A Review of Livestock Smart Farming for Sustainable Food Security

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***Abstract*— As the global community endeavours to reconcile the requirements of a burgeoning population with sustainable agricultural methodologies, challenges arise in sustaining large-scale food production to ensure food security. Food security is determined by the alignment of production capacity with population demand. Achieving food security necessitates the implementation of sustainable agricultural practices characterized by the integration of technologies. The implementation of smart farming practices for livestock farming can effectively optimize production capacity to meet the demands of the population. This endeavour aims to enhance both the productivity of food supply and agricultural sustainability within the smart livestock farming ecosystem by leveraging automation, data analytics, and advanced sensor technology towards fostering sustainable food security. This article reviews the techniques, parameters, IoT sensor technologies and data analysis using machine learning algorithms that will serve as the foundation for the development of the relevant livestock smart farming system for sustainable food security.**

***Keywords*— food security; smart farming; livestock; automation; data analytics; sensor technology.**

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I. INTRODUCTION

Amid the increasing global challenges in agricultural and food production management, there is a compelling need to enhance food security on a global scale. The concept of food security emphasizes the significance of concerted efforts among governments, organizations, and communities, utilizing data and technology adoption for automation and effective monitoring in smart farming. This involves optimizing production, distribution, and consumption processes, thereby augmenting adaptability to dynamic circumstances [1][2][3]. Research has indicated that the worldwide agricultural sector is confronted with a multitude of obstacles, one of which is the expanding global population, which drives up the need for food production and decreases already limited resources. The requirement for additional food to feed billions of people is made harder by this population rise. As a result, the strain on limited resources like crop land, water, and energy is more extensive. The nations have built their own comprehensive National Food Security Framework [4] to handle the difficulties in the agricultural and food production sectors that aim to safeguard the country's ability to produce, distribute, and receive adequate and healthy food. However, the traditional farming practices lack effective monitoring tools, making it difficult to recognize and address livestock general well-being issues quickly which affects the livestock well-being and decrease the production. Furthermore, the current farming practices lack of data-driven insights and automation leads to inefficiency in resource utilization and management.

Hence, in order to implement livestock smart farming practices that guide livestock production by promoting an integrated, sustainable, and resilient approach and recognise the interconnection of various components within the food system, the study explores the nuanced dimensions of the pivotal role played by automation, data analytics, and cutting-edge sensor technology in shaping food security strategies. These unique aspects of the practices also necessitate the adoption of innovative practices to increase the effectiveness and efficiency of livestock farming on a global scale. This paper presents a review of academic research papers concerning the global challenges in livestock agricultural and food production management and discussing the suitable cutting-edge technologies and strategics needed for addressing the trend and gap. The study also proposes a decent framework and guideline to develop a livestock smart farming that utilizes advanced sensor technologies, data

analytics, and automation to monitor livestock health, behavior, and environmental conditions. The proposed framework has the potential to support increase production in wider scale across the agricultural sector to optimize resource utilization, decrease environmental impact, and modernize farming practices in order to contribute the long-term food supply sustainability and adaptability in the face of evolving global demands. The paper is presented as follows: Section I presents the introduction. Section II presents the materials and methods adopted in this study. Section III presents the discussion of results, some future works based on the limitations and gaps identified from the review and Section IV presents the conclusion.

II. Materials and Methods

The technique used for this study is the systematic literature review. The literature review conducted for this study identified the gaps and trends in the use of smart technologies in livestock farming practices, providing a foundation for the development of the livestock smart farming framework. The method requires a thorough and complete review of academic journals on livestock management, sustainability, and the use of smart technology. It examines research papers to determine the most recent developments, effective implementations, and issues involved with using smart technologies in livestock farming practices and draw significant findings from the variety of information in research journals. This approach not only facilitates the understanding of the existing level of knowledge, but it also allows for the discovery of gaps, trends, and areas that require further research.

A series of academic research papers and journals from verified indexes and resources about the current systems related to the title [5][6] was reviewed to understand livestock management and smart technology use in livestock farming for sustainability. The PRISMA guideline by [7] was used for performing and reporting systematic reviews in this investigation and included the guidelines published by [8] for software engineering and other relevant fields. The subsequent sections provide an overview of the review methodology employed in this paper.

A. Research Question

The aim of this study is to address the challenges that arise in achieving both sustainable livestock production and the well-being of farm animals by introducing a sustainable livestock smart farming practices that integrates advanced sensor networks, data analytics and automation as a solution through literature-driven assessment. Hence, the study is interpreted with the guidance of 4 research questions (RQ) as follows. RQ1: What specific domain are required to monitor in livestock farming practices to ensure the welfare of livestock and increase production for sustainable food security? RQ2: What specific IoT sensor technologies and platforms are suitable for implementing as an optimistic and less manpower-dependent technology in smart livestock farming practices? RQ3: How can data be collected through livestock farming practices to achieve sustainability and improve livestock welfare for greater production and food security? RQ4: What are the algorithms that have demonstrated effectiveness in analysing data from livestock farming system to do prediction to enhancing productivity in livestock farming?

