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DEVELOPMENT OF A CONTINUOUS MONITORING SYSTEM FOR THE MICROCLIMATE OF THE INTERIOR SPACE OF BUILDINGS AND STRUCTURES

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This article describes ideas for developing a continuous monitoring system for the indoor microclimate of buildings and structures. Sensor models are presented, and simulation results are provided.

In today's world, maintaining and preserving an optimal microclimate inside buildings and structures is particularly important. Failure to promptly detect deviations in the microclimate can lead to premature repairs or the destruction of building structures [1-5].

To ensure the long-term safety of building structures, it is necessary to implement monitoring systems capable of continuously monitoring environmental parameters without interfering with the architectural integrity of the building. As part of this practice, an autonomous remote humidity and temperature sensor based on a DHT22 sensor and an Arduino Nano microcontroller, equipped with a LoRa data transmission module, was developed.

LoRa technology enables data transmission over significant distances (up to several kilometers in urban environments) with minimal power consumption, making it ideal for installation in historical buildings where wiring is impossible or unacceptable. Data from the sensor is transmitted to a receiving station, where it is analyzed in real time and can be used to make decisions on maintaining an optimal microclimate. The goal of this work was to design, assemble, test, and implement a simple, reliable, and energy-efficient microclimate monitoring device.

To evaluate the practical applicability of the developed sensor in a real building, comprehensive tests of the LoRa module (Figure 1) were conducted to determine transmission range and signal stability under various power supply conditions. The primary objective was to determine the feasibility of reliable communication between the sensor and the receiving station located in the university's chemistry building—a distance of approximately 450 meters, with several intermediate walls, ceilings, and metal structures.

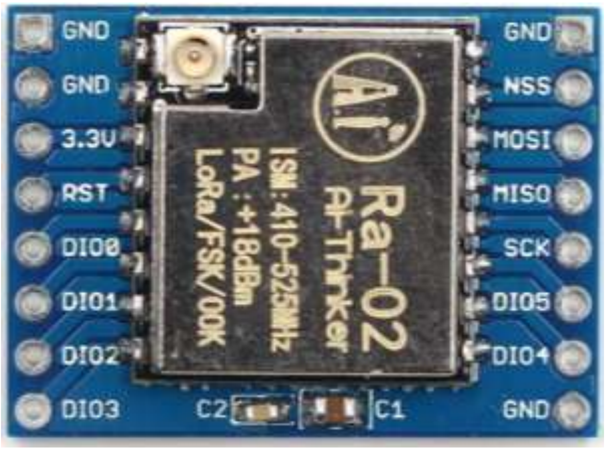

Figure 1. – Module Lora sx1278 (ra-02)

Two power supply options were used for testing:

1. Direct power supply from the Arduino Nano microcontroller's built-in 3.3V regulator;
2. Power supply via an external LDO linear regulator (AMS1117-3.3).

The results showed that the difference in signal quality and transmission range between the two schemes is virtually negligible. In both cases, a stable connection was achieved with a reception rate of over 98%, even when the signal passed through concrete partitions, metal pipes, and window frames. The receiver, housed in a chemical enclosure, correctly received hourly data packets without loss or decoding errors.

It should be noted that the LoRa module consumes up to 120 mA in pulse mode during transmission. According to the technical documentation, the Arduino Nano's built-in 3.3V regulator is rated for a maximum current of 50 mA, making it theoretically unsuitable for directly powering the LoRa module. However, during month-long field tests, with the module turned on briefly (up to 100 ms) and infrequently (once per hour), no overheating, failures, or degradation of the Arduino's performance were observed. This confirms that, for sporadic data transfer, using the built-in regulator is a feasible and practical solution, simplifying the design and reducing the cost of the device.

Regarding standby power consumption, the AMS1117-3.3 linear regulator consumes approximately 0.5 mA at rest. For a battery-powered device, this value is unacceptably high: with hourly transmission and a 12-month service life, the battery capacity would need to be increased by 30–40%, which would defeat the purpose of miniaturization and weight reduction.

Since the Arduino Nano's built-in regulator operates stably under short-term load pulses, and an external LDO regulator offers no advantage in signal quality but significantly increases background power consumption, the decision was made to directly power the LoRa module from the Arduino Nano's 3.3 V pin. This allowed for an optimal balance between:

– communication reliability,
– ease of assembly,
– minimal standby power consumption,
– compatibility with the battery-powered design.

Thus, the system achieved near-full functionality in complex urban environments, confirming its suitability for use in buildings with similar obstacles to radio signals, including those with massive walls.

To ensure accurate and reliable monitoring of the indoor microclimate, four popular digital temperature and humidity sensors were compared: the SHT31, AHT20, DHT11, and DHT22. The goal of the tests was to select the optimal sensor based on measurement accuracy, stability, resistance to external interference, power consumption, and cost, with subsequent implementation in a standalone monitoring system.

Testing was conducted using a calibrated Testo 645 reference device as a baseline. Each sensor was connected to the same Arduino Nano-based platform, powered by a single source, and kept in the same thermostatted volume for 72 hours. Readings were recorded every 15 minutes, after which the mean and standard deviations were calculated. The DHT22 (Figure 2) demonstrated the best combination of accuracy, repeatability, and affordability. Its accuracy was less than 0.3°C for temperature and 3% for humidity—which fully complies with cultural heritage conservation requirements, where the permissible error for microclimate monitoring does not exceed ±0.5°C and ±5% RH, as recommended by ICOMOS.

