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Smart Agriculture: IoT-based Greenhouse Monitoring System

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Abstract

The term "smart agriculture" refers to a management concept that is centered on industrial agriculture. It makes use of cutting-edge technologies such as big data, cloud, and the Internet of Things to monitor, automate, and evaluate agricultural operations. Smart agriculture is a management concept. Software and sensors are used in smart agriculture, also known as precision agriculture. Smart agriculture is managed by the software. This pa-per proposes the development of low-cost environment parameters and electrical quantities monitoring device. According to the findings, such Internet of Things devices are suited for digitizing the relevant data in order to ac-quire information that may help farmers make optimal changes.

Keywords: Digitization, Smart Agriculture, Wireless Sensors Network, Internet of Things.

1 Introduction

Currently, technology is pervasive and is mostly used to decrease or optimize human work. In order to boost the quality and quantity of crops, technology is making its way into agriculture. The majority of farmers are still unfamiliar with the phrase smart agriculture [1], which refers to the use of technology such as the Internet of Things (IoT), wireless sensors network, positioning systems, and Artificial Intelligence (AI) on farms [2]. Examples of such technologies utilized on farms include precision irrigation [3] and exact plant nutrition [4], climate management and control in greenhouses [5][6]. All of them functioning in tandem with specialized soft-ware to oversee and regulate a farm or greenhouse in order to maximize its yield.

Agriculture is the cornerstone of human civilization due to the fact that it is the primary source of food and has a considerable influence on the economy. Farmers still use the same methods they've been using for generations, which results in a lower crop yield. Implementation of modern science and technology is required in order to enhance the productivity of agricultural practices. We can anticipate that IoT will boost productivity in agricultural areas at a price that is reasonable if it is used to monitor the effectiveness of the soil, the temperature and humidity, the amount of precipitation, the effectiveness of the fertilizer, monitor the capacity of water tanks, and detect theft. Combining time-honored agricultural methods with forward-thinking technologies like the Internet of Things and wireless sensor net-works is one way to bring agriculture into the modern era. The wireless sensor net-work that compiles data from a wide variety of sensors and sends it to the primary server using some sort of wireless protocol. There are a number of additional factors that have a substantial influence on productivity. During the growth of the crop, it is subject to attack from a variety of wild animals and birds, as well as insects and other pests that can be managed with the application of the appropriate insecticides and pesticides. The unpredictability of monsoon rainfall is causing a decline in crop output, which, combined with a lack of available water and excessive consumption, presents a risk.

As a result of the inclusion of information and communication technologies in order to get ready for the next era of agriculture, the agricultural industry is currently going through a fourth revolution that has been given the moniker of "Farming 4.0." [7]. In recent years, various combinations of new technologies in smart agriculture, such as UAV technology [8][9], WSN [10] [11], AI [12], big data [13], data analytics [14][15] and IoT [16][17][18][19], have been the subject of intensive research and investigation.

There has been a proliferation of smart agriculture-based studies, projects, and books in recent years, which has led to the spread of information. Even though there have been a few publications on IoT-based smart agriculture [20][21][22], the primary focus of those publications has been on the development and application of IoT in agriculture, as well as the IoT platform and architecture. Connectivity technologies that are based on the Internet of Things play an important part in the agricultural sector both now and in the future.

