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Review

A Systematic Review of IoT Technology and Applications in Animals

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Abstract

Precision Livestock Farming (PLF) is a mechanism that manages a production system. This mechanism includes mathematical models and controllable inputs that can predict inputs with processes and results that can be monitored periodically. These parameters of PLF systems can improve resource use efficiency and reduce cultivation costs. Many situations, such as the behaviour of animals on farms, their nutrition, estrus cycles, and epidemics, can be monitored with wearable devices containing various sensors. However, real-time monitoring of the data collected by these devices is possible with Internet of Things (IoT) technology. IoT is a multi-layered network that enables sensors within the system to communicate with each other and implement certain decisions when necessary. Sensors and IoT devices extract information from the raw data they collect from the environment, which is then shared with other objects, devices, or servers via the internet. The real-time data collection, processing, and analysis provided by IoT enables improvements in the management of animal farms. This systematic review addresses IoT concepts and applications in the livestock sector from a systematic perspective for different animal farms.

Keywords: Animal husbandry, Aquaculture, Beekeeping, IoT, Precision livestock farming

Introduction

Livestock farming and agriculture play a key role in the economies of many countries. Livestock farming is an agricultural and economic activity in which various animal species are raised, generally for the benefit of people, to obtain products such as meat, milk, eggs, and wool or to sell the animals. It can be carried out to supply animal products for animal husbandry, food production, textiles, industry, and other industries. This activity often includes nutrition, shelter, health care, reproduction, and other management practices. Increasing urbanisation limits the amount of land available for animal farms; However, the demand for animal products is increasing day by day. Due to limited land and other limited natural resources, farmers are forced to feed more animals in smaller areas [1].

Feed and disease are among the most basic cost elements in livestock farming. Proper nutrition of animals is important for both the health of the animal itself and the efficiency of the products obtained from the animal [2]. Since animals live together in shelters, if one of them contracts an infectious disease, it may result in the loss of many animals. Therefore, to reduce animal losses in animal husbandry and increase animal product yield, the nutritional and health status of animals must be regularly monitored. In traditional animal husbandry, all of these are carried out by farm workers. Constant monitoring is required to prevent problems. However, since decisions are made by people, oversights or disruptions may occur due to humanitarian reasons in this process. Employing more personnel to ensure adequate monitoring brings additional costs.

As in many fields, the use of information technologies in the livestock sector is becoming more widespread day by day. In particular, internet of things applications have made rapid progress in smart livestock solutions. A sensor is a device that can measure and detect a physical, chemical, or biological condition. Smart livestock farming is a system that enables the health and welfare of animals to be monitored and analysed using various sensors integrated into the animals and/or the environment in which the animals live and to send feedback to the farmer and/or veterinarian in case of a critical situation [3].

The IoT is a technology that connects various objects without the need for human support. It has a multi-layered structure that includes both hardware and software. IoT systems include sensors and actuators. Sensors collect data from the environment, and actuators create commands based on the data and transform them into physical actions [4]. Collected data is usually stored in cloud-based areas, providing real-time monitoring. The stored data is used to detect deviations from normal or abnormal conditions. In this detection phase, artificial intelligence (AI) or machine learning (ML) algorithms are generally used. Sensors are usually integrated into a wearable device and placed on the animal [5]. When a situation that requires intervention is detected as a result of the analysis, techniques such as Radio Frequency Identification (RFID) and QR codes are used to enable IoT devices to identify the animal [6]. In an IoT system, human effort to control, protect, maintain, and monitor these smart devices should be minimal. With the correct interpretation of data from sensors, cost loss due to animal diseases can be reduced, and animal life cycles can be improved.

This study aimed to systematically review experimental studies analysing IoT systems in the field of animal husbandry. In this comprehensive review, state-of-the-art IoT systems developed for livestock and poultry, fish farms, and beekeeping are thoroughly examined and comparatively presented.

Material and Methods

The general framework for the use of IoT technology in animals is presented in *Fig. 1*. As seen in this flow chart, data collected from animals with sensors is transferred to devices such as computers, tablets, and phones. After the data is analysed by farmers, veterinarians, or experts, animals are intervened when necessary.

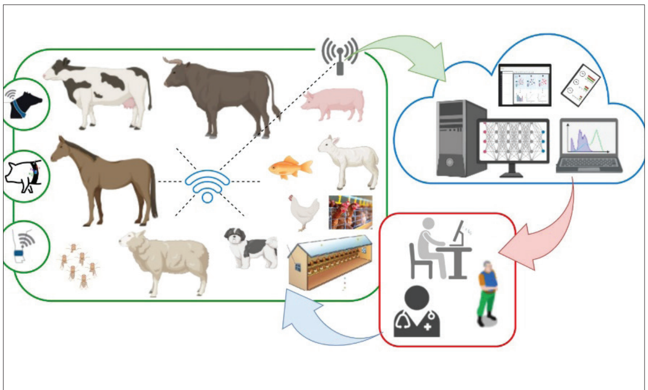

Fig 1. The general framework for IoT technology in livestock farming

In this review, studies on IoT-based livestock systems for different animal species were examined. The studies presented are limited to the years 2013-2023 to include current technology. Conference publications were not included, and only articles were focused on. Studies whose full text was not published or published in a language other than English were not included in this review. Since the focus of this review is IoT, studies conducted solely with information technologies such as image/audio processing have also been ignored. The research was conducted through Google Scholar, and the keywords used are as follows: IoT for animal estrus/calving/fertility, IoT for animal lameness, IoT for animal breeding, IoT for animal feeding, IoT for animal health, IoT for animal behaviour, IoT for fish farming, IoT for animal location tracking, IoT for bee/hive, IoT for poultry/chicken.

The results of the literature review are presented under the titles of animal health monitoring, animal activity detection, animal location tracking, animal smart feeding, animal estrus/calving detection, animal lameness detection, IoT for fish farming, IoT for beekeeping, and IoT for poultry management. Some studies may contain more than one title. For example, in some estrus/calving/lameness detection studies, the activities of the animals are also detected. Studies on animal health monitoring and animal smart feeding may also include animal location tracking. This systematic review, it was examined 23 studies for animal health monitoring, 6 studies for animal behaviour detection, 11 studies for estrus/calving detection, 7 studies for animal location tracking, 6 studies for animal smart feeding, 2 studies for lameness detection, 5 studies for beekeeping, 10 studies for fish farming, 6 studies for smart poultry. As a result, a total of 76 articles were reviewed.

Internet of Things (IoT)

IoT is a technology that provides the ability to exchange data in real time between multiple different smart devices [7]. In this way, data is collected by communicating between various devices, and this data is transmitted to a cloud system or an end device through a gateway using communication protocols such as Wi-Fi and Bluetooth [8]. There are 5 basic components in the IoT system: smart devices, gateway, data storage unit, IoT application, and graphical user interface. Smart devices consist of devices that can exchange data, such as sensors. Gateway allows data to be transmitted to other devices and includes encryption methods for data security by regulating the state of the network. Data storage is used to collect incoming data. Data coming from smart devices at various periods must be stored somewhere to be monitored and analysed. This data can be stored on a server or in a cloud system. IoT applications are software that integrates data from smart devices. It may include technologies such as machine learning and artificial intelligence to analyse data and make various decisions based on this data. The decisions taken are transmitted to the IoT device, allowing it to respond according to the incoming input. Graphical user interfaces are interfaces, such as a mobile application or website, used to monitor and control incoming data [9].

The Internet of Things is a network of subnets in which objects, animals, or people are equipped with unique identifiers and can enable data transfer without requiring human-to-human or human-computer interaction [10]. IoT architecture for livestock farming generally consists of four layers, and these layers are given in *Fig. 2* [11,12].

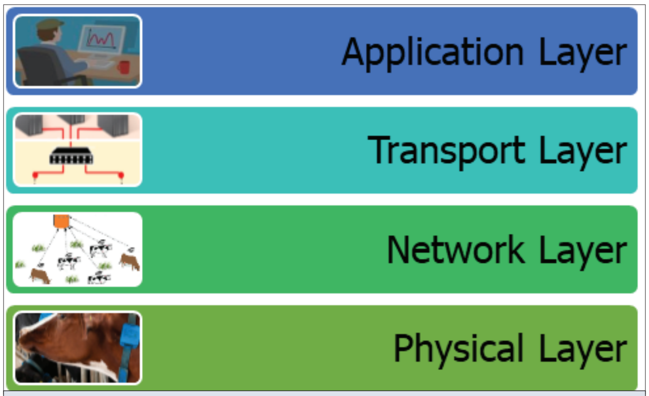

Fig 2. IoT livestock network architecture

Application layer: It is the top layer of the IoT network architecture and provides communication and interaction between IoT devices and applications [11]. The application layer is the most visible and user-friendly part of the IoT system. IoT applications in livestock farming are generally used for purposes such as tracking animals, monitoring health status, and farm management. The application layer supports various protocols and functions for such applications. In an IoT-based livestock application, the application layer supports functions such as data collection, data analysis, decision support, and application interface [13]. At the application layer, several different protocols can be used to enable data communication and interaction in IoT systems. Hypertext Transfer Protocol (HTTP), Message Queuing Telemetry Transport (MQTT), Constrained Application Protocol (CoAP), Advanced Message Queuing Protocol (AMQP), WebSocket, and Data Distribution Service (DDS) protocols are commonly used in IoT-based livestock applications [14,15].

Transport Layer: Acts as a link between the application layer and the network layer to enable communication between hardware and software. This layer allows animal information to be collected, transmitted, and analysed through sensors. It also ensures secure and error-free transmission of the obtained information using transmission control protocol (TCP) [12]. In this way, the health status of the animals, their movements, and other important information are reliably transmitted and analysed.

Network Layer: Transmits data as digital signals over the network to relevant platforms. This layer may contain only one relay point, with one interface connected to the sensor network and the other interface connected to the Internet [11]. It is also the base layer that monitors livestock applications such as animal health monitoring, tracking pet observation, etc., and transmits the information to the application layer. According to the concept of IoT network architecture, all wearable devices and sensors in livestock use 6LoWPAN and IPv6 systems to transmit data via the IEEE 802.15.4 protocol [12,16].

Physical layer: It is the lowest layer in the IoT network architecture and undertakes the task of collecting data through RFID, sensors, etc., and converting it into readable digital signals [11]. This layer monitors and measures several parameters related to the health status of the animals, such as their movements, body temperature, and digestive activity. It uses sensors and actuators to continuously monitor relevant parameters. Sensors collect data about the animal or the environment and convert it into analogue or digital signals. Z-wave, EPC-Global, LTE, and IEEE 802.15.4 are standards of the physical layer. The most popular among these is IEEE 802.15.4. Because IEEE 802.15.4 is less complex than others and has lower power consumption and cost [12].

Sensor Technologies

Sensors are devices that process physical information and convert it into electronic signals. IoT applications detect data from the outside world and convert them into digital and usable signals, enabling them to collect data from the outside world for functions such as actions and decisions. These data, obtained by measuring a physical, chemical, or biological condition or phenomenon, are used to predict deviations or abnormalities. In IoT applications, various sensors can communicate by sending and receiving data to each other over the internet. In IoT-based Precision Livestock Management applications, sensors are used to measure the suitability of the environment where animals live and to collect data about the animal's physical condition. This collected data is processed and analysed to monitor or detect various situations in advance. Sensor technologies and their purposes of usage in Precision Livestock Management applications are given in *Table I*.

Sensors can be grouped into external and invasive sensors. External sensors are usually mounted on a wearable device and placed on the animal's body. In this context, a wide variety of sensors are used. Accelerometers and pedometers are widely used to monitor animals' activity. Increased mobility in animals may be a sign of an estrus period, and a decrease may be a sign of lameness [17,18]. The health of the animals and the quality of the environment can be monitored with temperature and humidity sensors. Turning on a fan or heater depending Riaboff on the increase or decrease in temperature provides an increasing effect on animal welfare. It is important to monitor as increases in humidity levels can cause stress in animals. Increased humidity and temperature will also create a suitable environment for the transmission of diseases. Low humidity can cause breathing problems and result in dehydration. Animal sounds can be used for situations such as disease and estrus monitoring [19-21]. GPS can be used for activity tracking in conjunction with activity sensors, as well as tracking the location of animals. In addition to sensors, images collected from cameras and sound data collected from microphones are used to track information such as the activity of animals and disease status.

