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Development of an electromechanical device for real-time detection of litter moisture in commercial broiler

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ABSTRACT

Broiler litter quality is a critical factor in industrial broiler production systems, as it affects the environment and animal welfare. The litter is composed of thermal insulating materials such as wood shavings, peanut shells and, rice, among others, with the ability to absorb animal excreta. Its condition can impact environmental quality. Depending on its condition, it may increase the levels of gases and dust in the aviary, and may cause pododermatitis, compromising paw quality. Effective management requires analyzing litter quality by measuring moisture content. This article presents the development of an electronic sensor for detecting chicken litter moisture using microcontrollers and rapid prototyping sensors. The construction method involved three stages: prototyping a minimum viable product (MVP), conducting field tests to evaluate the sensor's humidity detection capability when integrated with a pre-existing robot, and mathematical modeling to determine the most suitable sensor for detecting litter humidity. This process utilized Technical Standard NBR 6457 to calibrate the equation for adjusting the detected humidity level. The findings confirmed the successful development of a calibrated electronic sensor for measuring litter humidity. This device was tested in a commercial poultry farm, producing a humidity map over a six-week production cycle.

1. Introduction

Broiler chickens raised in an artificial environment require precise control of environmental conditions and litter quality to achieve optimal productive performance. The litter is used to absorb excreta and act as a thermal insulator. Its condition directly affects the quality of the environment and the productive performance of the batch [1,2]. During the production cycle, the litter undergoes constant chemical and biological processes due to the interaction between the environment and animals. Controlling and monitoring humidity and gases resulting from these biochemical processes are necessary to maintain the quality of the microbiological litter and, consequently, satisfy the animals' homeostasis and well-being [3,4].

To reduce production costs, the practice of reusing litter for 5 to 6 production cycles is common [4,5]. However, this method can decrease the sanitary quality of the litter, increase the concentration of pathogenic microorganisms and reduce the liquid retention capacity, causing it to become easily saturated. The incidence of high humidity in the litter (>30 %) correlates with the increased production of gases inside the poultry house [6,7] and is associated with several diseases in animals, such as plantar pad dermatitis, hock dermatitis and chest skin dermatitis [8,9]. These diseases affect not only the quality of the carcasses, but also decrease feed conversion rates, as animals in pain are less likely to visit feeders and waterers [4,10,11].

Monitoring, mapping and analyzing variations in litter humidity in the poultry house is extremely important for understanding how it can influence the generation of gases, dust, diseases and feed conversion [12]. This work hypothesizes that it is possible to develop a technological tool that can measure the humidity values of chicken litter in real-time at different points, optimizing the diagnosis to determine better environmental and sanitary conditions for the animals, favoring better decision-making for implementing litter management.

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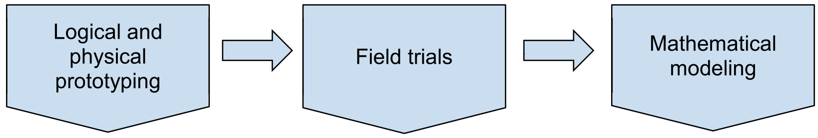


Fig. 1. Activities for MVP development.

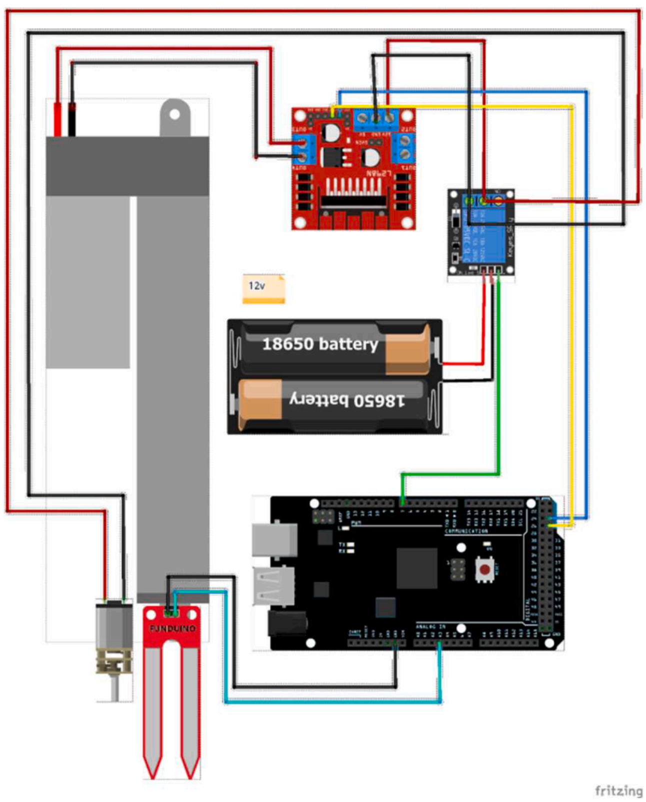


Fig. 2. Electrical schematic of the device circuit.

This study aims to build a device capable of measuring the relative humidity in chicken litter in real-time, enabling its analysis based on environmental indices. The specific objectives are to develop an electromechanical device capable of penetrating the litter through a Minimum Viable Product (MVP); attach this device to an existing robotic structure; measure the humidity of the litter and map the warehouse bringing the positions of each humidity measurement.

2. Materials and methods

The development and performance of the tests that validated the device as a Minimum Viable Product (MVP) model were conducted in three phases, as shown in Fig. 1 and described below.

1. Logical and physical prototyping stages were performed as follows: the development of the device was guided by technical premises based on the following functionalities:
   a) analysis of different soil moisture sensors compatible with the ATMega2560 microcontroller;
   b) ability to drill into the litter to allow the soil moisture sensor penetration; and
   c) ability to insert the soil moisture sensor into the drilled litter;
2. Field trials: The device was evaluated based on the following parameters at a commercial broiler poultry farm:
   a) ability of the soil moisture sensor to measure litter moisture throughout the six-week breeding period; and
   b) accurate readings taken as samples at predetermined points in the poultry shed.
3. Mathematical modeling: This phase involved the statistical analysis of the experiment and respective data collected on the following aspects:
   a) different models of soil moisture sensors were compared based on their moisture reading capabilities and validated using the statistical Pearson correlation method; and
   b) the moisture level of the samples taken by the device was compared with the analyses of the samples collected concurrently. These measurements were compared by drying the samples using the Técnica da Estufa (NBR 6457) and validated with the statistical curve fitting technique [13].