A smart greenhouse is a concept that assists in guiding the steps required to modify and reorient agricultural systems in order to successfully support their growth and assure food security in a changing climate [23][24]. A smart greenhouse is a method that assists in guiding the activities that must be made in order to alter and sustain the environment. The policy attempts to achieve three key goals: a sustainable in-crease in agricultural production; building resilience to climate change; and decreasing and eliminating greenhouse gas emissions wherever possible [25]. One of the most significant areas for the World Food Organization's strategic goals of improving resource mobilization and crop output is the smart greenhouse. It is aligned with the Food and Agriculture Organization (FAO) food vision and contributes to the organization's goal of making agriculture more productive and sustainable [26]. The Internet of Things is becoming increasingly popular as a means to connect various devices and collect data. IoT is utilized together with its frameworks to handle and interact with data and information. Within the system, users have the ability to register sensors, generate data streams, and process data. Applications in agriculture are another area where the Internet of Things can be useful. The Internet of Things has a wide variety of applications, some of which are listed below: smart cities, smart environments, smart water, smart metering, security and emergency response, industrial control, smart agriculture, home automation, and e-health. One of the most important technologies that goes into intelligent agriculture is the IoT. Connecting two or more devices to one another through the use of the Internet is the process known as "tethering." These gadgets include cellular phones, appliances for the home, as well as machinery used in industry and agriculture. They are operable and controllable due to the fact that data may be sent to them through the Internet and received from them at the same time [27]. One of the most important uses of the Internet of Things nowadays is in the field of intelligent agriculture. IoT agriculture systems are applied in a variety of spheres, including irrigation management, soil management, precision agriculture, and intelligent farming. Agriculture may be made more productive and have a more intelligent cropping system through the use of precision agriculture and smart farming techniques. These techniques allow farmers to develop and optimize all possible directions. In the meantime, the monitoring of agricultural pests and diseases has been connected with IoT technology. This has made it possible for farmers to enhance their profitability by safeguarding crops from pest attracts at early prediction stages. The goal is to accurately direct agriculture toward increased production at lower costs and with enhanced quality through the collection and utilization of precise information. For instance, remote sensors that are installed in fields offer farmers with accurate maps of the landscape and the resources available in a region. In addition to this, it is able to predict impending weather patterns by measuring variables such as the temperature and humidity of the soil [28]. Agriculture that is supported by IoT makes it easier to make better judgments on agricultural productivity. In addition, the data that are gathered and processed play

a significant part in the process of monitoring agricultural pests and determining the exact amount of pesticides that are necessary to prevent their improper application. Procedures for collecting and analyzing data that are similarly practical and sensible can be applied to irrigation water.
The monitored parameters of intelligent agricultural systems varied from one study to the next. According to the authors of [29], the majority of the efforts made use of sensors to monitor things like temperature, humidity, soil moisture, and the intensity of the light. The temperature of the soil has a significant influence on the amount of crop output. Alterations in soil temperature have a direct influence on the amount of moisture in the soil as well as the uptake of nutrients. In addition, the temperature of the air that has been measured can be exploited as a tool for monitoring the conditions of crops grown in open fields and greenhouses. The relative humidity level can be detected and measured with the assistance of the air humidity sensor, the soil humidity sensor, and the relative humidity sensor. Plant leaf growth, pollination, and photosynthesis are all influenced in various ways, both directly and indirectly, by humidity. Concerning soil moisture, it is utilized in the process of determining the water content and quality of the soil. The resistance of the soil moisture sensor is inversely proportional to the amount of moisture that is present in the soil, which is the key factor that influences the rate at which plants grow. The amount of moisture that is present in the ground is factored into the process of maintaining the water supply and any other suitable automated procedures over the entire field. The amount of light has a direct impact on the process of photosynthesis, which in turn has an effect on the growth of crops. In addition, pH is necessary for irrigation, which is used to determine the precise nutrient content of the soil. In addition, the velocity of the wind and the amount of precipitation are frequently used as factors in the regulation of water flow and the forecasting of the possibility of precipitation.
IoT-based agricultural systems are still subject to challenges and limitations, despite the fact that IoT devices provide beneficial information on a wide range of physical elements that can improve cultivation techniques and crop productivity in an agricultural environment. The following is a list of the key challenges associated with the implementation of smart agriculture applications, as seen by the authors of [29]. The challenges are arranged into groups according to the characteristics they present, as seen in Figure 1.

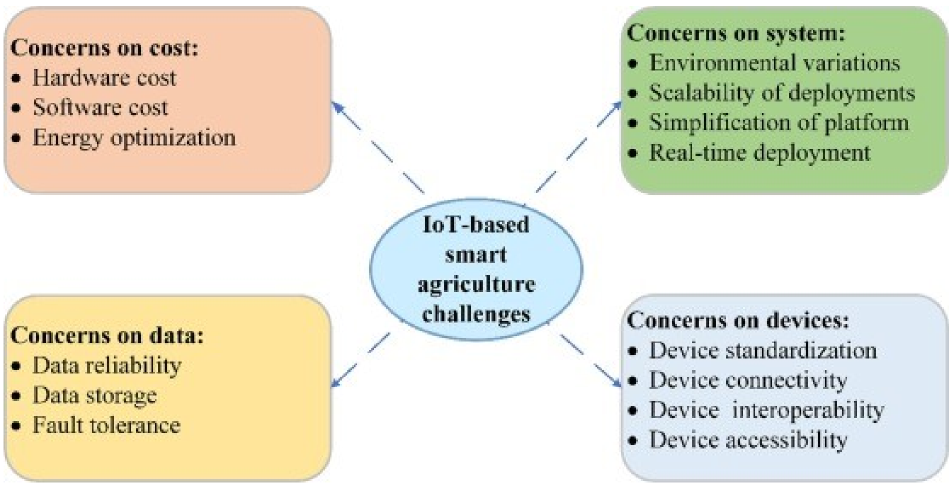


Figure 1: Categories of challenges in smart agriculture applications based on IoT.

