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Advancements in Cow Health Monitoring: A Systematic Literature Review of IoT Applications

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Abstract: The landscape of livestock farming is undergoing a significant transformation, primarily influenced by the integration of the Internet of Things (IoT) technology. This systematic literature review (SLR) critically examines the role of IoT in enhancing cow health monitoring, a burgeoning field of research drawing considerable attention in recent years. Spanning articles published from 2017 to 2023 in eminent academic forums, this study meticulously selected and analyzed thirty publications. These were chosen through a structured process, evaluating each for its relevance based on title and abstract. The review encapsulates a thorough investigation of the applications, sensors, and devices underpinning IoT-based cow health monitoring systems. It is observed that the current research landscape is dynamically evolving, marked by emerging trends and noticeable gaps in technology and application. This synthesis of existing literature offers an insightful overview of the potential and limitations inherent in current IoT solutions, highlighting their efficacy in real-world scenarios. Furthermore, this review delineates the challenges faced and posits future research directions to address unresolved issues in cow health monitoring. The primary objective of this systematic analysis is to consolidate research findings, thereby advancing the understanding of IoT's impact in this field. It also aims to foster a comprehensive dialogue on the technological advancements and their implications for future research endeavors in livestock farming.

Keywords: Internet of Things (IoT); Cow health monitoring; Devices; Sensors; Systematic literature review (SLR)

1 Introduction

Over the past two decades, the widespread adoption of the Internet has catalyzed significant advancements across various sectors, offering substantial benefits to both entrepreneurs and consumers. The primary advantage of this technological revolution has been the ability to generate and utilize services in real time. Emerging as a pivotal innovation in this digital landscape, IoT extends these benefits, exhibiting the potential to transform operational paradigms across multiple industries. This review explores the application of IoT in diverse sectors, with a particular focus on agriculture, livestock, healthcare, traffic management, security, retail, smart home technology, and urban development.

Specifically, the integration of IoT in livestock farming, especially in monitoring cow health, is identified as a highly promising approach. The utilization of various IoT devices and sensors for monitoring cows' health conditions exemplifies this trend. Recent technological advancements have enhanced cattle health monitoring systems, integrating comprehensive management and decision-making tools. For instance, an IoT monitoring system designed for dairy cows, encompassing hardware components, a cloud-based system, a user-friendly application, and advanced data measurement and analysis algorithms, has been noted [1]. This system is proficient in recording vital parameters such as body temperature, relative humidity, heart rate, and rumination rate at regular intervals. These parameters are pivotal in predicting milk yield and overall bovine health [2]. Furthermore, the introduction of "SmartDairyTracer" demonstrates the breadth of IoT applications, encompassing the tracking of cow well-being, milk processing, and transportation safety, and facilitating the dissemination of crucial data through a secure and reliable platform. This ensures stakeholders and customers have access to meaningful, verifiable information [3].

In light of the burgeoning research in the domain of IoT-based cow health monitoring, a comprehensive compilation and analysis of recent studies are imperative. This research is dedicated to presenting an in-depth, structured evaluation of literature in the field of IoT applications for cow health monitoring, encompassing various sensors and devices. This systematic review aims to encapsulate all pertinent studies, offering insights into the current state of technology and its applications. The contributions of this paper in the realm of IoT cow health monitoring are manifold. A detailed literature review pertaining to cow health monitoring technologies is outlined in Section 2. Section 3 delineates the research methodology, encompassing the research objectives, research questions, search strings, and the criteria for inclusion and exclusion, thereby ensuring the selection of studies specifically related to IoT in cow health monitoring. The results of the research are methodically presented in Section 4, utilizing tables and charts for clarity and comprehensiveness. In Section 5, the findings are synthesized, employing a research hierarchy to structure the analysis. Section 6 is dedicated to discussing potential avenues for future research, aimed at guiding scholars in the field of IoT cow health monitoring. Finally, the conclusion of the article is presented in Section 7.