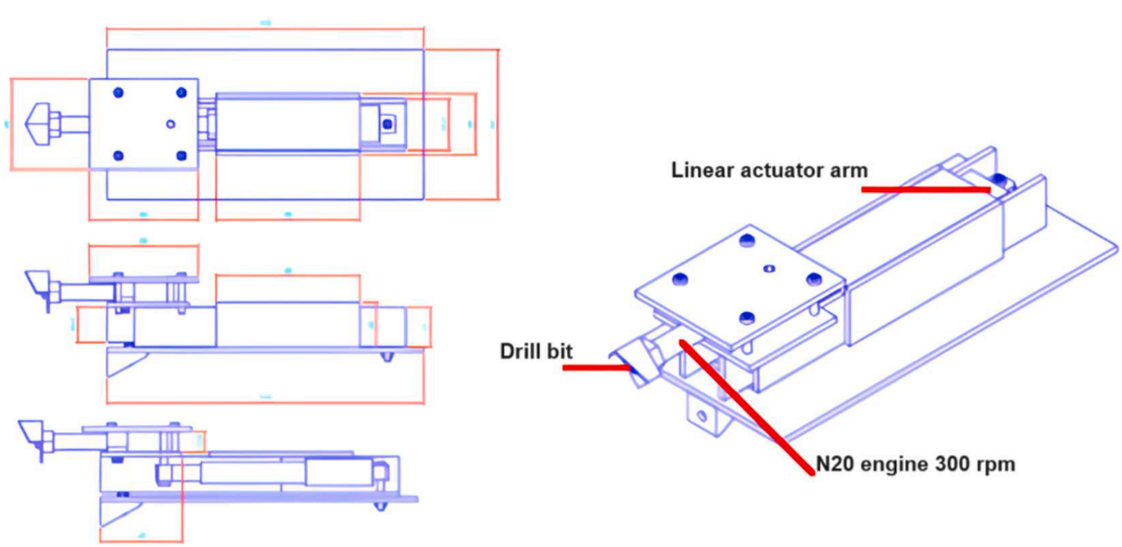
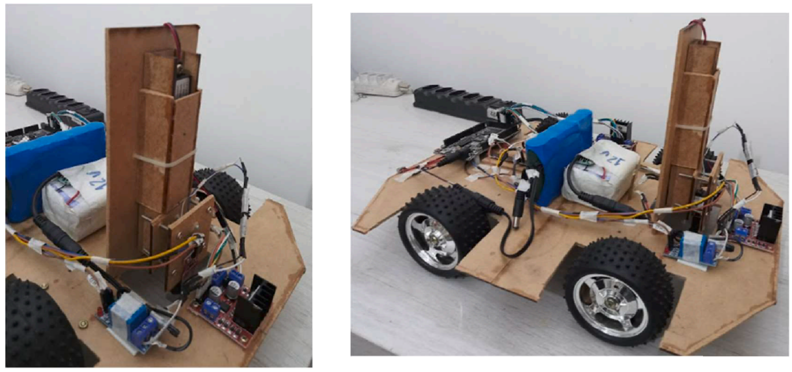


Fig. 3. Device modeling in AutoCAD software.



A B

Fig. 4. Physical implementation of the device. A: top view; B: side view.

Table 1
Humidity sensors analyzed.

Model	Manufacturer/Website	Description	Length
GBKP23	GBK Robotics (https://www.eletruscomp.com.br/arquivos/1488567050_dados_tecnicos_p23__gbk_sensor_de_umidade_d.pdf)	Moisture sensor used to detect variations in soil moisture, and can also be used on land, sand or directly in water.	48mm
GC-58	Funduino (https://funduino.de/wp-content/uploads/2019/04/001616242-an-01-en-BODENFEUCHTE_SENS_MOD_IDUINO_ME110–1.pdf)	Analog sensor, made in RF4 with output voltage: 0 ~ 2.3V , offering a long lifespan due to its high-quality construction and robustness.	55mm
YL-69	MH-SensorSeries (https://usermanual.wiki/Pdf/instructions.261306374/view)	Sensor that uses two probes to measure humidity by measuring the current between them with a trimpot in the circuit allowing the sensitivity to be adjusted.	60mm
HW-390	MH-SensorSeries (https://media.digikey.com/pdf/Data%20Sheets/DFRobot%20PDFs/SEN0193_Web.pdf)	Fixed frequency oscillator, based on the CI 555 (Timer), generating a square wave that is then converted into an analog signal.	97mm

3. Results and discussions

For the physical prototyping of the device, the following equipment was previously considered: WemosR3 Mega + ESP8266 microcontroller with 32 MB of memory, Integrated Development Environment (IDE) Arduino IDE with *C*++ programming language, a computer with an Intel Core i7–1165G7 processor (2.80 GHz) with 8GB of memory running Windows 11 Home Single Language operating system. The electrical circuit diagram was modeled using Fritzing software version 0.9.3 and the architectural model of the prototype was created in AutoCAD 2017 (Release 21.0).

3.1. Logical and physical prototyping

The device was developed using Medium Density Fiberboard (MDF) with a thickness of 3 mm to facilitate cutting and modeling, providing a rigid structure to support the components. Associated with the WemosR3 microcontroller, a 5 V and 10A relay was coupled, which was responsible for activating/deactivating the functioning of the mechanism. An L298N dual H-bridge driver module was used to control the lowering and raising of the actuator arm for drilling and litter penetration actions. This actuator arm was a linear model, with 12 V voltage, maximum length (open) of 150 mm and force of 19.2 N. Furthermore, the actuator arm was associated with the operation of the H-bridge. An N20 motor (voltage 6–12 V, rotation speed of 300 rpm) was coupled to its tip, and in parallel, a soil moisture sensor with a hygrometer rod (Funduino brand, model GC-58). The entire electrical circuit was powered by a 28,000 mAh 12 V battery. The electrical schematic for the device circuit is shown in Fig. 2.

The device was modeled using AutoCAD software, which made it possible to dimension the physical characteristics of the circuit. This allowed the creation of a model that can be coupled to a mobile robotic structure previously developed at NUPEA/ESALQ/USP, as shown in Fig. 3.

Fig. 4 shows the device attached to the chassis of the robotic structure. The device is activated by a relay that energizes the L298N H-bridge. A command via programming determines whether to lower or raise the actuator arm. When descending, the N20 motor is activated, and the attached drill bit begins to rotate. This drill penetrates the litter, creating a hole. Simultaneously, the GC-58 sensor penetrates the litter. After waiting 30 s for the GC-58 sensor to take the humidity reading, the arm rises, retrieving the sensor and the drill bit. A video is featured at: https://www.youtube.com/shorts/LH_zLPi6FD4.

3.2. Determination of soil moisture sensor

The selection of the Funduino hygrometer soil moisture sensor, model GC-58, was made through the analysis of different sensors of the same type. The prerequisite was that it be compatible with the Wemos R3 microcontroller and the Arduino IDE. Therefore, the following sensors were used in the comparison method to determine the reliability of the humidity reading: GBKP23, GC-58, YL-69 and HW-390.

Table 1 presents the information characterizing each of these sensors.

According to the specifications of the manufacturers of the GBKP23, GC-58, YL-69 and HW-390 sensors, only the readings of the analog ports are required to capture humidity indicators. Therefore, no Application Programming Interface (API) was needed, as reading the data could be done using a native function.

Afterwards, a physical prototype of the sensors coupled to the microcontroller was built, as shown in Fig. 5. The programming was modularized into four functions in the *C*++ language, performing twelve humidity readings with an interval of 500 milliseconds. At the end of 60 s, the humidity readings were collected. Outliers were identified and removed, and finally, the arithmetic average of these readings was calculated.

Next, humidity tests were conducted to discover the sensitivity of each sensor to different humidity levels, conducted from May 16 to 20, 2022. To this end, four different tests were implemented: ambient air (in a closed environment with windows shut on a dry day without air conditioning), direct contact with water (sensors immersed in a glass of

