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Enhancing Smart Farming Capabilities for Small-Scale Cattle Farmers in Chiang Rai, Thailand

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ABSTRACT

This research aims to develop an IoT-driven smart farming system for beef cattle management in Chiang Rai Province, Thailand. The system empowers small-scale farmers by enabling precise criteria for cattle care, optimized feeding, growth monitoring, breeding analysis, and cost estimation through WSN and cloud-based platforms. The sensors gather raw data on consumption from the feeding troughs and then transmit it to the cloud-based platform. Consumption data is then analyzed using Linear Regression Analysis. Key findings indicate a substantial correlation (0.995) between feed quantity and cattle weight gain, with a predictive capability of 99%. This system enhances precision and decision-making in cattle farming, offering significant benefits to small-scale farmers in the region.

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1. INTRODUCTION

Chiang Rai, situated in the upper northern region of Thailand, boasts a picturesque highland landscape with fertile plains along river basins, making it an ideal area for cultivating flora and fauna. The beef industry in this region has gained popularity among local and foreign stakeholders, witnessing a consistent annual increase in production [1]. However, farmers in that area need help developing a standardized culture procedure for beef cattle [2]. These challenges encompass setting culture process standards, implementing proper feeding practices, tracking growth progress, conducting breeding inspections, and accurately estimating costs. The adoption of Smart Farms has emerged as a promising solution to address these critical challenges and bridge the research gap. Smart Farms leverage advanced technologies, particularly the Internet of Things (IoT) and data analytics, to optimize farming practices, track growth patterns, and provide data-driven decision support [3, 4].

The agriculture industry has witnessed remarkable advancements through the integration of cutting-edge IoT technology, especially in the domain of Smart Farms [5]. This pioneering approach involves seamless data collection and transmission from diverse sensors and electronic devices, enabling cloud processing to yield actionable insights [6]. Such technology gives farmers instant access to invaluable agricultural data, facilitating precise weather forecasting, control over critical operations, vigilant monitoring of soil moisture levels, and well-informed cultivation decisions. Moreover, farmers can easily comprehend comprehensive farm reports in graphical formats delivered to their mobile devices [7]. The potential of IoT extends beyond crop cultivation, finding relevance in livestock farm management as well [4]. Their livestock monitoring solution, which relies on Wireless Sensor Networks (WSN) and cloud platforms, allows for real-time monitoring of animal behavior, prediction of animal health, and cost savings through reduced labor requirements.

Furthermore, Vijay Rana et al. showcased the effective adoption of IoT-based data-gathering systems in dairy farms, enhancing livestock health monitoring and facilitating the prompt diagnosis of disease outbreaks, thereby reducing potential losses [8]. Despite these significant strides in agricultural technologies, a distinct lack of solutions tailored to meet the spe-

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cific requirements of small-scale farmers persists. Essential aspects, such as comprehensive monitoring of the cattle fattening process, optimized feeding practices, meticulous tracking of growth patterns, precise breeding inspections, and accurate cost calculations, continue to present formidable challenges.

Therefore, the primary aims of this research are twofold: (I) To develop an intelligent farm customized for beef cattle, granting small-scale farmers the ability to set culture process standards, implement proper feeding practices, track growth progress, conduct breeding inspections, and accurately estimate consumption costs. Wireless sensor networks (WSN) form the basis of the system, interacting with specially designed programs on cloud platforms and providing notifications through social media applications. (II) To transfer Smart Farm technology for beef cattle fattening to small-scale farmers in Chiang Rai Province, Thailand. "***Fig. 1***" is the prototype cattle farming architecture featuring a specialized control system and application.

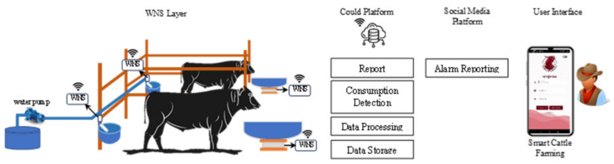

Fig.1: *Cattle Farming Architecture Equipped with a Specialized Control System.*

2. RELATED WORKS

2.1 The Concept of Fattening Beef Cattle

Fattening beef cattle is rapidly promoting their growth by providing a high-quality diet. To facilitate rapid development and ensure the production of high-quality meat, feed cattle not only straw or fresh grass but also supplemental concentrated feed. This insight comes from the Working Group's Beef Cattle Production Potential Enhancement Project from Knowledge and Technology Management [9].

The strategy for beef cattle fattening involves two distinct methods based on their diet. The first approach exclusively involves coarse feed, while the second incorporates roughage alongside concentrated feed containing a minimum of 14% protein. It's crucial to provide frequent but smaller feedings, at least twice a day, as established by a study conducted by the Beef Cattle Research and Development Group, Bureau of Animal Breeding [10]. Concentrated feeding and providing roughage for fattening usually begins when the cattle reach a weight of around 250 kilograms. Fattening continues until they get approximately 450 kilograms, spanning five months and two weeks. Throughout the feeding period, the cattle generally experience an increase of about 200 kilograms in weight, as specified in Table 1.

Table 1: *Criteria for Fattening Cattle Using Combined Concentrated Feed and Straw.*

Week	Weight	Concentrated food (kg/cattle/day)	Coarse food (kg/cattle/day)
Start	250.0	-	-
1-4	279.4	6.0	0.5
5-8	313.5	7.0	0.5
9-12	347.2	7.0	1.0
13-16	384.5	8.0	1.0
17-22	446.7	9.0	1.5

Regarding water consumption, cattle typically consume around 20–50 liters per day, a range influenced by factors such as weather conditions and the size of the cattle. It's worth noting that cattle consume less water and less food [10].

