Research Article

A DESIGN OF SMART FEEDING SYSTEM FOR DAIRY COWS FARM

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Abstract. *In this study, we present the design of an automatic food supply system for dairy cows using an expert calculation formula based on collected data, including temperature and humidity of the barns, cow movement, daily milk production, the breeds and ages of the herd. When the expert system calculates the amount of the total mixed ration (TMR) feed to provide to the cows, it will transfer the TMR value to the proposed system to provide the exact amount of the daily feed. The designed feeding system performs 3 tasks: 1) Accurately quantify the amount of the TMR feed ingredients according to the formula including chopped grass and fine feed portions; 2) Mixing the measured ingredients during a preset time from the system; 3) Transporting the feed after mixing to the feeding trough for dairy cows and then automatically retrieving the leftover feed. The proposed system was tested at the Tan Tai Loc dairy cow farm, Soc Trang City, Vietnam. The results show that the automatic weighing system can reach ±0.5% accuracy, and the proposed feeding system can minimize feed loss and eliminate overfeeding to promote good cow health and performance.*

Keywords

Total mixed ration, Smart feeding system, Dairy cows, Internet of Things, Agriculture.

1. Introduction

With the increasing demand for milk, the dairy farming industry is increasingly developing. The number of dairy cows and their milk production has increased over the years [1] and the dairy industry has become a major economic source for many countries [2].

Besides genes, food is the factor that most determines milk production [3]. Nutritional deficiencies cause reduced milk production, which is common in tropical regions [4]. Meanwhile, providing more food than needed causes waste and pollution [5]. Both underfeeding and overfeeding lead to reduced milk production and quality due to negative effects on the health of dairy cows.

Therefore, providing balanced feed is essential in dairy farming. A good dairy ration, known as total mixed ration (TMR), mainly includes forages and byproducts. TMR feeding has been shown to produce higher milk yields than grass feeding [3, 6, 7]. Moreover, TMR feeding guarantees the proportion of nutrition is the same every bite, so unattractive food cannot be intentionally avoided, and thus the feeding cost is reduced [8]. Well-operated TMR feeding systems reduce digestive disorders and subclinical ruminal acidosis [9] as well as improve rumen ecology [10]. Moreover, TMR changes the characteristics and processing capability of milk [11], also increase milk quality [12].

Traditionally, dairy feeding is performed manually, which suffers from low speed, inconsistency, and high labor cost. In addition, although dividing food into several meals has crucial positive impacts, it is not convenient for manual feeding due to these disadvantages. French and Kennelly compared 2 groups of dairy cows fed 12 and 2 times a day. The potential of hydrogen (pH) is significantly more stable, and the concentration of milk fat is higher for the group more frequently fed [13]. Milking frequency [14] and milk yield [15] increase with the number of feeding times. Moreover, DeVries discovered that feeding more frequently increases the equality of eating experience of dairy cows, and suggested frequent feeding for stabilizing cows' diets [16].

With the growth in farm size, while labor has been becoming increasingly expensive and scarce [17], manual feeding becomes obsolete, so has been gradually replaced by automatic feeding thank to the development of technologies. Fortunately, dairy cows was shown to be able to adapt effectively to feeding equipment [18]. Smart systems independently automatically rationing and feeding cows, especially dairy cows during lactation period, also known as SmartFeeders, are provided by worldwide companies. Delaval Optimat Feeding automatically weights, cuts, and mixes and distribute feed by a wagon. GEA's Dairyfeed F4800 feed pusher pushes and arranges feed toward the cow shed, with position and route are controlled intelligently thank to a transponder, sensors and a gyroscope. These machines improve cow health, increase milk production and profits, protect the environment, help farmers easily and flexibly control the cow herd. However, these systems are desired for herd about hundreds to a thousand of individuals, so are not cost-effective in Vietnam, with herds often small. A study in Italy suggests that feeding systems should be tailored to farm needs and farmer needs [19].

Therefore, feeding systems suitable for small herd are developed. A low-cost feeding robotic vehicle tracking and distributing food based on path and distance collected by sensors was developed in Nepal [20]. An automatic feeding system using monitoring sensors, a central controller and a data management system was developed in Russia [21].

