottom of the system, a slope plate is installed to collect feces efficiently. The feces on the floor and plate are collected regularly by using a water pump (a 110 V AC submersible pump) and transferred to a manure treatment pit using a manure collection device for composting, fermentation, and decomposition. During fermentation, layers of manure and soil are alternately added to enhance the process in the concrete pit of the system.

To provide livestock with a suitable growth environment, environmental temperature and humidity sensors (DHT11) were installed in the living area. Temperature and humidity are controlled with a fan (a seven-bladed fan with dimensions of $50 \times 50 \times 20$ mm^3 operating at 12 V DC), a 100 W ceramic infrared heat lamp (nonilluminating), and a mist sprayer (12 V 100 W compact pressure pump, 110 V AC to 12 V DC 10 A transformer, and 500 cm low-pressure spray tubing). Automatic feeding and water supply devices are also installed in the rest area for livestock and poultry. Fish ponds and planting areas (fruit trees, leafy vegetable plants, and pastures) in the outdoor area are also used for animal activities and as an additional natural feeding area to reduce feeding costs and increase meat quality. Poultry feeds on insects on the plants. The processed manure is used to increase the quantity of plankton in the pond for the growth of aquatic organisms. For safety and effective breeding management, poultry is kept in the system using a full-net fence, which is also effective in protecting it from wild animals. Infrared sensors, warning lights, and network cameras (wide-angle, 4 MP, 2.5K high resolution, full-color day/night, pan-and-tilt) are installed around the fence to detect foreign objects. Network cameras capture scenes and images continuously around the system, which are uploaded to a cloud server. When the IP camera detects an intrusion in the captured image, an intrusion alert is pushed to the farmer's mobile phone via a wireless network, allowing the farmer to view the image and confirm the presence of an intruder. An on-site warning light (800 mAh) is also activated to deter intruders. In addition, to prevent network failures at the farm from causing the IP camera to be unable to transmit intrusion alerts, the system is also equipped with a passive infrared sensor (PIR-501AC / PIR-5010C; operating voltage: AC 110–220 V; detection angle: 75° vertical and 130° horizontal; sensing distance: 8 m; delay time: 15–

600 s). When an intrusion is detected, the intrusion signal is sent to the microcontroller and then forwarded to the farm owner's remote personel computer (PC) via the LoRa module. Such a system notifies farmers in case of emergencies. The inventory of the livestock is monitored using RFID to ensure its safety. Owing to a lack of network access and the remote location of the system, the LoRa remote communication system is used for data transmission.

2.2 Data transmission and communication

The LoRa used in this study is a wireless modulation technology designed for low-power, long-distance data transmission in IoT systems. It is widely used in Low-Power Wide Area Networks (LPWANs). LoRa works in data transmission and communication and has been compared with other technologies, as shown in Table 1. It has some of the key features and mechanisms as follows.

A. Physical Layer – Chirp Spread Spectrum (CSS)
LoRa uses a CSS modulation method to transmit data. Signals are "chirped" (frequency increases or decreases over time), which spreads the signal over a wide bandwidth. This improves resistance to noise and interference and allows the reception of very weak signals below the noise floor.

B. Long-range Communication
Because of CSS and operation in sub-GHz unlicensed frequency bands (e.g., 433, 868, and 915 MHz), LoRa transmissions can span several kilometers in urban or rural environments without requiring high transmission power.

C. Low Power Consumption
Devices can sleep and only transmit briefly; LoRa supports asynchronous communication that reduces listening power. It trades off data rate for range and power efficiency.

LoRa excels in range and low energy use but has lower data rates and higher latency than cellular or Wi-Fi. It has a lower throughput but much better range and battery life than short-range protocols or cellular networks without base infrastructure.

Sensed environmental parameters including air temperature, air humidity, soil humidity, illumination, water level, gate operation, cleaning operation, feeding, and security checking are monitored and controlled using various sensors and RFID. The monitoring data are wirelessly

Table 1
LoRa is often compared with other wireless communication options for IoT as below.

