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High-tech herding: Exploring the use of IoT and UAV networks for improved health surveillance in dairy farm system

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ABSTRACT

The integration of IoT and UAVs in traditional farming has revolutionized operations, offering farmers increased output, better decision-making, and sustainability. This paper focuses on their use in dairy farming, aiming to enhance operational efficiency and health monitoring by providing real-time data for decision-making. The paper proposed an IoT-UAV system for cattle health monitoring. The proposed system is one in which IoT sensors on cattle gather health data, which is subsequently sent to UAVs for aerial surveillance and intervention. It evaluates two scenarios: one with 10 cattle and another with 50. Scenario 1 shows UAVs covering a large area with low overlap, while Scenario 2 focuses on close monitoring of cow clusters, with UAVs switching routes due to low energy. The cattle health status varies notably between the two scenarios. In Scenario 1, there's more diversity, with some cattle having higher health statuses around 0.9, while in Scenario 2, most fall into lower ranges, mainly between 0.2 and 0.6, indicating more uniformity. Additionally, UAV energy levels in Scenario 1 show considerable variation, from nearly full to around 20 %, suggesting energy depletion during observation. In Scenario 2, all UAVs maintain energy levels close to 100 %, indicating efficient and less frequent use compared to Scenario 1. Nearest Neighbor response plots show more uniform distances between cattle and UAVs in Scenario 2, where energy levels are considered, unlike in Scenario 1. This suggests a conservative approach to distance coverage, likely to conserve energy by avoiding long-distance travel.

Introduction

The UAV and IoT integration in smart farming is leading the way in agricultural technology evolution and has the potential to completely transform the operations of dairy farms [14,16]. The dairy industry, which is an essential part of the world's agricultural economy, has historically relied on labor-intensive techniques that are frequently ineffective and inefficient. The emergence of IoT and UAV technologies presents a game-changing opportunity, allowing for real-time decision-making and monitoring that are essential to the production and health of dairy herds. This study looks at how these technologies might improve health monitoring in dairy farms,

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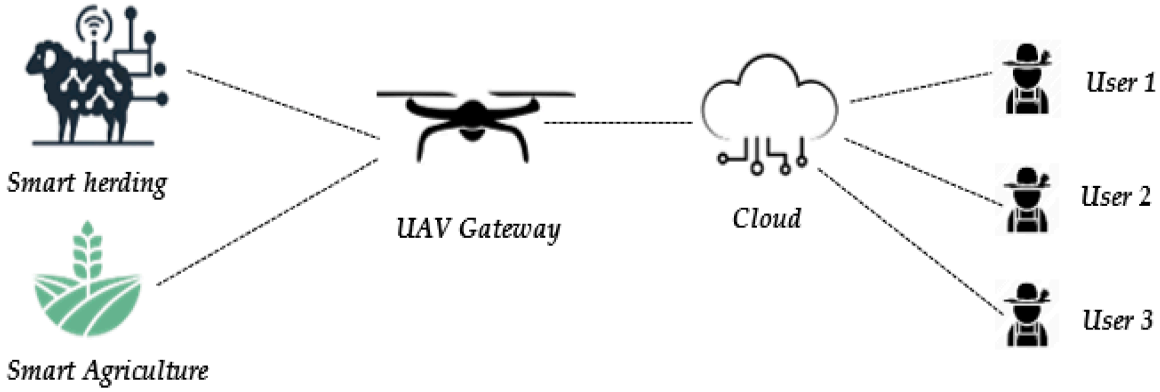


Fig. 1. Typical diagram of IoT-Based UAV smart agriculture.

which is important for preserving milk quality, animal welfare, and overall farm productivity [23]. With the ability to gather and share a vast array of data, such as temperature, humidity, and animal activity, IoT devices give farmers a level of insight into their herds' health and well-being that has never been possible before [30]. In addition, UAVs provide a distinct airborne viewpoint that makes it easier to monitor huge areas and react quickly to possible health problems. When various technologies come together, a synergistic network is formed that can identify, evaluate, and react to health signs faster and more precisely than with conventional techniques.

Stricter health regulations, increased productivity requirements, and the need for environmental stewardship have all put pressure on conventional dairy farming techniques. Within this framework, IoT and UAV technologies manifest not just as instruments of automation but also as precursors of an analytics-driven revolution in agricultural management [6,15]. The ability of IoT to continuously monitor an animal's health, behavior, and surroundings yields a wealth of information that may be used to manage a herd with an unprecedented degree of precision [12,25]. An analysis of this data can result in improved breeding programs, preventative health care, and optimum feeding tactics [18]. By providing airborne surveillance capabilities, UAVs enhance this data landscape. These capabilities are useful for following herd movements, monitoring pasture conditions, and even using thermal imaging to detect diseases early [9]. In large-scale farms where real-time surveillance of vast areas is crucial, the aerial perspective offered by UAVs is important. When combined, these technologies create a vast network that improves animal care and agricultural sustainability while also streamlining operations [29].

Traditional farming methods have undergone a substantial operational paradigm shift as a result of the integration of IoT and UAV systems, which goes beyond simple technological advancement [27,31]. As a result, the article focuses on technological capabilities, exploring the implementation's practicalities in the context of dairy farming. Therefore, "High-Tech Herding" lays the foundation for an in-depth investigation into the revolutionary effects of IoT and UAV networks in the dairy industry. It emphasizes how these technologies have the power to transform health surveillance, improve operational effectiveness, and advance environmentally friendly practices in the dairy sector. This study adds to the body of knowledge in agricultural technology while also providing useful information for the dairy industry's growth. Even while IoT and UAV technologies have many benefits, integrating them into dairy farming presents certain difficulties, including efficient algorithms that synchronize connection and data transfer between the IoT sensors, UAVs, and the cloud. As such it becomes pertinent to address this issue these issues with a view to fully utilizing high-tech solutions in dairy farming seamlessly.

In this work, we establish the integration of mUAVs and the IoT with dairy grazing systems. The idea is to equip cattle with IoT sensors that can monitor their vital signs and identify early indicators of stress or sickness. These sensors will gather information on the cattle's health, which will subsequently be sent to neighboring UAVs that are grazing field patrols considering the energy level of the communicating UAVs. The cameras on the UAVs will be used to visually watch and take pictures of any livestock showing symptoms of disease or unusual behavior. This image data will be mapped to the appropriate cattle and then uploaded to cloud storage, together with the health values gathered by the IoT sensors. Based on this, conceptual framework in Fig. 1 and the intent statement, the contributions of the paper are highlighted as follows:

1. Introduction of an innovative approach that improves UAV energy efficiency in farming situations, hence increasing the sustainability of UAV operations.
2. Real-time health monitoring system for cattle demonstration that allows for prompt actions and could result in better livestock productivity and health.
3. Because of the algorithm's capacity to scale and adapt to various farm sizes and types, it is a useful tool for precision agriculture.
4. The creative application of mathematical concepts in real-world agricultural applications is demonstrated by the efficient deployment of UAVs in response to alarms from IoT sensors using Euclidean distance computations.