The objectives of this study are to develop a dairy cow feeding system following 3 tasks: (1) Accurate quantify the amount of TMR feed ingredients according to the formula including chopped grass and fine feed portion, (2) Mixing the measured ingredients during preset time from the system, and (3) Transporting the feed after mixing to the feeding trough for dairy cows and then retrieving the leftover feed. This is a simple, easy-to-assemble, -move, -operate system, developed from the idea of FeedStar company with efficient configuration for small farms in Vietnam. The proposed system was tested on an actual farm with a trial scale of 20 dairy cows in Soc Trang province, Vietnam.

2. Materials and Methods

2.1. System Design

Figure 1 provides an overview of the system design, where F1-gateway is designed to communicate with all sensor nodes installed in the barn to collect data from the dairy herd throughout the day, control the mixing system, and provide feed for the herd. The data includes barn temperature and humidity, milk quantity, herd activity status, and milk extraction volume. Additionally, the gateway has the capability to connect to a webserver and a mobile application for remote data exchange and updates through the integrated ESP32 device.

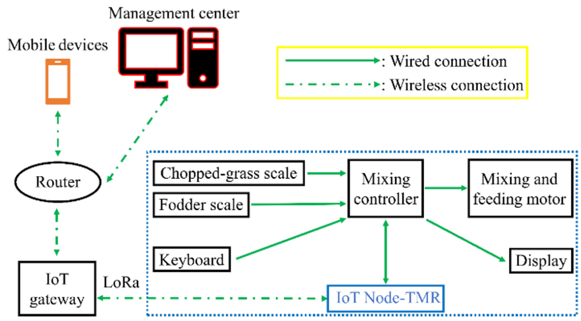

Fig. 1: The block diagram of the automated feeding system for dairy cows.

The TMR mixing system consists of two scales for measuring food components: the chopped grass scale and the fodder scale. The outputs of these two scales are connected to the mixer machine to evenly mix the food components after measurement. Simultaneously, the system transfers the measured food amounts to the loading trough to deliver them to the dairy herd. In this paper, we focus on the design of the mixing system and the control algorithms of the system.

2.2. Mechanical System Design

Figure 2 depicts the mechanical system design, consisting of two hoppers supplying fine feed and chopped grass. While the chopped grass is supplied to the 50kg scale system through the feeder conveyor, the fine feed is supplied to the 10kg scale system via a screw feeder. Below the two weighing bins are the mixing tanks that allow for TMR mixing based on preset time settings while simultaneously releasing valves to supply TMR to the dairy herd through the feeder conveyor system. Figure 3 shows the complete design system drawn by Solidworks. Details about sizes of the weighting systems and the mixing tank are shown in Fig. 4.

Technical specifications for the proposed system:

- Grooved trough for grass: 4,500 x 500 mm.

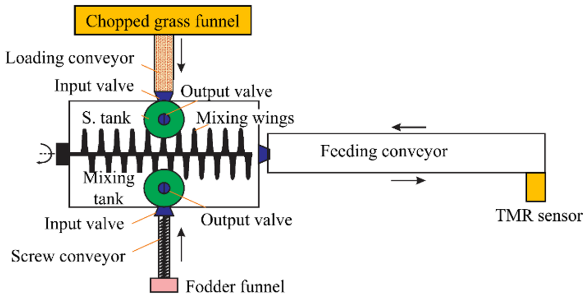

Fig. 2: Mechanical system design.

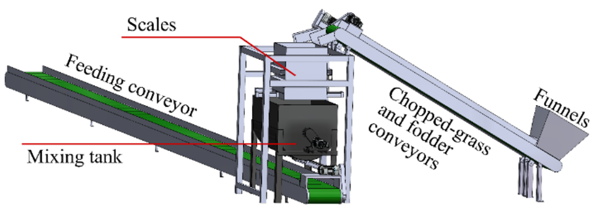

Fig. 3: 3D image of the proposed system.

