Design of a Database and Modules for IoT-Based Data Exchange in Herd Management Systems

Kamil Aykutalp Gündüz*, Fatih Başçiftçi**

**Selçuk University, Kadınhanı Faik İçil Vocational School, Department of Electronic and Automation, Kadınhanı, Konya 42800, Turkey; (Tel: +905386986092 e-mail: aykutalp@selcuk.edu.tr).*

***Selçuk University, Technology Faculty, Department of Computer Engineering, Selçuk University Campus, Konya 42075, Turkey;(e-mail: basciftci@selcuk.edu.tr).*

Abstract: Monitoring and recording the behavior of cattle in their environment with human eyes is one of the most challenging tasks in herd management systems. Labeling this type of movement in animals that usually act according to their habits and conveying them to the authorized veterinarians is difficult. Herd tracking systems are constantly being developed to record and interpret animal behavior and to make early diagnosis against diseases. Certain symptoms can be detected by monitoring the animals' behavior during the day for long periods of time or by monitoring their abnormal behavior and bodily discharge (spit, feces, sweat, etc.). Biosensors are devices that transform physical and behavioral bodily responses in animals with electronic signals. Real-time monitoring and assessing herd management is essential for increasing productivity and animal welfare in animal husbandry. Internet of Things (IoT) is a technology that is in frequent use and provides remarkable solutions for such systems. This study introduces a system solution that, in addition to having all the features that should be present in a herd management system, is compatible with IoT technology that can be attached to the bodies of the cattle, logs the data from biosensors in the system via wireless communication, presents the data to the user graphically, and can be monitored over the web. IoT-aided microcontrollers provide wireless communication, high-speed data transmission, and low power consumption. The system offers a solution that allows for real-time data monitoring and establishing a control system.

Keywords: Animal monitoring, database, internet of things, herd management, productivity.

1. INTRODUCTION

Animals are unable to talk like human beings do. They cannot express problems, discomfort, contentment, or stress about the conditions they are in. In addressing this issue, it is possible to measure the physiological and behavioral statuses of animals in real time and sensitively through sensor-based practices. Devices that operate with biosensors offer operators with reliable, quick, and simple solutions by providing them with various data related to issues such as early diagnosis of animal diseases, monitoring the behavior and movements of animals, detecting reproductive cycles, stress, and metabolic diseases. Figure 1 shows an example of status monitoring that enables such observations to be made. While most businesses in Turkey make these observations using manpower, there are also those that make use of technological opportunities.

Biosensors include wearable technologies such as accelerometers, collar sensors, calving sensors, motion sensors, ear tag sensors, tail sensors, vagina sensors, leg sensors, rumen sensors, neck sensors, and halter sensors. In this respect, the use of biosensors and wearable technologies is important in increasing animal welfare as well as providing economic benefits by facilitating the monitoring of animal health and herd management (Turan and Bülbüller, 2021).

There are diseases that reduce the milk production and fertility performance of cattle, and stress in animals is likely to be among the factors that cause such problems. Among the most common diseases seen in cattle are conditions such as rumen acidosis in terms of digestion, difficulty ascertaining the estrous period and reluctance to feed due to stress. These issues are among the factors that reduce both the welfare of the animals and the productivity of the herd (Altınçekiç and Koyuncu, 2012).

Fig. 1. An example of monitoring the status of animals.

Without the use of technology and automation systems, it is impossible for large-scale livestock operations to see the desired performance from animals with high genetic value. Animal husbandry practices that are carried out with the use of advanced technology in herd management provide breeders, animals, and consumers with various benefits. However, to get the expected benefits from these systems, it is necessary to know the features of the systems and to use them effectively (Göncü and Gökçe, 2017). The objective of herd management is to carry out all tasks related to animal husbandry in a timely manner and in the correct order. (Çelik and Tanışık, 2015).

Achieving the desired yield in dairy cattle and keeping the herd healthy is possible with successful management of the herd. Herd management refers to practices that must be done at the herd level to improve income and minimize the risk of death of animals in the herd (Akman, 1998). The goal in herd management is to manage the herd with a business approach while considering the comfort and convenience of animals. With this approach, data related to the animals are collected and evaluated, regardless of the number of animals in the herd, and business decisions are made and implemented (Öz and Bilgen, 2002).

Considering all these symptoms, monitoring the feeding parameters and behavior of animals becomes necessary. Proper detection of these symptoms is important for early diagnosis and treatment. This calls for a lot of manpower as it requires sustained monitoring and experience. The mindful and proper design of the management structure of a cattle breeding business is essential in preventing many problems that could be encountered in the future or taking any necessary measures to against possible risks in a timely manner (Yüzbaşıoğlu, 2022). The most vital practices in modern livestock businesses are animal identification, and collection, analysis and recording of data. The Internet of Things is a useful technology in this type of real-time data monitoring, data control and transfer, and it has been one of the key components of Industry 4.0 (Yoon-Min et al., 2016).

