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Original Article

Prototype of a Puppy Incubator System Using IoT for Low-Resource Veterinary Clinics in Peru

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***Abstract** - The Internet of Things (IoT) facilitates connections between various smart objects. In Peru, implementing IoT-based prototypes for animal healthcare is rare. Using a hybrid Top-Down methodology and a five-stage case study, a puppy incubator prototype was designed for installation in two veterinary clinics in Arequipa. The objective is to create an IoT-enabled incubator for puppies and small animals, using cost-effective sensors and Arduino Cloud for real-time monitoring, especially benefiting resource-limited clinics. Data is transmitted through the ESP8266 WIFI module to Arduino Cloud IoT, providing high interaction for pet owners and clinics. The prototype achieved a 97.5% accuracy, with data and indicators easily accessible on Arduino's open platform.*

***Keywords** - IoT, Animal health, Incubator, Arduino Cloud IoT, Veterinary Clinics.*

1. Introduction

The use of technology in animal health care, specifically in veterinary medicine, has advanced considerably in recent decades [1]. However, in Peru and other Latin American countries, implementing systems based on the Internet of Things (IoT) to improve conditions in veterinary clinics is still limited. This technological gap is evident in low-income clinics, which lack access to sophisticated medical equipment, such as incubators for small animals. Implementing IoT devices in this context is scarce, but studies on their feasibility and effectiveness are practically nonexistent. [2], [3]. Several IoT-related research studies have emerged in animal welfare, employing medical sensors, communication technologies, cybersecurity, and mobile applications [4], [7]. These technologies continuously and wirelessly collect the necessary data for further processing [6], [8]. In addition, they facilitate rapid diagnostic care that mitigates losses. Added to this is the need to control variables studied in veterinary medicine, such as temperature [9] or thermal sensation inside an incubator. The high cost of implementing an incubator poses a challenge for current veterinary practices in Peru [2]. Globally, advanced incubators often include high-precision sensors, but their implementation in low-resource veterinary clinics is unattainable due to their cost, which ranges from $300 to $2000 [16]. Moreover, existing commercial systems are usually designed for incubation in agriculture or biotechnology without specific adaptations for small animal veterinary clinics, which evidences an important gap in applied research. This work proposes an incubation system for puppies using low-cost, accessible, and scalable IoT technology based on the Arduino Cloud platform, with inexpensive components such as the DHT11 sensor to measure humidity and the LM35 sensor for temperature. At approximately $50 USD, this IoT solution presents a viable alternative to traditional incubators, particularly in regions with limited resources. While research studies and non-proprietary incubator prototypes exist within the scientific community, a significant proportion of these are designed to incubate poultry or biochemical materials. Concern for practical training among university students is high [10]. For example, in Peru, there was a 16.19% dropout rate during the 2020-2 academic period [11], attributed mainly to the lack of physical-practical materials and application of the knowledge imparted during their years of study. Additionally, there is a drive towards innovation in theories and precision of concepts [6]. Therefore, this project aims to develop an affordable IoT incubator prototype that specifically addresses the needs of low-resource veterinary clinics in Peru. Unlike other studies on large animal production systems, this research seeks to improve access to environmental monitoring technologies for neonates in veterinary clinics by offering an innovative and affordable solution. In addition, this prototype incorporates a real-time monitoring system through the cloud, which facilitates immediate interaction between the veterinarian and the incubator status, improving animal care and optimizing clinic resources. In addition, it is important to mention that the project's development is based on the Top-Down Hybrid methodology. The authors of this research propose an approach of hierarchy and subdivision of tasks to achieve a specific objective [12]. In other words, it involves the following steps: First, an initial design is proposed to serve as a reference for the final prototype. Second, requirements are delineated to verify the design easily. Third, the logical design is modeled and simulated to prevent future risks. Fourth, the developed system is abstracted and refined to ensure it remains aligned with the main objective. Finally, the prototype model is documented for future replication and optimization [13], incorporating a case study detailing the step-by-step construction of the prototype. This methodology allows revisiting previous stages at any time for continuous monitoring and improvement of the project.

This project will be implemented in 2 veterinary clinics in the city of Arequipa, Peru, where the processes of medical rest of pets, such as puppies and kittens, will be automated, involving variables such as temperature, thermal sensation and humidity, which will be displayed in web applications of the Arduino Cloud IoT platform. This research aims to design a prototype incubator for puppies and small animals using IoT, with inexpensive and functional sensors through the Arduino cloud platform and establish real-time communication. In addition, it is aimed at veterinary clinics with limited resources. This research work has been organized as follows: In section II, the literature review was exposed, making a comparative study with other research similar to development and contributions for continuous improvement. In Section III, the research method was proposed, specifying the crucial elements in developing the prototype. In Part IV, the case study was presented, showing the step-by-step process for prototype development. In this section V, the result achieved at each point examined can be seen. Then, in Section VI, the discussions on the topic studied in comparison with the research of other authors were detailed. Finally, in Section VII, the conclusion can be examined, as well as suggestions for future studies that have not been detailed in this article.

