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Low-cost electronic system for monitoring vapor pressure deficit and sunlight using a Raspberry Pi Pico board

Sistema electrónico de bajo costo para monitoreo de déficit de presión de vapor y luz solar utilizando una tarjeta Raspberry Pi Pico

Edgar Serrano-Pérez [a], Manuel Sandoval-Villa [b]

Abstract:

The development of an electronic system for monitoring atmospheric conditions in an experimental greenhouse is presented. The core of the system consists of a 2021 recently launched Raspberry Pi Pico board, programmed with the Micropython language. A DHT22 module and a light-dependent resistor were selected as sunlight sensors for monitoring the environmental conditions. The system performance test was carried out for 3 days during the germination stage of 6 red salad bowl lettuce and 6 Amaranthus seeds; agricultural foam was selected as substrate using the manual drip irrigation method. Temperature, relative humidity, vapor pressure deficit, and sunlight sensor readings data were captured, recorded, and accessed using the Thonny IDE in a text file with columnar format stored in the RP2040 microcontroller memory. The total cost of the electronic system used to design the system was around $US 11, which makes it an attractive alternative for academic activities and research projects.

Keywords:

Monitoring, vapor pressure deficit, microcontroller, low-cost

Resumen:

Se presenta el desarrollo de un sistema electrónico para monitorear las condiciones atmosféricas en un invernadero experimental. El núcleo del sistema consiste en una tarjeta Raspberry Pi Pico recientemente lanzada en 2021, programada con el lenguaje Micropython. Se seleccionó un módulo DHT22 y una resistencia dependiente de luz como sensor de luz solar para monitorear las condiciones ambientales. La prueba de rendimiento del sistema se llevó a cabo durante 3 días durante la etapa de germinación de 6 lechugas red salad bowl y 6 semillas de Amaranto; se seleccionó espuma agrícola como sustrato mediante el método de riego por goteo manual. Los datos de temperatura, humedad relativa, déficit de presión de vapor y lectura del sensor de luz solar se capturaron, registraron y accesaron utilizando el IDE de Thonny en un archivo de texto con formato de columnas almacenado en la memoria del microcontrolador RP2040. El costo total del sistema electrónico utilizado para diseñar el sistema fue de alrededor de US $ 11, lo que lo convierte en una alternativa atractiva para actividades académicas y proyectos de investigación.

***Palabras Clave**:*

Monitoreo, déficit de presión de vapor, microcontrolador, bajo costo

Introduction

Nowadays, there exists an increasing need to develop electronic devices for monitoring and controlling protected agricultural production environments, such as greenhouses. Air temperature and relative humidity are perhaps the most relevant, as they allow calculation of other variables, for example, dew point and the vapor pressure deficit (VPD). The VPD is an index for environmental conditions that favor or limit the transpiration and photosynthesis processes of plants during their growth and development. Most plants need environmental conditions in an optimal VPD range, from 0.2kPa to 2 kPa (Gates et al., 1998). According to the Magnus formula (Alduchov y Eskridge, 1996), temperature

[a] Autor de Correspondencia, Universidad Tecnológica de México - UNITEC MÉXICO - Campus Atizapán, https://orcid.org/0000-0003-4012-9709, Email: edgar_serrano@my.unitec.edu.mx

[b] Postgrado Edafología. Colegio de Postgraduados – Campus Montecillo, https://orcid.org/0000-0002-0228-0734, Email: msandoval@colpos.mx

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measurement and air relative humidity, become essential data for VPD calculation.

The main goal of the system is to evaluate a VPD and sunlight monitoring system through low-cost electronics into a hydroponic seed germination process taking place in a mini greenhouse. The low-cost electronic devices have allowed the development of numerous systems based on open source software, promoting the synthesis of electronic devices for academic and research objectives (González-Buesa y Salvador, 2019; Hubbard y Pearce, 2020; Zhang et al., 2019).

Among the great advantages of this situation, electronic devices can be modified, adapted, and updated for new operating scenarios through low-cost components (Pearce, 2020; Ravindran, 2020).