2.2 Internet of Things-based Smart Farms

Internet of Things (IoT)-based smart farming involves the utilization of sensors, electronic devices, tools, and applications to enhance the management of agricultural operations. This approach results in more precise information acquisition [11]. Smart farming, also called intelligent agriculture, represents an innovative approach to farming that harnesses climate data at Microclimate, Mesoclimate, and Macroclimate levels. By utilizing climate data, farmers can effectively monitor and cultivate their farmland based on the current climate conditions [12]. The foundational principle behind smart farming integrates data garnered from Wireless Sensor Networks (WSNs) strategically deployed throughout the farm. This data is then employed to make informed decisions regarding farm administration and management on time. Farmers can view report data via a computer, tablet, or smartphone. Also, farmers employ IoT to monitor animal health parameters, such as body temperature and heart rate. This application aids in health monitoring and epidemic prevention, as highlighted by references [13–15].

Additionally, data analysis has been employed to study animal behavior, as outlined in reference [16]. Referring to Wang's report exemplifies the examination of cattle's food and water consumption patterns to identify potential illnesses within a group of animals. This study utilized directional antennas and wireless network technology to gather data from sensors attached to the animals' ears [17]. Furthermore, Jung Kyu Park used IoT to track the grazing behavior of cows in fields, utilizing cloud-based analysis to monitor eating habits and real-time location on a map [4].

Nevertheless, despite these technological strides, the practical application of these innovations to assist small-scale cattle farmers has yet to be fully realized. Specifically, optimizing feeding guidelines for fattening beef cattle, precise tracking of growth patterns, thorough monitoring of breeding data, and accurate calculation of consumption costs all remain pivotal for making well-informed decisions in future planning. These crucial aspects continue to be essential requirements for farmers.

2.3 Cloud and Data Center

Cloud data storage is crucial for IoT-based innovative farming systems [18]. These systems collect and analyze real-time and stored data from various sources, such as sensors, cameras, and maps [19]. The cloud acts as a central data store, allowing farmers and specialists to access and utilize the processed data for improving farming skills, pre-disaster recovery, and market information [20]. Different architectures, such as the Central Cloud, Distributed Cloud, and Collaborative Computing Strategies, handle the massive data generated in smart farming. These architectures are evaluated based on user proximity, latency, scalability, and cost-effectiveness. Overall, cloud data storage in IoT-based smart farming enables remote monitoring, control, and optimization of farming systems while efficiently managing and analyzing large volumes of data. In this paper, the experiment used Hostinger as a cloud platform. The database uses the MySQL relational database server.

2.4 Monitoring and Management Application

Several research papers have proposed using IoT sensors to develop intelligent monitoring and management systems for cattle farming. The primary purpose of these systems is to improve livestock tracking, set geofencing boundaries, and monitor their health. This system reduces the need for manual intervention and cuts farming expenses. IoT technology enables the remote oversight and control of livestock, facilitating the collection of essential data regarding their location, well-being, and overall health [21]. This data, acquired from individual animals, can be employed to provide personalized care and ensure meticulous management of farming practices [3]. In addition, these systems can predict cattle illnesses by utilizing health monitoring modules based on fuzzy logic [22].

To summarize, these applications driven by IoT hold the potential to enhance the tracking of livestock, establish geofencing boundaries, and monitor their health. Hence, conducting a comparative study is crucial to identify gaps in intelligent monitoring and management systems for cattle farming. As a result, the research's primary goal was to develop systems that integrate sensors and electronics to aid smallholder farmers in adopting the same technique for beef cattle rearing while also delivering more precise real-time estimations of consumption and food costs.

2.5 Linear Regression Analysis

Chapman (2005) [23] delineates three primary types of regression analysis: Linear Regression Analysis, Polynomial Regression Analysis, and Logistic Regression Analysis. Linear Regression Analysis models the relationship between input and output variables. It provides estimates of the cause-and-effect relationship between the inputs and the outcome, along with an error estimate calculated using an optimization algorithm. Regression analytics can identify piecewise linear dependencies among variables and make predictions for mean-value aggregate queries [24]. In this research, we applied the Linear Regression Analysis method to analyze and compare consumption results against predefined criteria. This analysis can ascertain whether the relationship is consistent and follows the same direction.

3. MATERIALS AND METHODS

3.1 Sample Preparation

This research established the Smart Cattle Farm prototype at S.P. Supoj Farm in Chiang Rai, Thailand. Data collection spanned from December 3, 2022, to April 30, 2023, coinciding with cattle fattening activities. The dataset includes farm, cattle, feed, consumption, and breeding information. Feeding criteria were derived from the Beef Cattle Research and Development Group [10] and farmers with over a decade of experience in the field, as referenced in Table 2.

Subsequently, feeding data and consumption rates are systematically gathered through sensors and electronic devices placed at the food trough at a one-minute interval for data collection (Eq. 1–3). When cattle consume water, the system transmits the data to the cloud. Equation 5 represents the data for daily food intake, and the system promptly alerts the farmer when feed levels deplete to a certain threshold (Eq. 6). Additionally, it facilitates the computation of consumption costs as per Eq. 7.