2. Literature Review

This section will review how IoT has an essential role in the veterinary area and its application in cases of puppy incubation. In recent years, this technology has evolved, making some clinics dedicated to animal care more efficient in their attention, costs, time and quality of service. A comparison and differences between the research project under development and similar research will also be made. In a study conducted by Mayamiko et al. [31], an IoT system was developed to monitor temperature and humidity in newborn puppies using DHT11 sensors and an Arduino platform similar to the project under development. The system was designed to alert the caregiver in real time in case of dangerous fluctuations in environmental conditions. However, it focuses on remote monitoring, unlike the prototype developed in the present research that integrates complete incubation, where the effectiveness of low-cost sensors in animal neonatal health monitoring is validated. Upon completion of the prototype, it is expected to be functional and applied in low-income veterinary clinics, thus helping the welfare and care of puppies. As shown by [32], in their research article, they presented an IoT system intended to monitor the vital variables of neonatal puppies, including temperature and heart rate, using low-power sensors and real-time communication via WiFi. This system includes an interface for continuous data visualization, allowing the veterinarian or caregiver to intervene in case of irregularities quickly. The sensors' accuracy was a challenge they addressed through correction algorithms. In that sense, there is an excellent coincidence with the present project under development since it is of similar interest, having as a common goal to maintain a high level of accuracy in low resource conditions, with an added value is that the current project can also measure the humidity of the environment, even with this it is still low cost, compared to other equipment from large manufacturers.

In their research [33], they highlight the low cost of the sensors. They are an alternative to current air quality monitoring, temperature, and humidity technologies. Their study evidences problems with the calibration of temperature and humidity sensors, which limits their use in highly demanding clinical environments. The project under development achieved an accuracy level of 97.5%, validated with reliable instruments, significantly improving this aspect and providing accurate data in real-time that allows safe and adequate monitoring in low-resource veterinary clinics. The authors [34] propose an IoT system for environmental monitoring in veterinary clinics in their research article. However, their study indicates that their solution's lack of adaptability and scalability limits its application in varied environments. Unlike the prototype developed in the present research project, being based on a Top-Down methodology with accessible and scalable components, it overcomes this limitation. The integration with the Arduino Cloud platform allows greater flexibility to add sensors or functions according to the needs of each clinic, making it applicable to a wider variety of environments.

According to research, there are several IoT use cases in monitoring systems for farm animals and aquaculture, where real-time data collection helps to optimize production and animal welfare [9], [4]. For example, Treiber et al. [4] explored how using sensors on dairy farms improved herd management and reduced operating costs, demonstrating the effectiveness of IoT in monitoring environmental variables for large animals. Antonucci and Costa [9] extended these findings to the aquaculture sector, using IoT to improve accuracy and efficiency in fish farm management. Although these studies establish a solid foundation for the use of IoT in animal production environments, they do not offer solutions adapted to small animal veterinary medicine or in clinical settings with limited financial and technological resources. As stated by [6], they highlight the high cost of implementing IoT in specialized veterinary applications, an obstacle in clinics that cannot afford significant investments. On the other hand, with a total cost of approximately $50, the prototype developed in the present puppy incubator research project, which combines inexpensive sensors and an open-source platform, offers an economically affordable alternative compared to higher-cost solutions generally out of reach for clinics in disadvantaged settings. A study by Falcon and Cuya [35], in the context of poultry farming in Peru, highlights the lack of specific IoT solutions for small veterinary clinics, where neonatal care is not a priority in technological development. On the other hand, the prototype developed in the present project directly addresses this need, offering an adaptable and affordable tool that allows real-time monitoring of the health status of puppies in clinics with limited resources, representing an innovative and specific solution for the veterinary context in Peru. In [36], the authors describe research on a common goal: developing environmental monitoring prototypes using IoT to improve animal welfare. While the ongoing project focuses on incubation and real-time monitoring for puppies in veterinary clinics, the paper by Ramos-Cosi and Vargas-Cuentas addresses temperature and humidity control in domestic quail farms in Arequipa, Peru, also employing DHT11 and LM35 sensors together with Arduino, but without cloud connectivity for remote monitoring. In summary, the research conducted by the authors is focused on the development of IoT for industries. Likewise, none of them raises specific solutions for low-income veterinary clinics in rural areas, which is why this research work tries to fill this gap that has not yet been developed in order to serve puppies using IoT for low-income veterinary clinics in Peru, thus contributing to future researchers to delve deeper into this area as the current gap is significant.

3. Methodology

This study used the top-down methodology because it presents a structured approach in which the system is developed from a general vision to increasingly specific components. The process begins with the high-level design of the system, establishing the overall objectives and requirements. The system is then decomposed into more manageable modules, designed and implemented sequentially until complete detail is reached. This approach facilitates risk control and ensures that each design and development stage align with the project objectives. This is why, for developing the IoT puppy incubator prototype, the Top-Down methodology was fundamental, as it allowed structuring the design process logically and systematically, ensuring that each stage was aligned with the specific objectives of low cost, accuracy and adaptability in low-resource veterinary clinics. How it was applied at each stage of the project is explained below.

3.1. Initial Design

We started by creating a prototype document following the steps of the Top-Down methodology. This draft was later improved and used to guide the concepts explained later [13], [14]. At this stage, the project's central objective was to develop an affordable IoT incubator for real-time monitoring of critical variables such as temperature and humidity in low-income veterinary clinics in Peru. Cost (not to exceed $50), accuracy (at least 97.5%) and accessibility (interaction through Arduino Cloud IoT) requirements were also established. This initial design provided a clear vision of the system and delimited the scope.

3.2. Planning and Requirements

We identified the necessary components with the objective defined in this methodological phase [13], such as the ESP8266 WiFi module, the LM35 and DHT11 temperature and humidity sensors, and the cloud data platform (Arduino Cloud IoT). In this phase, hardware alternatives were analyzed, and those components that met the requirements of low cost and accuracy were selected. The necessary resources were also defined for developing and validating the prototype in two veterinary clinics in Arequipa, Peru. As previously indicated, an area investigation was carried out, and a set of exercises were designed and thoroughly completed to determine the degree of difficulty corresponding to each.

