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Research Article

Device to Measure, Monitor and Control Variables for Agricultural Purposes

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Abstract

The measurement of meteorological variables is important for decision-making in the field. Accurate data can help farmers optimize their activities to improve food production. Traditional methods of monitoring variables can be expensive or complex for small-scale farmers to use. This indicates a need for low-cost and user-friendly devices. Currently, there is technology for developing these types of devices, which could be useful to automate processes based on variable monitoring and improve food production. Due to this, a device based on the Arduino Mega™ board was developed to monitor air temperature, relative humidity, rain, and soil moisture. In addition, equipment was developed to be controlled based on a rain gauge. The device has a TFT touch screen for easy-user interaction and 4 menus for information display (summary, floor, date-time and manual equipment control). The program of the device required more lines of code (59.65%) to establish user-device interaction compared to its internal processes (18.66%) and variable declarations (21.68%). A container was 3D printed to house all the integrated circuits and the device was tested under both indoor (Jun-10, 2024 to July-17, 2024) and outdoor (Jul-22, 2024 to Aug-18, 2024) conditions. Under indoor conditions, a 3% difference was found in the temperature measurements taken under the same conditions (using DS18B20 and MLX90614 sensors). Under outdoor conditions it was found that the air temperature decreased by an average of 2.33 ℃ when increasing the height from 8ft to 16ft and the relative humidity decreased by an average 3.48% when increasing the height from 8ft to 16ft. There was a 3.4% difference in total rain measured by the rain gauges. Finally, the developed device performed adequately during the two months of testing in both conditions, measuring variables and controlling equipment (the equipment went from waiting mode to rain harvesting mode 92 times).

Keywords

Automation, Precision Agriculture, Soil Variables, User-Friendly, 3d Printing

1. Introduction

The agriculture sector is crucial and faces several challenges, such as, increasing energy demands, global warming and meteorological variability [1]. Monitoring meteorological variables has been studied and is very important especially in agriculture for food production, irrigation efficiency and equipment control [2-4]. In recent times, low-cost sensors are becoming popular. They promise high spatial and temporal resolutions at low-cost [5]. There are also commercial devices for monitoring variables but some of these systems are generally expensive and closed to modifications [6]. Due to this, this study presents a low-cost device capable of monitoring environmental variables of agricultural importance (air tem-

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perature, relative humidity and rain) and soil variables (moisture, temperature and electrical conductivity). Additionally it controls equipment to aid decision-making and improve the efficiency of agricultural operations.

2. Materials and Methods

This study was carried out at the facilities of the Montecillo Campus Postgraduate College, Mexico at coordinates 19°27'37.0" N and 98°54'12.1" W. The prototype development stages were: search for sensors and components, connection of the components, development of the program, development of protection containers and securing the components, control of rainwater harvesting prototype, operation testing under indoor conditions and, operation testing under outdoor conditions.

2.1. Search for Sensors and Components

To develop the device, variables such as air temperature, were taken into account and measured with the DS18B20™ sensor, which is digital and works with the 1-Wire library of the Arduino IDE™ software and has a precision of ±0.5 ℃ [7]. The temperature of an object and environment was measured with the MLX90614 GY-906™ infrared temperature sensor, which is digital, works with the Adafruit MLX90614 library of the Arduino IDE software, and has an accuracy of ±0.5 ℃ [8]. Relative humidity and air temperature were measured with a 3-pin digital DHT11™ sensor that works with the DHT11 library of the Arduino IDE software, having precisions of 5% for humidity and 2 ℃ for temperature [9]. Relative humidity was also measured with the analog HMZ333A1™ sensor. Leaf wetness was measured with the Meteor Group LWS™ sensor. Rain was measured with the WH-SP-RG™ MISOL digital rain gauge, which uses pulses and a digital pin type INPUT_PULLUP of the Arduino IDE program. Soil moisture, soil temperature and soil electrical conductivity with precision of 5%, 0.5 ℃ and 5% respectively were measured with the BGT-SEC Z2™ digital sensor using an ADI interface that is TTL compatible (0-3.6 V), and encodes in ASCII, with a baud rate of 1200bps, no parity, 8 data bits and 1 stop bit [10].

To take the time and store the information on a micro-SD card, DS1302™ RTC (real time clock) and MLMSD™ modules were used respectively. To create the user-device interface, a 3.5-inch TFT touch screen was used. The DHT11, MLX90614, DS18B20 and WH-SP-RG sensors were chosen because they have already been used in research [11-15].

2.2. Connecting Components with the Arduino Mega 2560™ Board

The components were connected to the digital pins of an Arduino Mega 2560 board as shown in Figure 1, which was responsible for controlling all the sensors and integrated circuits.

