SUSTAINABLE AGROCLIMATIC MODULE: INNOVATION FOR FOOD SYSTEMS IN THE FACE OF CLIMATE CHANGE

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ABSTRACT: Climate changes pose direct threats to agricultural production and food security, as they lead to alterations in natural cycles and patterns, resulting in unproductive soils and irregular rainfall cycles. The use of technology can be one way to mitigate the effects of climate change, as it allows the use of devices such as sensors and communication tools to capture agroclimatic data in real-time, enabling quick and cohesive decision-making. Thus, a climatic monitoring module was developed, utilizing a microcontroller, an ambient temperature sensor, a relative humidity sensor, and a Bluetooth module for transmitting this data to a smartphone. Additionally, a solar panel and a battery charger were added to make the system autonomous and free from non-renewable energy sources. The system was tested and has practical applications, considering its full functionality and the importance of the agroclimatic variables measured and transmitted via Bluetooth link for understanding the microclimate in the agricultural production area.

Keywords: Agricultural Monitoring. Climate Adaptation. Digital Agriculture.Food Security.

SUSTAINABLE MÓDULO AGROCLIMÁTICO SUSTENTÁVEL: INOVAÇÃO PARA SISTEMAS ALIMENTARES DIANTE DAS MUDANÇAS CLIMÁTICAS

Resumo: As mudanças climáticas representam ameaças diretas à produção agrícola e à segurança alimentar, uma vez que levam a alterações nos ciclos e padrões naturais, resultando em solos improdutivos e ciclos de precipitação irregulares. O uso de tecnologia pode ser uma forma de mitigar os efeitos das mudanças climáticas, pois permite o uso de dispositivos como sensores e ferramentas de comunicação para capturar dados agroclimáticos em tempo real, possibilitando a tomada de decisões rápidas e coesas. Assim, foi desenvolvido um módulo de monitoramento climático, utilizando um microcontrolador, um sensor de temperatura ambiente, um sensor de umidade relativa e um módulo Bluetooth para transmitir esses dados para um smartphone. Adicionalmente, foram adicionados um painel solar e um carregador de baterias para tornar o sistema autônomo e livre de fontes de energia não renováveis. O sistema foi testado e possui aplicações práticas, considerando sua funcionalidade completa e a importância das variáveis agroclimáticas medidas e transmitidas via link Bluetooth® para a compreensão do microclima na área de produção agrícola.

Palavras-chave: Agricultura Digital. Adaptação Climática. Monitoramento Agrícola. Segurança Alimentar.

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1. INTRODUTION

Climate change caused by anthropogenic activities directly threatens human life, considering the damage to the environment, which tends to directly affect food systems. In other words, with the alteration of natural patterns and cycles, there are risks to agricultural production and food security (Mirzabaev *et al*., 2023).

In this context, it is essential to develop perspectives and approaches that enable the understanding and adaptation of agricultural production to climatic adversities. To achieve this, it is necessary to understand how changes in edaphoclimatic conditions, particularly agroclimatic variables, affect the microclimate of agricultural regions.

One of the promising approaches today is the use of technologies in agriculture, an effort to integrate current techniques and devices used in the industry in pursuit of a smarter, more agile, and environmentally responsible agriculture (Balasundram *et al.*, 2023). The main demand of contemporary agriculture is data, such as agroclimatic variables. With this data, it is possible to provide information that makes decision-making more informed and effective (Zeginis *et al*., 2023).

Therefore, systems capable of measuring and providing these data in a secure and coherent manner are necessary, often utilizing sensors or networks of such devices. These systems are able to capture and record environmental and biophysical variables, with a set of them being referred to as a sensor network (Lloret *et al.*, 2021).

The current use of electronic components for creating parts and systems in both industrial and agricultural settings is attributed to their low financial cost and reduced energy consumption, as well as their potential to offer multifunctionality. This makes them accessible and applicable in various ways (Han *et al*., 2022). Moreover, the application of easy-to-access and user-friendly devices and systems in the field allows for the democratization of technology access among small and medium-sized producers (Mendes *et al.*, 2020)

Thus, an electronic system for capturing agricultural data can also contribute to achieving the Sustainable Development Goals (SDGs) set by the United Nations (UN), such as Goal 2, which aims to ensure and enhance the resilience of agricultural production and food systems in the face of climate change and to improve soil and water quality, as well as the productivity and quality of food produced at scale, as outlined in SDG 2.4.

2. OBJECTIVES

Develop an embedded monitoring system with low cost and reduced energy consumption, capable of capturing environmental variables (soil temperature, relative humidity), and transmitting the data through wireless communication.

