RFID Technology for Animal Tracking: A Survey

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***Abstract*—The application of animal tracking holds significant importance across diverse economic domains, encompassing sectors including livestock husbandry, agricultural practices, and the conservation of wildlife populations. It aims to track and understand animal behavior, movement patterns, and health status. The predominant use of RFID technology is observed within the domains of logistics, localization, and the tracking of goods. Notably, the application of this technology in the field of animal tracking has experienced a significant surge in popularity in recent years. This paper conducts a systematic literature review focused on understanding how RFID technology is being applied in the field of animal tracking. We have conducted a state-of-the-art research regarding animal tracking solutions in the scientific literature and patents. We have analyzed these solutions targeting which animals are being tracked, which problems are addressed, operating frequency, and whether other technologies are combined with RFID for animal tracking purposes. Among the categories of problems addressed, livestock management emerged as the main area, followed by animal tracking and traceability. Mammals, especially cattle, are the most common type of animal monitored. Considering RFID technology, passive UHF tags appeared more often. Moreover, many works also employed cameras and GPS together with RFID. Finally, this work can significantly contribute to this field by systematically presenting a state-of-the-art application of RFID for animal tracking.**

***Index Terms*—Radio frequency identification, animal tracking, RFID tag, RFID applications.**

I. Introduction

The FIELD of animal tracking plays a crucial role in scientific research and various economic sectors, such as agriculture, wildlife conservation, and aquaculture. It encompasses various techniques and technologies to track and understand animal behavior, movement patterns, and health status. This study area is significant because it provides valuable information on livestock management, ecological dynamics, and species conservation, leading to more efficient and sustainable practices. The size and scope of animal tracking are continually expanding with advances in sensor technologies, data analytics, and tracking systems. Its impact on the economy is significant, as precision agriculture and livestock monitoring, for example, have been shown to increase productivity and reduce resource waste, resulting in improved economic outcomes for farmers and stakeholders [1], [2], [3].

Radio Frequency Identification (RFID) is a wireless technology widely used in several applications such as supply chain management, localization, traceability, logistics, healthcare and access control, and even Internet of Things (IoT) [4]. This technology offers notable benefits due to its noncontact and nonline-of-sight nature, which allow tags to be read easily under various visually and environmentally demanding conditions [5].

In animal tracking, RFID can collect precise and real-time data on individual animals, their behavior, and health status in some applications [6], [7], [8]. RFID offers several advantages over traditional methods, such as visual observation and manual data collection. One key advantage is its noninvasive nature, which minimizes animal stress and discomfort during the monitoring process.

In the process of evaluating the application of an RFID system for animal tracking, there are some fundamental considerations. First, the system should be capable of simultaneously tracking and monitoring multiple animals housed in groups, such as on farms. Additionally, RFID tags should not have any adverse physical effects on animals or cause any alterations in their behavior. Furthermore, the systems should require minimal interventions or adjustments after installation, allowing undisturbed measurement of animal behavior and allowing their application on a larger scale [9]. Some issues regarding this technology's use should also be considered. These problems include high costs under certain conditions, performance affected by the type of antenna used, potential signal interference, and security concerns such as unauthorized access to the signal by rogue interrogators [10].

In this paper, we conduct a review of articles and patents to understand how RFID technology is being applied in the field of animal tracking. We highlight the main target animals for these solutions, the primary types of problems addressed, the countries where such solutions are most prevalent, and whether other technologies are combined with RFID for animal tracking purposes. The main question used in the review is "How RFID is applied to solve animal tracking problems?".

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This work is relevant because using RFID in animal tracking can improve the benefits of this area, and a systematic review of the literature can improve the communication of research findings to the scientific community, businesses, and policy-makers. We found works that perform similar reviews in the area of food industry 4.0 [11], fingerprinting techniques [12] and location and positioning methods [13], [14]. However, according to our research, no work systematically organizes articles and patents relating to RFID use in animal tracking.

The review is organized as follows. Section II provides a brief background on RFID technology and animal tracking, highlighting how the two subjects are connected. Section III explains the systematic review methodology considered in this work. Section IV provides the review results and discusses some of the findings, such as for which animals the applications are intended, what problem the publication solved, in which country the research was done, and if it uses other technologies in addition to RFID for animal tracking. In Section V, the conclusions of this article are presented.

II. Background

A. Radio Frequency Identification (RFID)

RFID technology has the basic premise of electronic tagging items using radio frequency. An interrogator (reader) sends power and communicates with these tags. Tags are composed of one antenna and one RFID chip. This chip is composed of an RF energy harvesting circuit, a finite-state machine, and a memory unity.

Depending on how the energy supply of the tag works, RFID tags can be divided into three categories: passive, semi-passive, and active. Passive tags get power wirelessly from the reader and communicate using the reader's magnetic or electromagnetic field. Semi-passive tags are powered using whatever available power source, such as a battery, a solar panel, or a piezoelectric plate. Semi-passive tags communicate similarly to passive tags by load modulation/backscattering the reader fields, whereas active tags are battery-powered and able to transmit information independently from a reader. An active tag can behave as a reader and tag depending on the application, for example, in smart sensor mesh networks. Active tags have higher operating distances compared to semi-passive and passive tags. Passive tags operate from just a few centimeters up to 12m. Semi-passive tags performance can be improved 2.5 times compared to highly performant passive tags. This limitation comes from the reader's reading sensitivity [15].

RFID technology can be used to track tagged objects in the context of tracking. Passive tags are used, for example, in equipment moving through facilities, locating books in libraries, and patients in hospitals, among others [16].