B. Digital Sources and Research Strategy

A search string using a keyword is constructed to accumulate and review relevant research papers, journals, and documents. The keywords "Smart Farming" and the keywords "Food Security" or "Farm Animals" are used as search terms. The entire literature review and research are enclosed in verified digital resources and databases including SCOPUS, IEEE Xplore, SCIENCE DIRECT, SPRINGER LINK, TAYLOR & FRANCIS, and PROQUEST.

C. Selection Criteria

The selection criteria describe a particular method used to choose relevant and appropriate research paper literature. To prevent and reduce bias and duplicate literature, proper inclusion and exclusion criteria are needed throughout the process.

D. Inclusion Criteria

The inclusion criteria for the research study focused on peer-reviewed papers from 2013 to 2023 obtained from web resources. Additionally, only smart livestock (animal) farming systems are included in the study. In the smart livestock (animal) farming system approach, only ruminant animals (cows, sheep, and livestock) are included.

E. Exclusion Criteria

The exclusion criteria for the research study aimed to remove irrelevant articles. Journal papers that lack a comprehensive or significant part of their methodology are not considered for inclusion. Figure. 1 illustrates the PRISMA Flowchart used in this study.

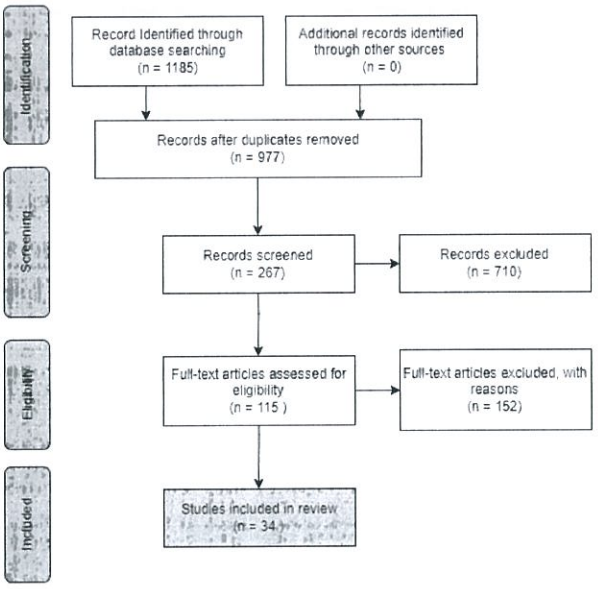

Fig. 1 PRISMA Flowchart

F. Data Extraction Process

A total of 34 papers were selected for the final literature review. The data extraction was conducted on these 34 papers.

III. Result and Discussion

This section discusses the data gathered from the journals and summarizes the review's findings. Figure 2 displays the descriptive data of animal group categorization, revealing that cow, cattle, sheep, and livestock are the most widely studied ruminant animal groups.

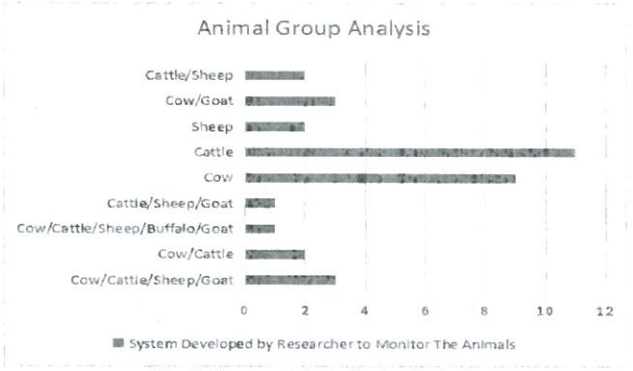

Fig. 2 Ruminant Animal-wise Analysis

Based on the data above, the ruminant animal group classification above indicates that the most extensively researched ruminant animal groups are cows and cattle based on the analysis of 34 publications. It can be concluded that that most research studies were carried out primarily with the cattle and cows category in mind; only a small number of studies were designed to research other ruminant species or to combine other species into their studies together. Thus, a greater degree of study approach diversification is needed by include all the ruminant animal group in the upcoming researches in order to achieve the research target of livestock smart farming for sustainable food security.

The following sections offer the results and observations of the systematic literature review based on the research questions.

RQ1: What specific domain are required to monitor in livestock farming practices to ensure the welfare of livestock and increase production for sustainable food security?

RQ1 focuses on understanding the specific domain used in the research of livestock farming practices, with a particular emphasis on protecting livestock welfare for the sake of food security. The assessment of the literature suggests essential to investigate strategies for completely monitoring essential elements such as livestock behaviour, health, and environmental conditions. This study attempts to uncover the broad range of tactics and technology used in the quest for sustainable and smart livestock farming by examining research papers.

The data extraction in Table I is based on the parameters of animal traits, animal behaviour, animal health, and environmental conditions. Animal traits refer to any physical characteristic or feature of a group of animals. Animal behaviour refers to the actions, reactions, or mannerisms of an animal in response to stimuli or situations in the environment. Animal health refers to the overall state of well-being of an animal, encompassing physical, mental, and social dimensions under a medical approach. Environmental conditions refer to the various factors present in the external surroundings that can influence animals and their ecosystems of natural processes.