Materials and Methods

A Raspberry Pi Pico board was selected as the core to develop the system. It has embedded the new RP2040 microcontroller recently launched in early 2021 (Adams, 2021). The $US4 cost is attractive for academic and research projects, moreover, it can be programmed through the Micropython language for the embedded-systems target. As a temperature and relative humidity sensor, the DHT22 module was selected. A light-dependent resistor (LDR) was connected for monitoring the diffuse sunlight in a 0.5 meters side cubic experimental mini greenhouse. The polyethylene cover has 30% shade, so it reduces the amount of solar radiation light into the greenhouse and the influence of external factors which could modify the inner temperature and relative humidity, such as wind currents and rain (Shamshiri et al., 2018). The reduced number of devices and physical connections maintains the system as simple as possible; a connection diagram for the whole electronic devices using Fritzing (Knörig et al., 2009) is shown in Figure 1.

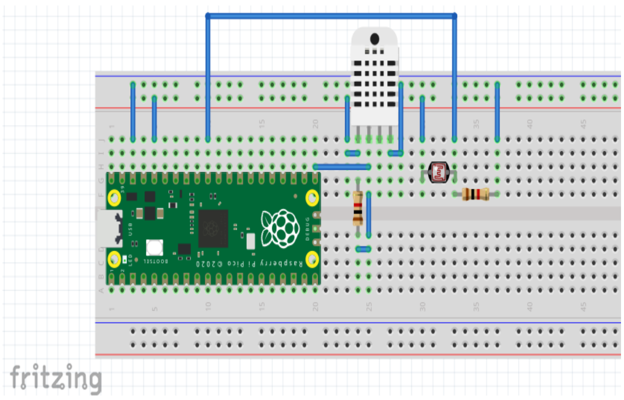

Figure 1. Physical Raspberry Pi Pico board connections with sensors for vapor pressure deficit and sunlight monitoring.

The Micropython source code was developed in the Thonny integrated development environment. For the temperature and relative humidity sensor, the PicoDHT22 library developed for the Raspberry Pi Pico was used (Perron, 2021/2022). The math and time libraries were used to compute the vapor pressure deficit and to obtain the actual local time for each reading from the computer respectively. The analog-to-digital conversion microcontroller pin 16 was used to capture the signal obtained from the light-dependent resistor. The resolution of the microcontroller converter is 12 bits, but in Micropython the analog signal is converted into a number between 0 and 65535 for processing the analog sensor voltage as an integer. The complete source code used for the monitoring system is shown in Figure 2.

Figure 2. Source code in Micropython language using

```
# DHT22 libray is available at https://github.com/danjperron/PicoDHT22
from machine import Pin
from machine import ADC
from DHT22 import DHT22
import time, math
from time import sleep
file=open("VPD & light.txt","w")
dht_sensor=DHT22(Pin(16))
vlight = ADC(Pin(26))
while True:
    y, mo, d, h, m, s, w, ye = time.localtime()
    T, H = dht_sensor.read()
    es=(6.1094*math.exp((17.625*T)/(243.04+T)))/10
    ea=(H/100)*es
    VPD=es-ea
    light = vlight.read_u16()
    Timenow = "{}-{}-{} {}:{}:{}\t"
    file.write(Timenow.format(y, mo, d, h, m, s))
    file.write(str(T) + "\t")
    file.write(str(H) + "\t")
    file.write(str(VPD) + "\t")
    file.write(str(light) + "\n")
    file.flush()
    print("Temp= {}°C Hum= {}%".format(T,H))
    print("lightval="+str(light))
    sleep(300)
```

Thonny IDE.

