

Interactive Mobile IoT Application for Monitoring Etawa Crossbreed (PE) Goat Growth in Rural Communal Farms

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ABSTRACT

The rapid development of communication and information technology has encouraged the adoption of the Internet of Things (IoT) in the agricultural sector, particularly in livestock management. This study presents the development of an interactive mobile IoT application for monitoring the growth of Etawa Crossbreed (PE) goats in rural communal farms. The proposed system integrates a load cell-based digital weighing scale with an IoT module to automatically record livestock weight data and store it in cloud storage, which can be accessed through a mobile application. The application also supports the recording of feed and health history to enable structured growth monitoring. The system was deployed and tested in a communal farm environment involving 20 rural farmers, where the IoT scale measured livestock weight and transmitted data wirelessly to the mobile application. A design thinking approach was employed to ensure usability and suitability for rural users. The usability evaluation using the System Usability Scale (SUS) produced an average score of 83.5, classified as excellent (Grade B), indicating high user acceptance. In addition, technical performance evaluation showed that all 20 monitoring records were successfully transmitted, resulting in a transmission success rate of 100%, with complete and consistent data storage achieving 100% data integrity. Observational latency results indicated that RFID reading required an average of 2.5 seconds, while the weighing and data synchronization process took an average of 7.5 seconds before appearing in the mobile application. These results demonstrate that the proposed system is not only user-friendly but also reliable and capable of supporting near real-time livestock monitoring in communal farming environments.

Keywords : *Design thinking; Etawa Crossbreed (PE) goats; Interactive mobile application; Internet of Things (IoT); IoT livestock scale; Livestock growth monitoring.*

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1. INTRODUCTION

Recently, the incorporation of technology into agriculture has become increasingly essential, especially in animal husbandry in rural areas [1], [2], [3]. The difficulties encountered by rural communal farms, including restricted access to veterinary services, insufficient monitoring tools, and the absence of real-time data on animal health, have required the development of novel solutions [4], [5]. The Etawa Crossbreed goat (PE), recognized for its flexibility and substantial milk yield, is a valuable resource for rural farmers [6]. Effective care of these goats requires a methodical approach to monitor their growth and health, which is sometimes absent in conventional farming approaches.

The Internet of Things (IoT) has emerged as a revolutionary technology in multiple sectors, including agriculture [7], [8], [9]. Farmers can leverage IoT devices to collect and assess data on livestock health and growth. This technique facilitates the incorporation of sensors, such as load cells, to assess goat weight and growth trends, offering farmers essential data on their livestock's health [10], [11]. The development of an interactive mobile IoT application tailored for monitoring Etawa Crossbreed goats can substantially improve the management practices of rural farmers, resulting in increased productivity and profitability, such as real-time weight monitoring, health tracking, and feed history documentation. The application guarantees effective utilization by farmers with minimal technological skills through a user-friendly interface based on design thinking [12], [13], [14]. This accessibility is key to encouraging the adoption of contemporary agricultural practices in rural communal farms.

In addition, the application functions as a medium for documenting and evaluating historical data, enabling farmers to discern trends and make informed management decisions. By monitoring growth rates and health metrics over time, farmers can improve feeding strategies and quickly identify potential health concerns. This proactive strategy improves animal welfare and promotes the overall sustainability of livestock farming in rural regions [15], [16].

Despite growing interest in IoT-based livestock monitoring, most existing solutions target large-scale commercial farms and rely on infrastructure impractical for communal rural settings. Few studies address the multi-user nature of communal pens where multiple farmers share a single space and require a unified, affordable monitoring platform.

The purpose of this study was to develop an interactive mobile IoT application to monitor the growth of Etawa Crossbreed goats, which provides a viable answer to the issues faced by rural communal farms. Using IoT technology, farmers can acquire critical data on the health and growth of their animals, and the main contributions of this study are: (1) development of a load cell-based IoT weighing system with RFID identification; (2) integration with a Flutter/Laravel mobile application for structured growth recording; (3) usability evaluation using SUS with 20 rural farmers; (4) technical performance evaluation.

