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IoT-Based Technology Solution for Monitoring Small Breed Cardiac Dogs with Heart Disease

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Abstract: Caring for geriatric small-breed dogs with heart disease from home is a challenge due to the lack of technological tools available in the market, specifically in South America. This lack limits the quality of life of these canine companions and hinders early detection of cardiac problems. Heart disease is common in geriatric dogs of small and medium breeds and the lack of accurate information about their health prevents proper care. In this study, a technological solution based on an IoT device is proposed for monitoring geriatric cardiac dogs in Peru. The device allows measuring temperature and heart rate and recording electrocardiograms in real time for early detection of cardiac problems in pets. For the development of the technological solution, a methodology based on four phases was applied: (1) Analysis of IoT devices, (2) Construction of IoT devices, (3) System construction and (4) System validation. Two experiments were conducted in a private veterinary medical center with two small-breed geriatric dogs with heart diseases, in which each dog had its Temperature (T) and Heart Rate (HR) measured in real-time. Comparing the results of both experiments, the temperature parameter had a better accuracy with an error rate (er) of less than 1%, compared to the average error rate of 7.95% for heart rate. In addition, a survey of veterinarians' experience with the resulting system showed high scores for usability and monitoring, confirming the potential of IoT systems for monitoring geriatric small breed dogs with cardiac problems with the novelty of being a low-cost, usable and reliable device.

Keywords: IoT, Heart Rate, Temperature, Dog, Monitoring, Sensor, Microcontroller

Introduction

The care of small-breed geriatric dogs has presented significant challenges in today's environment. The canine population at this life stage faces several unique health issues, such as arthritis or cardiac problems (McKenzie and Chen, 2022), that require constant monitoring. However, despite advances in veterinary medicine, the lack of specific technological tools for real-time monitoring of these conditions limits the quality of life of these canine companions (Hussain *et al*., 2022).

Currently, heart disease is among the most common chronic diseases reported in dogs, representing approximately 10% of cases in veterinary centers, where it has been observed that geriatric dogs of small and medium breeds have a greater predisposition to suffer from this type of disease (Noordin *et al*., 2022).

On the other hand, the care provided to pets directly affects the health of aging dogs. If veterinarians or dog owners are not aware of their pet's current condition, they will not be able to apply the appropriate treatments to prevent a deterioration of their health or prevent it from worsening (McKenzie and Chen, 2022).

In recent studies, the use of IoT technology has been proposed to monitor dog health more accurately and earlier. Bidoli *et al*. (2022) proposed an approach for cardiac monitoring of dogs during assisted education using a wearable, in order to be able to measure the stress level of the dogs. Ortmeyer *et al*. (2018) demonstrated the confidence of these wearables by combining the Actigraph accelerometer and PetPace collar data which were effective in establishing proximity levels and, in turn, "pulse variability" "respiration" and "heart rate". In (Hussain *et al*., 2022; Chambers *et al*., 2021; Kumpulainen *et al*., 2021) wearables are used to monitor dog's activities and classify their behavior. However, despite the growing interest in the use of wearables for

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early detection of health problems in dogs, there is an alarming lack of affordable options on the market and availability in Latin American countries.

Therefore, this study proposes a technological solution based on the construction of an IoT device for the monitoring of geriatric cardiac small-breed dogs in Peru. This study focuses on the evaluation and analysis of the data collected by the IoT device to measure two parameters: Temperature (T) and Heart Rate (HR) in real-time, to identify early possible cardiac problems in the pet.

Related Works

Different approaches to dog monitoring have emerged in the literature, such as (i) The application of IoT technologies for building wearables (Brložnik *et al*., 2019) and (ii) The use of commercial wearables (Ortmeyer *et al*., 2018). These studies have used healthy dogs of different breeds and sizes (Brugarolas *et al*., 2019), sick geriatric dogs (Shilo-Benjamini *et al*., 2022), trained dogs (Kasnesis *et al*., 2022), or dogs with epilepsy (Hirashima *et al*., 2022).

In terms of research related to the application of IoT technologies for the construction of wearables, several devices have been developed with promising results in data collection and behavioral classification. In the field of activity monitoring, the "whistle fit" wearable has demonstrated 90% accuracy in behavior classification using accelerometers embedded in the devices (Chambers *et al*., 2021), while another study implemented a wearable sensor in the collar of dogs with activity classification results with 85% accuracy for resting, 75% for standing, 90% during walking and 95% during jumping (Tajitsu *et al*., 2023). In addition, a portable device has been designed for search and rescue dogs that collects audio and movement signals by means of inertial sensors (Kasnesis *et al*., 2022). On the other hand, in the field of monitoring specific physiological data, a wireless and portable heart rate sensor system for puppies has been proposed to obtain information on cardiac changes (Foster *et al*., 2020). In addition, the use of ultra-wideband radar has made it possible to monitor the respiratory and heart rate of cats and dogs with an error rate of less than 5% (Wang *et al*., 2020).

As for research related to the use of commercial wearables, collars such as the "Actigraph" (Väätäjä *et al*., 2021), "Petpace" (Belda *et al*., 2018) and “Fitbark” (Colpoys and Decock, 2021) have been used in various investigations. These studies have shown that the combination of data collected by these devices can provide useful information about the physiological responses of dogs during activity and their relationship with their human handler (Ortmeyer *et al*., 2018). In addition, through the use of the "Actigraph" wearable, it has been determined that the accuracy in classifying the behavior of dogs is higher when using a motion sensor located in the harness on the back of the dog (Kumpulainen *et al*., 2021). It should be noted that some of these wearables have been combined with other technologies or techniques, such as the use of the "polar HR V800" monitor in conjunction with electrode transmission gel to promote conductivity and improve results (Bidoli *et al*., 2022).