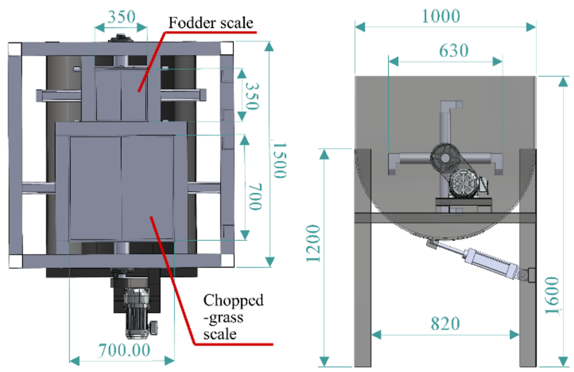

Fig. 4: Detailed 3D images of the automatic weighting system (left) and the mixing tank system (right).

- Screw feeder for flour, bran: 4,500 x 14 mm.
- Flour weighing bin: 35 x 35 x 800 mm.
- Grass weighing bin: 700 x 700 x 800 mm.
- 2-component mixer and discharge chute (TMR feed).
- Mixing tank: maximum 250kg per mixing cycle (capacity 300kg): (LxWxH: 1,500 x 1,000 x 1,000 mm).
  - Material: shaped iron, electrostatic paint.
  - Mixing type: horizontal shaft.
  - Cylinder, pneumatic: 01 set.
  - Hydraulic power and control cabinet: 01 unit.
  - Motor: 01 unit.
  - Drive system for mixing tank and feeder conveyors of the mixer machine.
  - Type of drive for mixing tank: Motor connection with mixing shaft using belt drive.
  - Transmission ratio 1:50.
- Calculation of motor power selection.
  - Weight of mixer shaft: 50 kg.
  - Maximum material weight pressed onto the shaft: 250 kg.
  - Total maximum weight: 300 kg.
  - $g = 9.8$ m/s^2; Coefficient of friction (minimum) $f = 0.8$
  - Pull force of the mixer shaft mass TK:

$$T_K = M \times g \times f[N] = 300 \times 9.8 \times 0.8 = 2352N \tag{1}$$

  - Inertial force due to the mixer shaft mass:

$$T_{BT} = M \times \alpha = M \times \left(\frac{dv}{dt}\right) \tag{2}$$

where α= maximum acceleration (m/s^2). dv = velocity change (m/s). dt = time interval when the change occurs (s). Assuming that when the conveyor starts operating, if the speed is increased to 2 m/minute in 0.2 seconds, then: dv = 2/60 = 0.03333 m/s; dt = 0.2 s
$T_{TB} = M \times \alpha = M \times \left(\frac{dv}{dt}\right) = 220 \times \left(\frac{0.03333}{0.2}\right) = 36.6N$

  - Total maximum pulling force Tmax:

$$T_{max} = T_K + T_{TB} = 2352 + 36.6 = 2388.6N \tag{3}$$

  - Motor power:

$$Motor\, power\,(W) = \frac{T_{max} \times V}{5.45 \times \eta} \tag{4}$$

with η= 0.85 motor efficiency, V: maximum stirring speed = 2 m/minute.
P (motor) = (2388.6 x 2) / (5.45 x 0.85) = 1031.2W
Therefore, a 1.5 kW (2 HP) motor is appropriate.

2.3. Design of the electro-mechanical system

The described system is a network of IoT devices connected and controlled via MQTT and LoRa protocols (Fig. 5). The main components of the system include a Broker Server, Gateway, IoT Node, and Web Server. The Broker Server serves as the central coordinator, receiving and transmitting control commands between the user application and IoT devices. Control commands