3.3. Logic Modeling and Design

It is understood that the incubator prototype must be guided by an independent and robust logic control system [12], [14]. Therefore, a logic model, including data flow and system architecture, was developed during this phase. This involved designing a flowchart of how the sensor data would be collected, transmitted and stored in the cloud using the ESP8266. The user interface was also modeled in Arduino Cloud, ensuring that the data would be visualized in real-time and in a manner accessible to the veterinarian. This involved finding the right tools for each stage of the target tasks defined in the previous phase.

3.4. Abstraction

In this phase, the actions and elements used are confirmed, where the initial validation or tests are carried out [14], and possible improvements are proposed to optimize the prototype. The system was divided into several functional modules:

3.4.1. Sensor Module

Includes the temperature and humidity sensors, which are responsible for capturing the critical variables of the incubator.

3.4.2. Communication Module

This consists of the ESP8266, which sends sensor data to the Arduino Cloud platform.

3.4.3. Control and Monitoring Module

Integration of the Arduino Cloud platform to visualize the data in real-time and trigger alerts when parameters exceed the default values. Each module was designed and tested separately to ensure proper operation before full integration.

3.5. Manifestation and Documentation

Completion of the article is subject to peer review. Subsequently, system accuracy and stability tests were conducted in two veterinary clinics in Arequipa. Sensor data were compared with reference instruments to confirm the 97.5% accuracy. During this phase, it was validated that real-time data transmission was performed without interruptions and that the interface in Arduino Cloud was intuitive and accessible to the veterinary staff. The research was written up to conclude the study, and new proposals for prototype improvement were found due to the literature review that is part of the writing process. Thanks to the methodology, it was possible to introduce beneficial changes to the puppy incubator prototype.

4. Case of Study

The incubator prototype implemented in low-resource veterinary clinics collects and monitors critical variables for the puppy's health. These variables include temperature, relative humidity, and thermal sensation. Once these objectives were established, guidelines and tasks for modeling, design, construction, and prototype implementation were followed.

4.1. 3D Prototype Design

Once the right parts for the puppy incubator prototype were determined, a 3D prototype design was completed to get a worldwide picture of where the incubator, sensors, and actuators were located. Furthermore, Figure 1, created using the open-access FreeCAD software (version), takes advantage of low graphics card requirements and resources with its characteristic efficiency. The design was broken down into elements, where the individual design of each component is presented and treated as an object, allowing for movement in three-dimensional space (x, y, z axes) [16]. Similarly, actual software components were used to construct mechanical components, including supports, sockets, and mobile structures. However, the electronic design presented a major obstacle because every component had a complicated design, and there was no library for the incubator's gadgets, such as the Arduino Nano v3.0 platform.

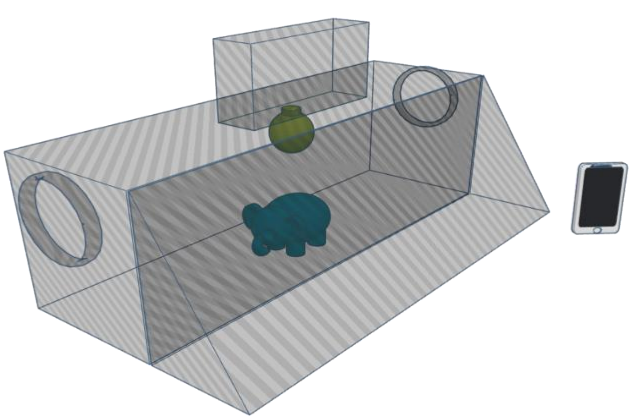

Fig. 1 The puppy incubator prototype's 3D design in free CAD 3D

After designing the incubator, cost estimation was one of the prototype's main objectives. It was discovered that the incubator prototype cost $50 in total, including the shell and structures, with electronic components making up 80% of the cost. Additionally, it is feasible to recommend and calculate the incubator's price for veterinary clinics with tight budgets.

4.2. Study Area and Requirements

The study area is located in the province of Arequipa, Peru. This area belongs to the lower mountainous region, characterized by a temperate and dry climate in the southern part of Peru [17], with an average annual temperature ranging from 7.0 ° C to 22.2 ° C. The region is relatively flat, with a high population density, which helps the application of the prototype due to the large number of pets in a given study area [9]. Furthermore, the development of the aforementioned methodological steps serves as guidelines for implementing the puppy incubator prototype. It begins with the designation of signals and components, which are then implemented into a control system.

4.3. Definition of Signals and Components

Once the target location of the application of the prototype was established, it was intended to achieve the direct construction of the incubator; however, it was necessary to define the typology of economic sensors on the market for data storage and processing.

The Arduino platform was used in this case, with the Arduino Nano v3.0 model, which has the Atmega 328p microcontroller [18]. It has adequate processing capacity to maintain measured and stored variables. The definition of the electronic components of the prototype incubator is shown in Table 1. The operation's objective is to recognize the capacity of the microcontroller with the various inputs and outputs, in addition to the respective plug and play modules that save the design of the prototype [18], [19] and make the design of its operation figure 2 more compact.