Concerns in this field are growing, a series of recent papers addressed the deployment of modern information and communication technologies in agriculture, for example [31][32][33].
Our research collective has been dealing with this problem for some time, our concerns being more and more directed towards small farmers, basically in the western part of Romania [34][35].
This paper contributes to creating smart greenhouses developing a multisensorial, low-cost, monitoring IoT solution. With the help of this solution, we are able to monitor certain environmental parameters, which allows us to improve the climate within the greenhouses. In addition, we are able to monitor the electrical energy consumption of the equipment that serves the greenhouse, which allows us to reduce the amount of electrical energy used by the greenhouse.

2 Solution Architecture

In this section the general architecture of the greenhouse monitoring solution is described. Figure 2 shows the general scheme of the developed infrastructure. The goal is to digitize as much data as possible (environment and electrical energy consumption), to offer the possibility to be analyzed, in order to generate optimal solutions in the operation of the greenhouses.

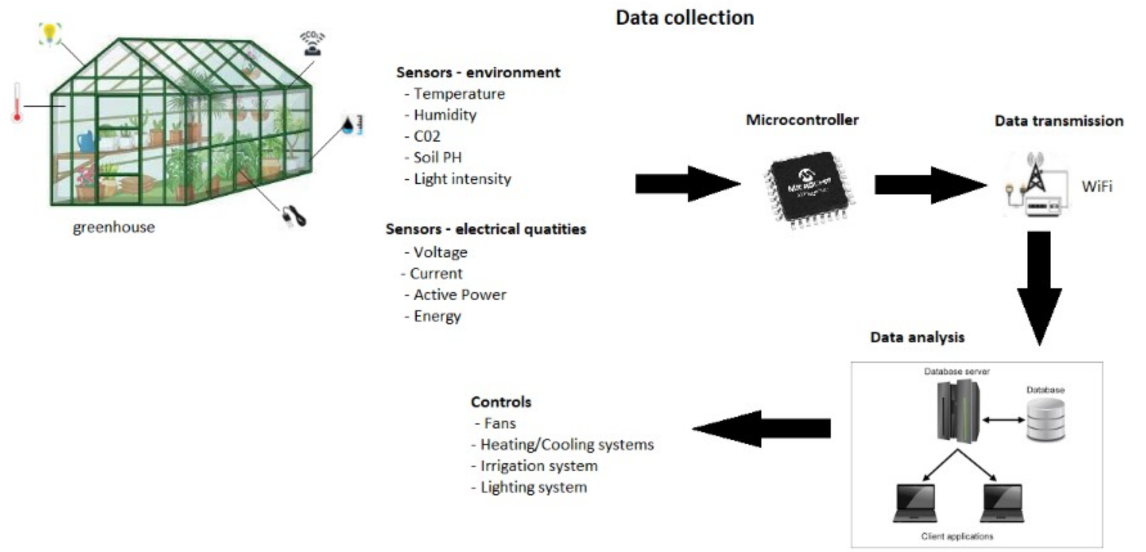


Figure 2: Solution architecture

According to the illustration, the data of interest will be gathered through the use of the sensors, and a microcontroller will retrieve and pre-process them before pack-aging them, with a package containing the recorded data being created every 15 minutes (the data transmission interval can be set from 1 second to 1 hour via the embedded software). After the data have been packed using the WiFi transmission mode, they are then transferred to a data server where they are saved in the influxDB database. The application that shows the data will subsequently collect the data from the database and display it.