The paper is structured as follows: it begins with an introduction of the subject matter, covering the concept, problem statement and the contributions. The next Section explores the fundamental concepts of UAV and IoT in smart agriculture and the related works that have contributed to the existing body of knowledge. The third section presents the methodology and algorithm whilst the fourth section presented the simulation discussion and results. The fifth section presented the conclusion to the work.

Related work

This Section presents the Background to IoT and UAV in relation to smart farming as well as related works to the research

Agriculture has undergone a paradigm shift with the introduction of the IoT [7], a network of connected devices that can gather, transmit, and analyze data [13]. This technology has demonstrated the ability to change a number of industries, including agriculture. Smart farming and precision agriculture are terms used to describe IoT applications in agriculture that use sensors, drones, GPS, and data analytics to optimize farm operations [17,19,21]. The benefits of IoT in Dairy Farming are but not limited to [1]:

- Health Monitoring: By spotting early indicators of disease or stress, IoT devices can keep a close eye on the health and welfare of dairy cattle.
- Environmental Control: By monitoring environmental parameters, sensors can guarantee the best circumstances for the well-being of cattle and the production of milk.
- Resource Optimization: IoT makes it possible to precisely manage resources, such as water and feed, which lowers waste and boosts sustainability.
- Data-Driven Decisions: Farmers can increase productivity and efficiency by using the acquired data to make well-informed decisions.

Drones, or UAVs, are useful not only in sports and media coverage [26] but also combined with IoT networks because they may be used for data collecting and aerial observation. UAVs can be utilized in dairy farming for a variety of purposes, including [2,5]:

- Monitoring pasture and crop health.
- Tracking cattle movements and behavior.
- Assessing farm infrastructure and environmental conditions.

The typical diagram of IoT-Based UAV smart agriculture is depicted in Fig. 1.

A thorough investigation into the application of UAV swarms in smart farming can be found in [22]. In particular, it tackles issues with decentralized and heterogeneous UAV swarm deployment, emphasizing effective data processing and swarm resource usage. To improve processing speeds and scalability while managing demanding processing workloads aerially, the study suggests a weighted intra-edge processing offload strategy based on Nash bargaining. It provides in-depth analyses of performance and comparisons with alternative network topologies, proving the usefulness of the suggested method in applications related to smart farming. The introduction, related works, system design, network traffic analysis, UAV node traffic modeling, and performance evaluation are all covered in the well-organized study's sections. The paper ends with noteworthy contributions and conclusions. The paper focuses on UAV swarms in smart farming generally. The study [20] focuses on creating an IoT-based system that employs machine learning to track the estrus cycle in cattle. It seeks to increase estrus detection's precision and effectiveness, which is necessary for dairy farming's artificial insemination process to be successful. Estrus detection is the main topic of the research, yet it is only one facet of general health surveillance in dairy farms, despite its importance. There is no discussion of the system's capabilities in more general areas of health surveillance, such as disease identification or nutritional assessment. Since the system mostly depends on hardware (sensors) and connection, it may not work well in rural areas with low resources. Data security and privacy issues are brought up while handling sensitive farm data, although these topics are not covered in detail in the study. The paper's restricted focus on estrus detection, however, is only one example of health surveillance; it does not include the wider range of applications that UAVs can enable, such as thorough health monitoring, behavioral analysis, or environmental assessment. Vate-U-Lan et al. [30] investigates the use of IoT technologies in dairy production. The study uses a case study from Ontario, Canada, to show how data-driven dairy production, genomic testing, sensor-driven crop management, digital tracking for cows, and other smart farming technologies can improve milk production without compromising the sustainability of the environment or the health of the cattle. The results' applicability to different geographical areas and farming circumstances may be limited because the findings and conclusions are based on a particular case study from Ontario. The study also went into greater detail on the difficulties and restrictions that come with using IoT technologies in dairy farming, including the expense, the need for technical know-how, and upkeep. The paper offers valuable insights into IoT applications in dairy farming, contributing to the understanding of high-tech herding, but it does not fully explore the combined potential of IoT and UAV networks for comprehensive health surveillance in dairy farm systems.

The goal of Chen [8] is to create a system that employs a Narrow-Band Internet of Things (NB-IoT) connection to track cows' estrus condition. To increase dairy farming efficiency, this approach uses physical status indicators such as body temperature and activity ability to detect estrus status. In places with inadequate connectivity or technological infrastructure, relying solely on NB-IoT technology may present difficulties. It does not, however, include UAV networks. Although the study advances our knowledge of IoT applications in dairy farming, it falls short in describing the entire breadth of health surveillance and the potential benefits of combining IoT with UAV networks. A video monitoring system is suggested by Zin et al. [32] to analyze the behavior of cattle. Using video surveillance technology, this system focuses on the early detection of aberrant behaviors in cows, such as lameness and estrus activities. For the purpose of understanding cow behavior, the framework uses methods such as various background modeling, Markov and Hidden Markov models, and dynamic programming. The reach may be limited by the primary emphasis on video surveillance as opposed to a fully integrated strategy that incorporates both IoT and UAV networks. IoT technologies, which could provide further data

Table 1
Summary of relevant works.