Materials and Methods

Materials used in this research:

- ESP32 WROOM-32 microcontroller
- MAX30102 integrated pulse oximetry and heart rate monitor module
- AD8232 module with integrated interface for cardiac biopotential signal conditioning for heart rate
- MT3608 DC-DC module that can step up a 3.3 input voltage to 5V.
- LiPo 3.7V 2000 mAh
- KCD11 switch (on/off)
- Battery indicator 1S
- Box material (polylactic acid)
- Generic dog collar and dog harness (Nylon)

The total cost of materials for this project amounted to $85. This strategic approach not only ensures affordability at the production stage but also paves the way to an affordable price for end users.

The research applies an experimental method. Figure 1 outlines the framework for a technological solution based on IoT for monitoring cardiac health in small breed dogs with heart conditions. The proposal comprises four phases: (1) Analysis of IoT devices, (2) Construction of IoT devices, (3) System construction and (4) System validation, whose processes and procedures are detailed step by step below.

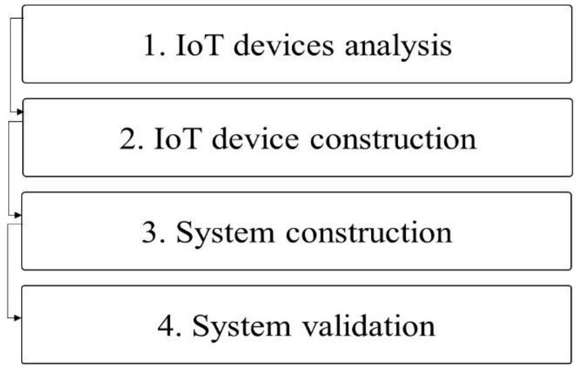

Fig. 1: Conceptualization of the framework proposed

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IoT Devices Analysis

Table 1 illustrates a comparative analysis of three distinct canine monitoring devices: The proposed device, petpace and the smart dog collar. Each device is assessed across four critical dimensions: Monitoring capabilities, price, reliability and support. In this study, "monitoring" delineates the scope and quality of physiological variables captured by the device, offering essential insights into the health status of small breed dogs with cardiac conditions. "price" reflects the affordability of these devices in the market, impacting accessibility for pet owners seeking effective monitoring solutions. "reliability" signifies the dependability of the collected data, leveraging existing literature to evaluate the accuracy and consistency of each device's performance. Lastly, "support" scrutinizes the availability and efficacy of user assistance, particularly within the Peruvian context, crucial for ensuring successful device implementation and utilization in real-world scenarios.

IoT Device Construction

The logical structure of the IoT device is shown in Fig. 2 and consists of 2 sensors with a microcontroller as the central IoT unit. The first sensor obtains the heart rate and temperature, while the second sensor obtains the electrical activity of the heart (ECG). The captured information is transmitted by cable to the microcontroller who is in charge of distributing the information to the end user via WIFI.

Table 1: Comparative analysis of canine monitoring devices

Features	Proposed device	Petpace	Smart dog collar
Monitoring	4	5	5
Price	4	2	2
Reliability	4	5	5
Support	5	0	0

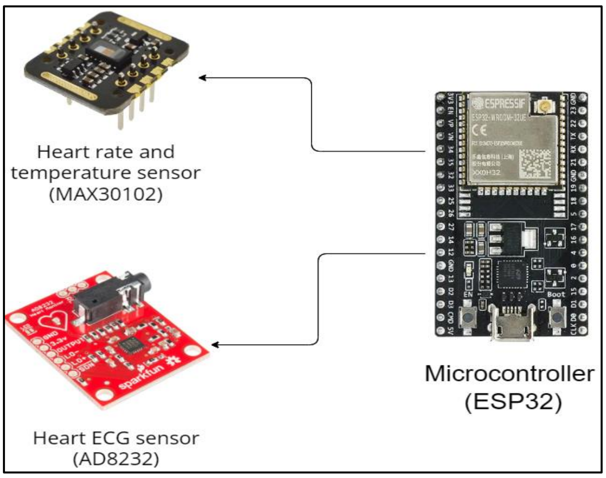

Fig. 2: Microcontroller source code flowchart

IoT Modules Selection

ESP32 WROOM-32. It is a microcontroller unit with WIFI and Bluetooth integration that, as a module, is used in a variety of applications, from sensor networks to demanding tasks such as voice coding and music, among others. The ESP32 has at its core a scalable and adaptable ESP32-D0WDQ6 chip and peripherals ranging from capacitive touch sensors and SD card interface to I2S and I2C (Espressif Systems, 2023).

MAX30102. It is an integrated pulse oximetry and heart rate monitor module that includes internal LEDs, photodetectors, optical elements and low-noise electronics. Its communication is through the standard I2C interface and its use is commonly applied in wearable devices Maxim Integrated (Products, 2018).

AD8232. It is a module with an integrated interface for cardiac biopotential signal conditioning for heart rate monitoring. It contains a specialized instrumentation amplifier that amplifies the electrocardiogram signal while rejecting the half-cell potential of the electrode in the same stage (Agung and Basari, 2017).

Microcontroller Programming

The preparation of the source code for the operation of the ESP32 microcontroller with the sensors required the use of the C++ programming language and the Arduino integrated development environment. The code libraries corresponding to each sensor were imported to convert the received data from byte format to user-understandable values. Figure 3 shows the flowchart with the sequence of functionalities implemented by the microcontroller.

