Smart sensors and Internet of Things (IoT) for sustainable environmental and agricultural management

Sensores inteligentes e Internet das Coisas (IoT) para gestão ambiental e agrícola sustentável

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ABSTRACT
With the advancement of smart sensors and the Internet of Things, innovative technologies for environmental monitoring and rural installations have become solutions to increase production sustainably. Thus, this work analyzes the application of smart sensors and the Internet of Things (IoT) in the environmental monitoring of rural facilities, aiming to promote sustainability and efficiency in agricultural production. Smart sensors can collect environmental data in real-time, which is essential in rural environments. IoT enables communication and integration of this data. These technologies bring several benefits, such as improvements in efficiency, productivity, and sustainability. The study addresses types of sensors used in monitoring, such as optical, acoustic, chemical, and physical, in addition to monitored parameters, such as air and soil quality. Emerging technologies are also explored, including wireless network sensors, multispectral monitoring, microsatellites, blockchain, and virtual reality. The review includes case studies on successful applications of IoT and sensors in contexts such as smart irrigation, precision agriculture, and animal facility monitoring. It is concluded that these technologies have a high potential to contribute to more sustainable agricultural systems and animal production. Challenges such as privacy, security, and ethical use of data are highlighted.

Keywords: digital agriculture, environmental monitoring, virtual reality.
RESUMO
Com o avanço dos sensores inteligentes e da Internet das Coisas, tecnologias inovadoras de monitoramento ambiental e de instalações rurais tornaram-se soluções para aumentar a produção de forma sustentável. Assim, este trabalho analisou a aplicação de sensores inteligentes e Internet das Coisas (IoT) no monitoramento ambiental de instalações rurais, visando promover a sustentabilidade e eficiência na produção agrícola. Sensores inteligentes podem recolher dados ambientais em tempo real, o que é essencial em ambientes rurais. A IoT permite a comunicação e integração desses dados. Essas tecnologias trazem diversos benefícios, como melhorias na eficiência, produtividade e sustentabilidade. O estudo abordou tipos de sensores utilizados no monitoramento, como ópticos, acústicos, químicos e físicos, além de parâmetros monitorados, como qualidade do ar e do solo. Tecnologias emergentes também são exploradas, incluindo sensores de rede sem fio, monitoramento multispectral, microssatélites, blockchain e realidade virtual. A revisão incluiu estudos de caso sobre aplicações bem-sucedidas de IoT e sensores em contextos como irrigação inteligente, agricultura de precisão e monitoramento de instalações para animais. Conclui-se que estas tecnologias têm um elevado potencial para contribuir para sistemas agrícolas e de produção animal mais sustentáveis. Desafios como privacidade, segurança e uso ético dos dados são destacados.

Palavras-chave: agricultura digital, monitoramento ambiental, realidade virtual.

1 INTRODUCTION
Agricultural production is a fundamental pillar of global food security. Considering the constant population growth, it is necessary to produce in order to meet the demands for food. However, the intensive use of natural resources faces challenges worsened by the imperative of sustainability, as society includes the environmental footprint in its customs.

With the advancement of smart sensors and the Internet of Things (IoT), revolutionizing environmental monitoring in rural installations, these technologies have become more than just innovative and dynamic tools for collecting and analyzing environmental data but also solving issues technological technologies aimed at increasing production (Lajoie-O’Malley et al., 2020).

Smart sensors have the ability to collect a wealth of information about the environment, from climate data to soil quality and water resource management. They operate in real-time, providing continuous updates on environmental conditions (Adu-Manu et al., 2020). This is particularly valuable
in rural environments, where conditions can vary significantly from location to location and season to season.

IoT is the backbone that connects these sensors and devices, enabling efficient communication and real-time data integration. This connectivity enables accurate and timely data-driven decision-making. Farmers and rural facility managers can monitor their fields, pastures, and animal production facilities remotely, ensuring more efficient use of resources and rapid response to unforeseen environmental events.

According to Munirathinam (2020), the Industrial Internet of Things (IoT) is a crucial technology in the fourth industrial revolution. This promising technology has the potential to significantly transform industrial sectors by incorporating interrelated computing devices and sensors. Its goal is to enable the integration of predictive analytics and artificial intelligence (AI) into the manufacturing process.

This article’s general objective is to analyze the application of smart sensors and the Internet of Things (IoT) in the environmental monitoring of rural facilities, aiming to promote sustainability and efficiency in agricultural production.

