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# Development of a Low-Cost Datalogger for Monitoring the Microclimate of Natural Blue-and-Yellow Macaw (Ara ararauna) Nests in Campo Grande, Brazil

***Desenvolvimento de Datalogger de Baixo Custo para Estudo do Microclima de Ninhos Naturais de Arara-Canindé (Ara ararauna) em Campo Grande, Brasil***

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**Abstract**

This study developed and evaluated a temperature and humidity datalogger for monitoring the microclimate of free-ranging *Ara ararauna* nests. The system was based on an Arduino Nano microcontroller, equipped with a data storage shield and a Real-Time Clock (RTC) module for time-stamping. DHT22 sensors were used to measure temperature and humidity, and the system was programmed to record data every 20 minutes. Three devices were assembled and tested under laboratory conditions to evaluate functionality and accuracy in environmental data collection. In addition, field tests were conducted to assess battery autonomy, resistance to environmental conditions, and the macaws' behavior of pecking at the devices. The results showed measurements consistent with the sensor specifications; however, battery autonomy was limited, with the system operating for slightly more than 13 hours before requiring recharging. Failures in two Arduino boards compromised data collection in the nests. The main proposed improvements include the adoption of lower-power microcontrollers, the use of solar panels for battery recharging, and the implementation of wireless data transmission for remote monitoring. The issues identified in the final version of the devices will contribute to the development of more efficient and reliable datalogger versions, with potential positive impacts on environmental.

**Keywords**: Monitoring Equipment. Arduino. DHT22 Sensors. Physical Factors of Nests. Psittacidae.

**Resumo**

Este estudo desenvolveu e avaliou um datalogger de temperatura e umidade para o monitoramento do microclima em ninhos de *Ara ararauna* em vida livre. O sistema foi baseado no microcontrolador Arduino Nano, equipado com um shield para armazenamento de dados e um módulo RTC para marcação temporal. Sensores DHT22 foram utilizados para medir a temperatura e a umidade, sendo o sistema programado para obter dados a cada 20 minutos. Foram confeccionados três equipamentos, que foram testados em laboratório quanto à funcionalidade e à precisão na obtenção dos dados ambientais. Além disso, foram avaliados em campo em relação à autonomia da bateria, à resistência às intempéries ambientais e ao comportamento das araras de debicar os dispositivos. Os resultados mostraram medições coerentes com as especificações do sensor, mas a autonomia da bateria foi limitada, com o sistema operando por pouco mais de 13 horas antes de necessitar de recarga. Falhas em dois Arduinos comprometeram a coleta de dados nos ninhos. Os principais aperfeiçoamentos propostos incluem a adoção de microcontroladores com menor consumo de energia, o uso de painéis solares para recarga da bateria e a implementação de transmissão de dados sem fio para monitoramento remoto. Os problemas identificados na versão final dos equipamentos contribuirão para o desenvolvimento de versões mais eficientes e confiáveis do datalogger, com potencial impacto positivo em projetos de monitoramento ambiental.



**Palavras-chave**: Equipamento de monitoramento. Arduino. Sensores DHT22. Fatores Físicos de Ninhos. Psittacidae.


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## 1 Introduction

In the face of environmental changes, increasing efforts have been made to investigate microclimatic conditions using environmental microcontroller sensors, for example, for monitoring temperature and humidity (Mühlbauer et al., 2023). Microclimatic studies have been conducted at multiple scales, including entire ecosystems, soil conditions for agricultural development, thermal comfort in urban areas, and the microclimate of bird nests (Ihlenfeld *et al.,* 2023; Joly *et al.,* 2024; Mühlbauer *et al*., 2023; Sudyka *et al*., 2022).

In birds, nests provide protection for eggs and nestlings throughout their developmental stages (Barbosa, 2018; Dawson *et al*., 2005; Sudyka *et al*., 2022). The microclimate created inside nests is a determining factor for egg and nestling survival and development (Dawson *et al.,* 2005; Sudyka et al., 2022). Understanding how the microclimate within these cavities functions can support management and conservation actions for free-ranging animals.

According to Porter and Kearney (2009), nest microclimates must provide thermal comfort for individuals, preventing physiological stress or impairment. Adult individuals are capable of adjusting to fluctuations in temperature and humidity within nests; however, young individuals do not yet possess this adaptive capacity efficiently. Therefore, nest microclimate is a crucial factor in protecting developing nestlings from external climatic conditions, reducing mortality and increasing reproductive success (Mueller *et al.*, 2019; Ospina *et al*., 2018; Sudyka *et al*., 2022).

However, little is known about the microclimate of nests of free-ranging animals, particularly large macaws. Ara ararauna is a species that reproduces in cavities of dead palm trees. Because the main nest entrance remains open, sunlight may directly reach the nest substrate, creating a peculiar microclimate that may negatively affect offspring development. In Campo Grande, this species has been studied by the Projeto Aves Urbanas – Araras na Cidade (Urban Birds Project – Macaws in the City), conducted by the Instituto Arara Azul (Hyacinth Macaw Institute), which carries out several studies on the reproductive biology of A. ararauna. However, little is known about the microclimate of nests of this species in Campo Grande.

One of the main challenges in conducting studies of this nature is related to equipment acquisition. The need for a considerable number of devices for installation and monitoring increases the costs of long-term projects, making them expensive. In this context, platforms composed of digital signal processors and microcontrollers, such as Arduino and similar systems, provide easier access to electronic and automation technologies (Nouman *et al.*, 2019; Romero  2020).