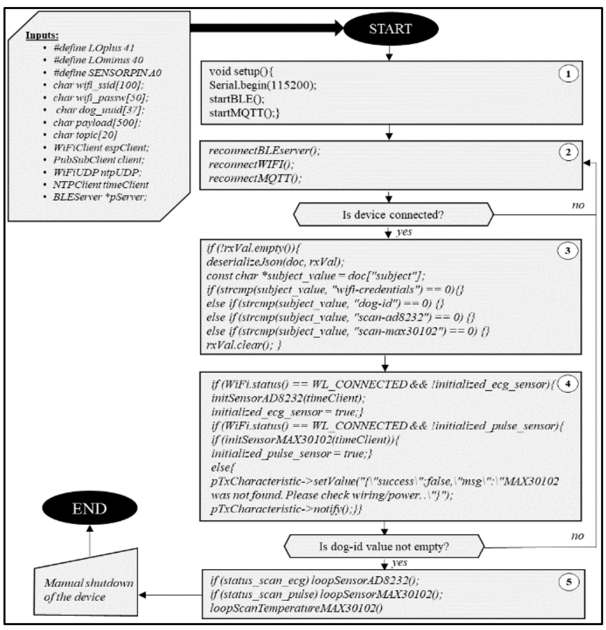

Fig. 3: Microcontroller source code flowchart

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As input data, variables and classes are considered. On the variable side, for example: The 3 pins necessary for communication with the ECG sensor (40, 41 and A0), the WIFI credentials, the dog ID, the topic and the payload for sending the data. While, on the classes side: The definition of the initiator class of the HR and T sensor (MAX30105), the classes that initialize the Wifi (WiFiClient and WiFiUDP) and Bluetooth (BLEServer) functionality of the microcontroller and, finally, the classes that initialize the communication via MQTT protocol (PubSubClient and NTPClient) with the cloud server.

Step 1. The initialization function of the microcontroller is executed. It starts by assigning the value 115200 as the baud rate. Then, it invokes the "startBLE" and "startMQTT" functions to configure the necessary parameters for the operation of the Bluetooth and server connection services, respectively.

Step 2. The microcontroller loop function is executed. It starts by executing the reconnection methods of the Wifi service, the Bluetooth service and the connection with the server via MQTT, which internally checks if the current status is disconnected to try to reconnect.

Step 3. It is verified if a mobile device has established a Bluetooth connection with the microcontroller. Subsequently, the microcontroller waits to receive by this means the Wifi connection credentials, the ID of the dog and the status (true or false) to start the scans with the sensors.

Step 4. The methods that initialize the configuration of the sensors are executed, which check if the Wifi connection status with a network is positive and if they have not yet been initialized. In case their initialization fails, a notification is sent to the connected mobile device via Bluetooth.

Step 5. It is verified if the microcontroller received a dog ID, since, if confirmed, it starts obtaining data from the sensors depending on the scanning status for each one.

IoT Device Assembly

This section explains how the assembly of the IoT device was performed using initially an electrical circuit prototyping board "breadboard". As shown in Fig. 4, the following steps are considered.

Connecting the ESP32 microcontroller to the power supply. The positive cable of the 3.7 V LiPo battery is extended to the input of the KCD11 switch and another cable is connected to the output of the switch with the VIN+ pin of the MT3608 booster module. The battery connection is completed by connecting the negative wire to the GND- pin of the module. The function of the module is to boost the input voltage to 5V. Next, the VOUT+ and GND- pins of the booster are wired to the VIN and GND pins of the microcontroller respectively, on the breadboard.

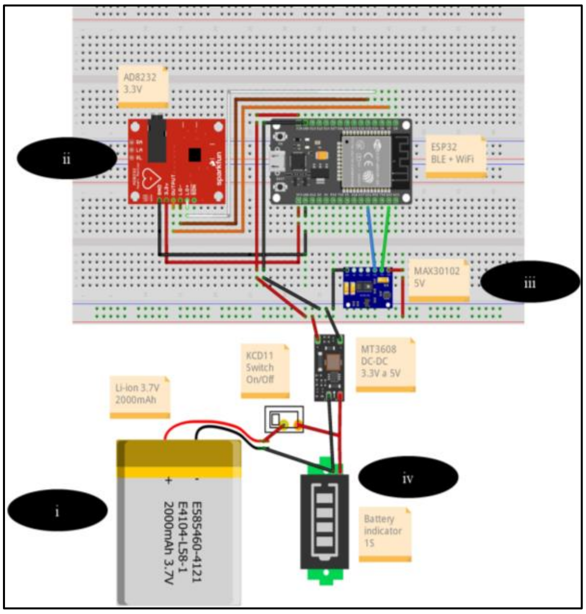

Fig. 4: IoT device prototype assembly diagram

Connection to sensor MAX30102. This module supports an input voltage in the range of 3.3-5V. Therefore, a direct connection of its VIN pin is made to the positive power supply on the breadboard, while its GND pin is connected to the negative power input point. Regarding the data transmission pins, the connection to the microcontroller is established by connecting the SCL pin to the D22 pin and the SDA pin to the D21 pin.

Connection to AD8232 sensor. This module supports a maximum voltage of 3.3 V and uses 5 pins: 3V3 (power supply), GND (ground), output, LO- and LO+. Its 3V3 and GND pins are connected to the positive (3V3) and negative (GND) pins of the microcontroller. Its output pin is connected to the VP pin, LO-to the D2 pin and the LO+ pin to the D3 pin. Finally, the electrode assembly is connected to the Jack 3.5 input of the sensor.

Integration of the battery level indicator module. One cable extends from its negative pin and connects to the negative cable of the LiPO battery, while one cable extends from its positive pin and connects to the output of the KCD11 switch. The indicator shows with LED illumination the current battery voltage level in 4 levels: 3.3 (25), 3.5 (50), 3.7 (75) and 3.9 V (100%).