2. LITERATURE REVIEW

Robert et al, in their article in 2021, an optimization model is proposed, applicable to the conditions of the Czech Republic, from the point of view of small-scale farmers on the management of cattle herds. (Hlavatý et al., 2021). (Francisco et al, at 2019), an IoT-based system has been developed with low-cost GPS collars that will enable herd monitoring (Maroto-Molina et al., 2019). A study conducted in 2014 examined sheep breeding businesses and sheep herd farms in Karaman, Turkey, and showed that the ratio of those who utilized computers in herd management and those who have received training on the subject was around 6% in both (Şahinli, 2014). Taşkın et al., investigated the state of herd management in 234 goat farms in the cities of İzmir, Çanakkale, and Balıkesir in Turkey (Taşkın et al., 2017). A study on the body language of animals examined how herd management should be done for the welfare and comfort of animals (Özbeyaz and Özbostancı, 2020). A study analyzing the availability of robotic herd management systems in the field of dairy cattle in various regions of Turkey has been examined (Çıkrıkçı, 2019). Herd management techniques used in cattle farms in İzmir's Ödemiş district were examined (Tatar and Esenbuğa, 2022). In a 2016 doctoral thesis, A. K. Yıldız examined the effects of factors related to estrus in cattle by using artificial neural network models (Yıldız, 2016). Hilal also examined studies carried out using artificial neural networks in the field of dairy farming (Hilal and Şahinli, 2022). In one study, Özgüven et al. discussed the wireless data transmission methods used in pedometers in the market (Özgüven and Tan, 2017). One study on sheep breeding activities of farmers participating in the herd management personnel course program in Niğde, Turkey, highlighted the importance of herd management systems (Çınar and Ceyhan, 2021). Reviews on modern technology applications used in the field of herd management in dairy cattle were examined (Tömek, 2006). A method proposed by Toprak in 2023 is a calculation based on known nearest neighbors and matrix completion to determine possible disease relationships and can be used with confidence predictively (Toprak, 2023). A study on the approaches observed in cattle breeding businesses and the preventive measures that can be taken in this field was examined (Göncü and Bozkurt, 2019). Precision dairy farming technologies, commonly used in cattle farms, and their purposes were examined (Kaya and Örs, 2013). A computer software was developed for the collection and evaluation of technical and financial data in livestock enterprises (Aydın and Günlü, 2009). Herd management systems used in the field of livestock in Turkey were examined (Karakuş et al., 2019). A study on the utilization of herd management systems via wireless sensor networks proves the practicality of WSN-based solutions for livestock monitoring applications (Kwong et al., 2011). A new gateway was designed to meet the requirements of herd management systems with a focus on the Internet of Things/Machine-2-Machine interaction (Nobrega et al., 2019). A field study was conducted to determine the prevalence of ketosis in Western European dairy herds, dairy herd management systems, and clinical conditions for fresh cows (Berge and Vertenten, 2014). The importance of ensuring a balanced ratio for growth, reproduction, and productivity performance of Begait cattle under different herd management systems in Northern Ethiopia was underlined (Mezgebe et al., 2018). Fernandes et al., carried out a reverse engineering and security evaluation of commercial tags for RFID-based IoT applications (Fernandes et al., 2018). Germani et al. introduced a new IoT Architecture for Continuous Livestock Monitoring Using LoRa LPWAN (Germani et al., 2019). Tzounis et al. presented the challenges and potential for the propagation of wireless sensor networks and IoT used in the agricultural sector (Tzounis et al., 2017).

3. MATERIALS AND METHOD

This section of the study provides detailed information about the materials used for a herd management system in cattle farms where data from wireless sensor devices attached to animals can be processed, monitored, and supervised.

The PHP scripting language, PHP for short, is a web-based programming language. PHP adds dynamism to static texts on the internet and performs best with MySQL database and Linux operating system. Created by Rasmus Lerdorf in 1995, PHP is still being developed today. (Avcı, 2010).

MySQL is a relational database management system. Designed as a system and software to define, create, use, modify databases, MySQL meets any operational requirements for database systems (Moore, 2018).

Apache web server is a distributed, high-performance messaging system (Gökalp, 2016). What we call big data in today's technology is growing rapidly and can crop up at any time.

REST web service approach is an architectural style that uses Hypertext Transfer Protocol (HTTP) for developing web services (Li et al., 2015). The basic principle in REST architecture is to use advanced HTTP architectural features data exchange between machines, rather than using a protocol running on top of the HTTP layer. REST interface performs web service operations using HTTP standard methods (GET, PUT, POST and DELETE). REST is data driven. Therefore, the server response is received as a JSON based dataset. This provides ease of use and flexibility (Oyucu and Polat, 2021).