Invasive sensors are often used to monitor physiological measurements such as core body temperature. It is administered either by the animal swallowing it or by implanting it into the animal. Invasive sensors can directly measure factors for monitoring animal health [22]. Therefore, they produce more accurate data than external sensors. They also enable the monitoring of parameters such as hormones, which are not possible to obtain with external sensors. However, since external sensors are integrated into animals with wearable devices, they are both reusable and easier to apply, causing less stress in animals. Also, it is lower in cost.

Sensors for animals are placed with wearable devices such as neck collars, headphones, and ankle collars that are attached directly to the animals. The data to be collected is the main element that determines where the device should be placed on the animal [23]. These sensors usually need to be in contact with the body, but hair on the animals can make direct measurement difficult. Additionally, wearable sensors mustn't be uncomfortable or heavy for animals; otherwise, the animal will try to get rid of the sensor. Considering the environment and activities of the animals, they need to be water and impact-resistant and long-lasting. Another important element for sensors is that they require energy to collect and transmit data. This energy is provided by batteries. Since frequent battery replacement is a difficult process for animals, it is also important that the energy source to be used is efficient [24].

Cloud Computing

The rapid development in technology has led to an increase in device usage and the number of users. Thus, data accumulation also increased. Users and companies want to store this accumulated data, access it whenever they want, and perform various analyses. However, the increase in data to be stored has also increased storage costs. Cloud computing is the general name for internet-based computing services. It offers an infrastructure where data can be accessed and shared via devices connected to the internet, such as computers and tablets. In addition to storing data, cloud computing also provides a platform where data can be analysed with artificial intelligence and machine learning [25].

Cloud computing services meet the need to store and analyze data in many IoT systems. In smart animal husbandry, data needs to be stored to monitor the welfare of the animals. Additionally, the detection of unusual situations can be made based on the analysis of historical data. In IoT-based smart livestock systems, developers use cloud computing to store data and/or detect abnormalities with machine learning algorithms using stored historical data [6].

Machine Learning

Machine learning is a subfield of artificial intelligence. The model obtained from data trained with algorithms is used to predict similar situations. The algorithm's ability to learn accurately depends on the good representation and size of the data [26].

There are two basic learning approaches in machine learning: supervised and unsupervised. Supervised learning enables a model to make specific inferences from input data or create a mapping corresponding to a specific output. For the algorithm to learn a specific input-output relationship, it must be trained with a labelled dataset [27]. Classification and regression problems are within the scope of supervised learning. Unsupervised learning is used to discover natural groupings or relationships between features in a data set, but data samples are not given labels. Using the similarity measures, it determines which group the unknown data may belong to based on its proximity to other data points [28]. Clustering is a common application area studied under unsupervised learning. Deep learning is an algorithm that can learn from large amounts of data using artificial neural networks that model the way the human brain works. It contains at least one multilayer artificial neural network and is capable of obtaining more precise results than traditional machine learning methods when a sufficient amount of data is available [29].

In IoT-based smart livestock systems, the actuator is responsible for alerting the farmer and/or veterinarians or automatically taking some measures within the system if a certain critical situation occurs. Nowadays, it is quite common to use predefined threshold values to determine the critical state. For example, they are sending a notification to the farmer or turning on a fan if the animal's body temperature is above a certain threshold. In

Table 1. Sensor technologies and their purposes of usage

Sensor	Function	Application
Temperature sensor	Determine the temperature of an animal or environment	Animal health tracking, environment temperature monitoring
Humidity sensor	Determine the humidity level of an animal body or environment	Animal health tracking, environment humidity monitoring
Microphone	Use to collect sounds of animals	Animal health tracking, estrus detection, swarm bee, flock poultry farming
Camera	Use to monitor the environment and animals	Animal activity, estrus, lameness detection
GPS	A satellite system used to determine the location on Earth	Animal location tracking, activity detection, smart feeding
Accelerometer	Use to detect and track activities of animals	Motion, lameness, mastitis, estrus, feeding, rumination, position detection
Heart rate/pulsometer	Use to measure how many times the heart beats per minute	Heart rate
Respiration	To determine respiratory rate and pattern by monitoring breathing	Animal health tracking
Pedometer	To count the steps taken by animals in a certain period	Activity tracking, estrus/calving/lameness detection
Ruminal sensors	Use to monitor and evaluate certain parameters in the digestive system of animals	Meal tracking, chewing, digestion, and nutrition according to pH in the rumen system
Rumination sensor	Use to track chewing and digestion processes in the digestive system	Animal health tracking, feeding
Saliva sensor	Use to measure specific components in saliva, especially biochemical or biological parameters	Animal health, hormone, and nutrition monitoring
Gas sensor	Detect level of different gases (like CO_2, NH_3, CH_3 etc.) in the environment	Monitoring the air quality in the environments where animals live
Load sensor	Use to measure the weight of the animal	Animal health tracking, smart feeding
Luminance	Use to measure environmental light levels to adjust the light level	Animal health and environment tracking
Posture sensor	Used to monitor and evaluate body position and physical activities	Animal health tracking, Animal activity recognition
Biosensors	Use to detect a biological reaction by placing it inside the bodies of animals and measure the information obtained from this reaction	Feeding, estrus, disease
RFID	Use to identify and track animals using radio frequency	Animal location tracking, animal identification
Ultrasonic sensor	Use ultrasonic sound waves to determine the location of an animal, silo and calculate its distance from the location	Smart feeding, fish farming

some systems, predictions of machine learning algorithms are used instead of threshold values [29]. These algorithms are used to make real-time predictions about the condition of animals or the environment with data from sensors and cameras. In this way, when critical situations arise, automatic solutions can be provided through actuators, or notifications can be sent to authorised persons.

Communication Protocols

Connectivity is the basic need of an IoT system. Devices within the IoT system must be connected with a communication protocol to exchange data. *Table 2* shows the advantages and disadvantages of various communication protocols compared to each other. Animal farms are generally established in areas far from the city centre. This may cause an interruption to the internet, which is one of the basic building blocks of IoT. It is important to determine the correct communication protocol for the healthy functioning of the system. The correct protocol depends on the system's requirements. The area covered by the animal farm where the IoT system will be installed determines how far the IoT devices need to communicate. The power consumed for data transmission is another decisive factor. Because it is preferred that batteries are not changed frequently in the field, another important factor is that the costs of different protocols are different.

LoRa is generally preferred for data transmission over longer distances. SigFox is widely used, like LoRa, because it can provide low-power real-time monitoring on large farms. ZigBee is preferred in shorter-range applications such as indoor monitoring. Similarly, Wi-Fi and Bluetooth

***Table 2.** Communication protocols and their technical specifications*

Protocol	Frequency Band	Transmission Range	Data Rate
Bluetooth	2.4 GHz	Indoor: Up to 10 m, Outdoor: Up to 1 km	1-24 Mbps
IEEE 802.11	2.4 GHz	Indoor: 20-70 m, Outdoor: 100-250 m	11-54 Mbps
ZigBee	2.4 GHz	10-100 m	Up to 250 Kbps
Wi-Fi	2.4-5 GHz	15-45 m	54-450 Mbps
LoRa	470-928 MHz, country-specific	Urban: 2-5 km, Rural: 5-15 km	0.3-50 Kbps
IEEE 802.15.4	868/915/2400 MHz	10 m	200-250 Kbps
GPRS/3G/4G/5G	850, 900, 1800, 1900 MHz, 3.3-3.8 GHz	Cellular area	7-300 Mbps
XBee	2.4 GHz/902-928 MHz /865-868 MHz	2 km	250 Kbps, 1 Mbps
MQTT	-	-	Up to 256 Mbps
SigFox	900 MHz	Rural: 30-50 km, Urban: 3-10 km	10-1000 bps
RF	<1 GHz	-	-
RFID	125KHz-915 MHz	3 m	400 Kbps

are also commonly used to monitor animals on a small scale or in confined spaces. It provides a high sampling rate and a high volume of data transmission. Another advantage of Wi-Fi is that it is easy to implement [30].

Results

Smart Agriculture and animal husbandry is an approach to animal husbandry that includes the use of modern technologies instead of traditional methods. This approach involves the use of innovative technologies such as sensors, data analytics, artificial intelligence, and internet connectivity. Smart livestock applications aim to make livestock activities more efficient, sustainable, and profitable. Thanks to these technologies, farmers can remotely monitor their fields, animals, and environmental conditions, increase productivity, and ensure more efficient use of resources. Smart farming has significant potential for the future of livestock farming and represents the digital transformation of the livestock industry. The taxonomy of smart animal husbandry applications is given in *Fig. 3*.

Today, smart agriculture is used to address many problems. In this review study, IoT applications were examined under the headings of precision livestock farming, health monitoring, tracking animal location, smart feeding, estrus/calving detection, lameness detection, animal activity detection, fish farming, precision beekeeping, and poultry.

Precision Livestock Farming

Livestock farming is a type of animal husbandry carried out for the production of foods that have an important place in human nutrition, such as meat and milk. In addition to animals raised for meat and milk, such as cows, cattle, buffalo, sheep, and goats, animals such as chickens and turkeys raised for meat and eggs are also included in the scope of livestock. Suitable land is needed for animals to shelter and continue their natural lives, and shelters such as barns and coops are needed for feeding animals. In addition to obtaining meat and eggs directly from livestock, by-products such as butter, cream, and cheese are also obtained. To increase the quantity and quality of the product obtained, animals of good breeds should be preferred, and animals should be fed with quality feed. Although efforts are made to increase productivity with the use of organic feed in traditional livestock farming, it includes various difficulties because it is based on constant monitoring and control [31].

Precision livestock farming (PLF) is the continuous monitoring of factors that will directly increase product yields, such as the location, health status, nutrition, and reproduction of animals, with the help of digital systems. These systems, also called livestock monitoring and control, are provided with technical devices such as cameras, GPS, various sensors, and RFID placed on livestock land and animals. Thus, information such as

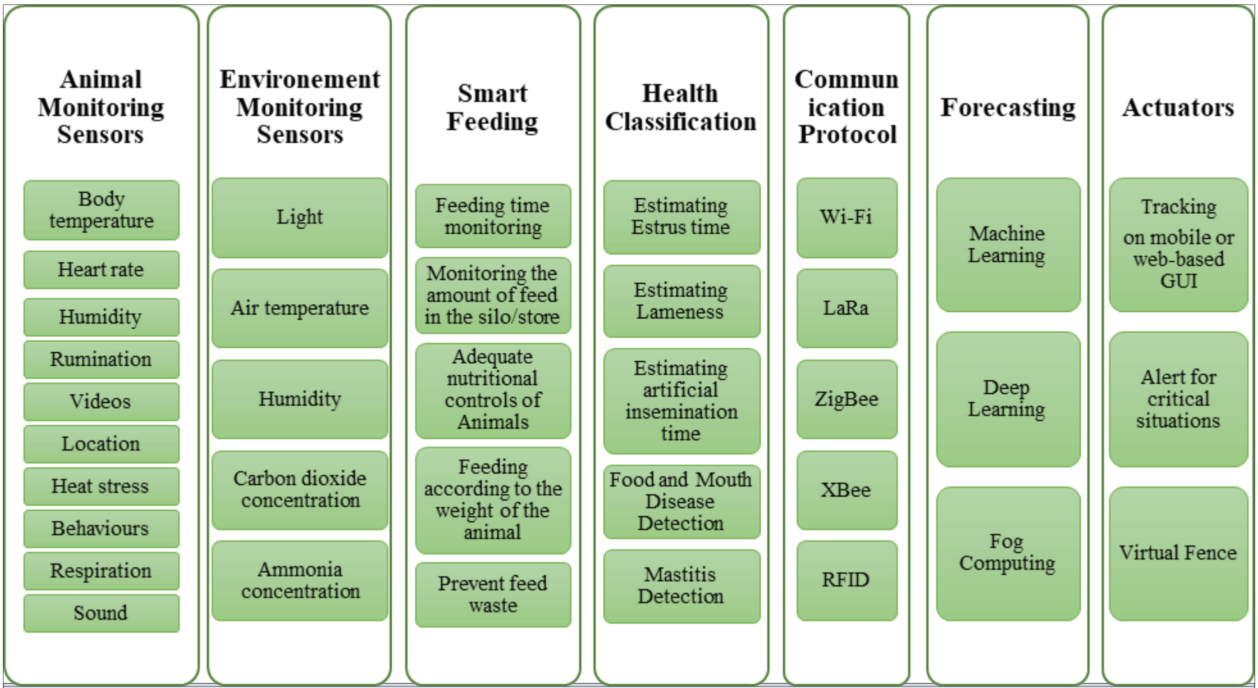

Fig 3. Taxonomy of applications in smart farming

the health status of the animals, their nutritional levels, and their locations can be monitored regularly [32]. Air and climate control in these living spaces is provided by sensors placed in livestock areas and/or indoor living spaces of animals. Data collected by sensor networks can be visualised and monitored through mobile or web-based applications, and the responsible person can be informed in critical situations [33]. PLF systems include modules such as livestock health monitoring, tracking their location, and smart feeding [32]. Within the scope of the study, each submodule was examined under a separate heading.