Fig. 2 Referential image of the prototype of incubator for puppies

Table 1. Description of the incubator components

Component	Name	Description
1	Wooden box	Trupan wood coated, dimensions 50cm x 50cm
2	Arduino Nano v3.0	Suggested operating voltage of 7-12V, with 14 digital input/output pins
3	LM35 Temperature sensor	Optimal voltage range of 3-5.5V, analog output of 10mV per °C
4	DHT11 Humidity sensor	Optimal voltage 3 -5.5v. Digital humidity output ± 0.5%, temperature range 0-50 ° C.
5	Relay module	Operates at 5V with an output capacity of 250V 10A
6	On/Off Switch	Enables automatic mode for control tasks
7	LCD 14x2	Operating voltage of 5V, alphanumeric display with 28 characters, I2C communication

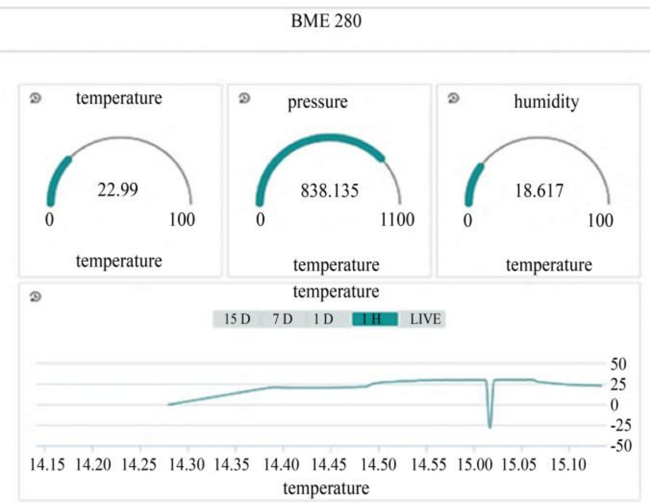

Fig. 3 Arduino Cloud IoT GUI image

4.4. System Control Modeling

The Arduino platform's IDE and programming language are renowned for their versatility [21]. However, it is also crucial to have a solid grasp of these control measures for the prototype and basic control procedures [6]. Control diagrams with stages and transitions (GRAFCET) representations, contact diagrams [22], block diagrams, and even flowcharts are among the most often used approaches for assessing the robustness of control activities [23]. This work relies on a flowchart, comprehensively addressing typical programming-related problem-solving tasks. As shown, the flowchart (Figure 5) provides a sequential explanation of the installation of the puppy incubator prototype. The instructions in this stage may include defining and initializing variables, setting measurement parameters, selecting the appropriate temperature for the type of puppy, and storing and processing the remaining variables.

After copying the instructions, the corresponding programming will be done. To store the recursions, programming was implemented using the Arduino IDE [21] (disabled access version) since libraries and instructions may be directly integrated into the Atmega 328p microcontroller using the programming device, which is compatible with the Arduino platform [18], [24].

4.5. Cloud Platform Usage and Documentation

Using an HMI (Human-Machine Interface) is important for various controls. An LCD screen (Figure 4d) and a control switch for the HMI were proposed for this puppy incubator prototype. The new and revamped Arduino Cloud IoT platform [25] was also employed. Figure 3 displays the graphical user interface (GUI), which receives data via the WIFI module ESP8266. Furthermore, this GUI generates a real-time graph of the received data, and this functionality can serve as an additional system to control, which was not incorporated into the prototype's design.

5. Results

Following the design, application of the methodology, and component validation, an experimental campaign of the puppy incubator prototype was carried out in veterinary clinics in Arequipa, Peru.

5.1. Methodology

Figure 6 displays the results from Q1 to Q4 in the methodology process, following the order of activities. As the prototype is developed and tasks are completed, new tasks and timeframes are addressed in the implementation process.

Regarding abstraction, an important aspect to highlight is the application of multitasking and time distribution in terms of literature and physical aspects. In the time distribution shown in Table 2, the estimated percentages for the final development of the prototype are displayed. Furthermore, it is considered a constant variable and multiplied according to the number of prototypes to be implemented.

5.2. Case of study

As the primary design objective of a puppy incubator prototype, Figure 4 presents the schematic circuit (Figure 4c) corresponding to the prototype, which includes the Arduino v3.0 board and the WIFI module ESP8266 with output terminals for connection (Figure 4a).

The arrangement and distribution of connectors are designed for the future scalability of the prototype and the addition of upcoming biomedical sensors dedicated to animal health (Figure 4b).