2 Literature Review

Recent advancements in the field of IoT-based cow health monitoring have been the subject of extensive research. This section collates and discusses various strategies identified in the literature for monitoring cow health using IoT technologies. A pivotal development in this area is the implementation of the Narrow-Band Internet of Things Communications (NB-IoT) platform, fundamental to an estrus detection system for cows. This technology, aimed at identifying significant changes in cows' physical conditions, facilitates timely estrus status recognition, thereby alerting farm administrators. The adoption of such technology has been observed to mitigate the workload on staff and augment the economic efficacy of pastures [4]. Additionally, an insightful study integrates IoT with artificial intelligence (AI) to enhance cattle health monitoring systems. This research not only describes existing cattle health monitoring architectures but also critically evaluates the challenges faced. Based on this evaluation, it proposes potential modifications to enhance future iterations of these systems [5]. Another noteworthy innovation is the "MOOnitor", an intelligent IoT device designed for livestock tracking. This neck-mounted gadget represents a significant step forward in livestock management technology [6].

The exploration of IoT-based systems for cow health management has yielded diverse and innovative solutions. A system combining health monitoring, disease detection, and management of ailing cows through IoT and intelligent system technologies has been developed. This system integrates monitoring and detection functionalities into a unified application, significantly enhancing farm management efficiency [7]. Further advancements are highlighted, where a proposed system allows farmers continuous online access to monitor vital parameters of each cattle, including body temperature, heart rate, humidity, and posture [8]. The cow disease prediction (CDP) method, a component of the LiveCare architecture, has been introduced as an unsupervised multiclass classifier [9]. Additionally, collar devices are employed for tracking cattle health, collecting data on body temperature, heart rate, and movement [10], thus facilitating proactive health management.

An innovative real-time cattle health monitoring system based on IoT has been proposed [11], employing wearable collars and IoT sensors. This approach enhances the efficiency of livestock management. Similarly, an IoT-based cloud-based Livestock Management System (LMS) is suggested [12], offering a comprehensive solution for tracking and monitoring animal health. An IoT-based system designed to identify cattle ailments and issue alerts for animals requiring assistance has been developed [13]. This system is pivotal in ensuring timely veterinary intervention. Lastly, a system capable of wirelessly storing data and monitoring and analyzing an animal's health has been created [14], representing a significant advancement in the field of livestock health technology. The scope of IoT applications in cattle health and activity monitoring continues to expand, as evidenced by recent studies. The CattleCare technology, an IoT-based innovation, plays a crucial role in monitoring the health and activities of cattle. This technology incorporates the "Cattle Activity Prediction" algorithm, which classifies cattle behavior, thus aiding in the detection of behavioral changes and other health-related aspects [15]. A notable development in this field is a system designed for tracking cattle movement and predicting their locations, effectively monitoring animals along set perimeters [16].

Additionally, the utilization of the Digital Smart Collar has been proposed for real-time tracking of cattle growth and health [17]. This device represents a significant leap in monitoring technologies, offering continuous health assessment. Further, a multi-sensor board specifically engineered to monitor various biological parameters, such as skin body temperature and heart rate, has been introduced [18]. This system underscores the importance of multi-faceted health monitoring in cattle. Moreover, a system has been constructed for regular health checks of dairy cows, with the aim of identifying diseases through symptomatic behavioral changes [19]. The integration of IoT and machine learning in estimating cow health status has been explored, highlighting the use of various wearable devices and sensors for precise livestock management [20]. This approach exemplifies the fusion of advanced technologies in enhancing cattle health monitoring. Lastly, a model employing Arduino-based sensors for disease identification in cattle has been proposed [21], reflecting the ongoing evolution of sensor technology in livestock health management.

3 Research Methodology

This study adopts a SLR as its primary research methodology. The focus is placed on analyzing current IoT-based applications, sensors, devices, and communication protocols pertinent to cow health monitoring. The approach, as delineated by Farooq et al. [22], has been employed to ensure impartiality in both the selection of information and the representation of findings. The methodology followed in this research is illustrated in Figure 1.