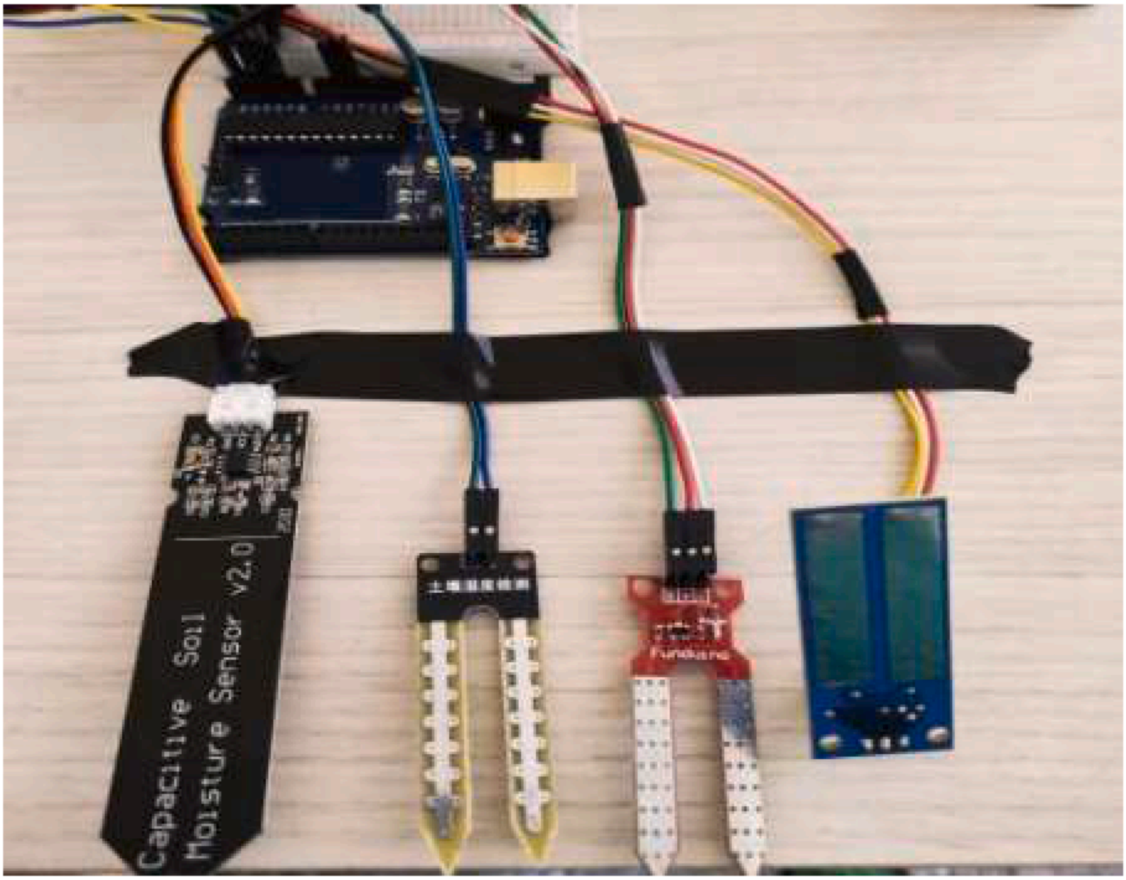
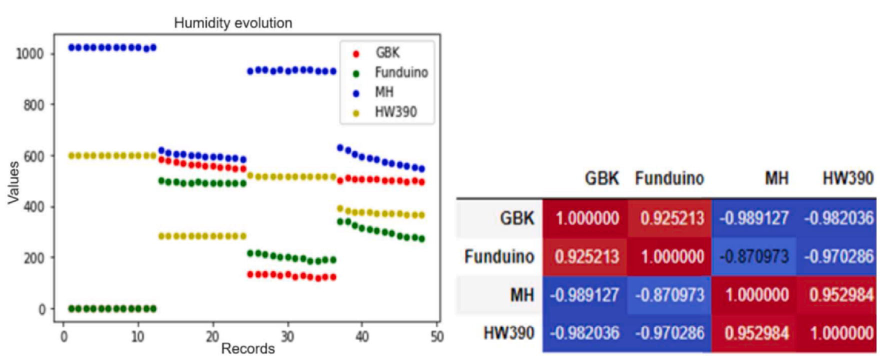


Fig. 5. Physical prototyping of sensors.



A B

Fig. 6. Correlation of data at distinct stages of the humidity method. A: Sensor analysis in the four tests; B: Pearson correlation between sensors.

water), dry soil (humidity percentage <10 %), and moist soil (humidity percentage > 30 %). The sensors were programmed to take readings every 5 s and were exposed for 60 s, generating 12 readings for each test. Freitas [14] and Eurachem [15] specify that the minimum value for analysis must be 10 records. The resulting data (values expressed by the resistance of the sensors) were plotted on images that show the dispersion throughout the capture of the records. An analysis was then conducted to understand the correlation between the data collected in all instances of execution of the four methods presented (Pearson's method). The results are presented in Fig. 6.

Analyzing the results obtained, it is evident that after conducting the tests, the sensors responded correctly to each stimulus presented. The values of the GBKP23 and Funduino GC-58 sensors increased as humidity levels rose and decreased as humidity levels dropped. Conversely, the MH YL-69 and HW-390 sensors exhibited the opposite behavior: their resistance values decreased with rising humidity and increased with falling humidity. The correlation between the sensors is high for the GBK P23 and Funduino GC-58 with a p-value of 0.925213. This result was expected, as both sensors work with the same data variation. The MH YL-69 and HW-390 sensors showed a high correlation with a p-value of 0.952984, however, their correlation with the GBKP23 and GC-58 sensors was inverse, which was also anticipated since their operating mechanisms differ from the other two sensors.

In conclusion all the humidity identification sensors responded correctly to the stimuli, though each displayed unique reading characteristics. This allowed any of the sensors to be used in the project.

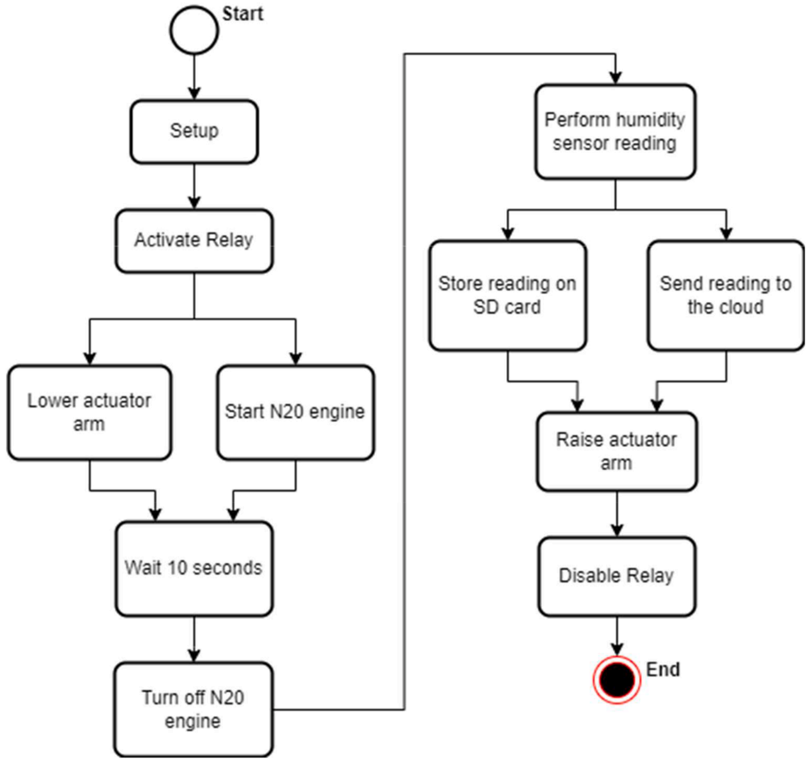


Fig. 7. Device operation flowchart.