RFID operating frequency is a relevant parameter when developing an RFID solution. It is a regulatory parameter. It means that each country regulates the frequency range to be employed and the power limits. Low frequency (LF) RFID operates between 120-134 kHz, with a read range of 10 cm and a slower read speed than higher frequencies. High Frequency (HF) tags have a band of 13.56 MHz and have a wide variety of uses. Ultra-high frequency (UHF) tags have many designations around the world. In the EU, it is 865-868 MHz; in the USA, it is 902-928 MHz; in India, it is 865-867 MHz; in Australia, it is 920-926 MHz while in Japan it is 952-954 MHz. Brazil uses 902-907 MHz and 915-928 MHz. UHF RFID tags are faster and more affordable than LF and HF [17]. There are also VHF (Very High Frequency) tags that operate between 30-300 MHz. Moreover, the operating frequency determines the physical principle responsible for the wireless power transfer through inductive coupling or electromagnetic waves. Inductively coupled tags operate in LF and HF. LF and HF RFID systems have a few centimeters lower read range than UHF tags, which can reach up to 10m or more.

Fig. 1. Typical cow tracking with RFID tags clipped to their ears. (Source: [18]).

B. Animal Tracking

With the emergence of new advanced sensor technologies, agriculture has shifted towards the "smart" approach. In this context, RFID technology has introduced a range of new applications for tracking animals in both agriculture and cities [20]. For example, countries like Northern Ireland and Israel require all dogs to be marked. Similarly, the U.S. and Canada have implemented animal identification systems focusing on farm animals [18]. Farm animals such as cows (Figure 1), horses, pigs, sheep, or goats can have RFID tags placed under their skin or clipped to their ears. On the other hand, domestic animals can be marked, such as using collars for cats and dogs or bands on birds' paws. Animal tracking applications are often used for the conservation of wildlife (Figure 2), monitoring domestic animals, and within the livestock industry [21]. These applications enable control, tracking, monitoring, management, detection, and identification of various animal species. The specific purposes of animal tracking are diverse; for example, tags can be designed to track fish or collect health statistics for larger animals. In a study by [22], the authors tagged wild animals to track their movements and activities.

Another application in the context is to store information related to an animal's health history, including vaccination records, medical treatments, and dietary requirements.

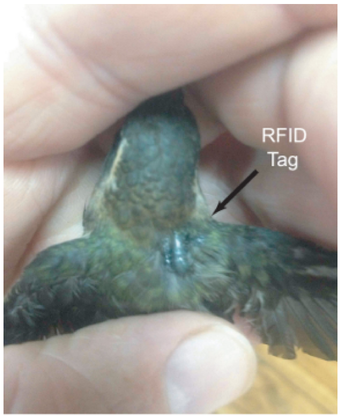

Fig. 2. Tag adhered to hummingbird (Source: [19]).

Veterinarians and animal caretakers can access this information by scanning the RFID tag, ensuring proper care and treatment. Some RFID tags are equipped with temperature sensors. This feature is particularly valuable for monitoring the body temperature of animals, helping to detect fevers or other health issues in real-time [23].

In animal tracking applications, passive RFID technology has some issues in outdoor environments because of the limited reading range. The reading range of passive RFID systems is affected by various factors, including interference, signal propagation, and environmental conditions. One of the main challenges is the need to increase the reading range and duration of the RFID tags, especially when placed in snow, water, vegetation, or underground. Another challenge is optimizing economic and environmental costs, as RFID monitoring requires using a set of antennas or ground and aerial vehicles to collect data or localize tags [24]. Overall, the challenges in using passive RFID technology in outdoor environments include increasing reading range, optimizing costs, mitigating ranging measurement errors, and improving security factors and standards. There are some studies about this short-range issue. In [25], the authors improve the Radar Cross Section of the tag by using a chipless RFID array configuration. In [26], the authors utilize software-controlled polarization to increase the range or reduce the transmit power of RFID readers. Additionally, techniques can be applied to correct the effects of meteorological factors, resulting in improved performance, as shown in [27].

In this work, we define four main issues in animal tracking: Animal behavior monitoring, livestock management, animal tracking and tracing, and finally, system design and development. Animal Behavior Monitoring aims to understand biodiversity patterns, ecological features of species, and population behavior. For example, it seeks to understand how animals adapt to changes in population dynamics, their ecological functions, and the ecological context in which they live. Livestock Management is interested in performing efficient animal capital management through tracking, enabling the acquisition of information about individual behavior, health, animal reproduction, birth records, and monitoring of vaccines and weight, among other information. The category Animal Tracking and Traceability encompasses works that aim at monitoring animals in general and tests that seek to verify the feasibility of monitoring certain animals, for example, by examining the use of RFID for monitoring wild birds. The category System Design and Development covers works that address the design and development of systems and devices for animal tracking, for example, the development of lighter and more compact devices and the development of systems that incorporate the integration of multiple devices and sensors, allowing for the collection, processing, and analysis of data.

III. Research Methodology

A. Systematic Literature Review

In this research, we performed a systematic review of the literature in three phases: planning, conducting, and reporting [28]. In the planning phase, we searched the scientific literature to evaluate articles that relate RFID technology to animal tracking problems. We then identified the need for a review to understand how and in which animal tracking RFID technology applications are being used, so that we could identify where contributions can be made in this field. Therefore, the research question was defined as: **"How RFID is applied to solve animal tracking problems?"**.