In addition, a case was created for the protection of the device considering the comfort of the pet. For this purpose, water-resistant, durable and non-toxic material (polylactic acid) was used. The design of the case is shown in Fig. 4, the dimensions (Fig. 5a), the interior of the case for the IoT device (Fig. 5b), the case with side holes for the dog's leash (Figs. 5c-d) the case with the protection cover, the inscription of the system name and the grids for the microcontroller ventilation are visualized.

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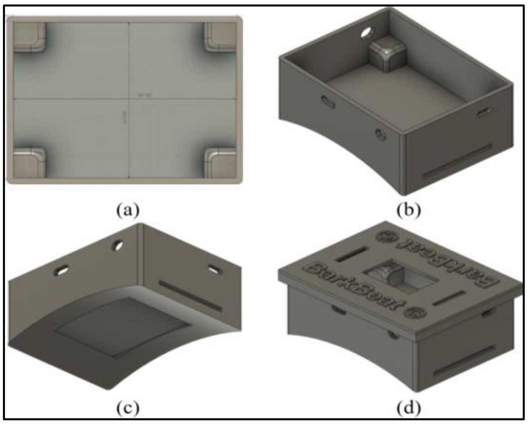

Fig. 5: 3D design of the case for the IoT device

System Construction

This section presents the architecture for the proposed IoT system called BarkBeat. The proposed architecture is shown in Fig. 6 and consists of 5 layers: Capture, connection, business logic, storage and presentation.

Layer 1 (capture). In this layer, the data of the canine patient's physiological variables are obtained with 2 sensors (heart rate with temperature and ECG) and an ESP32 microcontroller receives data from a mobile device to configure its connection parameters and transfer the received data to the next layer. As shown in Fig. 6, the capture layer is composed of 2 sensors that collect physiological data from the dog, the microcontroller (ESP32) and Bluetooth connectivity with the mobile device to configure its connection parameters to the cloud server.

Layer 2 (connection): Fig. 5 illustrates that the communication protocol is Wifi/4G mobile data, as, like any IoT device, information is automatically transmitted in real-time for access through the "business logic layer" restful API application.

Layer 3 (business logic): This layer receives and processes data for storage in a database. As business logic, it defines constraints for received parameters and response formats, provides access to user and general dog information, monitors the canine patient's health and sends alerts upon detecting anomalies in its cardiac records. This restful API has been developed in the NestJS open-source framework and written in the typescript programming language. Protection against cyber-attacks and unauthorized access for the Restful API methods is managed through the Kong API gateway.

Layer 4 (storage): This layer manages the persistence of information in an Amazon dynamo non-relational database. The system stores data such as veterinarian information, pet owner details, dog health history and identification information like name, breed and weight. The database schema includes a total of 9 collections: Owner, veterinarian, dog, goat, breed, report, temperature historic, pulse historic and ECG Historic, as shown in Fig. 3.

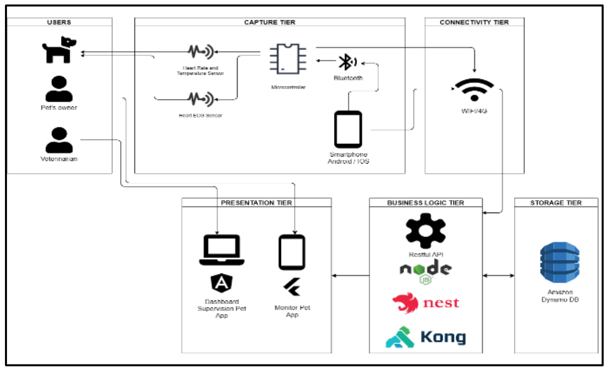

Fig. 6: Physical architecture diagram

Layer 5 (presentation). This layer presents the proposed system, consisting of 2 solutions. The first is a web application developed using the angular framework with typescript and libraries such as angular material and chart.js for data visualization. The second is a mobile application developed with the Flutter cross-platform framework.

Web application. Is provided to the veterinarian user and consists of 3 modules: (i) Monitoring the patient's dog, (ii) Generating reports and (iii) Comparing results with the average health of other dogs. This application is presented as an interactive dashboard allowing the veterinarian to analyze information and make more informed decisions.

Mobile application. Is provided to the dog owner and consists of 4 modules: (i) Registration of personal and pet information, (ii) General health panel of the dog, (iii) Simplified panel of cardiac health and dog temperature and (iv) Viewing information of the assigned veterinarian. With this information, pet owners can monitor the health of their elderly dog in more detail, prevent heart diseases and contact the veterinarian in case of emergencies.

This section also includes a diagram illustrating the logical architecture of the BarkBeat IoT system. The context diagram provides an overview of the services and external actors interacting with the BarkBeat IoT system, as depicted in Fig. 7, showing a relationship with individuals such as "owner," "veterinarian," and the "Google auth" service for secure login.

Finally, the production release of the BarkBeat IoT device with the integration of the proposed system will have an approximate retail price of $110 and will be an affordable product for end users.

System Validation

The validation of the proposed BarkBeat IoT system was conducted with two small breed dogs previously diagnosed with heart disease. These dogs belong to two veterinary centers in the districts of “Villa el Salvador” and “Chaclacayo” in Peru. Additionally, a survey was conducted with four veterinarians to assess the system's efficiency. Two experiments were carried out, with the control experiment being the veterinarian's diagnosis and the test experiment being the diagnosis with the system (Table 2).