TABLE I
DATA EXTRACTION BASED ON RANGE OF DOMAIN

No	No of Authors	Animal Traits	Animal Behavior	Animal Health	Environment condition
1.	[9]	x	x	x	x
2.	[10]				x
3.	[11]				x
4.	[12]	x	x	x	x
5.	[13]	x	x	x	x
6.	[14]				x
7.	[15]	x	x	x	x
8.	[16]		x	x	x
9.	[17]	x			
10.	[18]			x	x
11.	[19]		x		x
12.	[20]		x	x	x
13.	[21]				
14.	[22]	x	x		
15.	[23]				x
16.	[24]			x	x
17.	[25]	x	x	x	x
18.	[26]		x	x	x
19.	[27]		x	x	x
20.	[28]		x	x	x
21.	[29]		x	x	
22.	[30]		x	x	
23.	[31]		x	x	
24.	[32]	x	x	x	x
25.	[33]	x	x	x	x
26.	[34]		x		x
27.	[35]	x	x	x	x
28.	[36]		x		x
29.	[37]		x	x	
30.	[38]	x	x	x	
31.	[39]		x	x	
32.	[40]	x	x	x	x
33.	[41]		x		
34.	[42]			x	x
Total Count		12	25	23	24

The authors have a variety of opinions on their study approach, which can be categorized into animal traits, animal behaviour, animal health, and environmental conditions. Distinctly, almost two-thirds of the researchers conduct their analyses on animal behaviour, animal health, and environmental conditions. The authors [9][12][13][15][17][22][25][32] [33][35] [38][40] emphasize their research study on animal traits. Age of ruminants, growth of the ruminants, weight gain of the ruminants, breeding status of the ruminants, and physical characteristics of the ruminants are some of the variables the authors explored and discussed in their respective journals. The study of animal behaviours is the most reviewed approach among the parameters by the researchers. The authors [9][12][13][15][16][19][20][22][25][26][27][28][29][30][31]

[32][33][34][35][36][37][38][39][40][41] disputed about animal behaviour like sensation, rumination, movement of animals in the farm, their diet, reactions to insects, pest and wild animals, rest state, lameness, voluntary and involuntary actions in their study papers. The research on animal health focuses on diseases like bovine pneumonia and lumpy skin disease recognition, infection identification, heat stress and stroke detection, mental health analysis, and injury discerning.[9][12][13][15][16][18][20][24][25][26][27][28][29][30][31][32][33][35][37][38][39][40][42]. About 24 authors [9][10][11][12][13][14][15][16][18][19][20][23][24][25][26][27][28][32][33][34][35][36][40][42] researched the environmental conditions of the animals in their research report. The environmental conditions proposed and analysed by the authors include the surrounding area of the farm, the location of the farm, weather conditions, temperature, humidity, air circulation, and many more. Only 8 researchers [12][13][15][25][32][33][35][40] conducted their research study on all four categories of parameters. Hence, the analysis above shows that mainly the domains animal behaviour, animal health and environmental condition are the favorable scope and field of studies to be investigated to optimize the production and sustain the food security. The discovery holds paramount importance in ensuring the welfare of livestock, thereby facilitating optimal production and contributing to sustainable food security. The response met the research objective of the livestock smart farming practices for achieving the sustainable food security. Specific domain such as animal behaviour, animal health and environmental condition are required to monitor in livestock farming practices to ensure the welfare of livestock and increase production for sustainable food security. Thus, the research question is answered.

RQ2: What specific IoT sensor technologies and platforms are suitable for implementing as an optimistic and less manpower-dependent technology in smart livestock farming practices?

RQ2 emphasizes analysing research that investigates Internet of Things (IoT) sensors and technologies designed to create an optimistic and less dependent on humans in a smart livestock farming environment. This review highlights the relevance of technology improvements in optimizing livestock farming practices. Existing research articles show a rising priority for integrating IoT technologies to improve productivity, minimize reliance on humans, and provide optimal livestock welfare conditions. This study goes into the vast amount of literature to identify and analyse the wide range of IoT sensors and technologies that have been used or suggested in smart livestock farming, providing insights into their efficacy and applicability within the stated criteria.

TABLE II
DATA EXTRACTION BASED ON MONITORED IOT SENSORS AND TECHNOLOGIES

No of Authors	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
[9]	x	x	x	x	x												x																													
[10]	x					x											x															x														
[11]	x	x					x			x						x		x	x																					x						
[12]								x	x	x							x																								x						
[13]	x					x				x										x	x	x													x												
[14]	x					x					x																				x	x	x														
[15]	x	x		x						x		x	x	x	x	x	x			x								x	x					x	x											
[16]	x	x						x															x	x																						
[17]																									x																						
[18]	x																				x																										
[19]	x	x	x					x		x													x			x	x																				
[20]	x									x											x		x	x										x		x	x	x	x							
[21]	x	x																			x												x	x						x						
[22]																																										x					
[23]	x	x										x		x																										x							
[24]	x																				x																						x				
[25]	x									x													x											x						x						
[26]	x	x								x																								x						x						
[27]	x	x																		x	x	x											x													
[28]	x			x						x			x				x			x	x	x		x								x	x												
[29]	x																																	x												
[30]																																		x	x											
[31]	x																x				x																									
[32]	x	x		x						x		x	x							x	x													x	x									x		
[33]	x																x			x														x	x				x							
[34]	x	x																		x			x				x																			
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[38]																	x																								x						
[39]	x																																	x								x				
[40]	x																				x	x												x												x
[41]																	x			x															x												
[42]	x	x		x			x														x		x																								
Total	27	13	2	5	1	3	2	3	1	11	1	3	3	2	1	2	9	1	1	8	11	4	7	3	1	1	2	1	1	1	1	6	15	6	1	1	2	1	6	2	1	1	1	1	1