Table 2: *New Guidelines for Fattening Beef Cattle.*

Week	Projected weight (kg)	Concentrated food (kg/cattle/day)	Straw (kg/cattle/ day)	Fresh grass (kg/cattle/day)
Start	200.0	-	-	-
1-4	$\sim$ 230.0	4.0	0.5	1.0
5-8	$\sim$ 265.0	5.0	0.5	1.0
9-12	$\sim$ 300.0	5.0	1.0	1.5
13-16	$\sim$ 350.0	6.0	1.0	1.5
17-22	$\sim$ 400.0	6.0	1.5	1.5

The system also tracks growth data reported by farmers and provides monitoring for breeding activities through a bespoke application. Illustrated below is the prescribed equation in the context of consumption data management.

$$LU = (The\ latest\ value\ in\ the\ database) \vee (0 \ \leftrightarrow\ The\ database\ contains\ no\ *data) \tag{1}$$

$$C = ((LU - N) \leftrightarrow (N < LU)) \tag{2}$$

$$AF = (N \ \leftrightarrow\ ((N > 0) \wedge (LU \leq 0))) \vee ((N - LU) \leftrightarrow ((N > 0) \wedge (N > LU)) \vee (0 \rightarrow\ N = 0) \vee (0 \leftrightarrow None\ of\ the\ conditions\ align.)\ ) \tag{3}$$

$$WC = \sum_{i=0}^{D} W_i \tag{4}$$

$$CD = \sum_{i=0}^{D} C_i \tag{5}$$

$$A = Notify\ \leftrightarrow\ (CD < Guidelines\ in\ Table\ 2) \wedge \left(\frac{N \times 100}{M} \leq FA\right) \tag{6}$$

$$FC = \sum_{i=1}^{N} C_i P \tag{7}$$

Where LU is the latest feed quantity stored in the database, N is the current food volume read from the sensor, C is the recent consumption volume, CD is the amount of food consumed per day, D is the 24-hour time of the selection date, and AF is the amount of food added to the trough; WC is the amount of water consumed each time; W is the latest water consumption read from the sensor; A is alert when food is running low for farmers to refill; M is the Maximum amount of food in the rail; FA represents the quantity remaining to trigger an alert, and each farm can configure it individually via the Smart Cattle Farming application, as illustrated in "***Fig. 2:***". Regarding the feed cost of each fattening beef cattle, FC is the cost of feed consumption, and P is the feed price per unit. To manage food data transfer from the trough to the cloud (Eq. 3), the system, when executed initially or during maintenance, verifies (0 → N = 0) ∨ (0 ↔ None of the conditions align). In regular situations, it evaluates (N ↔ ((N > 0) ∧ (LU ≤ 0))) ∨ ((N - LU) ↔ ((N > 0) ∧ (N > LU))).

3.2 System Model

The establishment of feeding troughs for fattening beef cattle necessitates a consistent standardization encompassing size and shape to suit animal consumption requirements. The design of this prototype is derived from cattle fattening guidelines intended for small-scale farmers, as outlined by the Department of Livestock within the Ministry of Agriculture and Cooperatives [25]. Install it in front of the stall, boasting a height of approximately 60 centimeters and a width spanning 80 to 90 centimeters. The interior surface remains smooth, while the trough's base features a rounded configuration devoid of sharp corners. In alignment with this study, sensors and electronic components were systematically integrated to measure the weight of the feed, as illustrated in "***Fig. 3:***".

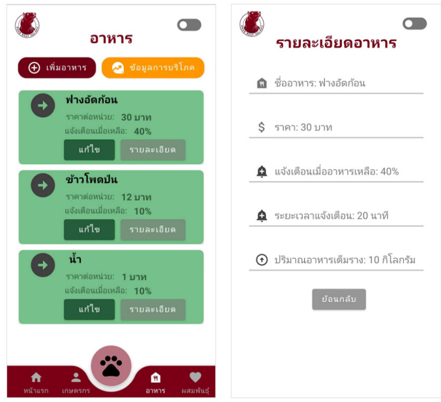

Fig.2: *Configure the Quantity Remaining in the Smart Cattle Farming Application to Generate an Alert.*

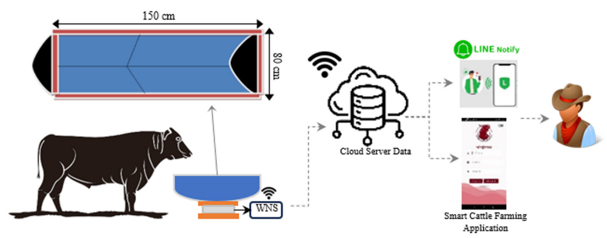

Fig.3: *A Food Trough Prototype Equipped with a Control System.*

Load cells, sensors converting pressure or tensile into electrical signals, can be used to make dosing scales in industry. In the research conducted by Rohan Basak et al. [26], load cells were employed to weigh trucks before they boarded overpasses. This research uses load cells (up to 100 KG, Model YZC-1B) attached to a load-bearing base and feeding trough to measure rail-based food weights. Signal amplification via a weight sensor amplifier (HX711) connects load cells with the wire cable to an ESP32 development board. Then, the ESP32 board connects through WiFi and communicates with a hotspot router to send data to the cloud, with a custom program processing and transmitting data to a cloud server while notifying food quantity via the Line application. Data processing, including consumption reports, occurs on the Android OS through the Smart Cattle Farming application. In "***Fig. 4:***", the experiment displays a food node module in use.