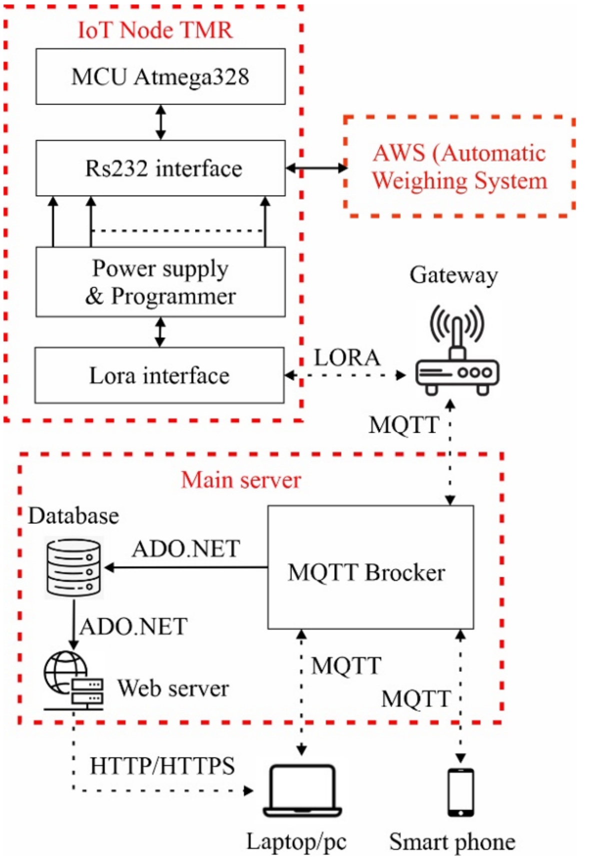

Fig. 5: The proposed IoT system with the automatic weighing system.

are sent from a smartphone application or a website to the Broker Server via the MQTT protocol. Upon receiving the commands, the Broker forwards them to the Gateway, which is responsible for transmitting the commands to the IoT Node over the LoRa network.

The power control system for the mixer machine is designed as depicted in Fig. 6. The inverters used for the conveyor belt motor and the mixer motor allow for easy speed adjustment and help reduce the power consumption by up to 30%. Currently, inverters are cost effective, making their use in the system reasonable. Figure 6 illustrates the connection of three inverters to the material supply system for the automatic weighing and mixer control. Inverter 1 controls the speed of the conveyor belt supplying material to the chopped grass weighing bin; inverter 2 controls the speed of the screw feeder supplying material to the fine feed weighing bin; and inverter 3 controls the speed of the mixer's rotating shaft.

2.4. System Control algorithms

Figure 7 is the algorithm flowchart of data exchange between the gateway and the automatic weighing

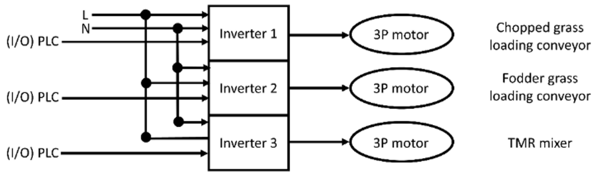

Fig. 6: The power control system of the mixer machine.

system. After the expert system collects enough daily data such as barn temperature and humidity, the activity level of individual dairy cows, milk yield during the day, and based on available data on dairy breed, milk yield, and age, it calculates the amount of the TMR feed with specific ingredient percentages to supply to the mixing system. Typically, the daily feed amount is calculated into the total TMR quantity with corresponding percentages of chopped grass and fine feed, which is then divided into 3 to 4 batches for mixing and feeding the cows throughout the day. For example, the feed amount for a dairy herd of 20 cows is 900Kg TMR consisting of 65% chopped grass and 35% fine feed. This feed amount is divided into 4 batches, with the first three batches being 250Kg each and the last batch being 150Kg. Then, the data exchange sequence is transmitted from the gateway to the IoTNode-TMR as follows (feeding times are set on the webserver):
Time 1: <0203>BGA250Kg35%
Time 2: <0203>BGB250Kg35%
Time 3: <0203>BGC250Kg35%
Time 4: <0203>BGE150Kg35%

At the end of each feeding time, the system will transmit back to the gateway the actual quantified feed amount, which is crucial data for technicians to check the stability of the system. The proposed algorithm for controlling the weighing system, mixer, and feeding of dairy cows as shown in Fig. 8.

After receiving the required amount of the TMR feed at a specific time of day, the automatic weighing system controller will divide the feed into several batches for weighing. This is because the weighing tank system is designed to be compact, so it cannot weigh the entire feed at once. For example, 250kg with 35% fine feed will be divided into 5 weighing cycles, each approximately 50kg. Then, the controller calculates the amount of chopped grass to control the conveyor belt transporting the material at high speed V1 to the weighing tank, while the screw feeder also operates at high speed V1 to transport the fine feed to the corresponding weighing tank. When the feed reaches level 2, indicating it is close to the required amount, the speed of both conveyor belts automatically decreases to V2 until each weighing tank has enough material, then the corresponding conveyor belt automatically stops.