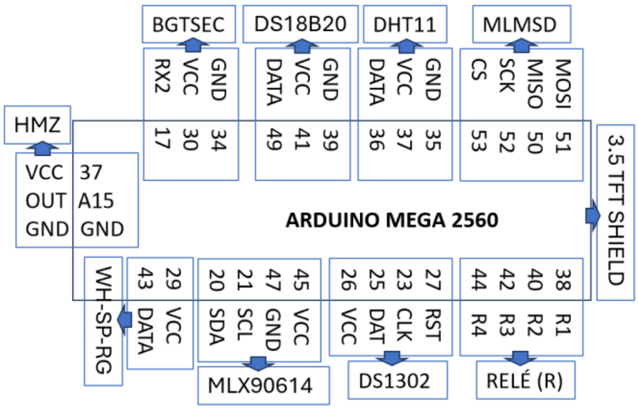

Figure 1. Connections diagram for the digital pins of the Arduino 2560 board with sensors and components of the device.

2.3. Development of the Program

The program was developed in the Arduino IDE application. A total of 2020 lines of code were developed, of which 377 lines (18.66%) are used to carry out the operating cycle for measurement and control of the equipment based on a rain gauge where user intervention is not required (loop). Additionally, 438 lines (21.68%) correspond to the beginning of the program (declaration of libraries, variables, digital pins and setup function) and 1205 lines (59.65%) of code correspond to the user device interface (TFT screen menus).

2.4. Development of Protection Containers and Securing Components

To protect all the integrated circuits, exact containers were designed using the Autocad™ program, and subsequently printed on an Ender 3 V2™ 3D printer. Figure 2 shows some designs prepared for the sensors and modules (MLMSD, DS1302, RELAYS, ARDUINO MEGA 2560, TFT screen and MLX90614 GY-906™).

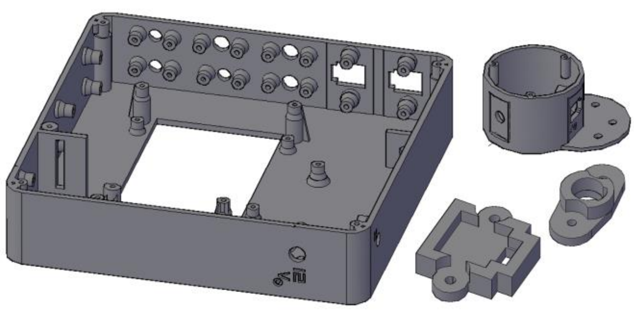

Figure 2. Designs made to contain the components of the elaborate device.

2.5. Control of the Rainwater Harvesting Prototype (RHA)

A scale demonstration mechanism was developed to capture rainwater (RHA). Some parts were designed and printed in 3D because it is a scale prototype that is not currently available on the market (Figure 3). It is worth mentioning that roofs are generally used to capture rainwater. This implies that when it rains, all the waste accumulated on the roof (such as dust and garbage) will be directed towards storage. To avoid this, it was proposed to establish a roof made up of bamboo gutters (to avoid an ecological footprint), which could conduct rainwater towards a main storage to store clean water. When it is not raining, the mechanism will make the bamboo gutters rotate 180°. With this, the collection surface will point downwards, ensuring that dust from the environment is deposited on the part of the channel that will not conduct rainwater (Figure 4).

The RHA prototype will generally be in standby mode (Figure 4 Left). It is linked to the WH-SP-RG™ rain gauge so that when it detects rainfall, the prototype immediately goes into water collection mode (Figure 4 Right). It is worth mentioning that the other variables are measured every hour. When measured, the RHA prototype will return to standby mode (Figure 4 Left). This cycle was tested 92 times under indoor conditions from May 20, 2024 to July 18, 2024.

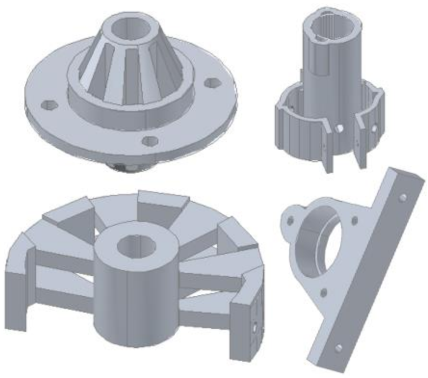

Figure 3. *Designs made for the construction of the scale rainwater harvesting prototype.*

Figure 4. *Scale rainwater harvesting prototype to capture rainwater (left: standby mode; right: collection mode).*

2.6. Operation Testing Under Indoor Conditions

The device was tested under indoor conditions. The measured variables were relative humidity (obtained with an HMZ333A1 sensor and the values were transformed into percentages according to the factory-calibration curve [16]), air temperature, soil moisture of the pot (the volume of the pot was estimated using a solid of revolution from the curve based on height and radius data) with a volume of 0.1845 ft^3 (5.225dm^3) without plants, soil temperature, electrical conductivity of the soil, object temperature obtained with the infrared sensor (pointing at the air), and air temperature obtained with the infrared sensor (pointing at the air). The values of the variables were obtained every hour from June 10, 2024 to July 17, 2024.