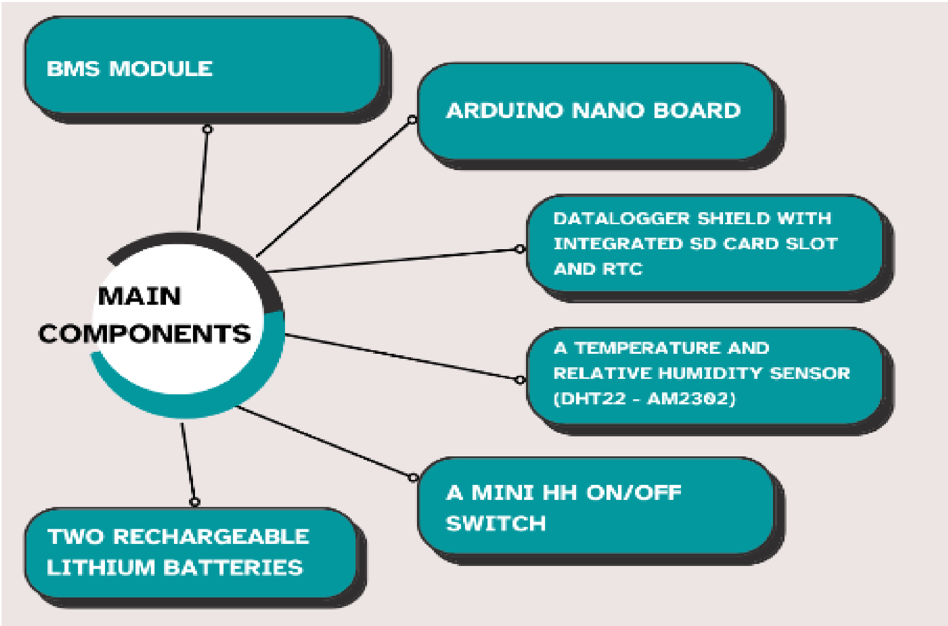
According to Banzi (2015), these resources enable the development of low-cost automated systems when compared to commercially available equipment. This is possible because Arduino is associated with open-source hardware and software platforms that provide a basis for the prototyping of interactive projects (Chokhachian *et al.,* 2018; McRoberts, 2015; Nouman *et al.,* 2019; Tentro *et al.*, 2018;). Additionally, macaws are curious animals with powerful beaks capable of damaging equipment, requiring replacement within short time intervals. Therefore, there is a need to develop a more resistant and cost-effective device to withstand damage caused by macaws.

Considering the importance of obtaining environmental data (temperature and humidity) from natural nests occupied by *A. ararauna* in Campo Grande, together with the practical and low-cost implementation of Arduino technology for the development of a temperature and relative humidity data acquisition system, the main objective of this study was to develop, build, and install a system and device (datalogger) for collecting temperature and humidity data that can be used in studies of *A. ararauna* nest microclimate. The specific objectives were to produce a low-cost and resistant temperature datalogger, test data acquisition and storage, and evaluate equipment performance in natural *A. ararauna* nests.

## 2 Material and Methods

The datalogger assembly method was based on that described by Santos and Rogério Júnior (2020). The main components included an Arduino Nano board, a datalogger shield with integrated SD card input and RTC module, a temperature and relative humidity sensor (DHT22 - AM2302), a mini HH on/off switch, two rechargeable lithium batteries, and a Battery Management System (BMS) module (Figure 1 and Table 1). The construction of the devices was supported by the SEBRAE Living Lab Laboratory.

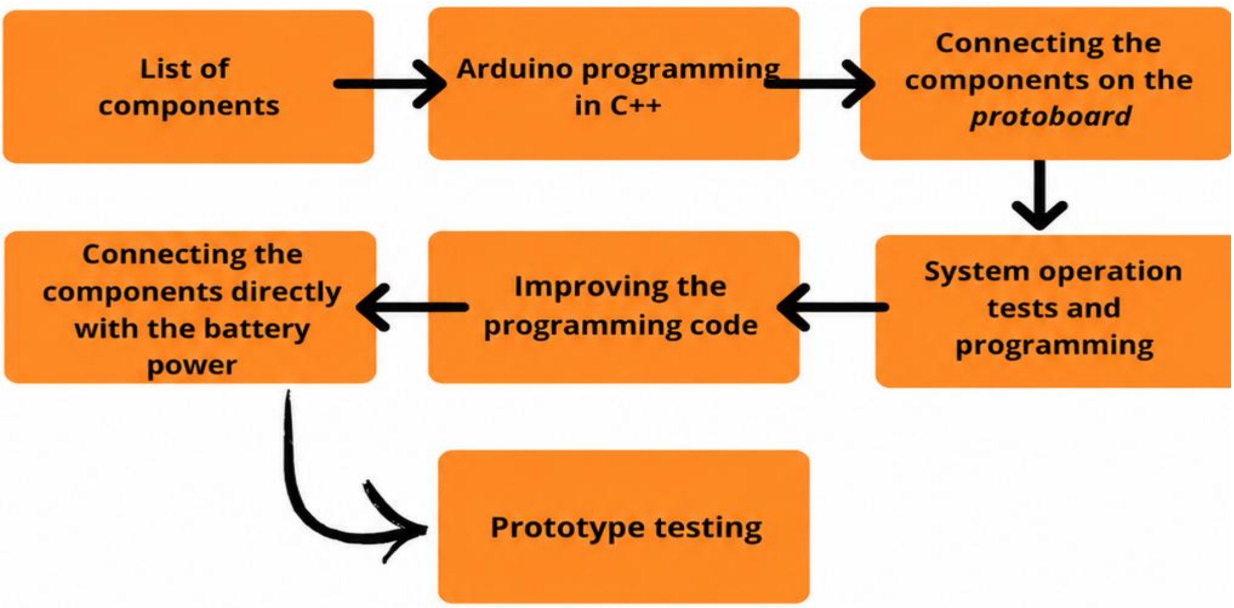
**Figure 1** – Schematic representation of the main components used in the assembly of the datalogger for temperature and relative humidity monitoring