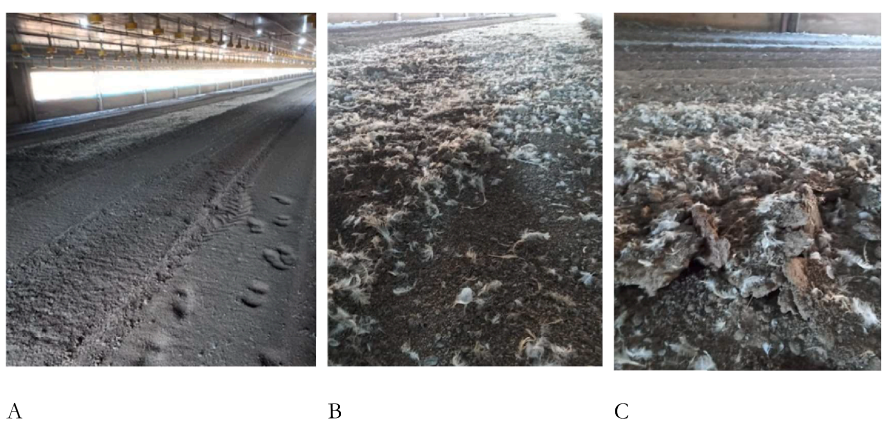


Fig. 8. Assessment of device penetration in bedding samples: A: soft, B: stony and C: compacted.

However, calibration with an industrial sensor or the use of a soil moisture analysis method was necessary to ensure data accuracy and to develop an adjustment curve equation to validate the readings. The determining factors for sensor selection were minimal length, appropriate shape, and sufficient rigidity to penetrate the ground via the actuator arm. Therefore, the GBKP23 sensor was disregarded due to its rectangular shape, which was not suitable for litter penetration. The other sensors had adequate rigidity to resist penetration and had a rectangular shape, yet with sharp edges that facilitated penetration. Therefore, among the three remaining sensors, the GC-58 was chosen for its smaller size, which subsequently facilitated coupling to the actuator arm for penetration into the litter broiler.

3.3. Moisture detection algorithm modeling and execution

An algorithm programmed in C++ language was implemented in the Arduino IDE to control the movement of the actuator arm, drive the motor for drilling into the litter, and perform the analysis of litter moisture using the soil moisture sensor. The algorithm flowchart is presented in Fig. 7.

The algorithm was executed and tested on the device using three samples of broiler litter collected from distinct parts of the aviary, each presenting distinct characteristics: the first was soft (fluffy); the second stony; and the third was cobbled (compacted) (Fig. 8). Furthermore, the device was coupled to an existing mobile robotic structure. Then, the device was activated and evaluated for its ability to pierce and insert the moisture sensor into the litter for each sample.

The first step was to analyze the motor and drill's ability to penetrate the soil for subsequent sensor insertion, quantifying the penetration depth in millimeters for each sample. The soft sample had a penetration depth of 50 mm; the stony sample, 38 mm; and the compacted sample, 7 mm. The sensor manufacturer recommends a minimum penetration of 40 mm for accurate humidity readings [16]. The soft sample met this requirement, the stony sample came remarkably close, however the

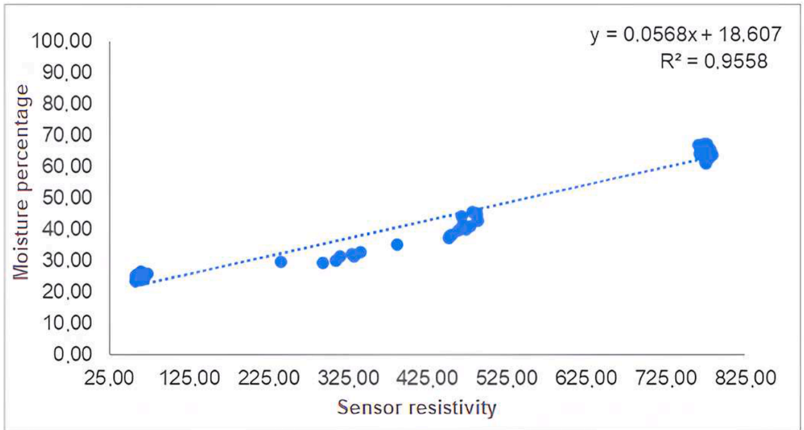


Fig. 9. Adjustment Curve resulting from GC-58 sensor calibration.

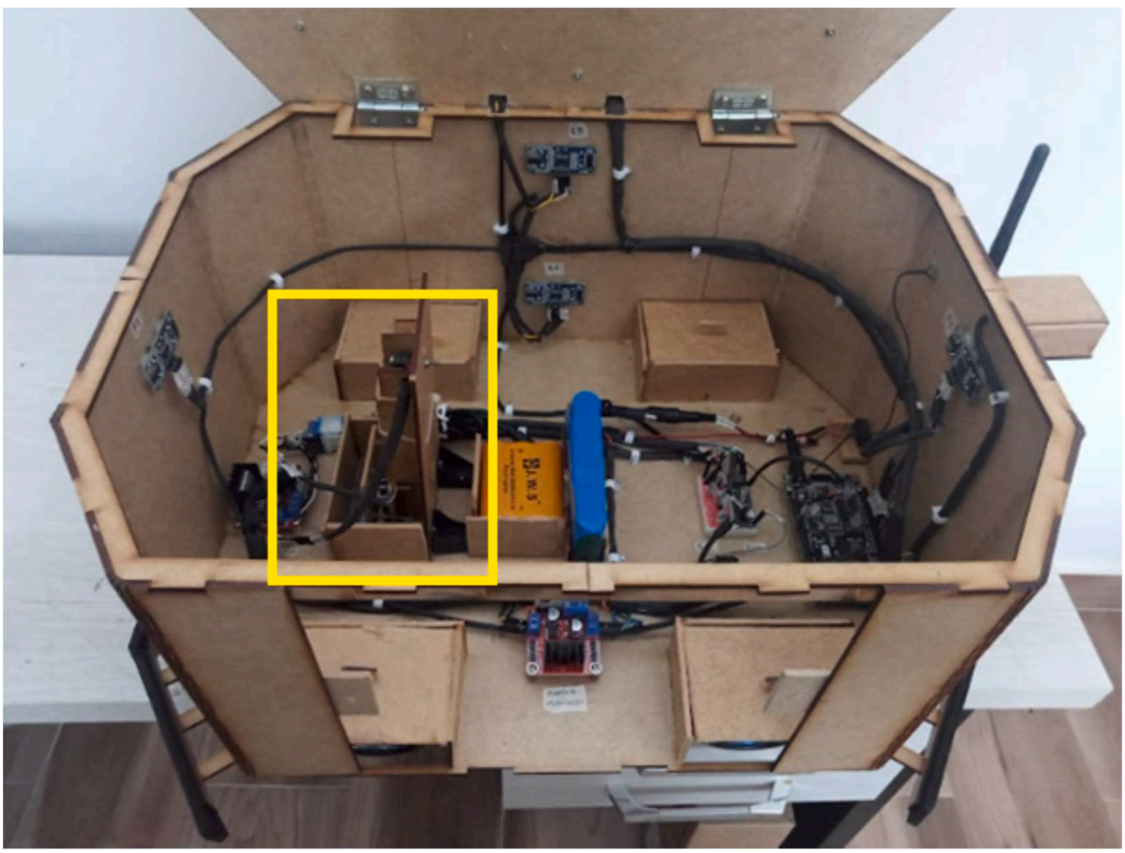


Fig. 10. Robotic prototype: internal view with highlight (yellow) for litter moisture measuring device.

compacted sample did not. Therefore, it is concluded that penetration is not feasible when the litter is compacted.

The second step was to analyze the GC-58 sensor's ability to measure humidity. When activated, this sensor does not display the humidity value directly, instead, it measures the difference in electrical resistivity between its two contact rods (electrodes). This difference is measured by varying the voltage between electrodes (between 0 and 5 V) which is then transformed into a numeric signal ranging from 0 to 1024, with 0 representing the lowest humidity detected and 1024 representing the highest humidity detected [17]. Thus, the relative humidity value was determined through a calibration process that validated the sensor. This process was conducted according to the Técnica da Estufa (NBR 6457) and the statistical Curve Adjustment method [13].