S/N	Citation	Methodology/Approach	Contributions	Limitations
1	[22]	implementation of a weighted intra-Edge processing offload technique based on bargaining	The study tackles the difficulties associated with deploying a decentralized and diverse swarm of Unmanned Aerial Vehicles (UAVs) in smart farming	Energy resources and consumption was not factored
2	[20]	The integration of IoT and machine learning model for livestock diseases	A system that can identify a typical symptom of diseases and estrus was presented	It may not work well in rural areas with low resources and herding operation.
3	[30]	Illustration using a real scenario case study on adapting innovation a smart technology in smart farming	a description of how a dairy farmer in Ontario has improved milk output while protecting the environment and his cattle's health by implementing smart farming technology	Limited only to conducting review on cattle health for improved production
4	[8]	Presented a cow estrus detection system based on NB-IoT communication	Development of a cow estrus monitoring system	It may not work well in rural areas with low resources and herding operation.
5	[32]	Application of Markov model for detecting various types of behaviour amongst dairy cows	Development of an image-based surveillance system using Markov model for health monitoring in dairy cows	Distance cattle of herding operation might not be able to get monitored
6	[4]	Involves the use of a low-cost WSN interconnected through a multi-agent architecture based on virtual organizations.	The system offers remote farm monitoring and traceability service	data collection and monitoring capabilities may be limited in herding operation. without the use of IoT devices and UAVs
7	[24]	The use of hardware devices like collar device, heart rate sensor was used to build a dairy cow health monitoring system	Implementation of a prediction system for dairy cow health monitoring	data collection and monitoring capabilities may be limited in herding operation. without the use of IoT devices and UAVs
8	[3]	The work presented a platform focused on using blockchain, edge computing, artificial intelligence, and Internet of Things techniques to smart farming situations.	utilizing the cutting-edge Global Edge Computing Architecture to guarantee the sustainability and traceability of the various production processes while keeping an eye on the condition of dairy cow and feed grain in real time.	data on condition of dairy cow may be limited in herding operation.
9	[10]	Investigation of the currently available knowledge regarding dairy cattle.	Strengthen the need for innovation in dairy farming	Limited to review only
10	[28]	Internet of Things (IoT)-based cow body weight recording system using RFID.	The paper's contribution is the creation of an intelligent tool system for body weight recording in cattle	Coverage is limited to the RFID's maximum distance
11	[11]	Using IoT and AI approaches, the paper's methodology entails designing a smart farm system for monitoring livestock.	The paper proposes a smart cattle monitoring system using IoT and AI to monitor individual animal behavior and health, optimize resource management, and boost farm productivity.	The paper designs a smart cattle monitoring system with IoT and AI, but does not discuss the potential of using UAVs for monitoring.

points and insights for health surveillance, are not included in the research. Although novel, the paper's method of using video surveillance for behavioral analysis falls short of capturing the high-tech fusion of IoT and UAV networks. In a dairy farm environment, a comprehensive system for livestock monitoring is presented by Barriuso et al. [4]. Wireless sensor networks (WSN) and multi-agent systems (MAS) are integrated into this system to monitor multiple facets of cow behavior and health. The study does not include UAV networks, which could offer more monitoring capabilities, and instead concentrates on ground-based sensor networks. Even if it is strong, the MAS and WSN integration may be difficult to scale and apply, particularly in larger farms with different environmental circumstances. Although the study makes a substantial contribution to the idea of high-tech herding and health surveillance, it focuses mostly on the IoT and machine learning aspects and does not incorporate UAV networks.

The goal of Pratama et al. [24] is to create a smart collar for dairy cows. This collar is intended to track multiple health indicators, including movement, heart rate, and body temperature. The system aims to provide real-time health monitoring of dairy cows by integrating microservices and IoT technologies for data collecting and analysis. UAV networks, which are a component of smart farming's wider use, are not included in this study. The research does not go into great detail on the smart collar system's scalability or cost implications, particularly for bigger dairy farms. The research provides insights into IoT applications in dairy farming, contributing to the field of high-tech herding, but does not fully explore the potential synergy of IoT with UAV networks. Alonso et al. [3] offers a cutting-edge platform for agricultural and dairy cow monitoring that combines blockchain, edge computing, artificial intelligence, and IoT technologies. The platform seeks to improve dairy farming's traceability, sustainability, and real-time monitoring. On a dairy farm, it has been implemented and evaluated, showing decreased data traffic and enhanced communication dependability between IoT-Edge layers and the Cloud. The utilization of UAV networks, which are crucial for thorough aerial monitoring and data collecting in dairy farming, is not explored in this research. The study makes a substantial contribution to the field of edge computing and IoT in dairy farming, although it focuses mostly on ground-based systems and does not fully explore the possibilities of UAV networks and IoT to provide thorough health surveillance in dairy farms.

Džermeikaitė et al. [10] is centered on the diagnosis of diseases in cattle husbandry through the use of several technologies and sensors. It examines several cutting-edge instruments, such as infrared thermography sensors and body condition score cameras, as

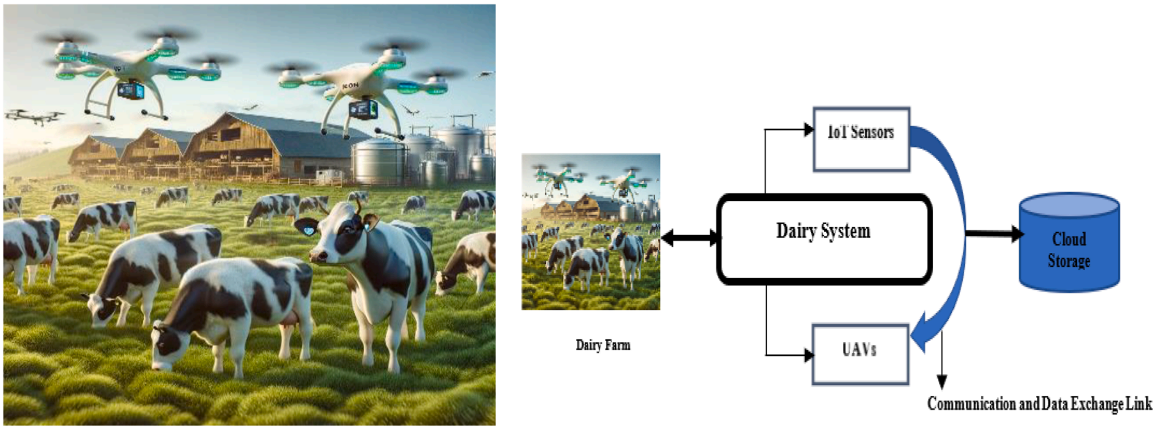


Fig. 2. Conceptual framework.

well as analyzers for milk, breath, perspiration, saliva and animal wearables. Without delving deeply into UAV networks, the article focuses on ground-based technology and sensors. Particular diagnostic technologies are given more attention than integrated surveillance systems that use both IoT and UAV networks.

In order to increase the effectiveness of the cattle body weight recording process, the paper [28] addresses the creation of an Internet of Things (IoT)-based cow body weight recording system. The system reads the identity of the cow using RFID sensors, measures the weight of the cattle using load cell sensors, and displays the results on a webpage. The device can connect to Firebase Realtime Database, transfer data to a database, scan RFID values at a minimum distance of 50 cm, and weigh livestock up to 1000 kg. In order to enhance farm productivity, animal welfare, and resource management, the authors of the work of El Moutaouakil and Falih [11] offers a concept for a smart cattle monitoring farm system that uses cutting-edge technology to gather and analyze data in real-time. The system gives cattle farms a real-time monitoring solution by integrating a variety of IoT sensors, cloud computing, and communication technologies. Farmers can proactively manage their herd by accessing data on behavior, health, and performance of their cattle through web and mobile applications, which are analyzed using machine learning (ML) algorithms. The system's main goals are to monitor each cow's health and behavior, enhance resource management, and boost farm productivity as a whole.