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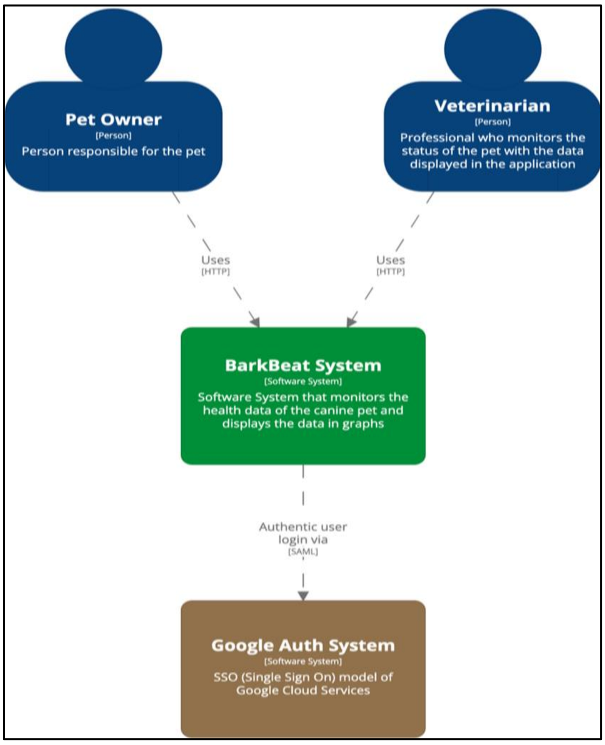

Fig. 7: Physical architecture diagram

Table 2: System validation scenarios

Experiment	Parameter	Participants
Veterinarian diagnosis	HR, T	1 nine-year-old Maltese dog with heart disease at rest (D1) 1 eleven-year-old small breed (mixed breed) dog with heart disease at rest (D2) 1 veterinarian
System diagnosis	HR, T	2 dogs with heart disease at rest

Experiment 1: Veterinarian Diagnosis

The experiment procedure involves the participation of three main actors: the veterinarian, the pet owner, and the dog. The veterinarian plays a central role in the process, starting by measuring the dog's heart rate manually, using a stethoscope to detect the femoral arteries and counting the pulses for a period of fifteen seconds. Subsequently, multiply this value by 4 to obtain the heart rate per minute. Given the requirement to collect data in a manner, the veterinarian is asked to repeat this procedure five times, allowing the pet owner to record the resulting values in a note table. Regarding the measurement of canine body temperature, the veterinarian uses a digital thermometer, inserting it rectally for a period of thirty seconds. Once the measurement is completed, the pet owner records the value obtained in the same notes.

Experiment 2: System Diagnosis

Hardware configuration. The validation of the proposed system was performed by turning on and placing the IoT BarkBeat device on the dog (Fig. 8) and ensuring that the sensors made contact with the skin of the shaved canine patient in those areas (Fig. 9).

Software configuration. To configure the system, the following steps were taken: Pet owner registration, acceptance of the application's terms and conditions, pet registration, selection of the pet to monitor, mobile application connection with the IoT device.

Data visualization in the mobile application. To view the data recorded by the device, the following steps were taken: Entering the monitoring view (Fig. 10a), entering the heart rate view (Fig. 10b) and entering the electrocardiogram view (Fig. 10c).

Data visualization in the web application. To view the data recorded by the device, the veterinarian must select a dog from their patient tray and follow these steps: Access the electrocardiogram section (Fig. 11a) and access the heart rate section (Fig. 11b).

At the end of the configuration, approximately 2 min were needed to record stable measurements, specifically in the heart rate sensor.

Expert Judgment

Furthermore, a validation of the study with expert judgment was conducted for them to use the system and provide their assessment. Four veterinarians were contacted for this purpose. The validation consisted of three steps: (i) an explanation of the system on a phone, (ii) the use of the system by the experts and (iii) the completion of a survey. The experiment was conducted separately, lasting approximately 30 min each.