2.1 Network Deployment

A secure WiFi network has been developed, including the different routers required to send the received data to a server through the network. This technology was chosen because the greenhouses in the case study where the solution was tested in real conditions are close to each other and it did not make sense to use technologies for long-distance data transmissions, such as LoRa, for example. Wi-Fi is a wireless networking technology that enables devices such as computers (laptops and desktops), mobile devices (smartphones and wearables), and other equipment to connect to the Internet (printers and video cameras). It makes it possible for all of these devices and many more to communicate data, which ultimately results in the formation of a network. The connection to the Internet is made through the use of a wireless router. When you join to a Wi-Fi network, you establish a connection to a wireless router. This establishes a connection between your Wi-Fi-enabled devices and the Internet. 5 WiFi routers provide coverage of the region of interest. These routers provides bidirectional communication between the devices connected to the network and the server, which is connected to the gateway through an Ethernet connection.

3 Design of the Monitoring Devices

This section presents the multisensory device for monitoring the environment in-side the greenhouse, respectively for monitoring the electricity consumption of the equipment that ensures the proper functioning of the greenhouse. It is important to mention the fact that these devices are prototypes, tested in laboratory conditions and later put into operation in a case study to test them in real conditions.
The main goal is to create this solution at a lower price than commercial devices, in order to provide for small farmers access to technologies that can improve their activities.

3.1 Greenhouse environment monitoring device

The purpose of this device is to provide data in real time but at the same time to generate data history, which will help farmers to take the best decisions regarding the development of plants in greenhouses at the optimal time. This device monitors the following parameters:

- Temperature;
- Humidity;
- CO_2;
- Light intensity;
- pH.

The hardware components used to build the prototype of the environmental parameters monitoring device are the following:

1. CCS811 Air Quality Gas Sensor Module (Fig. 3d) - is a digital gas sensor that can detect a broad spectrum of Total Volatile Organic Compounds (TVOCs), in addition to measuring levels of equivalent carbon dioxide (eCO_2) and metal oxide (MOX). The sensor is useful for monitoring the quality of the air inside buildings. A microcontroller unit (MCU) that possesses both an analog-to-digital converter (ADC) and an I2C interface is required in order to make use of this system.

2. SHT31 Humidity Temperature Sensor (Fig. 3c) - The SHT31 is the next generation of temperature and humidity sensors that Sensirion has developed. When compared to its predecessor, the SHT31 has improved specifications in terms of its intelligence, reliability, and accuracy. It is possible to read out the temperature and humidity using I2C communications, which is part of its functionality, which also includes improved signal processing. Has the following characteristics:
   - Dual Purpose Temperature and Humidity Sensor
   - Accuracy of ±2% Relative Humidity
   - 0-100% Humidity Sensing Range
   - -40 to +125°C (-40 to +257°F) Operating Temperature
   - 8-Second Sensor Response Time

3. BH1750 Ambient Light Sensor (Fig. 3b) - is a digital Ambient Light Sensor IC that uses the I2C bus for its interface. This sensor is capable of providing precise readings of the LUX value of light up to 65535. It detects light with the help of a photodiode and uses up very little electrical energy in the process. The BH1750 needs a supply voltage that ranges from 2.4V to 3.6V. In

order to function, the BH1750FVI, which is the core module of the sensor, needs 3.3V. One of the components of the circuit is a voltage regulator. I2C communication requires the SDA and SCL pins to be utilized, together with the I2C address. Pullup resistors of 4.7k ohms are utilized for these pins.

4. Soil pH Sensor (Fig. 3a) - a Soil pH Sensor that is both watertight and dustproof, and that has the capability of measuring the pH value of the soil anywhere from 3 to 9 with an accuracy of up to 0.3 pH. The sensor includes a protective cover that has an IP68 rating and is sealed with high-density epoxy resin, both of which work together to prevent moisture from penetrating the inside of the body. The sensor may be used in a variety of settings, including agricultural cultivation and production, industrial production and monitoring of the environment, animal husbandry and treatment of sewage.