Health Monitoring

In traditional livestock farming, the officer checks the health status of animals manually. If a disease occurring in an animal is not diagnosed in time, it may lead to the loss of the animal, or in the case of epidemics, it may spread between animals and cause mass animal losses. In health monitoring systems, the health status of animals is monitored with various sensors. Data such as heartbeat, body temperature, and blood pressure are collected through sensors and saved at regular intervals in a cloud-based storage unit via an internet protocol. Sensors are integrated into wearable devices such as collars and placed on the animal. The warning system ensures that information is conveyed to the farmer or the responsible veterinarian if any parameter in an animal deviates from normal. Additionally, the farmer can monitor at any time via a mobile or web interface. In this way, the problems of mass animal deaths and decrease in crop yield caused by diseases can be significantly reduced [34]. *Table 3* shows studies using IoT technologies in animal health monitoring.

Tracking Animal Location

To increase the productivity of animals, grazing animals must move around the livestock land. Especially in large feedlots, it is difficult for farmers to visually track the location of animals or requires intense physical strength. While grazing in open fields, an animal may not be able to return due to a snake bite or illness, and farmers may also encounter problems such as theft of animals. Technologies such as GPS used to track the location of animals allow determining where each animal is. Location tracking systems include methods that estimate the distance from the animal's current location to the barn's or farmer's location [57]. Thus, the farmer can see how far the animal is from the barn and set virtual boundaries for the animals. If the animal's distance to a key location, such as a barn, is over a certain unit, a notification can be sent to the farmer. This threshold unit can be defined relative to the boundaries of the farm, or a distance determined by the farmer. Geographically limiting animals will also prevent problems that may arise from animals entering another farm [19]. Studies on animal tracking systems are presented in *Table 4*.

Smart Feeding

Proper nutrition of animals is one of the factors that directly affect animal health and product productivity. Smart feeding systems include features such as monitoring the remaining food volumes in feedlots, monitoring feed

Table 3. *IoT applications in health monitoring*

Parameters	Sensors	MCU	Comm. Protocol	Critical Situation Decisive	Actuator	Animal	Ref.
Body temperature, heart rate, humidity	Accelerometer, body temperature (MLX90614) humidity (DHT11), heart pulse (KG011)	Arduino UNO	Bluetooth (HC05), Wi-Fi (HSP8266), IEEE 802.11 & 802.15	Threshold	N/A	Cow	[35]
Heart rate, rumination, body temperature, humidity	Temperature (DS18B20), Accelerometer for rumination (ADXL335)	Raspberry Pi3	IEEE 802.11 Wi-Fi standard	Threshold	Alert with GSM	Cow	[36]
Rumination, body temperature, heart rate, surrounding rate	Accelerometer for rumination (ADXL335), body temperature (TTC05102), heart rate (T56H), humidity (DHT11)	PIC18F455, XBee-PRO S2	Zigbee IEEE1451.1 standard	Threshold	Alert	Cow	[37]
Animal weight, number of approaches to the watering area, drinking time, and duration	There is a platform in the watering area to measure the weight	Arduino UNO	Wi-Fi	Threshold	N/A	Cattle	[38]
Temperature, acceleration, heartbeat, gas, sound, saliva, weight	Temperature sensor, accelerometer, heartbeat sensor, saliva sensor, gas sensor, microphone, load sensor	N/A	N/A	Fully connected neural network	Web-based monitoring	Cow	[39]
Temperature, humidity, heartbeat, rumination, respiration rate	Body temperature (LM 35), respiration, DHT 11 humidity sensor, heartbeat, and rumination	Arduino UNO	ESP8266 Wi-Fi	Threshold	N/A	N/A	[40]
Rumination sound, temperature, 3D movement	Rumination, temperature, motion sensors	Raspberry Pi 3	Wi-Fi	Artificial neural network	Alert to farmer	Cattle	[41]
Humidity, barometric levels, gyroscope, noise, GPS coordinates, heart rate, duration of activity, lying down	Video and thermal camera	N/A	LoRa and TCP, Wi-Fi	Boosted decision tree	Alert to farmer	N/A	[6]
Body temperature, humidity, heartbeat, position	Temperature and humidity (DHT22), heart rate (SON1205), gyro (GY-521 MPU-6050), Respiratory rate	N/A	HTTP	Light-gradient-boosting decision tree regression	Web-based monitoring	Cattle	[42]
Image, temperature, humidity, light	Temperature-humidity sensor: (SHT-71), luminance sensor (brightness sensor): GL5547	MCU (MSP430F1611)	ZigBee	Threshold	Water sprayer/fan, lighting	Cow	[43]
Animal movements, temperature, heartbeat	Temperature (LM 35), heart rates (infrared- IR sensor), postüre (ADXL 325)	MCU (16F877A)	Zigbee	Threshold	N/A	N/A	[44]
Temperature, heartbeat, location, pulse, respiration	Temperature (LM35), heart rate, pulse rate, respiratory, GPS	MCU	Zigbee. IEEE 802.15.4 standard	Threshold	Web-based monitoring	Pets	[45]
Environment temperature, humidity, light, CO_2 and NH_3 concentration Animal acceleration, rotation, body temperature, location	Temperature and humidity (AM2321), illuminance (GY-2561), CO_2 concentration (DFRobot SEN0219), NH_3 concentration (Winsen MQ137), acceleration (MPU-6050), GNSS, body temperature (DS18B20)	Raspberry Pi 3B, ATMega2560, M0 RFM95	LoRa low power wide area network (LPWAN)	Threshold	N/A	N/A	[46]

Table 3. *IoT applications in health monitoring (Continued)*

Parameters	Sensors	MCU	Comm. Protocol	Critical Situation Decisive	Actuator	Animal	Ref.
Environment temperature, humidity gas concentrations. animal temperature, heart rate, respiration rate, GPS, movement, activity	Air thermometer and humidity (SHT20), hygrometer, gas (CH4, H_2S, NH_3, CH20/H-CHO), body temperature, pulsometer, respiratory, accelerometer, gyroscope	Raspberry Pi, MCU (SoC)	Zigbee, Wi-Fi	Threshold	Web-based monitoring	N/A	[47]
Heart rate, body temperature, environment temperature, rumination, humidity	Infrared body temperature, 3-axis accelerometer, DHT 11 environmental temperature and humidity sensor	LPC 1313 MCU	LoRa	Threshold	Mobil based	Cow	[48]
Temperature, heart rate, weight, humidity	Temperature, load cell, humidity sensors	MCU	GPRS, Wi-Fi	Naive Bayes	Mobile-based alert	N/A	[49]
Rumen pH and temperature change	pH (TRY414.92) and temperature (DS18B20)	Arduino UNO R3	Serial Wi-Fi circuit	Fuzzy Logic	Web based monitoring	Cattle	[50]
Body temperature, heartbeat, animal falling	Temperature (LM35), heartbeat, piezoelectric sensors	AT89C51 MCU	ESP8266 Wi-Fi	Threshold	Mobile based alert	Cattle	[51]
Position, movement, heart rate	GPS (Pa1010D), heart rate (Maxin MAX30102), accelerometer and gyroscope (Adafruit LSM6DSOX)	M0 RFM95 MCU	LoRa, ESP8266, I2C	Threshold	E-mail alert	Horse	[52]
Heart rate, body temperature, acceleration	Heart rate, body temperature, inertial measurement unit	N/A	ESP 32 Wi-Fi, I2C	Threshold	N/A	Cow	[53]
Temperature, location, heart rate, water level, air quality, CO_2 concentration, environment humidity, temperature, light, virtual board	Temperature (DHT11), stethoscope (CR-747SS), ultrasonic (HC-SR4), air quality (MQ-135) sensors, GPS (NEO-6M)	NodeMCU	ESP8266 Wi-Fi	Threshold	Alert with GSM	Cow	[54]
Environmental temperature, humidity, CO_2, animal temperature, pulse	RFID, temperature and humidity (DHT11), CO_2 (MQ-135), body temperature and pulse sensors	Arduino	LoRa	Threshold	Turn on/off fans, open food, turn on/off massage, open/close Windows	Cow	[55]
Temperature, heart rate, oxygen separation level, respiratory range, position of the animal	SPO_2, temperature, humidity, respiratory, and heart rate sensors	Arduino UNO	Zigbee	Threshold	Alert with SMS, mobile app	Cow	[56]

Table 4. *Studies about animal location tracking*

GSM	GPS	GPRS	WSN	RFID	MCU	Comm. Protocol	Sensors	Actuator	Animal	Ref.
√	√		√		Arduino	XBee				[58]
	√	√					Ultrasonic sensor	Virtual board		[59]
			√	√	Raspberry Pi3	LoRa			Cattle	[60]
	√				MCU	LPWA network			Cow	[61]
	√				Arduino-compatible MCU	LoRa	Motion sensor (MPU-9250)		Grazing animals	[62]
	√				LPC 1313 MCU	LoRa		Virtual board	Cow	[48]
√		√		√					Cow	[63]

***Table 5.** IoT applications in smart feeding*

Parameters	Actuators	Sensors/Hardware	Comm. Protocol	MCU	Animal	Ref.
Animal's feeding time, amount of feed in the silo, amount of feed in the warehouse, presence of cattle near the feed	N/A	Ultrasonic sensor, load cell, servo motor	Wi-Fi	Arduino WeMos D1R2	Cow	[66]
Activity, amount of feeding from the feeder and in the pasture, height of hay bales	N/A	Accelerometer (LIS3DH), GPS (Neo-6 m GPS sensor), ultrasonic sensors	RF, GPRS, Wi-Fi	Arduino	Beef cattle	[67]
Dog breed, size, and weight	Calculate the amount of feed the dog should take according to its breed, size, and weight.	DC motor	ESP8266 Wi-Fi	ATMEGA328 MCU	Dog	[68]
N/A	Automatic feeding in the aquarium	N/A	ESP8266 Wi-Fi	Arduino UNO, ESP 12F, ROHM IOT Kit control boards	Aquarium fish	[69]
Weight of bait bowl	N/A	Weight sensor	LoRa	Arduino UNO	Stray animals	[70]
N/A	Automatic feeding	N/A	Wi-Fi	N/A	Aquarium fish	[71]

stocks, monitoring temperature and humidity values in the feed that will reduce the quality of the feed, and protecting the feed in silos and warehouses from animals such as insects and rodents [64]. Animals are fed with ready-made feed in shelter areas and by grazing in open fields. Which feeding method and for how long the animals are fed is important in terms of monitoring the amount of food they receive. In this way, animal grazing areas can also be arranged [19]. Monitoring nutritional status with sensors helps maximize individual growth rates by ensuring that each animal receives the right quantity and quality of feed at the right time [65]. Studies on smart nutrition systems are summarized in *Table 5*.

