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ELECTRICAL ENGINEERING

Temperature and humidity monitoring using the internet of things

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ABSTRACT. Internet of Things (IoT) is a concept that refers to the connection between everyday elements and the Internet, in a way that common daily activities can be automated and simplified. The addition of it to our daily routine allows ordinary actions to become more efficient. Furthermore, the use of Internet connection as a way of communicating enables live display at any place, which adds up advantages. Also in everyday life, temperature control becomes more and more necessary in many different environments, such as industrial, commercial, or residential. Thus, control processes need to accompany the evolution of internet connectivity in many fields, throughout applications that can be used in mobile devices alongside these processes. This paper proposes temperature monitoring of an environment, via wireless communication and with live interface display on a web page or a mobile application developed in MIT App Inventor (Massachusetts Institute of Technology). While implementing commands via hardware and software a procedure to lower room temperature was applied through a ventilation system. The data are collected through a DHT11 temperature sensor, and the wireless communication is through a Node MCU Wi-Fi module, alongside the development board Arduino UNO. It was possible to condition the cooler to work accordingly with a preset temperature range by using its IDE (Integrated Development Environment). Thereby, this project is a low-cost solution in low scale and advantageous alternative to temperature control while implementing the concept of IoT.

Keywords: IoT; Temperature control; remote monitoring; wireless communication; humidity measurement; mobile device.

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Introduction

The development of the Internet of Things (IoT) will revolutionize a range of sectors, from automation, transportation, and energy, to healthcare, financial services, and nanotechnology (Piyare & Tazil, 2011). This technology can be applied to create a new concept and broader development spaces for smart homes and condominiums, to provide comfort, improve quality of life and reduce energy consumption (Andrade et al., 2021). IoT can be introduced as the connection between physical and virtual components applied to different technologies, and implemented for communication and data processing that are changed according to pre-established commands (Khan, 2019). Therefore, the Internet of Things is a concept that refers to the relationship between everyday elements and the Internet, with the purpose of automating and simplifying daily actions. By adding it to everyday routines, common actions like turning lights or other appliances on and off become more efficient.

The Internet evolved according to the technological development implemented by society and can be named according to its phases or "eras" as pointed out by the work of Bhat et al. (2007); the levels of development presented range from virtual libraries on web pages, evolving to the online financial market, such as e-commerce (virtual commerce), moving on to social networks and finally incorporating the connection between machines and devices with the Internet of Things. Thus, it is perceived that the term, the meaning, and the use of the Internet evolve more and more in a way that accompanying this process becomes natural.

In a systematic review, written by Asghari et al. (2019), some of the applications in which IoT can be applied are presented, ranging from health care, through commercial, industrial and to smart cities. Each application presented, analyses its use and a method of applying it (Asghari et al., 2019), thus IoT still has the possibility of being explored. An area greatly explored is that of temperature and humidity monitoring and control, which can be applied to many different sectors, as seen in different works: Fauzi et al. (2023), Pereira et al. (2019), Tang et al. (2020). One of the applications of this area is exemplified by the work of Dao et al. (2024), where the monitoring and control of temperature and humidity present a great advantage in optimizing investment and maintenance of costs.

In addition, Guan et al. (2016) present three methods for measuring temperature and humidity, manual, wired and wireless measurements, while commenting on the disadvantages of the first two. Meanwhile, Woo-García et al. (2024) propose an autonomous energy wireless sensor network for monitoring environmental variables, which involve temperature and humidity. Rahman et al. (2020) point out that resources to monitor such parameters are a solution to the impractical activity of real time monitoring with human resources.

It is noted that, currently, the Internet is increasingly present in everyday activities and in different areas, such as industries and commercial areas. The variety of sectors in which it can be applied guarantees the need to adapt and develop applications. Wi-Fi, 4G and 5G connections offer opportunities in these applications through mobile devices, enabling real-time communication. There are several applications which require wireless communication, as such the work by (Pereira et al., 2019) who uses microcontrollers of two different Wi-Fi modules to allow for communication between the collected data of sensors and circuit components to an online application. Also, Sawidin et al. (2018) propose a system for temperature control by the means of a fan and a heater, via Ethernet connection for the transmission of data. While Fauzi et al. (2023) use the data collected from the sensor to activate a thermoelectric cooling component of the system.