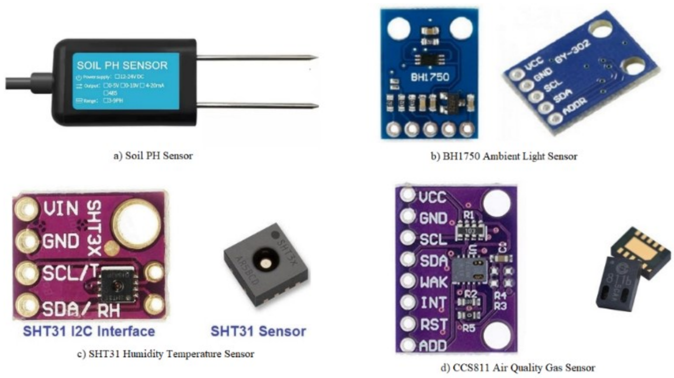


Figure 3: Sensors – environment monitoring device

The information collected by these sensors is sent to a development board which is controlled by an ATmega328P microcontroller. After the data have been processed, the package containing the measurements will be transferred with the assistance of an ESP8266. The components are shielded from harm by an ABS housing (Fig. 4), which features all of the appropriate cutouts for the sensors. This was done in order to achieve the best possible outcomes.

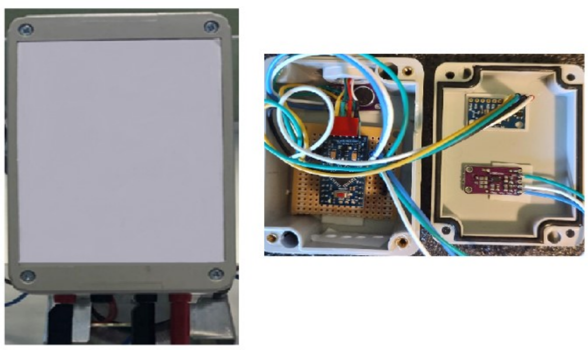


Figure 4: Environment monitoring device – prototype

It is the responsibility of the embedded software to collect data from sensors, package the data, and send it to the data server, from where data is retrieved and displayed for viewing and analysis.

3.2 Electrical energy monitoring device

The purpose of this device is to generate a database regarding the electrical energy consumption, which will allow farmers to improve the electrical energy consumption of greenhouses, of course correlating these data with those monitored by the environmental device. This device monitors the following parameters:

- Electrical voltage;
- Electrical current;
- Electrical active power;
- Electrical energy.

The hardware components used to build the prototype of the electrical quantities monitoring device are the following:

1. ZMPT101B AC Voltage Sensor Module – is based on a voltage transformer with a high level of accuracy called a ZMPT101B, and it is used to measure the AC voltage accurately using a voltage transformer. When using Arduino or ESP32 to detect alternating current voltage, this is an excellent alternative. The Modules are able to monitor voltage up to a maximum of 250V AC, and the analog output that corresponds to this measurement may be changed. The module is easy to use and is equipped with a trim potentiometer that has many turns, which may be used to tune and calibrate the ADC output.

2. SCT-013-030 Non-invasive AC Current Sensor – is a Non-invasive AC Current Sensor Split Core Type Clamp Meter Sensor that has the capacity to measure AC current of up to 100 amperes and does so without causing any damage to the circuit. Current transformers, often known as CTs, are a kind of sensor used to measure alternating current. They are very helpful for assessing the total power usage of a whole building. There is no need to do any high voltage electrical work in order to attach the SCT-013 current sensors since they can be hooked right into either the live or neutral wire. Has the following characteristics:

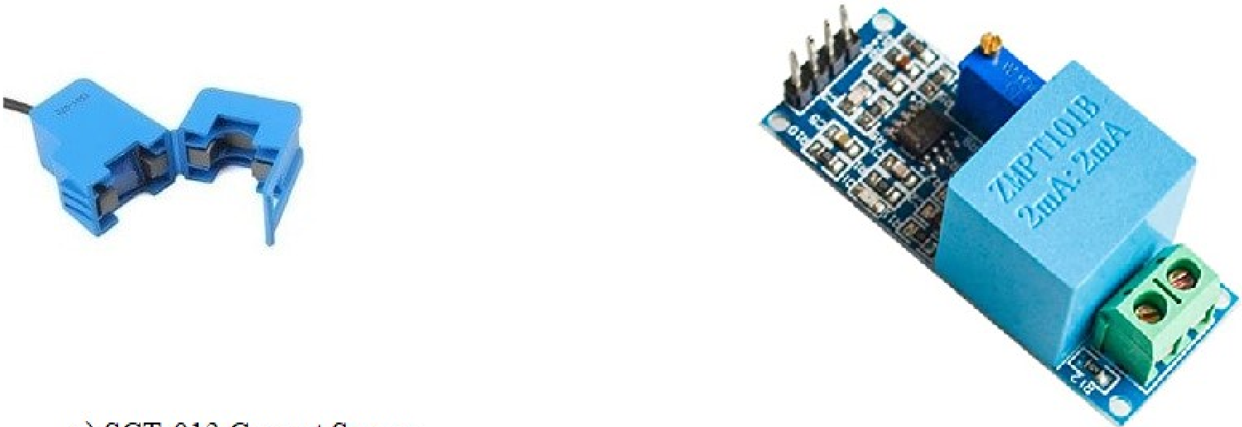
   - Input Current: 0-30A AC
   - Output Signal: DC 0-1 V
   - Non-linearity: 2-3
   - Build-in sampling resistance (RL): 62 Ohm
   - Turn Ratio: 1800:1
   - Resistance Grade: Grade B
   - Work Temperature: -25 °C +70 °C
   - Dielectric Strength (between shell and output): 1000 V AC / 1 min 5 mA