Technology	Range	Data Rate	Power Consumption	Notes
LoRa/LoRaWAN	Long (km)	Low (kbps)	Very low	Suited for sparse, long-range IoT data
Bluetooth	Short (≈10 m)	Moderate	Moderate	Best for personal area networks
Wi-Fi	Short-Medium (~100 m)	High	High	High throughput, not energy efficient for sensor IoT
NB-IoT / LTE-M	Long with infrastructure	Moderate	Moderate	Cellular IoT with better QoS but higher cost and power
Sigfox	Long	Ultralow	Low	Very limited payload size

transmitted to a remote control center via the LoRa (wireless transmission module SX1278/1276 LoRa, 8000 m range) protocol. The data are stored in a Microsoft Excel format on the remote server. The remote server is connected to a cloud server through the Internet. All the sensors are controlled by an Arduino Mega 2560 microcontroller (Fig. 2).

The control logic diagram of the near port for environmental parameter sensing, feeding, and security checking is shown in Fig. 3. Figures 4–6 show the flowchart of environmental parameter sensing, feeding, and security checking, respectively, and Fig. 7 presents the control logic diagram of the remote port.

The heater and fan of the system are activated when the temperature is detected as lower or higher than the threshold lower and higher values. The water sprinkler operates when the soil and air moisture is lower than the threshold. The water pump installed on the pond is operated to maintain its water level. The water pump is also used to clean and transfer the feces on the slope plate. During the day without rain, poultry is allowed to move to the activity space. Poultry is fed by the automatic feeding device (Fig. 4). Food and water are supplied according to the monitoring results of the infrared sensor and the water level gauge (Fig. 5). Feed is delivered by using a server motor that opens a feeding hole when the feed level is detected as lower than the preset

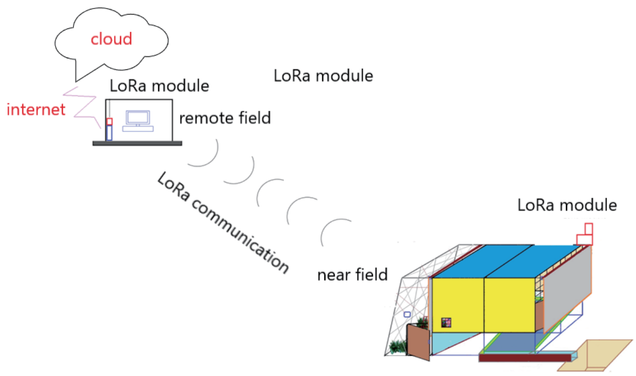


Fig. 2. (Color online) Data communication between developed system and remote server.

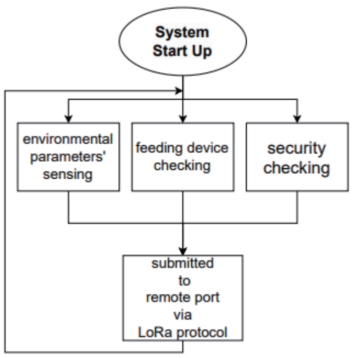


Fig. 3. Control logic diagram of near port for environmental parameter sensing, feeding, and security checking.

