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REVIEW ARTICLE

Internet of Things in Animal Healthcare (IoTAH): Review of Recent Advancements in Architecture, Sensing Technologies and Real-Time Monitoring

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Abstract
In recent days, the Internet of Things (IoT) used to connect many devices and communicate with each other, which created a greater impact on animal healthcare systems. IoT devices are in the form of wearable's that have been used to track the activities of humans. Now, the wearable devices are used in monitoring the activities of the animals. Internet of Things in Animal Healthcare (IoTAH) uses the biosensors and software for monitoring and maintaining the animal health records. These kinds of technologies make a precise health status and sickness projection which are most effective in humans but it can be applied to animals with few changes. Some of those recent technologies acquired the importance of their use in animal healthcare and development. The integration of available medical sensors creates a connected digital platform that empowers the connectivity with pets and livestock with improved efficiency. This article describes the scope of biosensors, computing, communicating, and wearable technologies available for animals. The main intention of this article is to review the recent advancements in the field of animal healthcare which includes domestic, farm, and wild animals. This article reviews the smart technologies available for various categories of animals. The outcomes of this survey are expected to improve the future research and development of animal welfare systems.

Keywords Internet of Things · Internet of Things in Animal Healthcare · Wearable devices · Sensors · Smart dairy · Livestock monitoring · Tracking

Introduction

The Internet of Things (IoT) has created a remarkable diversion among research community, public and industries. The traditional communication facilities are only between the limited number of devices and persons whereas; IoT interconnects all variety of things together to form a comprehensive intelligent computing network to act autonomously without human intervention. The merging of IoT technologies and wireless technologies enables the animal caregiver to monitor the health status of animals anywhere. Nowadays, engineering and sensing research together are decreasing the cost of electronic devices and resulted in the introduction of bio-sensing solutions and intelligent computing techniques which comprise cloud resources and internet connectivity to build cyber-physical systems [1]. These cyber-physical systems are facilitated to autonomously acquire the data like physiological parameters, dairy farm environment, yield measurement, and behavioral features. Similarly, electronic devices have become an essential part of human lives which are connected together and interact with each other. IoT devices are self-realizing which are facilitated with machine-readable identification and it can transmit data over the network without human intervention. Smart sensors are the key enabler of IoT which consumes low power. Smart sensors and communication have become predominant factors that

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transform the upcoming generation communication, sensing, and computing technologies and devices. The smart systems are connected together with a wide range of internet and cloud-oriented applications can collect, process, exchange and analyze the data. These technologies create greater societal and economic benefits in diversified areas. Though, the principles of IoT are still evolving and as many fields have adopted the supreme power of IoT with their traditional system and observed the improvement in productivity as well as effectiveness.

One of the important areas which benefit from smart technologies is animal healthcare. The animal healthcare smart systems are an integration of biosensors for building a capable animal health monitoring in real time.

In general, the IoTAH framework would consist of sensing unit, data transfer, and data center. In the sensing unit, the data gathered from the wearable animal health monitoring systems, which have incorporated sensors to extract the vital signs of a particular animal. Then, the data transfer unit communicates the sensed data to the data center via the gateway of wireless communication medium. In the data center unit, data received from the gateway are indulged in analysis and visualization. The data center provides dashboard functionality for users to view the real-time conditions of animal health. Real-time data are stored in the cloud storage which can be retrieved and used in the future. Figure 1 depicts the IoTAH general framework.

The livestock monitoring scenario is highly influenced by IoT, which results in avoiding losses. For example, most of the animal healthcare monitoring systems are in the form of wearables that use low-bandwidth communication technology for transmitting the data to the cloud. The wearable can monitor the blood pressure, heart rate, respiratory rate, and other vital signs which enables the caregivers to prevent the animals from severe illness. The IoT in animal healthcare is an upcoming paradigm and involves the combination of a variety of latest techniques along with its challenges. Those challenges can be prevailed by concentrating on the basic principles, particular application, and identification of limitations. The aim of the article is to offer a novel critical review about the role of IoT in animal healthcare, with respect to the following objectives:

- Provide an outline of the current scenario of IoT technologies in animal healthcare.
- The limelight of the proposed architecture for IoTAH with the usage of communication and routing protocols.
- Overview of the different applications of sensors and technologies in IoTAH.