(A) Temperature; (B) Humidity; (C) Moisture; (D) CO2 levels; (E) Odor levels; (F) pH; (G) Air quality; (H) Soil; (I) Weather; (J) Image/Camera; (K) Turbidity; (L) Air speed; (M) Ammonia; (N) Air pressure; (O) Feed level; (P) Water level; (Q) RFID sensor/tag; (R) Biogas; (S) Fire; (T) GPS Device; (U) Heart rate; (V) Respiratory; (W) Motion; (X) Body Pressure; (Y) POF; (Z) PIR; (AA) Raspberry Pi; (AB) Rumen bolus; (AC) UAV; (AD) MQTT; (AE) Node-RED; (AF)

Microcontroller; (AG) Accelerometer; (AH) Pedometer; (AI) Blood Pressure; (AJ) Oxygen Level; (AK) Micro Sensor; (AL) Blood glucose; (AM) WiFi; (AN) Pulse Oximeter; (AO) Weight sensor amplifier; (AP) Solar; (AQ) Breath; (AR) Inertial sensor; (AS) SCC sensor

Table II shows the data extraction from 34 selected journals based on the IoT sensors and technologies monitored throughout the respective articles. A list of Iot sensors and technologies monitored that have be displayed in the table with code is presented below the table. Based on the journal studies, a vast number of researchers [9][10][11][13][14][15][16][18][19][20][21][23][24][25][26][27][28][29][31][32][33][34][35][36][39][40][42] selected temperature sensor as their IoT sensors to monitor temperature variable. Temperatures for body thermal and environmental thermal can be included in both animal behaviour and environmental condition elements. Meanwhile, humidity sensor [9][11][15][16][19][21][23][26][27][32][34][36][42], image/camera sensor [11][12][13][15][19][20][25][26][28][32][35], Heart rate sensor [13][18][20][21][24][27][28][31][32][40][42], and accelerometer [13][15][20][21][25][26][28][29][30][32][33][35][36][39][40] are popular IoT sensors among the research. A few researchers picked RFID tags and sensors [9][10][13][15][28][31][33][38][42] and GPS technologies [13][15][27][28][32][33] [34][41] to conduct their studies on smart livestock farming. Air quality, feed, and water monitoring are not selected by many authors as their observation variables. The air quality of the farm, food, and water levels of animals are observed by [11][42] observed the air quality of the farm, while [15] observed the water level using an IoT sensor. Based on the literature review, there are a vast amount of IoT sensors and technologies that can be selected according to the developing requirement as parameters in the smart livestock farming practices but the temperature, humidity, feed consumption, and water intake monitoring sensors as primary sensors will enhance the overall farming activities and manpower requirement. Hence, scholars advocate for the development of a resilient smart livestock farming through the integration of temperature, humidity, feed consumption, and water sensors to achieve the research objective of the livestock smart farming practices for sustainable food security and thus answering the research question.

TABLE III
LISTS OF PARAMETERS

PARAMETERS	
Temperature	Humidity
Feed	Water

RQ3: How can data be collected through livestock smart farming practices to achieve sustainability and improve livestock welfare for greater production and food security?

RQ3 focuses on the critical investigation of how data may be efficiently collected from the through livestock farming practices to achieve sustainable goals and improve livestock welfare. The literature study provides insight into the different approaches and systems development for respective IoT devices used to collect and utilize data. It investigates the relationship between data gathering techniques and their influence on long-term smart livestock farming practices, offering new insights into innovations that lead to better welfare circumstances. This study attempts to extract findings from current research journals through the viewpoint of RQ3, providing a complete overview of the systems used to gather and run the data collected through IOT components for the twin purposes of sustainability and goat welfare development. Table IV review systems developed by researchers to enhance livestock farming practices. A list of systems used to collect data that have been displayed in the table with codes is provided below the table. The systems were solely developed by the respective researchers. The general livestock monitoring systems are the most used by researchers [9][23][24][26][27][28][30][32] [34][36][37][39][41][42] to gather and display the data collected from the IoT sensors and technologies. Other than that, specific health monitoring systems developed by researchers [18][25][29][38][40] efficiently gathered health-based data gained from vast IoT devices. About 4 researchers [13][14][21][35] did not have any specific system to integrate the data and 3 researchers [17][20][31] developed system information basic system which only display the main information. The rest of the researchers developed a specific system for their studies according to their respective needs which compile very few functions and features. This shows the livestock monitoring system gained a high demand among the existing systems developed by researchers for the well-being of ruminant animals. Therefore, it would be better and wiser to construct a universal system, such a livestock monitoring system, in the near future to support livestock smart farming practices. The IoT adoption in the proposed system discussed by literature in RQ3 should be the benchmark in future research for the livestock smart farming practices for sustainable food security and optimising production.