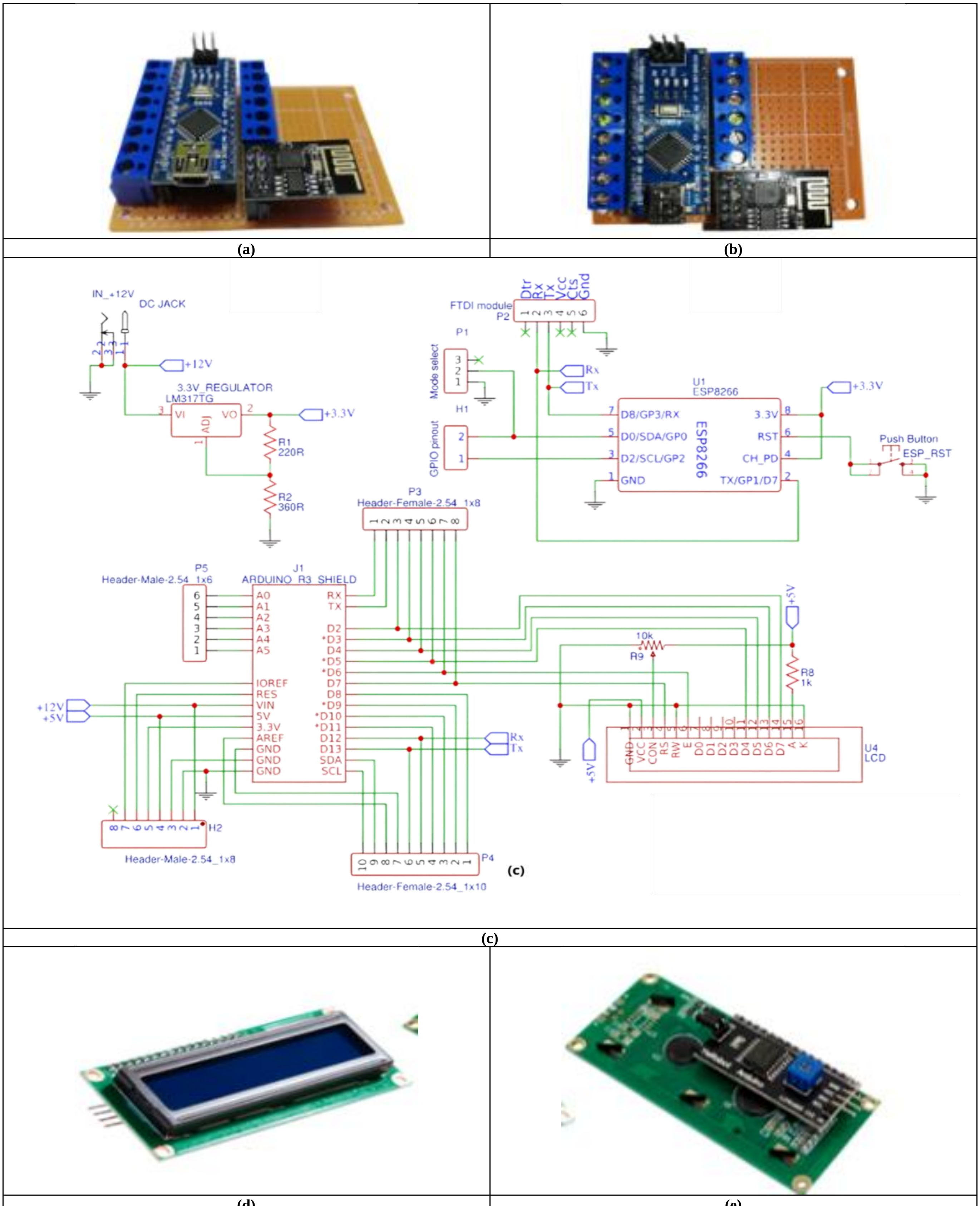

Fig. 4 (a) Control circuit (b) Circuit seen from above (c) Schematic diagram (d) LCD 14x2 (e) I2C module

Table 2. Time distribution

Category	Working time (days)	Percentage
Q1	3	4.41 %
Q2	7	10.29%
Q3	18	26.47%
Q4	30	44.11%
Feedback	10	14.7 %