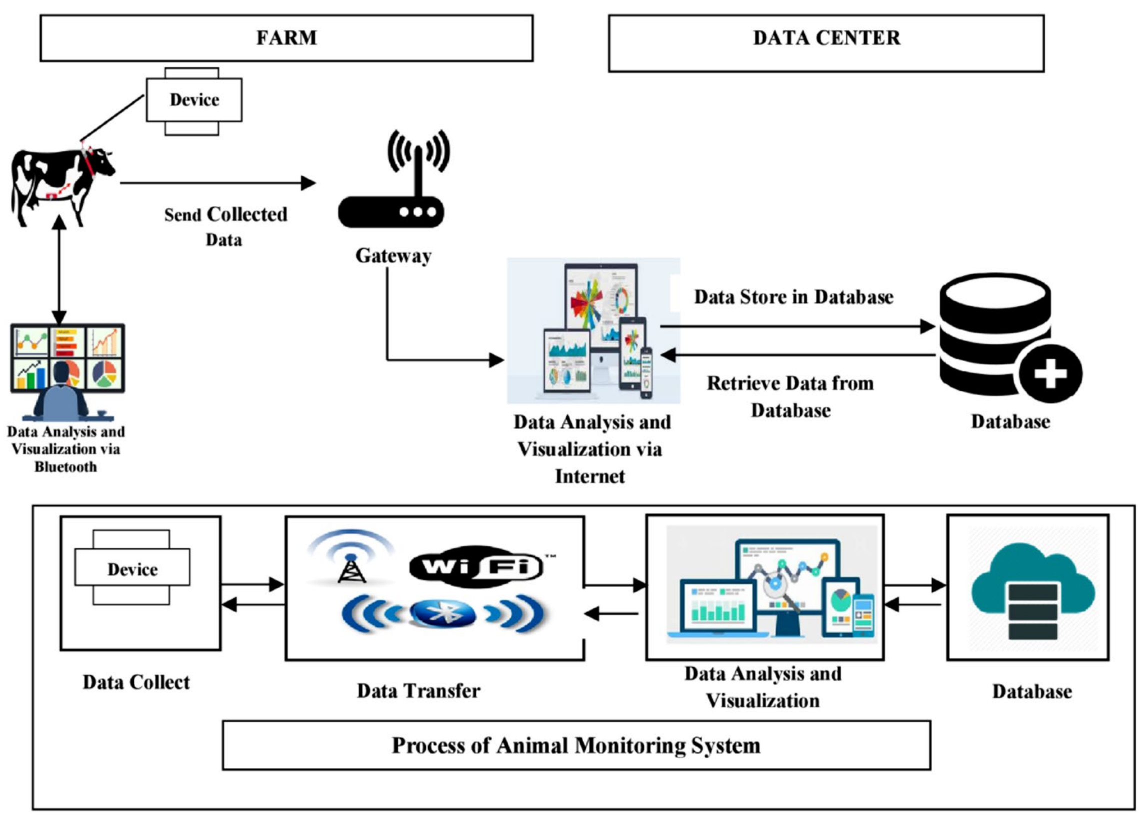


Fig. 1 General framework of IoTAH system

- Examine the major challenges encountered when adopting IoT technologies to animal healthcare.
- Present the future research direction in the field of IoTAH.

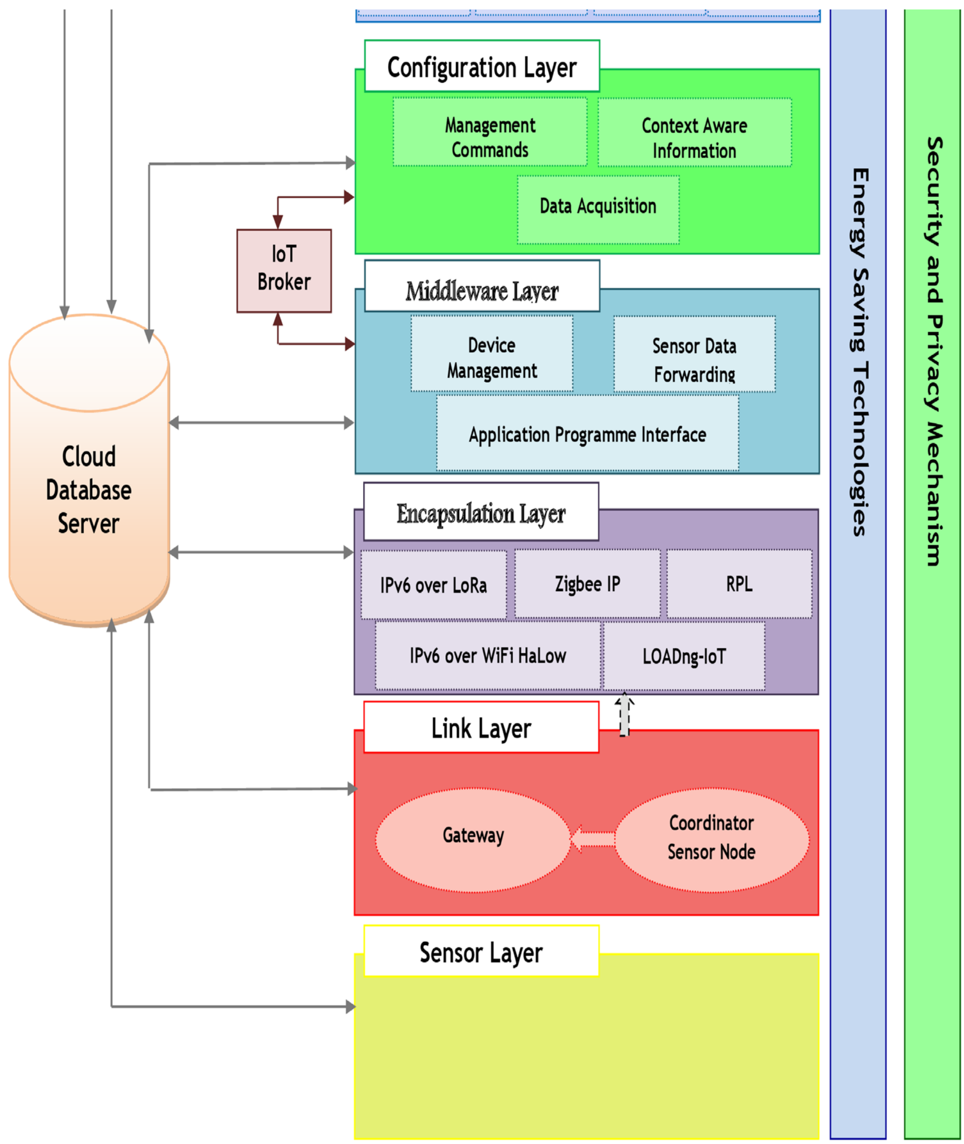
The findings of this review explain the smart technologies which are promising and economically feasible to ensure animal healthcare. The paper is organized as follows: Part II deals with the general architecture of IoTAH and summarizes the principles. Part III presents the sensor and innovative technologies used in the healthcare management of the animals against three broad categories. Part IV is intended to disclose the impacts of IoT on animal healthcare systems. Finally, part V concludes the review article and depicts the future directions for research.