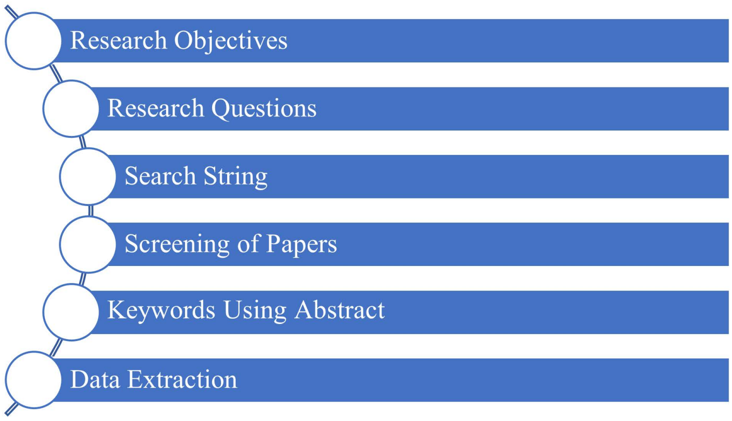

Figure 1. Research methodology diagram

3.1 Research Objectives

The objectives of this study are threefold:

O1: To identify more targeted state-of-the-art studies in the field of IoT cow health monitoring.

O2: To delineate the existing IoT applications, sensors, and devices utilized in cow health monitoring.

O3: To ascertain future research directions, particularly focusing on the challenges and unresolved issues in cow health monitoring.

3.2 Research Questions

As part of the SLR, four research questions have been formulated, each accompanied by their respective motivations, as presented in Table 1.

Table 1. Research questions

Sr#	Research Questions	Inspiration
RQ1	Which publication venues predominantly feature research on IoT cow health monitoring?	To identify key sources for future investigations and current research on IoT cow health monitoring.
RQ2	How has the prevalence of various approaches in IoT cow health monitoring evolved over time?	To discern trends and historical shifts in the use of IoT for cow health monitoring.
RQ3	What methodologies are being applied in addressing challenges within IoT-based cow health monitoring?	To explore the diverse methodologies discussed in literature regarding IoT in cow health monitoring.
RQ4	What types of IoT devices and sensors are prevalent in cow health monitoring applications?	To ascertain the significance of specific IoT devices and sensors in the realm of cow health monitoring.

3.3 Searching String

A searching string was devised to identify relevant published papers pertaining to the themes of the study. The focus was primarily on IoT applications in cow health monitoring, as determined by a preliminary search. Additionally, the use of IoT sensors, devices, and communication protocols was also considered during the initial search phase. Various search engines and digital libraries were utilized by researchers to gather data, ensuring the selection of the most authoritative sources to address the research questions. Based on their academic rigor and relevance to the study objectives, selected databases included Elsevier, IEEE, MDPI, and Springer. The subsequent phase involved outlining the standard procedures for operationalization and defining specific search terms for querying technical and scientific documentation in digital libraries and search engines. The search string used in this study is detailed in Table 2.

Table 2. Searching string

Sources	Searching String	Context
MDPI, Springer Link, Science Direct and IEEE Xplore	("IoT applications for cow health monitoring,"or "IoT sensors and devices for cow health monitoring") and ("IoT" or "Internet of Things")	Cow health monitoring

3.4 Screening of Relevant Papers

The evaluation of papers for their relevance to the research questions was a critical step in this study. The selection process, as guided by Farooq et al. [22], involved a meticulous screening of articles. Initially, papers were assessed based on their titles, with those not pertinent to the research questions being excluded. For example, articles identified through the keyword 'protocol' but unrelated to IoT technology for cow health monitoring were deemed outside the scope of this research and thus excluded. In the subsequent phase, the abstracts of the articles selected during the initial screening were thoroughly reviewed. This process further refined the selection, ensuring a focus on papers directly relevant to the study's objectives. The inclusion and exclusion criteria played a significant role in this process.