The gutter is positioned behind the stall and incor-

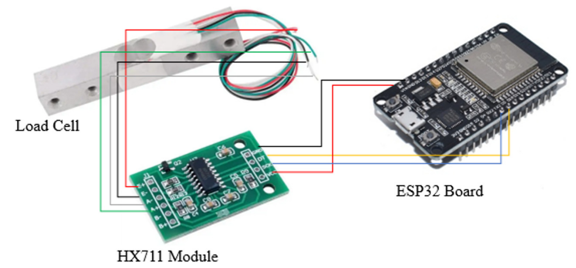

Fig.4: *A Food Node Module Used in The Experiment.*

porates sensors and electronic components to quantify water flow. Its dimensions are approximately 60 centimeters in height, with a size of 80 × 90 centimeters, as depicted in "***Fig. 5:***".

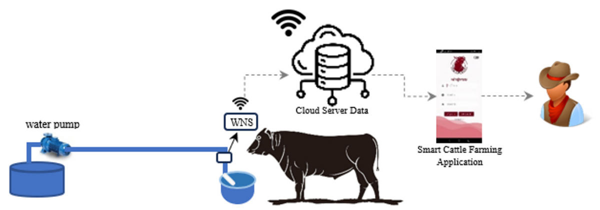

Fig.5: *Gutter Prototype with Functional Control System.*

The system accurately measures water consumption by utilizing a water flow sensor. The sensor operates within a voltage range of DC 4.5V to 24V, with a working voltage span of 5V to 18V, accommodating pressures up to 1.75 MPa and featuring 1/2" external threads. This sensor connects to an ESP32 Development Board ("***Fig. 6:***"), where a specialized program processes and transmits data to a Cloud Server. The Android application Smart Cattle Farming concentrates on managing consumption records and generating reports.

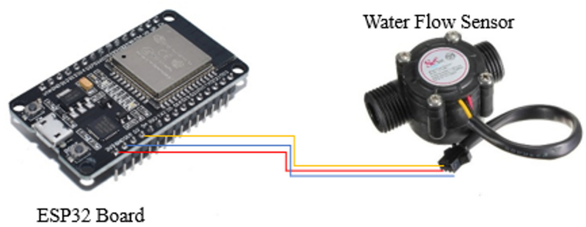

Fig.6: *A Water Node Module Used in The Experiment.*

3.3 User Interface

The system archives information collected from the food and water nodes in a database on the cloud. The main screen of the graphical user interface (GUI) application showcases real-time data on water and feed usage for the day. Additionally, five other pages provide information on user profiles, livestock details, feed requirements, consumption costs, and breeding insights. Communication between the cloud and applications relies on JSON data formats. The visual components, as depicted in "***Fig. 7:***", encompass the login page, the home page displaying food consumption (with an automatic 1-minute data refresh), user profiles, fattening cattle information, feed details, consumption costs, and breeding insights.

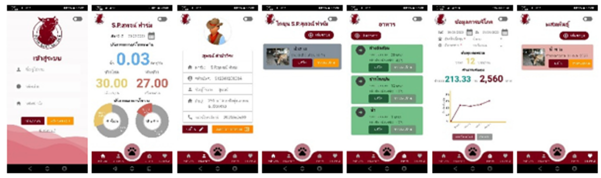

Fig.7: *Page of The Smart Cattle Farming Application.*

4. RESULTS AND EXPERIMENTS

The research involved three parts: 1) constructing a system of installed feeding troughs equipped with sensors and control mechanisms; 2) establishing installed gutters integrated with sensors and control devices; and 3) developing a Smart Cattle Farming application for monitoring food consumption data. This application encompasses user profiles, cattle records, feed details, real-time consumption cost computations, and breeding information. The breeding information portion makes it easier to schedule estrus checks, sends reminders, and establishes an accurate calving calendar.

4.1 Configuration of Feeding Troughs and Control Mechanisms

This setup for one beef cattle includes: 1) a roughage trough: 1 tray measuring 150 × 80 × 25 cm; and 2) a concentrate trough: 1 tray measuring 75 × 80 × 25 cm, constructed from durable steel. These troughs feature straight edges and a smooth surface. The base lacks sharp corners, is slightly elevated at the center to meet Department of Livestock Development standards, and includes sensors underneath. Additionally, each sensor is assigned a unique identification code. Mapping animal ear IDs to sensor IDs enhances the precise classification of food and water troughs for cattle. These troughs are fixed to the cement floor and connected to the control board unit at the cowshed's front, as depicted in "***Fig. 8:***". Each of the sensors can handle a weight of approximately 100 kilograms.

The feed chute has sensors and control systems attached. It is in charge of processing data on food additions and consumption. Subsequently, this processed data is sent to the cloud every minute. The transmitted information includes the Sensor ID, the

Fig.8: *The Feeding Trough Set and Control Apparatus.*

last recorded quantity of feed in the trough, the most recent cloud-stored food quantity, and the date and time of the readings. The system performs the calculations following the equations 1-3. When the daily feed consumption falls below the feeding threshold specified in Table 2, and the system projects a low feed quantity in the trough based on the calculation from Eq. 6, the system generates a notification. This notification is sent to the farmer via the LINE application, as demonstrated in "***Fig. 9:***".