IoTAH Smart Architecture

An IoTAH system generally comprises the location extraction of animals, sensing the health parameters, and data acquisition, transferring the data from animals to the central station for inferring the useful decision and actuating the system based on the decision inferred. In this article, the architecture proposed for IoTAH follows the OSI model, which includes seven layers. Though, the applications of IoT technologies and artificial intelligence abilities are defined into the layers of IoTAH smart architecture in Fig. 2.

Sensor layer (SL): This layer resembles the physical layer of the OSI reference model, which includes various healthcare sensors and smart wearable devices for data acquisition and real-time monitoring. The healthcare sensors can be placed on the animal body parts either in the form of

Fig. 2 IoTAH smart architecture



wearable or non-wearable devices. The sensors used for feeding and water intake monitoring are specially made as water-resistant and the environmental factors that can be measured are temperature, moisture, humidity, and solar radiation. Apart from this, thermal cameras are facilitated by vision imaging that is placed in the herd for detecting the heat released from objects and devices.

Link layer (LL): This layer refers to the data link layer of the OSI model, comprises communication and routing protocols for data transmission from sensor nodes. The modeling of efficient animal healthcare management, IoT technology utilizes wireless sensor networks (WSN). In IoTAH, WSN offers real-time monitoring and predicts the illness of animals, through which potential clinical intervention can be provided with high accuracy. The continuous monitoring of animals along with the environmental factors helps to sustain the optimal condition to increase productivity with the effective use of resources. Table 1 compares the communication technologies used in IoTAH systems.

Encapsulation layer (EL): This layer is similar to the network layer of the OSI model, which establishes the communication between the sensors to the external network. It offers encapsulation methods and routing protocols to regularize the network traffic. The EL enables the animal herd sensory data to be bound with IPv6 network packets and transferred to the cloud server.

Middleware layer (ML): In this layer, transport protocols of various application levels are used to forward the data originated from the IoTAH sensors and smart devices. ML also offers an interface for enabling actuation operations and also this layer has the capability of interoperability, as IoTAH comprises diversified standards of components.

Configuration layer (CL): This layer incorporates the functionalities of the session and presentation layers, which link the middleware and management layers. CL does the job of acquiring the sensory data from the smart devices, synchronize and aggregate them at a sink node, then the data can be transformed as context-aware information or the data allowed to stream for processing. This layer generates the actuation commands based on the processed data and distributed to the middleware layer.

Management layer (MGL): The MGL is responsible for processing and analyzing the raw sensory data and the efficient machine learning techniques are integrated for accurate prediction of abnormalities in animal's behavior and health conditions. It acts as a decision-support system for IoTAH that increases productivity, optimizes the dairy yields, offers animal health services, and reduces the resources utilized. Data analytics is the major component of IoTAH systems resulting in accurate prediction of diseases and offers remote intervention. Table 2 narrates the different services and software technologies used in the management layer.

Application layer (AL): This layer offers interfaces for implementing feed control, disease prediction, notification triggering upon the abnormal status of an animal. In addition, the farmer can monitor and maintain the herd or field efficiently. To enrich the user-friendliness, more visualization techniques can be incorporated which include heatmaps, graphs, two-dimensional and three-dimensional modeling.

IoTAH Sensing Technologies and Real-Time Monitoring

The study follows the definition provided in [1] where the animal healthcare is an interdisciplinary study of animal health science and animal computer interaction. The review has been conducted based on the four primary factors, such as communication, health, location, and monitoring. Communication denotes the smart systems that allow humans to communicate with animals. The major aspect of communication is to exchange the captured data and storing it remotely for further analysis. The health factor indicates the monitoring of animal health via smart systems and the monitoring refers to the remote observation of animal behavior. The location relates to where the animals are monitored and it can be either indoor or outdoor.

Animals are divided into three major groups which are domestic animals, farm-based animals, and wild animals. Domestic animals may include pets and other trained animals that serve humans. Then the farm-based animals are nurtured for animal products and used for farming purposes.