4. APPLICATION

This web-based software was created with PHP Model-View-Controller (MVC) pattern. The framework structure used in the software is among the most stable ones in the MVC architecture. Responsive web design is a design approach that ensures web pages are viewed in the best possible way on various devices and different screen sizes. Therefore, the structure of the web application was designed with this method, and a multi-directional output was obtained with a single application. Bootstrap 4 was added on to the application. Enhanced with the CSS and JavaScript infrastructure included in the web application, the software was designed in a structure that is fully compatible with mobile, tablet and desktop devices, easy to use and able to run smoothly on all devices with today's technology.

Table 1 shows the infrastructure specifications of the server where the automation was developed.

Table 1. Infrastructure specifications of the automation.

Specifications	Details
Processor	Intel™ Core™ i9-9900K CPU @ 3.60GHz
Server type	VPS (Virtual Private Server)
RAM	8 GB
Operating system	CentOS / Linux
Hard drive	1 Terabyte
Scripting language	PHP 7.4.30
Database server	MariaDB 10.3.35
Control Panel	Plesk Obsidian 18.0.44

A web page was designed to greet users and provide them with preliminary information about the system before they log into the automation system. This page was designed with HTML5.0, CSS, and Bootstrap technologies. The information page was configured on the web server under the domain name http://surutakipsistemi.com and directly in the /htdocs folder. The page was coded to fit the screen perfectly, taking shape according to the screen resolutions of the devices accessing it. A subdomain was created for the automation software, and it was put under http://sistem.surutakipsistemi.com/giris. Figure 2 shows the web page that first introduces the system.

The link to the modules on the introduction page provides the basic information contained in the system. Figure 3 shows the modules in the automation.

Applications section: A simple application has been developed to access the automation system via a mobile device running the Android operating system and the download link is placed in this section.

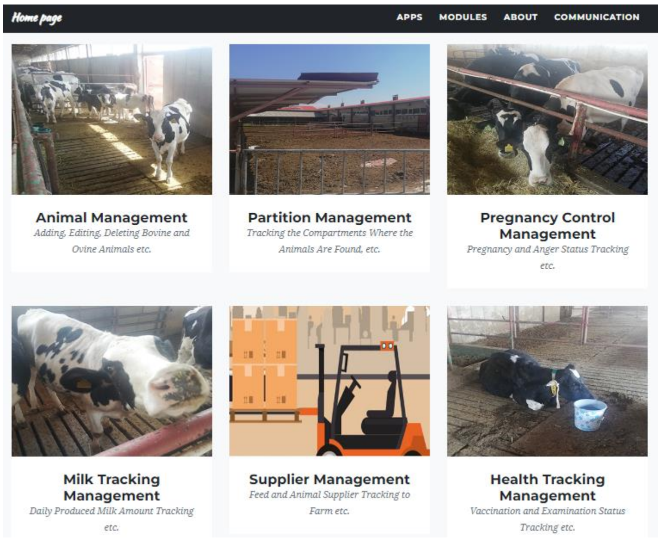

Fig. 2. The web page that introduces the system to the user.

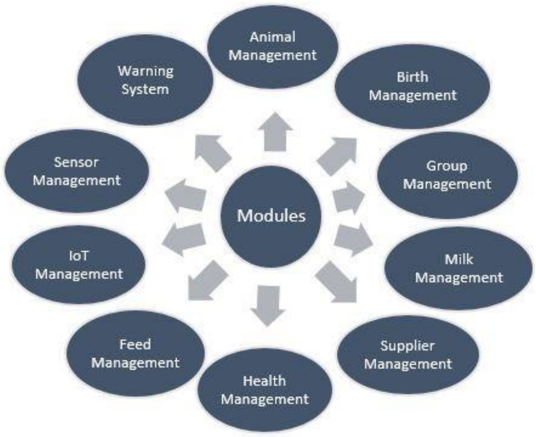

Fig. 3. Modules in the automation system.

Modules section: This section contains descriptions and details relating to the modules in the system. The modules contain basic information and are as follows:

- Cattle management
- Group (section) management
- Pregnancy and insemination control management
- Milk monitoring management
- Supplier management
- Health monitoring management
- Storage monitoring management
- Alarm system
- Feeding parameters management
- Location monitoring management
- Estrus monitoring management

About section: This section contains information about which functions the modules in the system have on a farm in general.

Contact section: This section contains the contact information to be used in case there are questions or information is needed about the automation system. As the system does not have a commercial infrastructure, the contact information in this section is personal. However, if any commercial application becomes involved, the corporate mail server and mail service infrastructure are all set.