Applications developed for mobile devices facilitate the management of activities such as controlling and monitoring the temperature in an environment. In a previous work (Castro & Mestria, 2022) the temperature control used electronic components with wireless communication via Bluetooth through a mobile device, showing the efficiency provided using an application; also in future works, it is pointed out that the application would benefit of incorporating IoT, using Wi-Fi or Ethernet, as the Bluetooth connection represents a clear disadvantage when the proximity between devices is not possible.

Therefore, the present work intends to develop upon the future work presented by Castro and Mestria (2022), using the concept of IoT in a smaller scale application that can, in the future, be applied to many areas of our daily lives as well as industries, if scaled-up. Another application of IoT is presented by Xiao and Li (2020), with a proposed system for monitoring temperature and humidity, but using Zigbee protocol for communication whereas this work proposes the use of IP (Internet Protocol).

The main contributions of this article are: conditioning a refrigeration system to work according to a predefined temperature range using an IDE (Integrated Development Environment); propose a low-cost alternative design for temperature/humidity monitoring and control through wireless communication and a fixed IP address, using HTTP (Hypertext Transfer Protocol) application layer of IP protocol; implement the concept of IoT, in which it allows observing scalar quantities such as temperature and humidity from a distance; develop web interfaces and applications that can be changed in a simple way according to the measurement and monitoring application of temperature/humidity measurements.

This article highlights the use of Wi-Fi to establish a connection between an updated web page and viewed in real time through an app or browser, with data obtained from a DHT11 temperature and humidity sensor. For that, wireless communication is established, along with a web page designed in the Arduino IDE by integrating C programming language with HTML programming language (HyperText Markup Language). In this IDE, the programming of the circuit components was also done, so that IoT was incorporated into the application. The use of the MIT (Massachusetts Institute of Technology) App Inventor development platform easily allowed the monitoring of temperature and humidity. Thus, it is proposed the feasibility of building a simple system from electronic components related to the Internet of Things to control and monitor the temperature of an environment.

The work is organized as follows: the methodology of the proposed system is presented in section 2. Section 3 contains the results and discussions about the development with the methods explored on the previous section, and the last section concludes the work and proposes future improvements.

Material and methods

This research proposes temperature control through an automatic ventilation system and the monitoring throughout a web page with visualization in a mobile application or via browser, using development boards and Wi-Fi communication. The programming involves Arduino and its IDE, a free software guided in a copyleft project (McRoberts, 2010). With this IDE, two codes were developed, one for the control of the system which later was embedded in Arduino, and another code to establish communication and to send data, which was uploaded to a Node MCU ESP8266, Table 1 presents the hardware components used in the project. The use of this development platform also allowed for the HTML programming language to be incorporated to the C programming language, native of the IDE, establishing it in the Node MCU ESP8266 code.

HTML is commonly used to build a webpage, being easily explored in other languages. To configure a web page, specific HTML commands are necessary, as well as to the communication between components presented in the circuit of the application. In this project, the language was responsible for establishing the connection with the Internet, by defining the IP address that is connected to a network, allowing for wireless communication and the access of the data page for the application.

Table 1. Hardware of the designed circuit.

Item	Components
1	DHT11 Temperature and Humidity Sensor
2	Arduino Uno
3	Wi-Fi Module ESP8266 Node MCU
4	Cooler
5	Protoboard
6	Resistors 10kΩ
7	Diode
8	NPN TIP122 Transistor
9	Jumpers male/male and male/female

The components represented by the items 5 through 9 of Table 1 are electronic devices responsible for connecting the main elements of the circuit, allowing or not for the current to flow and activate the cooler, as to maintain the correct performance of the system. The development board, Arduino, sends the control commands to activate the ventilation system according to the data captured by the DHT11 sensor. As for the Wi-Fi Module Node MCU ESP866, it establishes the communication between the sensor and the web page designed by the code. This is the device that when used, transforms the system in an Internet of Things application. An automatic temperature control system with real time monitoring, that can be applied to different devices and different networks on a daily routine. Figure 1 represents the relationship between the components, as described, and Figure 2 is the diagram of the project.