Table 1 Comparison of communication technologies used in IoTAH systems

Technologies	Data speed	Frequency band	Coverage	Limitation
IEEE 802.15.4	20–250 Kbps	2400/915/868 MHz	10 m	Low data rate
ZigBee	20–250 Kbps	2400/915/868 MHz	10–100 m	Low data rate, high interference
GPRS-2G	64 Kbps	900–1800 MHz	1–10 kms	Low data rate
3G	14.4 Kbps–2 Mbps	1.6–2 GHz	1–10 kms	Costly spectrum
Z-wave	40 Kbps	908.42 MHz	30 m	Low data rate, high interference
WiMax	75 Mbps	2.5/3.5/5.8 GHz	10 kms	Demand response
Bluetooth	1 Mbps	2.4–2.485 GHz	< 100 m	Short range
RFID	400 Kbps	125 KHz–915 MHz	3 m	Short range, low data rate

Table 2 Management layer tools and nature of services

Nature of service	Software tools	Narration
Data administration/information management	Database	The sensor data acquired from heterogeneous sources, data management commands, and user access information were stored in central database storage
	Process/admin logic	The process of visualizing the evaluated data in a user understandable form based on the management logical units
Data analytics	Hadoop framework	The process of investigating huge data with a target to unleash the meaningful insights which can assist in drawing the conclusion
	Big data platform	The platform for big data analytics highly depends on hardware scalability and platform characteristics
Data and image processing	Digital image processing	Dairy farm evaluation using indexes
	Machine learning classification algorithms	Removing the redundant information and classifying the data with specific applications
Data mining	Apache mahout framework	The process of detecting the hidden information or pattern from a large amount of data systematically
	Object analysis	The behavioral changes of animals can be predicted through the analysis of dairy farm images

The wild animals depend on the natural habitation which lives in zoos or sanctuaries.

Domestic Animals

This section deals with the analysis of domestic animals based upon the various distinguished factors which are treated individually. In Ref. [2], a prototype has been designed for human-to-dog communication which used the smartphone adapted to the dog. This system consists of communication facilities and sensing capabilities that include smelling, hearing, vibration, and touching. An exclusive platform is developed for pet animals in Ref. [3], which enables humans to monitor the activity of animals via RFID tags and the activity data automatically posted on social media. A system has been designed to deduce the postures and behaviors of dogs in natural environments. It also analyses the food intake habits and sleeping patterns via wearable systems [4]. Table 3 shows the various technologies used in IoTAH systems for domestic animals.

In Ref. [5], the authors integrated the accelerometer and gyroscope as a sensing device with the help of wireless sensor networks (WSN), and also the device uses machine learning algorithms to deduce various dog postures. The authors proposed algorithms for the interpretation of dog postures and also for non-domestic mammals in [9, 20]. A sensor-oriented system has been designed to communicate the dog to humans which incorporates the sensors and global positioning system (GPS). This system is capable of sending triggers to the users immediately upon the predefined situation [18]. The author has designed the wearable jacket for monitoring the health of the dogs and analyzing the health data. Table 4 illustrates the various categories of application, data gathered, and sensing systems used on domestic animals.

Table 3 Various sensing technologies used in IoTAH systems for domestic animals

Sensing technologies used	Systems proposed for domestic animals
Accelerometers	[4–9]
Gyroscopes	[5, 8]
Video	[8, 10–14]
Audio	[11–13, 15]
Animal health sensors	[7, 12, 15]
Microcontroller/SoC	[4, 5, 7, 8, 12, 14, 16]
Wireless mesh/WiFi	[7, 8, 12, 17]
Bluetooth	[5–7]
GPS	[8, 11, 12, 18]
RFID	[3]
Behavior detection system	[4, 5, 8, 12, 17, 19–21]

The analysis of animal sweat reveals the high degree of medical information and assists in inferring the health condition of individual animals [28–33]. The size of the sweat analyzers has not yet standardized and it is being developed with robustness by the researchers [34, 35]. Many research studies have made on sweat analyzers with respect to the minimization of size, which is shown in Table 5. The microfluid chip-integrated potentiometric-based strips have developed for real-time monitoring of sodium excretion via skin, and the level of sodium in the sweat was communicated using the wireless medium [36]. Gao et al. designed a Bluetooth-enabled non-invasive biomonitoring system which comprised potassium, sodium, glucose, and skin temperature sensors [30]. The adoption of these technologies into the

Table 4 Various categories of application and sensing systems used on domestic animals

Applications	References	Data aggregated	Wearable
Human-animal communication	[22–24]	Location, postures, and orientations	Pet jacket
Tracking and behavior monitoring	[2, 4, 25–27]	Postures, sleeping and eating patterns Walking and mounting stairs	Wireless accelerometer and gyroscope Motion sensor GPS sensors, RFID tags Speakers on the harness
Animal health	[7]	Heart rate (HR) Heart rate variability (HRV) Respiratory rate Vital signs	Electrocardiogram (ECG), photoplethysmogram (PPG) sensors and inertial measurement units (IMU)
Working dogs	[6, 8, 10–12, 17]	Continuous barking detection, posture detection Animal vital signs detection	Wearable wireless cameras Microphone, speakers, GPS Gas sensors EKG and PPG sensors

Table 5 Outline of sensory approaches used in sweat analysis

Bio-marker	Analysis methodology	Analytes and inference	References
Sweat	Conductometric sensor with impedance metering system	The concentration of pH, Na+, and Cl− are analyzed that helps in clinical monitoring of cystic fibrosis in animals	[28]
Sweat	Fringing field sensors integrated sweat analyzing multi-device	Monitors the glucose level in the sweat and assist in diabetes monitoring	[28]
Sweat	The miniaturized device with amperometric sensor and microprocessor	Detect the amount of ethanol content in the sweat	[28]
Sweat	Electro chemi-luminescence (ECL) biosensor integrated mini device	Determines the aerobic to anaerobic metabolic conditions	[28]
Sweat	Potentiometric sensory device	Analyze and determine the amount of ammonium, pH and Na+	[28]
Sweat	Amperometric sensory device	Determines metabolic conditions using lactate analysis	[28]
Sweat	Sensor array integrated multiplexed device for perspiration analysis	Detects glucose, lactate, sodium, potassium ions, and also monitors the skin temperature	[30]
Sweat	Electrochemical sensor inbuilt wearable device	Detects the zinc level	[39]

farm fields may change the way of animal health monitoring and also avoids the loss of animals due to health issues.