The microcontroller board connection with the sensors, loaded with the source code as the main.py file into the microcontroller's memory, allowed to print in the Thonny shell variables such as temperature, relative humidity, and light values sequentially. To collect and record all variables, a "VPD & light.txt" file was written each around 5 minutes in column format for better data organization and analysis through a spreadsheet program, such as Open Office Calc. The file content easily acceded through the Thonny IDE as soon as the microcontroller and computer connection was stopped. When the connection is enabled again, the file is automatically blanked to store new incoming values. To test the system's reliability, it has been used for data collection during 6 red salad bowls of lettuce and 6 Amaranthus seeds germinated into an experimental mini greenhouse. Each seed was located in an agricultural foam cylinder and manually drip irrigated every 8 hours to maintain the moisture in the substrate. The whole experimental setup is shown in Figure 3.

Figure 3. Experimental set-up for 12 seeds germination with manual drip irrigation.

The inner environment conditions in the greenhouse were successfully recorded to obtain the temperature, relative humidity, vapor pressure deficit, and sunlight variables evolution in the greenhouse. On the third day of the experiment, all seeds were germinated: initial roots became being enough visible for human eyes. The temperature reading value obtained from the DHT22 module allowed us to compute first the saturated vapor pressure. Secondly, through the saturated vapor pressure vapor and the relative humidity value reading, it was possible to obtain the current vapor pressure value. Finally, by applying the arithmetic subtraction of the saturated vapor pressure value minus the current vapor pressure, the actual vapor pressure deficit value was obtained. It is an interesting variable as it can be considered as an atmosphere reference value that leads to or limits the growth of plants, in their wide growth stages.

Results and Discussion

The acquisition and storage data test began on September 08, 2021, at 3:31 p.m. and ended on September 11, 2021, at 07:39 a.m. Each data recorded from date, time, temperature, humidity, and vapor pressure deficit data was obtained in tabular form, for later graphing using the OpenOffice Calc spreadsheet. After data recovering using the Thonny IDE, it was obtained the temperature and relative humidity chart shown in Figure 4.

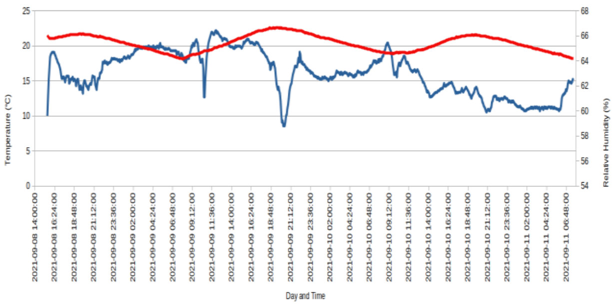

Figure 4. Temperature (red) and relative humidity (blue) evolution during seed germination into the greenhouse.

The minimum and maximum temperatures recorded were 18.1°C and 22.6 °C respectively. On other hand, the minimum and maximum relative humidities were 58.8% and 66.6%. In the case of the temperature variable, no sudden changes were observed, keeping the temperature stable throughout the whole time interval. In contrast, for the case of relative humidity, it was possible to observe some abrupt changes, mainly attributable to the moments of manual irrigation, made to keep the moisture in the agricultural foam. The process was carried out by opening the front main door of the greenhouse, which implied the renewal of the internal air with surrounding external air in the greenhouse. With temperature and humidity, data was possible to compute the vapor pressure deficit variable evolution, as shown in Figure 5.

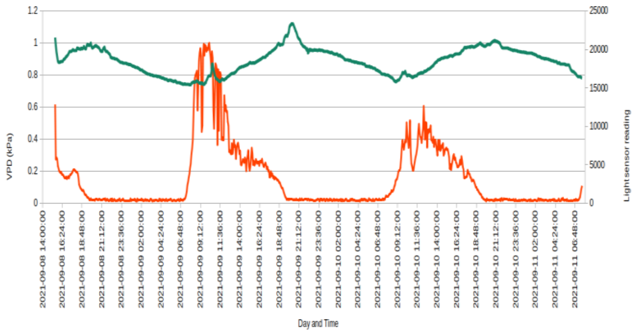

Figure 5. Vapor pressure deficit (green) and lighting sensor readings (orange) for monitoring environmental conditions during seed germination.