TABLE IV
DATA EXTRACTION BASED ON EXISTING SYSTEMS PROPOSED BY RESEARCHERS

No of Authors	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
[9]	x															
[10]		x	x	x												
[11]					x	x	x	x	x	x						
[12]											x					
[13]												x				
[14]												x				
[15]			x													
[16]													x			
[17]														x		
[18]															x	
[19]																x
[20]													x			
[21]												x				
[22]				x												

[23]	x														
[24]	x														
[25]														x	
[26]	x														
[27]	x														
[28]	x														
[29]														x	
[30]	x														
[31]												x			
[32]	x														
[33]										x					
[34]	x														
[35]											x				
[36]	x														
[37]	x														
[38]														x	
[39]	x														
[40]														x	
[41]	x														
[42]	x														
Total	14	1	2	2	1	1	1	1	1	2	1	4	3	1	5	1

(A) Livestock Monitoring System; (B) Antitheft System; (C) Environment Monitoring System; (D) Feed Monitoring System; (E) Biogas Control System; (F) Feed Control System; (G) Incubator Control System; (H) Fire Detection System; (I) Water Control System; (J) Surveillance System; (K) Support System; (L) No Specific System; (M) Information System; (N) Floor Sensor Pilot System; (O) Health Monitoring System; (P) Irrigation System

RQ4: What are the algorithms that have demonstrated effectiveness in analysing data from livestock farming system to do prediction to enhancing productivity in livestock farming?

RQ4 emphasizes the studies on finding specific machine learning algorithms that have proven useful in analysing data from smart livestock farming systems, with a focus on detecting and avoiding health issues while increasing production. The analysis of the literature suggests a growing interest in integrating machine learning approaches to maximize the value of data produced from smart livestock farming systems. The literature study, seen from the viewpoint of RQ4, gives a detailed overview of how these algorithms have been used to improve overall production and health outcomes in the field of smart livestock farming, providing significant insights for further research and practical application. The researchers either utilize machine learning algorithms or else no data analysis has been conducted [42]. Table V summarises whether the researchers did the analysis or used machine learning algorithms to analyse data. Based on the table, about 16 choose to not to conduct data analysis whereas the rest 18 researchers conducted the data analysis using various machine learning algorithms. The deployed machine learning algorithms are control algorithm [18], support vector machines (SVM) [21][28][36][37][40][41], neural network (NN) [21], decision tree [21][25][36][40][41], long short-term memory [13][24][32], deep reinforcement learning and multi-agent deep reinforcement learning [24], multi-layer perceptron [25] [28], K-nearest neighbour [25][28][37][41], fast Fourier transform [26], logistic regression [40], random forest classifier [40][41], Naive Bayes, XGBoost [41], particle swarm optimization, computational intelligence, round robin, equalization technique [42]. The 16 authors [9][10][11][12][14][15][20][23][27][29][30][31][33][34][35] [38] do not discuss data analysis on the data collection by their respective systems. From the this study, a machine learning algorithm has proven to be an optimum technique in performing analysis of the data gathered from the sustainable smart livestock farming system. Researchers stated that specific machine learning algorithms for data analytics were decided based on the data collected from the system of the approach study. Hence, this study confirmed that analysing and evaluating data collected from the smart livestock farming system to improve livestock well-being and productivity for food security by using a suitable machine learning algorithm is valid.

TABLE V
DATA EXTRACTION BASED ON DATA ANALYSED OR NOT

No of Authors	No Data Analysis	Machine Learning
[9]	x	
[10]	x	
[11]	x	
[12]	x	
[13]		x
[14]	x	
[15]	x	
[16]		x
[17]		x
[18]		x
[19]		x
[20]	x	
[21]		x
[22]		x
[23]	x	
[24]		x
[25]		x
[26]		x
[27]	x	
[28]		x
[29]	x	
[30]	x	
[31]	x	
[32]		x
[33]	x	
[34]	x	
[35]	x	
[36]		x
[37]		x
[38]	x	
[39]		x
[40]		x
[41]		x
[42]		x
Total	16	18

In summary, based on the research question analysis, this study justified that the fundamental idea behind developing a sustainable framework for smart livestock farming to monitor livestock well-being must considered the combination of

innovative and sustainable practices by adopting smart technologies including sensors technology and data analytics using machine learning. This approach will improve livestock welfare while also increasing production which will contribute to sustainable food security. Implementing sustainable agricultural practices should emphasise the critical components of integrating smart technology which are IoT devices and sensors, and data analytics. The conceptual framework must be designed for monitoring and optimising numerous critical variables which should include livestock health, behaviour and environmental conditions. It seeks to deliver real-time data, helping farmers to make better decisions and ensure efficient and sustainable livestock farming methods by adopting suitable technology. The conceptual framework for the upcoming livestock smart farming practices and system development includes the concept represented in Figure 3 [43][44].