We used the StArt software to conduct and manage the research. This software focuses on helping systematic review of the literature [29]. In developing the review protocol, we delimited the research scope to consider only publications from 2009 to 2023 to have a good overview of the field's current state. After searching for some publications in the animal tracking field, we defined a search string and several keywords for the search engine. The search string defined was **"rfid" AND "tracking" AND ("animal" OR "livestock")**. We considered only publications in the English language, which was facilitated by the choice of keywords. We selected the IEEE, Springer, Science Direct, and MDPI publication databases.

For the conducting phase of the review, we researched the selected databases using the defined search string and the date filter. We imported the search results into the StArt software. In this phase, we found 2310 publications. Figure 3 presents a graph showing the number of publications found for each chosen database.

Continuing with the work, we read the titles and abstracts of the publications and applied the exclusion criteria listed in Table I. After this process, 100 publications remained. Subsequently, we conducted a full-text reading of the publications and applied the inclusion criterion listed in Table I. At the end of the selection, 87 publications remained. The final distribution of the publications can be seen in Figure 4.

A flowchart depicting the entire process conducted for selecting publications can be seen in Figure 5, and a list containing all these publications is described in Table II.

Figure 6 shows the distribution of publications in different types of scholarly sources, including journals (scientific journals), conferences, and book chapters. This analysis aims to provide an overview of the variety of places where the articles were published.

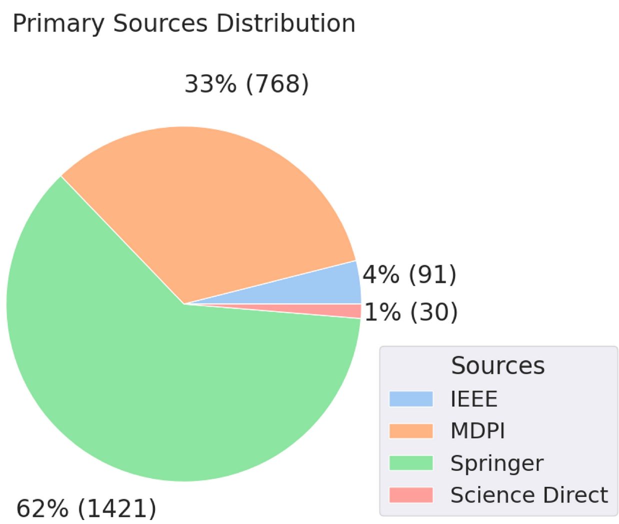

Fig. 3. Distribution of publications according to their databases (Source: Compiled by the author).

TABLE I
CRITERIA USED FOR INCLUSION AND EXCLUSION OF PUBLICATIONS

Criteria	Type
The paper is not an application of RFID on animal tracking	Exclusion
Duplicated Result	Exclusion
The paper is not from 2009-2023	Exclusion
The paper is not an Article or Conference Paper	Exclusion
The paper was not available online	Exclusion
The paper is an application of RFID on animal tracking	Inclusion

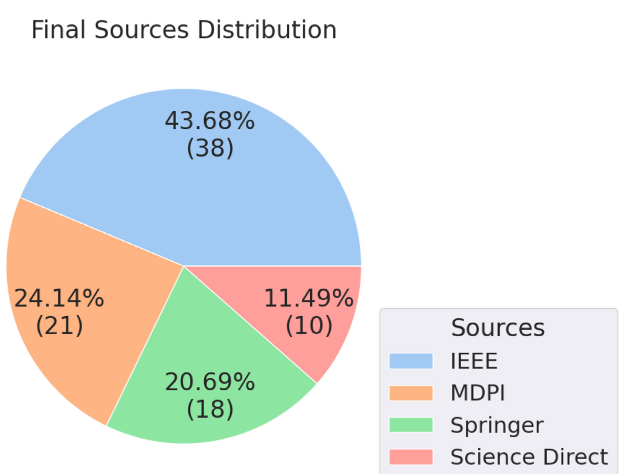

Fig. 4. Distribution of publications after the applied inclusion and exclusion criteria (Source: Compiled by the author).

Finally, all remaining publications were read to extract the following data.

1) Which animals did the application consider?
2) What problem did the publication solve?
3) In which country was the research conducted?
4) What was the RFID operating frequency used?
5) Did the research use other technologies besides RFID for animal tracking?
6) If the research used other technologies besides RFID, what was the technology?

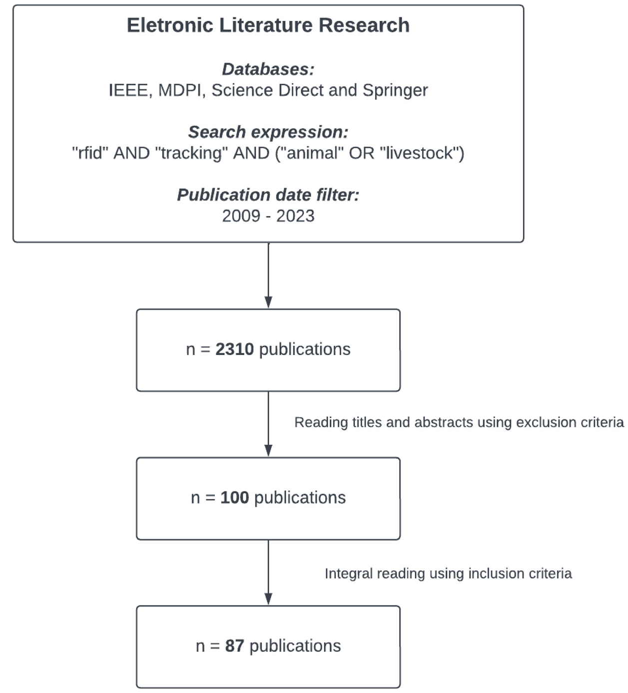

Fig. 5. Flowchart of the publication selection process (Source: Compiled by the author).

