



Development of an arduino based real time environmental monitor for animal facilities

Desenvolvimento de um monitor ambiental em tempo real baseado em arduino para instalações de animais

Wesley Jhannes Ramos Rolim

Master in Nuclear Technology

Institution: Instituto Federal de Educação, Ciência e Tecnologia de Rondônia

Address: Avenida Governador Jorge Teixeira 3146 Setor, Industrial, Porto Velho - RO, CEP: 76821-002

E-mail: wesley.rolim@ifro.edu.br

Patrick Jack Spencer

PhD in Nuclear Technology

Institution: Instituto Federal de Educação, Ciência e Tecnologia de Rondônia

Address: Avenida Governador Jorge Teixeira 3146 Setor, Industrial, Porto Velho - RO, CEP: 76821-002

E-mail: pspencer@ipen.br

Delvonei Alves de Andrade

PhD in Nuclear Technology

Institution: Instituto de Pesquisas Energéticas e Nucleares

Address: Avenida Governador Jorge Teixeira 3146 Setor, Industrial, Porto Velho - RO, CEP: 76821-002

E-mail: pspencer@ipen.br

ABSTRACT

Animal facilities are installations of great importance for the advancement of animal research, since it is where the activities of animal breeding, maintenance and experimentation are carried out. Based on this assumption, the present dissertation addresses the development of a monitoring system for environmental factors such as temperature, relative humidity, ammonia and luminosity in an automated way through open source hardware and software aiming at a low cost, accessible prototype that will contribute to guarantee animal welfare, the technical management of the facilities, shared monitoring in real time, decision making in case of irregularities in the observed factors and computerized systemic record. After installing the prototype in the breeding room of the IPEN animal facility, tests were carried out with calibrated detectors in order to validate the readings. Our data confirm the positive correlation obtained, thus validating the adoption of the open source sensor as a tool for monitoring.

Keywords: animal facility, environmental monitoring, open source.



RESUMO

O biotério é uma instalação que tem grande importância para o avanço na pesquisa com animais, pois nele são realizadas as atividades de criação, manutenção e experimentação animal. Partindo desse pressuposto o presente trabalho aborda o desenvolvimento de um sistema de monitoramento dos fatores ambientais como: temperatura, umidade relativa do ar, amônia e luminosidade de forma automatizada através de hardware e software open source visando um protótipo de baixo custo, acessível que contribuirá, para garantia do bem-estar animal, a gestão técnica das instalações, monitoramento compartilhado em tempo real, tomada de decisão em caso de irregularidades nos fatores observados e registro sistêmico informatizado. Após a instalação do protótipo na sala de criação do biotério do IPEN foram realizados testes com detectores calibrados a fim de validar as leituras onde foi possível verificar a correlação positiva obtida, validando assim a sua adoção como uma ferramenta para o monitoramento.

Palavras-chave: biotério, monitoramento ambiental, open source.

1 INTRODUCTION

A research oriented animal facility must be a controlled environment that suits the specific ambient conditions for each species such as temperature, light intensity and periodicity, air quality, and other parameters that may interfere in the life quality of the animals (CONCEA/RN 20 of 12/30/2014).

These facilities must follow the recommendations for breeding, maintenance and experimentation of each species, aiming to eliminate the environmental influence on physiological variables of the animal, which, in turn, could affect its health. Experimental results are, in principle, only valid in the conditions they were obtained and comparisons can only be made if all the information relative to the experimental conditions are available. The environment must guarantee a sanitary standard of the colonies and, simultaneously, the welfare of the animals, including dedicated edifications and appropriate functioning. The control and recording of the environmental variables is crucial for the production and maintenance of the animals, as well as for the validity of experimental data. (CONCEA/RN 15 of 12/16/2013).

At the animal facility of the Nuclear and Energy Research Institute IPEN–CNEN/SP, which provides rats and mice for research and quality control of



radiopharmaceuticals for the institute, the monitoring of the environment was performed by the technical team, through note-taking on a spreadsheet located on the door of each room, including temperature, humidity, air conditioning status, illumination and animal welfare. The present work aimed to measure the temperature relative humidity, ammonia levels and luminosity from a breeding room from our facility, automatically using a prototype with sensors, which would transmit the readings to a dedicated software. It enables the shared monitoring in real time, the generation of technical and operational reports with the measured parameters as well as the digital storage of this information. Such a transition from the manual recording of the parameters towards an automated data acquisition system enables the immediate detection of eventual problems and a prompt corrective intervention.

2 MATERIALS AND METHODS

Once the parameters to be measured were determined after consulting the literature and the facility technicians, we opted to develop a low cost prototype using open source software and hardware, including sensors and other affordable components.

The data collecting prototype was constructed using an Arduino Mega with a Atmega2560 microcontroller, a W5100 Ethernet shield, a custom printed circuit board to connect the sensors to their respective ports on the microcontroller, a MQ137 sensor to quantify atmospheric ammonia, a BH1750 luminosity sensor, a DHT 22 temperature and luminosity probe, a 20x4 I2C LCD display and a 1A, 9v DC power source (Figures 1-2). An enclosure to accommodate the prototype was printed with polylactic acid using a 3D printer.