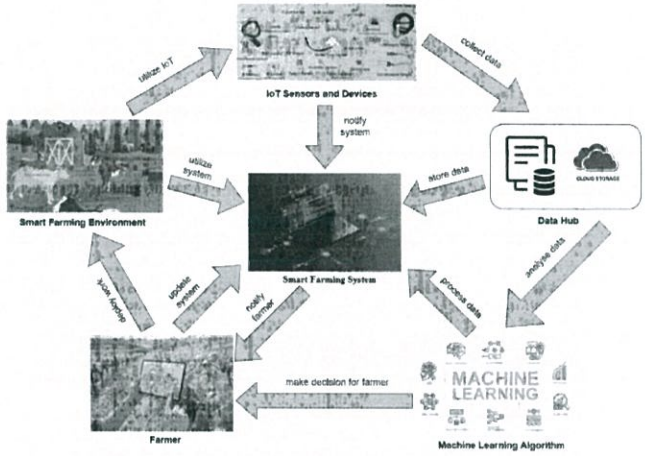

Fig. 3 Conceptual framework of the livestock smart farming ecosystem

IV. Conclusion

In conclusion, this study reviews valuable insights and direct implications for food production that significantly influence food security. This paper executed a systematic research of scholarly works to address particular questions, objectives and research questions to serve as the foundation for research in this area. A systematic literature review that involved a thorough selection process of 34 articles was conducted and the selection was performed based on carefully derived inclusion and exclusion criteria. The findings from this study play a crucial foundation role in the future development and implementation of sustainable smart livestock farming, contributing to the overall goal of ensuring food security. However, few challenges arise and being obstacles to achieve the ultimate goal. A lack of infrastructure to gather, analyse, and deploy sensors is one of the technological issues facing agriculture today, making customised farming difficult to implement. The absence of skilled workers who are knowledgeable about and capable of implementing cutting-edge technology and policies hinders the growth of human capital. Workers in agriculture and farming need to be educated and exposed to contemporary methods and equipment. Trade restrictions and political instability make it more difficult to distribute food internationally, which highlights the need for resilient and sustainable agricultural practices. The complications confronting government policy include creating and executing efficient policies that encourage the use of sustainable practices and technology. Comprehensive and flexible policies that support innovation while addressing resource constraints and environmental issues are required. To overcome these obstacles, government agencies, educational institutions, and technology suppliers must work together effectively. This review suggests that sustainable livestock smart farming systems should be thoroughly designed based on required criteria to meet any country's long-term food supply sustainability and adaptability to growing population and global demands. The absence of automation complicates process optimization, affecting overall efficiency and sustainability in livestock farming. This highlights the criticality of the development of thoroughly designed sustainable livestock smart farming systems that will be able to address these issues by proactively monitoring livestock activites, promising quick responses according to various parameters based on efficient machine learning data analytics that will encourage enhanced animal welfare and production. This initiative represents a critical step towards modernizing the industry, maintaining resilience and establishing progress towards the nation's long-term food security. Nevertheless, the growing deployment of interconnected IoT devices in urban environments heightens vulnerability to cyber threats. This study also highlights that IoT attacks have significant implications for the cybersecurity landscape within IoT-based implementation of livestock smart farming. In future work, the aspect of cybersecurity should also be taken into consideration to address the cybersecurity issue that could range from safeguarding the genuine IoT node sensors from malicious parties to network security issues in livestock smart farming. The adoption of blockchain technology is proposed as a measure to strengthen the access control mechanism for IoT devices and establish a reliable and robust solution [43][45][46][47][48][49].

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References

[1] Publication preview page | FAO | Food and Agriculture Organization of the United Nations. (n.d.). FAODocuments. Available: https://www.fao.org/documents/card/en?details=I7846E%2f

[2] Publication preview page | FAO | Food and Agriculture Organization of the United Nations. (n.d.-b). FAODocuments. Available: https://www.fao.org/documents/card/en/c/a5357f30-db89-4e29-b32a-f3eb167893a8

[3] Home | Food and Agriculture Organization of the United Nations. (n.d.). Available: https://www.fao.org/3/MR173EN/mr173en.pdf

[4] Pelan Tindakan Dasar Sekuriti Makanan Negara 2021-2025 - KPKM. (n.d.). Available: https://www.kpkm.gov.my/pelan-tindakan-dasar-sekuriti-makanan-2021-2025

[5] Literature review. (2023, December 18). The University of Edinburgh. Available: https://www.ed.ac.uk/institute-academic-development/study-hub/learning-resources/literature-review#:~:text=A%20literature%20review%20is%20a,rather%20than%20a%20literature%20report.

[6] Research Guides: Systematic reviews: *home*. (n.d.). Available: https://guides.library.ucla.edu/systematicreviews.

[7] Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ, 339*(jul21 1), b2535. Available: https://doi.org/10.1136/bmj.b2535.

[8] Kitchenham, B., Pretorius, R., Budgen, D., Brereton, O. P., Turner, M., Niazi, M., & Linkman, S. (2010). Systematic literature reviews in software engineering – A tertiary study. *Information & Software Technology, 52*(8), 792–805. Available: https://doi.org/10.1016/j.infsof.2010.03.006.

[9] Yang, L., Liu, X.-Y. and Kim, J.S. (2020) 'Cloud-based livestock monitoring system using RFID and blockchain technology', *2020 7th IEEE International Conference on Cyber Security and Cloud Computing (CSCloud)/2020 6th IEEE International Conference on Edge Computing and Scalable Cloud (EdgeCom)* [Preprint]. doi:10.1109/cscloud-edgecom49738.2020.00049

[10] Arko, A.R., Khan, S.H. and Islam, M.S. (2019) 'Smart Security, food and environment monitoring system for cows using microcontroller', *2019 International Conference on Communication and Electronics Systems (ICCES)* [Preprint]. doi:10.1109/icces45898.2019.9002293.