2.7. Operation Testing Under Outdoor Conditions

The device was installed outdoors at coordinates 19°29'59.9"N and 98°53'4.5"W between two two-story buildings. It is worth mentioning that the rainwater harvesting prototype was not installed. Only the sensors for measuring were installed. The variables that were measured were: temperature inside the soil in a pot with a volume of 0.2308 ft^3 (6.5360dm^3) without plants at 4 in depth (using the BGT-SEC Z2 sensor); soil surface temperature (using the MLX90614 sensor); temperature of the air at 1 in above soil surface (using the MLX90614 sensor); air temperature at 13 ft height in the shade (using the DS18B20 sensor) and; temperature of the air at a height of 16 ft (using the DHT11 sensor) from July 22, 2024 to August 18, 2024 under outdoor conditions. In addition variables such as rain (rain gauge WH-SP-RG), leaf wetness (LWS™ sensor), electrical conductivity in the soil (BGT-SEC Z2 sensor), and relative humidity (DHT11 sensor), were measured from July-22, 2024 to August-18, 2024. Additionally, a second identical device was made to measure the same variables except leaf wetness and air temperature with the DS18B20 sensor. The soil moisture sensor was placed directly in the soil.

2.8. Relationship Between Variables Measured in Indoor and Outdoor Conditions

To find the relationship, the observed values of the same variable measured by one sensor were plotted against the observed values from another sensor. The R^2 value and the equation of the linear regression in the form $y=\beta_1 x+\beta_0$ were estimated.

Under indoor conditions, the temperatures measured by the MLX90614 sensor (AST, Air Soil Temperature and SST, Soil Surface Temperature) were plotted against those observed by the DS18B20 sensor, because they were under similar conditions. The soil temperature measured by the BGT SEC Z2 sensor (InST, Inside Soil Temperature) was also compared with that of the DS18B20 sensor (AWT, Air Temperature) including only measurements taken in the absence of solar radiation.

On the other hand, under outdoor conditions the DS18B20 sensor (AWT) and the DHT11 sensor (AT, air temperature and RH, relative humidity) of both devices were compared because they were in shaded conditions, but at different heights. The same was done with the rainfall measurements from both WH-SP-RG^{TM} rain gauges (at 9 and 18 ft high). Furthermore, under different conditions (direct soil and pot), the temperature variables at 1 in (2.5cm) above the soil surface (AST of the MLX90614 sensor) were compared between both devices and the same was done for the soil surface temperature at 1 in height (SST of MLX90614 sensor).

3. Results

3.1. User-Device Interface

The 4 menus were developed (Figure 5) to display variables, show soil moisture, update date and time, and manually control the rainwater harvesting prototype if required.

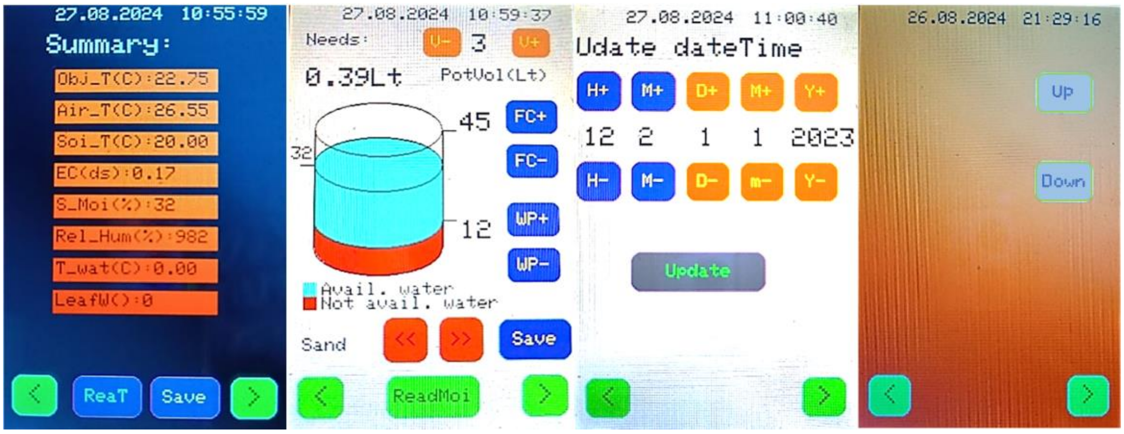

Figure 5. *Menus resulting from the developed device: visualization of variables (left), visualization of soil moisture (center left), date and time update (center right), and manual activation of the rainwater harvesting prototype (right).*

3.2. Development of Protection Containers and Securing the Components

The device has integrated circuits and was assembled inside the 3D-printed container (Figure 6). The ports were fixed to the container in such a way that the sensors, current eliminators, and current outputs can be connected.