Figure 1 – Prototype



Fonte: Rolim, Spencer and Andrade

Figure 2 – Interior of the Prototype



Fonte: Rolim, Spencer and Andrade

The prototype was programmed using the Arduino Integrated Development Environment (IDE) available at the official site (<https://www.arduino.cc/>).

The data gathered by the prototype are transmitted using the Modbus TCP/IP protocol through the Ethernet cable to the ScadaBR 1.1 CE supervisory system installed on a Raspberry Pi 3 running the Raspbian operating system (figure 3), which receives and stores the records, enabling real time control by several users connected to the network.



Figure 3 – Raspberry pi 3



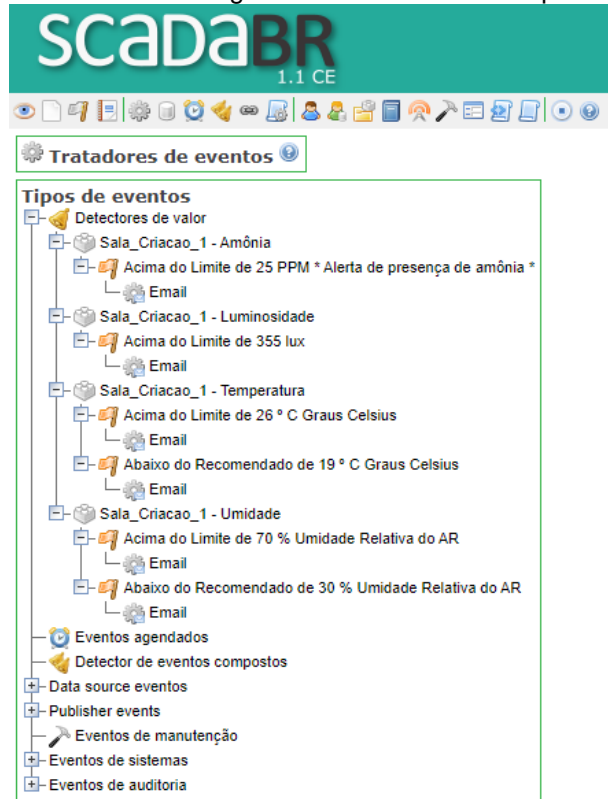
Fonte: Rolim, Spencer and Andrade

ScadaBR is a multi-platform open source SCADA system containing all the functionalities of a complete supervisory system, than can be installed on Windows or Linux operating systems. It is compatible with many communication protocols and includes a native databank and connection with SGBD MariaDB or MySQL, allowing the generation of graphics and reports with logs of the process, the detection of alarms and event logs with control panels for monitoring (SCADABR, 2010). The registers are kept by the SGBD MariaDB open source databank, which allows ensuring the data consistency, controlling the access, securing the data and providing access to the data and backups. (MARIADB, 2019).

Following the installation of the prototype and the supervisory in the mice breeding room, we performed the value detection event configuration using alarm parameters according to the CONCEA resolution 15 of 12/16/2013, as can be seen in figure 4. Values below or above the programmed limits will trigger an e-mail alert to the addresses inserted in this configuration.



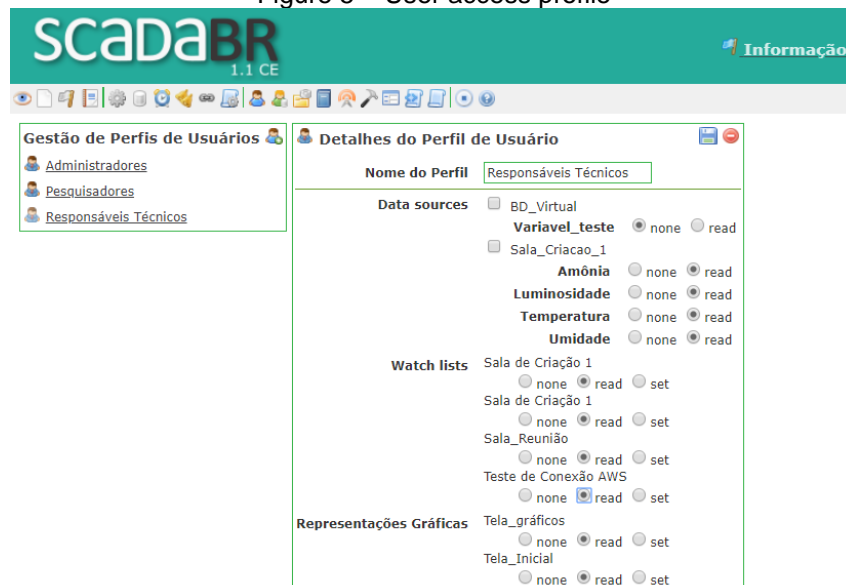
Figure 4 – Alarms configuration for the monitored parameters



Fonte: Rolim, Spencer and Andrade

Aiming to provide a shared monitoring, a profile for each attribution with different permissions was created, as depicted in figure 5.