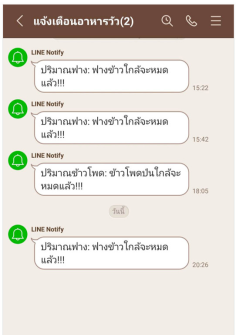

Fig.9: *Notification for Low Feed Level in the Trough.*

$$A = Notify \leftrightarrow (CD < Guidelines\ in\ Table\ 2) \wedge \left(\frac{N \times 100}{M} \leq FA\right) \quad (6)$$

This notification activates if the total daily consumption, represented by the CD value, does not meet the standards outlined in Table 2. The average food quantity in the trough, computed as (N × 100) divided by M, is less than the FA notification value. These notification parameters, including the FA value, M value, and notification time, can be customized inside the food function of the Smart Cattle Farming Application (***Fig. 2:***).

The fattening phase for the research cattle commenced on December 3, 2022, and concluded on April 30, 2023, spanning approximately five months. The feeding quantity is determined using the criteria listed in Table 2. Data from sensors (refer to "***Fig. 10:***") reveals a direct inverse correlation and fluctuating trend between feeding patterns and the expected cattle's weight, indicating a significant relationship.

Fig.10: *Food Consumption Data from the Cloud.*

In this context, the research employs multiple linear regression analysis [23] to investigate the linear relationship between the independent variables (coarse food and concentrated food) and the dependent variable (weight), as defined by Eq. 8.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \varepsilon \quad (8)$$

Where y represents the obtained data (output), β_0 signifies the constant value within the regression equation, serving as the intercept on the y-axis. Meanwhile, $\beta_1, \beta_2, \ldots \beta_k$ denote the regression coefficients for the respective initial variables $X_1, X_2, \ldots X_k$

This study's dependent variable (y) was the projected weight gain in fattening beef cattle. In contrast, the primary variables (X) were the quantities of coarse feed and concentrated food, as stated by the criteria in Table 2 as denoted by X_1 and X_2. The hypothesis, represented as H0, asserts that providing complete nutrition and coarse feed according to the requirements specified in Table 2 does not significantly affect the expected increase in the weight of cattle. Conversely, H1 suggests that allocating concentrated food and coarse feed according to the criteria outlined in Table 2 does impact the expected weight gain in cattle. Tables 3–5 present the findings of the analysis.

Conclusions derived from the multi-linear regression analysis revealed a robust association between the quantities of coarse and concentrated food and the weight of fattened beef cattle. These variables display a positive correlation and a substantial degree of relationship, as evidenced by a correlation coefficient of 0.995. Moreover, they possess a high predictive capability for the weight of fattened beef cattle, achieving a 99% level of reliability and demonstrating statistical significance at the 0.05 threshold. With a standard error level for prediction at ±8.378, as outlined in Table 3, and simultaneously a P-Value of 0.01 derived from Table 4, resulting in the rejection of the primary hypothesis H0 and acceptance of the alternative hypothesis H1, it is evident that the quantity of concentrated and coarse feed, following the criteria presented in Table 2, does indeed influence the expected weight gain in cattle. Additionally, the research used the reference data from Table 5 to formulate the following linear equation:

$$y = 60.811 + 0.654X_1 + 1.989X_2 \quad (9)$$

Table 3: *Summary of the Food Consumption Analysis Findings.*

Regression Statistics	Results	Explanation
Multiple R	0.995	Correlation coefficient: 0.995 means perfect correlation.
R Square	0.990	**Coefficient of determination:** How many points fall on the regression line? Here, 99% of points fall within the line.
Adjusted R Square	0.980	
Standard Error	8.378	
Observations	5	

Table 4: *The Food Consumption ANOVA.*

	df	SS	MS	F	Significance F
Regression	2	13960.40	6980.20	99.44	0.01
Residual	2	140.40	40.20		
Total	4	14100.80			

Table 5: *Variance in Food Consumption Analysis.*

	Coefficients	Std. Error	t Stat	P-Value	Lower 95%	Upper 95%
Intercept	60.811	27.621	2.202	0.159	-58.03	179.653
X_1	0.654	0.249	2.627	0.119	-0.417	1.725
X_2	1.989	0.294	6.766	0.021	0.724	3.254

The data in Table 6 is a sample of concentrated food data from the cloud and comprises the following columns: 1) "id," used to store the row code. 2) "sensor_code" is employed to store the code of each sensor for identifying the data source, specifically the food trough. 3) "added_amount" serves to record the quantity of food (kg) added to the food trough. 4) "update_real-time" is dedicated to storing the real-time data of food levels (kg) in the trough, transmitted from the sensor every minute. 5) "ate_amount" tracks the most recent consumption amount (kg). 6) "date_consumption" records the date and time of each consumption event. The sensor data transfers to the cloud every minute. An example exhibiting the calculation of data stored within the system, namely data in row 2, is presented. LU is the newest feed quantity stored in the database, N is the latest food volume read from the sensor, and C is the most recent consumption volume.