**Source:** the authors.

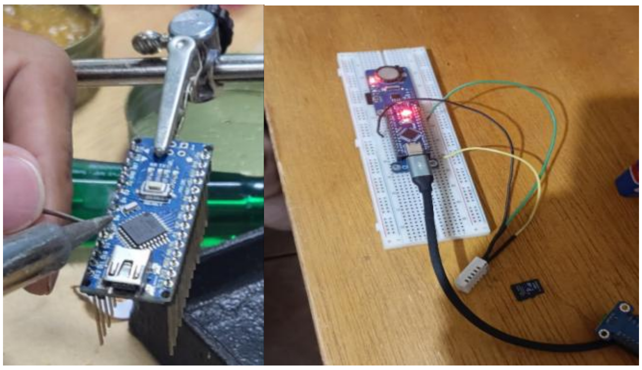
The microcontroller was programmed using the Arduino IDE software and written in C++. The first stage consisted of implementing a test code on the Arduino to validate system functionality. The Arduino board was prepared using male pin headers for connection to the shield, and a breadboard was subsequently used to perform connection tests with jumper wires (Figures 2 and 3).

**Figure 2** – Stages of prototype development




**Source:** the authors.

**Figure 3** – Soldering of the pin headers onto the Arduino board and circuit assembly



**Source:** the authors.

**Table 1** – List of prototype components and acquisition cost of each item

| Component | Description | Acquisition Cost |
|---|---|---|
| Arduino Nano | Microcontroller board for electronic projects | R$28,90 |
| Arduino Shield | Module that expands the functions of the Arduino board, including an RTC (Real-Time Clock to maintain accurate date and time) and an SD card reader for data storage | R$57,46 |
| DHT22 Sensor | Digital temperature and humidity sensor | R$25,90 |
| On/Off Switch | Switch used to control electrical current flow | R$3,99 |
| Rechargeable Battery | Reusable power source for electronic components | R$18,00 |
| Conector DC jack fêmea | Electrical power connector for circuits | R$3,99 |
| BMS Module | Battery Management System that protects against overcharging, deep discharge, short circuits, and balances battery cells | R$ 15,80 |

**Source:** research data.

The microcontroller selected for this study was the Arduino Nano, a compact option based on the ATmega328P, known for its versatility in connecting with a wide range of sensors and actuators. Due to its small size, it is particularly suitable for applications with limited space without compromising functionality. To expand its capabilities, a shield coupled to the Arduino Nano was used, equipped with an SD card reader and an integrated Real-Time Clock (RTC) module. This combination enabled the storage of large volumes of data and ensured accurate time-stamping, even during system shutdowns, an essential feature for the reliable recording of measurements over time.

Temperature and relative humidity measurements were performed using the DHT22 sensor, which comes factory-calibrated and provides high accuracy and easy integration with Arduino due to its digital output, facilitating data acquisition. The DHT22 offers a wide temperature measurement range from -40 °C to 80 °C (accuracy of ±0.5 °C) and relative humidity measurements ranging from 0% to 100% (accuracy varying between ±2% and ±5%). Both parameters have a response time of approximately 2 seconds, ensuring rapid and consistent measurements. The RTC module played a fundamental role in maintaining accurate date and time records, ensuring that each measurement was registered with the correct timestamp. All collected data were stored on an SD card at regular 20-

minute intervals, ensuring an organized database ready for subsequent analysis.

To ensure system autonomy under field conditions, the system was connected to a rechargeable lithium battery capable of continuously and stably powering all circuits. The electronic assembly was protected by an acrylic enclosure manufactured using a 3D printer, which provided resistance to environmental conditions, protection against macaw damage, and adequate insulation for the internal components (Figure 4).

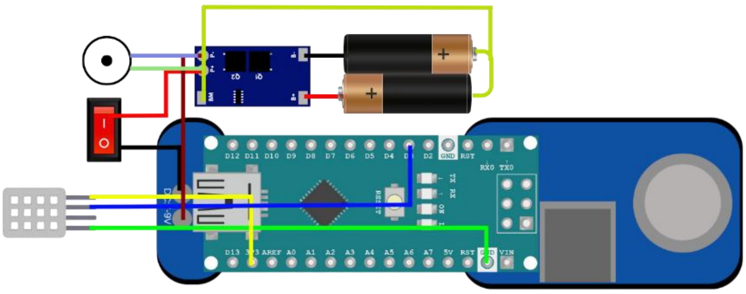
**Figure 4** – Control enclosure of the first prototype developed

**Source:** the authors.

### 2.1 Equipment Assembly

The components were integrated into a prototyping board following the wiring diagram provided by the manufacturers. The RTC module was configured to automatically synchronize with the local time. The shield was connected directly to the Arduino, facilitating the storage and retrieval of the collected data (Figure 5).