Three types of litter were analyzed in the aviary under different conditions: dry, stony and wet. For each condition, 20 samples of approximately 20 g each were collected, totaling 60 samples. Freitas [14] and Eurachem [15] suggest that the sample size must be at least 10 for the calculation of the adjustment curve. Each sample was deposited in a container that was weighed (initial gross weight); then, the GC-58 sensor was inserted into the sample and its resistivity value was stored in a database. Each sample was then placed in a Fanen® natural convection drying and sterilization oven, model 315 SE, for a period of 24 h at a constant temperature of 100 °C. After cooling, each sample was weighed again (final weight). Finally, according to [18] and [19] the percentage of moisture in the sample can be calculated according to Eq. (1).

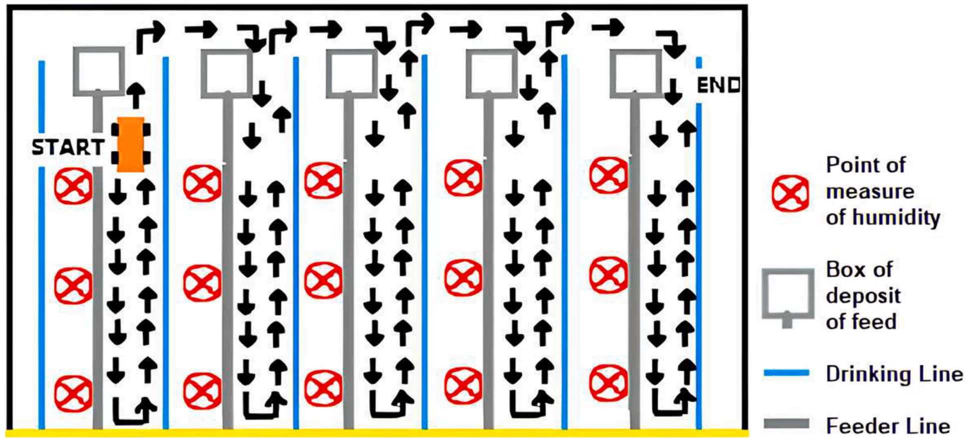


Fig. 11. Map of the robotic prototype's displacement and the moisture measurement points in the litter.

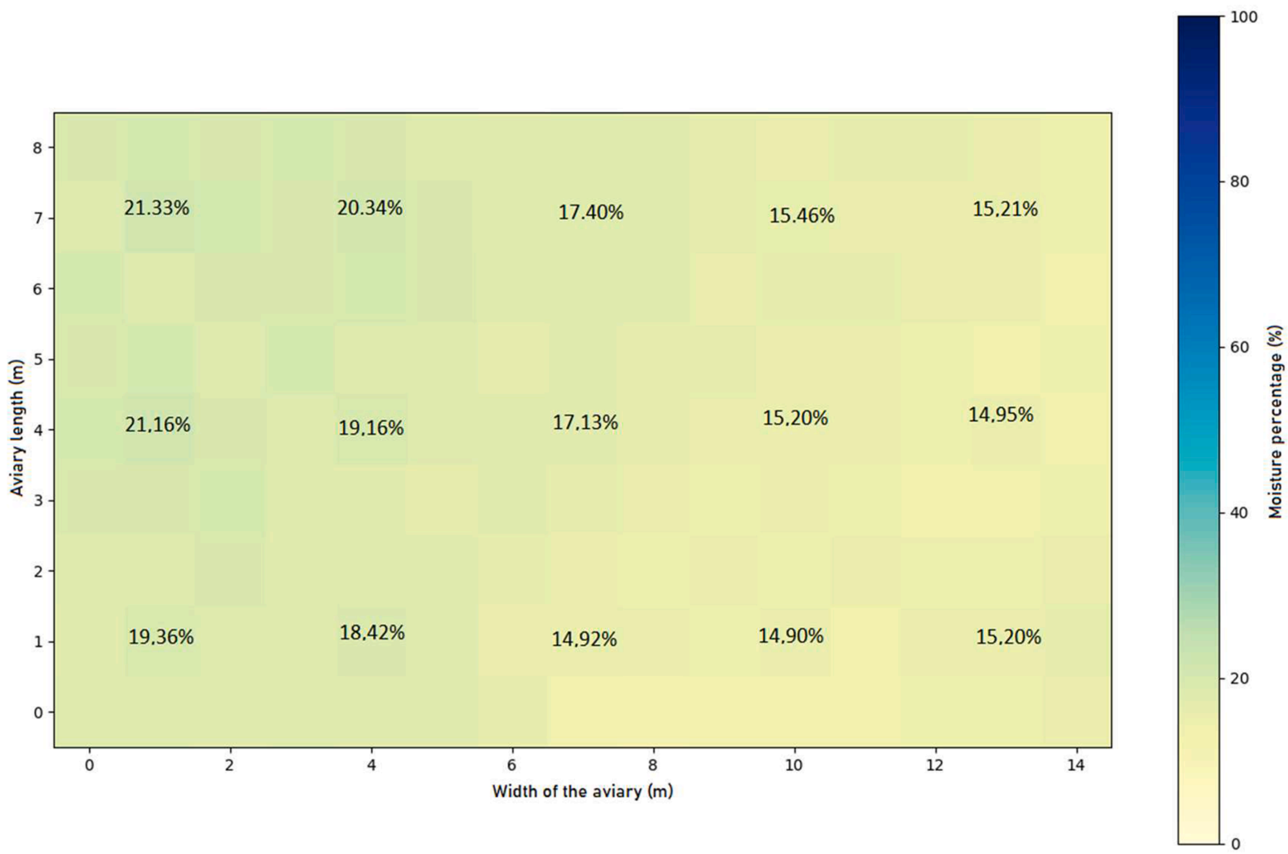


Fig. 12. Moisture distribution map in litter: week 1.

$$h = \left(\frac{(Igw - Fgw) * 100}{Igw - Inw}\right) \quad (1)$$

Source: [18,19]
Where:

h: relative humidity content (%)
Igw: Initial gross weight (g) – before being placed in the Técnica da Estufa.
Fgw: Final gross weight (g) – after being placed in the Técnica da Estufa.
Inw: Initial net weight (g) – before being placed in the oven.
Note: minus the value of the container: 0.97 g

Sample analysis was conducted by correlating sensor resistivity values with the obtained moisture percentage. The result showed a high correlation between the variables with $R^2 = 0.9558$ and Pearson Coefficient = 0.9761. The resulting equation is given in Eq. (2), and the corresponding trend curve from the GC-58 sensor calibration is shown in Fig. 9.

$$y = 0.0568x + 18.607 \quad (2)$$

Where:

y: resulting calibration value (moisture percentage)
x: sensor resistivity

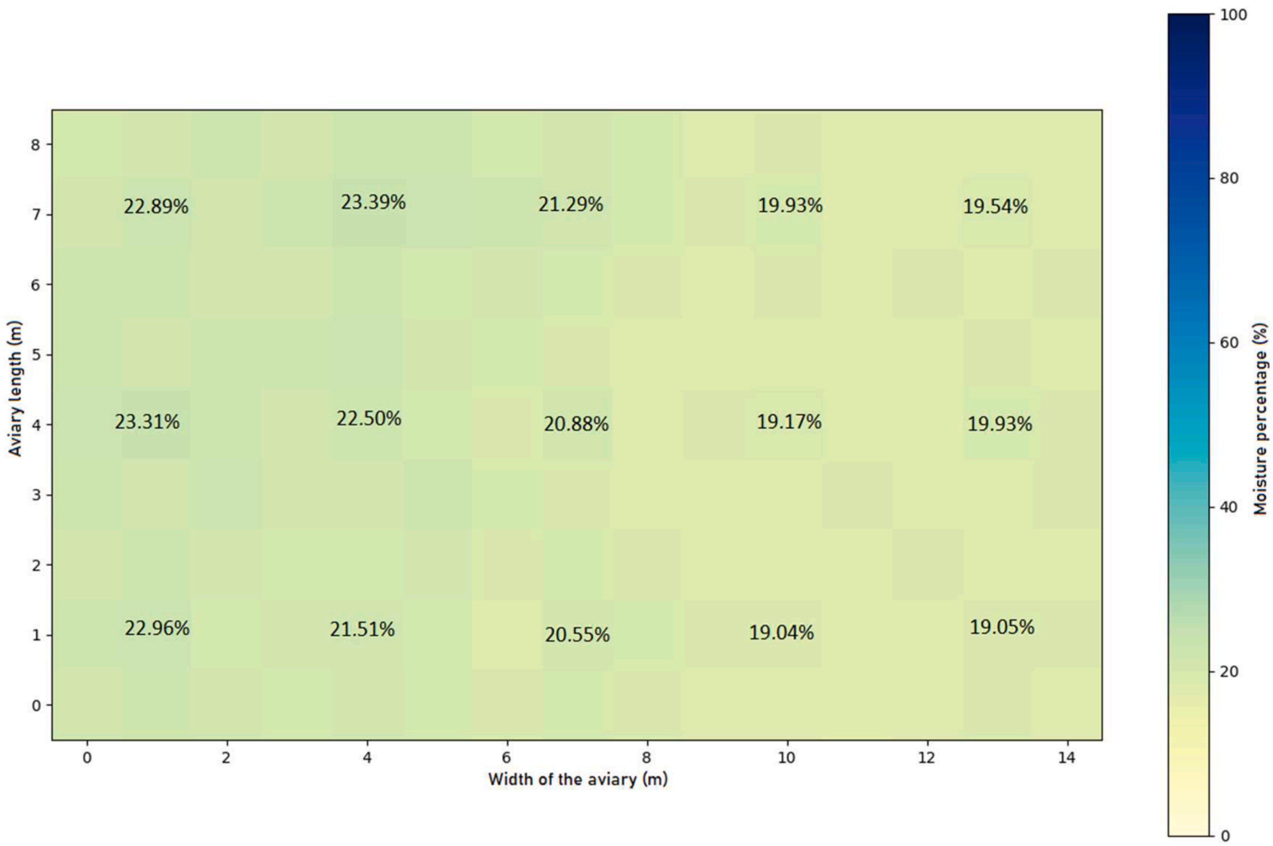


Fig. 13. Moisture distribution map in litter: week 2.

3.4. Assessment and determination of humidity in commercial poultry houses

This work was submitted, analyzed and approved by the Ethics Committee on the Use of Animals at the Luiz de Queiroz College of Agriculture of the University of São Paulo, under protocol number 7364,090,322. To conduct this project, a partnership was established with a chicken producer of the Cobb lineage, located in the city of Itatiba, São Paulo, Brazil, approximately 64 km from the capital, São Paulo. The farm is located at Latitude: −23.0068, Longitude: −46.8387, 23° 0′ 24″ South, 46° 50′ 19″ West; altitude 771 m, and is characterized by a humid subtropical climate (Köppen-Geiger climate classification: Cfa). The aviary operated under negative pressure, with dimensions of 135 m long, 14 m wide, 3 m ceiling height, composed of evaporative plates and exhaust fans, and also had an electronic system for monitoring relative humidity and dry air temperature (inoBram brand, model SMAAI 3 PE) that acted automatically. The litter was made entirely of wood shavings and was in its second use (second breeding cycle).

The device developed for this study was integrated into a robotic structure previously constructed by NUPEA/ESALQ/USP. This structure was a prototype robot equipped with four motors and 85 mm wheels. It measured 40 cm in length, 30 cm in width, 26 cm in height, and weighed 450 g. The robot was controlled by the WemosR3 Mega + ESP8266 microcontroller. Fig. 10 presents this robotic prototype.

The tests were conducted between November 22, 2022, and December 27, 2022, during which the moisture status of the chicken litter was evaluated throughout a complete broiler breeding cycle (6 weeks). The robotic prototype moved around the aviary, orienting itself along the feeder lines according to the scheme shown in Fig. 11. Therefore, it created a displacement trajectory starting from the beginning to the end of a feeder line, subsequently identifying the line of the next feeder and repeating the process until all 5 existing lines were finished. The robotic element was programmed to identify and count the feeders in each. Every 5 feeders, it stopped and measured the humidity of the litter, allowing the measurement to be carried out at 3 points for each feeder line.

The measurements conducted by the GC-58 sensor were programmed for conversion according to Eq. (2). The transformed data were then processed using the Python programming language in Google Colab to generate heat maps of humidity measurements (Figs. 12-17)

The values of the statistical measurements of litter moisture (confidence level at 95 %) are presented in Table 2.

According to the litter moisture values presented in Table 2, the following values were stipulated as an average for analysis in this study: minimum 22.50 % and maximum 31.67 %. The average results (Table 2) demonstrate that the breeding cycle began with a low moisture content in the litter (week 1: 17.34 %) and increased over the weeks (week 6: 33.36 %) with a positive variation rate of 92.39 % [13]. This finding corroborates studies by Gonçalves et al., [20] and Almeida [21] which demonstrate that the humidity of the litter tends to increase over the weeks due to the dumping of animal excreta and possible water leaks from drinking fountains.

The first four weeks did not present high humidity values, however, the fifth and sixth weeks presented respectively 3 and 9 high humidity points (all above 31.67 %). These points indicate areas in the aviary that require the litter to be turned to avoid formation of plaques or excessive humidity. Excessive humidity can lead to an increase in the microbial population in the litter, which in turn, can increase the presence of pathogens [22]. Additionally, it raises the probability of pododermatitis, chest injuries, skin burns, condemnations and/or losses in carcass quality [20].

The minimum humidity indicators (22.50 %) were identified more frequently in the litter, being higher in the initial weeks and lower in the final weeks: 15 in the first week, 10 in the second, 9 in the third, 6 in the