The system will calculate the 'Added Amount' column (the AF value) when the farmer places food in the trough, and the sensor captures its weight according to Eq. 3. However, if the scenario does not meet

Table 6: *A Sample of Concentrated Food Data from the Cloud.*

id	sensor_code	added_amount	update_real-time	ate_amount	date_consumoption
1	sc01	4.02	4.02	0.00	2022-12-03 09:20:52
2	sc01	0.00	3.94	0.08	2022-12-03 09:21:59
3	sc01	0.00	3.89	0.05	2022-12-03 09:23:06
4	sc01	0.00	3.78	0.11	2022-12-03 09:24:13
5	sc01	0.00	3.69	0.09	2022-12-03 09:25:20
6	sc01	0.00	3.69	0.00	2022-12-03 09:26:27
7	sc01	0.00	3.63	0.06	2022-12-03 09:27:34
8	sc01	0.00	3.53	0.10	2022-12-03 09:28:41
9	sc01	0.00	3.40	0.13	2022-12-03 09:29:48
10	sc01	0.00	3.28	0.12	2022-12-03 09:30:55
:	:	:	:	:	:
123 424	sc01	0.00	1.32	0.10	2023-04-30 04:46:09
123 425	sc01	0.00	1.22	0.12	2023-04-30 04:47:16

any conditions where N equals 3.94 and LU equals 4.02, the system will set the value of AF to 0.

$$\begin{aligned} AF = (N \leftrightarrow ((N > 0) \wedge (LU \leq 0))) \vee \\ ((N - LU) \leftrightarrow ((N > 0) \wedge (N > LU)) \vee \\ (0 \rightarrow N = 0) \vee (0 \leftrightarrow \\ \textit{None of the conditions align.})) \end{aligned} \quad (3)$$

The "Ate Amount" column (also known as the C value) refers to when the food level falls below the latest value in the database, which means the cattle have consumed food. It will be calculated according to Eq. 2. When N is 3.94 and LU is 4.02, the value of C = LU minus N is 0.08.

$$C = ((LU - N) \leftrightarrow (N < LU)) \quad (2)$$

The method for determining N, AF, and C values for straw consumption is the same as for calculating values for concentrated food.

4.2 Configuration of Water Troughs and Control Mechanisms

This water trough design enables cattle to drink water using their snouts. A trough equipped with sensors and a set of control boards is installed at the rear of the cowshed, positioned at a height of approximately 60 cm. This positioning aligns with cattle fattening guidelines for small-scale farmers [25], as illustrated in "***Fig. 11:***". When the sensors detect water flow, the system sends the data to the Cloud Server for storage. The transmitted dataset comprises the sensor ID, water quantity, as well as the date and time of measurement.

Fig.11: *Gutter and Control System.*

Water consumption data for fattening beef cattle is processed using sensors and control systems and stored in the cloud. The system calculates the quantity of water when beef cattle interact with or push the valve to drink water. The consumption results indicated a positive and linear association, or a variable relationship, between water intake trends and weight, as depicted in "***Fig. 12:***". The results indicated a positive and linear association, or a variable relationship, between water intake trends and weight.

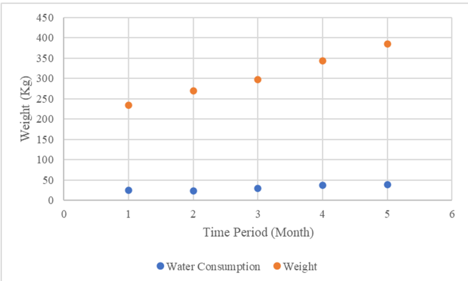

Fig.12: *Water Consumption Data from the Cloud.*

This study employed a simple linear regression analysis to determine the relationship between the two variables and build a mathematical equation model for predicting the value of the dependent variable. This study is in line with the concepts put forth by Chapman in 2005 [23], as demonstrated in Eq. 10.

$$y = \beta_0 + \beta_1 X \tag{10}$$

In this context, y represents the obtained data (output). In contrast, it means a constant value that impacts the variable y when the variable X equals 0, commonly called the y-intercept. The coefficient of the independent variable, B1, represents the change predicted in the variable y when X equals 1. And the variable X is the independent variable representing the value or factor influencing the variable y.

The dependent variable, y, in this study, reflects the projected weight gain in fattening beef cattle, and the primary variable, X, indicates the amount of water ingested by the cattle. The primary hypothesis H0 proposes that the amount of water cattle drink does not affect cattle weight gain. Still, the alternative hypothesis H1 proposes that the amount of water consumed by cattle affects bovine weight gain. Tables 7-9 present the findings of the analysis.

The findings of the Simple Linear Regression model study revealed a robust relationship between the quantity of water consumed and the weight of fattened beef cattle. The correlation coefficient of 0.922 signifies a positive and substantial correlation between these variables.

Table 7: *Summary of the Water Consumption Analysis Findings.*

Regression Statistics	Results	Explanation
Multiple R	0.922	Correlation coefficient: 0.922 means perfect correlation.
R Square	0.851	**Coefficient of determination:** How many points fall on the regression line? Here, 85% of points fall within the line.
Adjusted R Square	0.801	
Standard Error	26.478	
Observations	5	

Table 8: *The Water Consumption ANOVA.*

	df	SS	MS	F	Significance F
Regression	1	11997.50	11997.50	17.11	0.03
Residual	3	2103.30	701.10		
Total	4	14100.80			

Table 9: *Variance in Water Consumption Analysis.*

	Coefficients	Std. Error	t Stat	P-Value	Lower 95%	Upper 95%
Intercept	65.91	59.19	1.11	0.35	-122.44	254.27
X	7.76	1.87	4.14	0.03	1.79	13.72

Furthermore, they can predict the weight of fattened beef cattle with an accuracy of 85%, affirming statistical significance at the 0.05 level. The prediction has a standard error level of ±26.478, as detailed in Table 7, and Table 8 shows a P-value of 0.03, leading to the rejection of the primary hypothesis H0 and acceptance of H1. This result implies that the quantity of water cattle consume affects their increased weight. Furthermore, reference results from Table 9 can be employed to formulate the following linear equation:

$$y = 65.91 + 7.76X \tag{11}$$

The sample of water consumption data in Table 10 comprises the following columns: 1) "id," used to store the row code. 2) "sensor_code" is employed to store the code of each sensor for identifying the data source, specifically the water trough. 3) "flow_rate_liter_min" stores the water flow rate per minute. 4) "cumulative_volumn" serves to record the quantity of the recent water consumption amount (liter). 5) "date_consumption" is the date and time of consumption when recorded. The data is transferred to the cloud when the sensors detect water flow.