The summary of the reviewed works is provided in Table 1.

Collectively, the reviewed works investigate how cutting-edge technologies can be integrated into dairy farming. Specifically, they highlight the use of the IoT, machine learning, sensor technologies, and UAV swarms for a range of purposes, including health monitoring, estrus detection, and general farm management. These studies show how UAV swarms can be used for smart farming, how IoT-based systems can be used to track the health of cattle, and how video monitoring, smart collars, and blockchain may be used to improve farm management. The underutilized potential of UAV networks and IoT technologies to create more complete monitoring and management systems, however, is a recurring shortcoming among all research. Furthermore, issues with cost, scalability, and the limitations of rural areas' technological infrastructure are mentioned. Notwithstanding these difficulties, the contributions show how high-tech herding and smart farming are developing, highlighting the necessity for integrated solutions that incorporate UAV, IoT, and other cutting-edge technology for productive and sustainable dairy farming.

Methodology

In this work, we propose the integration of the IoT with multiple unmanned aerial vehicles (mUAVs) in dairy grazing systems. The idea is to equip animals with IoT sensors to track their health indicators and identify stress or illness early on. The information that these sensors gather about the health of the animals will be sent to UAVs that are roving the grazing grounds. The camera-equipped UAVs will monitor and take pictures of any livestock exhibiting symptoms of illness or unusual behavior. These images will be linked to the individual animals and sent to cloud storage, along with the health data gathered by the IoT sensors. By giving farm owners instant access to information about the health and welfare of their animals, this integration seeks to improve farm management and possibly raise the dairy operation's total output. Based on this, the conceptual framework is presented in Fig. 2.

The use of contemporary technologies into a dairy farm management system to improve productivity and data management is demonstrated by this conceptual framework. It stands for the actual place where the dairy animals are reared. The dairy farm system is equipped with sensors connected via IoT. These sensors are affixed to the cattle to check their health. These sensors send their data to the Dairy System for processing. The dairy farm is observed from above by UAVs. They can supply the Dairy System with extra data and aerial imagery by being fitted with cameras and other sensors. The distant computers that house the Dairy System's data are represented by the cloud storage. It makes it possible to safely store enormous volumes of data and retrieve or analyze them as needed. The information flow between the system's components is shown by the communication link. For instance, the Dairy System receives data from IoT sensors and UAVs, processes it, and saves it in cloud storage. In order to ensure that all components of the system are updated with the most recent information, this link is essential for real-time data transmission.

Using the conceptual framework, two problem statements are derived from this analysis requiring the underlisted assumptions.

Assumption 1. UAV is assigned to monitor a subset of the cattle based on proximity
Assumption 2. UAVs have a limited energy supply that needs to be well managed, with safeguards in place to make sure they don't run below a certain energy threshold.
Assumption 3. UAVs can decide whether to approach particular cattle depending on its position and health, necessitating some kind of autonomous decision-making capabilities in the UAVs.
Assumption 4: presupposes a system for managing and storing images and health information gathered from the cattle, indicating a requirement for data processing and storage capabilities.
Assumption 5: argues that a dynamic reallocation procedure should be in place to guarantee ongoing surveillance in the event that the UAV initially assigned to cattle has low energy.

Problem statement

Definition 1: Let Nbe the total number of cattle and be the total number of UAVs. Each cattle$i$, where $i = 1, 2, ...N,$is equipped with an IoT sensor that collects data on various parameters, represented as a vector $H_i(t)$at a time t. This data is transmitted to the nearest UAV. Assume there are$M$ UAVs, and the distance between cattle and UAVj at a time t is$d_{ij}(t)$. The cattle health status function possesses the sensor data and outputs a health index. A threshold value $\theta$is set, such that if $f(H_i(t)) \leq \theta$, the cattle is flagged for potential health issues. Each UAV must decide whether to move towards cattle based on its health status and current location. This decision can be represented by a binary variable$x_{ij}(t)$, where it UAV$j$moves towards cattle$i$ at time$t$ and 0 otherwise. Therefore, one of the objectives will be to minimize the total distance traveled by all UAVs while ensuring all cattle with potential health issues are monitored. This can be expressed as:

$$\begin{aligned} &\min \sum_{i=1}^{N} \sum_{j=1}^{M} x_{ij}(t) d_{ij}(t) \\ &\textit{subject}\text{to}: \\ &x_{ij}(t) \in \{0, 1\}, \\ &\sum_{j=1}^{M} x_{ij}(t) \geq 1 \text{if} f(H_i(t)) \leq \theta \end{aligned} \tag{1}$$

Definition 2: Let Nbe the total number of cattle and be the total number of UAVs. Each cattle$i$, where $i = 1, 2, ...N,$is equipped with an IoT sensor that collects data on various parameters, represented as a vector $H_i(t)$at a time t. This data is transmitted to the nearest UAV. Assume there are$M$ UAVs, the Energy level of UAVj at a time t is denoted as$E_j(t)$, and a minimum energy threshold for operation is given by $E_{\min}$and the distance between cattle and UAVj at a time t is$d_{ij}(t)$. Data from cattle$i$ will be transmitted to the nearest UAV that meets the energy requirement: $E_j(t) \geq E_{\min}$. The cattle health status function possesses the sensor data and outputs a health index. A threshold value $\theta$is set, such that if $f(H_i(t)) \leq \theta$, the cattle is flagged for potential health issues. Each UAV must decide whether to move towards cattle based on its health status and current location. This decision can be represented by a binary variable$x_{ij}(t)$, where it UAV$j$moves towards cattle$i$ at time$t$ and 0 otherwise. Therefore, one of the objectives will be to minimize the total distance traveled by all UAVs while ensuring all cattle with potential health issues are monitored by UAVs with sufficient energy levels. This can be expressed as:

$$\begin{aligned} &\min \sum_{i=1}^{N} \sum_{j=1}^{M} x_{ij}(t) d_{ij}(t) \\ &\textit{subject}\text{to}: \\ &x_{ij}(t) \in \{0, 1\}, \\ &E_j(t) \geq E_{\min} \text{if} x_{ij}(t) = 1 \\ &\sum_{j=1}^{M} x_{ij}(t) \geq 1 \text{if} f(H_i(t)) \leq \theta \end{aligned} \tag{2}$$

Algorithms

The integration of IoT sensors and UAVs in the system architecture allows for the effective and energy-efficient monitoring of cattle health. The algorithms take energy consumption and health status information into account as they minimize UAV travel distance while maintaining efficient observation. Based on Definitions 1 and 2 presented in section 1 (otherwise called scenario 1 and scenario 2), the IoT-Based UAV Synchronization Algorithm and IoT-Based UAV Energy Centric Synchronization Algorithm are generated.