TABLE II
PUBLICATIONS SELECTED FROM EACH DATABASE

Database	Publication Reference
IEEE	[30], [31], [3], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [6], [53], [54], [55], [56], [19], [57], [58], [59], [60], [61], [62], [63], [64]
MDPI	[65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85]
Science Direct	[86], [87], [88], [89], [90], [91], [92], [93], [94], [95]
Springer	[96], [97], [98], [99], [100], [101], [21], [8], [18], [102], [103], [104], [105], [106], [107], [108], [109], [7]

B. Patents Review

In addition to scientific articles, we also conducted a review of patents registered in the field of animal tracking using RFID. For this review, we defined several keywords and searched for combinations of these keywords in patent search engines. The searched keywords were: **"active"**, **"animal"**, **"auricular"**, **"ear"**, **"label"**, **"livestock"**, **"plastic"**, **"radio"**, **"rfid"**, **"tag"**, **"tracking"**, **"uhf"**. We used Google Patents and the European Patent Office (EPO) as search engines. We selected the patents through an initial reading of titles and abstracts, and subsequently, when they fit the theme, we performed a full-text reading. At the end of this process, we selected 70 patents and organized them into a table. Figure 7 shows the distribution of patents according to the search engine.

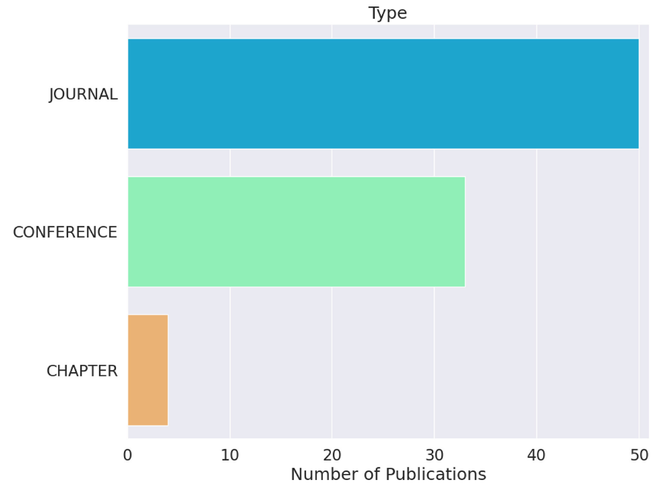

Fig. 6. Distribution of publications in academic sources (Source: Compiled by the author).

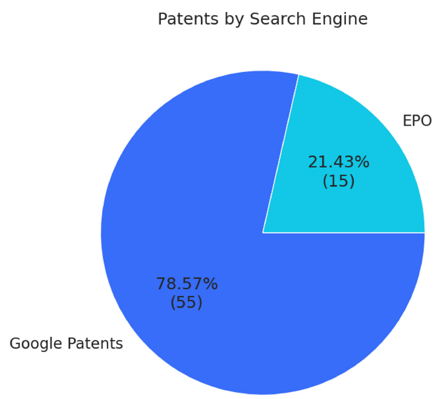

Fig. 7. Distribution of selected patents by search engine (Source: Compiled by the author).

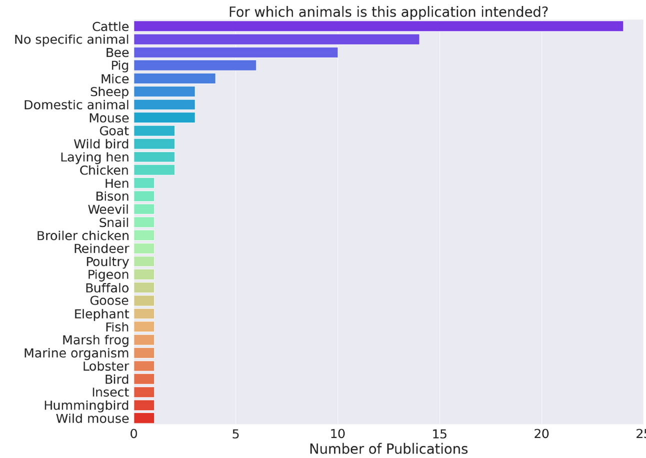

Fig. 8. Animals whose applications were intended (Source: Compiled by the author).

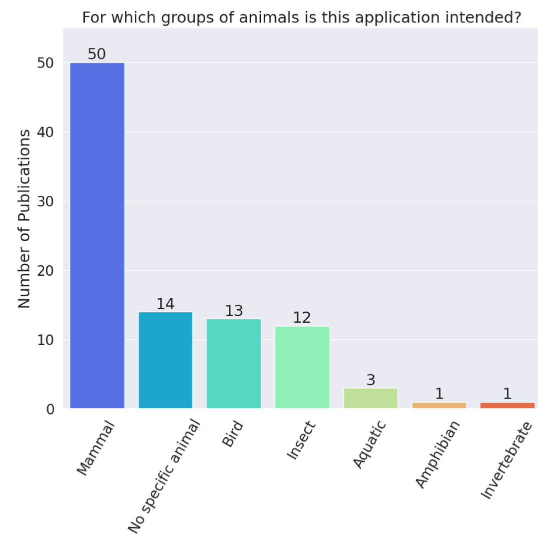

Fig. 9. Animal types which applications were intended (Source: Compiled by the author).