Specific Objectives are:
• Investigate the fundamentals and applications of smart sensors and IoT in the context of agriculture and environmental monitoring;
• Evaluate the main types of sensors used for environmental monitoring;
• Analyze sensor networks and IoT in precision agriculture;
• Explore the use of sensors in monitoring animal welfare and their contribution to sustainable practices;
• Investigate methods for collecting and analyzing environmental data in real-time;
• Discuss current challenges and future perspectives related to the application of smart sensors and IoT in the context of environmental monitoring.
2 METHODOLOGY

This review was conducted through extensive bibliographic research in the Scopus, Web of Science, Google Scholar, and PubMed databases. Priority was given to articles published in the last 5 (five) years in peer-reviewed journals. Older literature was also considered if it presented a high degree of pertinence and relevance to the topics covered.

The search terms, both in Portuguese and English, were carefully selected and covered keywords such as "Internet of Things," "Smart Sensors," "Precision Agriculture," "Environmental Monitoring," "Rural Facilities," "Agriculture," "Crop Monitoring," and "Animal Welfare," among other related topics, to encompass the complete spectrum of the topic under analysis.

The order of priority in the selection of studies took into account not only their suitability for the search criteria but also the number of citations of the articles, reflecting their impact on the academic community. The assessment of study eligibility began with analyzing the titles, followed by reading the abstracts and conclusions and a complete reading of the studies, ensuring a careful screening.

To ensure the quality and accuracy of the process, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were adopted, as proposed by (Ruths et al., 2023), enabling a structured approach, which guaranteed the inclusion of essential elements at all stages of the review.

The selected studies underwent a thorough and complete analysis in which relevant data were extracted, systematized, and organized in order to compose a critical and cohesive review of current knowledge on the topic. The application of a systematic review strategy provided transparency and reproducibility of the search, selection, and analysis methods of information, thus providing greater robustness and reliability to the results presented.

3 SMART SENSORS AND IOT: FUNDAMENTALS AND APPLICATIONS

The Internet of Things (IoT) era is redefining agriculture and sustainable environmental monitoring in rural facilities, and smart sensors play a central role
in this technological revolution. To understand the impact of these technologies, it is essential to explore the concepts that support them.

Smart sensors are electronic devices designed to detect, measure, and collect data from their environment. Their inherent adaptability allows them to respond to changing environmental conditions, making them essential elements in the IoT era. The intelligence of these sensors lies in their ability to process information and provide valuable data in real-time (Singh et al., 2020).

According to (Sikder et al., 2018), these devices operate based on solid principles that guarantee the precision and effectiveness of their functions, including:

1) Detection: Smart sensors are equipped with components capable of detecting a wide variety of parameters such as temperature, humidity, light, movement, and gases. They translate real-world information into understandable electrical signals.

2) Measurement: Accurate measurement capability is critical. Smart sensors translate detected information into measurable data. For example, a moisture sensor can provide the exact soil moisture percentage.

3) Data Communication: The data collected by sensors needs to be transmitted to management and processing systems. Smart sensors are able to communicate with devices and networks, often via the Internet, ensuring information is available in real-time.

One of the most distinctive features of smart sensors is their ability to collect information in real-time, providing data that is constantly updated and available for immediate analysis (Aheleroff et al., 2022). This characteristic is essential in agricultural environments, where conditions can change quickly. Furthermore, according to (Balkrishna et al., 2023), the remarkable adaptability of smart sensors is a trait that makes them a powerful tool for farmers and rural producers seeking to make informed and accurate decisions in their operations, adapting to a variety of scenarios and conditions.
3.1 INTERNET OF THINGS (IOT): OVERVIEW OF YOUR AGRICULTURAL INSERTION

The significant impact of acquiring accurate data in agriculture, with the application of various technologies, was emphasized by (Kikuchi et al., 2021). This imminent advancement is considered innovative and aimed at improving ecology and sustainability. The ability to collect data with greater precision gives farmers a more comprehensive view to identify and solve complex problems related to both agricultural production and environmental preservation.

IoT includes devices that collect and send data about themselves or their surroundings. According to (Mrabet et al., 2020), IoT describes a network equipped with sensors, software, and network connectivity, allowing the collection and exchange of data between itself and the surrounding environment. The diagram represented in Figure 1 presents the basic operating architecture of the Internet of Things.

The diagram represented in Figure 1 presents the basic operating architecture of the Internet of Things.

Figure 1. The operating architecture of the Internet of Things

Source: The authors (2023).