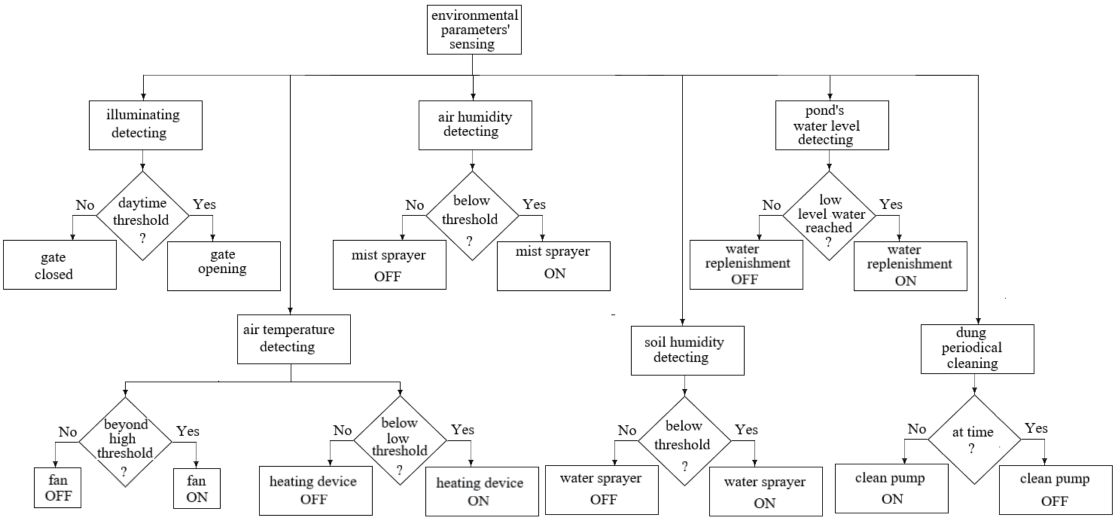


Fig. 4. Flowchart of environmental parameter sensing in near port.

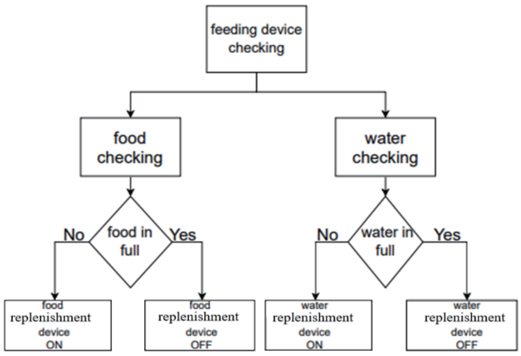


Fig. 5. Flowchart of food device checking in near port.

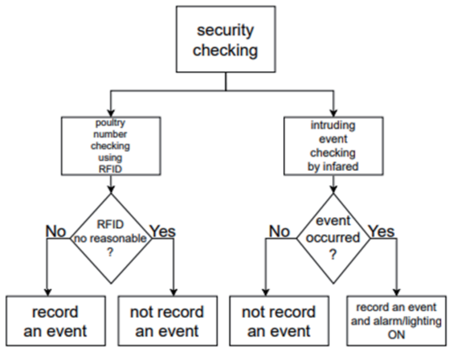


Fig. 6. Flowchart of security checking in near port.

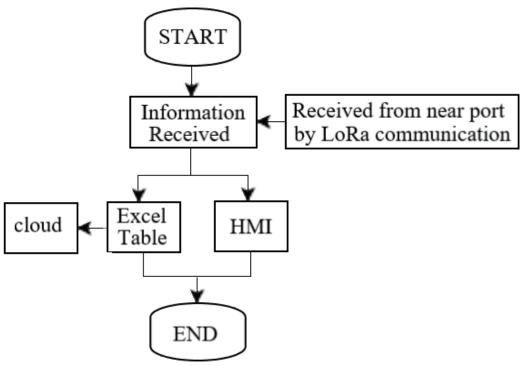


Fig. 7. Control logic diagram of remote port.

level. Similarly, the water pump is operated according to the detected water level of the water tank for the poultry.

The number of poultry is detected using RFID. Infrared sensors are installed on the net to detect the intrusion of animals. The alarm and lights are actuated when an intrusion is detected. Data on missing poultry and intrusions are transmitted to the remote server to warn farmers (Fig. 6). The remote port receives the monitored data of the system from the near port via the LoRa communication. The data are stored in a Microsoft Excel format and presented on the human–machine interface (HMI) of the remote server (Fig. 7).