IV. Results and Discussion

This section presents the results divided by scientific literature and patents. We discuss the scientific results considering the questions defined in Section III-A, and we discuss the patents results considering the number of publications per year, the country of the publication, the target animal of the patent, the frequency used for the device, the type of the device and the patent status.

A. Systematic Literature Review Results

1) Which Animals Did the Application Consider?: Figure 8 presents the different animals considered in the applications presented in the publications. Some publications, such as [54], did not have a specific animal as their objective. For these cases, the option “No specific animal” was added, which ended up being the second most frequent. There is a significant difference in the number of applications targeting cattle compared to the others.

We constructed Table III to group the animals by type, thus having a better visualization of the most researched animal types in this field. Figure 9 shows how mammals are the most common types, but we also see many studies targeting birds and insects.

2) What Problem Did the Publication Solve?: We identified the problems addressed by the publications and categorized them into four different labels: **Animal Behavior Monitoring**, **Livestock Management**, **Animal Tracking and Traceability**, and **System Design and Development**. The list of categories for each publication can be seen in Table IV. When an article fits into more than one category, we chose a primary category based on its strongest association. An illustration of the distribution of these primary categories can be seen in Figure 10.

3) In Which Country Was the Research Conducted?: We compiled a list of countries mentioned in the publications as the locations where the experiments took place. In cases where the publication did not mention the experimental location or no experiment was conducted, we considered the countries of the authors for this purpose. The results can be seen in Figure 11, where the United States leads with 14 mentions, followed by China with 10.

4) What Was the RFID Operating Frequency Used?: Figure 12 shows the distribution of the devices’ operating

TABLE III
ANIMAL TYPES CLASSIFICATION

Type	Animals	References
Insect	Bee	[67], [83], [105]
	Insect	[50]
	Weevil	[77]
Bird	Bird	[32]
	Broiler chicken	[53]
	Chicken	[47], [73]
	Goose	[69]
	Hen	[68]
	Hummingbird	[19]
	Laying hen	[33], [71]
	Pigeon	[49]
	Poultry	[52]
	Wild bird	[30], [99]
Mammal	Bison	[107]
	Buffalo	[95]
	Cattle	[89], [36], [51], [94], [38], [3], [57], [43], [74], [91], [35], [76], [52], [90], [8], [18], [80], [7], [88], [42], [87], [85], [62], [58]
	Domestic animal	[18], [61], [82]
	Elephant	[63]
	Goat	[57], [60]
	Mice	[64], [66], [79], [102]
	Mouse	[46], [84], [96]
	Pig	[48], [52], [78], [103], [106], [37]
	Reindeer	[59]
	Sheep	[8], [57], [89]
	Wild mouse	[81]
Aquatic	Fish	[39]
	Lobster	[92]
	Marine organism	[101]
Amphibian	Marsh frog	[6]
Invertebrate	Snail	[93]
No specific animal	-	[21], [86], [55], [70], [31], [44], [34], [65], [98], [54], [104], [72], [56], [109]

frequencies considered in the publications. The Generic RFID category describes cases where the publication did not specify the frequency. UHF RFID devices were the most used, with 27 publications, and LF RFID appeared in 24 publications.

5) Did the Research Use Other Technologies Besides RFID for Animal Tracking?: We verified that 64.37% of the articles used only RFID for this purpose.

TABLE IV
CATEGORIZATION OF TYPES OF PROBLEMS

Types of Problems	Publication Reference
Animal Behavior Monitoring	[94], [67], [41], [101], [19], [53], [42], [33], [96], [92], [63], [7], [84], [32], [93], [64], [102], [86], [44], [105], [104], [6], [80], [75], [30], [82], [108], [109], [31], [34]
Livestock Management	[51], [57], [89], [90], [103], [69], [52], [95], [91], [73], [35], [38], [21], [48], [37], [61], [107], [39], [8], [106], [76], [6], [80], [47], [68], [54], [74], [3], [40]
Animal Tracking and Traceability	[32], [93], [64], [102], [86], [44], [83], [45], [66], [99], [65], [100], [71], [56], [18], [98], [59], [62], [87], [88], [77], [81], [78], [43], [85], [49], [105], [104], [51], [47], [68], [54], [74], [70], [50], [75], [30]
System Design and Development	[3], [40], [46], [60], [97], [79], [72], [36], [55], [58], [82], [108], [109], [31], [34], [70], [50], [75], [30]

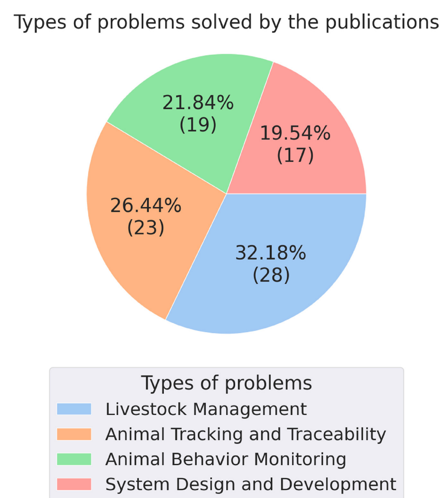

Fig. 10. Primary categories of the problem types aimed by the publications (Source: Compiled by the author).

Considering the other technologies used, the results can be seen in Figure 13, where it is noticeable that cameras and GPS are the majority.