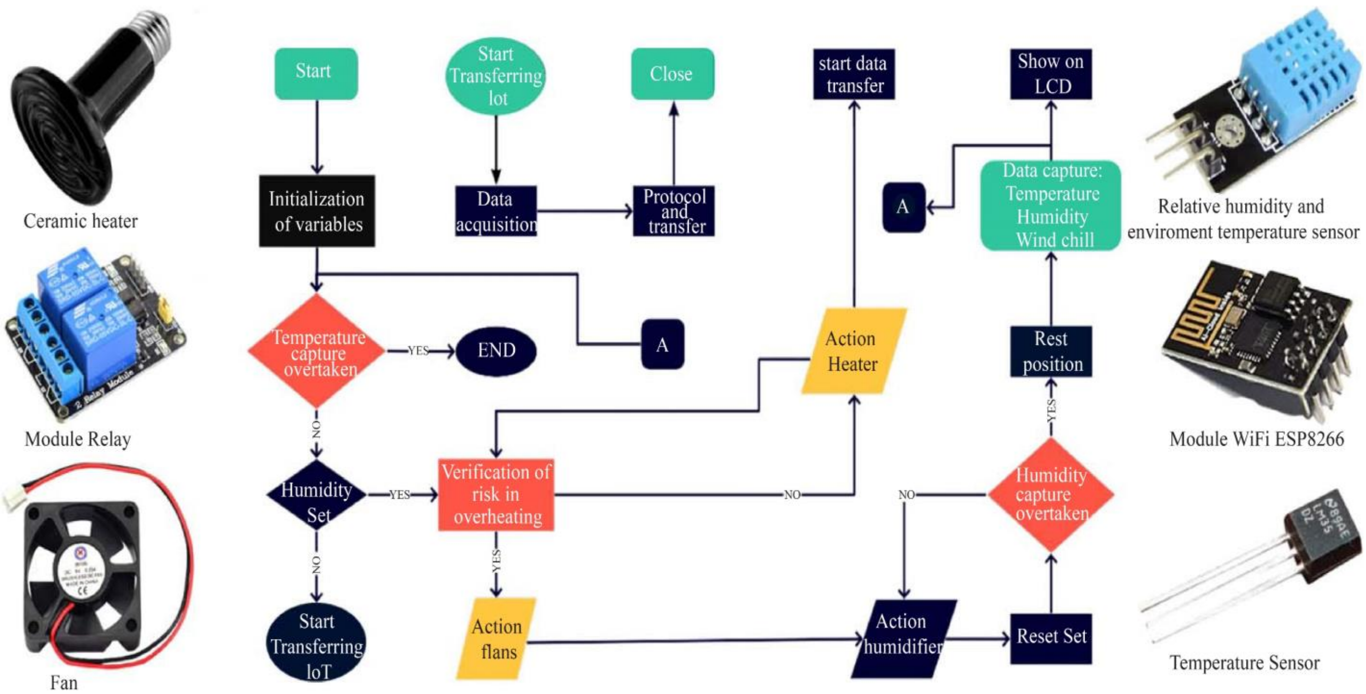

Fig. 5 Flow chart, sensors and actuators

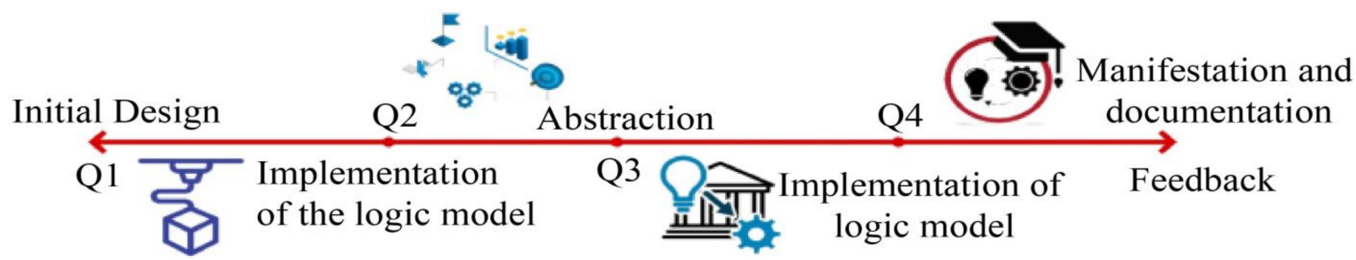

Fig. 6 Timeline of the methodology

5.3. Thermal sensation and relative humidity

The output of the sensors connected to the Arduino V3.0 maintains a continuous data transmission. The DHT11 sensor was used to calculate the wind chill. The voltage output was connected to the Arduino's 5V and GND to the corresponding pin, following the schematic registers in Figure 4c. Signal sampling was performed at 1-second intervals. Figure 7 shows the estimated data for two situations: First, in blue and gray, representing relative humidity and wind chill respectively, in an outdoor environment with the incubator open; Second, in orange and green, representing relative humidity and wind chill, respectively, in a veterinarian-controlled environment with the puppy inside the incubator. In the same way, the output of the sensors connected to Arduino V3.0 maintains a continuous data transmission. The LM35 sensor was used to calculate the temperature sensation. The voltage output was connected to the 5V of Arduino and the GND to the corresponding pin, following the schematic registers in Figure 4c. Signal sampling was performed at 1 second intervals. Figure 8 shows the estimated data for two situations: First, in blue and orange, representing temperature and sensation terminates respectively, in an outdoor environment with the incubator open; Second, in lead and green, representing temperature and sensation terminates respectively, in a veterinarian-controlled environment with the puppy inside the incubator.