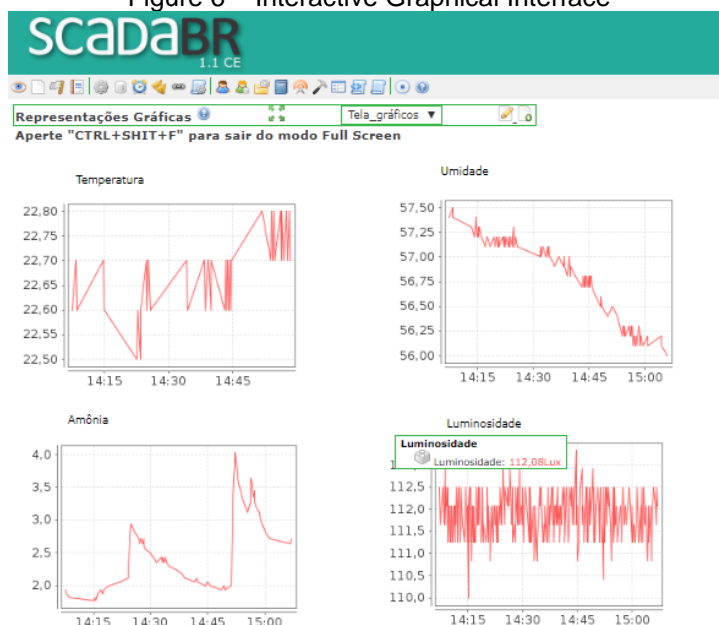
Figure 5 – User access profile



Fonte: Rolim, Spencer and Andrade

To simplify the monitoring, an interactive graphical interface displaying the last hour parameters as graphics was created (figure 6)

Figure 6 – Interactive Graphical Interface



Fonte: Rolim, Spencer and Andrade

After the final configuration, a training step was done to capacitate the technicians to use the ScadaBR to monitor the environment and generate operational reports.

3 RESULTS

The prototype and sensors were installed in the breeding room (figure 8) on 10/10/2019 50 cm above the ground, on the top of a plastic box, together with calibrated commercial detectors (figure 7). Thirteen readings were collected on 10/14/2019, to obtain the correlation between the prototype and its commercial counterparts.



Figure 7 – Detectors in the breeding room



Fonte: Rolim, Spencer and Andrade

Figure 8 – Breeding room



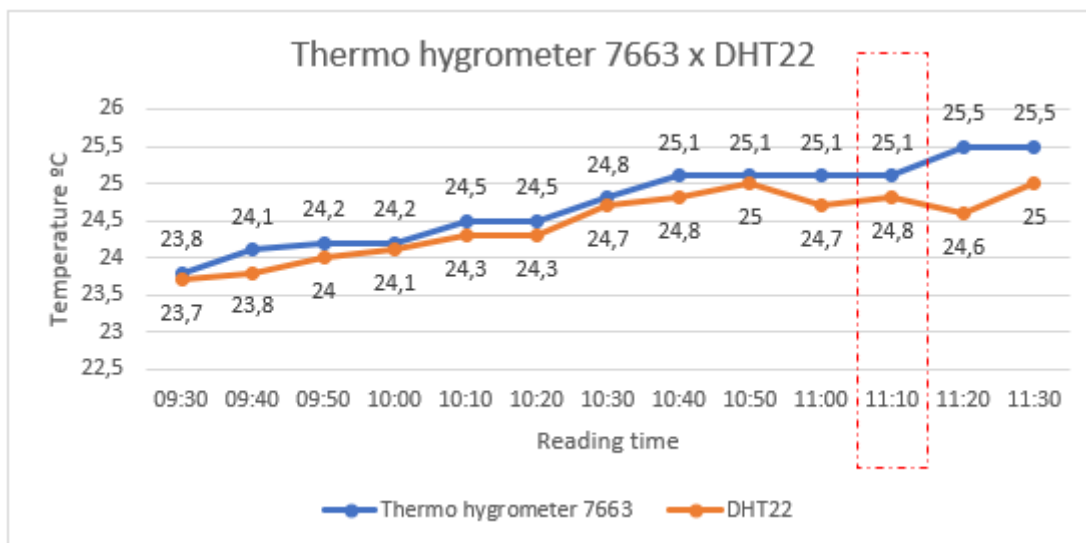
Fonte: Rolim, Spencer and Andrade

The readings collected allowed establishing the correlation between the prototype and the calibrated detectors. For the temperature and humidity parameter, we used a calibrated incoterm 7663 thermo-hygrometer with a temperature range of -50°C to 70°C and precision of $\pm 1^{\circ}\text{C}$. The relative humidity range of this sensor is of 15% to 95% $\pm 5\%$ (INCOTERM, 2019).

As seen in figure 9, a minimal deviation of 0.1°C was observed at 9:30 am, and a maximal one of 0.9°C at 11:20.