The system monitors the water flow rate (measured in liters per minute) and the water consumption. When the gutter valve is triggered or touched, data from the water sensor is directly received and recorded in the columns "flow_rate_liter_min" and "cumulative_volumn" in a database.

Table 10: *A Sample of Water Data from the Cloud.*

id	sensor_code	flow_rate_liter_min	cumulative_volumn	date_consumption
1	wt01	2.27	0.19	2022-12-03 07:02:39
2	wt01	0.27	0.02	2022-12-03 07:28:17
3	wt01	0.13	0.01	2022-12-03 09:02:39
4	wt01	0.4	0.04	2022-12-03 09:28:17
5	wt01	0.13	0.01	2022-12-03 11:44:12
6	wt01	0.13	0.01	2022-12-03 11:26:21
7	wt01	0.13	0.01	2022-12-03 11:27:34
8	wt01	1.6	0.13	2022-12-03 11:38:41
9	wt01	0.13	0.1	2022-12-03 02:29:28
10	wt01	0.4	0.03	2022-12-03 02:30:05
:	:	:	:	:
10702	wt01	1.47	0.12	2023-04-30 03:12:19
10703	wt01	1.07	0.09	2023-04-30 03:40:17

4.3 Smart Cattle Farming Application

The Smart Cattle Farming application employed JSON for cloud-based data communication, utilizing a Java-based user interface. This application empowers farmers to monitor food consumption, calculate costs, and receive timely alerts related to food quantities. Furthermore, it handles various aspects such as cattle growth data, user details, feed information, breeding records, and estrus reversal notifications. It's compatible with Android mobile devices and has undergone a comprehensive performance assessment, as detailed below.

1) Performance Evaluation via Black Box Testing: Black box testing is a methodology employed to assess the functionality and quality of an application, regardless of its internal architecture; according to M. E. Khan, software testing involves analyzing data to identify disparities between the necessary and available conditions. The black box testing technique aids in uncovering defects, ensuring that the developed software aligns with the stated functional requirements and produces anticipated outcomes [27]. Therefore, in evaluating system performance, this research used a Black Box methodology to test the application, and Table 1 displays the results.

Table 11: *Black Box Testing in Smart Cattle Farming Application.*

Test Process	Expected Results	Accuracy (%)
1. Logging in.	1. Login using the username, password, and farm code. Upon success, the system will direct you to the main page.	100.00
2. Membership registration.	1. The system features a membership registration function, allowing you to register after completing all the required information. Subsequently, you can use the user's data to access the system.	99.00
3. Password recovery.	1. There is a function available for password recovery and changing passwords. 2. Once you have changed the password, you can use this new password to log in to the system.	98.00
4. Displaying real-time consumption data.	1. After logging in, the homepage will display current-day numerical water and food consumption totals. Additionally, a graph will illustrate the latest food quantity in the trough. Users can also access historical consumption data. 2. Trigger a Line application notification if food quantity drops below the set threshold and consumption remains under the specified reference threshold, as outlined in Table 2.	100.00
5. User data management.	1. A page is available to display user information, add new data, edit existing information, and delete data.	99.00
6. Beef cattle data management.	1. A page is available to display beef cattle information, add new data, and edit existing information.	99.00
7. Food data management.	1. A page is available to display food information, add new data, and edit existing information.	99.00
8. Instantaneous computation of consumption costs.	1. A dedicated page displays consumption data, with options to retrieve data based on defined time intervals, specific cattle, and distinct food items. 2. Consumption costs are presented numerically and in graph format. 3. The system includes a feature for downloading stored consumption data in PDF format.	98.00
9. Breeding data management	1. The system enables displaying, adding, editing, and deleting breeding data. 2. It provides notifications for scheduled pregnancy checks on bred cattle and the ability to send alerts to a Line group.	99.00
10. The value is transmitted to the cloud. (on the ESP32 board)	1. The sensor calculates the food value from the trough and sends it to the cloud, minute by minute.	100.00
The Overall Average %		99.10

The evaluation found that all 100 performance tests involving four devices in the system and encompassing ten separate processes were successful. The tests demonstrated exceptional overall performance, with an average precision of 99.10. This comprehensive validation confirms that the Cattle Smart Farming software functionalities align accurately with the intended outcomes.

2) Compatibility Test

The testing procedure involved compatibility assessment through the installation and execution of the application on diverse Android operating system versions, covering a range of screen sizes as outlined in Table 12.