Estrus/Calving Detection

In livestock farming, calving is important to increase or at least protect the number of animals on the farm. In dairy cows, the milk production efficiency of the animals depends on the calving intervals and calving between 12-14 months has a significant effect on lifelong milk production [72]. For this reason, the estrus periods of animals are monitored on farms. If the period cannot be detected, a 21-day non-pregnancy period occurs for the cows, and the fertilization period is disrupted. This situation causes a decrease in milk yield along with the cost of additional feed and artificial insemination for the cows [73].

Symptoms of animals' estrus periods include behavioral and hormonal changes. Behavioral symptoms usually manifest as irritability and restlessness. Animals may become anxious, avoid people, eat less, and make various sounds. Additionally, their number of steps may increase, and they may exhibit behaviors such as walking around other cows and sniffing. Hormonally, the animal's body temperature decreases before estrus and increases with the beginning of the period [74].

The estrus period for livestock lasts approximately 18 hours. Ovulation occurs within 8-11 h after the start of the period [75]. In traditional animal husbandry, this process is monitored by an observer. However, especially in large farms, situations such as the lack of a sufficient number of observers, the experience of the observer, the frequency of observation, falling at night or at a time when no one is on the farm may cause the estrus period not to be determined [76]. With the developments in smart animal husbandry, monitoring, and detection of estrus periods can be carried out automatically. While hormonal changes can be monitored through biosensors placed on the animals' bodies, changes in body temperature due to the estrus period and their movements can be monitored with accelerometers or cameras, thanks to wearable sensors. The data obtained is analyzed on IoT platforms and a notification is sent to the farmer or the responsible person via GSM or mobile application when the animal enters the estrus period. In this way, farmers are relieved of the obligation to make constant observations, and the risks associated with missing the period are also prevented.

Table 6. *IoT applications in estrus/calving detection*

Sensor/ Hardware	Parameters	MCU	Comm. Protocol	Animal	Actuator	Critical Situation Decisive	Ref.
Accelerometer	x, y, z coordination	Arduino UNO	Bluetooth (HC05), Wi-Fi (HSP8266), IEEE 802.11 & 802.15	Cow	Web-based monitoring	N/A	[35]
Infrared thermometer	Heat stress, body temperature	Arduino atmega 328p	Bluetooth, Wi-Fi (ESP8266)	Cow	N/A	N/A	[78]
Accelerometer (MMA7260)	Acceleration	MSP430 MCU	N/A	Cow	Web and smart-based monitoring	Expectation maximization, random forest, and CNN	[79]
IP camera (DH-SD22404T-GN)	Images and videos	Arduino UNO R3	Wi-Fi	Cow	Alert with GSM	Faster R-CNN	[80]
Digestible Biosensor (in rumen)	Internal body temperature	N/A	N/A	Cow	Alert with mobile app	N/A	[81]
Accelerometer (ADXL345)	Acceleration	ESP8266 Node MCU	N/A	Cow	N/A	N/A	[82]
Infrared thermometer (MLX90614ESF-BAA), accelerometer (MMA8451)	Step count, skin temperature	Wemos d1 mini (ESP8266EX)	Wi-Fi 802.11 b/g/n standards	Cow	N/A	N/A	[83]
Accelerometer (LIS3DH), GPS (Neo-6 m GPS sensor), vaginal thermometer	Location, movement, temperature	Arduino	RF, GPRS, Wi-Fi	Beef cattle	Mobile and web-based monitoring	N/A	[67]
Pedometer (afitag), activity meter (Heatime-RuminAct and HeatPhone)	Step count, calving date, lactation number, dairy production, progesterone in milk	N/A	Infrared connection, radio frequency	Cow	Alert	N/A	[84]
Pedometer	Step activity for estrus, lying time, and pregnancy stage for calving	N/A	MQTT	N/A	Alert with SMS	Random Forest, K-NN	[85]
Inertial measurement unit (IC-20948), GNSS, thermometer (DS18B20)	The number of transitions between lying and standing	nRF52840-dongle MCU	LoRa	Cow	N/A	N/A	[77]

Similarly, detecting the moment of birth of animals helps prevent the loss of dam and offspring by intervening early in various problems that may arise during birth. Therefore, in smart animal husbandry, the calving periods of animals are monitored by monitoring the animals' movements, behavioral changes, and body and hormone parameters. When the calving season comes, changes occur in the behavior of the animals. While there is a decrease in behaviors related to feeding and rumination, an increase can be observed in lying down. Behavior patterns and durations in animals can be monitored with sensors such as accelerometers and pedometers [77]. In *Table 6*, details of studies on IoT applications for estrus/calving detection are presented.

Lameness Detection

Lameness is one of the most common problems on livestock farms, after infertility and mastitis. Lameness, which reduces the fertility level and efficiency of milk production, especially for dairy cows, negatively affects the feeding and rumination processes of the animals [86]. Locomotor deficits and hoof and limb lesions are the main causes of lameness. In animals, behavioral changes such as slow movement, tendency to lie down, and lowering the head while walking determine this condition [3]. In traditional animal husbandry, these behavioural changes are detected observationally. However, this detection method can be subjective, time-consuming, and costly. Therefore, with the developments in smart animal husbandry, the

***Table 7.** IoT applications in lameness detection*

Parameters	Sensors	Comm. Protocol	MCU	Animal	Critical Situation Decisive	Ref.
Physical activity	Accelerometer	Bluetooth	ARM Cortex-M0 MCU	Cattle	One class SVM	[88]
Number of steps, lying time, and number of transitions between them (swap)	Pedometer	Message Queue Telemetry Transport (MQTT)	N/A	Cow	SVN, RF, K-NN, Decision tree	[14]

use of IoT systems for lameness detection is preferred. IoT systems both reduce observer costs and provide early diagnosis in detecting lameness. Early diagnosed lameness allows intervention to be made early, allowing savings in expenses such as antibiotics and veterinarians [14]. Generally, approaches to lameness detection are categorized into three groups according to the variables measured: kinetic, kinematic, and indirect measurement. In kinetic approaches, the forces involved in movement are evaluated; for example, the weight distribution and hoof strength of animals are examined during standing and walking. Kinematic approaches, on the other hand, focus on specific posture changes; They take into account variables such as the size, length, height, and back curves of the animals' steps. Indirect measurement examines behavioural changes; Values such as the animal's lying and standing time and milk yield are measured with the data obtained from the sensors integrated into the animals. Due to variations in measurement methods, even animals of the same species can exhibit different symptoms [87]. Studies about lameness are more limited than other fields, and the lameness detection studies discussed in this review are presented in *Table 7*.

Animal Activity Detection

Animals express their interactions with their environment through their behaviour. In situations such as illness, they go beyond their normal behavioural routines. So, behavioural changes can be a sign of the animal's health status. For example, if there is lameness, the animal's tendency to lie down increases, and during estrus periods, its steps increase. Feeding and rumination periods of animals are also among the values monitored in determining their health status. For a healthy animal, feeding and rumination periods are generally specific. Changes in these periods and durations may be a sign that there is something unusual in the animal. Therefore, monitoring the behaviour of animals is an important parameter in terms of their health status. Smart farming applications also include monitoring animal activities to monitor the

***Table 8.** IoT applications in activity/behavior monitoring*

Detected Activities	Sensors	Parameters	MCU	Comm. Protocol	Animal	Critical Situation Decisive	Ref.
Standing, lying, standing and ruminating, lying and ruminating, walking, walking and grazing	Temperature sensor, GPS (Neo-6M), 3-axis accelerometer (MPU 6050)	Temperature, acceleration on the x y, and z axes, latitude, longitude, and speed	ATMEL 328 MCU, Ardunio UNO	GSM (SIM 800)	Cattle	XGBoost, Random Forest	[90]
Standing, lying, walking	Pedometer	Step count, lying time, standing time, lying bouts, number of movements from lying down to standing up per hour	N/A	MQTT	N/A	Random Forest, K-NN	[85]
Grazing/eating, ruminating, neutral, walking, standing, lying	Inertial measurement unit (IC-20948)	N/A	nRF52840-dongle MCU	LoRa	Cow	Threshold	[77]
Walking, feeding, lying, and standing	3-axis accelerometer, GPS		Atmega328 MCU	LoRa	Cow	Random forest	[91]
Standing, lying, normal walking, active walking, standing up, and lying down	3-axis accelerometer (ADXL345)	Acceleration on the x y and z axes	MSP430 MCU	RF	Cow	Adaboost	[92]
Lying, standing	Ruuvitag sensor	Accelerometer, air temperature pressure, and humidity	Raspberry Pi	Bluetooth	N/A	N/A	[93]

animals' health status. The behaviour pattern monitored is determined depending on the application, but generally, the behaviours monitored are general behaviours such as walking, standing, lying down, and rumination. Sensors commonly used to detect behaviours exhibited by the animal include GPS, accelerometer, and step counter. In some studies, the activity of the animal is determined by classifying animal images collected with cameras. Additionally, by taking sound data from animals through microphones, behaviours such as grazing and rumination can be detected. It is also used for situations such as determined activities of animals, estrus, birth, and lameness detection [3,23,89]. Studies conducted in this field are given in *Table 8*.

Fish Farming

Depending on changing climatic conditions, ecological balances in nature also change. These changes bring about a decrease in water levels and an increase in water pollution. The demand for fish in the world's increasing population cannot be met by natural breeding methods [94]. For this reason, fish farming in farms is becoming increasingly common.

Water quality is a factor that directly affects the health and survival of fish. Dissolved gases in water, such as carbon dioxide, ammonia, and oxygen, affect water quality. Increasing the concentration of dissolved carbon dioxide can cause oxygen levels to drop, which can lead to fish suffocation. The increase in ammonia concentration causes fish poisoning. The higher the dissolved oxygen concentration in the water, the better the water quality. The amount of oxygen dissolved in water also depends on the salt level and temperature of the water. The recommended optimal water temperature for fish is 25-27 degrees, which may vary depending on the type of fish grown [69,95]. High or low pH is dangerous as it will cause fish to become sick, poisoned, or unable to grow. The recommended appropriate pH value is between 6.5-8.5. Certain water levels must be maintained for fish to survive. High volumes of precipitation and flooding cause ponds to overflow, which can cause fish to flush out. The increase in air temperatures will reduce the water level due to excessive evaporation [96].

Nowadays, fish farms can be monitored remotely thanks

Table 9. *IoT applications in fish farming*

Parameters	Sensors/Hardware	Actuators	Comm. Protocol	MCU	Ref.
Water temperature, depth, dissolved oxygen value, air pressure	Infrared distance (GP2Y0A02YK), pH (SEN0169), dissolved oxygen (SEN0237-A), pressure (BME280) sensors	N/A	Wi-Fi ESP8266	MSP430G2553 MCU	[95]
Temperature, pH, electrical conductivity, dissolved oxygen, total dissolved solids, water level	Temperature, pH, electrical conductivity, oxygen, dissolved solids water level sensors	Food feeder, pump, heater, fan, light, UV, RO (reverse osmosis)	Wi-Fi ESP8266	Arduino UNO, ESP8266 ESP 12F, ROHM IoT Kit control boards	[69]
pH value, salinity, and temperature of water	pH, salinity and temperature sensors, servo motor	Lowering or raising the pH	N/A	Arduino, Raspberry Pi	[97]
Temperature, water level, oxygen, pH	Temperature, oxygen, pH sensors	Water pump, fish feeder, pond heater lighting led	Wi-Fi, Zigbee	N/A	[94]
Temperature, pH value, dissolved oxygen, water level, and life expectancy	Temperature, pH, dissolved oxygen sensors	Alert to farmer	LoRa	Arduino Mega 2560 MCU	[96]
Water temperature, water level, light	Temperature (DS12B20), light intensity (RTC-DST1302), water level sensors	Heater, Buzzer, RGB Led, LCD Display, Led light	Http, wivity module	Arduino Mega 2560	[98]
pH, dissolved oxygen and ammonia levels, water temperature	pH, CO_2, NH_3 and temperature (DS18B20) sensors	Alert via mobile phone	ESP-12E Wi-Fi	Node MCU	[99]
pH, water temperature, water level	pH, temperature (LM35), water level sensors, DC motor	PC based monitoring	Wi-Fi	ARM LPC 2148 MCU	[100]
Water temperature, electrical conductivity, level, pH value, body turbidity and dissolved oxygen	Temperature (DS18B20), electrical conductivity (TDS), water level, pH (E-201-C), water body turbidity (Eater WT-RCOT), and oxygen (YHT-8402) sensors	Water supply and drainage pumps, aerators, feeders, water filtration purifiers	LoRa, GPRS	N/A	[101]
Water temperature, turbidity, pH, water level, CO_2	Water temperature, turbidity, pH, water level, CO_2 sensors	N/A	ESP 8266 Wi-Fi	Ardunio	[102]

to IoT systems. In this way, environmental factors are monitored in closed fish farming areas and productivity is increased by keeping the parameters of these factors at optimal levels. With this method, profits are maximized by reducing costs and increasing product quantity. Thanks to sensors that measure values such as temperature, pH, and dissolved oxygen integrated into water tanks, growers can instantly monitor the water values via mobile or web-based applications. In addition, various actuators are activated according to the data coming from the sensors, and automatic intervention can be made when water parameters such as temperature and gas go beyond safe limits. *Table 9* presents studies on IoT technologies developed/used for fish farming.