Some studies, such as [47] and [56], compared the use of RFID and other technology. The first one compared an RFID system and a video system for the determination of broiler location and movement. The second is a review describing the current and upcoming traceability technologies for farm animals and their products. Other studies combined RFID with other technologies to build a more robust system. In [109], the authors combined RFID and a wireless camera sensor network to identify and track animals at a zoo. In [92], the authors proposed a system using infrared and RFID technology to locate and track lobster species to extract information on their activity and behavior.

B. Patents Review Results

Figure 14 presents the number of patent publications per year from 1970 to 2023. One can see that the number

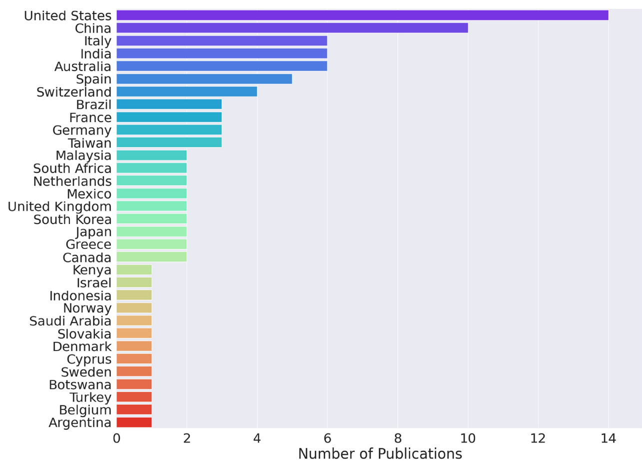

Fig. 11. Countries where the research was conducted (Source: Compiled by the author).

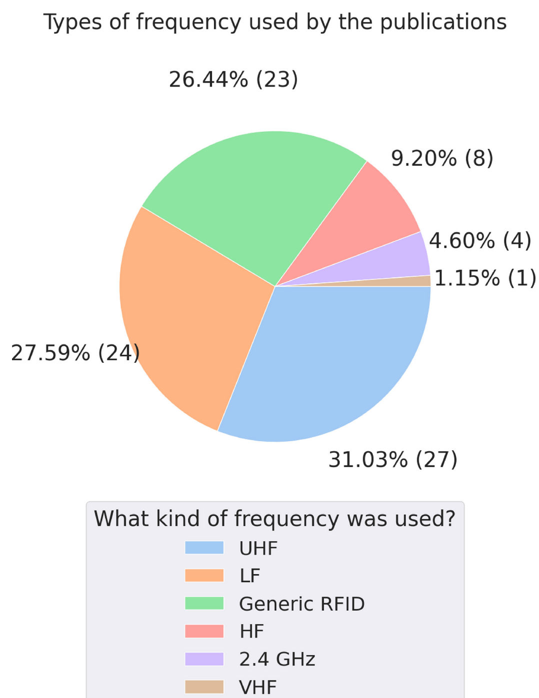

Fig. 12. Frequencies from the devices used in the publications (Source: Compiled by the author).

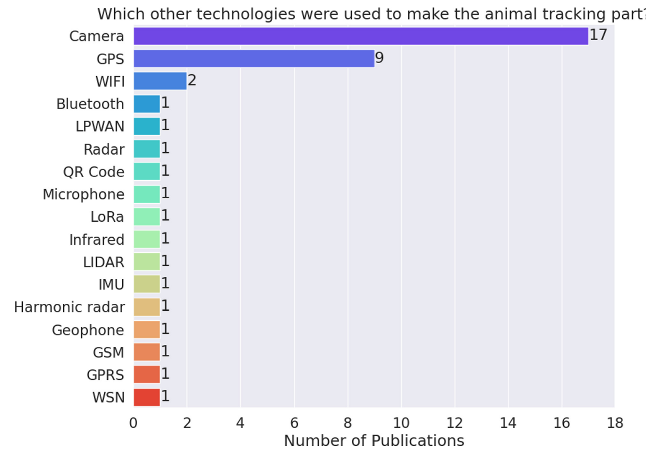

Fig. 13. List of technologies used for animal tracking in the articles, excluding publications that exclusively used RFID (Source: Compiled by the author).

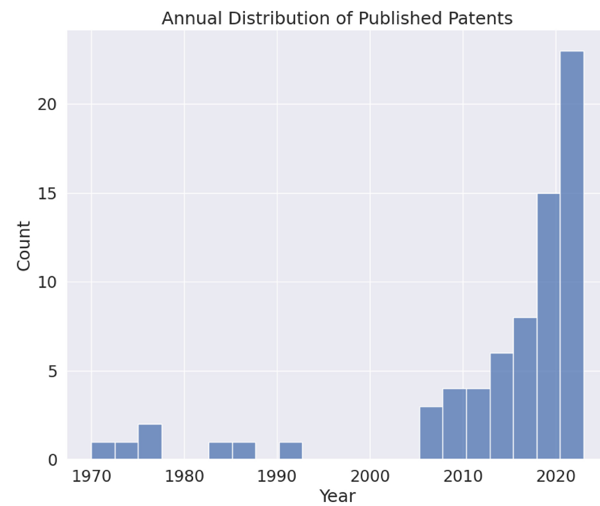

Fig. 14. Number of patents publication per year (Source: Compiled by the author).