Farm-Based Animals

In divergence to domestic animals, farm-based animal's needs typical farm settings which are raised for the commercial effectiveness of the products yield by them may include eggs, dairy, meat, and leather [37, 38]. The implementation of smart systems in this domain will give rise to economic growth. This section deals with the review of smart technologies applied for farm-based animals. A system has been presented in Ref. [40], which monitors the health status of the cattle remotely and a veterinary e-medicine infrastructure contains wearable sensors and bluetooth. A similar system has been identified in Ref. [41], which uses accelerometer and magnetometer to monitor heartbeat rate and activity of the cattle. A ZigBee-based wireless sensor network system has been proposed in Refs. [42] and [43], which detects the animal body temperature and movements. A system in Ref. [44] provided a solution for identifying lameness in cows that uses camera sensors to predict curve formation. In Ref. [45], a climate monitoring and control system was developed to enhance the comfort level of farm-based indoor animals.

Most of the above studies focus on cattle, where many of the works have been found on other types of species. A growth monitoring and climate control system in Ref. [46] focuses on the growth of pig via climate adjustments. This system consists of GPRS system, temperature sensor, humidity sensor, and light intensity sensor. TinyOS-based sensor system has been developed for monitoring the welfare of pigs by measuring the body temperature and various ambient parameters [47]. Another porcine health monitoring system is identified in Ref. [48], which detects the respiratory rate and implements an image processing technique for measuring the abdominal activity of the pig with the support of cameras and sensors. The system presented in Refs.

[49, 50] monitors the cattle behavior with simulators and screens the diseases in cows. The system designed in Refs. [51–54] can be categorized as animal activity and inactivity monitoring systems which incorporate the accelerometer and magnetometer to predict the head posture and angle of cows. A different work has been identified in Ref. [55] which detects the diseases or pregnancy in cows. Table 6 depicts the various applications and technologies used in farm-based animal healthcare.

Precision Livestock Farming

The important application of IoT is precision livestock farming (PLF), which renovated the field of the livestock industry and anticipated towards animal healthcare. Such kinds of systems accompany the advantages and guarantee the utilization of entire resources for monitoring the health of animals. Therefore, PLF increases productivity even under diverging environment, through real-time monitoring of animals as shown in Table 7. This system assimilates the sensing and computing technology that ensures the data acquired through continuous measurements can assist the farmers in the decision-making process with respect to farming and cattle management.

Smart Diary Farming

Smart dairy farming is one of the prominent concepts which incredibly persuade the increasing demand for dairy products. This reduces the negative impacts on environment, optimizes the resource use and monitors the animal health with the support of sensing and sensor data analytics. In the past, there was a dissimilarity between the dairy production and beef production but high degree of care was bound to yield large amount of milk. Table 8 depicts the major causes for low milk yield and solutions offered to overcome the drawback in the literature. The classification analysis of sensors widely used in smart dairy farming is elaborated in Fig. 3.

In this case, IoT assists the farmers using wearable devices that keep track and monitors the status of the individual cow. IoT systems perform efficiently and accurately in the process of detecting the problems in cows prior to the reduction in milk production. The smart diary caregiver is responsible for placing the wearable devices onto the cow's body part, such as ear, neck, or legs, for gathering the real-time sensory data. Then, the real-time data can be analyzed for inferring useful insights like cows activity detection, behavioral changes prediction, disease prediction, feed consumption, and prediction of low milk yields [79]. In

Table 7 Technologies used in precision livestock farming

Precision livestock farming technologies	References
Cattle monitoring and behavior tracking system	[66–68]
Vision oriented system for weight assessment of pigs	[69]
Animal respiratory infection detection system for cough analysis using audio and video data	[70, 71]
Analysis of sounds for tracking the behavior	[72]
Pig scream identification	[73]
Stress prediction in laying hens	[74]
Evaluation of thermal comfort for chick using noise analysis	[75]
Progesterone identification using the sensory device	[76]
Cows pregnancy detection using wireless monitoring of body temperature and behavioral changes	[77]

Table 6 Various applications and technologies used in farm-based animal healthcare

Farm-based animal type	Application type	References	Technologies used
Cattle	Health monitoring	[42–44, 56]	Wearable sensors, cameras, ZigBee
	Activity and tracking	[57]	Cows equipped with active transponders, GPS receivers, accelerometer and magnetometer
	Dairy production	[41]	Heart rate monitoring, magnetometer, accelerometer for activity
	Ambient monitoring	[55]	Accurate climate control through sensors, feed and fluid monitoring
Pigs	Ambient monitoring	[46, 58–60]	Sensors to monitor temperature, humidity, air-cooling, light intensity
	Meat production	[61]	ZigBee, RFID tags
	Porcine health	[48, 49]	Image processing used to measure The abdominal movement of a pig Level of animal stress
Hens	Ambient monitoring	[62, 63]	Humidity, temperature, climate quality sensors And wearable RFID tags
	Activity monitoring	[64]	Body-mounted accelerometers
Rabbit	Ambient monitoring	[65]	Temperature sensors mounted Inside rabbit cage