Smart Beekeeping

Bees are vital to environmental well-being and provide pollination, which is essential in agriculture. Bee pollination provides far-reaching benefits to food processing, raw materials, pharmaceuticals, plants, social and cultural values, and the maintenance of biodiversity and environmental protection [103]. Although all bee species contribute to pollination, honeybees are the primary pollinators of almonds, citrus fruits, blueberries, and cucurbits. Therefore, any changes in bee colony behavior and health, as well as declines in population sizes, can have dramatic impacts on the food industry. For this purpose, constant monitoring of bee health and colony strength is carried out by beekeepers. Limitations of manual observation include the difficulty for beekeepers to regularly monitor bee colonies and assess their health status. For this reason, there is an increasing trend towards new technologies that automate and extend hive monitoring technologies.

Humidity and temperature levels in the hive are important for the queen's egg production, larvae rearing, and food preservation. In smart beekeeping systems, hive values can be monitored and controlled remotely with temperature and humidity sensors [104,105]. Colony weight is one of the oldest monitored hive indicators of hive health, colony workforce, and hive food stores. Weight scales are more expensive than sensors and require more complex setups [106]. For a professional beekeeper managing hundreds or thousands of hives, adding a weight scale to each hive would be a huge expense. Therefore, recently beehive weight scales, which can automatically send periodic data to data storage using IoT and SMS technology, have gained popularity for continuous monitoring [107-109]. Pests and diseases always pose a threat to beehives. This can cause the rapid collapse of entire hives, a phenomenon called Colony Collapse Disorder (CCD) [110]. To mitigate the potential effects of these devastating pest and disease outbreaks, disease and pest control can be carried out in beehives with IoT systems. Image sensor-based approaches [111] and gas sensor-based approaches [112] involving thermal imaging are used in honey bee hives. Audio and imaging techniques called hive health monitors are also used to monitor beehives. Studies discussing hive health in terms

Table 10. *IoT applications in beekeeping*

Parameters	Sensors/Hardware	Duty	Comm. Protocol	MCU	Critical Situation Decisive	Actuator	Ref.
Bee sound	Audio receiver	Swarm activity classification	N/A	N/A	Deep neural network	N/A	[113]
Temperature, humidity, pressure, beehive weight	Temperature (DHT 11), LDR light, weight sensors, servo motor	Remotely monitoring and controlling the status of hives	LoRaWAN	ATmega32u4 MCU	N/A	Web-based monitoring, LED diode for status signaling, SG90 Micro Servo actuator	[108]
Temperature, humidity, light intensity, and rain level	N/A	A prediction and early warning system for the population daily loss rate of bee colonies	UDP socket	Raspberry Pi 3	Temporal convolutional network	Mobile based monitoring	[114]
Temperature and humidity	Temperature and humidity (DHT22), sound (MAX4466 amplified) sensor	Colony health monitoring	TCP/IP, ESP8266, local Wi-Fi network	NODE MCU, Arduino ATmega2560	N/A	API, Web-based, mobile based	[115]
Video, temperature, humidity, weight, and audio	Video, audio, temperature and humidity AM2302, weight sensors	Warning and monitoring system to prevent significant losses in the population of hives.	FTP, MQTT SSH	Raspberry Pi 4	N/A	Web-based monitoring and alert	[116]

of hive characteristics generally include brood size and/or dynamics, forager workforce size and/or dynamics, hive internal environment, hive audio, hive resources, and pathogen infestation. IoT studies conducted in the field of beekeeping are summarized in *Table 10*.

Smart Poultry

People consume poultry extensively. Chicken meat is the most preferred among poultry. As the demand for chicken meat increases globally, so do poultry quality concerns. Modern technological advances are helping the poultry industry in monitoring chicken health [117]. These advances include detecting the disease and health of chickens using video surveillance, audio observations, and IoT-based wearable sensor devices. These devices are placed on chickens and/or in coops and used for further analysis.

The use of modern advances provides the opportunity to monitor and early detect chicken diseases in poultry farms. These chicken monitoring techniques may include vocal analysis [118], which can automatically monitor the chicken's behaviour without direct interaction with the chicken's body. Wearable sensing devices [119] help determine the location of chickens and automatically identify and track their real-time movement with radio frequency identification devices. Surveillance of chicken farms through image processing [120] is another technological advance to identify activity behaviours and detect disease early. Diseases such as the H5N1 bird flu virus in poultry cause the death of animals but also affect human health. However, since chickens are housed in very close proximity to each other in coops, a viral disease can spread very quickly. Monitoring the body temperatures of animals is effective in taking early precautions in case of an epidemic [121]. The main goal of chicken breeders is to ensure maximum growth by maintaining the optimal weight of the animal. Chickens should gain weight quickly, but since this also restricts egg laying, it must be kept in balance. Therefore, the amount of food consumed by chickens can be determined according to their weight.

The environmental conditions of the poultry environment have a direct impact on productivity. These environmental inputs can be temperature, humidity, and concentration of various gases such as carbon dioxide and ammonia. Environmental parameters such as temperature (house temperature should be 20-26°C), humidity (should be approximately 50-70%), ammonia gas (should be below 10 ppm), and light are environmental conditions that directly affect chicken welfare. When concentrations of ammonia and carbon dioxide gas in the air increase, it can cause

Table 11. *IoT applications in poultry*

Parameters	Sensors/Hardware	Duty	MCU	Comm. Protocol	Actuator	Critical Situation Decisive	Ref.
Temperature, humidity, ammonia concentration, light, luminosity	Temperature and humidity (DHT22) Electrochemical (MQ-137) LDR sensors	Monitoring environmental conditions for poultry houses	*Wemos* Mini D1 MCU	ESP826, Wi-Fi	Mobile based monitoring	Least Squares Method (MMQ)	[126]
Temperature, humidity, gas	Temperature, humidity, gas (CO_2, O_2, NH_3) sensors	Monitoring environmental conditions for poultry houses	Raspberry Pi	Sim900 GSM, WSN	Mobile alerts, dashboard	N/A	[127]
Pecking, Preening, Dustbathing	RFID microchips and accelerometers	Disease monitoring for chickens	RFID microchips	Radio Frequenc, CSMA	Web-based monitoring	Decision Tree, Logistic Regression, KNN, Gaussian Naive Bayes, RF, SVM, TabNet	[128]
Temperature, humidity, gas	Temperature and humidity (DHT11), gas (MQ135) sensors	Monitoring environmental conditions for poultry houses	Raspberry Pi	Inter-integrated Circuit (I_2C), Wi-Fi	Web-based monitoring	N/A	[129]
Temperature, humidity, light, CO_2, ammonia and hydrogen concentrations	Temperature, humidity, light, CO_2, NH_3, and hydrogen sulfide concentration sensors	Monitoring environmental conditions for poultry houses	N/A	Zigbee, GPRS	Alert, ventilate, light, temperature, humidity,	N/A	[130]
CO_2, NH_3 concentration, poultry temperature	CO_2 and NH_3 concentration, temperature, and humidity (DHT22) sensors	Monitoring environmental conditions for poultry houses	N/A	UTC-4432B1 wireless module	N/A	N/A	[131]

vision difficulties in animals, affect the respiratory system, and eventually cause death [122]. Especially during breeding periods, the temperature in the chicken coop is desired to remain within the recommended range [123]. Because hot or cold can cause stress in animals. Low relative humidity increases the rate of heat dissipation through evaporation and negatively affects the performance of animals [124]. Animals are sensitive to light. Exposure to more or less daylight than recommended affects nutritional intake and sexual maturity in chickens [125]. To monitor and improve environmental conditions, developed IoT-based systems are given in *Table 11*.

Discussion

In general, livestock management systems consist of three distinct processes: sensing and monitoring, analysis and decision-making, and intervention. PLF systems facilitate the management of these processes by reducing the need for manual observation and human-based decision-making. In traditional animal husbandry, all of these processes rely on human labour. However, in IoT-based systems, sensors, cameras, microphones, and other hardware are utilised for sensing and monitoring, machine learning algorithms are employed for analysis and decision-making, and automatic actuators are activated for intervention. This significantly reduces the time and labour costs required to manage a large number of livestock. Furthermore, these systems, when established with correct parameters, hardware, and algorithms, can prevent losses resulting from human negligence or error. Consequently, producers are enabled to manage more animals with fewer maintenance costs.

IoT applications in animal husbandry are becoming increasingly popular. This technology offers farmers a range of advantages. Firstly, IoT provides real-time data by monitoring the behaviour, health status, and environmental conditions of animals, thereby offering valuable insights for farmers to make more efficient and effective decisions. For instance, receiving early warnings about the health status of animals enables early diagnosis and treatment of diseases, thus reducing animal losses and veterinary expenses. Secondly, IoT enables more efficient use of resources. Resources such as feed and water consumption become traceable and manageable, leading to savings for farmers and enhancing environmental sustainability. Additionally, IoT automates and facilitates business processes. Providing remote access and automatic control increases labour productivity and enables farmers to manage their time more effectively. Moreover, IoT aids in predicting future trends through the analysis of collected data, providing farmers with a valuable tool for making strategic decisions. Therefore, IoT applications play a significant role in the livestock sector and are expected to become even more widespread in the future.

Due to the numerous benefits of IoT technology in animal husbandry, applications are being developed in various areas, and there has been an increase in academic research in this field in recent years. Although there are some studies on IoT in PLF systems in the literature, their scope is more limited. They focus on examining equipment that may be needed within an IoT system, such as a single animal species like chickens or fish [5,23,133,135-139], a few application areas like animal health monitoring [132-139], or technologies used in the scope of IoT [4,137]. However, in this compilation, a much more comprehensive review of IoT application areas in animal husbandry has been conducted without being limited to specific animal species. Additionally, information regarding the technologies needed in the development phase of an IoT-based smart livestock system has been provided.

Studies generally focus on monitoring the health of animals based on values such as body temperature and heart rate. However, it is observed that sensors like GPS, pedometers, and accelerometers are widely used in various application areas. In most studies, suitable threshold values for parameters have been defined, and warning systems have been developed based on data from sensors. Deviation from the specified threshold values in sensor data can pose a problem. It is expected that the use of machine learning algorithms that can predict based on past data and provide warnings before critical situations occur will become more widespread in the near future. Additionally, as observed from the reviewed studies, the scope of actuators, an important component of an IoT system, is generally limited to providing notifications. With the increasing use of IoT systems, the proliferation of automatic systems capable of problem-solving or providing pre-solutions without human intervention is also expected.

When examining IoT applications in animal husbandry and the compilation of articles in this field, it is noted that most studies will be conducted in the near future. This indicates that IoT technology is rapidly advancing in the livestock sector and that research and applications in this area are increasing. These recently conducted studies highlight the potential and importance of IoT technology in animal husbandry. However, the limitations of research in this field and future studies that need to be conducted should also be considered. Specifically, further research and assessment are required regarding the cost-effectiveness, reliability, and efficacy of IoT applications in animal husbandry. Furthermore, the broad-ranging effects of IoT technology on the livestock sector and its potential contributions to sustainability are worth further investigation. In this context, it is expected that future studies will focus on further enhancing the applications of IoT technology in animal husbandry and increasing efficiency in the sector.