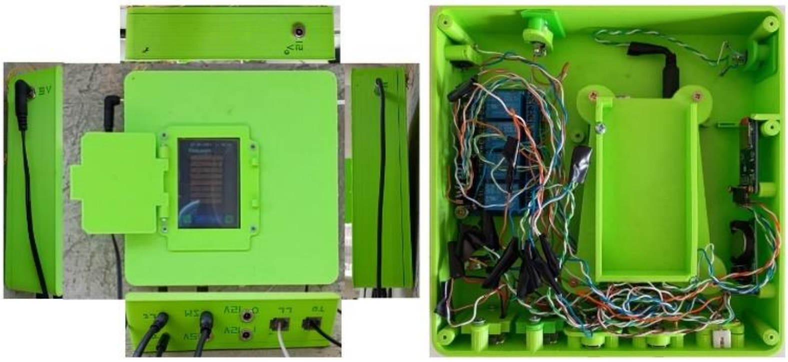

Figure 6. *Front view with side ports (left) and interior view of the manufactured device (with green PLA plastic as the printing material).*

3.3. Variables Measured Under Indoor Conditions

The variables measured under indoor conditions are shown in Figure 7 (temperatures) and Figure 8. It is worth mentioning that there was a power cut around day 22 of the study (May 30, 2024 11: 00 a.m. to June 1, 2024 11: 00 a.m.), so that information was not plotted.

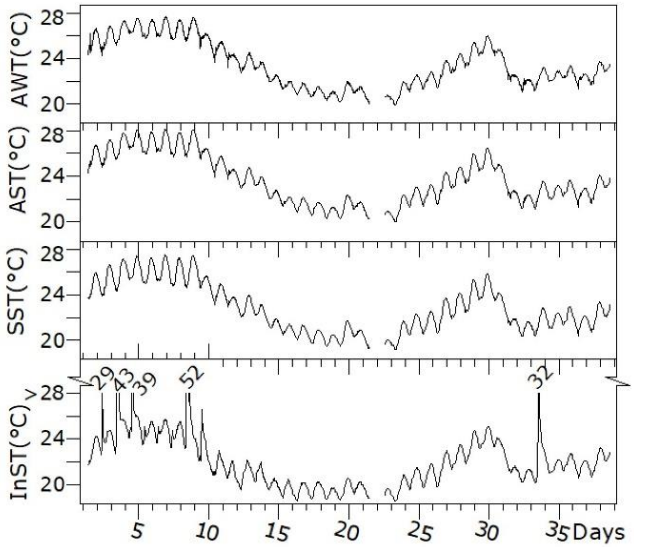

Figure 7. Temperatures: inside soil (InST, measured with the BGT-SEC Z2 sensor at a depth of 3 in); on the pot surface (SST, measured with the MLX90614 sensor at 1in above the floor surface); of air (AST, measured with the MLX90614 sensor at 1 in above the floor surface); and of air (AWT, measured with the DS18B20 sensor at 1 in above the ground surface), from June 10, 2024 to July 17, 2024 under indoor conditions.

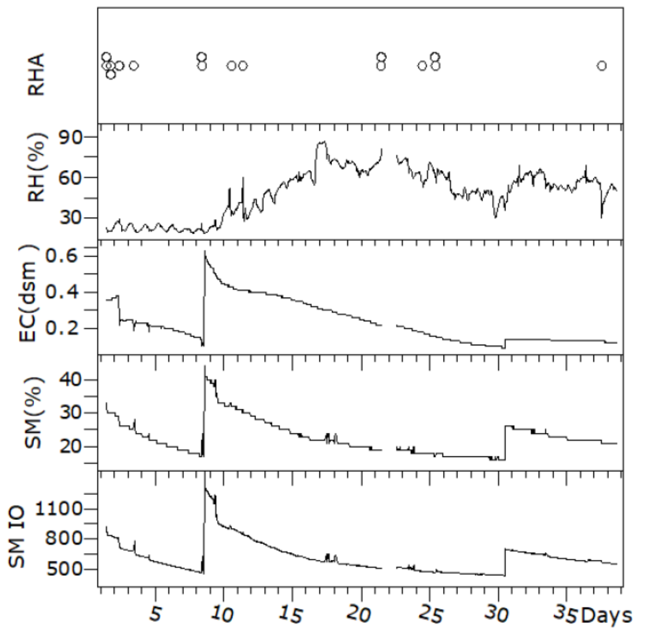

Figure 8. Variables: Integer output soil moisture values (SM IO, measured with the BGT-SEC Z2 sensor); soil moisture (SM, measured with the BGT-SEC Z2 sensor but only integer values were plotted without taking decimals into account); soil electrical conductivity (EC, measured with the BGT-SEC Z2 sensor); relative humidity (RH, measured with the HMZ333A1 sensor) and; collection and standby events of the rainwater harvesting prototype (RHA), from June 10, 2024 to July 17, 2024 under indoor conditions.

