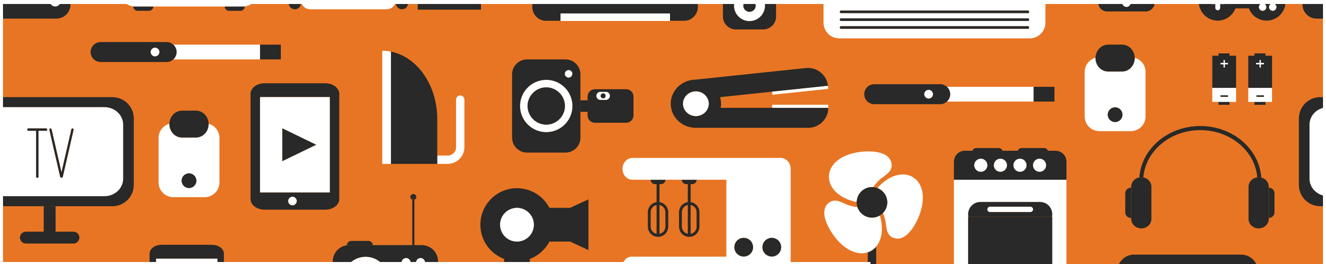

The State of IoT for Agribusiness in Brazil

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The Internet of Things (IoT) plays a significant role in advancing Agro 4.0 in Brazil. This article explores current IoT trends, benefits, and challenges of the IoT in the agriculture industry.

Agribusiness is one of the domains that have been revolutionized by the Internet of Things (IoT). Agribusiness corresponds to the set of economic activities that derive from or are related to agricultural production. Agribusiness has a production chain based on agriculture (vegetable farming) and livestock (raising animals for human consumption or product derivation).

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INTRODUCTION

Both agriculture and livestock comprise critical activities with relevant variables, such as temperature and humidity, that should be accordingly monitored and satisfied as they can greatly impact production. In agriculture, the level of humidity in the soil can determine the presence or absence of plagues (such as fungi and bacteria). In livestock, an inappropriate level of humidity and/or temperature in the production environment can, for instance, lead to the development of diseases and inflammation in the glands of animals, which may lead to reduced or lost production.

Hence, there is a prominent need for the control of the aforementioned variables so that the production is preserved (and hopefully increased). The need for precision when dealing with those variables motivated the large-scale adoption of technology, including the IoT, in agribusiness, culminating with the ascension of what is known as *Agriculture 4.0* or *Agro 4.0*. This term is an analogy to Industry 4.0 and emerged from disruptive technologies such as the IoT, big data, artificial intelligence, and robotics to extend, speed up, and increase the efficiency of activities that affect the entire production chain.

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This article presents the IoT for agribusiness from two perspectives.

- First, it addresses livestock with a discussion supported by the results from a case study of deployed IoT-based systems in farm settings in Brazil.
- Second, it addresses agriculture, with a presentation of the results from a conducted literature review on activities supported by the IoT as well as benefits perceived and challenges that remain.

BACKGROUND: AGRIBUSINESS IN BRAZIL

Brazil plays an important role in global agribusiness as it is one of the largest food producers in the world. According to a study conducted in a partnership between the Center for Advanced Studies in Applied Economics of the University of São Paulo (Cepea/Esalq-USP) and the Brazilian Confederation for Agriculture and Livestock (CNA) in 2021, the share of agribusiness in the Brazilian gross domestic product (GDP) exceeded 30% of the total Brazilian GDP, which is around US$1.74 trillion.

However, Brazil shares with several countries a reality of extremities. On the one side, rich producers possess the budgets that allow them to invest in technology and acquire expensive agricultural machinery. Contrastingly, small- and medium-sized farmers, whose production is domestic, for their own consumption, and for selling in their surrounding regions, operate with a limited budget and with limited access to technological solutions for production. Nevertheless, the importance of small- and medium-sized farmers' businesses and their impact on the economy is not considered negligible. CNA data from 2020 estimated that family farming covers the food need for nearly 70% of the population of the country.