In order to log in to the automation system, a username and password given by the system must be used. Username and password are provided by the system administrator. There are 4 user authorizations in the current system. They are:

- Root (administrator) authorization
- Veterinarian authorization
- Zootechnician authorization
- User authorization

Root authorization is above all farms and all user authorizations created in the database part of the system. Figure 4 shows the screen that welcomes the user after logging into the system with Root user authorization.

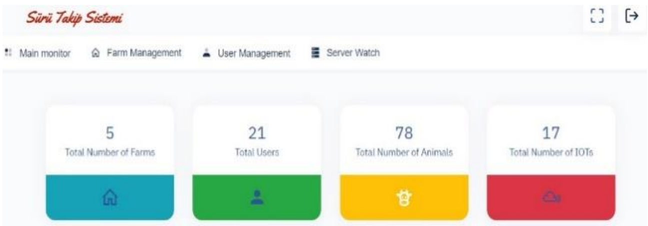

Fig. 4. Root (administator) screen.

Root (administrator) home page has 4 main menus and their submenus. These are:

* Home_screen: shows the total number of farms registered in the system, the total number of users at registered farms, the total number of animals in the system, and the total number of IoT devices connected to the animals.

* Farm management: shows a list of the farms registered in the system, is used for the tasks of registering new farms and deleting registered farms. Figure 5 shows the information entered and listed in the farm management section.

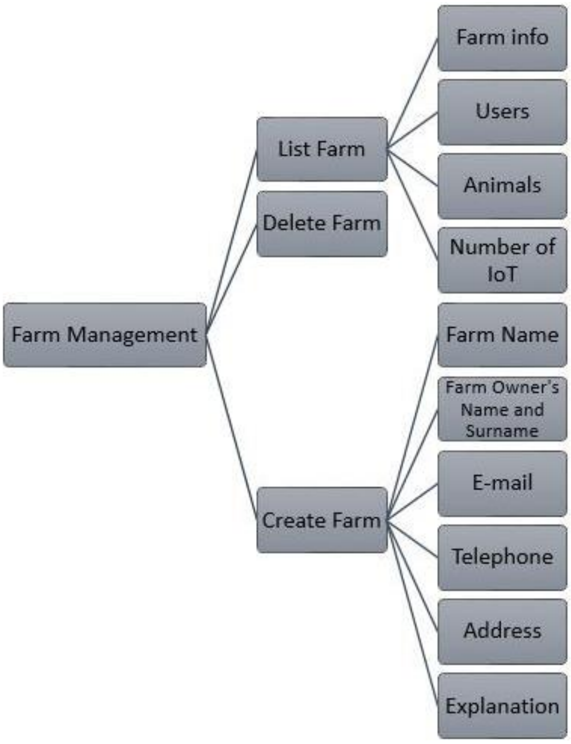

Fig. 5. Farm Management Info.

* User management: This section lists the users in the system and contains the functions of user creation, user deletion, and authorization assignment. These functions are:

Veterinarians are assigned to farms in this section. The system allows one veterinarian to be assigned to multiple farms simultaneously.

A veterinarian's authority in a farm where they are assigned can be terminated in this section. Figure 6 shows the information entered and listed in the user management section.

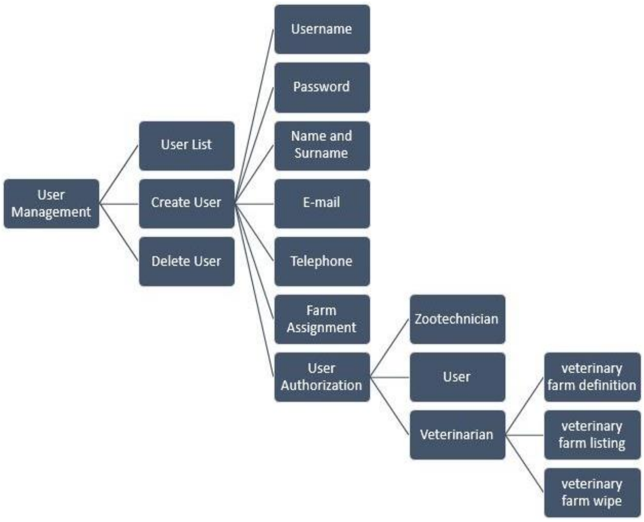

Fig. 6. User Management Info.

* Track server: Information about the server where the automation system is configured and running, the current processor (CPU), memory (RAM) usage, and the status of the hard disk used by the existing database tables can be tracked in this section.