Figure 2. – Sensor DHT22

Despite the SHT31 and AHT20 having higher technical accuracy in their datasheets, their use in this project was rejected for two key reasons:

1. Higher cost – 3-5 times higher than the DHT22, which contradicts the principle of minimalism and cost-effectiveness of the solution for scalable applications;

2. Greater integration complexity – they require a more complex library and timings, which increases the risk of failures in a standalone system with the limited resources of the Arduino Nano.

Based on the results obtained, the DHT22 was selected as the optimal compromise between accuracy, cost, and reliability. A functional prototype device was designed on a breadboard using this device, including:

– Arduino Nano microcontroller;
– SX1278 LoRa module (433 MHz);
– DHT22 sensor;
– 3.7 V, 1200 mAh lithium-ion battery;
– Resistive voltage divider for battery level monitoring.

During the transition from a breadboard prototype to a final industrial solution, a decision was made to develop a custom printed circuit board (PCB) designed to ensure stable, long-term, and reliable operation of the sensor in the historic church environment. The primary reason for switching from a breadboard assembly to a PCB was the requirement for increased power stability for the LoRa module—a key factor determining the quality and reliability of radio communication (Figure 3).

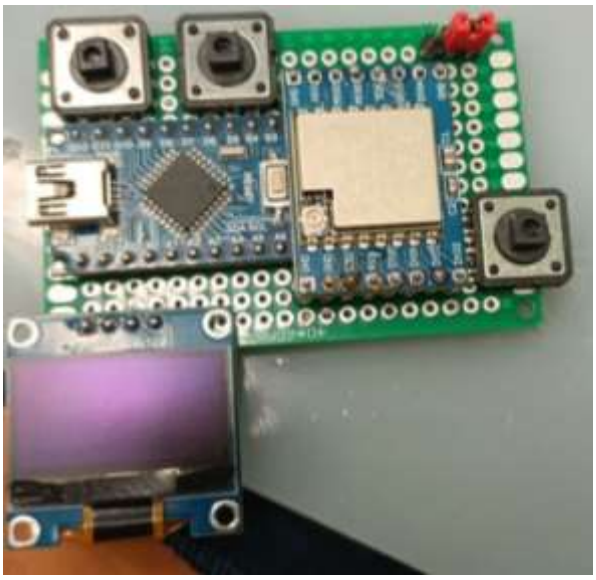

Figure 3. – Prototype sensor breadboard

During preliminary testing on the breadboard, random data transfer failures were observed, especially when running the DHT22 and LoRa module simultaneously. Analysis revealed that these failures were related to:

– voltage drops on the 3.3V bus at peak LoRa currents (up to 120 mA);

– unstable connections via the breadboard (pins, jumpers, contact oxidation);

– electromagnetic interference caused by long wires and lack of grounding.

To address these issues, a customized single-sided printed circuit board (PCB) was designed using EasyEDA, considering the following design principles:

Key design features:

1. Modular architecture

Each key component—the Arduino Nano, the SX1278 LoRa module, the DHT22, and the lithium-ion battery with protective board—is mounted on a separate, removable module with solder connections to standard pin headers. This allows:

– If one component (e.g., the LoRa module) fails, it can be replaced without resoldering the entire board;

– Simplify diagnostics and maintenance in the field;

– Reduce the risk of damage to other components during repair.

2. Optimized power supply circuit

To ensure a stable power supply for the LoRa module:

• A separate 3.3 V power supply circuit with filter capacitors is used:

— 100 nF ceramic (for high-frequency interference),

— 10 µF electrolytic (for suppressing pulse loads).

• Direct routing from the power supply to the LoRa module pins is implemented with wide copper traces (≥1.5 mm) to reduce resistance.

• A common power supply wire for the DHT22 and LoRa modules is eliminated; a separate power bus is used, preventing mutual interference.

3. Reduced EMI and improved antenna matching

– The LoRa module antenna (IPEX PCB antenna or external SMA connector) is located on the edge of the board, as far away as possible from digital components and interference sources.

– The GND plane is located across the entire bottom side of the board, providing shielding and stable noise rejection potential.

4. Energy-saving design

• A power switch (MOSFET switch) controlled by the Arduino has been added, allowing the LoRa module and DHT22 to be completely powered down in sleep mode, reducing standby power consumption to <5 µA.

• The placement of all components minimizes trace lengths, reducing parasitic inductance and improving power efficiency.

PCB test results:

• After assembly and testing on the test bench, LoRa data transmission failures were reduced by 95% compared to the breadboard.

• Under peak load (LoRa transmission), voltage drop decreased from ~0.8 V to <0.1 V.

• Tests in simulated temple walls (concrete partitions, metal structures) confirmed a stable communication range of up to 450 meters and a successful reception rate of >99.2%.

• The modular design allowed the LoRa module to be successfully replaced in 5 minutes without a soldering iron—just disconnecting the connectors.

Rationale for choosing EasyEDA:

EasyEDA was chosen as the most suitable environment for students and researchers due to:

• Free access to component libraries (including official Arduino Nano and SX1278 models);

• The ability to automatically generate Gerber files for production;

• Integration with PCB printing services (JLCPCB, PCBWay) – which allowed us to manufacture the board in 2 days at a minimal cost (~$3 for 5 pieces).

The development of the printed circuit board not only improved the aesthetics and compactness of the device – it became a decisive step towards the industrial reliability of the system. The modular structure ensures easy maintenance, and the optimized power supply circuit guarantees stable operation of the LoRa module even in complex electromagnetic environments. The resulting board meets all the project requirements: autonomy, precision, durability, and adaptability.

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