Analyzing the information in Table 12 leads to a clear conclusion: the application effectively demonstrates compatibility with the Android platform, operating seamlessly across various devices, including

Table 12: *Compatibility Test Data.*

No.	Device	Screen Resolution	Android Version	Accuracy (%)
1.	Xiaomi P20 Pro	1080 × 2240	10.0.0	25.00
2.	Oppo A3s	720 × 1520	8.1.0	24.50
3.	Xiaomi 5A	1080 × 1920	7.1.2	25.00
4.	Asus Zenfone C	480 × 854	4.4.2	24.60
The Evaluation Summary				99.10

different models and screen resolutions. This adaptable application demonstrates effectiveness across various Android versions, with the minimum requirement being Android version 4 and the lowest screen resolution being 480 × 854 pixels. The results indicated that all 100 performance tests across four devices (25 tests per device) were deemed acceptable. The overall performance of the tests was exceptional; the overall average precision is 99.10.

3) Application Deployment

The "Smart Cattle Farming" application has been completed, including disseminating knowledge to Chiang Rai province, Thailand cattle farmers. It is also conveniently accessible for farmers to install via the Google Play Store on the Android operating system, as illustrated in "***Fig. 13:***".

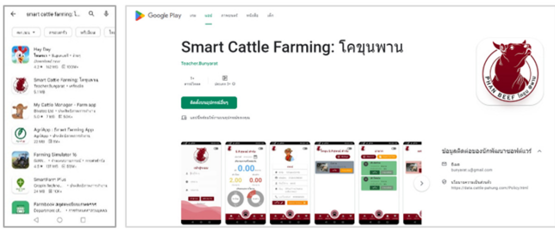

Fig.13: *Releasing the Application via the Google Play Store.*

4) Application Reporting

The Smart Cattle Farming application empowered farmers to monitor and access four distinct reports within its scope, as follows:

1. The report encapsulates real-time consumption data.
2. The data encompasses consumption costs.
3. The pertinent breeding information.
4. The application's feature of delivering timely notifications encompassing feeding quantities and breeding alerts.

Please refer to the information below for more comprehensive insights about "***Fig. 14:*** - ***Fig. 17:***".

This report (***Fig. 14***) calculates the daily water consumption according to Eq. 4.

$$WC = \sum_{i=0}^{D} W_i \tag{4}$$

For example, while investigating water consumption on the 24-hour time of the selected date, written as the D value, the system will include the data collected in the cumulative_volumn column, or W value. As a result, WC contains the water consumption for that particular day.

Fig.14: *The Real-Time Consumption Data Report.*

Fig.15: *The Consumption Cost Data Report (Reference price: https://www.thaimaizeandproduce.org, June 2023).*

Eq. 7 is used to calculate the information on food consumption (shown in ***Fig. 15:***).

$$FC = \sum_{i=1}^{N} C_i P \tag{7}$$

This section summarizes the consumption of the selected food (designated as C) multiplied by the unit price of the associated food item (denoted as P). Consequently, FC reflects the cost of feed consumption in the report.

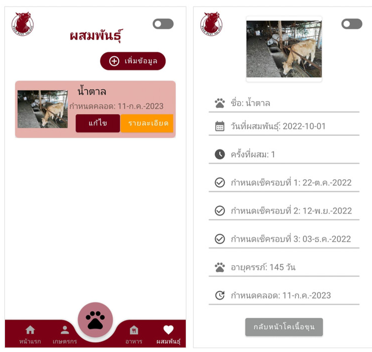

Fig.16: *The Breeding Information Report.*

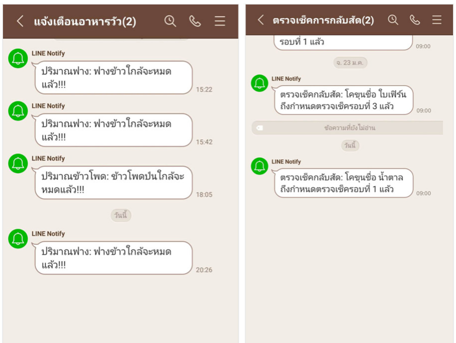

Fig.17: *Notifications for Feeding Quantity and Breeding Alerts.*

5. CONCLUSION

In this article, we propose an innovative food trough system for providing food and water that can collect real-time consumption data. This system incorporates a Wireless Sensor Network (WSN) to transmit consumption data to a cloud platform for storage and analysis. "Smart Cattle Farming," an Android application, has been developed to enable farmers to monitor real-time consumption data, perform cost calculations, and receive instant notifications. Furthermore, the system offers convenience in managing food-related data, assisting in calculating the necessary daily feed quantity based on the established theoretical framework. It also issues alerts when consumption fails to meet the predefined targets. The system aids in managing breeding data by sending alerts for scheduled check-ups and calving times. Each farm is provided access to its specific farm's information through user login. Accurate information received by farmers aids them in efficiently analyzing and making well-informed decisions for their upcoming cattle farming endeavors. Hereupon, Consumption data is then analyzed using Linear Regression Analysis. Key findings indicate a substantial correlation (0.995) between feed quantity and cattle weight gain, with a predictive capability of 99%. There is statistical significance at the 0.05 threshold, with a standard error level for prediction at ± 8.378.

In the future, we will strive to develop a system that integrates advanced auto-feed technology with fuzzy logic. This system will connect closely with knowledge-based data analysis in beef cattle breeding. The goal is to integrate this system to achieve beef products with specific qualities and attributes desired by the market, ensuring precise provisioning of daily feed quantities. It is imperative that comprehensive performance testing be carried out throughout all stages of the cattle's lifecycle, commencing with their rearing and continuing until they reach maturity. This rigorous evaluation is essential to gauge the system's efficiency accurately. Ultimately, this comprehensive process will enable us to measure the actual effectiveness of the system in delivering the desired beef quality that aligns with the market's demands.

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