The exclusion criteria applied were as follows:

- Articles not presenting novel ideas or findings were excluded.
- Papers published outside of recognized academic platforms such as conferences, journals, and symposia were omitted.
- Non-English language publications were not considered.
- Articles published prior to 2017 were excluded, aligning with the study's focus on recent developments.
- Papers not aligning with the defined searching string were disregarded.

Following these criteria, articles were chosen for a detailed review of their abstracts, ensuring the selection was highly relevant to the research scope.

3.5 Keyword Analysis Based on Abstracts

Following the procedure described in the study [22], keyword analysis was conducted utilizing abstracts of the selected papers. This process entailed two stages. Initially, the main concepts and keywords in each abstract, which succinctly encapsulated the contribution of the studies, were analyzed. Subsequently, these keywords facilitated a more in-depth understanding and classification of the research contributions.

3.6 Data Extraction Method

To address the defined research questions, a systematic data extraction approach was employed, aimed at generating a set of probable findings.

RQ1: For each study, the publication sources and channels were identified to respond to this question.

RQ2: Articles were categorized based on their year of publication to quantify their frequency over time.

RQ3: Research methodologies in the selected studies were categorized according to the emerging techniques, encompassing applications, solutions, systems, methods, frameworks, etc.

RQ4: The objective of this research question was to ascertain the specific sensors, devices, and applications employed in IoT cow health monitoring solutions.

4 Analysis

This section elucidates the findings derived from the SLR questions, as delineated in Table 1. Following the established screening procedure, selected research papers have been scrutinized to elucidate responses to each research question, thereby contributing significantly to the field of IoT cow health monitoring.

4.1 Evaluation of RQ1

An examination of the primary publication venues for research on IoT cow health monitoring has been conducted, with the findings presented in Table 3. This table enumerates the various sources and channels where articles pertinent to this field have been published.

Table 3. Publication sources

Publication Sources	References	Channel	Number of Articles
International Conference on Computational Science	[1]	Conference	1
International Conference on Smart Systems and Inventive Technology	[2]	Conference	1
Ad Hoc Networks	[3]	Journal	1
International Conference on Electronic Engineering and Informatics	[4]	Conference	1
Electronics	[5]	Journal	1
Sensors and Actuators	[6]	Journal	1
International Electronics Symposium	[7]	Symposium	1
Computers	[8]	Journal	1
IEEE Transactions on Consumer Electronics	[9]	Journal	1
International Electronics Symposium	[10]	Symposium	1
International Conference on Smart Communities	[11]	Conference	1
Sensor Review	[12]	Journal	1
OITS International Conference on Information Technology (OCIT)	[13]	Conference	1
International Conference for Convergence in Technology (I2CT)	[14]	Conference	1
International Conference on Futuristic Technologies (INCOFT)	[15]	Conference	1
International Conference on Intelligent Engineering and Management (ICIEM)	[16]	Conference	1
International Symposium on Electronics and Smart Devices (ISESD)	[17]	Symposium	1
International Conference on Computer and Information Technology (ICCIT)	[18]	Conference	1
International Conference on Intelligent Technologies (CONIT)	[19]	Conference	1
International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON)	[20]	Conference	1
International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE)	[21]	Conference	1
Procedia Computer Science	[23]	Journal	1
International Electronics Symposium	[24]	Symposium	1
Journal of Animal Science	[25]	Journal	1
Materials Today: Proceedings	[26]	Journal	1
International Conference on Sensing, Signal Processing and Security (ICSSS)	[27]	Conference	1
Applied Animal Science	[28]	Journal	1
Emerging Research in Electronics, Computer Science and Technology.	[29]	Journal	1
International Conference on Smart Communities	[30]	Conference	1
International Journal of Advanced Studies of Scientific Research	[31]	Journal	1
		Total:	**30**

4.2 Evaluation of RQ2

The trend in publications related to IoT cow health monitoring from 2017 to 2023 is illustrated in Figure 2. An initial observation indicates a modest number of articles published between 2017 and 2018. However, a notable increase in research output is evident from 2019 to 2022. Given that 2023 is ongoing, it is anticipated that the number of publications will rise significantly, reflecting the escalating interest in IoT for cow health monitoring.