The agricultural sector is increasingly incorporating IoT technologies and sensors with the potential to improve agricultural productivity, efficiency, and sustainability. According to Sinha and Dhanalakshmi (2022), the Internet of Things (IoT) transforms agriculture with connected devices that can monitor environmental conditions, track plant growth, and diagnose diseases. This information can be used to assist in decision-making and increase the efficiency
of agricultural production. Table 1 presents the main advantages and disadvantages of adopting IoT in agriculture.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved productivity: Farmers can make more informed decisions based on data collected by sensors. This can lead to greater productivity.</td>
<td>Cost: Implementing IoT in agriculture can be expensive.</td>
</tr>
<tr>
<td>Increased efficiency: Farmers can automate agricultural tasks, which can free up time for other activities.</td>
<td>Security: IoT systems can be vulnerable to cyberattacks.</td>
</tr>
<tr>
<td>Improved sustainability: Farmers can optimize the use of resources, which can reduce the environmental impact of agriculture.</td>
<td>Complexity: Implementing IoT in agriculture can be complex.</td>
</tr>
<tr>
<td>Cost reduction: Farmers can reduce costs, such as water and fertilizers, based on sensor collections.</td>
<td>Cultural: Some farmers resist changes to new technologies.</td>
</tr>
</tbody>
</table>

Source: The authors (2023).

The Internet of Things encompasses an ecosystem of interconnected devices that are equipped with sensors, actuators, and communication technology. These devices collect and share data with computer systems. The breadth of this network of devices ranges from smartphones and smart home appliances to agricultural sensors on farms and industrial equipment.

The basis of IoT is the interconnection of devices. Each device is equipped with sensors that collect relevant data such as temperature, humidity, geographic location, and more. This data is then transmitted via communications networks such as the Internet, wireless networks (Wi-Fi, Bluetooth, LPWAN), and other technologies to a central processing location.

One of the main strengths of IoT is its ability to collect, transmit, and analyze data on a large scale (Costa et al., 2023). This means that a wide variety of information can be collected from many devices in different locations. This data can be used for a variety of purposes, from real-time environmental monitoring to long-term trend analysis. In agriculture, sensors in fields can collect data on soil moisture, temperature, crop growth, light intensity, and more, allowing for accurate management of operations (Saiz-Rubio & Rovira-Más, 2020).

Smart sensors are crucial in revolutionizing agriculture and its sustainability, providing a wide range of applications that boost efficiency, productivity, and management in rural facilities (Martos et al., 2021). They also
enable accurate tracking of assets, such as agricultural equipment and livestock, preventing losses and resulting in time savings and operating in conjunction with global positioning systems (GPS), enabling the creation of agricultural maps.

3.2 BENEFITS OF IMPLEMENTING SMART SYSTEMS

The introduction of smart sensors and the Internet of Things (IoT) in agriculture brings a series of substantial benefits capable of revolutionizing the efficiency, sustainability, and quality of agricultural production. For example, according to (Zhou et al., 2019), soil moisture sensors can accurately indicate the time and place to irrigate, avoiding water waste and ensuring that plants remain at ideal humidity.

Improving efficiency not only leads to resource savings but also to reduced operating costs. With the ability to monitor assets, detect problems early, and automate processes, farmers can save on labor, maintenance, and inputs, making their operations more profitable (Mahmud et al., 2020).

In a context where sustainable agriculture becomes a growing priority, smart sensors play a fundamental role. Collecting environmental data in real-time allows the monitoring of more sustainable agricultural practices, including reducing the use of pesticides and fertilizers, which results in a lower environmental impact.

Technologies associated with the Internet of Things (IoT) have also enabled more efficient management of agricultural resources by providing real-time environmental data. This information allows for more accurate and sustainable decision-making, from optimizing water use and reducing the use of agrochemicals to correct animal monitoring. IoT sensors provide an affordable and direct way to collect, in real-time, data on weather conditions, light intensity, gas levels, and other variables of interest for monitoring confined spaces, as described by Kumar (2021) and Santos et al. (2023).

4 SENSORS FOR ENVIRONMENTAL MONITORING

Environmental monitoring in rural facilities depends on accurate data collection on a wide variety of parameters. In this topic, we will explore the types
of sensors used, the main environmental parameters monitored, and some of the emerging technologies that are shaping this field.

Lovatto et al. (2020) and Ullo & Sinha (2020)) stated that the high degree of quality of environmental monitoring in agricultural facilities depends on the accurate collection of data from a wide variety of parameters, such as the types of sensors used, the environmental parameters monitored and the technologies involved in the devices.