Table 8 Causes for low milk production and its solutions

Smart diary farming issue type	Cause	Solutions
Healthcare	Many studies have revealed that healthy cows can able to produce a high quantity of milk and also the milk yield is proportionally influenced by cow's weight. Therefore balancing the weight and health of cows is an essential factor [78–80]	Individual data analysis and context-aware inference [81]
	Mastitis is also identified as an important cause for reduction in milk yield. It is a kind of bacterial disease which affects the udder part cow and multiplies inside the milk tissues [79, 82, 83]	Detection of udder disease using intelligent milking claws [81, 83]
Feed and nutrition	The key substances of cows feed to improve the milk production ratio are calcium, sodium, potassium, chlorine, magnesium, and sulfur [77, 79, 84]	Automatic real-time monitoring of nutritional contents in the feed [81]
	The water content of milk will be 85% and also the research studies show that insufficient water intake may reduce milk production [85, 86]	Thirsty observation and automatic water supply [81, 86]
Atmosphere and hygiene management	The stress-free nature and cleanliness of dairy cows can increase milk production and also improves the nutritional content of milk. Congested and greasy floor are the two significant causes for creating discomfort in cows and also decreases the milk yield [87–89]	Continuous monitoring of behavioral changes [81, 90]

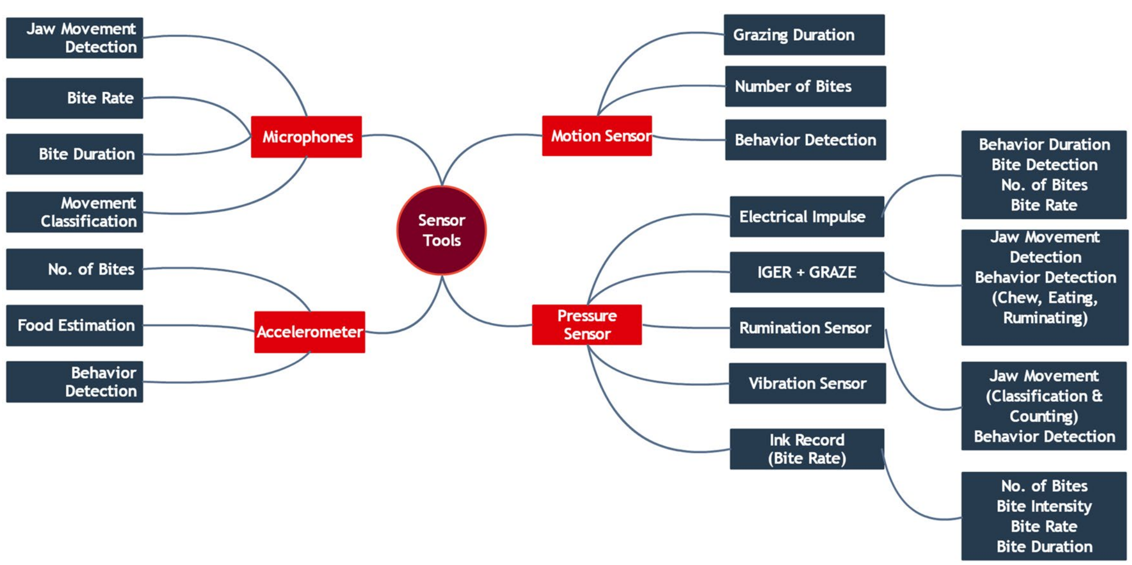


Fig. 3 Mindmap of sensor tools used in smart dairy farming for animals health monitoring

this fast-growing world, a huge number of issues and constraints have been experienced by the dairy farmers, which are herd maintenance, fixed dairy production, and expensive human resources. Table 9 depicts the comparative analysis of research studies on smart dairy farms.

The previous section focused on how the cow's health condition affects dairy production and how it can be tracked by the clinical signs using sensing technology. The behavior of animals may also be a symptom or a sign of disease which are analyzed and presented in Table 10. The table depicts the mapping of health clause with the appropriate sensors that detect the behavioral changes due to diseases.

Table 9 Comparative analysis of research studies made on smart dairy farms

Research studies	Cow observation		Smart monitoring		Feeding		Milking	
	Fog computing platform	Wearable and non-wearable devices	Decision support systems	Smart herd	Efficient feeding using ontology	Feed watching technique	Automated milking	Haar-cascade classifier
[91]					Yes			
[92]	Yes			Yes				
[92]		Yes						
[93]								
[94]	Yes							
[95]						Yes		
[96]					Yes			
[97]			Yes			Yes		
[98]			Yes				Yes	
[99]			Yes					Yes
[100, 101]								

Table 10 Mapping of health clause with behavioral changes

Diseases	Sensors	Health clause	Behavioral changes
Fever	Temperature sensor	Temperature	Abnormal temperature
	Accelerometer	Discomfort	Less activity
	Microphone	Abnormal mooing	Mooing
Lameness	Accelerometer	Motion changes	Lying or standing
	Load sensor	–	Less grazing
	GPS	–	Abnormal back arch
Oestrus	Accelerometer	Imbalanced hormone level	–
Mastitis	Accelerometer	Low milk yield	Behavioral changes
Ovarian cyst	Pressure sensor	Low milk yield	Less/more grazing
	Temperature sensor	Temperature	Abnormal body temperature
	Electrical conductivity sensor	Milk quality	Electrical conductivity
Ketosis	Accelerometer	Breath ketones	Grazing
	Microphone	–	Eating/rumination
	Gas sensor	–	Abnormal levels of VOC in breath
	Accelerometer	No movement	Stiffness
	Microphone	Abnormal mooing	Mooing
	Load sensor	Weight	Weakness
	Temperature sensor	Fever	High temperature
	Pulse sensor	Heart rate	Abnormal heart rate
Heifer pneumonia	Microphone	Cough	Coughing sound
	Microphone	Increased respiratory rate	Whistling sound during breath
	Accelerometer	Decreased appetite	Less grazing/feeding