Similar to the environment monitoring device, this device also is based on a development board that contains an ATmega328P microcontroller. The Atmega328P microcontroller is responsible for taking the data from the sensors and processing them. After this, the data are sent to an ESP8266, which is the module that is responsible for transmitting them to a data server so that they can be analyzed.

It is the responsibility of the embedded software to collect data from sensors, package the data, and send it to the data server, from where data is retrieved and displayed for viewing and analysis.

4 Results

The multisensorial solution was tested and calibrated in laboratory conditions. After performing the calibrations, the solution was put into operation in real conditions, at a company in Romania, Timis county. Figure 7 shows the greenhouses where the measurements were made, the equipment's



a) SCT-013 Current Sensor

b) ZMPT101B AC Single Phase Voltage Sensor

Figure 5: Sensors – electrical quantities monitoring device

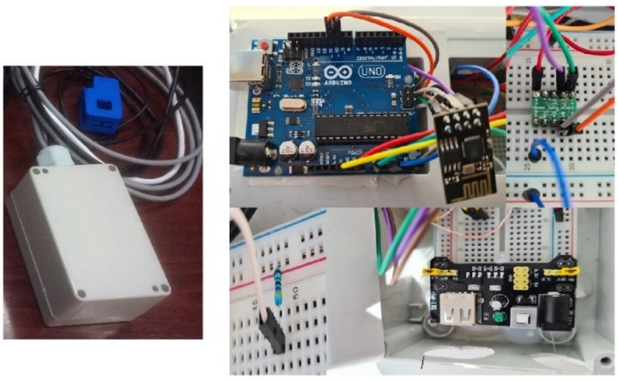


Figure 6: Electrical quantities monitoring device

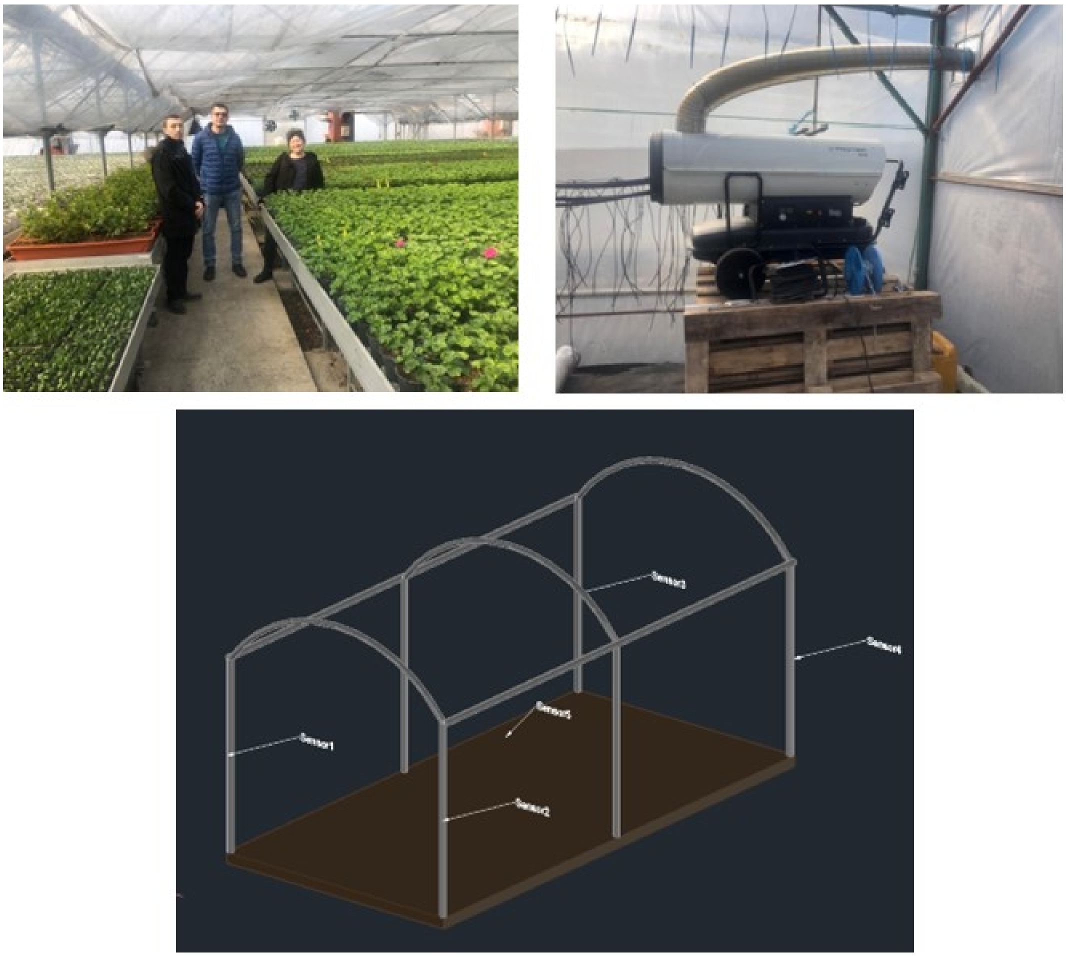


Figure 7: Greenhouse monitoring – case study

that serves these greenhouses, respectively the 3D diagram showing where the sensors were placed.

Our goal was the development of a multisensorial monitoring solution that would respond to the needs of small farmers, in the direction of the digitization of data from everything that means greenhouses in their farms, in order to optimize efforts, both from the point of view of production and from the point of view of electrical energy consumption. The results obtained are satisfactory, the devices work in the direction in which they were created, they provide the necessary data for further actions. The monitoring of electrical energy consumption was done in a single green-house, in March 2022. The main electricity consumers can be found in Table 1, and the measurements can be seen in figures 8-11.

No.	Components	Quantity
1.	Developing board with ATmega328P	1
2.	ESP8266	1
3.	Soil pH Sensor	1
4.	BH1750 Ambient Light Sensor	1