2. METHOD

The research methodology for this study is divided into three main segments: materials, data collection methods, and implementation methods.

2.1. Materials

a. Microcontroller

ESP32. The ESP32 was chosen in this study due to its superior capabilities as a low-cost yet high-performance system-on-chip (SoC) for IoT-based data processing and acquisition needs [17]. The ESP32 is equipped with a dual-core processor, integrated Wi-Fi and Bluetooth connectivity support, enabling real-time sensor data processing as well as direct communication with external systems without additional modules. In addition, the ESP32 supports various communication interfaces (SPI, I2C, UART, CAN), which increases the efficiency, security, and flexibility of embedded system development. ESP32 is adaptive for both rapid prototyping and complex and scalable system implementations, making it relevant for monitoring, control, and data processing applications.

b. Sensors

Load Cell Sensor and HX711 Module. The use of a load cell with an HX711 module in weight measurement was chosen because the combination of the two can provide high accuracy and precision in a microcontroller-based measurement system [18], [19]. Strain gauge type load cells work by converting force or load into proportional changes in electrical resistance, thus producing a very small but linear analog signal to the measured weight. The HX711 module plays an important role as a 24-bit analog-to-digital converter (ADC) with an integrated amplifier, which can stably amplify the microvolt signal from the load cell and convert it into digital data that can be processed accurately by the control system. Test results show that the combination of the load cell and HX711 produces very small measurement deviations (on average below 0.5%) so that it is reliable for static and dynamic weighing applications.

c. Hardware extension

RFID Module. The use of 13.56 MHz RFID (HF RFID) for goat tagging was chosen because this technology is most suitable for the needs of secure, stable, and efficient individual livestock identification in the context of precision livestock farming [20], [21]. RFID operates on near-field communication, making it relatively resistant to environmental disturbances such as humidity, dust, and the presence of many animals in proximity, while minimizing cross-reading errors. This technology also supports international standards (e.g., ISO 15693) with unique IDs, enabling accurate recording of goat history, from birth, growth, health, and production. Furthermore, HF RFID tags are passive (battery-free), small, animal-safe, and have a long lifespan, making them suitable for long-term implementation on small- to medium-scale farms.

3S Lithium-ion (12.6V). The use of 3S Lithium-ion batteries as the power source for IoT devices was chosen because they provide the optimal balance between high energy density, voltage stability, and efficiency for low-power embedded systems applications [22], [23]. A 3S configuration of three 3.7 V Li-ion cells in series produces a nominal voltage of approximately 11.1–12.6 V, suitable for various IoT modules, sensors, and DC-DC converter

circuits without requiring complex adjustments. Compared to lead-acid batteries, Li-ion batteries have a lighter weight, longer charging cycles (>3000 cycles), high efficiency, and no memory effect, making them ideal for IoT systems that require long-term operation and portability.

2.2. Data Collection Method

A comprehensive data collection process was conducted to support this research. The methods included a literature study, field observations, focus group discussions (FGD), and usability evaluation. Relevant data were gathered from books, peer-reviewed journal articles, and reputable online sources related to interactive mobile applications, Internet of Things (IoT), livestock growth monitoring, design thinking, and usability evaluation. Field observations and FGDs with rural communal farmers were carried out to understand user needs, existing monitoring practices, and challenges in livestock management. In addition, questionnaire data were collected and analyzed using the System Usability Scale (SUS) method to evaluate the usability of the developed mobile IoT application. These data collection activities provided a comprehensive foundation for system design, development, and evaluation.