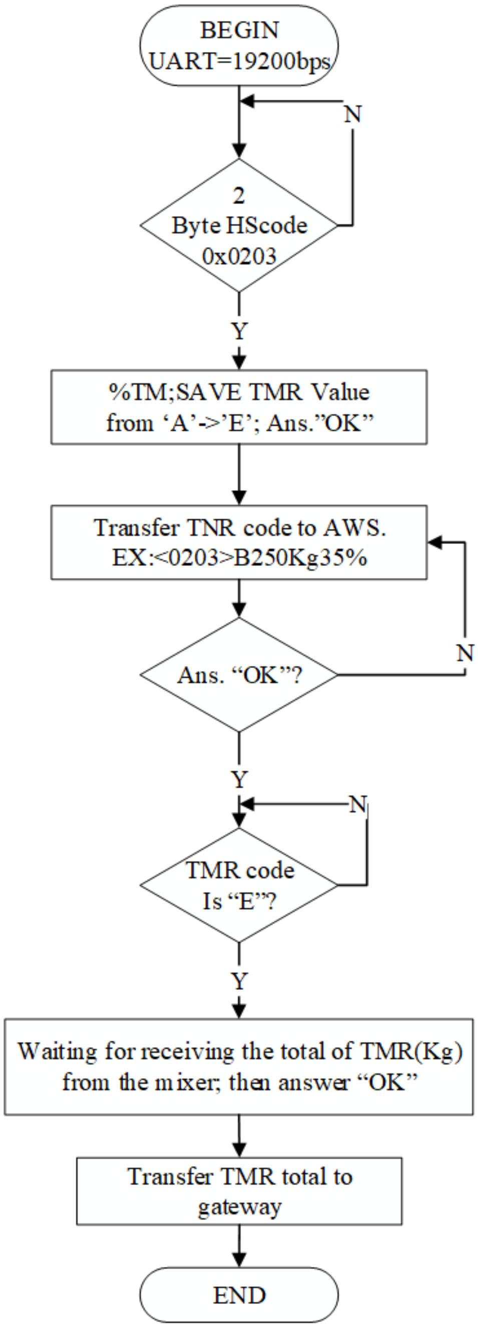

Fig. 7: Algorithm flowchart for data exchange between the gateway and the automatic weighing system.

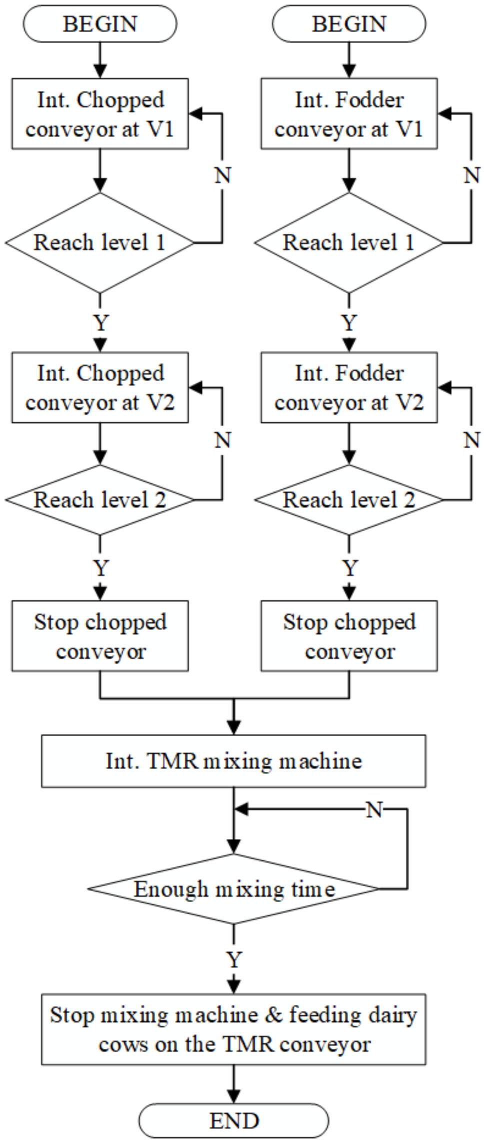

Fig. 8: Algorithm flowchart for controlling the automatic weighing system, mixer, and feeding of dairy cows.