Fig. 8: Cardiopathic dog with equipped device

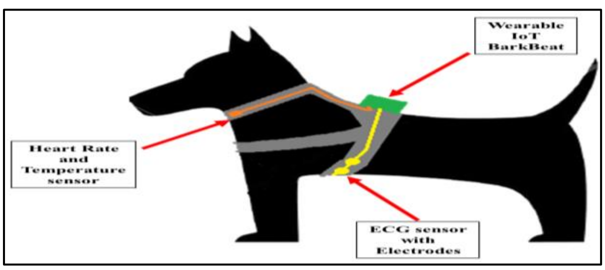

Fig. 9: Dog harness with device sensors

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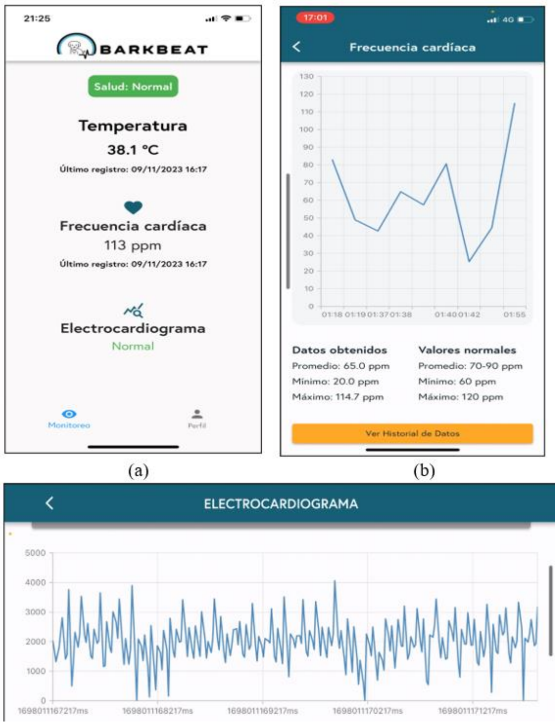
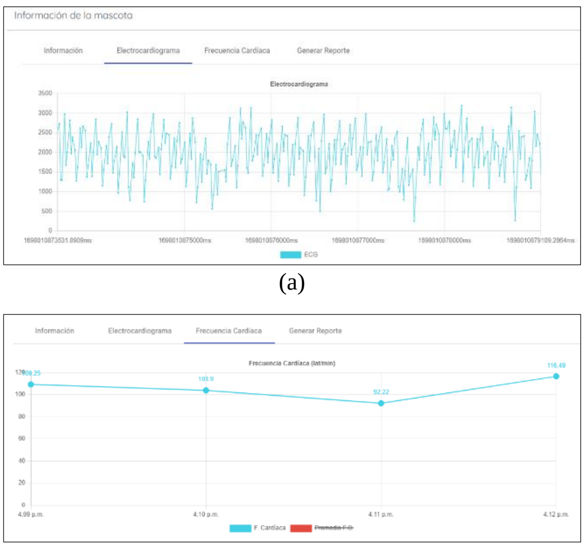


(c)

Fig. 10: Monitoring graphs in the mobile application



(b)

Fig. 11: Monitoring graphs in the web application

For the use of the system, the following steps were taken:

- Experts were asked to create a pet owner account and a pet within the system
- The IoT device was turned on and placed on the pet's harness
- Bluetooth pairing was performed from the application with the device

Finally, a virtual survey (Izarra and Evangelista, 2023) was conducted, consisting of five closed-ended questions and one open-ended question (Table 3), applying the Likert scale for the closed-ended questions (1 = totally disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = totally agree). The open-ended question aimed to identify opportunities for improvement.

Table 3: Survey questions

Category	Question	Type
Usability	Q1 Do you think it was easy to Navigate through the application.	Close
	Q2 Was it easy for you to configure and synchronize the IoT device with The mobile application?	Closed
Monitoring	Q3 Do the graphs displayed on the screen help you monitor a dog?	Closed
	Q4 Do you consider that the application's features allow for efficient monitoring of a dog's health?	Closed
Reliability	Q5 Does the application provide accurate data on detected parameters?	Closed
User experience	Q6 Based on your experience, what aspects should be improved in the application to fulfill its purpose?	Open

Results and Discussion

Table 4 shows the results of experiments 1 and 2. The results of experiment 1 show that the average Heart Rate (HR) was 114.4 for the 1st Dog (D1) and 89.6 for the 2nd Dog (D2), with an outlier value above the average in D1 but not alarming in these dogs. The temperatures obtained were 38.40 and 38.1°C for D1 and D2, respectively. For experiment 2, using the IoT BarkBeat system, the results show that the average HR was 107.2 and 81.0 for D1 and D2, respectively. In the case of Temperature (T), the values obtained were 38.44°C for D1 and 38.11°C for D2.

To effectively compare the results of experiment 1 (control) and experiment 2 (test), Eq. (1) was used to determine the difference (d) between the measured values and Eq. (2) to determine the *error rate* (er). The variables used were *miot* (measurement with IoT device) and *mmv* (veterinarian's measurement). These variables are based on data obtained from HR and T:

$$d = |mmv - miot| \quad (1)$$

$$er = (\lfloor mmv - miot \rfloor \div mmv) \times 100 \quad (2)$$

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Table 4: Results of experiments 1 and 2

			Minutes				
Exp	Dog	P[a]	1	2	3	4	5
1	D1	HR	96.00	156.00	116.00	96.00	108.00
		T	38.40				
	D2	HR	92.00	84.00	84.00	88.00	100.00
		T	38.10				
2	D1	HR	101.00	146.00	101.00	91.00	97.00
		T	38.44	38.44	38.43	38.43	38.44
	D2	HR	81.00	74.00	79.00	82.00	89.00
		T	38.10	38.11	38.11	38.11	38.11

Parameter

Table 5 provides a summary of the results obtained by applying Eqs. (1-2) to the results of both experiments. The *er* for *T* in both dogs (D1 and D2) was less than 1%, demonstrating that the measurement of this variable with the IoT system is quite accurate. On the other hand, the *HR* measurement had an average ER of 7.945%, which can be attributed to the error rate of experiment 1 when considering only the first fifteen seconds and the sensor's error tolerance.

Figure 12 shows the results obtained from the surveys conducted with the four experts, grouped into three categories: Usability, monitoring and reliability. On average, the "usability" of the system scored 5, demonstrating that both the web and mobile presentations of the system are easy to use. The averages for "monitoring" and "reliability" were 4.375 and 4 respectively, indicating that the system fulfills its purpose but still requires improvement.

Regarding the "user experience" category, one expert recommended improving the sensor's contact with the dog's skin. Additionally, three of them recommended reducing the size of the IoT device.