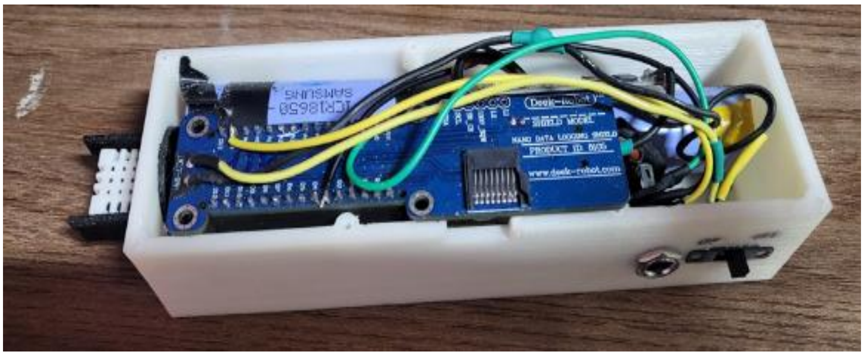
**Figure 5** – Electrical diagram of the datalogger



**Source:** the authors.

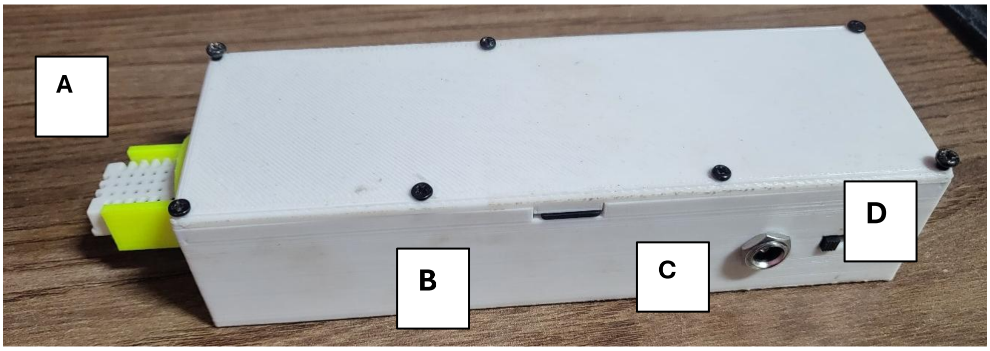
Following the construction of the first prototype, tests were carried out to verify device functionality, including soldering quality, component connections, and the accuracy of the code for data acquisition and storage. After the initial prototype tests, a new control enclosure model was manufactured using a GTMAX Core A3 3D printer, resulting in a more resistant, functional, and visually improved design (Figures 3 and 4). In this new model, the device included the following layout: an on/off switch, a power input connector, and an SD card slot (Figure 6). The equipment was tested under controlled conditions and demonstrated proper functionality in the data acquisition and storage system. Three devices were assembled, one of which was painted black to evaluate whether coloration would influence the breeding pair's acceptance of the object inside the nest (Figures 7 and 8).

**Figure 6** – Internal system of the device with the new control enclosure



**Source:** the authors.

**Figure 7** – Finalized control enclosure. A (Sensor); B (SD card slot); C (Power input connector); D (On/Off switch)




**Source:** the authors.

**Figure 8** – Control enclosure painted black

**Source:** the authors.

## 2.2 Field Performance Tests

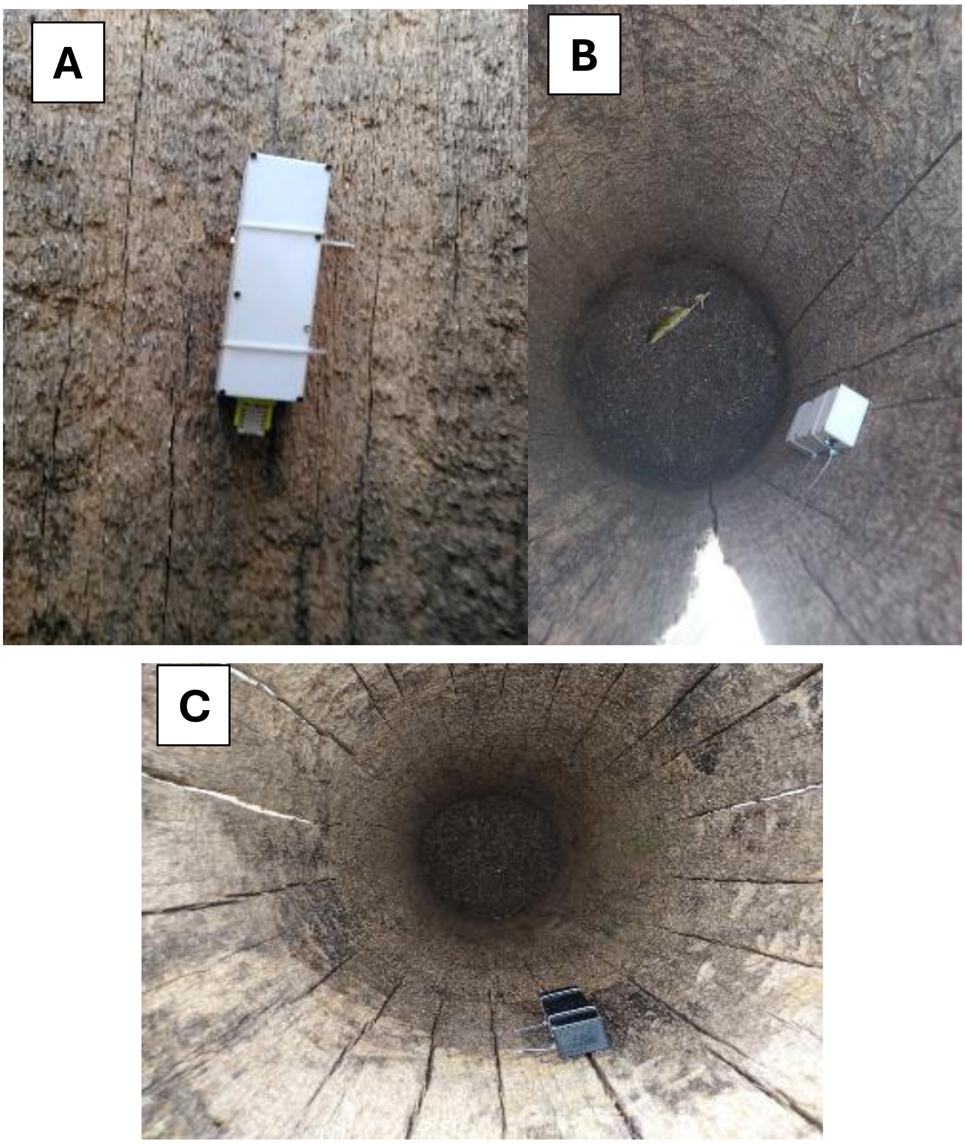
Following the initial laboratory tests of the prototypes, all devices were tested under field conditions to evaluate battery durability, equipment resistance to environmental conditions, and the behavioral response of macaws, thereby validating the equipment for studies of the nest microclimate of *A. ararauna*.