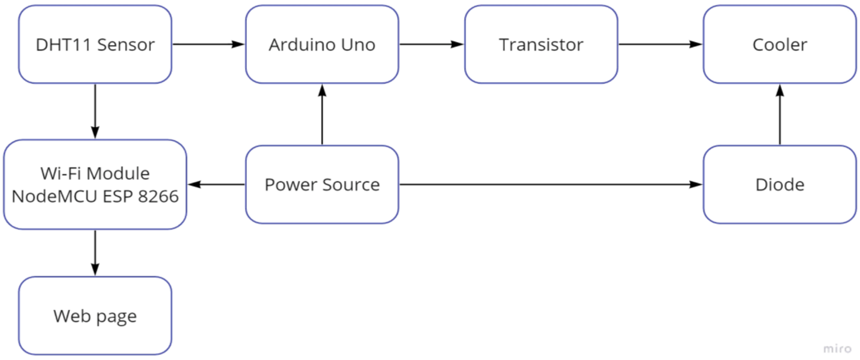

Figure 1. Block diagram of the hardware operation system.

The block diagram in Figure 1 shows the operation of the circuit elements, with the power source connected to the components, the DHT11 sensor sending the data both to the Arduino, influencing the control of the system, and to the Wi-Fi module, ensuring data monitoring. Figure 2 represents each of the hardware used and how they were connected to ensure a working system.

For testing purposes, temperature parameters were established in the code to automatically control the ventilation system. Therefore, a range of variation considered as ambient temperature was defined, with values in the range of 20 to 27°C. Temperatures below 20°C are considered below the range, therefore they should not trigger the cooler, and temperatures above 27°C are above the range, implying the need for temperature reduction and activation of the ventilation system. However, for each environment in which the system is applied, the temperature range must be changed, varying according to the needs of the application or environment.

As for the humidity variable, for this system, its expected behavior is that it should be concomitant with the temperature, that is, as the temperature increases, the humidity decreases and as the temperature decreases, the humidity increases. Therefore, the humidity is related to the application that the system is applied to, so that the automatic control of the ventilation system can be adjusted to stabilize the humidity and the temperature together, not just the temperature range.