Table 2
Simulation parameters.

S/N	Simulation parameters	Values
1	Farm size	100×100
2	Number of Cattles	10
3	Number of UAVs	5
4	UAV Range	100
5	IoT Range	50
6	UAV Energy Value	100
7	UAV health Threshold	0.5
8	UAV Energy Consumption	1

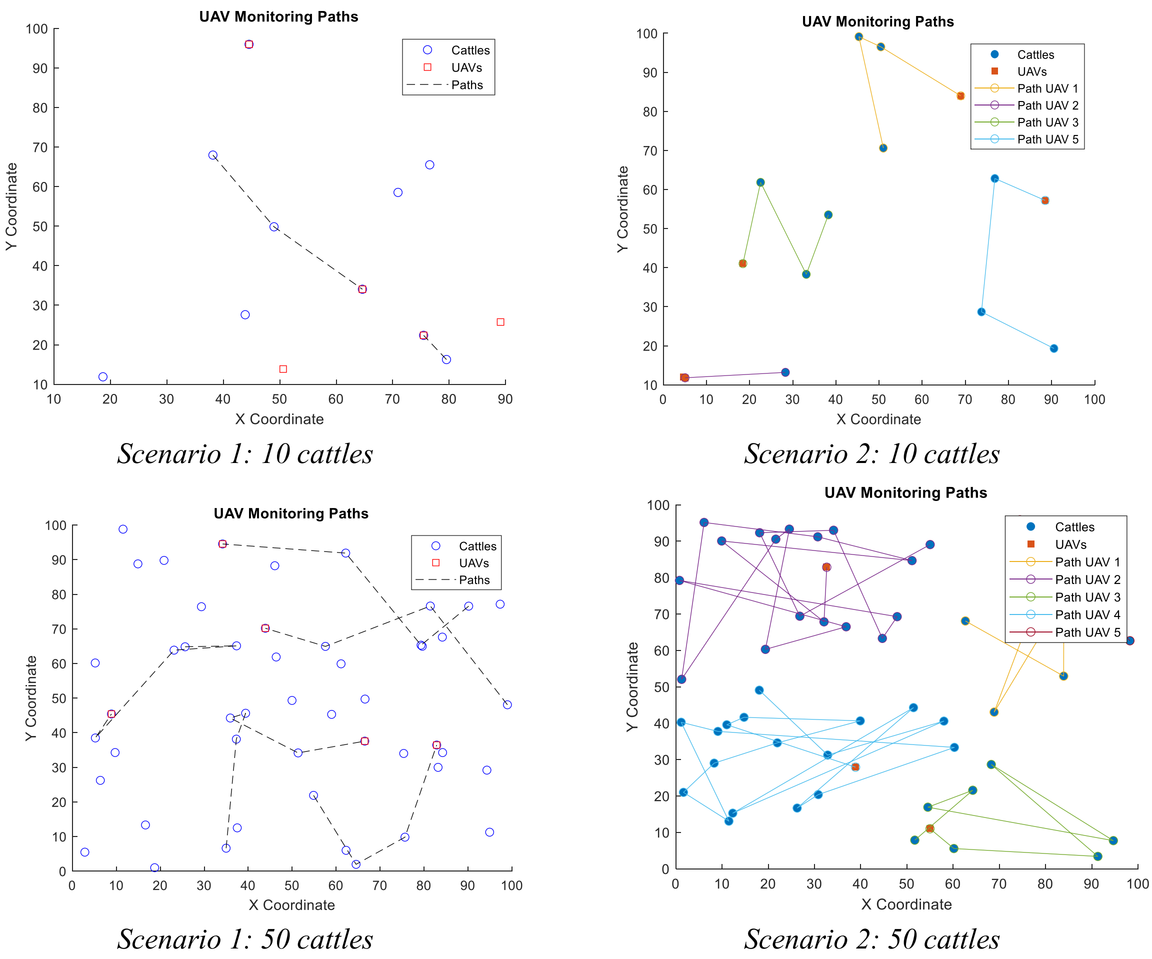
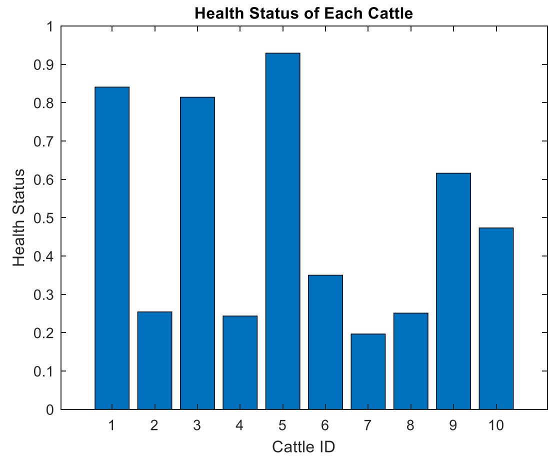
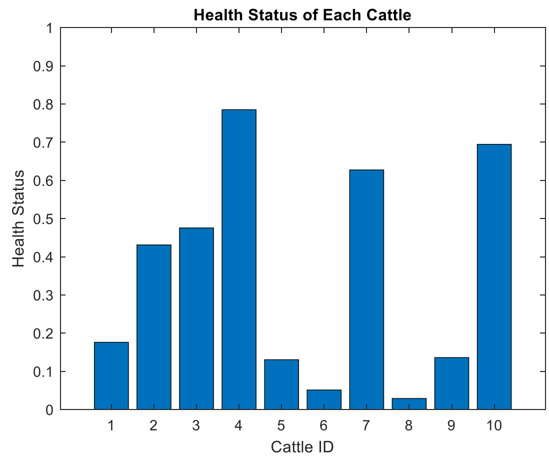


Fig. 3. UAV monitoring paths plot.

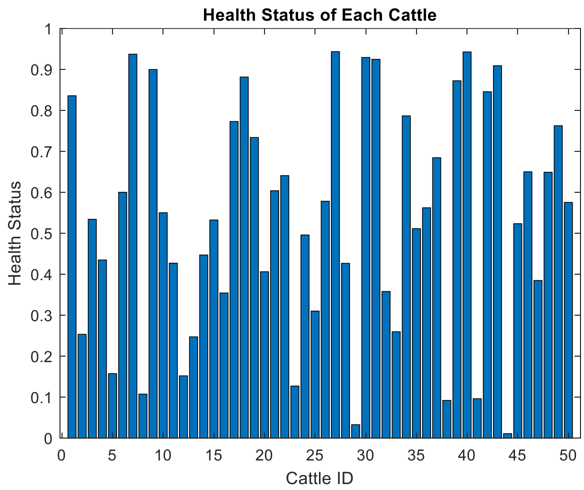
The objective of the system is to keep all potentially ill cattle under observation while minimizing the overall distance that UAVs travel to. It involves setting up the IoT sensors on the cattle, assessing the health of each animal, and calculating whether or not a UAV should approach cattle in light of its position and health. The total number of cattle and UAVs, together with constants like energy values, health thresholds, IoT range, and UAV range, are input into the algorithm. The mapping of livestock to UAVs and the UAV flight path are the outputs. In the second algorithm, an IoT-Based UAV Energy Centric Synchronization Algorithm is presented. Its goal is to maximize UAV energy consumption while guaranteeing thorough cattle health monitoring. This algorithm emphasizes the energy efficiency of UAV operations and makes UAVs make judgments depending on the energy levels of the UAVs as well as the cattle's health. livestock's IoT sensors are initialized, their health is evaluated, and UAV energy levels are monitored to ascertain UAV movements in relation to livestock.