Next, the mixer shaft in the mixing tank starts before the weighing tanks sequentially discharge the material into the mixer tank. After the preset mixing time in the system is completed, the TMR feed conveyor operates before the mixer tank discharges the TMR feed onto the conveyor belt for transportation to the barn door for the dairy cows to eat. When the TMR feed reaches the end of the conveyor belt (Fig. 2), the sensor signals allow the controller to stop the conveyor belt. After a predetermined time for the cows to finish eating the TMR feed on the conveyor belt, the conveyor belt starts in the opposite direction to recover the excess feed components.

3. Results and Discussion

Figure 9 shows the system control interface of the mixing system deployed at the Tan Tai Loc dairy farm. The system allows users to operate in both MANUAL and AUTO modes. When switched to automatic mode, the system receives commands to weigh and mix the feed before each scheduled feeding time, and the entire process of weighing, mixing, and distributing feed is executed according to the algorithm shown in Figure 8. In

Fig. 9: Control screen of the proposed system.

case of an Internet connection loss, the system can still control the feeding process based on pre-configured data from the previous day. When the Internet connection to the server is restored, the expert system calculates and updates the TMR feed ration for the next day. The calculation of the herd's feed ration is provided by veterinary experts for each farm based on breed standards, total herd weight, and age. However, factors such as barn temperature and milk yield also influence the next day's feed ration. (In this study, it is assumed that all dairy cows are uniform, so the feed ration is standardized for the entire herd). In practical applications, during periods of high temperatures exceeding 30°C, the feed ration must be reduced by 2–5%. Conversely, if the milk yield exceeds the preset average level, the feed amount will increase by 2–3% for the following day. The detailed calculation formulas for feed rations and milk yield are considered confidential information for each company. If the local LoRa network encounters an issue, the farm manager can switch to MANUAL mode and manually set the mixing formula to provide feed for the herd.

$$\widehat{m}_{TMR} = \widehat{m}_{chopped\,grass} + \widehat{m}_{fodder} \tag{5}$$

$$E_{TMR} = \frac{|\widehat{m}_{TMR} - m_{TMR}|}{m_{TMR}} \tag{6}$$

$$E_{chopped\,grass} = \frac{|\widehat{m}_{chopped\,grass} - m_{chopped\,grass}|}{m_{chopped\,grass}} \tag{7}$$

$$E_{fodder} = \frac{|\widehat{m}_{fodder} - m_{fodder}|}{m_{fodder}} \tag{8}$$

Fig. 10: The automatic feeding system for dairy cows has been installed at Tan Tai Loc Dairy Farm, Soc Trang City, Vietnam.

where m is the expected weight, $\widehat{m}$ is the actual weight scaled by the system, E is the relative error.

The TMR feed mixing system receives the feed formulation from the gateway, which is sent by the expert system from the server at the end of the previous day. The actual amount of feed delivered to the automatic feeding trough is recorded and stored in the database at the end of each day. In Fig. 11, we observe that the TMR feed generated from the expert formula through the automatic weighing system exhibits stable accuracy and falls within the acceptable range for the dairy farm, with an error rate fluctuating around $\pm 0.5\%$. Meanwhile, in Fig. 12, the specialized design of the screw feeder for the fine feed results in a lower error rate, fluctuating around $\pm 0.2\%$, whereas the chopped grass material and conveyor system are prone to larger errors and some unstable values, but overall still fall within the acceptable range of about $\pm 0.5\%$.

The system's error for a herd of 20 cows under testing, corresponding to the design of the TMR feed conveyor, is 18m, with 15m located within the designated area for a density of 20 cows in the project's experimental model. In practice, when scaling up to a larger number of 40-50 cows per barn row, the system can extend the conveyor by 15 to 20 meters while still ensuring the feed mixer meets the demand (300 kg per mixing cycle, with multiple feedings per day, averaging 3-4 times daily). The system's design objective is to reduce labor requirements in the barn, ensure the correct composition and quantity of feed, and adhere to the recommendations of livestock experts. The proposed system has been operating stably and has been accepted according to the published results No. 2024-24-0972/NS-KQNC. It has also been recognized by the Ministry of Science and Technology of Vietnam under Decision No. 3123/QĐ-BKHCN.