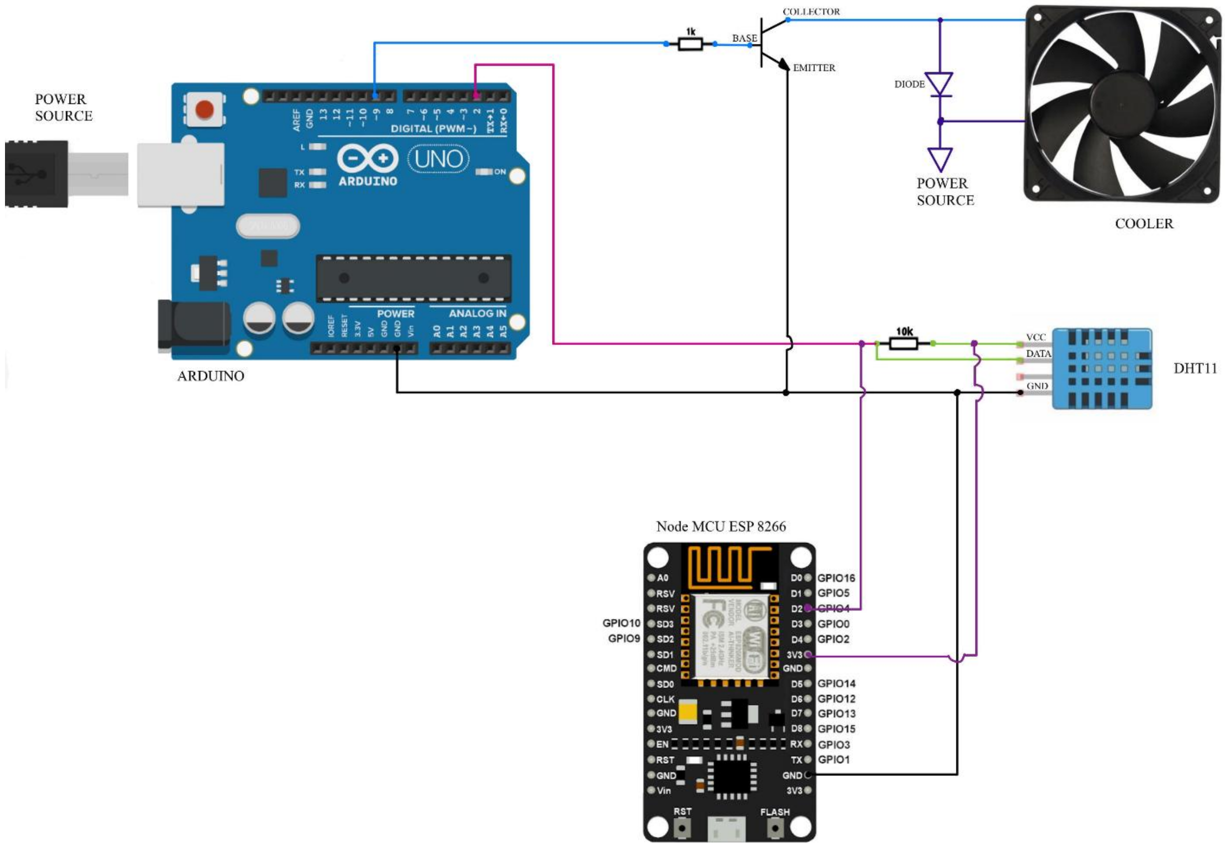

Figure 2. Diagram of the system built.

For the project, with the components presented in Table 1, the physical connections can be made, while for the proposed performance is necessary to elaborate the code. The flowchart shown by Figure 3 represents the programming development for sending data, and connecting to the Internet.

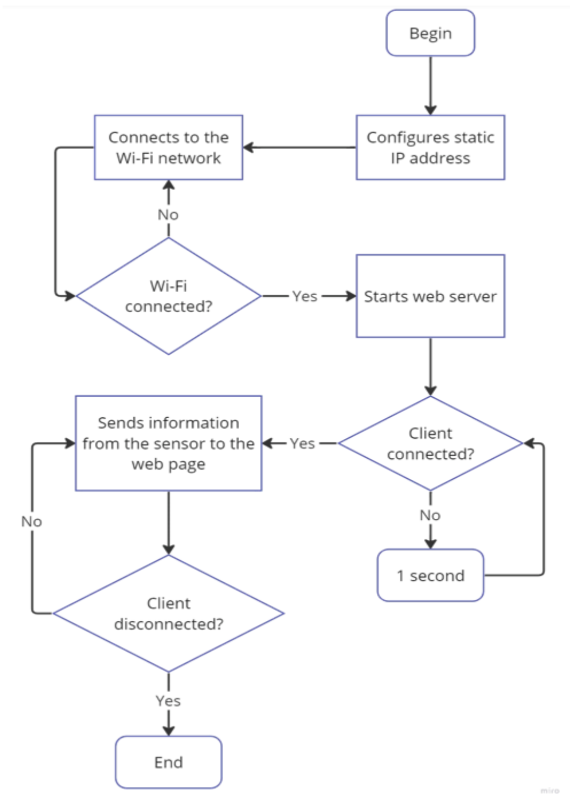

Figure 3. Flowchart of code operation for the application.

The flowchart, Figure 3, organizes the order of events elaborated in the programming, meaning that, when the program is started, the IP address defined in the code is configured for the application, so that a connection with the serial monitor will not be necessary to know the IP address. Subsequently, it connects to the Wi-Fi network configured on the code with the name and password, checks the connection and proceeds to start the web server when it is connected. The server waits to receive a request from a client to access the page and, upon receiving it, sends the information collected by the DHT11 sensor to the web page, updating it as the information is received. After the connection established by the client is finished, the server again waits for another connection. The flowchart shown by Figure 4 shows the Server and Client relationship, commonly applied when using IoT.