2.3. Implementation Method

The Design Thinking approach is used in this study (Figure 1) because it has proven effective in addressing the complexity of IoT systems and product development, which is multidisciplinary, user-oriented, and involves interactions between humans, hardware, and software. Various studies have shown that Design Thinking is able to strengthen the requirements engineering process by placing users at the center of design, so that real needs, usage contexts, and field challenges can be identified more comprehensively [24], [25], [26], [27], [28]. The empathize stage is used to understand the experiences, needs, and problems of users and stakeholders through observation, interviews, and empathy maps; the define stage functions to formulate core problems clearly and focused based on empathy findings, often formulated in the form of How Might We; the ideate stage encourages solution exploration through brainstorming and

combining creative ideas that consider technological, business, and user aspects; the prototype stage allows for the rapid realization of selected ideas into prototypes to visualize solutions; and the test stage is used to evaluate prototypes with users to obtain feedback and refine them iteratively [29], [30], [31], [32], [33].

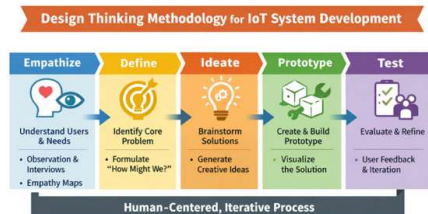


Figure 1. Design Thinking Adoption for IoT System Development

3. RESULTS AND DISCUSSION

In this research, the system developed used design thinking methods on development process. The design thinking process consists of five stages: empathize, define, ideate, prototype, and test. The design thinking approach was used to ensure that the application and use of the IoT were appropriate for the conditions of the communal farms in rural areas.

3.1. Empathize

In this phase, researchers gained a deeper understanding of the conditions of Etawa Crossbreed (PE) goat farmers in rural communal. We conducted a Focus Group Discussion (FGD) with 20 members of the farmer group to accurately understand the existing problems. Field observations and discussions were conducted to identify farmer work patterns, livestock weighing methods, feed recording, and manual health records. This phase also revealed limitations in digital literacy, time constraints, and the need for a simple yet informative recording system.

Table 1. Empathy map from 20 participants

Aspects	Results
Thinking & feeling	Farmers struggle to monitor livestock growth consistently and worry about losing data but are open to easy-to-use technology.
Hearing	Farmers have heard about the importance of growth recording from fellow farmers but have not had a practical digital solution.
Seeing	The weighing and recording process is still manual and not uniform in communal pens.
Saying & doing	Recording is done simply (paper/memory); farmers are used to using smartphones.

Pain	Growth data is not well documented and difficult to trace back.
Gain	Want a simple mobile system that records livestock weight, feed history, and health in an integrated manner.

The empathy map results from the FGD in Table 1 indicate that the main problem lies in the limitations of manual and unintegrated livestock growth recording, particularly in communal housing environments. Although farmers face limited digital literacy, they have demonstrated a willingness to adopt simple and easy-to-use mobile applications.

3.2. Define

Based on the results of the empathize phase, the define phase was formulated using the How Might We (HMW) approach to translate livestock farmers' needs and problems into targeted design challenges in Table 2. HMW questions focused on simplifying livestock growth monitoring processes, standardizing recording in communal pens, and utilizing smartphone devices familiar to livestock farmers.

Table 2. HMW questions

No	Code	How Might We (HMW) Questions
1	HMW1	How might we design a simple mobile application that enables farmers to monitor livestock growth consistently without adding complexity to their daily routines?
2	HMW2	How might we provide a practical digital growth-recording solution that aligns with the information farmers receive from peers?
3	HMW3	How might we standardize the weighing and recording process in communal farms using an IoT-based system?
4	HMW4	How might we leverage farmers' familiarity with smartphones to replace manual recording with a mobile-based system?
5	HMW5	How might we ensure livestock growth data is stored, organized, and easily traceable over time?
6	HMW6	How might we integrate weight measurement, feed history, and health records into a single, easy-to-use mobile application?