Wild Animals

The technology with ultra-low weight and extremely low battery power consumption is designed to establish the protection and scientific research of wildlife behavior and monitoring its physical characteristics through wireless sensor networks. To deal with wild animal behavior and face various environmental conditions, the systems are designed and built to deal with intermittent connectivity. An additional category of recent work proposes a more genetic IoT technology framework, as the development of wireless sensor networks moves towards more diversity, including cellular networks, substitute versions of radio technologies. The limited bandwidth of wireless sensor networks leads to visual sensing through cameras and has not been deployed to reach their full potential like visual recognition and in situ image processing.

In some scenario, IoT has applied successfully to the ecology of specific wild species with various research goals like disease prediction, techniques for processing the sensor data, and remote surveillance. IoT devices entailed the concurrent task of numerous information engineering methods implemented to the wildlife principles, which consist of complex network as shown in Fig. 4. The process of complex network is to detect the signal, processing and inferring the insights at server site and therefore, the researchers and caregivers can take optimal decisions.

Tracking

Before the development of the internet, human curiosity and fascination with nature motivate the research in wild animal tracking. Nowadays, technology allows to process real-time and long-term data and continuous analysis into the animal classes. Tracking devices are designed with an acceleration sensor to find the exact position and track the motion of the animal. The adoption of existing technologies with