Figure 4 is indicating that the client is the one that requires certain information from the webpage when accessing an IP address. The server will then receive a notification that there is an attempt to access, a HTTP request, and check whether the client has permission to access the database or not. From that, the server allows the transmission of information over the Internet to the specified IP address.

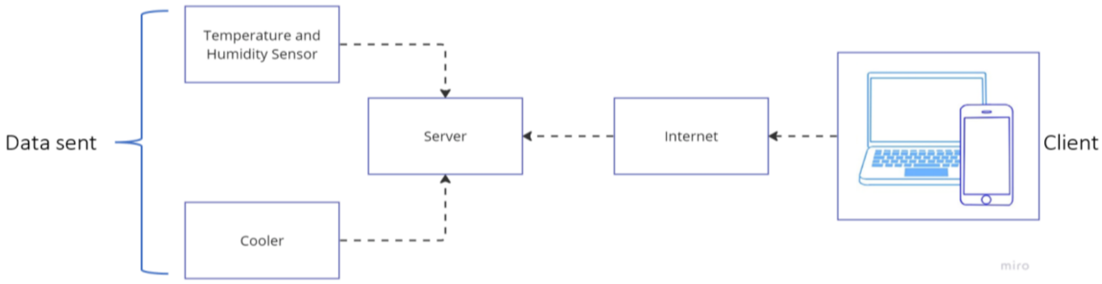

Figure 4. Flowchart of the relationship between Server and Client.

Therefore, for the proposed application, the database is composed by the information captured by the DHT11 temperature and humidity sensor, as well as the information corresponding to the state of the ventilation system, whether it is turned on or off. The customer will access an address through the browser or using the application. The server has a pre-established fixed IP address giving access to database information.

Thus, an application is built through the MIT App Inventor development platform, so that the pre-established IP address in the application code is the default address, so that it is enough to click on the "Connect" button and the web page will be displayed with temperature conditions viewed in real time. Since this programming environment is easily accessible, it becomes efficient to develop more functionalities to the application. Thus, the mobile application acts as a “browser” by allowing you to change the address for viewing a different web page, by clicking on the “New IP” button, the two options can be viewed in the initial interface, Figure 5. The interface established by the application when using the predefined IP address can also be viewed through a common browser, as in Figure 6.

Figure 5. View of the main page of the app, with two options: connection with standard IP or new IP address.

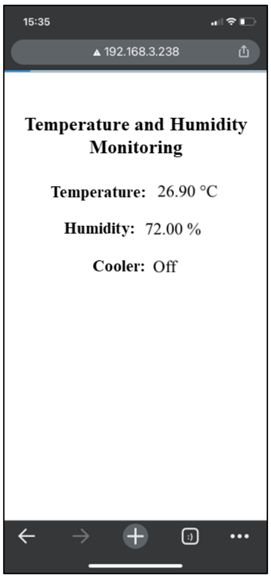

Figure 6. Web page view with predefined IP address, temperature, humidity, and cooler status information.

Furthermore, for the efficiency analysis of the control system, the MATLAB programming tool was used, where graphs were created with the behavior of the temperature and humidity variables. The graph was made using the data sent by the DHT11 sensor to an online spreadsheet, using the communication channel already established with Node MCU ESP8266, sending the data in real time and via Wi-Fi. Therefore, the communication and the implemented IoT system were used to establish and record the results displayed in the browser and use them to study the proposed system.

Results and discussion

The code programmed and shown in Figure 3 can be changed, so that different networks are used as the basis for the connection between the web page and the data to be displayed. That is, inserting new user and password parameters allows the use of a different server for a new system application.