Sensors play a central role in environmental monitoring, allowing the acquisition of critical data for decision-making. Based on its operating principles, Javaid et al. (2021) categorize sensors into optical, acoustic, chemical, and physical.

Table 2 presents a classification of sensor types, their operating principles, and applications.

<table>
<thead>
<tr>
<th>Types of Sensors</th>
<th>Operation principle</th>
<th>Applications</th>
</tr>
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<tbody>
<tr>
<td>Optical Sensor</td>
<td>Based on light or electromagnetic spectrum</td>
<td></td>
</tr>
<tr>
<td>Acoustic Sensor</td>
<td>Monitors sounds and vibrations</td>
<td>Water quality, plant growth</td>
</tr>
<tr>
<td>Chemical Sensors</td>
<td>They detect specific chemical substances in the environment.</td>
<td>Detection of pests and animal activity.</td>
</tr>
<tr>
<td>Physical Sensors</td>
<td>They measure physical parameters, such as temperature, soil humidity, pressure.</td>
<td>Monitoring of pesticides and pollutants.</td>
</tr>
</tbody>
</table>

Source: Javaid et al. (2021), adapted.

The diversity of sensors available on the market is remarkable, and each type has specific characteristics that meet different environmental monitoring needs. A wide range of environmental parameters are monitored in agricultural environments, including rural facilities, aiming at sustainability and productive quality. According to Singh et al. (2021), some of the key parameters include:

- Air Quality: Monitoring air quality is essential to control atmospheric pollutants and ensure the health of plants, animals, and rural workers. The identification and control of gaseous pollutants and suspended particles are crucial elements of this process.
5 EMERGING TECHNOLOGIES FOR ENVIRONMENTAL MONITORING

Environmental monitoring in rural facilities is undergoing a significant transformation due to the rapid development of emerging technologies in the field of the Internet of Things (IoT). These technologies have the potential to change how information is collected, processed, and applied in rural contexts. According to Sharma et al. (2021), there are several innovative technologies that deserve to be highlighted:

- **Artificial Intelligence (AI):** It has been widely used to analyze large volumes of sensor data. It plays an important role in interpreting environmental information, predicting future conditions such as climate change, and optimizing agricultural practices.
- **Machine Learning:** Algorithms that involve machine learning, such as Neural Networks and Fuzzy Logic, allow sensors to act with expert systems, refining data collection and interpretation.
- **Big Data Analysis:** The analysis of large sets of environmental data is a growing area that allows trends to be identified and decisions to be made based on detailed, real-time information.

In addition to the technologies that are already consolidating and are in constant dissemination, promising solutions are emerging that deserve
exposure as state-of-the-art on the topic. These are innovations that include wireless network sensors, multispectral monitoring, data acquisition with microsatellites and unmanned aerial vehicles, advanced chemical sensors, application of blockchain for data integrity, and cybersecurity in Internet of Things (IoT) environments.

5.1 WIRELESS NETWORK SENSORS

One of the most notable developments in IoT is the proliferation of wireless network sensors. These compact, energy-efficient devices are capable of collecting data in a distributed manner and transmitting it in real-time to processing centers. They are essential for monitoring large and remote areas, such as farms and forests, where wired connectivity is impractical. They are also very effective for collecting data in rural installations and constructions as they do not require a fixed electrical installation network, thus making it possible to have their sensors placed in locations of interest for data measurement (Santos et al., 2023).

5.2 MULTISPECTRAL MONITORING

The ability to collect data across multiple bands of the electromagnetic spectrum is becoming increasingly accessible. According to Heinemann et al. (2020), multispectral sensors can measure characteristics invisible to the naked eye, such as soil temperature and humidity. This data provides detailed information on environmental conditions. They are also great sensors for observing thermal aspects and subsequent evaluation (Figure 2).

Figure 2. Environmental assessment with multispectral thermal sensors

Source: iStock – Andril Yalanskyi (2023)  Source: iStock – Buzun Maksimilian (2023)
5.3 MICROSATELLITES AND UNMANNED AERIAL VEHICLES (UAVS)

The combination of IoT with microsatellites and UAVs offers a unique perspective for environmental monitoring. These devices can collect large-scale, high-resolution geospatial data. Furthermore, they allow access to remote areas, comprehensively monitoring aspects such as land use, pest proliferation, climate conditions, and deforestation.