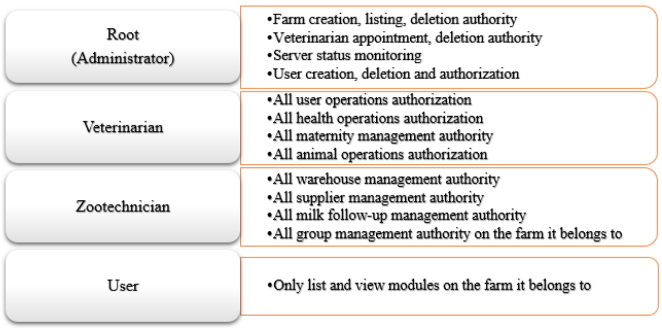

Fig. 7. User and authorization hierarchy.

Figure 7 shows the types of users created and authorized in the system as well as their authorization status.

To authorize users and assign farms in the system, a farm must be created first. Figure 8 shows the workflow diagram of adding and authorizing users in the system.

Additionally, by assigning a new user and task, authorization can be restricted after the farm's manager takes action. Any veterinarian can be assigned too many different farms. The system has been established in such a way that one veterinarian can be assigned to each farm, or the same veterinarian can be assigned to different farms.

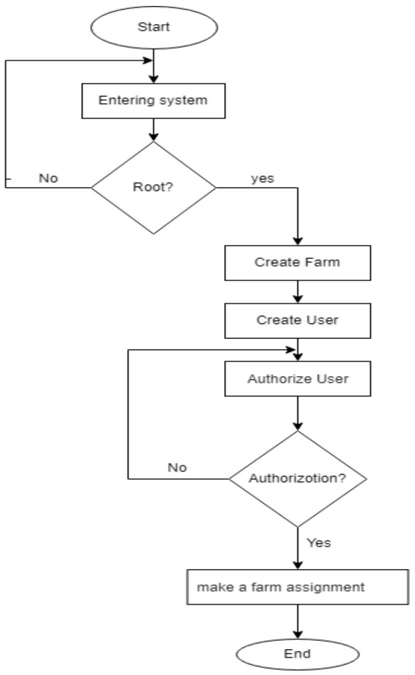

Fig. 8. General workflow diagram for farm creation and user authorization.

IoT management: Devices attached to animals are managed in this section. Figure 9 shows the information entered and listed in the IoT device management section. These are as follows:

- List IoT; lists all available IoT devices.
- Create IoT; adds a new IoT device.
- Delete IoT; deletes an IoT device.

Fig. 9. IoT device management information.

Sensor management: Sensors connected to IoT devices that are attached to animals are managed in this section. Figure 10 shows the information entered and listed in the sensor management section. These are:

- List sensors list sensors connected to existing IoT devices.
- Create sensor adds the information of a new sensor.
- Delete sensor deletes the sensor connected to an existing IoT device.

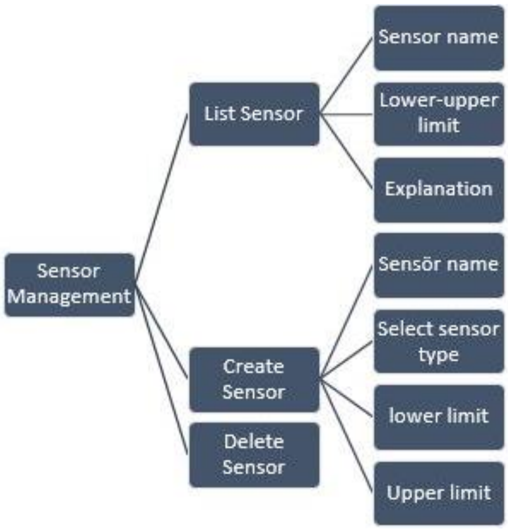

Fig. 10. Sensor Management Info.

Alarm system: Abnormal data based on sensor data from animals fitted with a device are listed in this section. Animal-based filtering is possible. Figure 11 shows the information listed in the alarm system section.

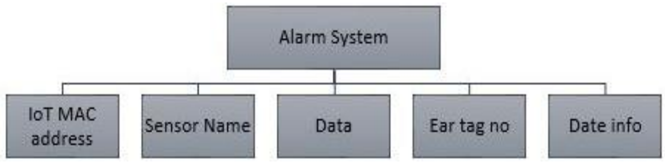

Fig. 11. Warning system Info.

The alarm system is designed to provide access to animal information by clicking on an animal's ear tag number when the data on the page is listed.

The Controller section has 5 separate sub-controller pages to manage the automation. Figure 12 shows the pages under the main controller section.

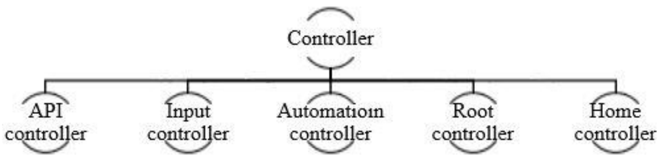

Fig. 12. Controller page sub-sections.