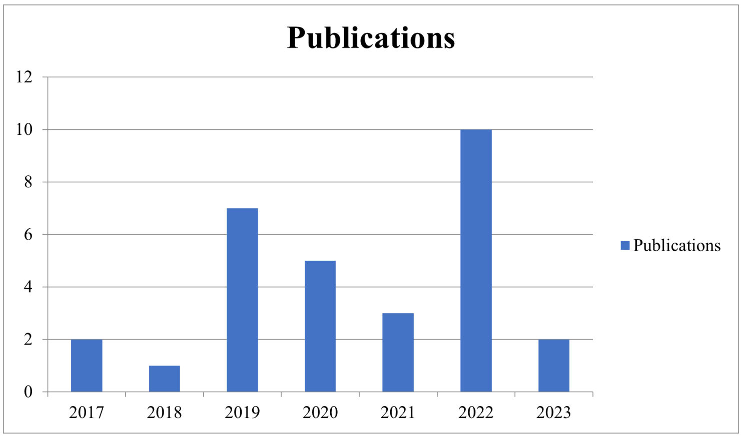

Figure 2. Publication trends from 2017 to 2023 in IoT cow health monitoring

4.3 Evaluation of RQ3

Figure 3 presents the methodologies employed in the selected articles to address challenges within IoT-based cow health monitoring. This visualization categorizes the research methods used, offering insights into the diverse approaches adopted in the field.

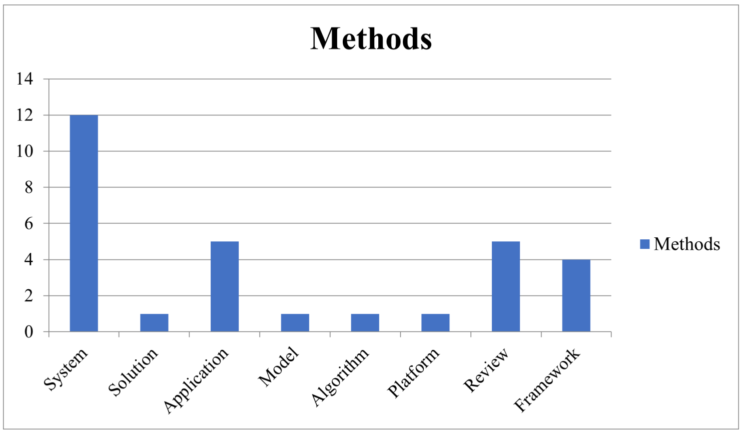

Figure 3. Research methods used in IoT cow health monitoring

4.4 Evaluation of RQ4

The analysis of the types of IoT devices and sensors employed in cow health monitoring is presented in Table 4. This table categorizes the studies based on the observed parameters and the specific devices or sensors used in each research.

Table 4. Sensors and devices used in cow health monitoring

Reference	Study Objective	Observed Parameters	Devices/Sensors Used
[1]	Automated dairy cow health evaluation system development based on IoT.	Ruminating, feeding, sleeping and moving	Rumination sensor, accelerometer, and Wifi
[2]	System demonstration for recording cow body measurements and milk yield prediction.	Body temperature, relative humidity, heart rate, and rumination rate	Temperature sensor, heart rate sensor, humidity sensor, rumination sensor, Atmega328p, NodeMCU