With the concepts of the IoT, traditional animal husbandry has begun to be replaced by smart farming. This change helps solve problems such as labour costs commonly encountered in traditional agriculture. For smart farming systems to operate efficiently, there are trends such as data collection and analysis, health monitoring and management, and the control of environmental units. Data are collected through wearable devices and sensors in the environment. This data is stored in cloud environments or local storage areas and processed using extensive data analysis methods or artificial intelligence. In this way, the health of the animals, their location and nutrition, and the welfare of their living environment can be monitored. Additionally, IoT sensors can optimise waste management.

While smart livestock systems offer many benefits, they also bring various challenges. The most important of these are data privacy and security. Since sensor data is transmitted over wireless systems like Bluetooth and radio frequency, it is more vulnerable to cyber-attacks. Additionally, various measures and monitoring must be implemented to ensure the privacy of the stored data. IoT systems particularly require financial investment during the initial setup phase due to the need for sensors, wearable devices, software, and data communication. After the setup, the maintenance and updates of these systems necessitate continuous investment. The typical establishment of livestock farms in rural areas, away from city centres, can lead to connectivity issues and technological infrastructure problems. To maximise the benefits of smart farming systems, farmers must adapt to the relevant technologies. Overcoming these challenges and ensuring continuous development is crucial for deriving maximum benefit from these technologies.

Conclusion

PLF systems, powered by IoT technology, offer significant benefits in optimising livestock management. By automating sensing, monitoring, analysis, and decision-making processes, PLF systems reduce reliance on manual labour, thus enhancing operational efficiency and reducing costs. IoT applications enable real-time monitoring of animal health, behaviour, and environmental conditions, empowering farmers with valuable insights for informed decision-making. Furthermore, IoT facilitates resource optimisation, business process automation, and future trend prediction, leading to improved productivity and sustainability in the livestock sector.

Although IoT technology in animals is rapidly advancing, further research and development are necessary to explore broader IoT integration and enhance cost-effectiveness and sustainability in managing livestock. Future studies should focus on addressing the reliability and efficacy of IoT applications and their potential contributions to sustainability. Additionally, advancements in machine learning algorithms and proactive problem-solving automatic actuators hold promise for further enhancing the efficiency of IoT-based livestock management systems.

Overall, the comprehensive review of IoT applications highlights its transformative potential in livestock farming. With ongoing advancements and interdisciplinary collaboration, IoT-enabled PLF systems are poised to drive sustainable improvements in productivity, animal welfare, and resource utilisation within the animal industry.

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References

1. Neethirajan S: The role of sensors, big data and machine learning in modern animal farming. *Sens Bio-Sens Res,* 29:100367, 2020. DOI: 10.1016/j.sbsr.2020.100367

2. Dione MM, Ouma EA, Roesel K, Kungu J, Lule P, Pezo D: Participatory assessment of animal health and husbandry practices in smallholder pig production systems in three high poverty districts in Uganda. *Prev Vet Med,* 117 (3-4): 565-576, 2014. DOI: 10.1016/j.prevetmed.2014.10.012

3. Qiao Y, Kong H, Clark C, Lomax S, Su D, Eiffert S, Sukkarieh S: Intelligent perception-based cattle lameness detection and behaviour recognition: A review. *Animals,* 11 (11):3033, 2021. DOI: 10.3390/ani11113033

4. Akhigbe BI, Munir K, Akinade O, Akanbi L, Oyedele LO: IoT technologies for livestock management: A review of present status, opportunities, and future trends. *Big Data Cogn Comput,* 5 (1):10, 2021. DOI: 10.3390/bdcc5010010

5. Karthick G, Sridhar M, Pankajavalli P: Internet of things in animal healthcare (IoTAH): Review of recent advancements in architecture, sensing technologies and real-time monitoring. *SN Comput Sci,* 1:301, 2020. DOI: 10.1007/s42979-020-00310-z

6. Dineva K, Atanasova T: Design of scalable IoT architecture based on AWS for smart livestock. *Animals,* 11 (9):2697, 2021. DOI: 10.3390/ani11092697

7. Cihan P: IoT technology in smart agriculture. *2nd International Conference on Recent Academic Studies.* 185-192. Konya, Türkiye, 19-20 Oct, 023.

8. Weber RH, Weber R: Internet of Things: Legal Perspectives. Springer, 2010.

9. Koptez H: Real-time systems: design principles for distributed embedded applications. Kluwer Academic Publisher, 1997.

10. Atzori L, Iera A, Morabito G: The internet of things: A survey. *Comput Netw,* 54 (15): 2787-2805, 2010. DOI: 10.1016/j.comnet.2010.05.010

11. Zeng X, Garg SK, Strazdins P, Jayaraman PP, Georgakopoulos D, Ranjan R: IOTSim: A simulator for analysing IoT applications. *J Syst Architect,* 72, 93-107, 2017. DOI: 10.1016/j.sysarc.2016.06.008

12. Farooq MS, Sohail OO, Abid A, Rasheed S: A survey on the role of iot in agriculture for the implementation of smart livestock environment.

IEEE Access, 10, 9483-9505, 2022. DOI: 10.1109/ACCESS.2022.3142848

13. Khan R, Khan SU, Zaheer R, Khan S: Future internet: The internet of things architecture, possible applications and key challenges. *10th International Conference on Frontiers of Information Technology (Fit 2012).* 257-260, Islamabad, Pakistan, 17-19 Dec, 2012.

14. Taneja M, Jalodia N, Malone P, Byabazaire J, Davy A, Olariu C: Connected cows: Utilizing fog and cloud analytics toward data-driven decisions for smart dairy farming. *IEEE Internet of Things J,* 2 (4): 32-37, 2019. DOI: 10.1109/IOTM.0001.1900045

15. Zabasta A, Grunde U, Sematovica I, Kunicina N, Judvaitis J, Malniece A, Vitols K, Greitans M, Galkins I, Duritis I: Low-power wireless sensor network system for early diagnostic of subacute rumen acidosis in cows. 7th IEEE Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE). Latvia, 15-16 Nov, 2019.

16. Giordano S, Seitanidis I, Ojo M, Adami D, Vignoli F: IoT solutions for crop protection against wild animal attacks. IEEE international conference on Environmental Engineering (EE). IEEE, 12-14 March, 2018.

17. Riaboff L, Relun A, Petiot CE, Feuilloy M, Couvreur S, Madouasse A: Identification of discriminating behavioural and movement variables in lameness scores of dairy cows at pasture from accelerometer and GPS sensors using a Partial Least Squares Discriminant Analysis. *Prev Vet Med,* 193:105383, 2021. DOI: 10.1016/j.prevetmed.2021.105383

18. Jukan A, Masip-Bruin X, Amla N: Smart computing and sensing technologies for animal welfare: A systematic review. *ACM Comput Surv,* 50 (1):10, 2017. DOI: 10.1145/3041960

19. Hassan M, Park JH, Han MH: Enhancing livestock management with IoT-based wireless sensor networks: A comprehensive approach for health monitoring, location tracking, behavior analysis, and environmental optimization. *J Sustain Urban Future,* 13 (6): 34-46, 2023.

20. Alipio M, Villena ML: Intelligent wearable devices and biosensors for monitoring cattle health conditions: A review and classification. *Smart Health,* 27:100369, 2023. DOI: 10.1016/j.smhl.2022.100369

21. Han Y: Design and implementation of IoT enabled generic platform for precision livestock farming and applications. United Kingdom: University of Strathclyde; 2020.

22. Mancuso D, Castagnolo G, Porto SMC: Cow behavioural activities in extensive farms: Challenges of adopting automatic monitoring systems. *Sensors (Basel),* 23 (8):3828, 2023. DOI: 10.3390/s23083828

23. Sharma B, Koundal D: Cattle health monitoring system using wireless sensor network: A survey from innovation perspective. *IET Wirel Sens Syst,* 8 (4): 143-151, 2018. DOI: 10.1049/iet-wss.2017.0060

24. Iwasaki W, Morita N, Nagata MPB: IoT sensors for smart livestock management. Chemical, Gas, and Biosensors for Internet of Things and Related Applicationsed., 207-221, Elsevier, 2019.

25. Sunyaev A, Sunyaev A: Cloud computing. Internet Computinged., 195-236, 2020.

26. Zhou ZH: Machi ne Learning. Springer Nature, 2021.

27. Muhammad I, Yan Z: Supervised machine learning approaches: A survey. *ICTACT J Soft Computing,* 5 (3): 946-952, 2015. DOI: 10.21917/ijsc.2015.0133

28. Hahne F, Huber W, Gentleman R, Falcon S: Unsupervised machine learning. *Bioconductor Case Studies*: 137-157, 2008. DOI: 10.1007/978-0-387-77240-0_10

29. Kelleher JD: Deep Learning. The MIT Press, 2019.

30. Evstatiev B, Kadirova S, Valov N: Analysis of the wireless communication technologies used in livestock monitoring. *International Conference on Communications, Information, Electronic and Energy Systems (CIEES)*. IEEE, 24-26 Nov, 2022.

31. Berckmans D: General introduction to precision livestock farming. *Anim Front,* 7 (1): 6-11, 2017. DOI: 10.2527/af.2017.0102

32. Neethirajan S, Kemp B: Digital livestock farming. *Sens Bio-Sens Res,* 32:100408, 2021. DOI: 10.1016/j.sbsr.2021.100408

33. Doncha G: IoT application to sustainable animal production. *Fascicle Ecotoxicol Anim Husb Food Sci Technol,* 16/A, 103-111, 2017.

34. Helwatkar A, Riordan D, Walsh J: Sensor technology for animal health monitoring. *Int J Smart Sens Intell Syst,* 7 (5): 1-6, 2014. DOI: 10.21307/ijssis-2019-057

35. Saravanan K, Saraniya S: Cloud IOT based novel livestock monitoring and identification system using UID. *Sensor Rev,* 38 (1): 21-33, 2018. DOI: 10.1108/Sr-08-2017-0152

36. Kumari S, Yadav SK: Development of IoT Based Smart Animal Health Monitoring System Using Raspberry Pi. *Int J Adv Stud Sci Res,* 3 (8):2018, 2018.

37. Kumar A, Hancke GP: A zigbee-based animal health monitoring system. *IEEE Sens J,* 15 (1): 610-617, 2015. DOI: 10.1109/Jsen.2014.2349073

38. Mirmanov A, Alimbayev A, Baiguanysh S, Nabiev N, Sharipov A, Kokcholokov A, Caratelli D: Development of an IoT platform for stress-free monitoring of cattle productivity in precision animal husbandry. *Adv Sci Technol Eng Syst,* 6 (1): 501-508, 2021. DOI: 10.25046/aj060155

39. Chatterjee PS, Ray NK, Mohanty SP: LiveCare: An IoT-based healthcare framework for livestock in smart agriculture. *IEEE T Consum Electr,* 67 (4): 257-265, 2021. DOI: 10.1109/Tce.2021.3128236

40. Meenakshi M, Kharde SS: Advance cattle health monitoring system using Arduino and IOT. *Int J Adv Res Elect Electron Instrum Eng,* 5 (4): 3365-3370, 2016.

41. Vyas S, Shukla V, Doshi N: FMD and mastitis disease detection in cows using internet of things (IOT). *Procedia Comput Sci,* 160, 728-733, 2019. DOI: 10.1016/j.procs.2019.11.019

42. Shabani I, Biba T, Çiço B: Design of a cattle-health-monitoring system using microservices and IoT devices. *Computers,* 11 (5):79, 2022. DOI: 10.3390/computers11050079

43. Jegadeesan S, Venkatesan GP: Smart cow health monitoring, farm environmental monitoring and control system using wireless sensor networks. *Int J Adv Eng Tech,* 7, 2016.