API Controller: This controller page is the point where the data from the devices is first collected and saved in the database. The rough codes of the section on the apicontroller.php page that connects IoT devices and automation:

```
if($GET["sensor"] && $GET["data"] && $GET["mac"]){
        $data = $GET["data"];
        $sensor = $GET["sensor"];
        $mac = $GET["mac"];
        $lat = $GET["lat"];
        $lng = $GET["lng"];
                if(($lat == null || $lat == "") && ($lng
        == null || $lng == ""))
                {$lat = 0; $lng = 0;}
        }
```

There are 39 classes and view pages with controller functions that are used to process data entry.

Web-based automation database configured on MySQL server consists of 22 tables. Figure 13 shows the tables of the database.

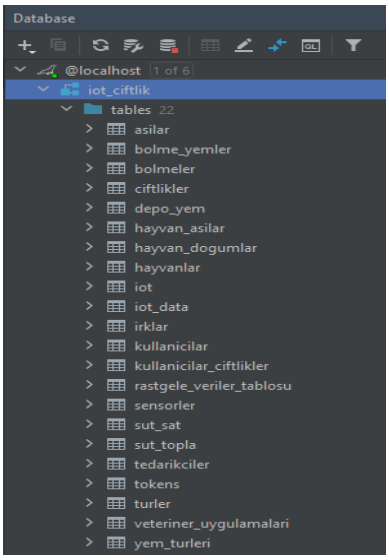

Fig. 13. Database Tables.

Figure 14 shows the structure of the tables displaying the amount and types of products and animal food in the warehouse on a farm, the data related to the milk produced on the farm, the information of the company or individuals supplying products to the farm, and the data related to the sections and groups that constitute the farm.

Figure 15 shows the UML structure of the tables displaying the authorized user information on the farm, the information of the veterinarian assigned to the farm, and the token information to login to the automation system. Figure 16 shows the UML structure of the tables displaying the information of all animals registered on the farm, the IoT devices assigned to the animals, and the sensor information of these devices.

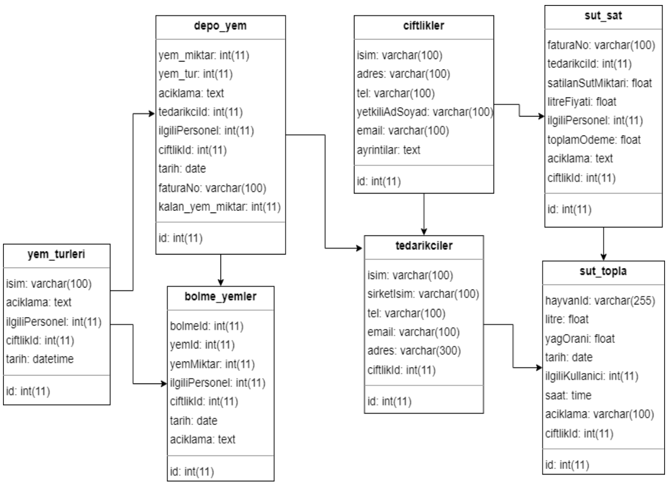

Fig. 14. Tables showing a farm's feed, warehouse, supplier, section, and milk data.

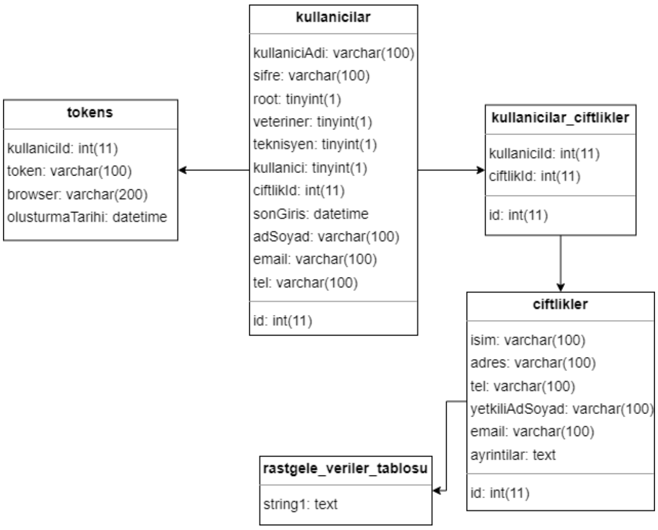

Fig. 15. Tables showing a farm's user authorization, user information, and system access information.