Reference	Study Objective	Observed Parameters	Devices/Sensors Used
[3]	IoT application in cow health, milk processing, and transport security.	Real-time location, temperature, heart rate, breath, and rumination	Temperature sensor, heart rate sensor, rumination sensor, Bluetooth Low Energy (BLE), ZigBee
[4]	Technology utilization for identifying unusual changes in cows' physical conditions.	Estrus monitoring, milk movement, activity, and temperature	Acceleration sensor (accelerometer), pedometer, temperature sensor,
[5]	Discussion on IoT and AI-integrated cattle health monitoring devices.	Body temperature, heart rate and rumination	Heart rate sensor, temperature sensor, rumination sensor, ZigBee, WSN
[6]	Introduction of the "MOOnitor", an intelligent IoT device for cow health monitoring.	Estrus monitoring, temperature, and diseases	Temperature sensor, global positioning system (GPS), accelerometer, cellular global system for mobile communication (GSM) module
[7]	Development of a health management system for dairy cows.	Temperature, heart rate	Heart rate sensor, temperature sensor, Arduino mini pro, ESP 32
[8]	Proposal of a comprehensive cattle health tracking system.	Temperature of body, humidity, heart rate, and position	Humidity sensor, temperature sensor, heart rate sensor, gyro sensor
[9]	Development of a method for cow disease prediction.	Temperature, sound, motion, the heart rate and estrus monitoring	Accelerometer sensor, temperature sensor, and a heartbeat sensor
[10]	Design of a collar device for cattle health tracking.	Temperature, heart rate	Temperature sensor, heart rate sensor, Wemos (a micro-controller)
[11]	Development of a real-time cattle health monitoring system utilizing IoT.	Skin temperature, heart rate, humidity, rumination	Temperature sensor, heart rate sensor, rumination sensor, humidity sensor, GSM technology
[12]	Proposal of an IoT-based cloud-based LMS for health tracking and monitoring.	Temperature, relative humidity, heartbeat, eating and positioning	Temperature sensor, heart rate sensor, humidity sensor, accelerometer sensor, Arduino, Bluetooth/WiFi module, wearable collar device
[13]	Framework development for the identification of cattle ailments.	Body temperature, heart rate, and rumination rate	A heart rate sensor, temperature sensor, rumination sensor
[14]	Design of a system for animal health monitoring.	Activity, temperature, heart rate, rumination	Accelerometer sensor, temperature sensor, heart rate sensor, rumination sensor
[15]	Implementation of an IoT-based system for cow health and activity monitoring.	Temperature, activity, heart rate	Accelerometer sensor, temperature sensor, heart rate sensor, WiFi
[16]	Development of a system for cattle movement and health monitoring.	Body temperature, heart rate, activity, location	Heart rate sensor, temperature sensor, accelerometer sensor, GPS tracker, batteries, WSN
[17]	Utilization of the Digital Smart Collar for real-time cattle growth and health tracking.	Body temperature, and the heart rate	Temperature sensor, heart rate sensor, smart collar, micro-controller, WiFi/Bluetooth
[18]	Proposal of a system to oversee livestock health.	Body temperature, heart rate, humidity	Temperature sensor, heart rate sensor, humidity sensor, WiFi module

Reference	Study Objective	Observed Parameters	Devices/Sensors Used
[19]	Creation of a system for regular health checks of dairy cows.	Temperature, and the heart rate	Heart rate sensor, temperature sensor, WSN
[20]	Conducting a literature review to predict cow health using machine learning.	Movement, physically condition, food and fluid intake	Accelerometer sensor, temperature sensor, heart rate sensor
[21]	Development of a model focusing on cattle health monitoring.	Temperature of the body, the heart rate, and the relative humidity	Temperature sensor, heart rate sensor, humidity sensor, Arduino
[23]	Consideration of IoT for detecting diseases such as foot and mouth disease FMD and mastitis in cows.	Motion, temperature, sound, etc.	Raspberry Pi, motion sensor, rumination sensor,and temperature sensor
[24]	Utilization of wireless networks and IoT devices for cow health monitoring.	Motion, temperature, and heart rate	GSM, RL78, sensor modules, and an Android application
[25]	Research on the use of sensors, AI, big data, and machine learning in enhancing cow well-being and reducing costs.	Animal voice messages, visual evidence of diverse animal actions, and other similar data about animal behaviour	Hardware sensors include cameras, vision sensors, temperature sensors, RFID tags, accelerometers, motion sensors, pedometers, facial recognition machine vision sensors, infrared thermal imaging sensors, and microphones.
[26]	Implementation of IoT sensors in a fuzzy-based smart cow health monitoring system for precise illness detection.	Information on the body temperature, heartbeat, pulse rate, ruminations, and breathing	Arduino, a WiFi module, and sensors
[27]	Demonstration of a system for tracking cow health indicators to detect health declines.	Body temperature, heart rate, rumination, and humidity	A combination of sensors, an Xbee module, and an Arduino NANO
[28]	Discussion on the use of wearable precision dairy technology (WPDT) for early disease diagnosis.	Feed bunk, time spent ruminating, eating, lying, standing, walking, and temperature	Wearable precision technologies, including leg tags, torso bands, and neck collars, etc.
[29]	Application of machine learning techniques and IoT devices for cow health monitoring.	Body movement, heart rate, and body temperature	Accelerometer sensor, body temperature sensor, heart rate sensor, and the Raspberry Pi
[30]	Evaluation of technology-based solutions and tools for cow health monitoring.	Time spent ruminating, skin temperature, heart rate, and its variability	IoT-based sensor system to measure different health-related metrics.
[31]	Discussion on IoT-based smart cow health monitoring systems.	Heart rate, body temperature and rumination	Raspberry Pi and a combination of sensors