To install the prototypes inside *A. ararauna* nests (N1, N2, and N3), support was provided by the Projeto Aves Urbanas – Araras na Cidade (Urban Birds Project – Macaws in the City), which studies this species in the urban area of Campo Grande, Mato Grosso do Sul (Figure 9). To secure the equipment to the inner wall of the nest cavity, a drill and two nylon cable ties were used (Figure 10).

**Figure 9** – Team of the Projeto Aves Urbanas – Araras na Cidade providing support for the installation of temperature and humidity dataloggers in natural *A. ararauna* nests

**Source:** the authors.

**Figure 10** – (A) Datalogger installed inside nest N1; (B) Datalogger installed inside nest N2; (C) Datalogger installed inside nest N3



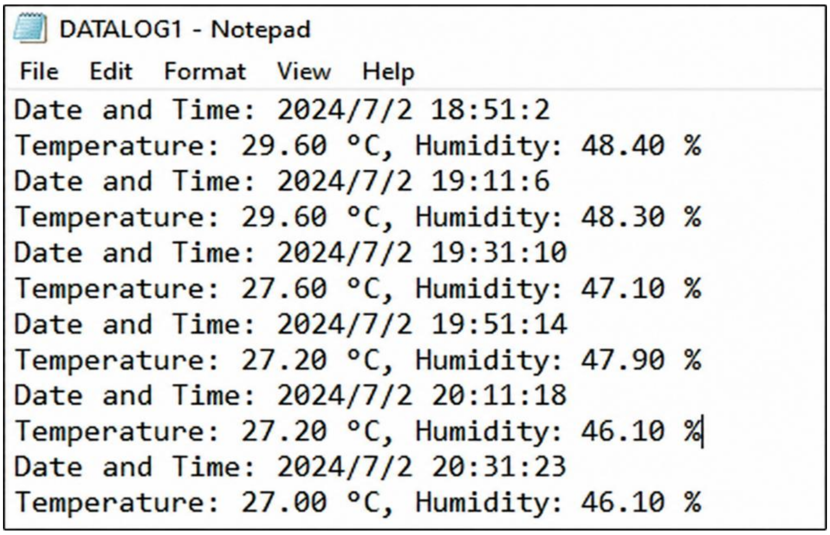

**Source:** the authors.

## 3 Results and Discussion

### 3.1 Laboratory Tests

Three devices for measuring and storing temperature and relative humidity data were assembled. Following the construction of the first prototype, tests were conducted to verify device functionality and the accuracy of the code used for data acquisition and storage. The equipment was tested under controlled conditions and demonstrated efficient performance. The recorded data were subsequently accessed through text files stored on an SD card (Figure 11).