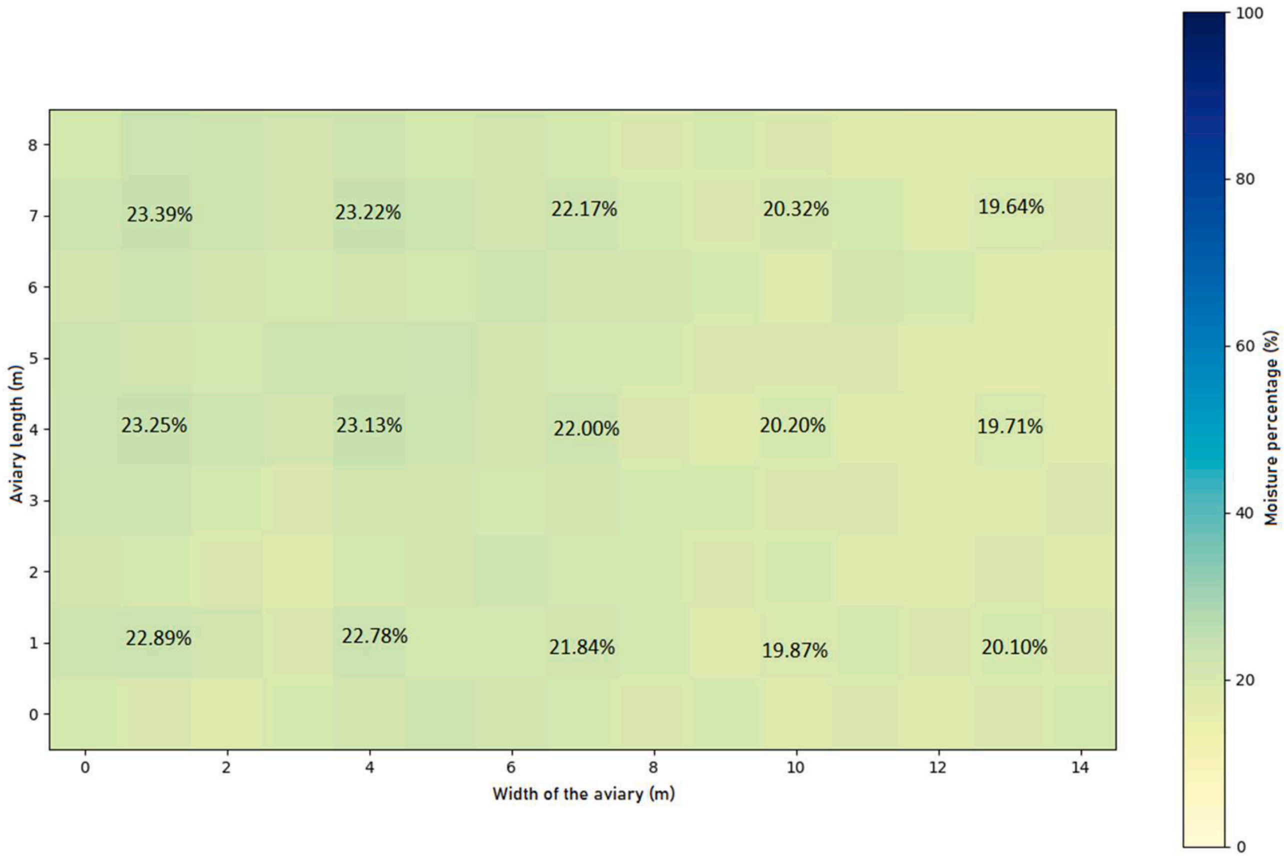


Fig. 14. Moisture distribution map in litter: week 3.

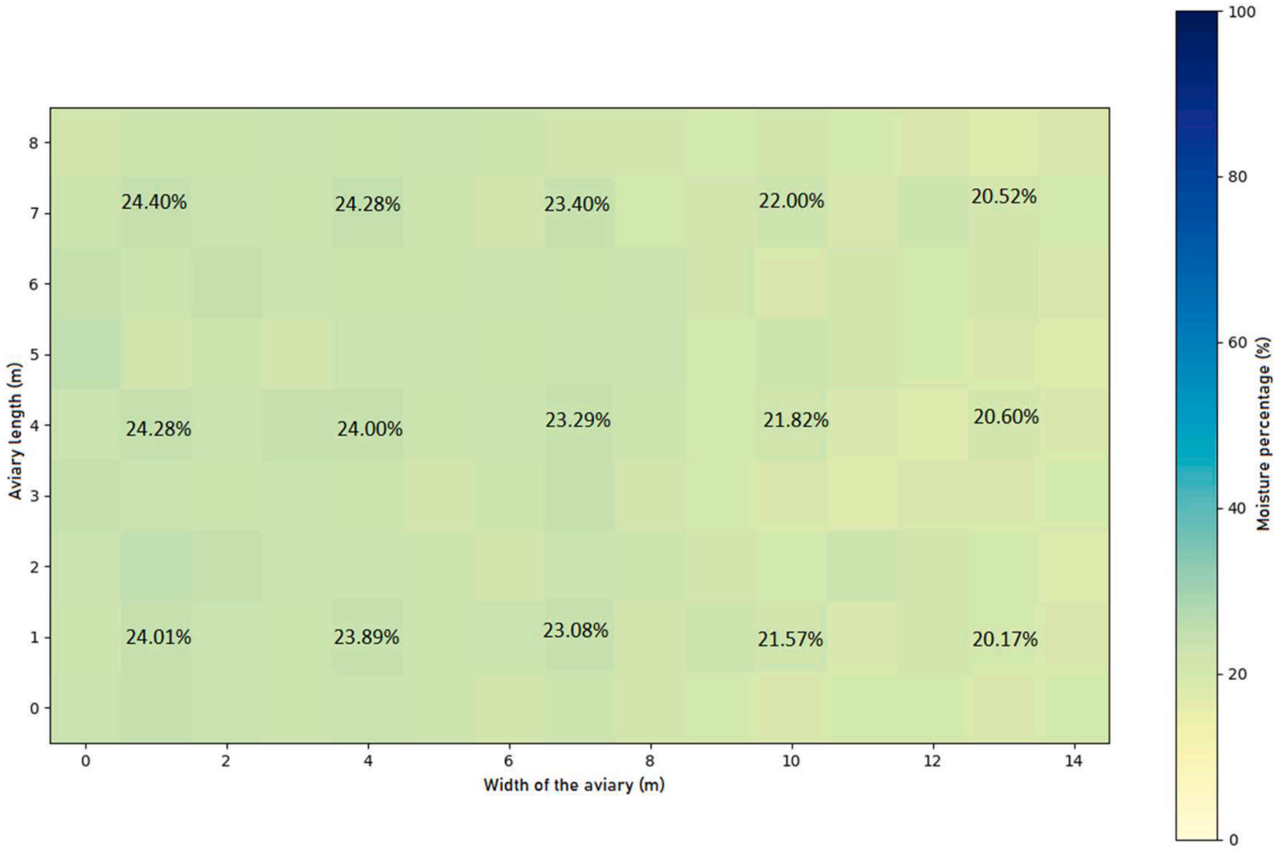


Fig. 15. Moisture distribution map in litter: week 4.

fourth, 3 in the fifth and 0 in the sixth week. Low levels of humidity cause a higher concentration of dust in the poultry house, predisposing the animals to a higher incidence of respiratory diseases and being the second biggest cause of abnormalities that totally or partially condemn the carcasses at slaughter [20,23–25].

The spatial variability of litter humidity in poultry houses is multifactorial as it depends on factors that can be controlled by the producer and during litter management. These factors include population density, type of litter (absorption capacity), ventilation, number of litter usage, and the efficiency of the cooling system throughout the entire poultry house, among others. Therefore, an electromechanical system that can efficiently and accurately measure litter moisture can provide a clear view of the spatial variability of this moisture, enabling the producer to make assertive decisions.

4. Conclusions

This article presented the construction and validation steps of an electromechanical device capable of penetrating and measuring humidity in chicken litter. Utilizing a mobile robotic mechanism, the device identifies points and maps the spatial variability throughout the poultry house in real-time. The device can be coupled to different systems, to enable humidity assessment across facilities, enabling the real-time collection, local storage, and transmission of data.

Ethical committee approval

This work is part of a research on robotics with broiler chickens that was submitted, analyzed and approved by the Ethics Committee on the Use of Animals of the Luiz de Queiroz College of Agriculture of the University of São Paulo, under protocol number 7364,090,322.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Ethical statement

Not applicable: This manuscript does not include human or animal research.

CRediT authorship contribution statement

Glauber da Rocha Balthazar: Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Data curation. **Robson Mateus Freitas Silveira:** Writing – review & editing, Visualization, Validation, Methodology, Conceptualization. **Marcos Vinicius Amato da Cruz:** Writing – review & editing, Visualization, Validation, Investigation. **Iran José Oliveira da Silva:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

All persons gave their informed consent prior to their inclusion in the study and the authors declare have no relevant financial or non-financial interests to disclose.