Table 5: Comparison of parameter results between experiments 1 and 2

Dog	Parameter	Exp 1	Exp 2	*d*	*er (%)*
D1	HR	114.04	107.02	7.02	6.29
	T	38.40	38.44	0.04	0.10
D2	HR	89.06	81.00	8.06	9.60
	T	38.10	38.11	0.01	0.03

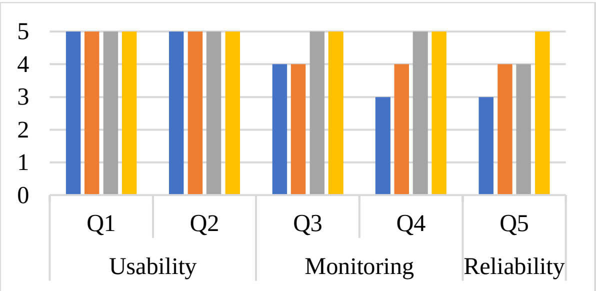

Fig. 12: Summary of expert survey responses

The results obtained in this study demonstrate that the use of IoT devices to monitor Heart Rate (HR) and Temperature (T) in dogs can be quite accurate, with an error rate (er) for temperature below 1%. This finding is consistent with what was reported who found that wearable technology can be a valuable tool for monitoring canine behavior and physiological conditions. However, the average error rate for HR measurement was 7.945%, suggesting that there are certain limitations in the accuracy of IoT devices, possibly due to sensor tolerance and variability in initial HR measurements.

Additionally, the comparison of monitoring methods showed that the IoT BarkBeat device performed comparably to veterinary measurements, which is a positive indication for the applicability of these technologies in uncontrolled environments. The accuracy in *HR* and *T* measurements supports the conclusions of Tajitsu *et al.* (2023), who achieved high concordance rates using piezoelectric sensors in dogs at rest and in motion.

Conclusion

Providing care for geriatric dogs with heart conditions at home poses a challenge due to the lack of available technological tools in the market. Various studies in the literature explored the monitoring of dogs using wearables (Kumpulainen *et al*., 2021; Foster *et al*., 2020; Wang *et al*., 2020; Hirashima *et al*., 2022). However, none of them is affordable in Peru due to the country's situation. This deficiency limits the quality of life for our canines and hinders the early detection of cardiac problems, which can only be identified through periodic veterinary check-ups on our pets. While factors such as breed, age, etc., can influence the development of heart disease in dogs, it is true that all dogs can suffer from it, with these cardiac diseases being more common in geriatric dogs of small and medium breeds.

Therefore, in this study, a system was proposed to monitor small-breed geriatric dogs with heart conditions in real time. This was achieved through the construction of an IoT device, the implementation of a web application and a mobile application. The proposed system was implemented in five layers: Capture, connection, business logic, storage and presentation. Experiments were conducted in a private veterinary medical center and the proposed device was validated through expert judgment. Each dog participated in two experiments, each lasting 30 min.

To validate the results obtained in both Heart Rate (HR) and Temperature (T), these were compared with those of the veterinarian to determine the difference (d) between the measured values and the error rate (er). The "er" for T was less than 1%, demonstrating the IoT system's precision in measuring this variable. On the other hand, the HR measurement had an average ER of 7.945%, which was attributed to the error rate in the first experiment, considering only the first fifteen seconds and the sensor's error tolerance.

Additionally, to validate the utility and ease of use of the proposal, surveys were conducted with experts, grouped into categories of usability, monitoring, reliability and user experience. On average, the "usability" of the system scored 5, indicating that both the web and mobile presentations are user-friendly. Meanwhile, the averages for "monitoring" and "reliability" were 4.375 and 4, respectively, demonstrating that the system fulfills its purpose but still requires some improvement. Finally, in the "user experience" category, it was recommended to improve the sensor's contact with the dog, which is a limitation in the device and reduce the size of the IoT device because it is a disadvantage for its use. Due to the results obtained in the experiments, it was demonstrated that monitoring the dog's health is possible through the proposed mobile application in this study.

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Author's Contributions

Jeremias Evangelista and Carlos Izarra: Analysis of existing literature, IoT device design and construction, system construction, data collection, validation of the study, analysis, interpretation of results and manuscript written.

José Luis Castillo-Sequera: Manuscript review discussion of obtained results and their connection with previous studies.

Lenis Wong: Study supervision. Result analysis of the experiment. Manuscript review. Discussion of obtained results and their connection with previous studies.

Ethics

The article is authentic and contains unpublished material. The corresponding author affirms that no ethical concerns exist and all authors have read and endorsed the article.

References

Agung, M. A., & Basari. (2017). 3-lead acquisition using single channel ECG device developed on AD8232 analog front end for wireless ECG application. *AIP Conference Proceedings*, 040015. https://doi.org/10.1063/1.4976800

Belda, B., Enomoto, M., Case, B. C., & Lascelles, B. D. X. (2018). Initial evaluation of PetPace activity monitor. *The Veterinary Journal*, *237*, 63–68. https://doi.org/10.1016/j.tvjl.2018.05.011

Bidoli, E. M. Y., Erhard, M. H., & Döring, D. (2022). Heart rate and heart rate variability in school dogs. *Applied Animal Behaviour Science*, *248*, 105574. https://doi.org/10.1016/j.applanim.2022.105574

Brložnik, M., Likar, Š., Krvavica, A., Avbelj, V., & Domanjko Petrič, A. (2019). Wireless body sensor for electrocardiographic monitoring in dogs and cats. *Journal of Small Animal Practice*, *60*(4), 223–230. https://doi.org/10.1111/jsap.12963

Brugarolas, R., Yuschak, S., Adin, D., Roberts, D. L., Sherman, B. L., & Bozkurt, A. (2019). Simultaneous Monitoring of Canine Heart Rate and Respiratory Patterns During Scent Detection Tasks. *IEEE Sensors Journal*, *19*(4), 1454–1462. https://doi.org/10.1109/jsen.2018.2883066

Chambers, R. D., Yoder, N. C., Carson, A. B., Junge, C., Allen, D. E., Prescott, L. M., Bradley, S., Wymore, G., Lloyd, K., & Lyle, S. (2021). Deep Learning Classification of Canine Behavior Using a Single Collar-Mounted Accelerometer: Real-World Validation. *Animals*, *11*(6), 1549. https://doi.org/10.3390/ani11061549