The communication presented by the flowchart in Figure 4 proposes that the network used by the client does not need to be the same network used by the server to get the electronic circuit data, thus, through 3G, 4G, 5G and other Wi-Fi networks it is possible to access the browser and view the current state of the system, receiving constant updates. Therefore, the application of Internet of Things is advantageous since it allows viewing in real time from a distance, without the need for proximity between mobile devices and the electronic components that make up the circuit. In a previous work the disadvantage of wireless communication via Bluetooth is the need for short distances between system components and other devices (Castro & Mestria, 2022), therefore the project in question overcomes this step and its analysis.

Using Table 1 and analyzing the values of each component in Table 2, it is possible to conclude that the proposed system is low cost, being applied to an increasingly imminent concept, to be inserted in the means of embedded, electronic, automation and control systems, among others, the so-called IoT.

Table 2. Values of the hardware for the designed circuit.

Item	Components	R$ (Real)
1	Temperature and Humidity DHT11 Sensor	21.76
2	Arduino Uno SMD and Power Cable of the hardware	56.91
3	Wi-Fi Module ESP8266 Node MCU	32.20
4	Cooler	9.00
5	Protoboard	19.80
6	10 Resistors 10kΩ	1.43
7	Diode 1N4007	0.10
8	NPN TIP122 Transistor	1.50
9	65 Jumpers male/male and male/female	23.50

From the analysis of Tables 1 and 2, the application is presented as viable in its cost since the components are easy to acquire and of low monetary value. Its control is through sensors and a simple refrigeration system that operates automatically, allowing the construction of an effective system.

Furthermore, the advantage and easiness provided by the application and the browser stand out, as they are controlled with digital values. No need to depend on an analog system, which in cases of precision, is subject to parallax errors. The control settings given by the application provide greater accuracy of the temperature to be controlled and measured. The use of the project in domestic and small-scale systems is feasible, allowing the exploration of the system according to the specific application, such as a refrigeration system.

The graphical analysis of Figure 7 and Figure 8 demonstrate the efficiency and applicability of the proposed system. Two tests were performed, in an environment where the temperature tended to increase. Thus, the red lines represent the situation without the automatic control proposed by the project, and the blue lines are the behavior of the same environment with the presented control.

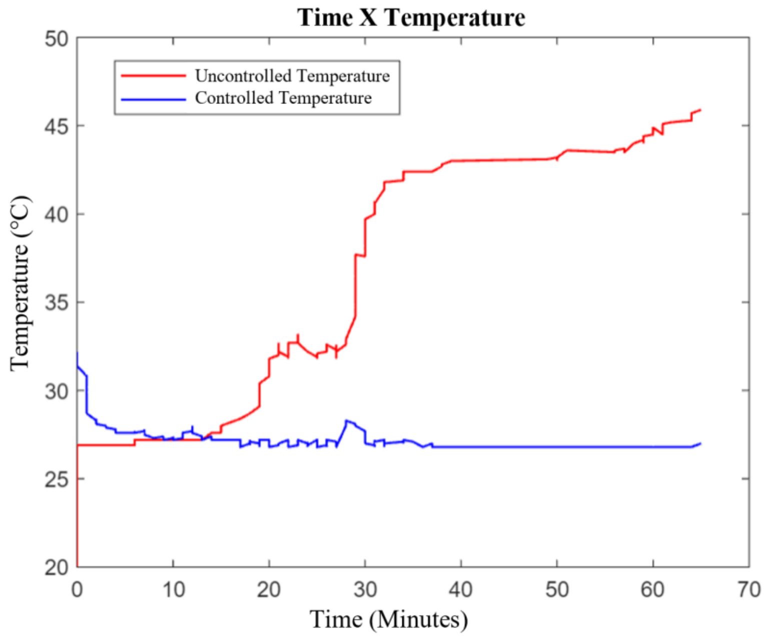

Figure 7. Graphic view in the same environment for controlled and uncontrolled temperature.