In Figure 8, the integer output values of soil moisture returned by the sensor (SM IO) were plotted. It is worth mentioning that the changes in this plot appear gradual. On the other hand, the soil moisture values in percentage, truncated to a whole number, were also plotted in Figure 8 (SM-%) with the intention of observing the amount of time required for the moisture to change by 1%. It is necessary to indicate that in Figure 8, the RHA plot corresponds to the occasions when the RHA was switched to rainwater collection mode and then returned to standby mode.

3.4. Variables Measured Under Outdoor Conditions

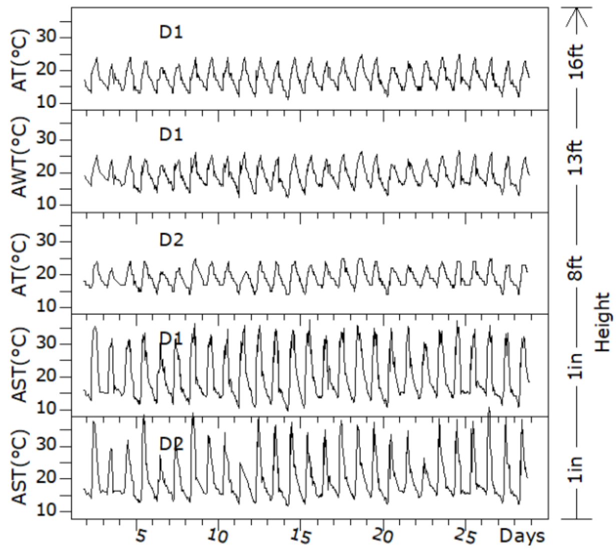

Figure 9. Temperatures of devices D1 (pot) and D2 (direct soil) measured in: air at 1 in above the soil surface (AST, measured with the MLX90614 sensor); air at 13 feet height (AWT, measured with the DS18B20 sensor removing false readings) and; air at 8 and 16 ft height (AT, measured with the DHT11 sensor removing false readings), from July 22, 2024 to August 18, 2024 under outdoor conditions.

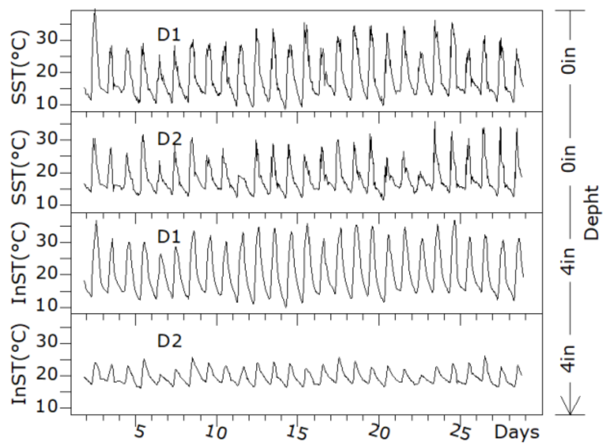

Figure 10. Temperatures of devices D1 (pot) and D2 (direct soil): inside soil (InST, measured with the BGT-SEC Z2 sensor at a depth of 4 in) and; on the soil surface (SST, measured with the MLX90614 sensor), from July 22, 2024 to August 18, 2024 under outdoor conditions.

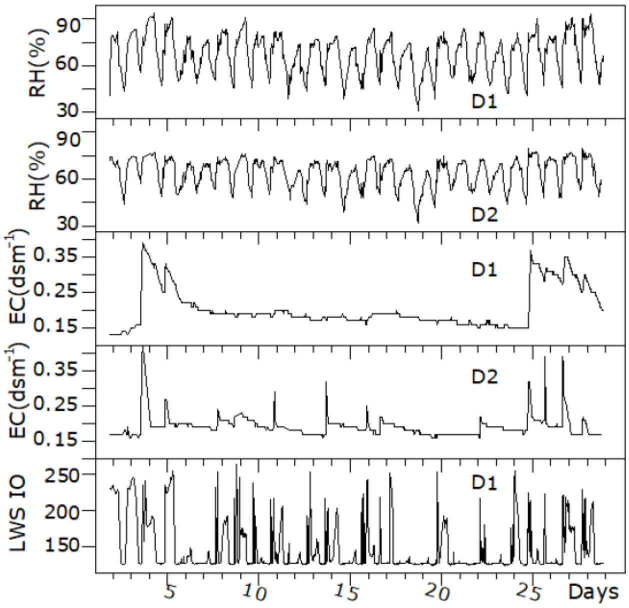

Figure 11. *Variables recorded from devices D1 (pot) and D2 (direct soil): Leaf wetness (LWS IO, measured with the Meteor Group LWS[TM] sensor); electrical conductivity in the soil (EC, measured with the BGT-SEC Z2 sensor); and relative humidity (RH, measured with the DHT11 sensor removing false readings), from July 22, 2024 to August 18, 2024 under outdoor conditions.*