44. Vijayan A, Suresh M: Wearable sensors for animal health monitoring using Zigbee. *Int Adv Res J Sci Eng Technol,* 3 (3): 369-373, 2016. DOI: 10.17148/IARJSET

45. Keertana P, Vanathi B: IoT based animal health monitoring and tracking system using Zigbee. *Int J Res Trends Innov,* 2 (4): 234-238, 2017.

46. Germani L, Mecarelli V, Baruffa G, Rugini L, Frescura F: An IoT architecture for continuous livestock monitoring using LoRa LPWAN. *Electronics,* 8 (12):1435, 2019. DOI: 10.3390/electronics8121435

47. Alonso RS, Sittón-Candanedo I, García O, Prieto J, Rodríguez-González S: An intelligent Edge-IoT platform for monitoring livestock and crops in a dairy farming scenario. *Ad Hoc Netw,* 98:102047, 2020. DOI: 10.1016/j.adhoc.2019.102047

48. Sundaramoorthi P, Rajeenamol P, Anoopkumar M: Animal health monitoring with missing and theft prevention device using wireless sensor network and internet of things. *Int J Adv Sig Img Sci,* 6 (1): 38-44, 2020. DOI: 10.29284/ijasis.6.1.2020.38-44

49. Shinde TA, Prasad JR: IoT based animal health monitoring with naive Bayes classification. *Int J Emerg Trends Technol,* 4 (2): 252-257, 2017.

50. Gürcan F, Doğru İA, Dörterler M, Atacak İ: Development of internet of things-based rumen health monitoring prototype with fuzzy logic controllers for cattle. *Gazi J Eng Sci (GJES),* 8 (1): 135-149, 2022. DOI: 10.30855/gmbd.2022.01.13

51. Jha S, Taral A, Salgaonkar K, Shinde V, Salgaonkar S: E-cattle health monitoring system using IoT. *J Netw Commun Emerg Technol,* 7 (8): 19-23, 2017.

52. Miller M, Byfield R, Crosby M, Lin J: Networked wearable sensors for monitoring health and activities of an equine herd: An IoT approach to improve horse welfare. *IEEE,* 2023. DOI: 10.36227/techrxiv.24216420

53. Tippannavar SS, Nayak P, Punith G: Smart collar for cattle tracking and health monitoring using IoT on ESP32. *Int J Innov Res Adv Eng,* 10 (3): 81-85, 2023. DOI: 10.26562/ijirae.2023.v1003.06

54. Arshad J, Rehman AU, Ben Othman MT, Ahmad M, Bin Tariq H, Khalid MA, Moosa MAR, Shafiq M, Hamam H: Deployment of wireless sensor network and iot platform to implement an intelligent animal monitoring system. *Sustainability,* 14 (10): 6249, 2022. DOI: 10.3390/

su14106249

55. Katemboh EM, Abdulla R, Jayapal V, Selvaperumal SK, Ratnadurai D: Integrated Animal health care using Iot. *Int J Adv Sci Technol,* 29 (1): 42-56, 2020.

56. Rajendran JG, Alagarsamy M, Seva V, Dinesh PM, Rajangam B, Suriyan K: IoT based tracking cattle health monitoring system using wireless sensors. *Bull Electr Eng Inform,* 12 (5): 3086-3094, 2023. DOI: 10.11591/eei.v12i5.4610

57. Kays R, Tilak S, Crofoot M, Fountain T, Obando D, Ortega A, Kuemmeth F, Mandel J, Swenson G, Lambert T: Tracking animal location and activity with an automated radio telemetry system in a tropical rainforest. *Comput J,* 54 (12): 1931-1948, 2011. DOI: 10.1093/comjnl/bxr072

58. Maphane O, Matsebe O, Namoshe M: Development of electronic control circuits for WSN: Towards a Livestock tracking and identification system. *Am J Eng Appl Sci,* 10 (4): 781-789, 2017. DOI: 10.3844/ajeassp.2017.781.789

59. Ilyas QM, Ahmad M: Smart farming: An enhanced pursuit of sustainable remote livestock tracking and geofencing using IoT and GPRS. *Wirel Commun Mob Com,* 2020:6660733, 2020. DOI: 10.1155/2020/6660733

60. Dieng O, Diop B, Thiare O, Pham C: A study on IoT solutions for preventing cattle rustling in African context. *Proceedings of the Second International Conference on Internet of Things, Data and Cloud Computing (Icc 2017),* 22-23 March, 2017.

61. Maroto-Molina F, Navarro-García J, Príncipe-Aguirre K, Gómez-Maqueda I, Guerrero-Ginel JE, Garrido-Varo A, Pérez-Marín DC: A low-cost IoT-based system to monitor the location of a whole herd. *Sensors,* 19 (10):2298, 2019. DOI: 10.3390/s19102298

62. dos Reis BR, Easton Z, White RR, Fuka D: A LoRa sensor network for monitoring pastured livestock location and activity. *Transl Anim Sci,* 5 (2):txab010, 2021. DOI: 10.1093/tas/txab010

63. Addo-Tenkorang R, Gwangwava N, Ogunmuyiwa EN, Ude AU: Advanced animal track-&-trace supply-chain conceptual framework: An internet of things approach. *Procedia Manuf,* 30, 56-63, 2019. DOI: 10.1016/j.promfg.2019.02.009

64. Agrawal H, Prieto J, Ramos C, Corchado JM: Smart feeding in farming through IoT in silos. Int J Intell Syst Technol Appl, 355-366. Springer, 2016.

65. Saxena S, Shrivastava S, Kumar A, Sharma A: Applications of Internet of Things in animal science. IoT-Based Data Analytics for the Healthcare Industryed., 249-260, Elsevier, 2021.

66. Fakharulrazi AN, Yakub F: Control and monitoring system for livestock feeding time via smartphone. *J Sustain Nat Resour,* 1 (2): 21-26, 2020.

67. Barriuso AL, González GV, De Paz JF, Lozano A, Bajo J: Combination of multi-agent systems and wireless sensor networks for the monitoring of cattle. *Sensors,* 18 (1):108, 2018. DOI: 10.3390/s18010108

68. Quiñonez Y, Lizarraga C, Aguayo R, Arredondo D: Communication architecture based on IoT technology to control and monitor pets feeding. *J Univers Comput Sci,* 27 (2): 190-207, 2021. DOI: 10.3897/jucs.65094

69. Lin YB, Tseng HC: FishTalk: An IoT-based mini aquarium system. *IEEE Access,* 7, 35457-35469, 2019. DOI: 10.1109/Access.2019.2905017

70. Yaşar FN, Barabanshchikova R, Taş İ, Yoğurucu NN: An IoT based feed system for stray animals. IEEE, 2021:2021. DOI: 10.13140/RG.2.2.26049.58723

71. Meshram S, Meshram G, Rokde B, Kapse R, Hedaoo O, Mandhata C: Fish Feeder using internet of things. *Int Res J Eng Technol,* 6, 1680-1682, 2019.

72. Shahriar MS, Smith D, Rahman A, Freeman M, Hills J, Rawnsley R, Henry D, Bishop-Hurley G: Detecting heat events in dairy cows using accelerometers and unsupervised learning. *Comput Electron Agr,* 128, 20-26, 2016. DOI: 10.1016/j.compag.2016.08.009

73. In K, Lee J, Xu Z, Park D, Chung Y, Chang H: Real-time vocalization aquisition and oestrus detection of Korean native cows. *J Korean Inst Infor Technol,* 13 (12): 123-132, 2015.

74. Suthar VS, Burfeind O, Patel JS, Dhami AJ, Heuwieser W: Body temperature around induced estrus in dairy cows. *J. Dairy Sci.,* 94 (5): 2368-2373, 2011. DOI: 10.3168/jds.2010-3858

75. Roelofs J, Lopez-Gatius F, Hunter R, Van Eerdenburg F, Hanzen C: When is a cow in estrus? Clinical and practical aspects. *Theriogenology,* 74 (3): 327-344, 2010. DOI: 10.1016/j.theriogenology.2010.02.016

76. Guo YY, Zhang ZR, He DJ, Niu JY, Tan Y: Detection of cow mounting behavior using region geometry and optical flow characteristics. *Comput Electron Agr,* 163, 2019. DOI: 10.1016/j.compag.2019.05.037

77. Gonzalez-Sanchez C, Sanchez-Brizuela G, Cisnal A, Fraile JC, Perez-Turiel J, Fuente-Lopez ED: Prediction of cow calving in extensive livestock using a new neck-mounted sensorized wearable device: A pilot study. *Sensors,* 21 (23): 8060, 2021. DOI: 10.3390/s21238060

78. Saravanan K, Saranya S: An integrated animal husbandry livestock management system. *J Adv Chem,* 13 (6): 6259-6265, 2017.

79. Lee M: IoT livestock estrus monitoring system based on machine learning. *APJCRI,* 4 (3): 119-128, 2018. DOI: 10.14257/apjcri.2018.09.12

80. Arago NM, Alvarez CI, Mabale AG, Legista CG, Repiso NE, Amado TM, Jorda RL, Thio-ac AC, Tolentino LKS, Velasco JS: Smart dairy cattle farming and in-heat detection through the internet of things (IoT). *Int J Integr Eng,* 14 (1): 157-172, 2022. DOI: 10.30880/ijie.2022.14.01.014

81. Kim H, Oh S, Ahn S, Choi B: Real-time Temperature monitoring to enhance estrus detection in cattle utilizing ingestible bio-sensors: Method & case studies. *JKIIT,* 15 (11): 65-75, 2017. DOI: 10.14801/jkiit.2017.15.11.65

82. Janweerawong W, Prabpal P, Phuphanin A: Algorithm comparison for a cow estrus detection with accelerometer sensor by discrete wavelet transform using microcontroller and MATLAB. *IEET,* 9 (1): 9-12, 2023.

83. Gündüz KA, Başçiftçi F: Collecting information on estrus in cattle using the internet of things. *Arq Bras Med Vet Zoo,* 75 (4): 599-611, 2023. DOI: 10.1590/1678-4162-12940

84. Chanvallon A, Coyral-Castel S, Gatien J, Lamy JM, Ribaud D, Allain C, Clément P, Salvetti P: Comparison of three devices for the automated detection of estrus in dairy cows. *Theriogenology,* 82 (5): 734-741, 2014. DOI: 10.1016/j.theriogenology.2014.06.010

85. Taneja M, Jalodia N, Byabazaire J, Davy A, Olariu C: SmartHerd management: A microservices-based fog computing-assisted IoT platform towards data-driven smart dairy farming. *Software Pract Exper,* 49 (7): 1055-1078, 2019. DOI: 10.1002/spe.2704

86. Thorup VM, Munksgaard L, Robert PE, Erhard HW, Thomsen PT, Friggens NC: Lameness detection via leg-mounted accelerometers on dairy cows on four commercial farms. *Animal,* 9 (10): 1704-1712, 2015. DOI: 10.1017/S1751731115000890

87. Alsaaod M, Fadul M, Steiner A: Automatic lameness detection in cattle. *Vet J,* 246, 35-44, 2019. DOI: 10.1016/j.tvjl.2019.01.005

88. Haladjian J, Haug J, Nüske S, Bruegge B: A wearable sensor system for lameness detection in dairy cattle. *Multimodal Technol Interact,* 2 (2):27, 2018. DOI: 10.3390/mti2020027

89. Kleanthous N, Hussain AJ, Khan W, Sneddon J, Al-Shamma'a A, Liatsis P: A survey of machine learning approaches in animal behaviour. *Neurocomputing,* 491, 442-463, 2022. DOI: 10.1016/j.neucom.2021.10.126

90. Dutta D, Natta D, Mandal S, Ghosh N: MOOnitor: An IoT based multi-sensory intelligent device for cattle activity monitoring. *Sensor Actuat a-Phys,* 333, 2022. DOI: 10.1016/j.sna.2021.113271

91. Tran DN, Nguyen TN, Khanh PCP, Tran DT: An IoT-based design using accelerometers in animal behavior recognition systems. *IEEE Sens J,* 22 (18): 17515-17528, 2022. DOI: 10.1109/Jsen.2021.3051194

92. Wang J, He ZT, Ji JT, Zhao KX, Zhang HY: IoT-based measurement system for classifying cow behavior from tri-axial accelerometer. *Cienc. Rural,* 49 (6):2019, 2019. DOI: 10.1590/0103-8478cr20180627

93. Arcidiacono C, Mancino M, Porto SMC, Bloch V, Pastell M: IoT device-based data acquisition system with on-board computation of variables for cow behaviour recognition. *Comput Electron Agr,* 191:106500, 2021. DOI: 10.1016/j.compag.2021.106500

94. Hang L, Ullah I, Kim DH: A secure fish farm platform based on blockchain for agriculture data integrity. *Comput Electron Agr,* 170:105251, 2020. DOI: 10.1016/j.compag.2020.105251

95. Lee C, Wang YJ: Development of a cloud-based IoT monitoring system for Fish metabolism and activity in aquaponics. *Aquac Eng,* 90:102067, 2020.