3. Results and Discussion

To enhance the capacity of agriculture and animal husbandry, we developed an intelligent management system. To mitigate the effect of the lack of Internet access in a remote area, a LoRa-based communication system was adopted in the system. The online monitoring and automatic management capacity of the developed system enables stable growth and a high survival rate of livestock and poultry. To promote the quality of the livestock poultry products, an outdoor space with a planting zone and a pond is included in the system. Water quality and level are sustained by using the ponds and fish dwelling in it. Plankton in the pond effectively and organically processes livestock feces. The program was created to control the system (Figs. 8 and 9). In Fig. 8, the abstract of the program is the livestock counting by the RFID module. In Fig. 9, the habitat temperature is regulated by a fan based on a predefined temperature threshold. When the detected temperature exceeds 27 °C, the fan is activated and the temperature indicator turns red; otherwise, the fan remains off and the indicator is shown in green. For the automated monitoring and control of environmental parameters, feeding and watering devices, and security, actuators and sensors are integrated into the system (Fig. 10). An alarm system is also integrated to alert farmers of emergencies such as security warnings, a loss of livestock and poultry, and intrusion. The prototype of the developed system and the output data are presented in Figs. 11 and 12, respectively.

We compared related studies on smart farming. Karthikeyan *et al.* integrated various sensors (e.g., gas sensors) to detect hazardous environmental conditions and used actuators and automation modules to enhance farm safety.(26) However, their study primarily focused on a single safety function (such as gas detection) and did not consider system stability and accuracy under multiple environmental interferences or false alarm scenarios. Terence *et al.* reviewed the applications of IoT in livestock management, including animal and environmental monitoring, automated environmental control, and data management.(27) Nevertheless, IoT systems tend to be relatively costly and lack adequate data storage mechanisms, which can affect user adoption. Sutanto *et al.* proposed an automated poultry farm system that integrates IoT and edge computing, using a microcontroller to control automated functions such as feeding and water supply, thereby reducing labor.(28) However, in this study, they did not thoroughly test the system's reliability under complex environmental changes, such as network instability or equipment failures.

Fig. 8. (Color online) Abstract of control program for near port of developed system.

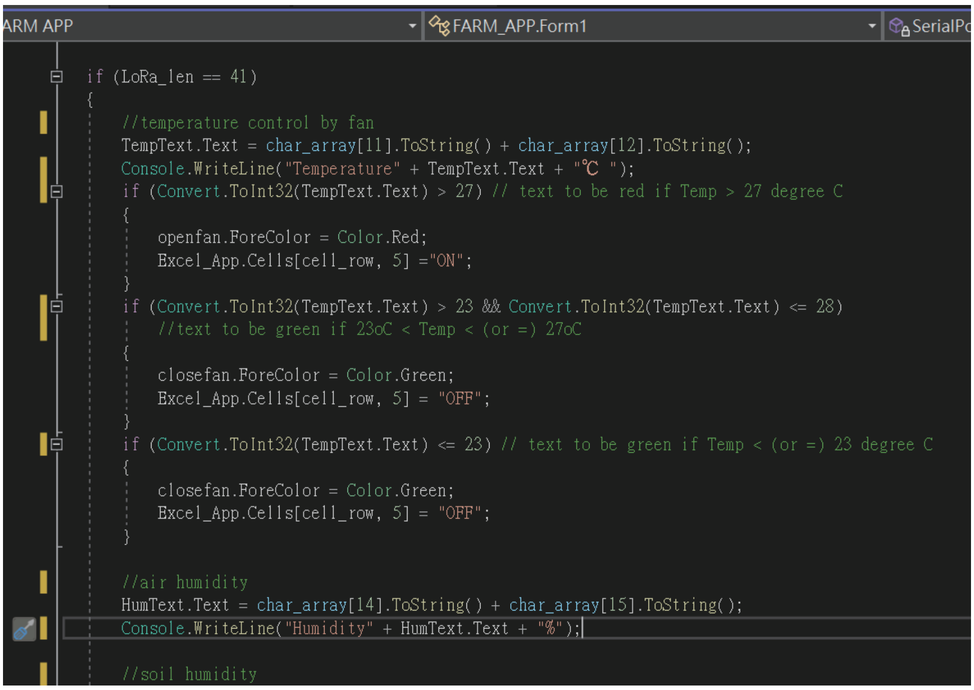


Fig. 9. (Color online) Part of C# program in human–machine interface of control system for remote port developed system.