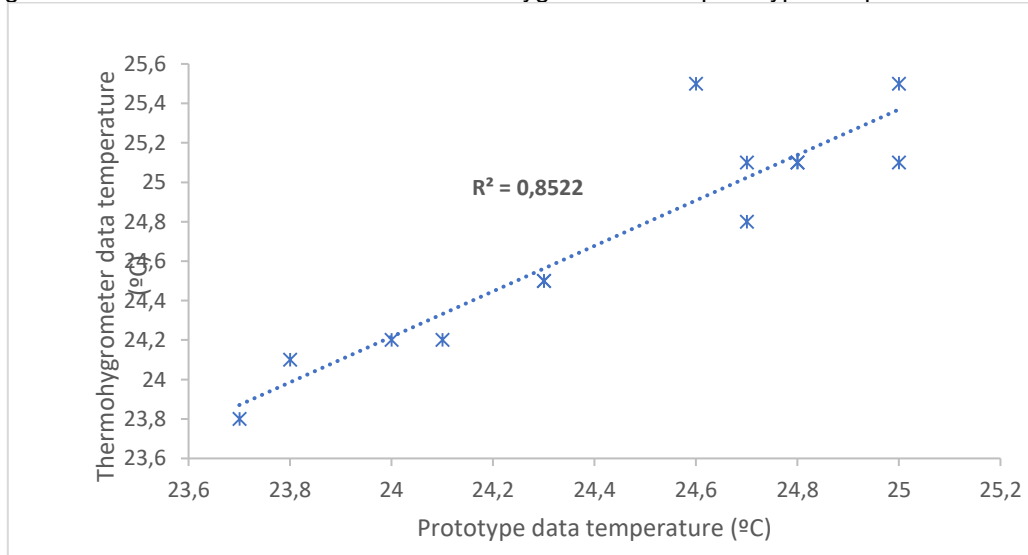
Figure 9 – Temperatures recorded by the thermo-hygrometer and the DHT22 sensor



Fonte: Rolim, Spencer and Andrade

From these data, we were able to calculate, using excel, the correlation (R^2) for temperature readings between the two equipment, which was of $R^2=0,852$ indicating that the tested sensor was an efficient alternative when compared to the conventional equipment.

Figure 10 – Correlation between the thermo-hygrometer and prototype temperature readings

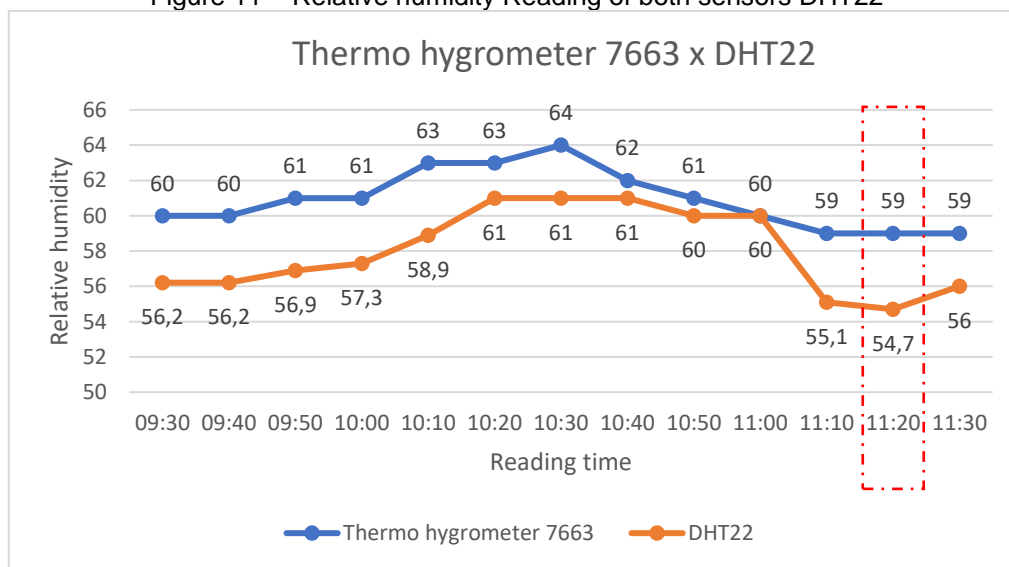


Fonte: Rolim, Spencer and Andrade



When comparing the humidity records from both sensors (figure 23), identical readings were obtained at 11:00 am and a 4.3% maximal deviation at 11:20am.

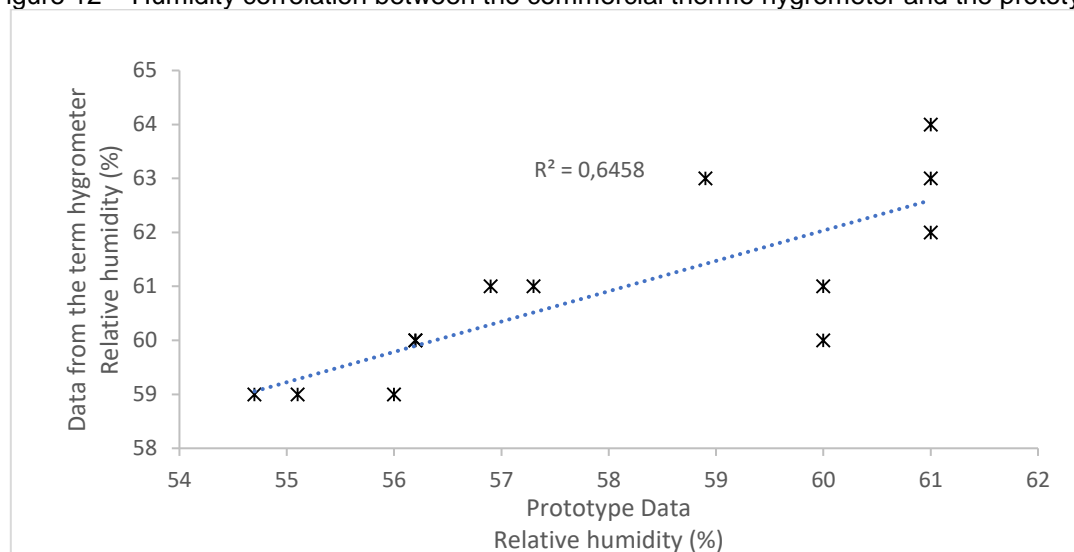
Figure 11 – Relative humidity Reading of both sensors DHT22



Fonte: Rolim, Spencer and Andrade

The relative humidity measurements correlation was calculated and resulted in a value of $R^2=0.64$ (figure 12).