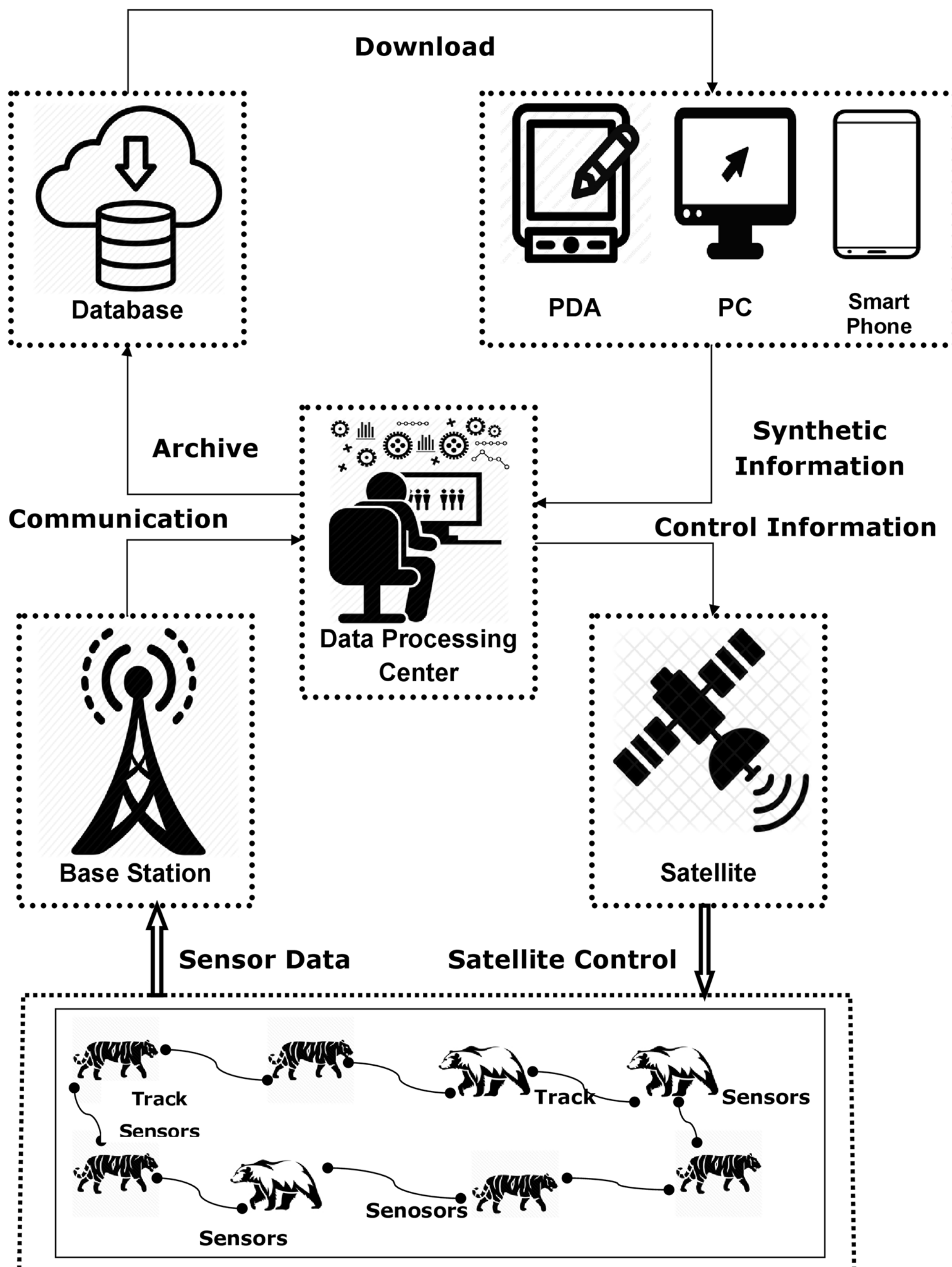


Fig. 4 Wild animal and environment monitoring using IoT

animal behavior leads to the innovation of animal welfare applications and scientific discovery. And the smart system inspired by specified animal behavior is the core concept of new innovation in network architecture. With the help of wearable and non-wearable sensor systems, the wild animals can also be tracked. A novel hybrid architecture [102] for monitoring whooping cranes, an endangered species, uses global cellular networks in their annual migration of 4000 km, and a short-range, ad hoc networks in breeding and nesting grounds. This platform leads to a new class called cellular sensor networks. An early work on wild animal tracking [103], also known as Zebranet, proposes a wireless ad hoc sensor system to minimize energy consumption and storage and support wildlife tracking among large geographic areas. Uploading sensor data from mobile nodes to base stations with limited power and to track wild horses and methods, an interesting method known as Virtual-Beacon, is used. And the challenges of this method are addressed in Ref. [104]. In Ref. [105], mountain lions were studied with a network system controlled by mobile and static nodes with sensing, processing, storage, and communication. Zigbee- and GPRS-based monitoring techniques [106] have been used to monitor two types of monkeys under risk in the Mexican jungle. This research reviewed a specialized tracking device or a GPS-based collar. One of the revolutionary works [107], known as Duck Island, designs and develops a complete WSN for habitat monitoring. A group of papers [108–110] focus on integrated image processing for animal detection, camera-sensor network systems, tracking, class classification, and cloud-based data management. To maximize monitoring performance in remote areas, an animal-to-animal internet sharing capability method is proposed in Ref. [111]. Finally, paper [112] proposed the use of magnets in localization of underground animals with the help of receiver antennas, which are described in the paper that ensures monitoring over long periods of time.

Human–Animal Cohabitation

The WSN system with passive nodes and infrasonic sounds is used to prevent elephants from crossing railways [113]. Additionally, the IR sensor and seismic sensors are used for detection. A new WSN system [114, 115] uses adaptive actuation of light signals to alert drivers about dangerous situations caused by wildlife crossing. Camera-based sensors with image processing can be used for animal recognition and protection. To minimize the number of samples which leads to high power consumption, a new methodology applies the comprehensive sensing for sound recognition and classification in WSN systems [116]. To detect unlawful human intrusion in protected wild areas, Rusu [117] proposes a new technique called sparsogram which is used for the classification of collected audios. A radar system [118] is used to detect enclosed microwave reflecting objects to keep fawns from death during the paddock mowing.

Wild Animals Confinement

The ACI science community focuses the wild animals in confinement, including animal sanctuaries and zoos to enhance animal welfare and to study the human–animal interactions for education and conservation. To help animals to overcome isolation and poor physical condition, the paper [119] proposed a new scenario called Intelligent Playful Environment for Animals (IPE4A), and it extracts animals from repetitive training exercises and remote digital interaction with humans. The importance of ACI and new technologies that are used to improve animal welfare are discussed in paper [120].

Benefits of IoT in Animal Healthcare Management

The tracking and monitoring of the health of animals is a tedious task in livestock management, in which traditional techniques monitor the animals individually for identifying the symptoms of diseases. Such methods are ultimately costlier and unreliable. IoT-based livestock management systems take the utmost care of animal's health with the introduction of wearable devices, tags, low-powered sensors, and wireless data transmission. This enables the farmers to monitor the health status and location of each individual animal from a remote location and also receive emergency notifications immediately upon the abnormal condition of animals. In addition, global positioning system (GPS) allows tracking the location of animals and also the information of the desired grazing spot. The major benefits are:

Health monitoring: The real-time health monitoring of livestock that enables the caregiver to offer immediate intervention and avoid the spreading of disease.

Grazing spot detection: Tracing the animals eases the identification of frequent grazing spots.

Disease pattern identification: Gathering and analyzing the health data of animals to determine the patterns of diseased animals.

Loss prevention: Remote monitoring of birth which avoids the death of animals and also optimizes the breeding behaviors.

Increased production: The determination of animal's specific needs via sensing technologies increases the milk yield and other productivity ratios. Also, offering immediate attention towards diseased animals which results in increased productivity.

Real-time data acquisition and insights: The visualization of production, feed intake, behavioral changes, and physiological data remotely helps in inferring useful insights and allows the users to take appropriate decisions.

Reduced operational cost: The automation of feeding, movement monitoring, and tracing has constantly reduced resource utilization, human prone errors, and cost involved in operations.

Conclusion

The IoT has undoubtedly improved animal healthcare management by allowing data acquisition, real-time healthcare intervention, decision-making, and process automation with reduced cost. Likewise, the benefits discussed, IoTAH solutions are the key concern for livestock farmers and smart dairy farmers. This article steadily reviewed the various sensing and other technologies used in animal healthcare in terms of domestic, farm-based, and wild animals. Researchers and development organizations have started to discover solutions for improving animal healthcare. IoT has been changed into the traditional healthcare services used in animal healthcare into smart services. The technologies reviewed the major contributions towards specifics cases and situations, but most of the technologies contain centralized storage which allows the end-users to track and share the information that provides numerous societal and economic benefits.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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