**Figure 11** – Data recorded by the device




**Source:** research data.

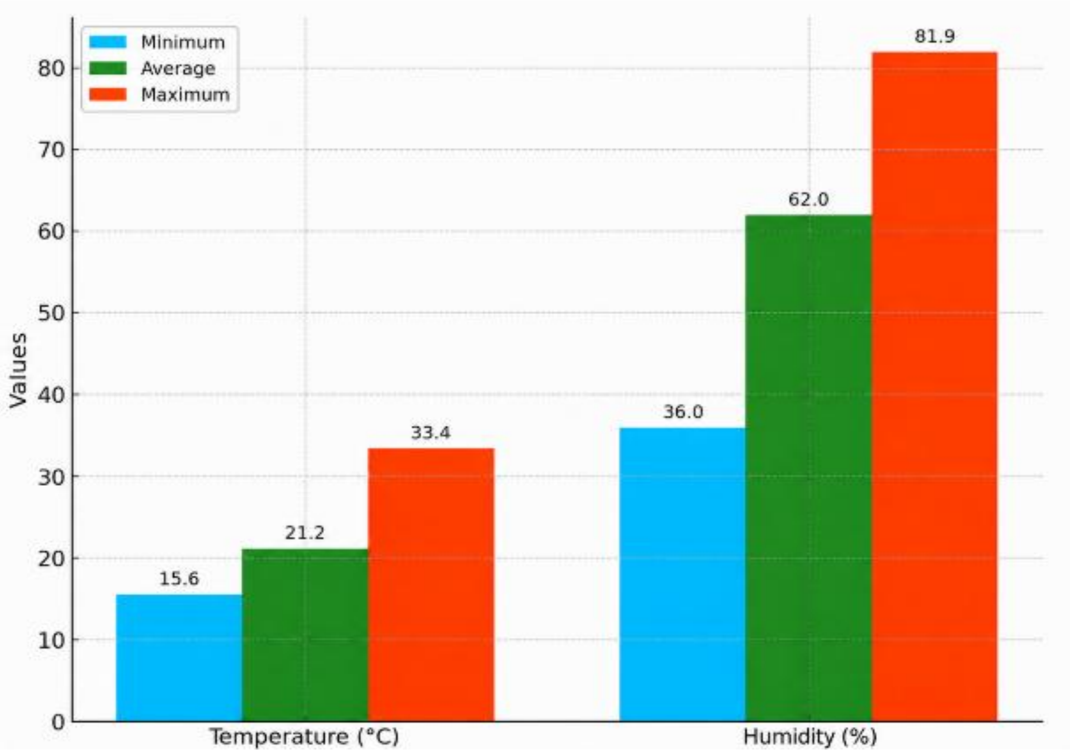
### 3.2 Field Tests

After the necessary adjustments, the devices were tested under field conditions and installed inside natural nests occupied by *A. ararauna* (Figures 5 and 6). Installation was simple and rapid, taking an average of 12 minutes. All devices remained in the nests for five days (installed on Sunday and retrieved the following Saturday) and were removed due to battery depletion.

Only the device installed in nest N1 functioned properly and recorded data at 20-minute intervals. The other two devices experienced Arduino failures, which prevented data collection. Because only one device successfully recorded field data, the present results should be interpreted as a preliminary proof-of-concept. Future studies involving a larger sample size and improved system reliability are necessary to validate the applicability of the datalogger under long-term field conditions.

The functioning device demonstrated consistent performance in temperature and humidity measurements using DHT22 sensors, whose manufacturer specifications indicate an accuracy of ±0.5 °C for temperature and ±2–5% for relative humidity. Although no comparative calibration was performed using a reference instrument, the values obtained were within the environmental range expected for the sampling period and were consistent with the manufacturer's specifications. However, battery autonomy represented a significant challenge, with an operational duration of 13 h 16 min 5 s and only 62 recorded measurements. The mean temperature recorded inside nest N1 was 21.2 °C, while the mean relative humidity was 62% (Figure 12). Temperature ranged from 15.6 °C to 33.4 °C, whereas relative humidity varied between 36% and 81.6%. The morning period recorded the lowest temperatures and highest humidity levels, while an inverse pattern for both variables was observed during the afternoon.

**Figure 12** – Minimum, mean, and maximum temperature (°C) and humidity (%) records obtained by the device tested in a natural *A. ararauna* nest




**Source:** research data.

The system operated for less than one day before requiring recharging, which negatively affected continuous data collection. Therefore, the limited battery autonomy highlighted the need for more effective energy management solutions, and the use of lower-power microcontrollers may represent a promising strategy to increase battery life. The limited battery life observed in this study highlights a common challenge of low-cost environmental monitoring systems based on microcontrollers. Similar limitations have been reported by Mühlbauer *et al*. (2023) e Majcan *et al*. (2023), emphasizing that energy optimization remains one of the main barriers to long-term autonomous environmental monitoring.

Parra *et al*. (2023) reported that low-cost environmental sensing systems often require hardware and operational adjustments to ensure long-term deployment under field conditions.

In addition to the Arduino failures and limited battery autonomy, other challenges were encountered and will be discussed in the following section. In response to the limited autonomy, we are investigating the implementation of a more energy-efficient microcontroller. Other potential improvements include the implementation of a wireless data transmission system for remote monitoring and the incorporation of a solar panel for battery recharging, similar approaches were described by Soemphol *et al*. (2025). Majcan *et al*. (2023) listed strategies to solve energy autonomy problems such as deep sleep, opting for low-power microcontrollers, and data management.

Regarding the behavior of *A. ararauna* breeding pairs toward the equipment, beak marks and one cut nylon cable tie were observed only in nest N2 (Figure 13). This particular pair exhibited strong defensive behavior, which may explain the curiosity and attempts to remove the equipment. The beak marks observed on the equipment suggest exploratory interactions by the breeding pair occupying the nest.

**Figure 13** – Datalogger showing beak marks and a cut nylon cable tie in the nest substrate of N2

**Source:** Hyacinth Macaw Institute Archive (2024).

López-López (2022) reported physical interactions between birds and video monitoring equipment installed near raptor nests, leading to equipment replacement and frequent maintenance, highlighting one of the challenges associated with wildlife monitoring studies involving technological devices.

Psittacidae are known to use their beaks extensively for object and food manipulation, nest construction and modification, as well as environmental exploration during nest occupation (Toft; Wright, 2015). Olah *et al*. (2014) reported challenges in studies involving *Ara macao* in Peru due to the tendency of individuals to physically interact with installed structures, such as artificial nests requiring reinforced and "macaw-resistant" equipment designs. Therefore, future versions of the datalogger may require a more robust housing to minimize potential damage caused by animal interactions. However, the device demonstrated durability and effectively protected the internal system, causing no damage and showing promise for studies on the nest microclimate of *A. ararauna.*

Beyond its application in the present study, low-cost microcontroller-based systems have been increasingly adopted in several environmental monitoring applications. Figure 14 summarizes some of the main fields in which these technologies have been successfully employed.