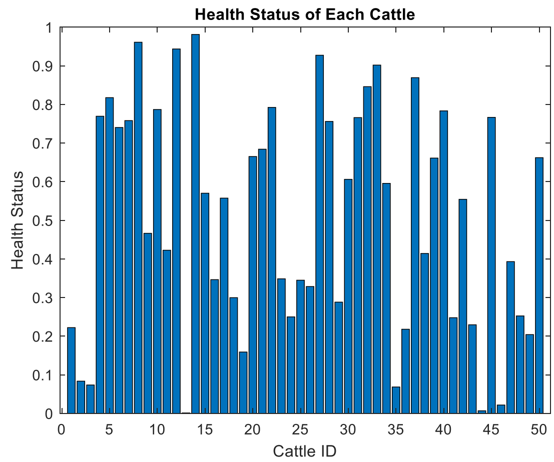
Scenario 1: 10 cattles



Scenario 2: 10 cattles



Scenario 1: 50 cattles



Scenario 2: 50 cattles

Fig. 4. UAV health status plot.

Simulation results and discussion

The empirical findings of an innovative investigation on the implementation of an IoT and UAV-based synchronization system intended for the careful monitoring of cattle health are presented in this paper's results section. The premise behind this experiment was that by combining UAVs with IoT sensors, health surveillance methods in dairy farming may be made much more accurate and efficient, which will lead to better animal management and increased agricultural output. The simulation parameters used to obtain the presented results are presented in Table 2.

We present these results together with a thorough analysis of the performance metrics of the algorithms that were put into practice, such as the IoT-Based UAV Energy Centric Synchronization Algorithm and the IoT-Based UAV Synchronization Algorithm. We clarified the efficacy of the algorithms in reducing the overall distance traveled by UAVs, improving energy efficiency, and guaranteeing the precise and timely monitoring of cattle health conditions through a thorough examination. Furthermore, the system's scalability, dependability, and flexibility to different farming conditions and operational issues are critically examined in the results section.

The UAV monitoring path plots provide insights into the efficiency of the UAV allocation, the health status distribution among cattle, and operational considerations such as energy management and distance optimization. The plot displays the starting locations of the UAVs (red squares) and animals (blue circles), as well as the pathways (dashed lines) that the UAVs take to get to the sick calves. The pathways show which UAVs are assigned to which animals and how the algorithm uses the closest UAV to minimize journey distance. The results are shown in Fig. 3.

The health status plot indicates the health status of each cattle, with values below a certain threshold signaling a potential health issue. Cattle with lower bars would be prioritized for monitoring, as they represent individuals with lower health metrics. The results

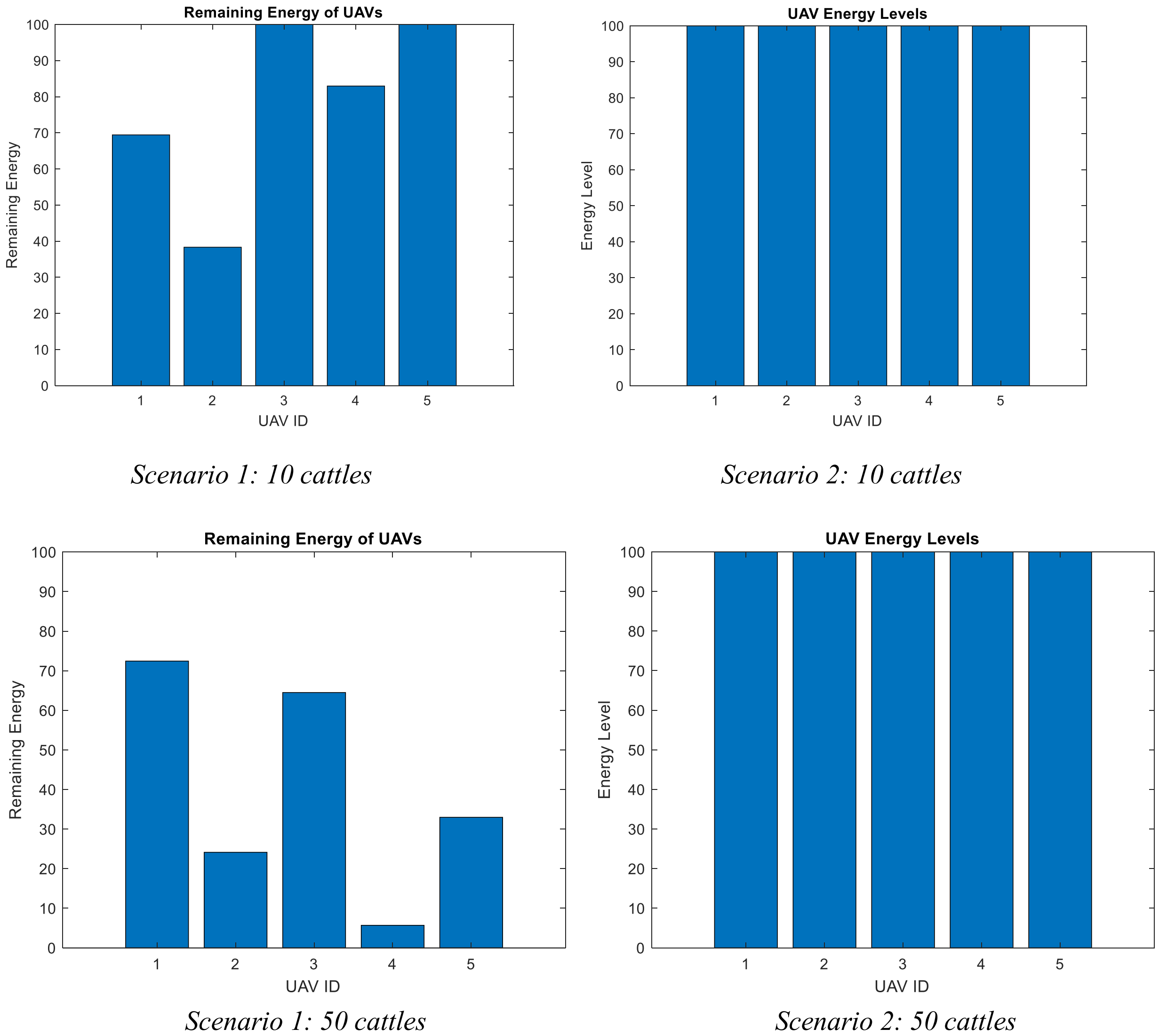


Fig. 5. UAV energy values plot.

are shown in Fig. 4.