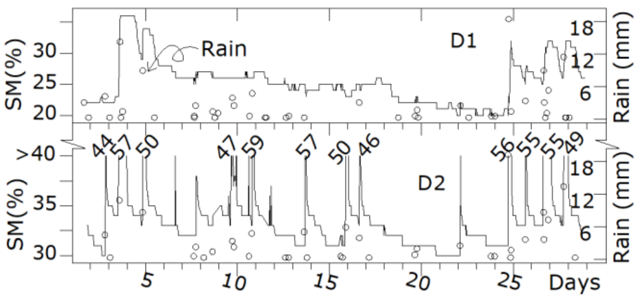

Figure 12. *Variables of the devices D1 (pot) and D2 (direct soil): Soil moisture (SM, measured with the BGT-SEC Z2 sensor but only integer values were plotted without taking the decimals into account); and rainfall (Rain, measured with the WH-SP-RG rain gauge) from July 22, 2024 to August 18, 2024 under outdoors conditions.*

Figure 9 (temperature), Figure 10 (temperature), Figure 11, and Figure 12 show the variables measured under outdoor conditions. It is necessary to mention that during the installation of the devices, events occurred where the Arduino Mega 2560 board stopped working. These events occurred two or three days after installation. To avoid this, the device was reset twice a day with a timer at 13:00 and 00:00. With the above setup, the data could be measured continuously. It is worth mentioning that when restarting the devices, due to the arrangement of the digital sensor's connection with the Arduino Mega 2560 board, the DS18B20 and DHT11 sensors gave false readings for air temperatures at 13 ft high (AWT of Figure 9), air temperature at 16ft high (AT- D1 and AT-D2 of Figure 9) and relative humidity (RH-D1 and RH-D2 of Figure 10). Because of this, readings immediately after device reboot were not taken into account for these variables. For all other variables, no false readings occurred.

3.5. Relationship Between Variables Measured Under Indoor and Outdoor Conditions

Figure 13 shows the relationships between the temperatures measured under indoor conditions. Figures 14 and 15 shows the relationship between temperature, relative humidity and rainfall measured with different sensors at various heights under outdoor conditions.

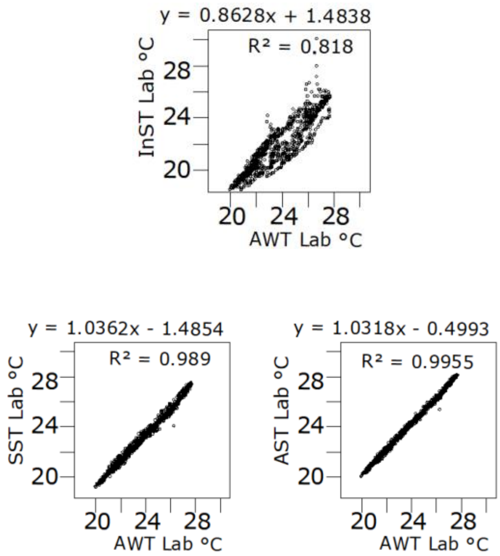

Figure 13. *Relationship between temperatures measured with the DS18B20 sensor (AWT) and those obtained with the BGT SEC Z2 (InST-soil temperature) and MLX90614 (SST and AST pointing at air) sensors under indoor conditions.*

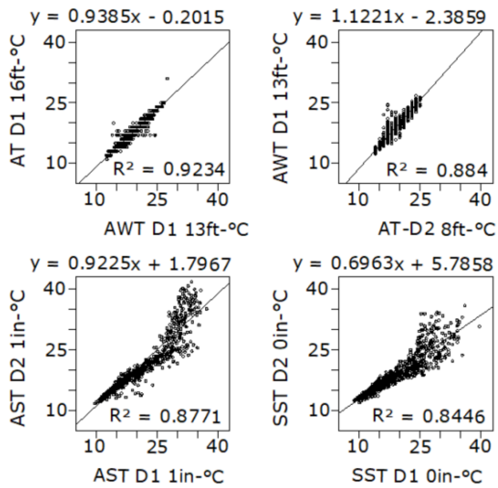

Figure 14. *Relationship between variables measured with sensors: DHT11 (AT, air temperature), DS18B20 (AWT, air temperature), MLX90614 (AST, air temperature), and BGT SEC Z2 (SST, soil surface temperature), from devices D1 (pot) and D2 (direct soil) at different heights under outdoor conditions.*