3. METHODOLOGICAL PROCEDURES

In developing the module for the collection and transmission of agricultural data, we adhered to the structure proposed by Arshad (2020) and Mahbub (2020). This structure encompasses four main components: (i) a management and control system (microcontroller), (ii) a data acquisition system (sensors), (iii) a power system (energy management and supply), and (iv) a communication system (data transmission via cables or wireless).

The system was developed based on a module for the monitoring of agricultural environmental data, the management of power supply, and the transmission of data to the user. First, the electronic components were specified. The MSP430FR2155 microcontroller (Texas Instruments Inc., 2019) was selected due to its low cost, ultra-low power consumption, and numerous GPIOs, which facilitate the use of sensors and communication alternatives.

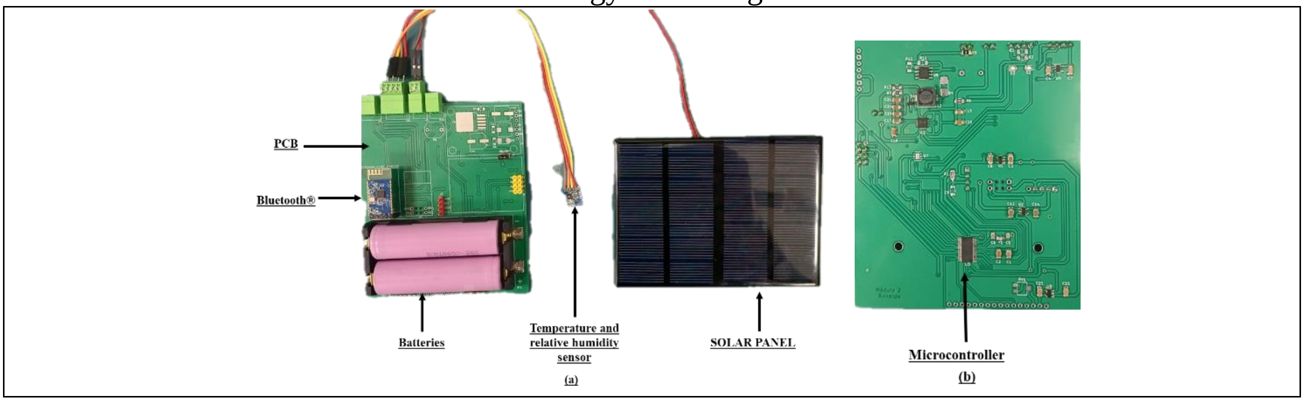
To obtain data pertaining to the agroclimatic conditions, the HDC1080 sensor (Texas Instruments Inc., 2016) was employed. This device is capable of measuring temperature and humidity with a high degree of precision, thereby reducing the expenditure of processing power and capital.

The device was powered by two rechargeable 2600 mAh batteries, with a 12V solar panel for autonomous charging and the utilization of renewable energy sources. Data communication was conducted via the JDY-31 Bluetooth® module (Zhang, 2020), with the Serial Bluetooth Terminal app (Meitiner & Seneviratne, 2020) employed to store the data in .txt files.

The module is still in the process of being developed, with future plans to incorporate additional forms of transmission, including LoRa for long-distance communication, WiFi for data transfer to the cloud, and GPRS for the utilization of 2G and 3G networks.

Once the components had been defined, the hardware layout was designed using the KiCad® 7.0.0 software (2023). This was followed by the creation of a virtual 3D prototype and production in China by JLCPCB (2024), which employed a double-sided copper board. Subsequently, the components were soldered, tested with a multimeter, and finally, the firmware was implemented in C language using the Code Composer Studio environment (2024) to control the module's systems.

Figure 1 – Agricultural monitoring system with temperature and relative humidity sensor and solar energy harvesting.



Source: authors.
(a) top layer, (b) bottom layer.