3.3. Ideate

In the ideate stage, the solution design process was carried out through brainstorming activities using Focus Group Discussions (FGDs) involving 5 participants consisting of expert and experienced farmers as end users. These group discussions aimed to explore various possible solutions to the How Might We (HMW) questions formulated in the define stage. Through FGDs, ideas related to application features, usage flows, and livestock

data recording mechanisms were collaboratively developed, considering the work habits of livestock farmers in communal pens. The ideation stage resulted on Table 3 with six HMW Code questions and six proposed

solution ideas that guided the design of the proposed mobile IoT application.

Table 3. Proposed solution

No	HMW Code	Solution Idea
1	HMW1	[ID001] A mobile application was designed with a simple user interface, minimal navigation, and clear livestock growth graphs, enabling one-step data input with intuitive action buttons.
2	HMW2	[ID002] A load cell-based livestock weighing feature was implemented, following weighing standards commonly practiced by farmers.
3	HMW3	[ID003] Digital scales integrated with an IoT system were developed to automatically and uniformly record livestock weight data in a shared database.
4	HMW4	[ID004] An Android mobile application was designed using icon-based inputs, simple dropdown menus, and short forms for recording feed and health history.
5	HMW5	[ID005] Livestock growth, feed, and health data were stored in a cloud database with historical records and filtering features based on livestock identity and time period.
6	HMW6	[ID006] An integrated dashboard was developed to display current livestock weight, growth trends, and feed and health history within a single application interface.

3.4. Prototype

In the prototype stage, the solution ideas generated during the ideate stage were realized through the development of an IoT system in this study, designed an integrated digital scale to measure livestock weight and automatically transmit communications data to a mobile application displayed at Figure 2. The load cell sensor measures the livestock's weight, and the resulting analog signal is converted into digital data by the HX711 module. This data is read and processed by the ESP32 microcontroller, which acts as the system's control center. In addition to reading weight data, the ESP32 also communicates with the MFRC522 RFID module to identify livestock, enabling each weighing result to be associated with the corresponding livestock identity. Weight and livestock identity information are displayed locally on a 16x2 LCD display for immediate user feedback. The processed weighing data is then sent by the ESP32 wirelessly to a server for storage in a centralized database. The system is equipped with a pushbutton as a user input interface to control the weighing process, and a self-contained power source, a lithium battery stabilized by a DC-DC buck converter module. This configuration ensures the system can operate stably and flexibly in a rural communal pen environment. The integration between sensors, microcontrollers, communication modules, and user interfaces allows the livestock growth monitoring process to be carried out automatically, accurately, and well-documented through an IoT-based mobile application.

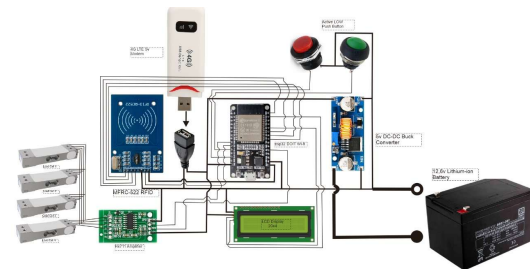


Figure 2. Hardware schematics

This prototype was designed to automate the livestock weighing process, store growth data centrally, and provide feed and health history recording features through an interactive mobile application. The integration between IoT devices, databases, and mobile applications allows livestock growth data to be consistently accessed and tracked by farmers in communal areas. Figure 3 depicts an integrated monitoring system in which livestock weight data, recorded by load cell sensors in the barn, are automatically transmitted via the internet to a central server for processing and storage. The processed data are then presented to farmers through a mobile application in the form of real-time growth charts. In addition, the application allows farmers to manually input health and feed data, thereby establishing a two-way information loop that supports data-driven decision-making for more effective livestock management.