Table 1: Large consumers of electrical energy in case study greenhouses

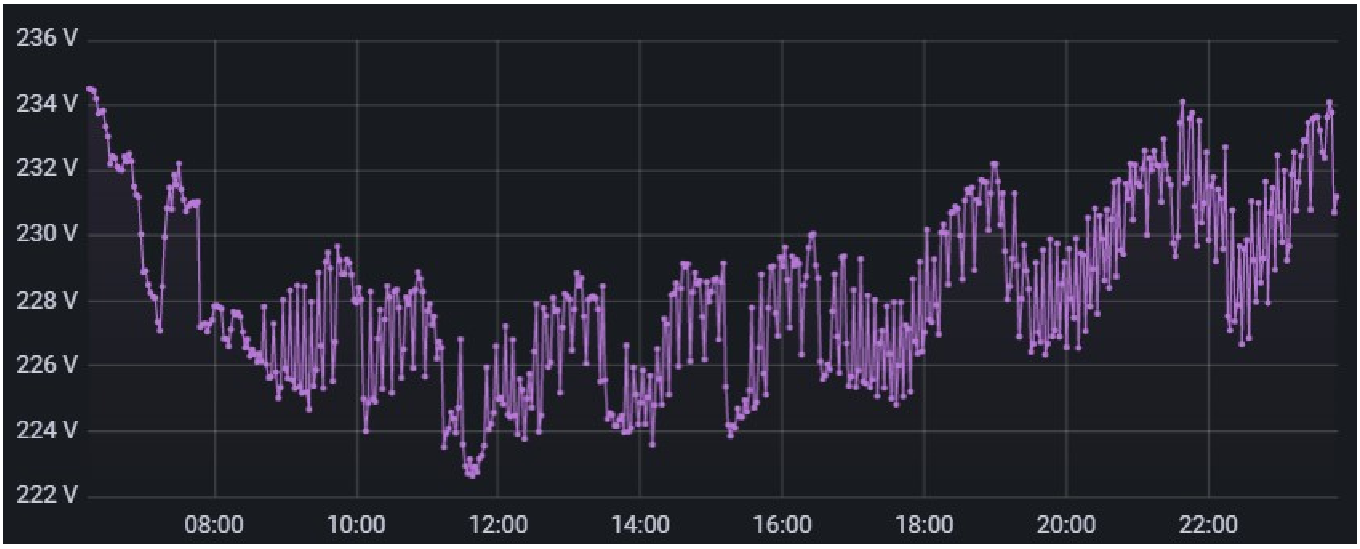


Figure 8: Electrical voltage

The data collected by environmental sensors for the same period of the year (March 2022) can be seen on figures 12-15.

The pH of the soil, according to the measurements of CO_2 concentration in air (fig. 12), is within the range 6.8-5.4, on the graph it can be seen that on March 13, there was an intervention on the pH with special solutions, in order to reduce its value. The graphs show that the temperature is at its lowest in the morning, but that it has the potential to rise throughout the course of the day. As the temperature increases, the humidity level declines, and fans are only needed in the morning and at night to circulate the