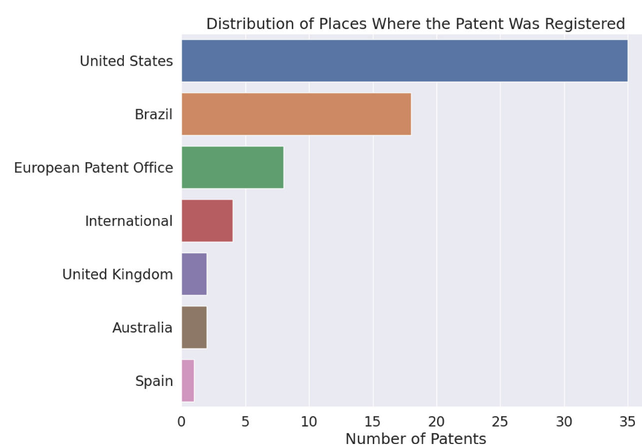

Fig. 15. Locations and number of patents published (Source: Compiled by the author).

of patents increased significantly from 2010. This could be attributed to technological advancements and increased market demand for solutions related to animal identification problems.

The distribution of the locations where the patents were registered can be seen in Figure 15. The higher number of patents from United States and Brazil compared to others may be indicative of these countries' heightened focus on the mechanization of their agricultural production. Some patents registered at the European Patent Office did not specify a country, so they were classified using the office name. Patents registered through the PCT - International Patent System [110] were classified as "International".

We also verified whether the patent was still valid. This information can be checked through the expiration date indicated in the document or by the non-payment of fees by the applicant, which can be seen in the search engine itself. The majority (67.14%) of the selected patents were still valid.

Notably, most scientific articles demonstrate the use of RFID technology for animal identification in a specific context,

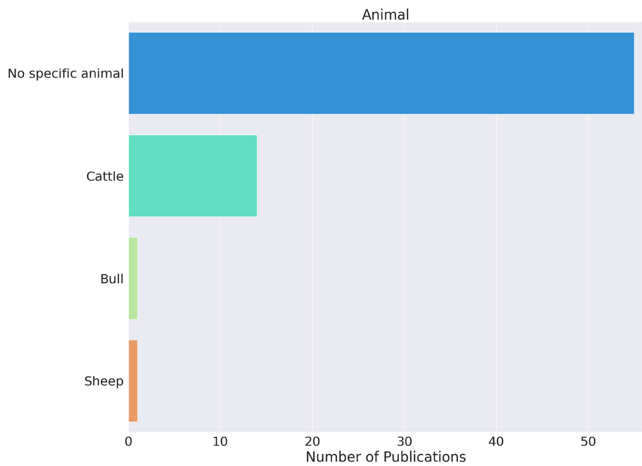

Fig. 16. Animal types which patents were intended (Source: Compiled by the author).

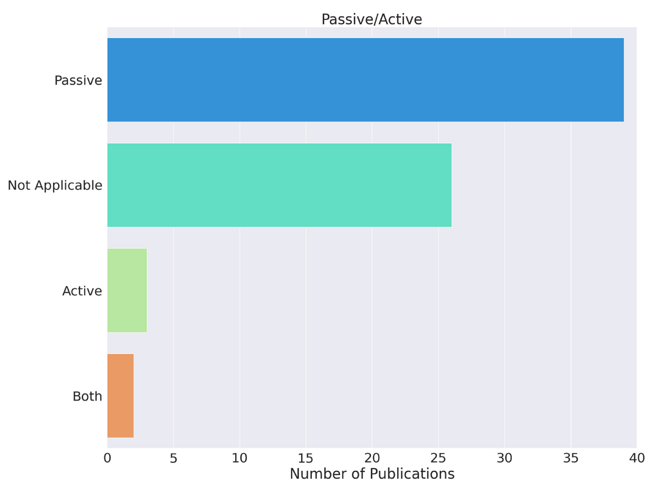

Fig. 17. Categorization of devices of the patents searched in passive/active (Source: Compiled by the author).

such as identifying bees in a hive or wild birds in the environment. On the other hand, patents focus on a product, a ready-to-use solution, or a proposal, such as electronic RFID tags for cattle monitoring.

Figure 16 presents data on the intended animals of the patents in a specific field. The vertical axis represents the animals, while the horizontal axis displays the quantity of animals. The graph highlights the predominance of patents related to mammals, with a significant focus on cattle.

Figure 17 illustrates the distribution of incidences of passive and active tags, as well as occurrences where both tags are applied, along with a category marked as Not Applicable for when the patent does not mention or have no relation to these types of RFID.

Figure 18 illustrates the frequency ranges found in the patents. The 'Generic RFID' represents patents that offer a versatile approach to frequency implementation. These patents can be used across various frequency ranges. This adaptability makes them suitable for diverse applications and industries, allowing flexibility and ease of integration. The 'Not Applicable' encompasses patents in which the application of frequency ranges is irrelevant or non-existent.

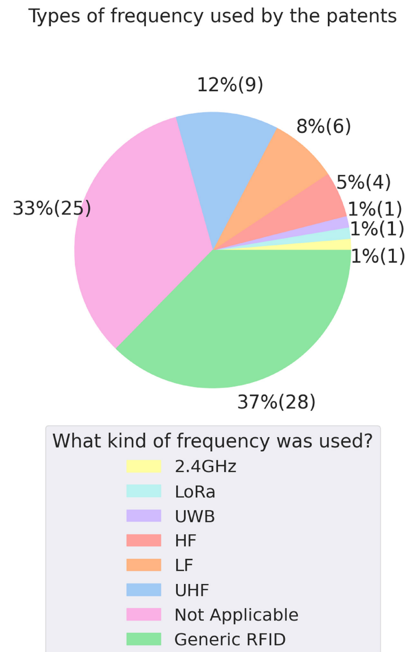

Fig. 18. Frequencies from the devices of the patents (Source: Compiled by the author).