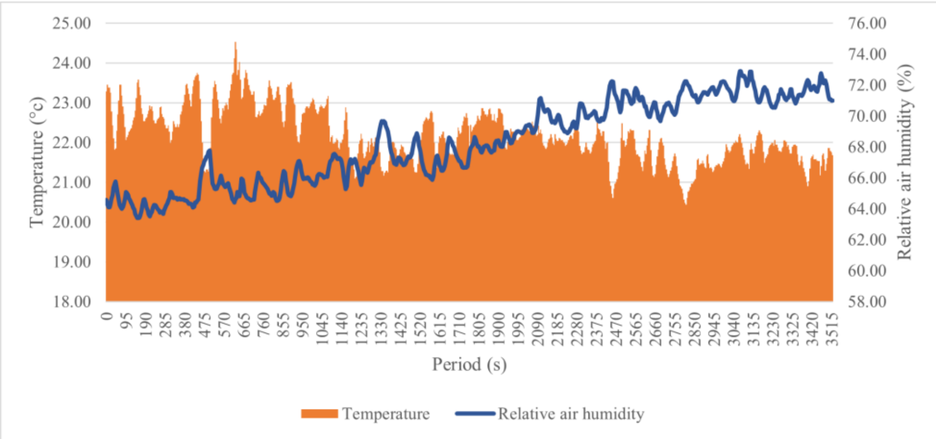
The module underwent operational testing. The power system was subjected to solar exposure while the sensor test was simultaneously conducted. The voltage and current generated by the solar panel and the system's energy consumption were measured using a multimeter. The module was situated in an outdoor setting in the morning hours of July in Cerqueira César, São Paulo, Brazil, a location with a temperate climate (Köppen-Geiger). Over the course of one hour, readings were taken at one-second intervals for both ambient temperature and relative humidity. Subsequently, the data was transmitted to a smartphone and subsequently analyzed using Microsoft Excel version 2207. Furthermore, the data was compared with records from the nearest meteorological station, located in Avaré, São Paulo, provided by the National Meteorological Institute (INMET, 2024).

4. RESULTS AND DISCUSSIONS

The voltage measurements taken from the battery pack and solar panel demonstrated that the voltage remained constant after the readings, indicating minimal energy consumption by the microcontroller and sensor. This behavior is consistent with the findings of Yang (2020), which demonstrated that the HDC1080 sensor and the MCU exhibit reduced energy consumption, thereby enabling the continued operation of agricultural applications. Furthermore, the sensor readings were successfully conducted, with the communication module operating effectively and transmitting data continuously without any loss of integrity. The data regarding ambient temperature and relative humidity, obtained from both the module and the meteorological station, are presented in Figure 2.

Figure 2 – Reading of the HDC1080 Sensor for Temperature and Relative Humidity Over One

Hour.



Source: Research data

The analysis of the sensor data, in comparison with that from the meteorological station, indicates that the sensor is functioning properly, despite being exposed to sunlight and wind. The maximum temperature variation recorded by the sensor was 0.9°C, while the relative humidity exhibited a variation of 23%. Notwithstanding the considerable distance between the municipalities, the temperature data exhibits a high degree of consistency with that of the meteorological station.

However, meteorological stations are equipped with shelters that safeguard their sensors from adverse weather conditions, thereby reducing the likelihood of external interference. This discrepancy in protection may account for the observed disparity in relative humidity readings. This underscores the necessity of utilizing an appropriate shelter for the sensor in future measurements to ensure the acquisition of more accurate and comparable data.

A cost assessment for the development of the module was conducted using data from manufacturers and sales websites. Additionally, miscellaneous items, including resistors, capacitors, LEDs, and other components, were considered. The U.S. dollar was utilized as the currency for purchases, as a considerable number of components are sold in this currency. Accordingly, Table 1 was prepared for the purpose of presenting the relevant data.

Table 1 - Component Costs and Manufacturing Expenses for the Data Collection Module.

Component	Cost per Unit ($)	Quantity	Total Cost ($)
MSP430FR2155	1.27	1	1.27
HDC1080	0.90	1	0.90
Miscellaneous	3.00	1	3.00
Solar panel	2.55	1	2.55
Battery	10.96	2	21.92
Bluetooth® Module	2.99	1	2.99
PCB Manufacturing	2.00	1	2.00
Total			$34.66

Source: Research data

As evidenced in Table 1, the batteries represent the greatest financial burden. Despite their rechargeable nature, the manufacturing of lithium-ion batteries has been found to have a considerable environmental impact (Vivoda *et al*., 2024). As an alternative, options such as supercapacitors, which are available on the consumer electronics market, offer similar functionalities, along with a lower cost and a reduced environmental impact (Benoy *et al*., 2022).

5. FINAL CONSIDERATIONS

From the standpoint of technological advancement in this domain, this research offers a methodology for the creation of an agricultural monitoring module, which has been identified as having substantial potential applications. The environmental variables measured are of great importance for the biophysical aspects of agricultural production. The system operates continuously and reliably, using renewable energy. It is also essential that, in the future, additional communication methods such as LoRa, WiFi, and GPRS be implemented to enhance range and connectivity options. Furthermore, it was found that the use of supercapacitors could result in a reduction of costs and an improvement of the environmental impact, compared to the use of batteries.

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