From this perspective, the IoT emerges as a reasonable solution for agribusiness, providing solutions not only to rich farmers but particularly for small- and medium-sized producers. Some IoT-based solutions have been reported and brought important advances for both agriculture[1] and livestock.[2]

THE IoT IN LIVESTOCK

Our research group invested in the use of the IoT for monitoring and automated decision making in the context of compost-bedded pack barns and aviaries.[3] Sensors and actuators have been used, for instance, to monitor and regulate temperature and humidity in aviaries, autonomously turning on/off lamps and fans according to the readings received by sensors.[3,4] This type of solution is particularly important due to the sensitivity of birds to humidity and temperature. In particular, an IoT-based system was deployed on a farm in Posse, Goiás, Brazil, and worked for three days in 2021. The high-level architecture for the deployed system is shown in Figure 1. During its operation, the system succeeded in monitoring the humidity and temperature for 24 h over 13 days. The lamps and fans were turned on/off to maintain the temperature above 30° Celsius but below 37° Celsius.

Overall, 50 birds were monitored during that period. There were only two losses. The farmers were interviewed after the process, and they classified the final result as effective due to the automated control. The acquisition cost was relatively low, costing around US$150 for the entire solution, which is reasonable for small producers given the comfort and gains brought.

THE IoT IN AGRIBUSINESS: THE BENEFITS AND CHALLENGES

We conducted a systematic mapping study to investigate the potential of the IoT to enhance agriculture business. The research protocol is summarized in Table 1.

Thirty-five primary studies that either proposed or evaluated IoT-based systems in the agriculture domain were included and analyzed. The complete list of these primary studies can be found at http://shorturl.at/COY38. We particularly analyzed 1) the technical descriptions of the reported solutions; 2) the activities supported by the IoT in precision agriculture; 3) the specific domains supported; 4) the benefits expected and observed due to the adoption of IoT-based systems; and 5) the challenges that still remain as reported by these studies.

As for the technical solutions, the motivation for the majority of the studies focuses on data monitoring to assist rural workers in their activities. Many studies also reported the adoption of machine learning techniques. The top three areas of focus from the extracted solutions are: 1) predicting climate changes based on sensors and then acting accordingly; 2) monitoring particular planting

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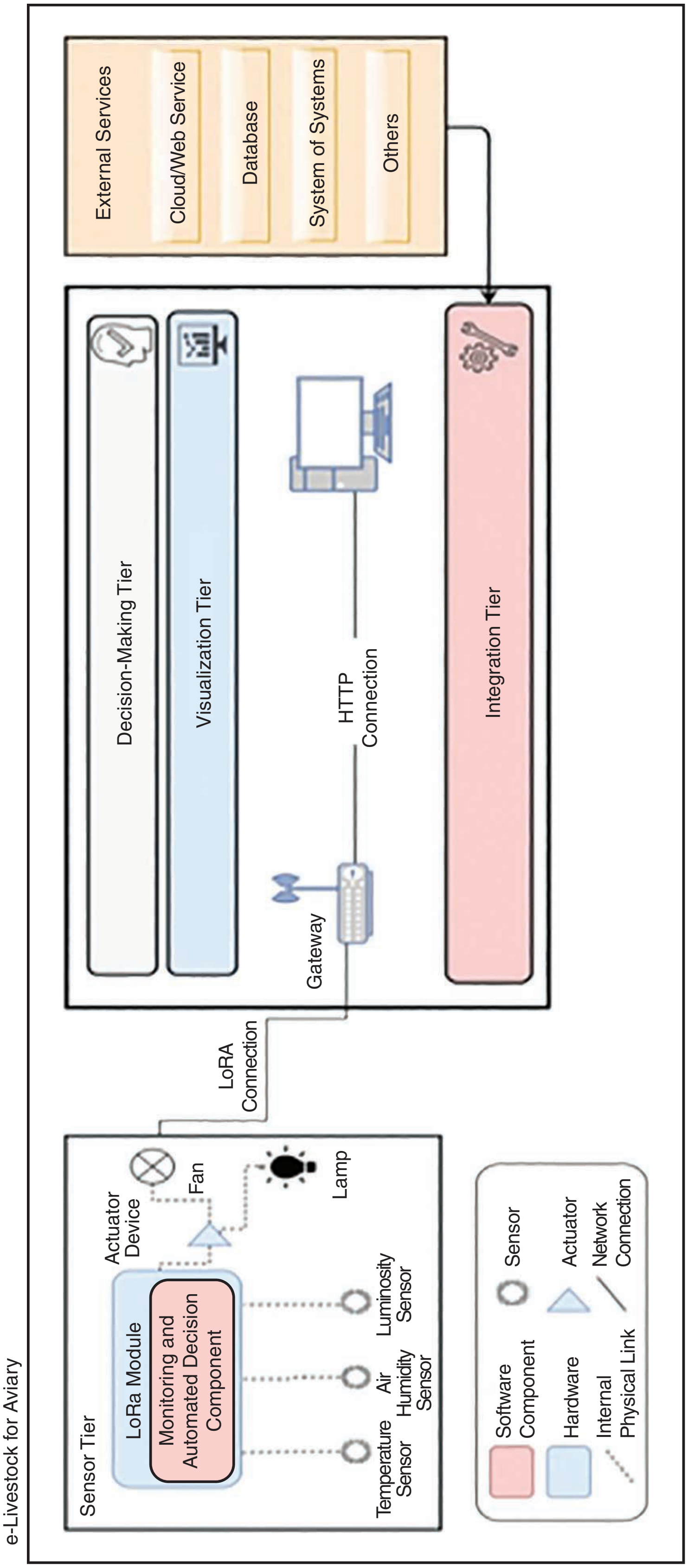