C. Discussion

Considering the patents that specify which animal is the target, they all refer to types of mammals, primarily cattle, due to marketing reasons. Observing the same data regarding scientific articles, we see a greater variety of animal types, although mammals, particularly cattle, also represent the majority. This result is expected since the number of head of cattle has reached gigantic numbers worldwide. The number has increased by 100% in the last 40 years, now surpassing the human population in number [111]. According to the Food and Agriculture Organization, there are almost 1.5 billion head of cattle in the world [112]. Indeed, many other animals can be tracked using RFID technology, as seen in the literature, but they are not being commercially explored, as there are no related patents. Creating patents related to bees, chickens, fish, and other animals could be a market opportunity.

The results obtained regarding passive and active tags observed in Figure 17 reveal that passive tags are still widely preferred over active tags in commercial animal tracking projects. We found 39 patents related to passive tags, while only three patents were related to active tags. This significant difference in the number of patents can be attributed to several reasons. Firstly, passive tags are generally considered more suitable for monitoring due to their low cost and low impact on animals. Their smaller size minimizes disturbance to animal natural behavior. Additionally, passive tags are often lighter and less intrusive, allowing prolonged monitoring without the need for frequent replacement. On the other hand, active tags require a battery or another power source, which can result in a larger and heavier device. Moreover, they are considerably more expensive, although a larger area can be covered at a higher bandwidth. Active tags in some applications are the only viable option.

The high prevalence of articles addressing animal tracking technologies in Figure 13, such as GPS and cameras, is justified by their capabilities to provide crucial information for researchers and wildlife managers. With its precision in providing real-time location data, GPS proves to be especially valuable in studying migratory animals and understanding their survival strategies in constantly changing environments. Similarly, cameras provide detailed visual insights into animal behavior, social interactions, and habitat use. This non-invasive approach is particularly relevant in delicate environments where direct human contact could disturb natural animal activities and affect the validity of research findings. Moreover, cameras' effectiveness in remote and difficult-to-reach locations allows the study of species inhabiting isolated and unexplored environments.

When comparing tracking technologies, passive RFID emerges as an advantageous option compared to active tags and other hybrid technologies in high volume. However, UHF RFID readers, with highest performance, are the costly part of the solution. However, passive tags cost around tenth's of USD, which can compensate for the reader costs in a very high volume. For instance, active tags using BLE, LoRa, and GPS have a higher power consumption and unitary cost. Battery lifetime is an issue, and the expected battery lifetime for IoT applications, animal tracking included, varies from 2 to more than ten years. So, the battery represents a significant part of the total product cost and occupies volume in the product, making active tags heavier than their passive counterpart. In some cases, the weight of the tag and attaching methods can modify the animal's behavior. Some applications using cameras are being proposed complementary to RFID to increase reliability. A camera-based solution alone can be cost-effective in some scenarios, but the number of cameras increases for covering huge areas. Also, this does not guarantee the absence of blind spots. In the end, each application needs to be drawn considering the trade-offs of the available technologies for animal tracking. A research opportunity lies in conducting a comparative study using UHF RFID and cameras in an animal tracking application focused on costs, efficiency, and spatial coverage.

Lastly, we can highlight Figure 18 and Figure 12, where patterns in the frequencies' incidences are observed in articles and patents. It can be seen that UHF, LF, HF, and 2.4 GHz frequencies follow the same order pattern, with UHF being the most used frequency in both articles and patents, possibly because of the smaller size, lower cost in high volume production and higher read distance than LF and HF.

Furthermore, it was noticed that there is an increase in the classification "Generic RFID" in patents, indicating that the same product family covered by this patent can be deployed at a more suitable frequency.

V. Conclusion

This study conducted a systematic literature review aiming to understand how Radio Frequency Identification (RFID) is being applied to solve animal tracking problems. It highlighted the target animals, the problems addressed in the publications, the countries where the research was conducted, the frequencies of the devices used in the research, and the other technologies employed in conjunction with RFID for identification purposes. Additionally, a review of patents was conducted to gain insight into how the market employs this technology for such problems, focusing on the number of publications over the years, the type of RFID tag related to the patent and its frequency, and the countries with the highest number of patents published.

The results revealed more articles focused on mammals, particularly cattle. Among the categories of problems addressed, livestock management emerged as the main area, followed by animal tracking and traceability. The main technologies used alongside RFID for animal tracking were cameras and GPS. The United States and China led in terms of the number of scientific articles published in this field. In patent publications, United States and Brazil took the lead. The number of patent publications has increased significantly since the 2010s, suggesting a growing interest and relevance in this field. UHF was the most used frequency in articles and patents, possibly due to its ability to cover a larger area than LF devices, although they require more power. It was also observed that passive tags are widely preferred over active tags in commercial animal tracking projects.

Finally, we believe that this work can make a significant contribution to the field of animal tracking by systematically presenting the state-of-the-art in RFID application. This will provide researchers with a more precise direction of the articles to be considered, and it will also help entrepreneurs and government officials make better decisions about the application of technologies for animal tracking. This survey marks the group's inaugural endeavor in this field, and we have opted for a broader approach, laying the foundation for forthcoming research in this domain. In future work, a cost and performance analysis related to the utilization of tags, antennas, and other equipment in animal tracking applications may be undertaken. There are also plans for an analysis focused on solution architectures and their software.

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