Figure 12 – Humidity correlation between the commercial thermo hygrometer and the prototype

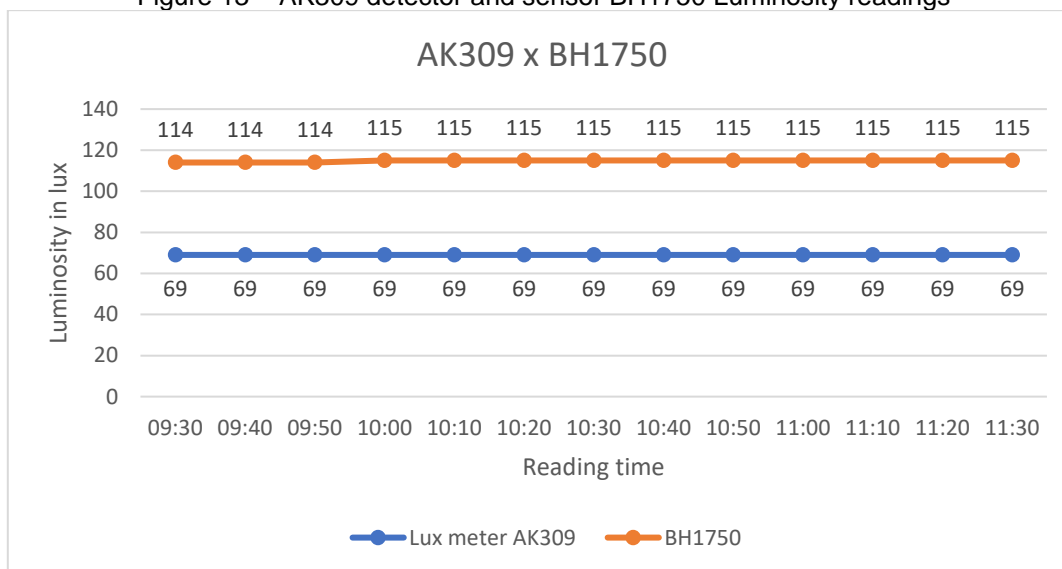


Fonte: Rolim, Spencer and Andrade



For luminosity measurements, an AK309 luximeter with a 0-50,000 Lux and the sensitivity range we used was the highest (0-2,000) with a precision of $\pm 5\%$ (AKOS, 2019). Figure 13 shows a minimal deviation of 46 Lux at 10:00 am. As there was no luminosity variation, no correlation was calculated.

Figure 13 – AK309 detector and sensor BH1750 Luminosity readings

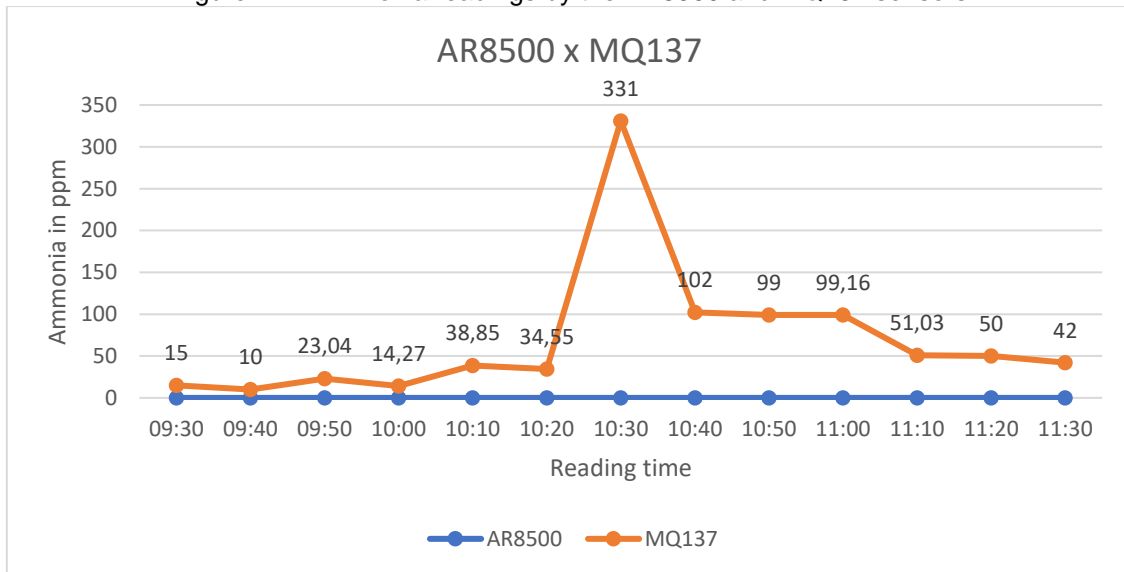


Fonte: Rolim, Spencer and Andrade

For the ammonia measurements, a Smart sensor AR with a 0-100 ppm reading range and a precision range of $\pm 2\%$ (SMART, 2019). The MQ137 sensor also responds to two other gases: ethanol and carbon monoxide. Thus, when any of these chemicals are present, the MQ137 readings may be affected. Figure 26 indicates high ammonia readings. A counterproof was done with the AR8500 and no ammonia was detected. During the measurements, a routine procedure in the room, that requires the use of 70% ethanol, was being executed, impairing the ammonia readings of the MQ137 sensor.