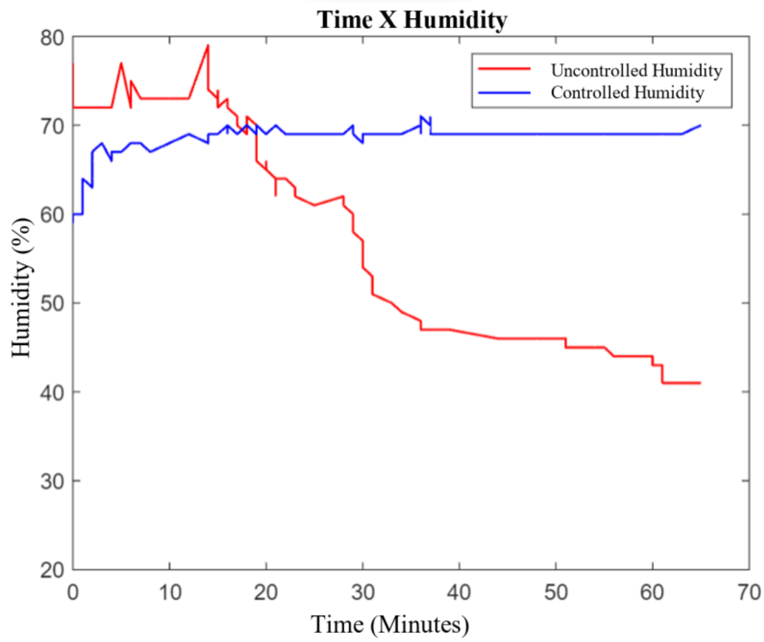

Figure 8. Graphic view in the same environment for controlled and uncontrolled humidity.

Figure 7 presents, as the red line, the temperature trend in an uncontrolled environment. Thus, it is concluded that, in a period of approximately 60 minutes, with constant measurements and monitoring, the temperature ranged from 26 to 45°C, while the controlled temperature curve presents the temperature with low variations and following the predetermined set point of 27°C for the automatic control operation. In Figure 8, the humidity resultant from the same environment is presented.

Like the temperature graph, Figure 8 presents the behavior of humidity in the same initially uncontrolled environment. Thus, as the temperature increases, the humidity decreases, indicating that the environment is drier. For the case of the controlled environment, the humidity tends to a balance, remaining around a value of 69%, following the time interval measured for temperature, since the DHT11 sensor sends the data of both process variables simultaneously.

Despite the advantages presented and the functionality of the system, the project can be improved so that it can cover different scalar quantities, have an interface with greater usability and even more improved functions. In future projects, it is possible to build an application with the implementation of new commands, such as increasing or decreasing the temperature using buttons. With this, it exerts greater control over the system in which the project is applied, it can also be expanded through other ventilation tools, enriching the project. Thus, a more complete system might be implemented where the temperature would be controlled through a more user-friendly interface and the control could be automatic, as already discussed, or in a second way, manually, based on changes to the language codes and hardware.

In addition, the development of a survey to verify the energy consumption of the current project is suggested, and the reduction of energy consumption, as well as its use in an intelligent way, might be added to its advantages. Still, as future work, it is possible to evaluate the operation of the mobile application by people from different areas to verify if it meets the requirements of usability, functionality, and efficiency. As future research, it is proposed to build other applications for home automation and irrigation control. The idea of cross platform is also proposed, a concept in which the application's programming allows its use on Android, iOS, and other operating systems.

Also, the application can be elaborated with a different temperature and humidity sensor, with greater precision since the system is comprehensive and can be modified according to the area in which it is applied. Therefore, modifications such as: increasing the number of sensors, using a different ventilation system to change the environment’s temperature, varying the temperature range for control, among others, do not imply radical changes in the proposed system's functioning process. The proposal for the application of Internet of Things, developed from these new electronic devices and with changes in the codes of programming languages and hypertext markings, is maintained.

Conclusion

This work developed a low scale low-cost control and monitoring system composed of a web page interface with visualization through a browser or a mobile application. The system used electronic devices and development boards to control and monitor temperature and humidity. The idea of the system can be used in several areas such as residential, commercial, logistics chains, industrial processes, and product transport by refining it to apply on a larger scale.

Acknowledgments

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