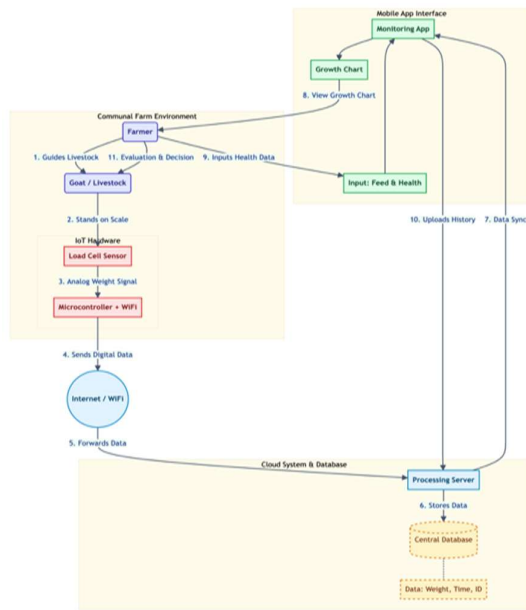


Figure 3. System communication diagrams

The proposed solution [ID001, ID002, ID003, ID004, ID005, ID006] was realized through the development of a mobile application featuring a straightforward and user-friendly interface, a streamlined navigation structure, and clearly designated action buttons to enhance user simplicity to communicate with digital scale IoT device can be seen on Figure 4. The figure illustrates the workflow of an IoT-based livestock growth monitoring system and an interactive mobile application with a feature for recording feeds, health history and livestock growth data can be filter per livestock or period and integrated dashboard that's displays currents weight, growth graph, feed and health history.

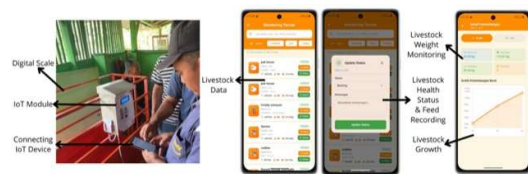


Figure 4. The display of the weight recording integrated with digital scales IoT device

The process begins with an IoT-based digital scale used to weigh livestock in a communal pen, with the IoT module acting as a link between the weighing device and the digital system. Weighing data is then sent and displayed on a mobile application, which presents livestock information in the form of a livestock data list. Through this application, farmers can record and update livestock

conditions, including health status and feeding history.

The integration between IoT devices and this mobile application enables the process of recording, monitoring health, and evaluating livestock growth to be carried out in a structured, user-friendly manner, and in accordance with the needs of rural communal livestock farming. Each solution idea was implemented as a prototype on the Android platform using Flutter, communicating with a Laravel-based REST API backend.

3.5. Test

This stage aims to test the prototype user interface design on real users. Testing was conducted using the System Usability Scale (SUS), in which users were asked to try using the system interface and then provide an assessment through a questionnaire. A total of 20 communal livestock farmers were involved as respondents in the user interface testing. The questionnaire instrument consisted of 10 statements measured on a 1–5 Likert scale at Table 4, ranging from Strongly Disagree to Strongly Agree.

Table 4. SUS questions

No	SUS Questions
1	I think that I would like to use this system frequently.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to be able to use this system.
5	I found the various functions in this system were well integrated.
6	I thought there was too much inconsistency in this system.
7	I would imagine that most people would learn to use this system very quickly.
8	I found the system very awkward to use.
9	I felt very confident using the system.
10	I needed to learn many things before I could get going with this system.

Next, the questionnaire data was analyzed using the System Usability Scale (SUS) method. The test results showed that the IoT mobile application obtained an average SUS score of 83.5, which is included in the excellent category with a B scale. This achievement indicates that the application interface design has a high level of usability and is considered easy to use, acceptable, and suitable for use by users in supporting IoT-based livestock monitoring activities.

In addition to usability evaluation, as shown in Table 5 showed the system was further assessed through technical performance

testing to address reliability and real-world applicability. Based on field testing results, a total of 20 livestock monitoring records were successfully transmitted from the IoT device to the centralized system, resulting in a transmission success rate of 100% (20/20), indicating robust communication performance. Furthermore, all recorded data were stored consistently without any mismatch in livestock identity, weight measurements, health status and timestamps, achieving a data integrity rate of 100% (20/20). The system also demonstrated stable operation in a real communal farming environment, as evidenced by continuous monitoring across multiple timestamps without

system failure. In terms of system responsiveness, observational latency measurements show that RFID reading required approximately 2–3 seconds (average 2.5 seconds), while the weighing and data synchronization process ranged between 5–10 seconds (average 7.5 seconds) before the data appeared in the mobile application. These results complement the high SUS score by confirming that the proposed system is not only user-friendly but also technically reliable and capable of supporting near real-time livestock monitoring in practical rural farming conditions.