[11] M. H. Memon, W. Kumar, A. Memon, B. S. Chowdhry, M. Aamir and P. Kumar (2016) "Internet of Things (IoT) enabled smart animal farm," *2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom)*, New Delhi, India, 2016, pp. 2067-2072.

[12] Noinan, K. *et al.* (2021) 'Requirements analysis and design for Thai beef-Cattle Farm Management System', *2021 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunication Engineering* [Preprint]. doi:10.1109/ectidamtncon51128.2021.9425779.

[13] Valov, N., Mladenova, T. and Valova, I. (2021) 'IOT and big data in animal farming', *2021 5th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)* [Preprint]. doi:10.1109/ismsit52890.2021.9604671.

[14] Billah, M.M. *et al.* (2019) 'Real-time monitoring of water quality in Animal Farm: An IOT application', *2019 IEEE International Conference on Smart Instrumentation, Measurement and Application (ICSIMA)* [Preprint]. doi:10.1109/icsima47653.2019.9057320.

[15] Alexy, M. and Haidegger, T. (2022) 'Precision Solutions in livestock farming – feasibility and applicability of Digital Data Collection', *2022 IEEE 10th Jubilee International Conference on Computational Cybernetics and Cyber-Medical Systems (ICCC)* [Preprint]. doi:10.1109/iccc202255925.2022.9922883.

[16] Valova, I. and Mladenova, T. (2022) 'An information system for livestock and pasture surveillance', *2022 13th National Conference with International Participation (ELECTRONICA)* [Preprint]. doi:10.1109/electronica55578.2022.9874425.

[17] Vaughan, J. *et al.* (2017) 'Floor sensors of animal weight and gait for precision livestock farming', *2017 IEEE SENSORS* [Preprint]. doi:10.1109/icsens.2017.8234202.

[18] Huang, Y. *et al.* (2023) 'Health Monitoring System for dairy farming', *2023 IEEE 3rd International Conference on Electronic Communications, Internet of Things and Big Data (ICEIB)* [Preprint]. doi:10.1109/iceib57887.2023.10170269.

[19] N, B.K. and K, S. (2021) 'Farm vigilance: Smart IOT system for farmland monitoring and animal intrusion detection using neural network', *2021 Asian Conference on Innovation in Technology (ASIANCON)* [Preprint]. doi:10.1109/asiancon51346.2021.9544926.

[20] Paunova-Hubenova, E. and Trichkova-Kashamova, E. (2021) 'Smart Solutions for control and management in Livestock Farms', *2021 Big Data, Knowledge and Control Systems Engineering (BdKCSE)* [Preprint]. doi:10.1109/bdkcse53180.2021.9627269.

[21] Aunindita, R.F. *et al.* (2022) 'Use of machine learning and IOT for monitoring and tracking of livestock', *2022 25th International Conference on Computer and Information Technology (ICCIT)* [Preprint]. doi:10.1109/iccit57492.2022.10055766.

[22] Sokullu, R., Tanriverdi, B.Y. and Goleva, R. (2022) 'IOT based livestock precision feeding system using machine learning', *2022 8th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE)* [Preprint]. doi:10.1109/eeae53789.2022.9831244.

[23] Bovo, M. *et al.* (2020) 'A smart monitoring system for a future Smarter Dairy Farming', *2020 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor)* [Preprint]. doi:10.1109/metroagrifor50201.2020.9277547.

[24] Zhang, Q. *et al.* (2022) 'An attack-resilient and energy-adaptive monitoring system for Smart Farms', *GLOBECOM 2022 - 2022 IEEE Global Communications Conference* [Preprint]. doi:10.1109/globecom48099.2022.10001060.

[25] Kaur, D. and Kaur, A. (2022) 'IOT and machine learning-based systems for predicting cattle health status for precision livestock farming', *2022 International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON)* [Preprint]. doi:10.1109/smartgencon56628.2022.10083995.

[26] Caria, M. *et al.* (2017) 'Smart Farm Computing Systems for Animal Welfare Monitoring', *2017 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)* [Preprint]. doi:10.23919/mipro.2017.7973408.

[27] Anand, J.A. *et al.* (2022) 'Real time livestock rearing', *2022 International Conference on Computer, Power and Communications (ICCPC)* [Preprint]. doi:10.1109/iccpc55978.2022.10072153.

[28] Yaseer, A. and Chen, H. (2021) 'A review of sensors and machine learning in animal farming', *2021 IEEE 11th Annual International Conference on CYBER Technology in Automation, Control, and Intelligent Systems (CYBER)* [Preprint]. doi:10.1109/cyber53097.2021.9588295.

[29] DEBDAS, S. *et al.* (2022) 'An IOT solution for cattle health monitoring and tracking', *2022 OITS International Conference on Information Technology (OCIT)* [Preprint]. doi:10.1109/ocit56763.2022.00101.

[30] Taneja, M. *et al.* (2018) 'Fog assisted application support for Animal Behaviour Analysis and health monitoring in dairy farming', *2018 IEEE 4th World Forum on Internet of Things (WF-IoT)* [Preprint]. doi:10.1109/wf-iot.2018.8355141.