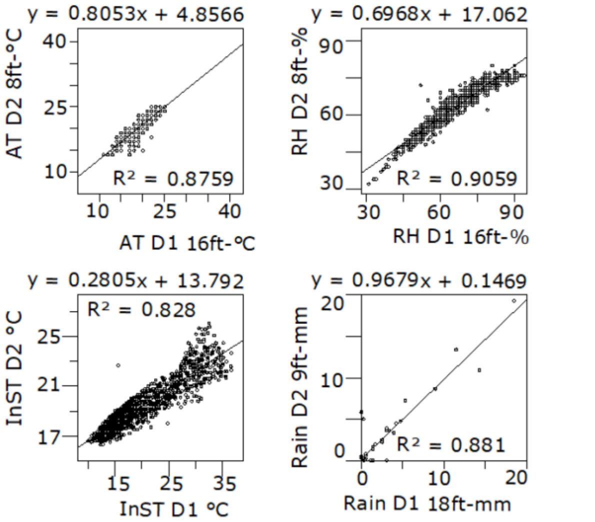

Figure 15. *Relationship between variables measured with sensors: DHT11 (AT, air temperature), BGT SEC Z2 (InST, in soil temperature), DHT11 (RH, relative humidity), and WH-SP-RG (Rain, rainfall), from devices D1 (pot) and D2 (direct soil) at different heights under outdoor conditions.*

4. Discussion

The temperature sensors used in this research have shown good accuracy in previously conducted studies. Inayah *et al.* [12], used the MLX90614 sensor and found differences ranging from 0 to 0.2 ℃ compared with a commercial thermometer. The DS18B20 sensor, which has an accuracy of ±0.5 ℃, will be more stable than the mercury thermometer according to Mahardika and Gunawan's research [13].

Taking the above as a reference point, it coincides with what was found in this research. When comparing the temperature of the MLX90614 sensor with the DS18B20 under indoor conditions at the same height, there was a minimum difference between them with R^2 value greater than 0.98 (Figure 13). In addition, the hypothesis test (β_1 = 1.03) was carried out on the slope using the methodology of Infante-Gil and Zarate-Lara [17], obtaining a t_0 value of 1.4 for the AWT-SST line and a t_0 value of 1.94 for the AWT-AST line, indicating that there is no significant difference between the readings ($t_{0.05/2,1170}$=1.984), with a slope of 1.03 (3% difference) using the DS18B20 sensor as a reference.

Ahmad and Rasul [18], by comparing soil temperature with air temperature, found that the R^2 value varies for different seasons. They found that the highest value (0.86) was in the spring season and the lowest value (0.32) was in the winter season. This coincides with this study, where an R^2 value of 0.818 was found (within the range 0.32-0.86), for air temperature compared to soil temperature (AWT-InST) under indoor conditions (Figure 13).

On the other hand, under outdoor conditions, it was checked whether the sensors could detect variations between the variables. For the DHT11 sensor, precision values of 99.93% and 99.95% were found for measuring temperature and humidity in previous research [11]. Due to their precision, these DHT11 sensor values were considered as observed. Aflaki *et al*. [19], in their study, found that the air temperature on higher floors is cooler than on lower floors. Under outdoor conditions, the devices were installed between two two-level buildings. Therefore, this result coincides with this research, since at higher altitudes, the temperature decreases. The average air temperatures of the sensors for the entire measured period were estimated at 8ft (19.93 ℃), 13 ft (18.96 ℃) and, 16ft (17.60 ℃). Additionally, the differences are clearly visible in Figure 14. The R^2 values (0.9234, 0.884 and 0.9759) indicate that for each unit one variable advances, the other variable does not advance by the same unit.

The temperature and relative humidity in Figures 9 and 11, respectively, indicate that as one variable increases, the other decreases. Therefore, by increasing the height, the relative humidity is expected to increase. This was confirmed by finding the average relative humidity during the period measured at 8ft (64.28%) and 16ft (67.76%). This result coincides with the research of Samad *et al*. [20], who found the same behavior of temperature and relative humidity when plotting it hourly in the period from Oct 31 to Nov 21.

On the other hand, soil temperature (SST) and air temperature (AST) at 1 in above the soil surface have a large spread above 25 ℃ (Figure 14). This is because in direct soil conditions, the shadow of the two-story building fell directly on the sensor of the D1 device. On the other hand, the sensor placed in the pot (D2) received sunlight all day. This is also reflected in the internal soil temperature (InST) in Figure 14, where a temperature difference is clearly seen.

Regarding rainfall, the WH-SP-RG rain gauge sensor has already been used in research [14]. In Figure 14 it is noted that both rain gauges detected similar amounts of rainfall (3.4% difference), because the total was 116.79mm for device D1 and 120.98mm for device D2 (spaced 20 ft horizontally and 9 ft vertically). This indicates that there is variation in the measurement and coincides with what was found by Fathizadeh *et al*. [4], who studied the spatial variability of throughfall and its implications for sampling during the leafless period of oak trees.