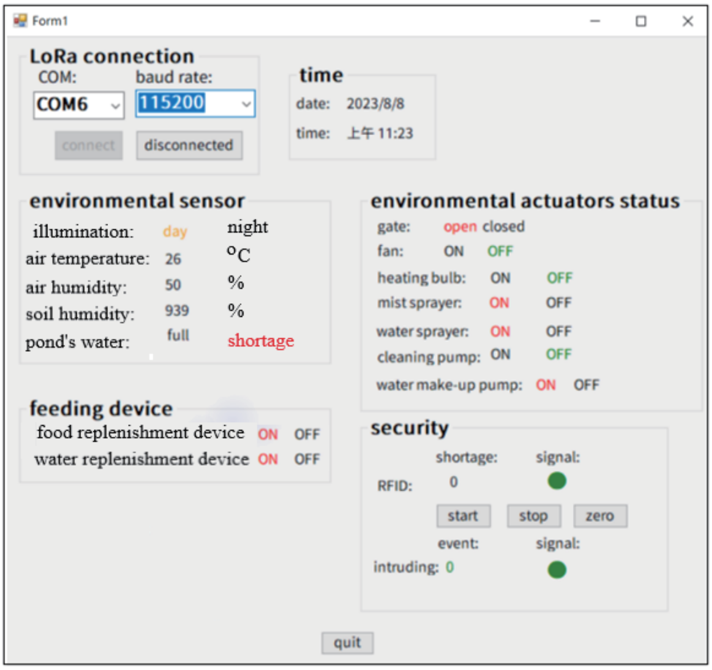


Fig. 10. (Color online) HMI (programmed by C#) displayed on remote port.