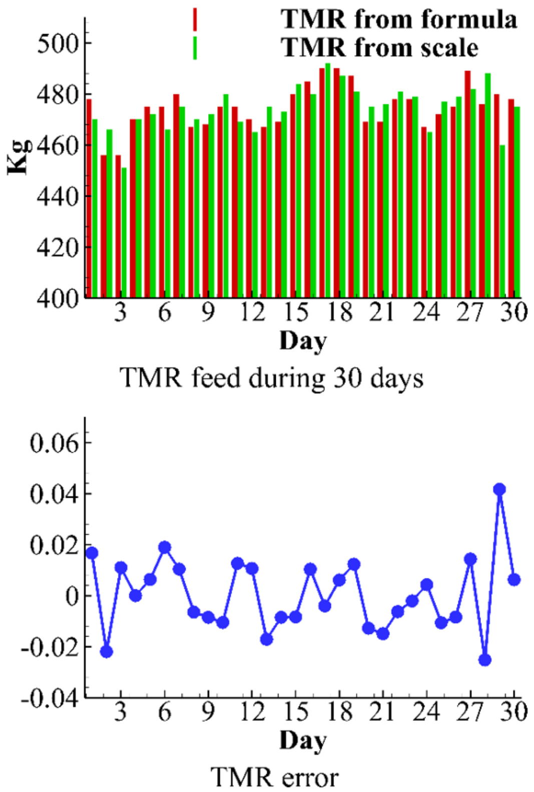

Fig. 11: The discrepancy in feed quantity from the expert formula compared to the automatic weighing system.

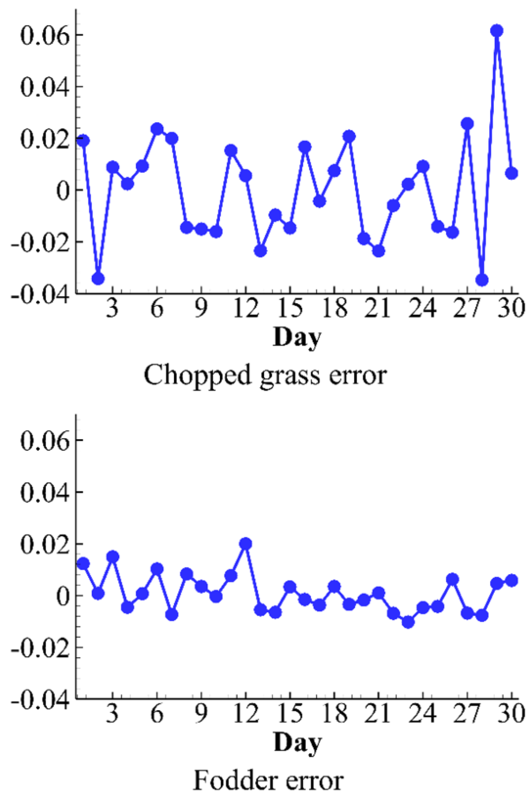

Fig. 12: The discrepancy in feed quantity from the expert formula compared to the automatic weighing system with chopped grass and fine feed.

4. Conclusion

In this study, we proposed an automatic feeding system that is appropriate for small and medium-sized dairy herds. The system has been designed, installed, tested, and put into practical operation. The implementation process has demonstrated the accurate operation of communication protocols within the system, and the electromechanical structure operates stably. Monitoring data collected continuously over 30 days shows that the system operates steadily with acceptable precision. Longer experimental time may be needed to verify the effectiveness of the designed system in the high-tech dairy farming sector. The proposed system is expected to improve the health, milk quality, and lifespan of the dairy herd, contributing to enhancing the economic efficiency of the locality and Vietnam as a whole in the future.

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Author Contributions

Both N.M.T and C.N.N developed the design of the study. Both N.M.T and T.V.T built the system with the support of M.N.H on programming. T.V.T collected raw data and raw images. N.M.T.N did data processing, prepared figures and formatted the manuscript. Both N.M.T and T.V.T wrote the manuscript. C.N.N supervised the project.

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