Finally, the device was working correctly during the analyzed period (2 months). This also coincides with the system of Payero *et al*. [3], which was successfully tested in the field for more than two months. Zhu *et al*. [2], and Bitella *et al*. [21], also used Arduino in their research finding favorable results in their study.

5. Conclusions

The device made with the Arduino board performed adequately during months of testing under indoor and outdoor conditions, measuring variables and controlling a device (more than 92 events). The developed device requires more lines of code (59.65%) to establish user-device interaction compared to its internal processes (18.66%) and variable declarations (21.68%).

With respect to the measured variables, it was found that the average air temperature decreased by 2.33℃ when increasing the height from 8ft (19.93℃) to 16ft (17.60℃) during the period from July 22 to August 18. The relative humidity decreased on average 3.48% as the height increased from 8ft (64.28%) to 16ft (67.76%). The rainfall measured by the two different rain gauges varied by 3.4%.

Additionally a difference of 3% was found between the DS18B20 and MLX90614 sensors, with respect to their measurements under the same indoor conditions.

Abbreviations

SD	Secure Digital
TTL	Transistor-Transistor Logic
TFT	Touch Screen (Thin-Film Transistor)
IDE	Integrated Development Environment
DS1302	Real Time Clock Sensor
RTC	Real Time Clock
MLMSD	SD Module
DS18B20	Sensor for Measuring Air Temperature
HMZ	HMZ333A1 Sensor
HMZ333A1	Sensor for Measuring Relative Humidity
WH-SP-RG	Sensor for Measuring Rainfall
MLX90614	Sensor for Measuring Air and Object Temperature
DHT11	Sensor for Measuring Air Temperature and Relative Humidity
BGT-SEC Z2	Sensor for Measuring Soil Moisture, Soil Temperature and Electrical Conductivity
ADI	Analog Devices Inc.
ASCII	American Standard Code for Information Interchange
RHA	Rainwater Harvesting Prototype
AST	Air Soil Temperature Measured with the MLX90614 Sensor
SST	Soil Surface Temperature Measured with the MLX90614 Sensor
InST	Inside Soil Temperature Measured with the BGT-SEC Z2 Sensor
AWT	Air Temperature Measured with the DS18B20 Sensor
AT	Air Temperature Measured with the DHT11 Sensor.
RH	Relative Himidity Measured with the DHT11 Sensor.
SM IO	Integer Output Values of Soil Moisture
SM	Soil Moisture
D1	Device 1 of the Prototype Measuring variables in a Pot
D2	Device 2 of the Prototype Measuring Variables in Direct Soil

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Author Contributions

Abel Quevedo-Nolasco: Conceptualization, Supervision, Methodology.

Graciano-Javier Aguado-Rodriguez: Data curation, Investigation, Writing – review & editing.

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Abel Quevedo-Nolasco is an Agronomist, Specialist in irrigation (1988), graduated from the Autonomous University of Chapingo. Master of Science in Agrometeorology (1994) with honorable mention, and Doctor of Science in Edaphology (2005), by the Postgraduate College. He made update curses at the University of Tottori, Japan and the United States Forest Service. He has participated in the training of undergraduate, master's and doctoral students. He has been a professor of the Bachelor's degree in Hydrology at the Metropolitan Autonomous University - UAM. He is currently a Research Professor of the Postgraduate Program in Hydrosciences, has published scientific articles, co- authored two books, co-translator and compiler. He is a Member of the National System of Researchers (Level 1: 2015-2018, 2021-2025). Coordinator of the first meeting on "Innovation in Water, Agriculture and Environment (2013)". He was Coordinator of the Postgraduate Program in Hydrosciences (2015-2016).

Graciano-Javier Aguado-Rodriguez is an Irrigation Engineer from the Autonomous University of Chapingo and Doctor of Science in Hydrosciences from the Postgraduate College. He has an honorable mention in his undergraduate thesis and congratulations for his academic career in his doctoral thesis. He has worked at the Polytechnic University of Francisco I. Madero for eight years, teaching subjects in Agrotechnology Engineering and in the Master of Science in Sustainable Agrotechnological Development. He is a Member of the National System of Researchers (Level 1: 2021-2024). He has conducted irrigation research primarily designing prototypes that control irrigation systems. In addition, he has worked with image analysis to detect problems due to diseases in fruits.

Research Fields

Abel Quevedo-Nolasco: Agrometeorology, Agroclimatology, Irrigation, Software Design, Hydrology.
Graciano-Javier Aguado-Rodriguez: Irrigation, Software Design, Water Balance in Plants, 3D Printing, Sensor Reading.