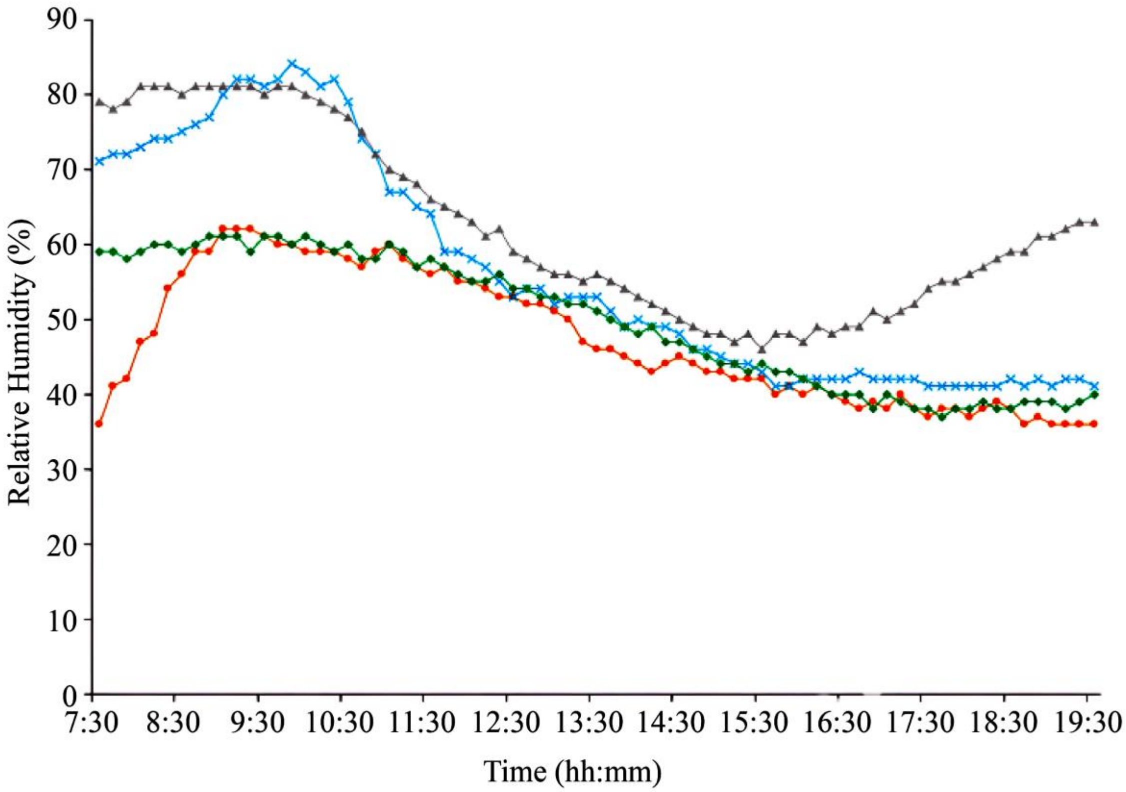

Fig. 7 Relative humidity and thermal sensation

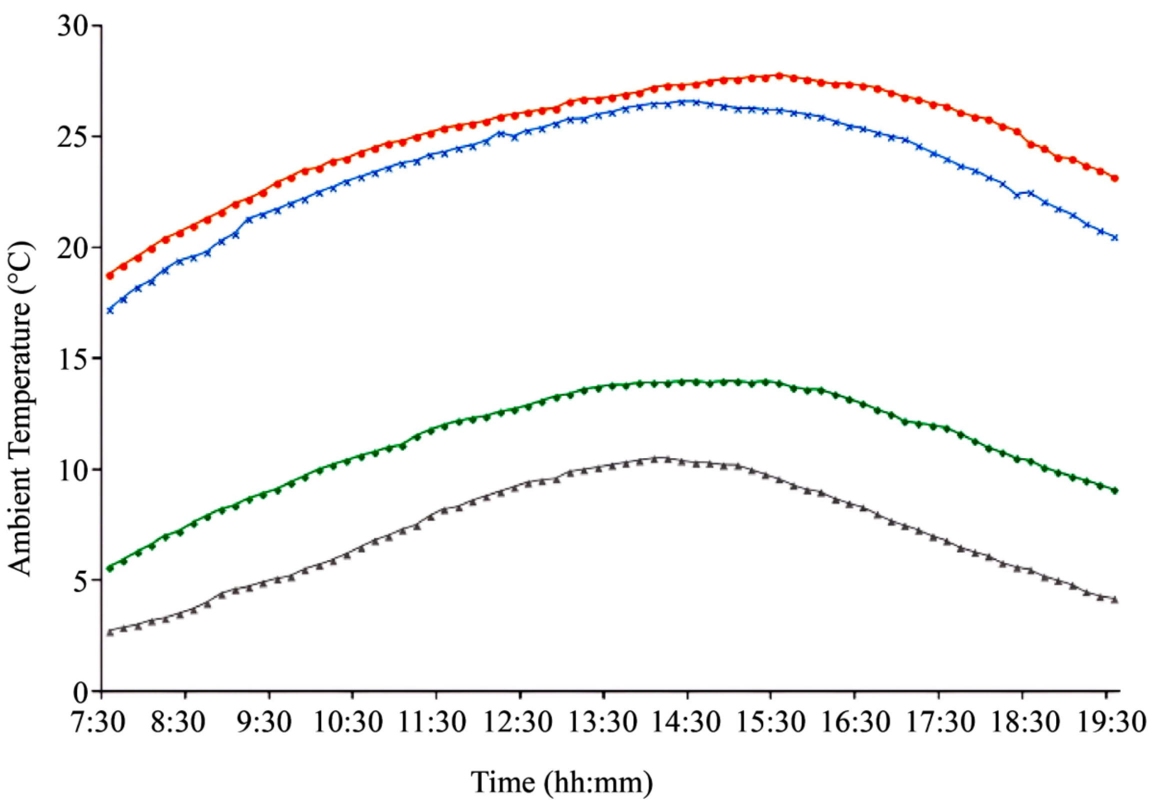

Fig. 8 Room temperature and thermal sensation

Table 3. Data and sensor validation

Sensor	Hora	Precision table			
		Real	Censored	Difference	Precision %
DHT11	8:30	85%	80.0%	5	95%
	11:30	70%	68.0%	2	98%
	14:30	54%	52.0%	2	98%
	17:30	51%	57.0%	6	94%
	19:30	67%	65.0%	2	98%
LM35	8:30	20 ºc	18.0 ºc	2	98%
	11:30	22 ºc	23.0 ºc	1	99%
	14:30	25 ºc	26.0 ºc	1	99%
	17:30	23 ºc	22.5 ºc	0.5	99.5%
	19:30	20 ºc	21.0 ºc	1	99%