**Figure 14** – Main applications of low-cost environmental microcontrollers in monitoring and microclimate studies


**Source:** the authors.

According to the data obtained, the equipment demonstrated potential applicability for microclimate studies, although operational limitations were observed, particularly those related to energy autonomy and failures in electronic components. Nevertheless, the system shows strong potential for further improvement, as it relies on commercially accessible, low-cost technologies less expensive than similar equipment currently available on the market (Table 2). The final cost of prototype assembly was R$138.24, making it a promising alternative for studies of the nest microclimate of *A. ararauna* and other environmental monitoring research.

**Table 2** – Comparison between the developed datalogger and commercially available equipment

| Characteristic | Proposed Equipment | Commercial Equipment (Models) | |
|---|---|---|---|
| | | AKROM KR430 | ASKO AK174 |
| Cost (R$) | R$138.24 | R$521.41 | R$1117.86 |
| Temperature (°C) | Yes | Yes | Yes |
| Humidity (%) | Yes | Yes | Yes |
| Time-stamping | Yes | Yes | Yes |
| Resistance to Macaw Damage* | High | Low | Low |
| Open-source Code | Yes | No | No |
| Power Source | Rechargeable lithium batteries | Lithium battery | Lithium battery |
| Enclosure | Simple | Sophisticated | Sophisticated |

***Note:** Resistance to macaw damage was qualitatively assessed based on observed interactions of *A. ararauna* with the equipment, considering beak marks, attempted removal, and structural integrity after field exposure. Commercial models were classified based on enclosure characteristics, as no direct testing with macaws was performed.
**Source:** Prepared by the authors based on the technical specifications and prices of the prototype and the commercial models AKROM KR430 and ASKO AK174 available on the market (2026).

When compared to commercially available equipment commonly used in environmental monitoring, such as the AKROM KR430 and ASKO AK174 models, the developed prototype demonstrated a cost reduction of 73.49% and 87.63%, respectively. Although limitations related to energy autonomy and operational robustness remain, the substantial reduction in cost reinforces the prototype's potential as a low-cost alternative for microclimatic studies in natural *A. ararauna* nests.

The cost reduction achieved in the development of the equipment proposed in this study, when compared to commercially available dataloggers, may increase the feasibility of ecological studies by improving accessibility to this type of technology and consequently expanding monitoring coverage, particularly in conservation projects with limited financial resources (Chan *et al.*, 2021). Cannon *et al.* (2022) reported similar advantages of low-cost environmental monitoring systems, in which reduced equipment costs enabled an increase in the number of monitoring devices and broader spatial coverage, thereby improving the robustness of ecological studies. Similar findings have also been reported by Mao *et al.* (2019) and Chan *et al.* (2021), who highlighted that low-cost environmental sensor systems can facilitate larger-scale and long-term ecological monitoring.

### 3.3 Operational Limitations and Improvement Perspectives

The main challenges encountered during this study included delays in the delivery of imported components; the development of a code capable of optimizing battery consumption while performing temperature and humidity readings and storing data on the SD card in the desired format; the design of a compact enclosure capable of efficiently protecting the entire system; errors during the soldering process, which resulted in multiple replacements of system components; and difficulties in obtaining equipment and partnerships to develop a product with improved aesthetic finishing.

Nevertheless, as previously discussed, adjustments are still required to improve the equipment's energy efficiency and increase its autonomy for continuous data acquisition. In addition, modifications in the data storage format are necessary to improve data visualization and subsequent analysis.

## 4 Conclusion

The development and implementation of the datalogger for microclimate monitoring demonstrated the feasibility of the system, with the use of the Arduino Nano, SD shield, and RTC module proving effective for data collection and storage. The DHT22 sensors provided accurate temperature and humidity measurements, which were fundamental to the system's effectiveness.

Despite the satisfactory accuracy of the measurements, the overall reliability of the datalogger was affected by failures in two Arduino boards, which prevented data collection in two nests. Battery autonomy also represented a critical limitation, with the system operating for less than one day before requiring recharging. Therefore, the adoption of lower-power microcontrollers represents a promising strategy to increase system autonomy and reduce the frequency of recharging. The incorporation of technologies such as solar panels and wireless data transmission systems may also provide alternatives to overcome autonomy limitations and enable more effective remote monitoring.

In this context, the challenges encountered during the study will serve as a basis for the development of more advanced and robust versions of the system, with potential positive impacts on conservation projects that require environmental monitoring.

Despite limitations related to energy autonomy, the low cost, accessibility, and adaptability of the equipment highlight its potential for application in studies of the microclimate of natural *A. ararauna* nests under free-ranging conditions and, following technical improvements, may enable adaptation for other environmental monitoring applications.

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**References**

BANZI, M.; SHILOH, M. *Primeiros passos com o Arduino*: a plataforma de prototipagem eletrônica open source. São Paulo: Novatec Editora, 2015.

BARBOSA, L.T. *Fatores que influenciam o sucesso reprodutivo da arara-canindé (Ara ararauna) em Campo Grande, Mato Grosso do Sul*. 2018. 121f. Tese (Doutorado em Meio Ambiente e Desenvolvimento Regional) - Universidade Anhanguera-Uniderp, Campo Grande, 2024.

CANNON, J.B. *et al.* Applications of low-cost environmental monitoring systems for fine-scale abiotic measurements in forest ecology. *Agricul. Forest Meteorol.*, v.321, p.108973, 2022. doi: https://doi.org/10.1016/j.agrformet.2022.108973.

CHAN, K. *et al.* Low-cost electronic sensors for environmental research: pitfalls and opportunities. Progress Phys. Geogr. *Earth Environ.*, v.45, n.3, p.289-317, 2021. doi: https://doi.org/10.1177/0309133320956567.