The vapor pressure deficit data evolution in time was in the range from 0.73kPa to 1.12kPa. Some coincidental abrupt peaks were also successfully recorded with the system; they were mainly found at times when the relative humidity variable presented a significant decrease with a stable temperature of around 22 °C. On other hand, temperature variable evolution drove the shape and tendency of the vapor pressure deficit variable. Relative humidity seems to be a faster variable to modify the vapor pressure variable behavior than temperature. Relative humidity was strongly influenced by the outside air inlet during the manual drip irrigation process. The sunlight variable had an important role in temperature and relative humidity evolution into the greenhouse. The range was found to be from 208 to 20821 for the sensor readings. Minimum values were found in the range 0:00 am to 7:00 am coincidental range time with the hours with the lowest temperatures registered by the electronic monitoring system. The absence of sunlight also influenced a perceptible decrease in the vapor pressure deficit variable during night hours. As soon as the sun appeared at around 7:00 a.m. of each day, the temperature and vapor pressure deficit became constantly increased until reaching higher values around 8:00 pm. These variables' behavior was replicated during the whole data recording test in a continuous cycle for each day, with exception of the fast response of the relative humidity variable, which was more strongly influenced by the outside air renewal during the greenhouse opening door. It must be noted that although educational boards with microcontrollers have not been designed for industrial production environments they represent an attractive low-cost option for monitoring small micro-climate processes involved in urban agriculture (De Anda y Shear, 2017; Eduardo Vergara Pérez et al., 2018; Orsini et al., 2013). To build the whole electronic system which allowed to compute the vapor pressure deficit and monitoring sunlight in a mini greenhouse, it was considered the acquisition of low-cost electronic elements, which recently have gradually increased their availability in different electronic stores. The summary of the costs updated until September 2021 is shown in Table 1.

Hardware device	**Cost $US**	**Internet portal**
Raspberry Pi Pico	4.20	https://mexico.newark.com
DHT22	6.45	https://mexico.newark.com
2M LDR	0.25	https://agelectronica.com
2 resistors 1 Kohm ¼ w	0.10	https://agelectronica.com
TOTAL	11.00	
Industrial Device WATCHDOG 2475	115.00	https://proain.com

Table 1 . Cost for electronic components

The synthesis of the proposed electronic system implies the acquisition of very few electronic components, with a total cost of around $US 11. The price is attractive for the system implementation, mainly for its implementation in small agricultural production systems focused on research or self-consumption. In this sense, the proposed electronic system can be used as an educational development tool and for research objectives. As the microcontroller board is flexible and adaptable to make more processes, it can be updated and improved to include other variables of interest in a greenhouse, such as CO2 or soil/substrate moisture monitoring. Thus, the presented system is presented to promote the development and implementation of control algorithms, focused to regulate the particular interest variables that lead to improving the inner atmosphere conditions of production systems in protected environments.

Conclusions

Through the integration of a few electronic devices, it was possible to synthesize an environmental monitoring system into an experimental cubic greenhouse. It allowed the data acquisition of date, time, temperature, relative humidity, vapor pressure deficit, and sunlight written to a .text file in columnar format. Recorded data was easily taken to a spreadsheet for graphic data processing. The core of the system was a Raspberry Pi Pico board recently launched in early 2021 year programmed through the Micropython language. The low-cost microcontroller board and electronic devices, allowed building and integration of the system for around $USD 11; an attractive option for academic and research objectives. To investigate the system’s reliability, its operation was carried out autonomously and continuously throughout the 24 hours day and night. The system successfully captured and processed the different temperature and humidity gradients for 3 days into a greenhouse used to germinate 6 red salad bowl lettuce and 6 Amaranthus seeds using agricultural foam as substrate with manual drip irrigation. All seeds were successfully germinated and the electronic circuits did not show any faults during their continuous operation. No considerable damage was observed on the surface of the electronic devices which could lead to interrupt/modify their operation. The implementation of the presented technological development is intended to be a starting point to explore new mechanisms for monitoring and controlling interest variables in protected production environments. It could eventually lead to a transition for testing and implementing diverse control strategies for better regulation of the inner atmosphere in a greenhouse.

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