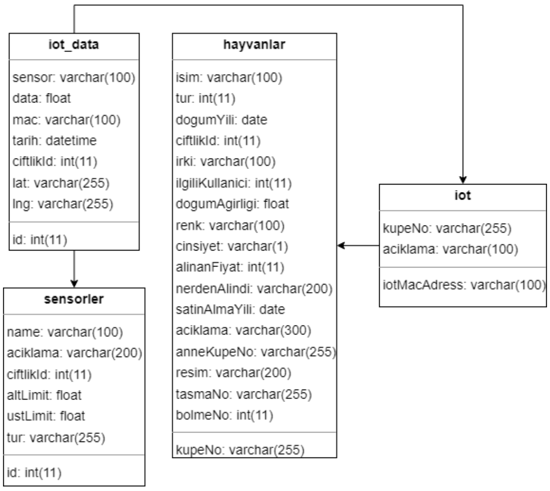

Fig. 16. Animal, IoT devices, and sensor information tables.

Figure 17 shows the UML structure of the tables displaying the information on the vaccines administered to all animals on the farm, and the information on the veterinary interventions made.

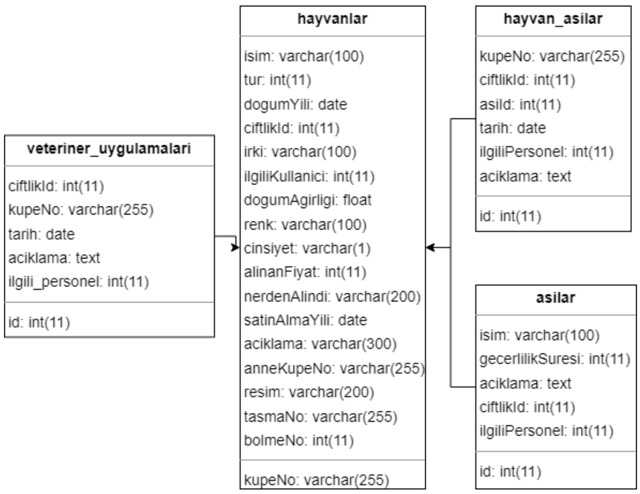

Fig. 17. Tables showing information about vaccines administered to animals and veterinary interventions.

Figure 18 shows the UML structure of the tables displaying the breed, species, group, and birth information of all animals registered on the farm.

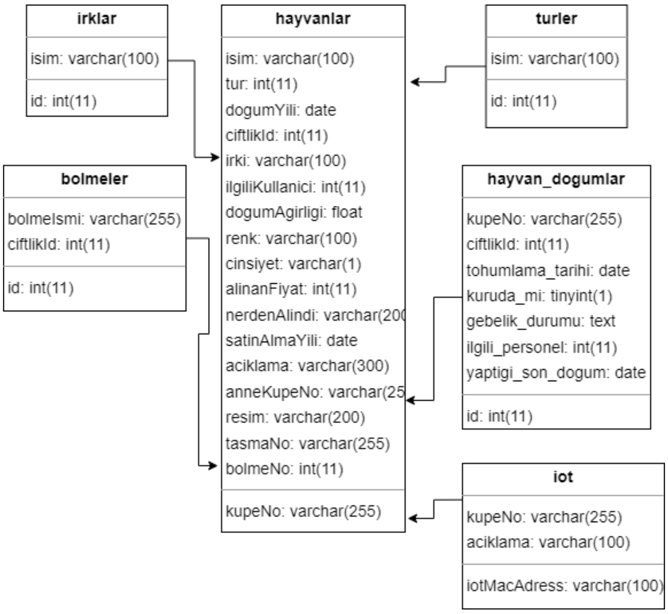

Fig. 18. Tables showing the breed, species, group and birth information of animals.

5. DISCUSSION

The system established in the study was configured on the domain http://surutakipsistemi.com. 66 cattle belonging to the model application farm were registered in the automation. IoT devices attached to these animals were integrated into the system and the data streams they sent to the system were put under control. Figure 19 shows the interface that displays the data graphically.

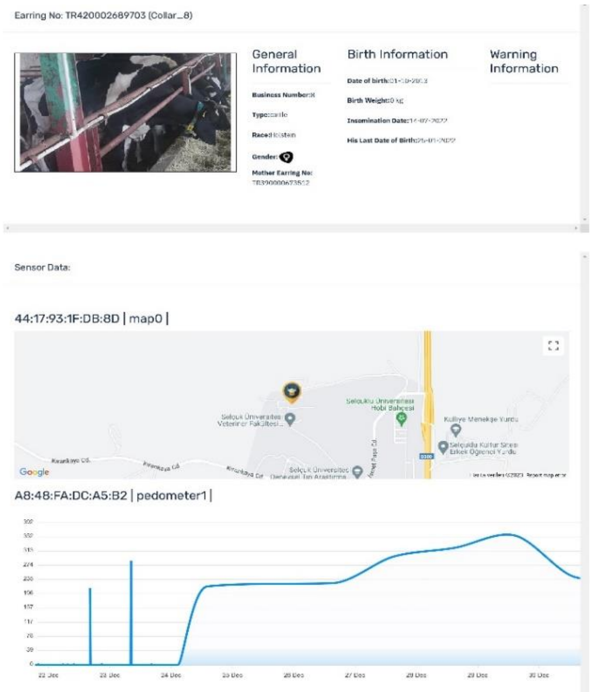

Fig. 19. Graphical display of data from sensors attached to animals.