Table 5. Field testing results of IoT-based livestock monitoring system

No	Gender	Monitoring Time	Weight (kg)	RFID Reading Time (s)	Weighing & Data Sync Time (s)	Transmission Status	Data Integrity	Health Status
1	Female	2025-12-19 21:06:56	28.38	2	7	Success	Valid	Good
2	Female	2025-12-19 15:57:43	24.72	3	8	Success	Valid	Good
3	Female	2025-12-19 15:55:20	24.48	2	6	Success	Valid	Good
4	Female	2025-12-19 15:53:39	30.82	3	9	Success	Valid	Good
5	Female	2025-12-19 15:51:07	25.56	2	7	Success	Valid	Good
6	Female	2025-12-19 15:45:12	24.92	3	8	Success	Valid	Good
7	Female	2025-12-19 15:37:53	27.16	2	6	Success	Valid	Good
8	Female	2025-12-19 15:36:11	25.91	3	9	Success	Valid	Good
9	Female	2025-12-19 15:34:42	29.94	2	7	Success	Valid	Good
10	Female	2025-12-19 15:33:06	29.54	3	8	Success	Valid	Good
11	Female	2025-12-19 15:28:49	26.07	2	6	Success	Valid	Good
12	Female	2025-12-19 15:20:59	27.48	3	7	Success	Valid	Good
13	Female	2025-12-19 15:17:52	32.71	2	10	Success	Valid	Good
14	Female	2025-12-19 15:15:11	25.72	3	8	Success	Valid	Good
15	Male	2025-11-28 14:51:02	25.07	2	5	Success	Valid	Good
16	Male	2025-11-28 14:34:25	25.26	3	10	Success	Valid	Good
17	Female	2025-11-22 10:56:30	15.35	2	6	Success	Valid	Require attention
18	Female	2025-11-22 10:26:30	16.65	2	6	Success	Valid	Require attention
19	Male	2025-11-20 14:46:18	44.18	3	9	Success	Valid	Good
20	Female	2025-12-19 15:28:49	26.07	2	6	Success	Valid	Good

CONCLUSION

This research successfully developed an interactive IoT mobile application for monitoring the growth of Etawa Crossbreed (PE) goats in rural communal farm environments using a Design Thinking approach. Four key contributions were achieved: first, a load cell-based IoT weighing

system was developed integrating an ESP32 microcontroller, HX711 module, and RFID livestock identification for automated weight data collection; second, a mobile application was developed on the Android platform using Flutter and a Laravel API backend, providing an integrated interface for livestock weight monitoring, feed history, and health records; third, usability evaluation using the System

Usability Scale (SUS) with 20 communal farmers produced an average score of 83.5 (Grade B, excellent), confirming the application's acceptability for real-world use; and fourth, technical performance evaluation through field testing demonstrated that all 20 monitoring records were successfully transmitted, resulting in a transmission success rate of 100%, while all data were stored consistently without mismatch, achieving a data integrity rate of 100%. The system also showed stable operation in a real communal farming environment across multiple monitoring sessions without failure. Furthermore, observational latency measurements indicated that RFID reading required approximately 2–3 seconds (average 2.5 seconds), while the weighing and data synchronization process took approximately 5–10 seconds (average 7.5 seconds) before appearing in the mobile application. These results confirm that the proposed system is not only user-friendly but also technically reliable and capable of supporting near real-time livestock monitoring in practical rural farming conditions, with future work directed toward integrating additional sensors, artificial intelligence-based analytics, and system scalability for broader deployment.

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