The UAV Energy results display the remaining energy levels for each UAV after completing their paths. UAVs with lower energy levels indicate more activity, either due to longer travel distances or multiple visits to cattle. Conserving energy is crucial for extended operation times. This is shown in Fig. 5.

The Nearest Neighbor response plot illustrates the distance from each cattle to their nearest UAV before dispatch. Shorter distances suggest efficient UAV deployment, as UAVs are likely assigned to nearby cattle, reducing the time to reach cattle in distress. This is shown in Fig. 6.

Highlighting the efficiency of the proposed IoT-Based UAV systems in cattle health monitoring, the simulation section comes to a conclusion. It illustrates how UAV energy management and distance optimization can improve operations. According to the simulations, UAVs are more effectively deployed when they preserve energy, as demonstrated in Scenario 2. In contrast, Scenario 1 places more emphasis on wide coverage of the area, independent of the UAV's energy level. The results highlight how these algorithms can improve animal management and increase agricultural productivity.

The UAV monitoring tactics of Scenarios 1 and 2, which involve 10 and 50 cattle respectively, differ significantly from one another. The first scenario depicts a large dispersion of UAV trajectories that provide low overlap and a spread-out coverage, indicating effective cattle surveillance over a large area. On the other hand, Scenario 2 displays a convoluted network of UAV routes with significant overlap. This overlap is explained by the UAV switching that occurs when a UAV's energy is low. In the second scenario, UAVs prioritize intimate monitoring over wide-area surveillance by concentrating on particular cow clusters. The divergent trends indicate that, although Scenario 2 focuses on rigorous monitoring of cattle groups in clusters, Scenario 1 prioritizes large area coverage. The

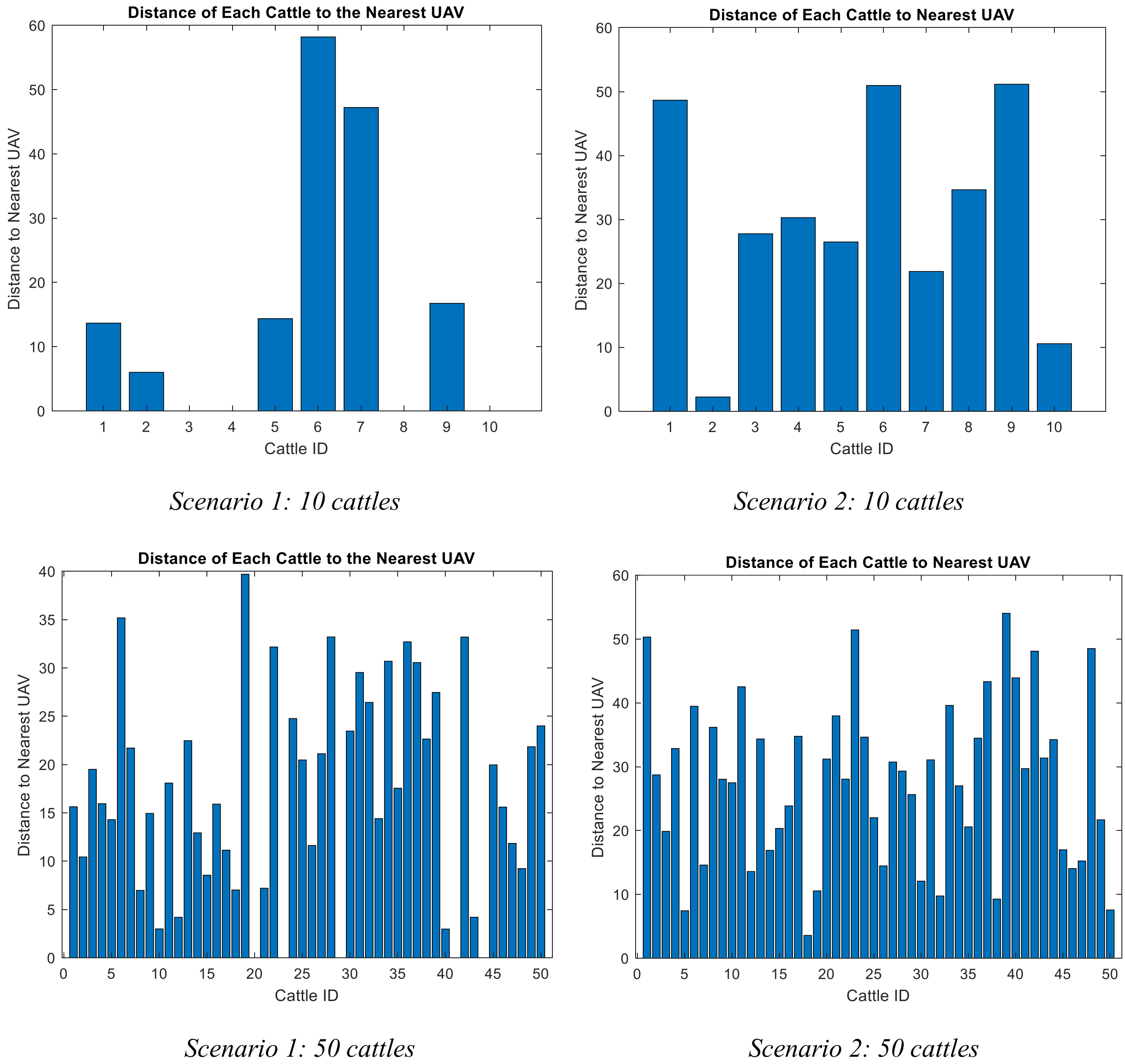


Fig. 6. UAV nearest neighbor response plot.

health status plot shows the random health status of the cattle. However, we can see significant variations in the cattle's health status distribution from the health status plots in the two scenarios. There seems to be more variation in the health status in Scenario 1, with some cattle having a higher health status near or around 0.9 and fewer in the mid-range around 0.5. Whereas none of the cattle in Scenario 2 achieve the higher health status levels seen in Scenario 1, most of them fall into the lower range, mainly between 0.2 and 0.6. Scenario 2 displays a more uniform distribution. This implies that, in comparison to Scenario 2, where the cattle appear to have more uniformly moderate to low health statuses, the cattle in Scenario 1 are either typically healthier or there is a bigger disparity in their health statuses.