FIGURE 1. An IoT-based architecture for aviaries.[3]

activities; and 3) preventing the spread of plant diseases.

Python 3.0 was the most chosen programming language to implement proposed solutions. C++ was also utilized for implementing Arduino applications, and R was utilized for developing monitoring features. Three studies mentioned the use of ThingSpeak Cloud as the storage technology, while two studies used OwnCloud and Dropbox. In addition, the analyzed studies report a significant demand for mobile platforms, which have become increasingly accessible in rural areas. A significant portion of the studies also reported the use of Arduino technologies; Raspberry Pi as microprocessors; Wi-Fi Zigbee modules; Espressif ESP8266; ATMEGA 2560; and the Samsung S3C44B0X platform. Regarding sensors, the studies majorly reported the use of DHT22 and AM2302 humidity sensors and the use of Wi-Fi modules based on the Zigbee transmitter.

Apart from the technicality of the solutions reported, the results reveal that three high-level activities in agriculture have been recurrently supported by IoT-based systems: management, monitoring, and control. Table 2 provides a mapping of the studies to each area of these activities.

Management is concerned with the activities related to supporting a precise analysis and strategic decisions of a production. The data collected by sensors can serve as input for decisions regarding the farm budget and the administration of the entire production. For instance, if a relevant part of soy production has a lower size than expected, this can be an input parameter for a management system that can adjust/suggest commercialization prices.

Monitoring, on the other hand, is the activity delivered by sensors to support management activities. Humidity, temperature, plant sizes, and overall production are examples that can be monitored using sensors. Monitoring cultures have the potential to prevent losses and improve overall productivity.

TABLE 1. The research protocol's choices.

Research questions	**Q1:** What are the characteristics of the IoT-based systems introduced for the precision agriculture domain at the software level? **Q2:** What are the characteristics of the IoT-based systems introduced for the precision agriculture domain at the hardware level? **Q3:** What activities of precision agriculture have been supported by the IoT-based systems? **Q4:** What are the expected benefits of adopting the proposed IoT-based systems in the precision agriculture domain? **Q5:** What barriers to the adoption of the IoT-based systems in the precision agriculture domain have been reported by previous studies?
Search string	*(software AND (IoT OR "Internet of Things") AND ("precision agriculture" OR "smart agriculture" OR "agriculture 4.0" OR "smart farming" OR "intelligent Agriculture" OR "agritech"))*
Search strategy	SCOPUS (www.scopus.com) + Embrapa
Inclusion criteria	**IC01:** The study proposes or evaluates an IoT-based system for precision agriculture
Exclusion criteria	**EC01:** The study does not describe a primary study OR **EC02"** The full text from the study is not written in English or Portuguese OR **EC03:** The document is a book chapter, tutorial, summary, poster study, white study, or link OR **EC04:** The study is an old version of another one already considered OR **EC05:** The full text of the study is not available for access OR **EC06:** The study was published before the year 2010 or after the year 2020 OR **EC07:** The study does not propose or evaluate an IoT-based system for precision agriculture
Languages accepted	English + Portuguese

Abbreviations: Q: question; IC, inclusion criteria; EC, exclusion criteria.