Colpoys, J., & DeCock, D. (2021). Evaluation of the FitBark Activity Monitor for Measuring Physical Activity in Dogs. *Animals*, *11*(3), 781. https://doi.org/10.3390/ani11030781

Foster, M., Brugarolas, R., Walker, K., Mealin, S., Cleghern, Z., Yuschak, S., Clark, J. C., Adin, D., Russenberger, J., Gruen, M., Sherman, B. L., Roberts, D. L., & Bozkurt, A. (2020). Preliminary Evaluation of a Wearable Sensor System for Heart Rate Assessment in Guide Dog Puppies. *IEEE Sensors Journal*, *20*(16), 9449–9459. https://doi.org/10.1109/jsen.2020.2986159

Hirashima, J., Saito, M., Kuriyama, T., Akamatsu, T., & Yokomori, M. (2022). Detection of Generalized Tonic–Clonic Seizures in Dogs with a Seizure Detection System Established Using Acceleration Data and the Mahalanobis Distance: A Preliminary Study. *Frontiers in Veterinary Science*, *9*, 848604. https://doi.org/10.3389/fvets.2022.848604

Hussain, A., Ali, S., Abdullah, & Kim, H.-C. (2022). Activity Detection for the Wellbeing of Dogs Using Wearable Sensors Based on Deep Learning. *IEEE Access*, *10*, 53153–53163. https://doi.org/10.1109/access.2022.3174813

Izarra, C., & Evangelista, J. (2023). *Encuesta: Solución tecnológica para el monitoreo de perros cardiópatas de raza pequeña basado en IoT*. https://docs.google.com/forms/d/e/1FAIpQLSfvacOU41Hw8GMeNV0eMiXRGcWzMO44YfTkLnu2gNWdTlKiJQ/viewform

Kasnesis, P., Doulgerakis, V., Uzunidis, D., Kogias, D. G., Funcia, S. I., González, M. B., Giannousis, C., & Patrikakis, C. Z. (2022). Deep Learning Empowered Wearable-Based Behavior Recognition for Search and Rescue Dogs. *Sensors*, *22*(3), 993. https://doi.org/10.3390/s22030993

Kumpulainen, P., Cardó, A. V., Somppi, S., Törnqvist, H., Väätäjä, H., Majaranta, P., Gizatdinova, Y., Hoog Antink, C., Surakka, V., Kujala, M. V., Vainio, O., & Vehkaoja, A. (2021). Dog behaviour classification with movement sensors placed on the harness and the collar. *Applied Animal Behaviour Science*, *241*, 105393. https://doi.org/10.1016/j.applanim.2021.105393

McKenzie, B. A., & Chen, F. L. (2022). Assessment and Management of Declining Physical Function in Aging Dogs. *Topics in Companion Animal Medicine*, *51*, 100732. https://doi.org/10.1016/j.tcam.2022.100732

Noordin, N., Hua Khor, K., Lee Ee, K., Lau, S. F., & Ramanoon, S. Z. (2020). Risk Factors for Heart Disease in Pet Dogs Attended at a Veterinary Teaching Hospital in Malaysia. *International Journal of Veterinary Science*, *11*(4), 504–513. https://doi.org/10.47278/journal.ijvs/2022.154

Ortmeyer, H. K., Robey, L., & McDonald, T. (2018). Combining Actigraph Link and PetPace Collar Data to Measure Activity, Proximity and Physiological Responses in Freely Moving Dogs in a Natural Environment. *Animals*, *8*(12), 230. https://doi.org/10.3390/ani8120230

Products, M. I., & Inc. (2018). *High-Sensitivity Pulse Oximeter and Heart-Rate Sensor*. MAX30105.

Shilo-Benjamini, Y., Cern, A., Zilbersheid, D., Hod, A., Lavy, E., Barasch, D., & Barenholz, Y. (2022). A Case Report of Subcutaneously Injected Liposomal Cannabidiol Formulation Used as a Compassion Therapy for Pain Management in a Dog. *Frontiers in Veterinary Science*, *9*, 892306. https://doi.org/10.3389/fvets.2022.892306

Espressif Systems. (2023). ESP32WROOM32 Datasheet. https://www.espressif.com/sites/default/files/documentation/esp32-wroom-32_datasheet_en.pdf

Tajitsu, Y., Takarada, J., Hikichi, T., Sugii, R., Takatani, K., Yanagimoto, H., Nakanishi, R., Shiomi, S., Kitamoto, D., Nakiri, T., Takeuchi, O., Deguchi, M., Muto, T., Kuroki, K., Amano, W., Misumi, A., Takahashi, M., Sugiyama, K., Tanabe, A., … Takeshita, K. (2023). Application of Piezoelectric PLLA Braided Cord as Wearable Sensor to Realize Monitoring System for Indoor Dogs with Less Physical or Mental Stress. *Micromachines*, *14*(1), 143. https://doi.org/10.3390/mi14010143

Väätäjä, H., Majaranta, P., Cardó, A. V., Isokoski, P., Somppi, S., Vehkaoja, A., Vainio, O., & Surakka, V. (2021). The Interplay Between Affect, Dog's Physical Activity and Dog–Owner Relationship. *Frontiers in Veterinary Science*, *8*, 673407. https://doi.org/10.3389/fvets.2021.673407

Wang, P., Ma, Y., Liang, F., Zhang, Y., Yu, X., Li, Z., An, Q., Lv, H., & Wang, J. (2020). Non-Contact Vital Signs Monitoring of Dog and Cat Using a UWB Radar. *Animals*, *10*(2), 205. https://doi.org/10.3390/ani10020205