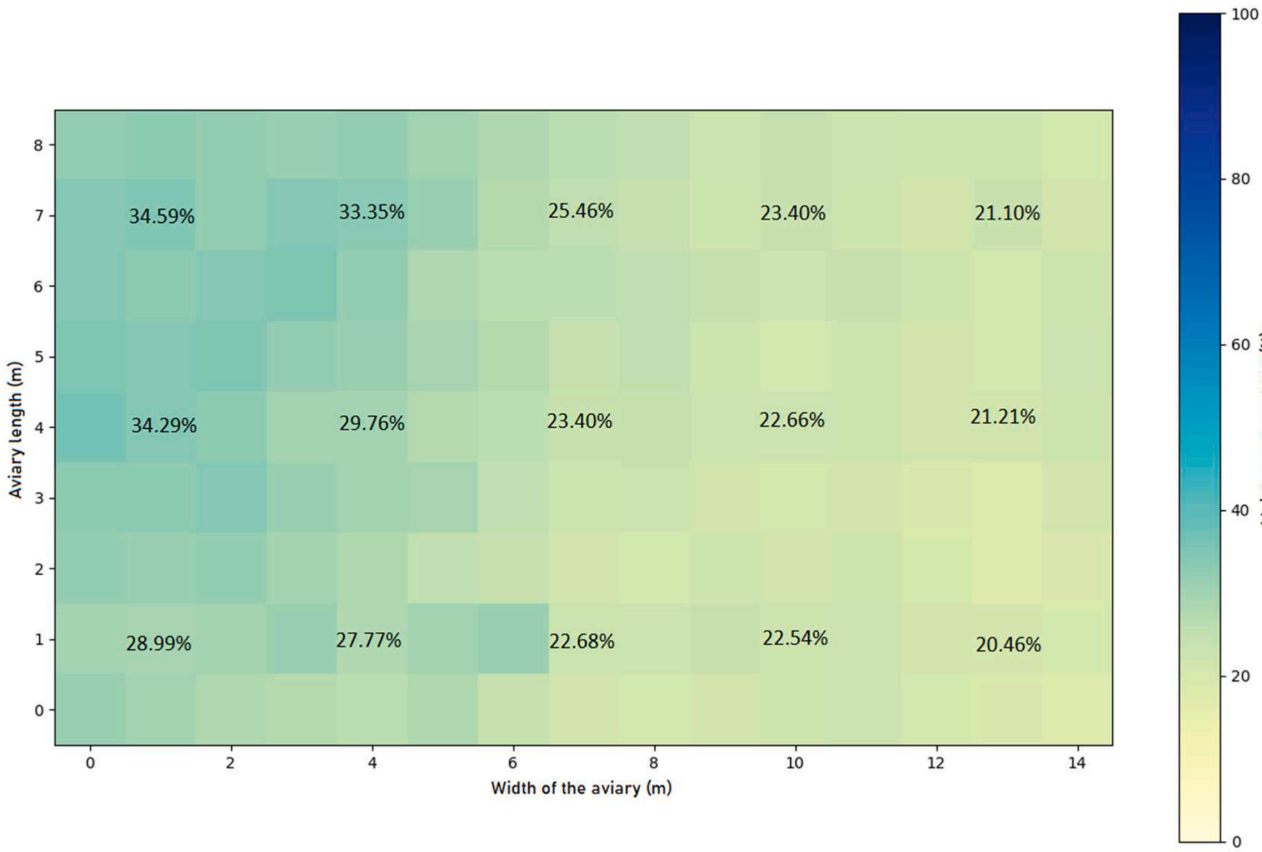


Fig. 16. Moisture distribution map in litter: week 5.

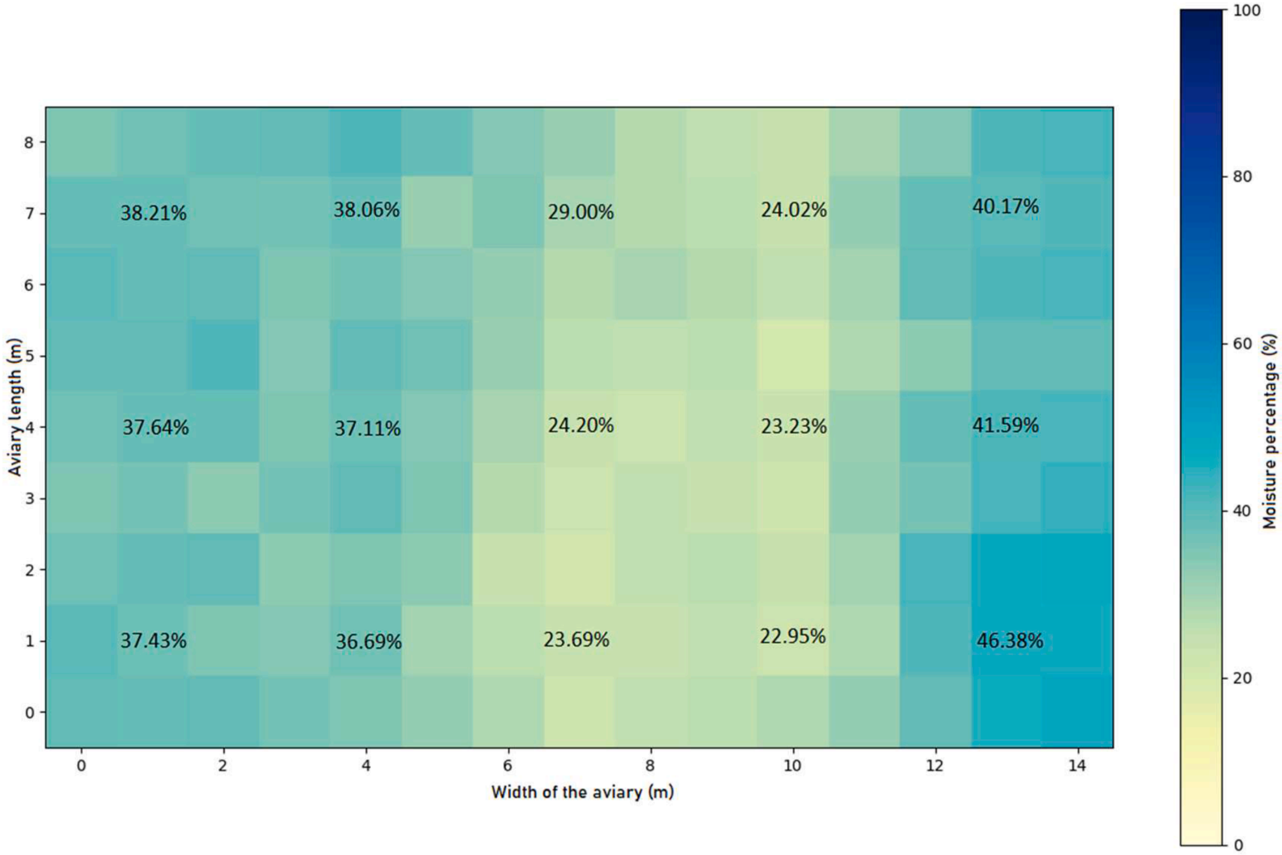


Fig. 17. Moisture distribution map in litter: week 6.

Table 2
Statistical measurements of moisture in litter (values expressed in %).

Week	AVG	RC	SE	SD	Min	Max
1	17.34	–	0.63	2.44	14.91	21.33
2	21.06	21.45	0.42	1.62	19.04	23.39
3	21.64	2.75	0.38	1.48	19.65	23.39
4	22.76	5.18	0.01	0.01	20.17	34.13
5	26.12	14.76	0.01	0.05	20.47	34.60
6	33.36	27.72	0.02	0.08	22.95	46.39

AVG: Average; RC: Rate of Change; SE: Standard Error; Standard Deviation; Min: Minimum; Max: Maximum.

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Data availability

Data will be made available on request.

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