The UAV energy levels in Scenario 1 exhibit considerable variation, with the greatest level approaching full at approximately 90 % and the lowest level at approximately 20 %. This suggests a notable disparity in the UAVs' energy use. This suggests that while the cattle are being observed, energy levels decrease. On the other hand, all of the UAVs in Scenario 2 display an energy level that is either at or very close to 100 %. This consistency, as opposed to the fluctuating levels observed in Scenario 1, which suggests differential utilization or tasks that consumed varied amounts of energy, suggests that the UAVs in Scenario 2 have been used less and more efficiently as a result of the swapping operation of the UAVs based on Energy consumption. From the Nearest Neighbor response plot, the distances differ significantly in Scenario 1, where the energy of the UAV is not taken into account. Some cattle are quite close to a UAV (shown by the shorter bars), while others are considerably farther away (shown by the taller bars). The maximum distance is just over 50 units. This suggests a non-uniform distribution, probably because some UAVs traveled farther than others when they were

Algorithm 1
IoT-Based UAV synchronization algorithm.

Input: Number of cattle, Number of UAVs
Constants: UAV Range, IoT Range, UAV Energy Value, Health Threshold, UAV Energy Consumption.

1. /* Set dairy farm area */
2. /* Initialize the IoT sensors */
3. **for** each cattle $i - N$ do
4. determine the cattle's health $H_i(t)$
5. **if** $f(H_i(t)) \leq \theta$ then
6. Save cattle readings
7. end
8. /* initialize UAVs */
9. /* initialize IoT for range discovery */
10. Determine the distance $d_{ij}(t)$ between cattle i and UAVj at time t
11. **if** $x_{ij}(t)= 1$ then
12. j^{th} UAV move towards i^{th} cattles at $d_{ij}(t)$to capture cattles images
13. Save cattle images with IoT details
14. else
15. go to 12
16. end
17. end
Output: UAV flight path, Throughput, cattle to UAV mapping

Algorithm 2
IoT-Based UAV energy-centric synchronization algorithm.

Input: Number of Cattles, Number of UAVs
Constants: UAV Range, IoT Range, UAV Energy Value, Health Threshold, UAV Energy Consumption.

1. /* Set dairy farm area */
2. /* Initialize the IoT sensors */
3. **for** each cattle $i - N$ do
4. determine the cattle's health $H_i(t)$
5. **if** $f(H_i(t)) \leq \theta$ then
6. Save cattles readings
7. end
8. /* initialize UAVs */
9. /* initialize IoT for range discovery */
10. /* initialize UAVs energy level */
11. Determine the distance $d_{ij}(t)$ between cattle i and UAVj at time t
12. **if** $E_j(t) \geq E_{\min}$
13. go to 20
14. else
15. Disp "UAV energy level is low for peering
16. /*Initialize UAV node exchange*/
17. Compute the nearest UAV to low energy UAV using equation
18. /*Peer with new discovered UAV*/
19. end
20. **if** $x_{ij}(t)= 1$ then
21. j^{th} UAV move towards i^{th} cattles at $d_{ij}(t)$to capture cattles images
22. Save cattle images with IoT details
23. else
24. go to 11
25. end
26. end
Output: UAV flight path, Throughput, cattle to UAV mapping

launched because it did not matter how much energy they had left. Though they are generally farther away than in Scenario 1, Scenario 2, which takes into account the energy of UAVs, displays a more equal distribution of distances, with numerous distances also peaking at a little above 50 units. The consideration of UAV energy levels in Scenario 2 seems to result in a more conservative approach to distance coverage, possibly to preserve energy by avoiding long-distance travel to reach distant cattle.

The application of an IoT and UAV-based system for tracking livestock health is evaluated by the simulation. The effectiveness of two algorithms, the IoT-Based UAV Energy Centric Synchronization Algorithm and the IoT-Based UAV Synchronization Algorithm in lowering the total distance covered by UAVs, enhancing energy efficiency, and guaranteeing accurate and timely monitoring of cattle health conditions was examined through performance metrics analysis. The simulation results showed that the algorithms could efficiently handle operational factors such as energy management, cattle health status distribution, and UAV allocation. Specifically, Scenario 1 demonstrated a broad distribution of UAV trajectories, suggesting efficient livestock monitoring throughout a greater region without taking UAV energy levels into account. By prioritizing the monitoring of cattle groups in clusters and utilizing UAV switching operations to preserve energy, Scenario 2 on the other hand, showed a more cautious and energy-efficient method that produced more consistent UAV energy levels when their monitoring pathways were completed. This implies that potentially as a result of improved energy management techniques, the UAVs in Scenario 2 were utilized more effectively (Algorithms 1, 2).

Conclusion

The major findings and contributions of the research paper "High-Tech Herding: Exploring the Use of IoT and UAV Networks for Improved Health Surveillance in Dairy Farm Systems" are summarized in this conclusion. This study confirms that using IoT and UAV technology to monitor cattle health more effectively is feasible. By carefully examining technological, operational, and financial aspects, this research adds to the growing body of information that underpins developments in smart farming and precision agriculture. It illustrates useful system implementation techniques and establishes a standard for further research in this quickly developing field. In addition to improving operational effectiveness and health monitoring, the paper describes how integrating IoT sensors and UAVs into dairy farming will advance agricultural methods in the future. The system makes use of real-time data collecting and processing to facilitate timely actions, which may enhance farm output and animal health. Moreover, the system's versatility and scalability to different farm sizes and conditions highlight its usefulness in precision agriculture. The study presents novel strategies for UAV energy management and illustrates the sustainability of the system. The successful deployment of UAVs in response to IoT sensor warnings, which is based on distance optimization and energy efficiency algorithms, demonstrates how mathematical models may be used to solve practical agricultural problems. In conclusion, the study's findings highlight the viability and efficiency of combining UAV and IoT technology for cattle health monitoring and pave the way for further research into smart agricultural solutions. By offering a blueprint for the effective and long-lasting use of cutting-edge technologies in dairy production, it advances precision agriculture.

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CRediT authorship contribution statement

Bashir Olaniyi Sadiq: Investigation, Software, Writing – original draft, Conceptualization, Resources. **Mohammed Dahiru Buhari:** Resources, Writing – review & editing. **Yale Ibrahim Danjuma:** Visualization, Validation. **Olayinka Sikiru Zakariyya:** Software, Resources. **Aliyu Nuhu Shuaibu:** Resources, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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