Microsatellites such as CubeSats have a variable spatial resolution, generally ranging from 3 to 30 meters, and operate for extended periods of five years or more (McCabe et al., 2017), while UAVs such as the DJI Matrice 300 RTK offer a resolution of about 2 centimeters per pixel with an average flight autonomy of 55 minutes (Štroner et al., 2021). Data processing is conducted by software such as QGIS and Pix4D, which allow detailed analysis and georeferencing of agricultural areas and rural facilities.

Cesca et al. (2021) and Silva et al. (2020) used spatial interpolation and data processing techniques to study the levels of animal comfort provided in hot climate regions in Brazil. In the end, they highlighted the importance of sustainable technologies for geospatial assessment in order to have consistent observation results. Figure 3 exemplifies microsatellite and UAV technologies.

Figure 3. Interaction of microsatellites and Drone with mechanization

Source: IStock – Dedmityay (2023)  Source IStock – gremlin (2023)

5.4 ADVANCED CHEMICAL SENSORS

Chemical sensors are becoming more sophisticated and specific. Instead of just detecting the presence of a substance, they can identify complex chemical compounds and measure their concentrations with high precision. This is particularly relevant for pollutant detection and monitoring of agricultural chemicals.
Sensors such as gas chromatographs coupled to mass spectrometers (GC-MS) exemplify this device, which has the ability to identify and quantify complex chemical compounds with remarkable precision (Torres et al., 2021). GC-MS is used to analyze air samples in agricultural facilities, allowing the identification of potentially harmful volatile compounds such as pesticides or exhaust gases. Its ability to discriminate between different compounds and measure their concentrations minimizes possible environmental risks.

5.5 BLOCKCHAIN FOR DATA INTEGRITY

Blockchain technology is being explored to ensure the integrity and authenticity of environmental data collected by sensors. The use of immutable and decentralized records increases the reliability of information, which is essential in contexts where data accuracy is fundamental for decision-making, such as in agriculture.

In this context, Torky and Hassanein (2020) state that blockchain acts as a trust mechanism, ensuring that environmental data is not tampered with or compromised in any way. As sensors collect essential information, such as data on soil quality, pollutant levels, or weather conditions, these are recorded in individual blocks linked to the previous one, creating a tamper-proof chain of information. This way, any attempt to modify the data would be identified and rejected by the blockchain network.

5.6 ADVANCED HUMAN-MACHINE INTERFACE

In the context of environmental monitoring in agricultural areas and facilities, advanced human-machine interfaces interact with operators' environments with technologies such as Augmented Reality (AR) and Virtual Reality (VR).

AR allows virtual elements to be superimposed on the real world, such as the quality of soil, plants, and fruits, in real-time while they are working (Holzinger et al., 2022). This facilitates decision-making regarding irrigation, management, and harvesting (Figure 4).
Figure 4. An example of Augmented Reality showing that it is possible to check characteristics of the observed culture in real time

Source: iStock – Nastasic (2023)

VR offers immersive environments, allowing professionals to explore scenarios, simulating real environments in Metaverses. Environments can be reproduced on a 1:1 scale, enabling detailed analysis, early identification of problems, and precise adjustments. VR can be used for operator training, allowing the practice of real situations in simulated environments (Bordegoni & Ferrise, 2023). For example, training in the maintenance of virtual machines and equipment similar to those in the real world contributes to a better understanding of scenarios and the development of essential interpretation and decision-making skills, maintaining the safety of those being trained.

6 CASE STUDIES AND RESULTS

The use of smart sensors and the Internet of Things (IoT) for environmental monitoring and agricultural facilities has been increasingly used to improve productivity, efficiency, and sustainability. Below are some case studies that demonstrate the success of this approach.

6.1 CASE STUDY 1: UNMANNED AERIAL VEHICLE AND GEOSPATIAL ANALYSIS IN SMART IRRIGATION

Zhao et al. (2023) discussed the use of big data analytics and the Internet of Things (IoT) in smart agriculture, specifically in the context of irrigation and crop monitoring using unmanned aerial vehicles (UAVs). IoT-assisted smart agriculture combined with big data analytics and geospatial analysis aims to improve crop yield, accuracy rate, and cost reduction. The article highlights the
importance of geospatial information systems (GIS) in analyzing soil data, mapping crops, and forecasting weather conditions.

In the end, the article concludes that implementing smart agriculture assisted by IoT allows a better understanding of crop monitoring, irrigation, and agricultural requirements through big data, in addition to contributing to the planning of planting and harvesting seasons.