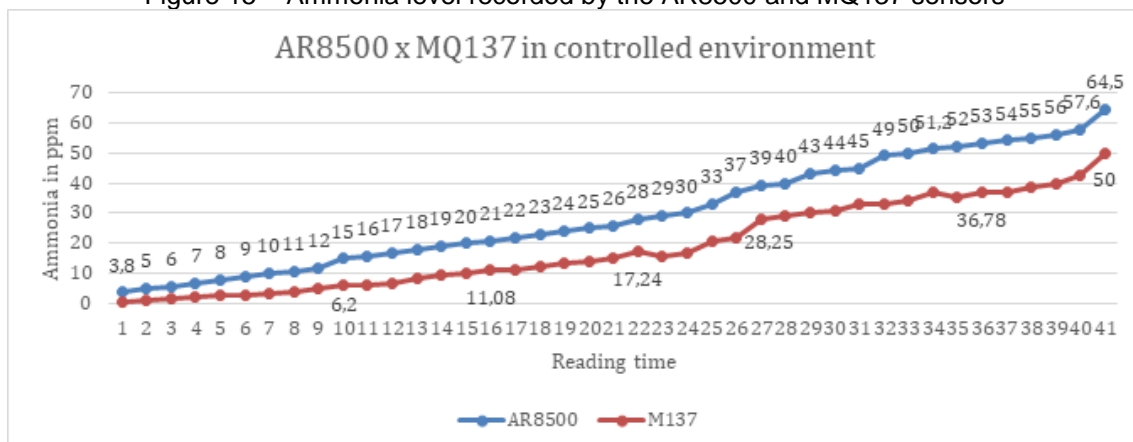
Figure 14 – Ammonia readings by the AR8500 and MQ137 sensors



Fonte: Rolim, Spencer and Andrade

In order to calibrate the NH₃ sensor following the equation provided by the manufacturer, the prototype and the AR8500 were kept in a 25 L sealed enclosure (figure 17) and, a using hose with a flow controller, this setup was connected to a glass recipient containing 1 mL of 5% ammonia which was insufflated as needed. Once the sensor readings stabilized, the data were recorded. A minimal deviation of 2.92 ppm was observed for the first Reading and a maximal value of 16.22 ppm for the 36th measurement (figure 15).

Figure 15 – Ammonia level recorded by the AR8500 and MQ137 sensors

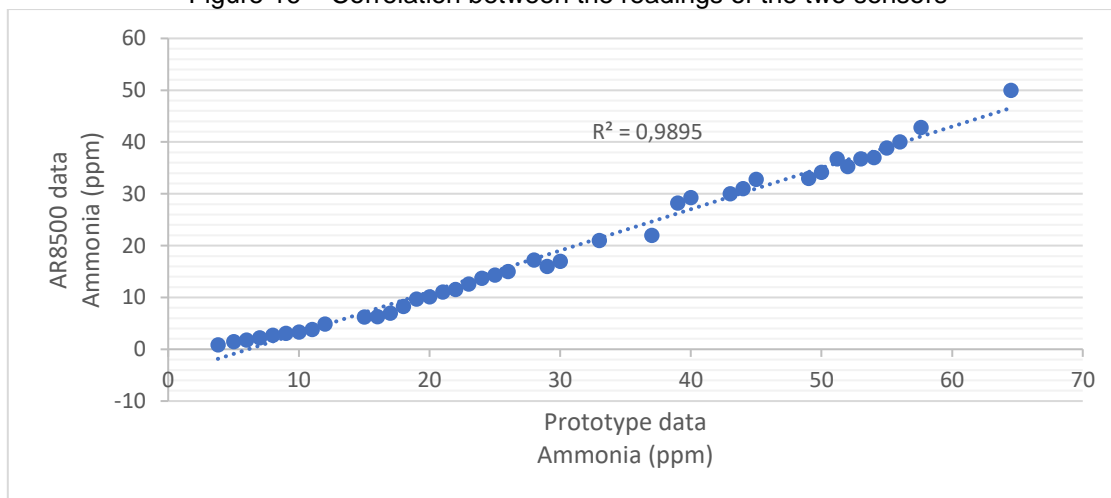


Fonte: Rolim, Spencer and Andrade

The correlation between the two sets of data was of $R^2=0.98$ (figure 16).