Table 4 enumerates various IoT devices and sensors applied in the domain of cow health monitoring.

5 Discussion

This section has systematically elucidated the array of IoT applications, sensors, and devices dedicated to cow health monitoring. The insights gleaned from this study have been coherently organized into a hierarchical structure, as depicted in Figure 4.

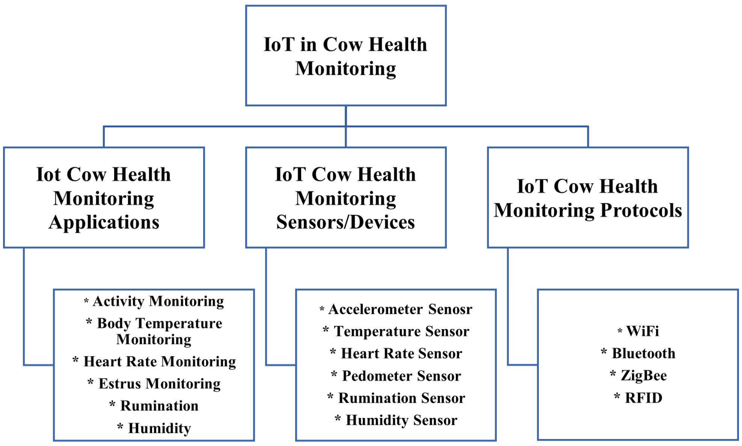

Figure 4. Hierarchical structure of IoT cow health monitoring

The hierarchy consists of three primary components. Firstly, the applications of IoT in cow health monitoring encompass monitoring, control, and tracking of bovine health conditions. Secondly, sensors and devices, often integrated into Wireless Sensor Networks (WSN), play a pivotal role in gathering essential data by sensing and tracking multiple health-related parameters. Finally, communication protocols such as ZigBee, RFID, Bluetooth, and WiFi are instrumental in transmitting the data collected by these sensors and monitoring devices for user analysis.

6 Future Research Directions

The transformation of the livestock industry through the application of IoT in monitoring the health of cows and other cattle presents a promising research avenue. The development of miniature, wireless sensors for the continuous monitoring of health indicators such as heart rate, body temperature, and digestive activity emerges as a crucial area of focus. The integration of advanced data analytics, underpinned by machine learning and AI, holds the potential for precise health predictions and early disease detection, thereby enhancing livestock management efficiency.

7 Conclusions

This study has provided a systematic review of the literature in the domain of IoT-based cow health monitoring. A structured methodology was employed to select thirty pertinent studies for this review. The study then delved into an analysis of various IoT sensors, devices, and applications utilized in cow health monitoring. Finally, the study highlighted potential future research directions, underscoring the challenges and unresolved issues in this field, thereby offering a roadmap for researchers.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares no conflict of interest.

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