DOI: 10.1016/j.aquaeng.2020.102067

96. Chen CH, Wu YC, Zhang JX, Chen YH: IoT-based fish farm water quality monitoring system. *Sensors,* 22 (17):6700, 2022. DOI: 10.3390/s22176700

97. Periyadi P, Hapsari GI, Wakid Z, Mudopar S: IoT-based guppy fish farming monitoring and controlling system. *TELKOMNIKA (Telecommunication Computing Electronics and Control),* 18 (3): 1538-1545, 2020. DOI: 10.12928/telkomnika.v18i3.14850

98. Nocheski S, Naumoski A: Water monitoring iot system for fish farming ponds. *Int Sci J Ind 4.0,* 2, 77-79, 2018.

99. Tamim A, Begum H, Shachcho SA, Khan MM, Yeboah-Akowuah B, Masud M, Al-Amri JF: Development of IoT based fish monitoring system for aquaculture. *Intell Autom Soft Comput,* 32 (1): 55-71, 2022. DOI: 10.32604/iasc.2022.021559

100. Kiruthika SU, Kanaga S, Jaichandran R: IOT based automation of fish farming *J Adv Res Dyn Control Syst,* 9 (1): 50-57, 2017.

101. Gao GD, Xiao K, Chen MM: An intelligent IoT-based control and traceability system to forecast and maintain water quality in freshwater fish farms. *Comput Electron Agr,* 166, 2019. DOI: 10.1016/j.compag.2019.105013

102. Islam MM Kafhem MA, Islam Jui FI Aqua fishing monitoring system using IoT devices. *Int J Innov Sci Eng Technol,* **6 (11):** 108-114, 2019.

103. Khalifa SAM, Elshafiey EH, Shetaia AA, Abd El-Wahed AA, Algethami AF, Musharraf SG, AlAjmi MF, Zhao C, Masry SHD, Abdel-Daim MM, Halabi MF, Kai GY, Al Naggar Y, Bishr M, Diab MAM, El-Seedi HR: Overview of bee pollination and its economic value for crop production. *Insects,* 12 (8):688, 2021. DOI: 10.3390/insects12080688

104. Human H, Nicolson SW, Dietemann V: Do honeybees, *Apis mellifera scutellata,* regulate humidity in their nest? *Naturwissenschaften,* 93, 397-401, 2006. DOI: 10.1007/s00114-006-0117-y

105. Cecchi S, Spinsante S, Terenzi A, Orcioni S: A smart sensor-based measurement system for advanced bee hive monitoring. *Sensors,* 20 (9):2726, 2020. DOI: 10.3390/s20092726

106. Ammar D, Savinien J, Radisson L: The makers' beehives: Smart beehives for monitoring honey-bees' activities. *Proceedings of the 9th International Conference on the Internet of Things.* 22-25 Oct, 2019.

107. Hong W, Xu BH, Chi XP, Cui XP, Yan YF, Li TY: Long-term and extensive monitoring for bee colonies based on internet of things. *IEEE Internet Things J,* 7 (8): 7148-7155, 2020. DOI: 10.1109/Jiot.2020.2981681

108. Poposki R, Gjorgjevikj D: Precision apiculture-IoT system for remote monitoring of honeybee colonies. *17th International Conference on Informatics and Information Technologies,* 8-10 May, 2020.

109. Kviesis A, Zacepins A, Fiedler S, Komasilovs V, Laceklis-Bertmanis J: Automated system for bee colony weight monitoring. *Agrofor,* 5 (2):2020, 2020. DOI: 10.7251/AGRENG2002044K

110. Evans JD, Chen Y: Colony collapse disorder and honey bee health. **In,** Kane TR, Faux CM (Eds): Honey Bee Medicine for the Veterinary Practitioner. 229-234, Wiley, 2021.

111. Bjerge K, Frigaard CE, Mikkelsen PH, Nielsen TH, Misbih M, Kryger P: A computer vision system to monitor the infestation level of *Varroa destructor* in a honeybee colony. *Comput Electron Agr,* 164:104898, 2019. DOI: 10.1016/j.compag.2019.104898

112. Bak B, Wilk J, Artiemjew P, Wilde J, Siuda M: Diagnosis of varroosis based on bee brood samples testing with use of semiconductor gas sensors. *Sensors,* 20 (14):4014, 2020. DOI: 10.3390/s20144014

113. Zgank A: IoT-based bee swarm activity acoustic classification using deep neural networks. *Sensors,* 21 (3):676, 2021. DOI: 10.3390/s21030676

114. Ngo TN, Rustia DJA, Yang EC, Lin TT: Honey bee colony population daily loss rate forecasting and an early warning method using temporal convolutional networks. *Sensors,* 21 (11):3900, 2021. DOI: 10.3390/s21113900

115. Cota D, Martins J, Mamede H, Branco F: BHiveSense: An integrated information system architecture for sustainable remote monitoring and management of apiaries based on IoT and microservices. *J Open Innov: Technol Mark Complex,* 9 (3):100110, 2023. DOI: 10.1016/j.joitmc.2023.100110

116. Tashakkori R, Hamza AS, Crawford MB: Beemon: An IoT-based beehive monitoring system. *Comput Electron Agr,* 190:106427, 2021. DOI: 10.1016/j.compag.2021.106427

117. Ahmadi MR, Hussien NA, Smaisim GF, Falai NM: A survey of smart control system for poultry farm techniques. *Proc of the International Conference on Distributed Computing and High Performance Computing (DCHPC2018).* 25-27 Nov, 2018.

118. Huang J, Wang W, Zhang T: Method for detecting avian influenza disease of chickens based on sound analysis. *Biosys Eng,* 180, 16-24, 2019. DOI: 10.1016/j.biosystemseng.2019.01.015

119. Feiyang Z, Yueming H, Liancheng C, Lihong G, Wenjie D, Lu W: Monitoring behavior of poultry based on RFID radio frequency network. *Int J Agric Biol Eng,* 9 (6): 139-147, 2016. DOI: 10.3965/j.ijabe.20160906.1568

120. Zhuang X, Bi M, Guo J, Wu S, Zhang T: Development of an early warning algorithm to detect sick broilers. *Comput Electron Agr,* 144, 102-113, 2018. DOI: 10.1016/j.compag.2017.11.032

121. Astill J, Dara RA, Fraser ED, Roberts B, Sharif S: Smart poultry management: Smart sensors, big data, and the internet of things. *Comput Electron Agr,* 170:105291, 2020. DOI: 10.1016/j.compag.2020.105291

122. David B, Mejdell C, Michel V, Lund V, Oppermann Moe R: Air quality in alternative housing systems may have an impact on laying hen welfare. Part II-Ammonia. *Animals,* 5 (3): 886-896, 2015. DOI: 10.3390/ani5030389

123. Gebregeziabhear E, Ameha N, Zeit D, Dawa D: The effect of stress on productivity of animals: A review. *J Biol Agric Healthcare,* 5 (3): 165-172, 2015.

124. Najafi P, Zulkifli I, Amat Jajuli N, Farjam AS, Ramiah SK, Amir AA, O'Reily E, Eckersall D: Environmental temperature and stocking density effects on acute phase proteins, heat shock protein 70, circulating corticosterone and performance in broiler chickens. *Int J Biometeorol,* 59, 1577-1583, 2015. DOI: 10.1007/s00484-015-0964-3

125. Jácome I, Rossi L, Borille R: Influence of artificial lighting on the performance and egg quality of commercial layers: a review. *Brazil J Poult Sci,* 16, 337-344, 2014. DOI: 10.1590/1516-635X1604337-344

126. Pereira WF, Fonseca LD, Putti FF, Góes BC, Naves LD: Environmental monitoring in a poultry farm using an instrument developed with the internet of things concept. *Comput Electron Agr,* 170, 2020. DOI: 10.1016/j.compag.2020.105257

127. Lashari MH, Memon AA, Shah SAA, Nenwani K, Shafqat F: IoT based poultry environment monitoring system. *2018 IEEE International Conference on Internet of Things and Intelligence System (IOTAIS).* IEEE, 01-03 Nov, 2018.

128. Ahmed G, Malick RAS, Akhunzada A, Zahid S, Sagri MR, Gani A: An approach towards IoT-based predictive service for early detection of diseases in poultry chickens. *Sustainability,* 13 (23):13396, 2021. DOI: 10.3390/su132313396

129. Lufyagila B, Machuve D, Clemen T: IoT-powered system for environmental conditions monitoring in poultry house: A case of Tanzania. *Afr J Sci Technol Innov Dev,* 14 (4): 1020-1031, 2022. DOI: 10.1080/20421338.2021.1924348

130. Zhang Y, Chen QY, Liu GT, Shen WZ, Wang GL: Environment parameters control based on wireless sensor network in livestock buildings. *Int J Distrib Sens Netw,* 12 (5): 2016, 2016. DOI: 10.1155/2016/9079748

131. Li H, Wang H, Yin WQ, Li YW, Qian Y, Hu F: Development of a remote monitoring system for henhouse environment based on IoT technology. *Future Internet,* 7 (3): 329-341, 2015. DOI: 10.3390/fi7030329

132. Vigneswari T, Kalaiselvi N, Mathumitha K, Niveditha A, Sowmian A: Smart IoT cloud based livestock monitoring system: A survey. *TURKOMAT,* 12 (10): 3308-3315, 2021.

133. El Moutaouakil K, Jdi H, Jabir B, Falih N: Digital Farming: A Survey on IoT-based Cattle Monitoring Systems and Dashboards. *AGRIS On-line Pap Econ Inform,* 15 (2): 31-39, 2023. DOI: 10.22004/ag.econ.337998

134. Kim MJ, Mo C, Kim HT, Cho BK, Hong SJ, Lee DH, Shin CS, Jang KJ, Kim YH, Baek I: Research and technology trend analysis by big data-based smart livestock technology: A review. *J Biosyst Eng,* 46, 386-398, 2021. DOI:

10.1007/s42853-021-00115-9

135. Alleri M, Amoroso S, Catania P, Lo Verde G, Orlando S, Ragusa E, Sinacori M, Vallone M, Vella A: Recent developments on precision beekeeping: A systematic literature review. *J Agr Food Res,* 14:100726, 2023. DOI: 10.1016/j.jafr.2023.100726

136. Abdollahi M, Giovenazzo P, Falk TH: Automated beehive acoustics monitoring: A comprehensive review of the literature and recommendations for future work. *Appl Sci,* 12 (8):3920, 2022. DOI: 10.3390/app12083920

137. Mazunga F, Mzikamwi T, Mazunga G, Mashasha M, Mazheke V: IoT based remote poultry monitoring systems for improving food security and nutrition: Recent trends and issues. *J Agric Sci Technol,* 22 (2): 4-21, 2023.

138. Ojo RO, Ajayi AO, Owolabi HA, Oyedele LO, Akanbi LA: Internet of things and machine learning techniques in poultry health and welfare management: A systematic literature review. *Comput Electron Agr,* 200:107266, 2022. DOI: 10.1016/j.compag.2022.107266

139. Prapti DR, Mohamed Shariff AR, Che Man H, Ramli NM, Perumal T, Shariff M: Internet of Things (IoT)-based aquaculture: An overview of IoT application on water quality monitoring. *Rev Aquac,* 14 (2): 979-992, 2022. DOI: 10.1111/raq.12637