Figure 16 – Correlation between the readings of the two sensors



Fonte: Rolim, Spencer and Andrade

Figure 17 – Setup for the ammonia sensor calibration



Fonte: Rolim, Spencer and Andrade

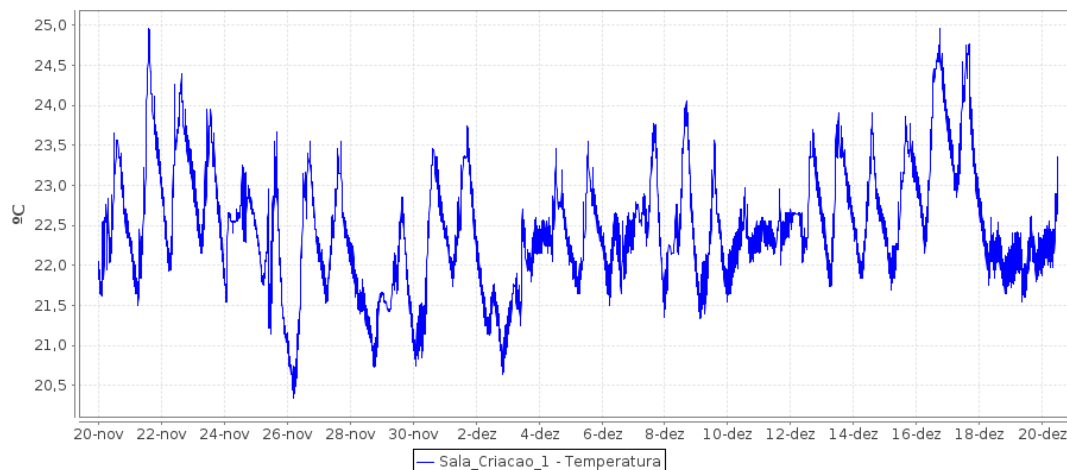
From 11/20/2019 to 12/20/2019 the prototype successfully recorded the data in the breeding room (figures 18-21). From this date, environmental data as well as logs are available to all the technicians involved in animal welfare and breeding.



Figure 18 – Temperature recorded from 11/20/2019 to 12/20/2019

Sala_Criacao_1 - Temperatura	
Tipo de dados	Númerico
Início	21,9°C
Mínimo	20,3°C @ 2019/11/26 04:36
Máximo	25°C @ 2019/11/21 14:29
Média	22,44°C
Soma	820008,2°C
Contagem	36549

Gráfico consolidado

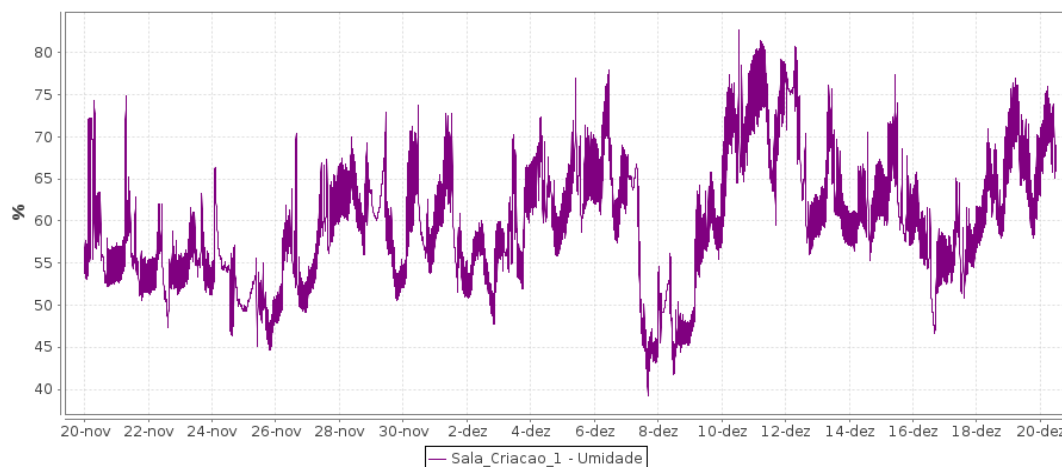


Fonte: Rolim, Spencer and Andrade

Figure 19 – Humidity recorded from 11/20/2019 to 12/20/2019

Sala_Criacao_1 - Umidade	
Tipo de dados	Númerico
Início	53,9%
Mínimo	39,2% @ 2019/12/07 16:18
Máximo	83,7% @ 2019/12/10 13:00
Média	59,6%
Soma	7778469,1%
Contagem	128181

Gráfico consolidado



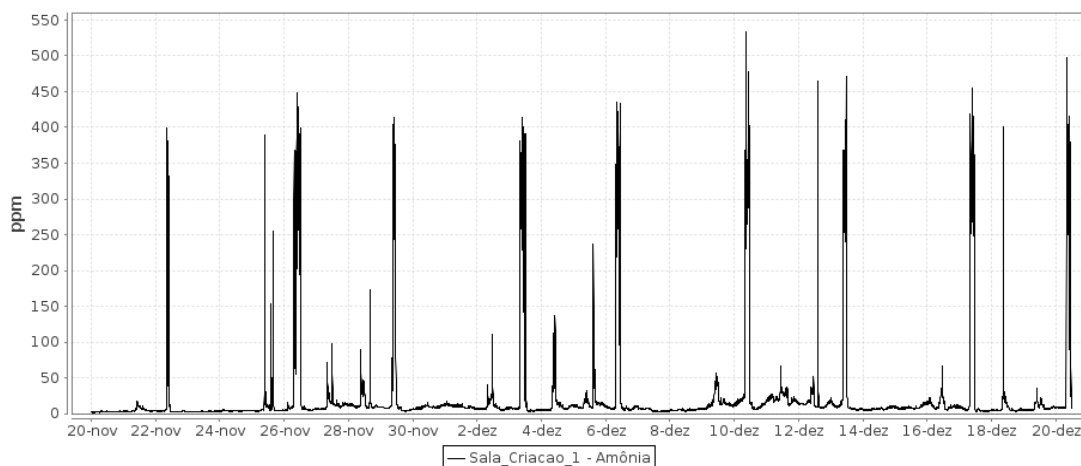
Fonte: Rolim, Spencer and Andrade



Figure 20 – Ammonia levels recorded from 11/20/2019 to 12/20/2019

Sala_Criacao_1 - Amônia	
Tipo de dados	Númerico
Início	1,88ppm
Mínimo	1,57ppm @ 2019/11/20 01:13
Máximo	650,46ppm @ 2019/12/13 11:07
Média	21,8ppm
Soma	3787385,77ppm
Contagem	68339