Finally, control is related to the actuators and how they support the activities that can be automated or semiautomated, such as

1. watering plants with the right amount of water required by that specific type of crop
2. delivering the ideal and empirically proven amount of pesticides that can protect the plant from pests while maintaining low levels of toxicity for the final consumer
3. harvesting in an automated way; optimizing the use of plant bodies; avoiding losses; and taking care of sustainability and natural resources.

TABLE 2. Mapping of the primary studies (http://shorturl.at/COY38) to high-level agriculture activities.

Management and monitoring	Monitoring only	Control and management
S1, S2, S4, S6, S8, S9, S14, S15, S18, S20, S24, S25, S27, S29, S30, and S32	S3, S10, S11, S13, S16, S21, S23, S26, S28, S33, and S34	S5, S7, S12, S17, S19, S22, S31, and S35

Abbreviations: S: study.

Growth in the diversity of domains supported by the IoT was also observed. In the early years, studies on precision agriculture were mainly concerned with gathering data from the culture, but over the years, there has been an increase in the diversification of application areas, and new application contexts have been emerging. For example, the IoT has been increasingly utilized in viticulture (the study of grape cultivation); hydroponics (the process of growing plants in sand, gravel, or liquid); irrigation (the supply of water to land or crops to help growth, typically using channels); and greenhouse monitoring.

Regarding the benefits observed and expected, the analyzed studies reported on the potential of IoT systems for preventing unnecessary water expenses as a means to save natural resources and reduce the ecological impact of agricultural production. Other advantages worth mentioning include solving specific problems, such as

1. automation for avoiding the consequences of human exhaustion due to

continuous and repetitive work for long hours
2. addressing the need for fast and precise decisions
3. reducing the need for (and errors derived from) the human presence at the monitoring place.

Several of the studies also reported the low-cost nature of the proposed solutions. Fourteen out of 35 studies (40% of all primary studies) argue that their systems are based on low-cost development, using platforms such as Arduino. This thereby suggests that the technologies reported have been introduced to be financially accessible.

Finally, *service-related barriers* refer to the dependency that IoT-based systems may have on specific services, usually provided by third parties. This dependency may be particularly challenging when it involves a certain learning complexity to solve how to communicate with the service effectively and efficiently.

This article discussed how the IoT has revolutionized agribusiness, inaugurating a trend named *Agro 4.0*, in which the IoT plays a major role. A real application case was presented, and the results of a literature review showed a technical description of the solutions reported in the analyzed studies; a set of activities supported by the IoT in precision agriculture; the specific agriculture subdomains that have been supported; the benefits expected and reported due to the adoption of IoT-based systems; and the challenges that remain.

We conducted a systematic mapping study to investigate the potential of the IoT to enhance agriculture business.

Despite all the advances reached so far, challenges in the adoption of the IoT in agribusiness still remain. The instantiation of the same IoT-based systems in different application scenarios, such as different types of animal farming, planting, or culture, is one of the challenges. In general, the solutions are not abstractly described and are highly technology dependent. Then, a shift in the logic of the specification of those systems should be observed so that the same architecture could be deployed in different domains. Other challenges remain regarding communication issues, such as the unavailability of Internet connection on certain occasions and regions as well as the difficulty of intercommunicating hardware devices of different specifications. Another major challenge is choosing sensors that meet the precision necessary for supporting a particular precision agriculture activity. Indeed, some sensors provide insufficient data or are inadequate in a specific context, for example, for use in very large properties.

The IoT has the potential to support small- and medium-sized producers in several countries, optimizing their gains and automating tasks, besides possibly increasing their production, particularly in the livestock domain. Nevertheless, we remark on the need to make the technologies accessible to the agricultural industry.

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