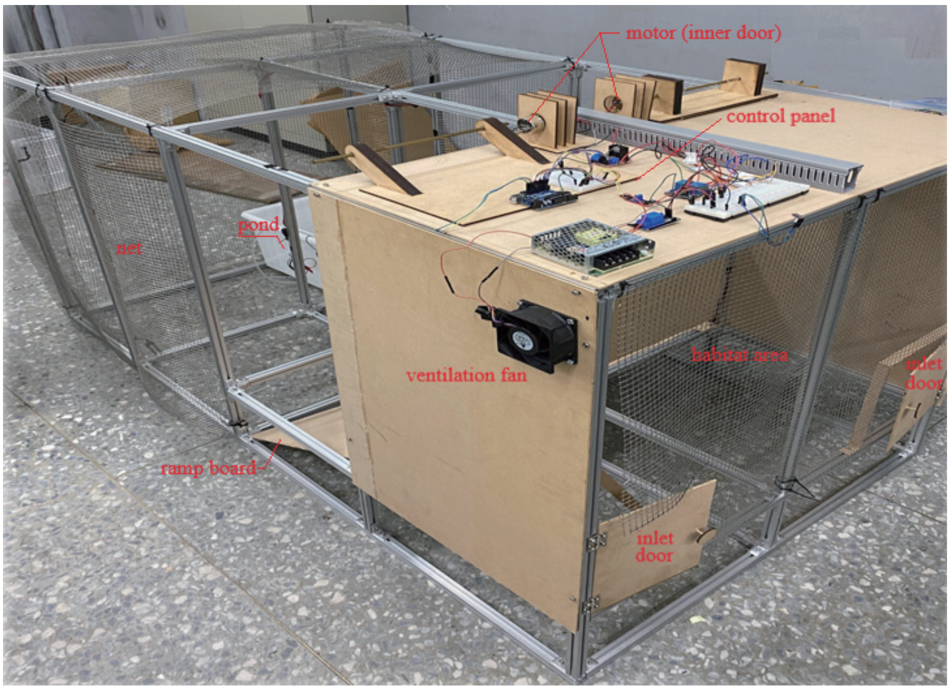


Fig. 11. (Color online) Prototype of developed system.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	time	illuminatic	gate	air temper	fan	heating bu	air humidi	mist spray	soil humic	water spra	pond's wat	water mak	cleaning p	food devic	water devi	RFID shor	intruding event	
2	11:21:05am	day	opening	26	OFF	OFF	51	ON	935	ON	shortage	ON	OFF	OFF	OFF	0	0	
3	11:21:10am	day	opening	26	OFF	OFF	51	ON	935	ON	shortage	ON	OFF	OFF	OFF	0	0	
4	11:21:15am	day	opening	26	OFF	OFF	51	ON	930	ON	shortage	ON	OFF	OFF	OFF	0	0	
5	11:21:20am	day	opening	26	OFF	OFF	51	ON	929	ON	shortage	ON	OFF	OFF	OFF	0	0	
6	11:21:25am	day	opening	26	OFF	OFF	51	ON	925	ON	shortage	ON	OFF	OFF	OFF	0	0	
7	11:21:30am	day	opening	26	OFF	OFF	51	ON	925	ON	shortage	ON	OFF	OFF	OFF	0	0	
8	11:21:35am	day	opening	26	OFF	OFF	51	ON	927	ON	shortage	ON	OFF	OFF	OFF	0	0	
9	11:21:40am	day	opening	26	OFF	OFF	51	ON	925	ON	shortage	ON	OFF	OFF	OFF	0	0	
10	11:21:45am	day	opening	26	OFF	OFF	51	ON	929	ON	shortage	ON	OFF	OFF	OFF	0	0	
11	11:21:50am	day	opening	26	OFF	OFF	51	ON	930	ON	shortage	ON	OFF	OFF	OFF	0	0	
12	11:21:55am	day	opening	26	OFF	OFF	51	ON	933	ON	shortage	ON	OFF	OFF	OFF	0	0	
13	11:22:00am	day	opening	26	OFF	OFF	51	ON	931	ON	shortage	ON	OFF	OFF	OFF	0	0	
14	11:22:05am	day	opening	26	OFF	OFF	50	ON	932	ON	shortage	ON	OFF	OFF	OFF	0	0	
15	11:22:10am	day	opening	26	OFF	OFF	50	ON	929	ON	shortage	ON	OFF	OFF	OFF	0	0	
16	11:22:15am	day	opening	26	OFF	OFF	50	ON	931	ON	shortage	ON	OFF	OFF	OFF	0	0	
17	11:22:20am	day	opening	26	OFF	OFF	50	ON	932	ON	shortage	ON	OFF	OFF	OFF	0	0	
18	11:22:25am	day	opening	27	OFF	OFF	50	ON	927	ON	shortage	ON	OFF	OFF	OFF	0	0	
19	11:22:30am	day	opening	27	OFF	OFF	50	ON	940	ON	shortage	ON	OFF	OFF	OFF	0	0	

Fig. 12. (Color online) Data output in Microsoft Excel file.

In our study, historical detection data can be recorded using Excel. In addition, all monitoring data are transmitted to the farm owner's remote PC via the LoRa module, eliminating reliance on a wireless network. This approach avoids the impact of unstable network conditions at the farm location. For security monitoring, however, we employed a combination of wireless network (with IP cameras) and LoRa communication (with infrared sensors). When using the wireless network with IP cameras, the farmer can view the pushed images from the IP camera to further confirm the presence of intruders and avoid false alarms.

4. Conclusions

We developed an intelligent management system for organic farming and livestock and poultry breeding based on LoRa communication. The system integrates environmental sensing, water and feed management, and security monitoring for sustainable farming based on self-contained eco-farming. Sensors, actuators, and solar and wind energy sources with software controls enable the remote monitoring and management of the system to enhance agricultural productivity and sustainable farming with rainwater recycling, organic waste processing, and natural feeding. The reuse of manure as fertilizer and a pond for natural feeding and LoRa communication address environmental and connectivity issues in remote areas. By monitoring environmental parameters such as temperature, humidity, water levels, feed and water supply, and intrusion, high survival rates and better product quality can be ensured.

Despite its promising performance, further improvement of the system is necessary. The system's long-term reliability must be validated, and the LoRa network's signal interference or range limitations need to be overcome. The cost and technical complexity must also be considered for farmers. A cost–benefit analysis is also needed to assess the feasibility of deploying the developed system in developing regions.

Acknowledgments

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