CHOKHACHIAN, A. *et al.* Sensing transient outdoor comfort: A georeferenced method to monitor and map microclimate. *J. Build. Eng.*, v.20, n.1, p.94-104, 2018. doi: https://doi.org/10.1016/j.jobe.2018.07.003.

DAWSON, R.D.; LAWRIE, C.C.; O'Brien, E.L. The importance of microclimate variation in determining the size, growth, and survival of avian offspring: experimental evidence from a cavity nesting passerine. *Oecologia*, v.144, p.499-507, 2005. doi: https://doi.org/10.1007/s00442-005-0075-7.

IHLENFELD, W. *et al.* Prototipação de sistema portátil de monitoramento ambiental de baixo custo para estudos de conforto ambiental em espaços abertos. In: ENCONTRO LATINO-AMERICANO DE CONFORTO NO AMBIENTE CONSTRUÍDO, 2023. doi:

https://doi.org/10.46421/encac.v17i1.3844.

JOLLY, F.A. *et al.* Analyzing the efficiency of Arduino UNO microcontroller in monitoring and controlling the microclimatic parameters of greenhouse. *J. Agrom.*, v.26, n.1, p.51-55, 2024. doi: https://doi.org/10.54386/jam.v26i1.2520.

LÓPEZ-LÓPEZ, P. Potential negative effects of the installation of video surveillance cameras in raptors' nests. *Scientific Reports*, v.12, p.21969, 2022. doi: https://doi.org/10.1038/s41598-022-26153-7.

MAJCAN, T.C.; OULD, S.; BENNETT, N.S. Investigating pathways to minimize sensor power usage for the Internet of Remote Things. *Sensors*, v.23, n.21, p.8871, 2023. doi: https://doi.org/10.3390/s23218871.

MUELLER, A.J.; MILLER, K.D.; BOWERS, E.K. Nest microclimate during incubation affects posthatching development and parental care in wild birds. *Scie. Rep.*, v.9, p.5161, 2019. doi: https://doi.org/10.1038/s41598-019-41690-4.

MAO, F. et al. Low-cost environmental sensor networks: Recent advances and future directions. *Frontiers in Earth Science*, v.7, p.221, 2019. doi: https://doi.org/10.3389/feart.2019.00221.

MCROBERTS, M. *Arduino Básico: Crie projetos simples e práticos com arduino*. São Paulo: Novatec, 2015.

MÜHLBAUER, L.K. *et al.* Arduinos in the wild: A novel, low-cost sensor network for high-resolution microclimate monitoring in remote ecosystems. *Ecol. Solut. Evid.,* v.4, e12255, 2023. doi: https://doi.org/10.1002/2688-8319.12255.

NOUMAN, A.S. *et al.* Prototyping of Environmental Kit for Georeferenced Transient Outdoor Comfort Assessment. *ISPRS Int. J. Geo-Inf.*, v.8, n.76, p.1-23, 2019. doi: https://doi.org/10.3390/ijgi8020076.

OSPINA, E.A; MERRILL, L.; BENSON, T.J. Incubation tem¬perature impacts nestling growth and survival in an open-cup nesting passerine. *Ecol. Evol.*, v.8, p.3270-3279, 2018. doi: https://doi.org/10.1002/ece3.3911.

OLAH, G. *et al*. Nest site selection and efficacy of artificial nests for breeding success of Scarlet Macaws (Ara macao macao) in lowland Peru. *J. Nat. Conserv.*, v.22, n.2, p.176-185, 2014. doi: https://doi.org/10.1016/j.jnc.2013.11.003.

PARRA, L. *et al.* Low-cost microcontroller-based multiparametric probe for coastal area monitoring. *Sensors*, v.23, n.4, p.1871, 2023. doi: https://doi.org/10.3390/s23041871.

PORTER, W.P.; KEARNEY, M. Size, shape and the thermal niche of endotherms. *Proc. Natl Acad. Sci.*, v. 106, p. 19666-19672, 2009. doi: https://doi.org/10.1073/pnas.0907321106.

ROMERO, M.A.B. *et al.* Instrumentação para medições em escala microclimática: uma proposta de mochila bioclimática. *Cad. Arquit. Urban.*, v.1, n.26, p.96-105, 2020. doi: https://doi.org/10.18830/issn.1679-0944.n26.2020.07.

SANTOS, R.J.; ROGÉRIO JÚNIOR, L. Desenvolvimento e confeccção de um datalogger aplicado ao monitoramento de temperatura e umidade relativa do ar de uma granja cunícola. *Rev. Eng. Tecnol.*, v.12, n.4, p.249-256, 2020.

SOEMPHOL, C. *et al.* Design and implementation of a solar-powered IoT-based real-time air quality monitoring system. *Bull. Electr. Eng. Inform.*, v.14, n.1, p.465–474, 2025. doi: https://doi.org/10.11591/eei.v14i1.10473.

SUDYKA, J.; LECCE, I.; SZULKIN, M. Microclimate shifts in nest-boxes and natural cavities throughout reproduction. *J. Avian Biol.*, v.1, e03000, 2023. doi: https://doi.org/10.1111/jav.03000.

TOFT, C. A.; WRIGHT, T.F. *Parrots of the wild*: a natural history of the world's most captivating birds. Oakland: University of California Press, 2015.

TRENTO, D.; TRENTO, T.P.W.; KRUGER, E.L. Application of Arduino-Based Systems as Monitoring Tools in Indoor Comfort Studies: a bibliometric analysis. *Int. J. Arch. Eng. Technol.*, v.7, n. 1, p. 1-12, 2020. doi: https://doi.org/10.15377/2409-9821.2020.07.1.