[31] Ariff, M.H. and Ismail, I. (2013) 'Livestock Information System using Android smartphone', *2013 IEEE Conference on Systems, Process & Control (ICSPC)* [Preprint]. doi:10.1109/spc.2013.6735123.

[32] Dineva, K. *et al.* (2021) 'Towards CPS/IOT system for Livestock Smart Farm Monitoring', *2021 International Conference Automatics and Informatics (ICAI)* [Preprint]. doi:10.1109/icai52893.2021.9639460.

[33] Markov, N. *et al.* (2022) 'Smart Dairy Farm - Digitalization and innovation', *2022 8th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE)* [Preprint]. doi:10.1109/eeae53789.2022.9831220.

[34] Joshitha, C. *et al.* (2021) 'Lorawan based Cattle Monitoring Smart System', *2021 7th International Conference on Electrical Energy Systems (ICEES)* [Preprint]. doi:10.1109/icees51510.2021.9383749.

[35] Angrisani, L. *et al.* (2021) 'Buff4l.0: Veterinary and engineering sciences at the crossroads in the industry 4.0 age', *2021 IEEE 6th International Forum on Research and Technology for Society and Industry (RTSI)* [Preprint]. doi:10.1109/rtsi50628.2021.9597308.

[36] Dang, T.-H. *et al.* (2022) 'A Lorawan-based smart sensor tag for cow behavior monitoring', *2022 IEEE Sensors* [Preprint]. doi:10.1109/sensors52175.2022.9967209.

[37] Shi, Z. *et al.* (2023) 'Internet-of- things behavior monitoring system based on wearable inertial sensors for classifying dairy cattle health using machine learning', *2023 IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET)* [Preprint]. doi:10.1109/iicaiet59451.2023.10291766.

[38] Ariff, M.H., Ismarani, I. and Shamsuddin, N. (2014) 'RFID based Systematic Livestock Health Management System', *2014 IEEE Conference on Systems, Process and Control (ICSPC 2014)* [Preprint]. doi:10.1109/spc.2014.7086240.

[39] Chaudhry, A.A. *et al.* (2020) 'Internet of things (IOT) and machine learning (ML) enabled livestock monitoring', *2020 IEEE 17th International Conference on Smart Communities: Improving Quality of Life Using ICT, IoT and AI (HONET)* [Preprint]. doi:10.1109/honet50430.2020.9322666.

[40] Trivedi, A. and Chatterjee, P.S. (2022) 'Care: IOT enabled cow health monitoring system', *2022 2nd International Conference on Intelligent Technologies (CONIT)* [Preprint]. doi:10.1109/conit55038.2022.9847701.

[41] Nobrega, L. *et al.* (2018) 'Animal monitoring based on IOT Technologies', *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany (IOT Tuscany)* [Preprint]. doi:10.1109/iot-tuscany.2018.8373045.

[42] Ur Rehman, A. *et al.* (2022) 'Implementation of an intelligent animal monitoring system using wireless sensor network and IOT Platform', *2022 International Conference on Cyber Resilience (ICCR)* [Preprint]. doi:10.1109/iccr56254.2022.9996080.

[43] M. Noorafiza, H. Maeda, R. Uda, T. Kinoshita and M. Shiratori, "Vulnerability analysis using network timestamps in full virtualization virtual machine," 2015 International Conference on Information

Systems Security and Privacy (ICISSP), Angers, France, 2015, pp. 83-89.

[44] N. A. M. Razali et al., "Political Security Threat Prediction Framework Using Hybrid Lexicon-Based Approach and Machine Learning Technique," in IEEE Access, vol. 11, pp. 17151-17164, 2023, [Preprint]. doi: 10.1109/ACCESS.2023.3246162.

[45] W. N. W. Muhamad et al., "Evaluation of blockchain-based data sharing acceptance among intelligence community," Int. J. Adv. Comput. Sci. Appl., vol. 11, no. 12, 2020.

[46] N. M. Noor, N. A. M. Razali, S. N. S. A. Sham, K. K. Ishak, M. Wook, and N. A. Hasbullah, "Decentralised Access Control Framework using Blockchain: Smart Farming Case," Int. J. Adv. Comput. Sci. Appl., vol. 14, no. 5, 2023.

[47] N. Noor, N. Matrazali, N. Malizan, K. Ishak, M. Wook, and N. Hasbullah, "Decentralized Access Control using Blockchain Technology for Application in Smart Farming," Int. J. Adv. Comput. Sci. Appl., vol. 13, Jan. 2022, doi: 10.14569/IJACSA.2022.0130993.

[48] N. A. M. Razali, W. N. W. Muhamad, K. K. Ishak, N. J. A. M. Saad, M. Wook, and S. Ramli, "Secure Blockchain-Based Data-Sharing Model and Adoption among Intelligence Communities," IAENG Int. J. Comput. Sci., vol. 48, no. 1, 2021.

[49] Z. Ishak, N. Rajendran, O. I. Al-Sanjary and N. A. Mat Razali, "Secure Biometric Lock System for Files and Applications: A Review," 2020 16th IEEE International Colloquium on Signal Processing & Its Applications (CSPA), Langkawi, Malaysia, 2020, pp. 23-28.