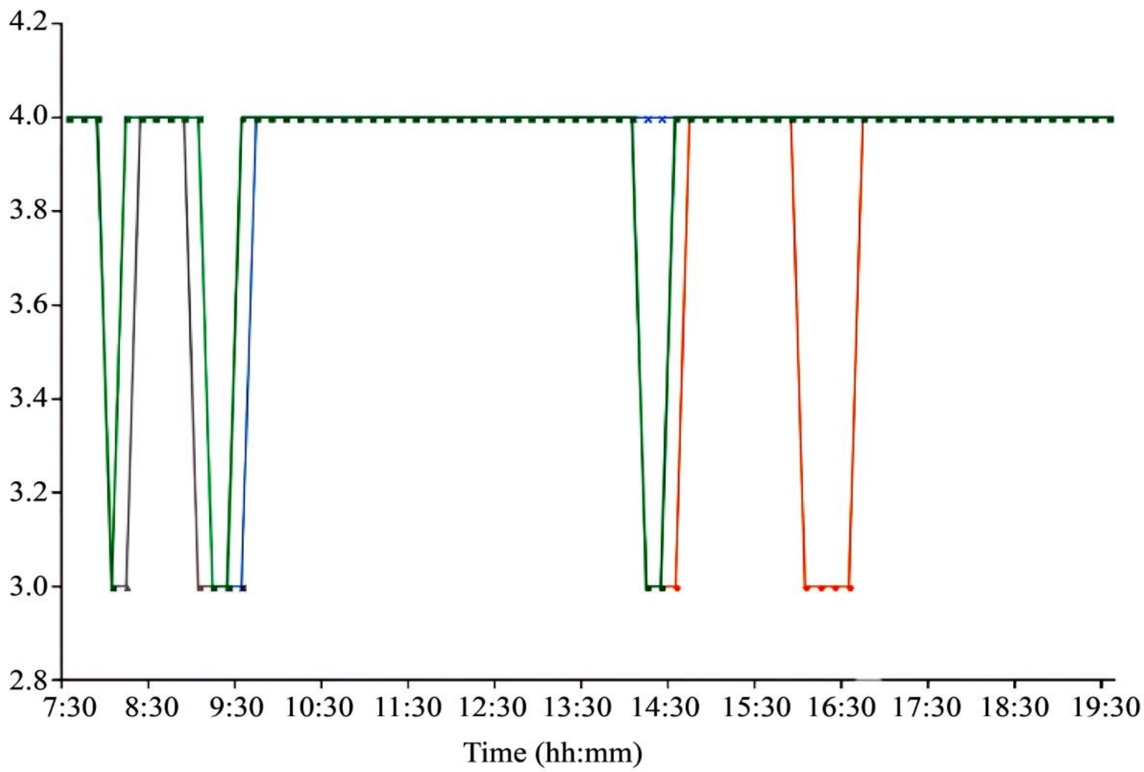

Fig. 9 Use of LED lighting

5.4. Data Validation

During the prototype's application in the veterinary clinics of Arequipa, a sensor validation was conducted to determine accuracy. The instrument used was a Proskit desktop relative humidity and temperature meter with a resolution of 0.1°C and 1% humidity. Table 3 presents the data collected over 6 hours distributed throughout the day, and by calculating the difference between the real and recorded values, the prototype's accuracy against real-world conditions was obtained. Similarly, in Figure 9, the LED lights installed in the incubator were recorded to track usage time and calculate future electricity consumption since one of the incubator's objectives is to install them in low-resource veterinary clinics.

5.5. GUI Testing

The Arduino Cloud IoT platform provides users with graphical data visualization; however, there is room for improvement in latency, as the real-time graph presented by flow blocks included in the same Cloud IoT library [25] can be slow. On the other hand, there is an issue with overheating in the WIFI module ESP8266, which, lacking its 3.3V power supply [21], delivers a voltage of 3.9V through a voltage divider integrated into the Arduino board.

Nevertheless, for aesthetic data representation, the Arduino Cloud IoT platform, which offers a free service, is appealing to developers, including features like bar charts or pie charts, and it is rated at 4.5 out of 5 stars [25].

6. Discussion

Considering the literature review of the proposed methodology [12],[15], there is a question about the lack of continuous feedback between the stages [13]. Only the initial design vision seems sufficient for the complete prototype design. However, it is pertinent to provide paused analysis times between stages (Figure 6). Furthermore, a multitasking scenario was presented in the abstraction stage due to its critical nature in the entire prototyping process [12]. Measuring ambient temperature is fundamental [26], [28] for conditioning the prototype in various situations where the puppy may find itself during treatment. In contrast to Álvarez [9], whose research emphasizes the importance of various sensors and temperature measurements for animal well-being. Humidity supports the puppy's condition [29], [30], indicating the puppy's state if it has a fever above the ambient temperature caused by the incubator heaters.

From these humidity measurements taken in incubation conditions and an empty state (Figure 7), it can be observed that the trend is decreasing as the midday approaches. This is caused by two reasons: First, the puppy's oxygenation status and temperature variation within the enclosed environment, which is the incubator, decrease the humidity level. Lastly, being in a controlled environment, such as the veterinary facility, also negatively affects the recorded humidity.

7. Conclusion and Future Work

The Top-Down methodology allowed for a structured and controlled development of the IoT incubator prototype. By breaking down the system into specific modules and decomposing each phase of the design, a system that meets the requirements of accuracy and low cost was achieved. This methodology was key to meeting the technical and economic challenges of the project, ensuring that each stage of development was aligned with the overall objectives and adapted to the needs of low-income veterinary clinics in Peru. Despite its flaws, it is concluded that the Top-Down methodology is one of the best options for developing a prototype oriented to animal health and IoT implementation. The variables the prototype addresses are of great scientific relevance in the innovation and development of veterinary products. The prototype is available for scalability, and the validation process it underwent contributes to substantial improvements in future research implementations. This invites not only electronics or control developers but also researchers in veterinary medicine to integrate the project into various ecosystems, thus increasing scientific output in various research areas. The design of this prototype was built and validated to help low-income veterinary clinics that do not have a properly equipped puppy incubator. In this sense, the research focuses on contributing to the practical training of zootechnics and veterinary medicine students. The average accuracy level of the prototype puppy incubator is 97.5%, according to the sensors, which is more than enough during the rehabilitation or resting of a puppy.

The puppy incubator prototype designed in this work fulfils the main objective of safeguarding the puppy's life and collecting its data. However, it has some shortcomings, which could be the subject of future research. First, the design is made of MDF wood, which could be mass-produced using PVC material to reduce its cost further. Secondly, filters should be used not to affect the puppy's vision. Finally, incorporating a camera and microphone inside the incubator to interact in real-time with the puppy's family would contribute to both the quality of the prototype and the veterinary service.

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