Gráfico consolidado

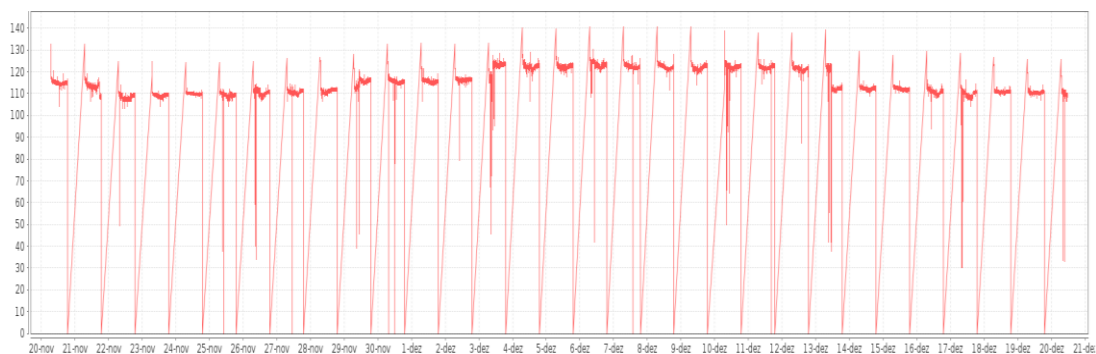


Fonte: Rolim, Spencer and Andrade

Figure 21 – Luminosity recorded from 11/20/2019 to 12/20/2019

Sala_Criacao_1 - Luminosidade	
Tipo de dados	Númerico
Início	0Lux
Mínimo	0Lux @ 2019/11/20 00:00
Máximo	140,83Lux @ 2019/12/06 07:01
Média	57,58Lux
Soma	11491212,17Lux
Contagem	99468

Gráfico consolidado



Fonte: Rolim, Spencer and Andrade

The ammonia sensor showed high readings for a few days, which can be assigned to the presence of ethyl alcohol, since readings were performed with an AR8500 detector and there was no presence of NH₃ in the rearing room.



Figure 21 only depicts the readings from 07:00 to 19:00 due to the lighting schedule that has 12 hours cycles. Up spikes are due to sunlight as the animal rooms face east and thus receive the early sunrays, whereas the negative spikes are due to technicians working in the room and throwing shadow on the sensor.

The results obtained are related to the implementation of the prototype.

ScadaBR proved to be a friendly interface, with user management for simple access, with interactive screens to present the monitoring satisfactorily and with the generation of notification emails when an alarm is triggered in a functional way.

CONCEA recommends that the Animal Ethics committees conduct their actions, incorporating the principle of the three R's (Replacement, Reduction, and Refinement). It is possible to identify that this work is directly related to the principle of refinement by introducing an automated method to verify temperature, humidity, ammonia and luminosity in the room. It enables real-time control and send warnings when parameters that are out of line with expectations, giving the responsible person the opportunity to act as soon as possible in atypical situations and consequently offering the animals a better response to the monitored variable

4 FINAL CONSIDERATIONS

We can see that despite the deviation between the readings of the prototype and the respective detectors, we obtained a strong correlation in the parameters of temperature, relative humidity and ammonia and an approximate variation in luminosity that can be corrected.

The built prototype efficiently communicated and recorded the measured environmental parameters. It represents a low-cost alternative for monitoring temperature, relative humidity, ammonia and luminosity, enabling shared monitoring in real time with those responsible and researchers through the platform that can be accessed on IPEN's corporate network through a browser, sends e-mails when the parameters are out of standard, stores the parameter record and allows the issuance of reports for analysis.



ScadaBR can receive other prototypes that use Modbus TCP/IP communication or other communication protocols. As perspectives, we can mention the possibility of using another sensor for detecting ammonia. One that does not suffer interference from ethyl alcohol and carbon monoxide gases and does not require a 24-hour preheating. With the aim of making it more portable, a wireless connection and a bank of batteries inside the equipment could be added, so as not to depend on the network infrastructure or a UPS.

Based on the analysis of the equipment available for environmental monitoring in animal facilities, we concluded that the solution presented by the built prototype presents several advantages in relation to the existing market solutions. In addition to allowing the integration of sensors and the sending of data to a supervisory system, the total cost of the solution is significantly lower than the available alternatives. Although some individual equipment could replace the proposed solution, they usually require more manual control and constant checks by the animal facility professionals, which can lead to human errors and animal welfare issues. In summary, while off-the-shelf solutions may offer some advantages in terms of ease of use, our solution is more flexible and offers a more affordable and effective alternative for environmental monitoring in animal facilities.



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