6.2 CASE STUDY 2: APPLICATION OF THE INTERNET OF THINGS (IOT) AND SENSORS IN SMART AGRICULTURE

Mehmood et al. (2022) researched the applications of sensors and wireless networks in agriculture, highlighting their potential benefits. The authors presented a low-cost smartphone-controlled sensor based on image analysis to estimate nitrogen in plant tissues. They discussed using decision support tools in agriculture, such as the APSIM and DSSAT models.

Overall, the article provided information on using wireless sensors, decision support tools, and modeling techniques in agriculture to increase productivity and sustainability. Moreover, he stated that the low-cost sensor controlled by a smartphone has potential applications in agriculture, contributing to agricultural sustainability.

6.3 CASE STUDY 3: DESIGN OF A LOW-COST WIRELESS SENSOR NETWORK FOR DRIP IRRIGATION MONITORING

The research developed by Vandôme et al. (2023) developed a low-cost wireless sensor network for monitoring drip irrigation in Tunisia. The importance of this equipment was due to it efficiently addressing the lack of available water data and the limited use of decision support tools in agricultural water management. Sensor data was collected and displayed on an online platform accessible to registered farmers.

They developed an open-source wireless soil moisture sensor. They ultimately concluded that the equipment showed promise for monitoring irrigation in real-time and making decisions about water management and irrigation with low energy consumption.
6.4 CASE STUDY 4: TRAINING SYSTEM FOR COMPLEX ASSEMBLIES BASED ON VIRTUAL REALITY AND PROCESS MINING.

Roldán et al. (2019) researched a training system for machine operators in assembly tasks using virtual reality and process mining technologies. In the metaverse, intern workers used an immersive interface with tips to learn the assemblies introduced by specialized workers. In virtual reality, the training system involved four montages of different difficulty levels. Twenty volunteers participated in the experiments, and the results were evaluated based on user feedback and performance measures.

In the end, they concluded that user evaluations indicated better performance in terms of mental demand, learning, and results. The proposed training system is competitive with conventional alternatives regarding performance and user ratings.

6.5 CASE STUDY 5: WIRELESS SENSOR NETWORKS FOR MONITORING AND CONTROLLING ANIMAL FACILITIES

Abdulwahab et al. (2022) used wireless sensor networks (WSNs) in poultry farms for real-time facility monitoring and control purposes. Various parameters were evaluated, such as temperature, humidity, and ammonia levels, to ensure the well-being and productivity of the birds. The project included Arduino, water level, temperature, and light control sensors. In the end, they concluded that the system works correctly as designed, being a low-cost and easy-to-use device.

Santos et al. (2023) developed a hardware system for instantaneously measuring thermal well-being levels, light intensity, and gas concentration in swine facilities. Using a web protocol, the system allowed remote monitoring of the various variables analyzed, and in the end, it was highly recommended for use in animal production.

7 CALL TO ACTION AND FUTURE RESEARCH

Environmental monitoring is an essential activity for environmental management, as it allows the monitoring of environmental parameters, which enables the identification and mitigation of environmental problems more quickly
and effectively. However, it raises a number of ethical questions, such as privacy, security, and responsible use of data.

With increasing connectivity, cybersecurity becomes a critical consideration. Although it is still in its infancy, innovative approaches are already being developed to protect environmental monitoring systems and rural facilities against cyber threats. The implementation of security protocols, such as multi-factor authentication and data encryption, is being studied to prevent security breaches.

Research that includes implementing advanced techniques such as Identity-Based Security (SBI) and Quantum Security offers authentication that links devices to unique identities, reducing spoofing. The principles in Quantum Security involve the generation of quantum encryption keys, which are shared between communicating parties (Li et al., 2023). Any attempt to intercept a key during transmission is immediately noticed due to the sensitive nature of quantum mechanics, making this approach highly secure.

8 FINAL CONSIDERATIONS

Sustainability is one of the main challenges facing agriculture and animal production. Modern instrumentation, including smart sensors and IoT, has the potential to contribute to the development of more sustainable agricultural and animal production systems.

Modern instrumentation makes it possible to collect real-time data on a wide range of environmental and operational parameters that contribute to increasing agricultural production and improving its quality.

Real-time monitoring of animal welfare levels enables appropriate management, preventing diseases and promoting better animal/environment interaction, resulting in sustainable production.

Monitoring plant growth, animal productivity levels, and resource use increases production efficiency.

The real-time monitoring that these technologies enable of the quality of air, water, and soil contributes to reducing the environmental impact of agriculture and animal production.
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REFERENCES