The matching of the data coming from the sensors with the animal is checked on the automation, and lastly, the sensor values are graphically displayed to the user on the page that has the animal's information. Figure 20 shows the actions on the API controller page.

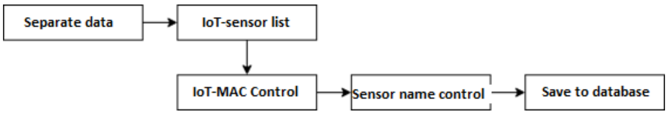

Fig. 20. API controller function act.

All health procedures and vaccination information of 66 cattle have been registered in the system. This allows tracking insemination and birth information as well. Figure 21 shows the data sending method designed with API RESTful service.

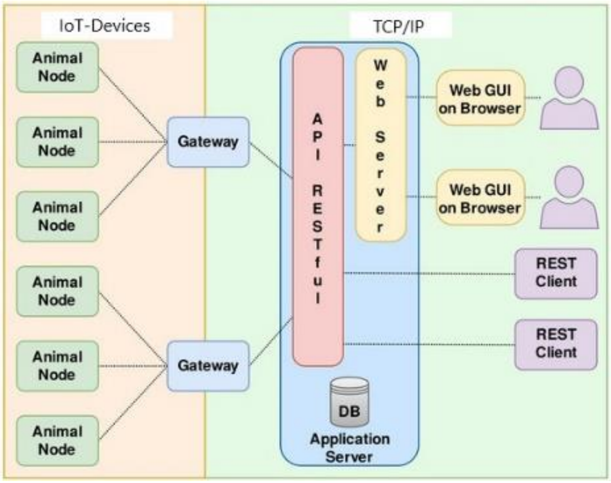

Fig. 21. General data stream services.

Compared to the web-based herd management systems available in the market and currently in use, this system stands out with its compatibility with IoT devices.

The automation system designed in the study was tested at Selçuk University Faculty of Veterinary Medicine Application Farm. 66 animals on the farm were integrated into the system. Intra-ruminal pH and temperature data of two cannulated animals were recorded and observed over 5 days. Feed stock status was monitored for 4 months.

Diminished protein feed amount for the calves was detected early with the alert system and more feed was supplied to the warehouse before the feed had run out. Veterinary interventions and vaccinations for all animals were recorded retrospectively for one year.

Action was taken upon the alert that one of the two animals whose estrus status was monitored with a pedometer approach could enter estrus, and insemination was carried out successfully. The status of the farm was previously supervised on an Excel file via remote desktop connection. With the implementation of this system, the status and information of all animals became available to monitor online. Within the scope of this study, as an alternative to the herd management systems available and currently in use in the market, all the necessary modules were designed, presented, and tested at an active farm by adding compatible IoT devices to the system.

Some of the herd management systems available in the market have IoT devices that work in integration with their own systems. Table 2 shows this comparison.

Table 2. Comparison of detection modules in devices produced in compatibility with the systems.

Herd Management Systems	**Detection modules**						
	Estrus Detection Pedometer	*Location Detection Gps*	*Behavior Detection*	*Rumination Count Detection*	*Skin Temperature Detection*	*Cystic Detection*	*Rumen ph and temperature detection*
EcoHerd	+	-	-	-	-	+	-
*Afimilk	+	-	+	+	-	-	-
CowMaster	-	-	-	-	-	-	-
**Çiftlik yönetimi	-	-	-	-	-	-	-
Delaval	+	+	+	-	-	+	-
Metfarm GEA	+	+	+	+	-	-	-
Miligram TR	-	-	-	-	-	-	-
Nedapvelos	+	+	+	+	-	-	-
Uniform agri	+	+	+	+	-	-	-
Sezer sürü	-	-	-	-	-	-	-
Dataflow II	+	+	+	+	-	-	-
Designed System	+	+	+	-	+	-	+

* Afimilk herd management system (Afifarm v5.5) https://www.afimilk.com/herd-management-solutions/
** Online farm management system https://www.ciftlikyonetimi.com/

6. CONCLUSION

Compared to other software working with the same principle, the system and the software implemented in the study stand out with IoT device support. In later stages, it is possible to use the infrastructure designed in the study by testing it on more animals, as well as on calves. The difference in the models or brands of the microcontrollers used in the study does not necessitate any change in the system. As long as the TCP/IP protocol is used, the system continues to run smoothly.

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