air that has been heated. By spraying the flowers, the relative humidity is maintained at a level of between 60 and 70 percent. As the measurements show over a period of four days, the temperatures fits between 18-25 degrees Celsius, and as for the humidity values, these are in the range of 52-75% (fig. 13). The CO_2 con-centration is within the range 800-1400 ppm, as the measurements show (fig. 14).
The questions that need to be answered are about the price of these devices and whether or not they are worth the investment for farmers. If we focus simply on the worth of the individual parts (Table 2 and Table 3), we can see that the whole in-vestment is not that significant but still yields favorable outcomes.

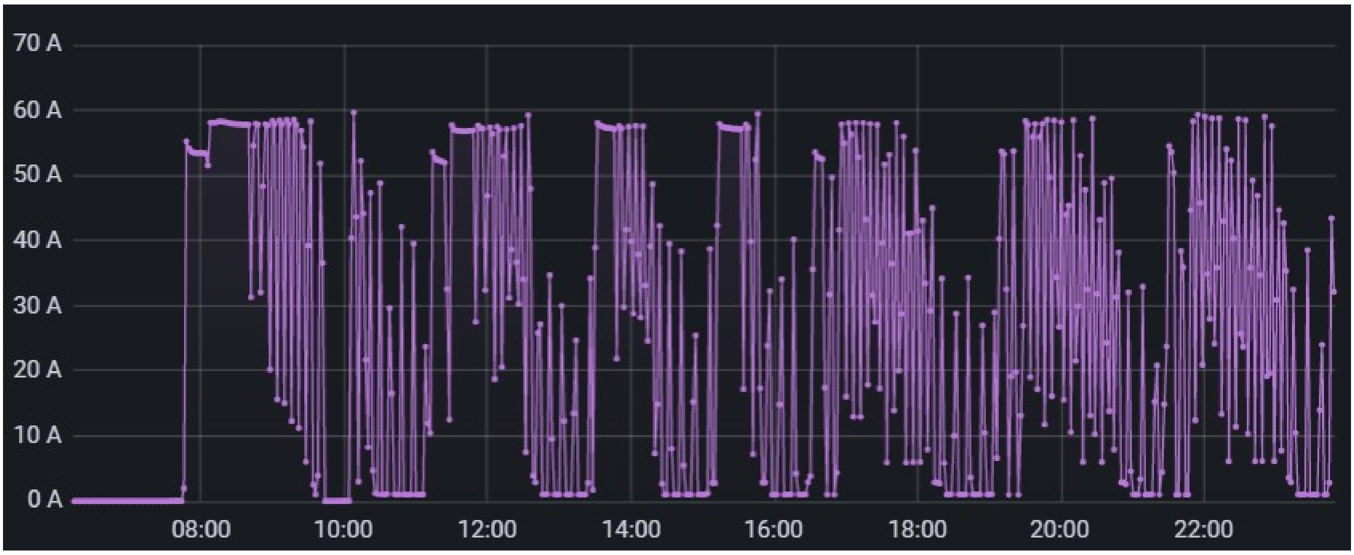


Figure 9: Electrical current

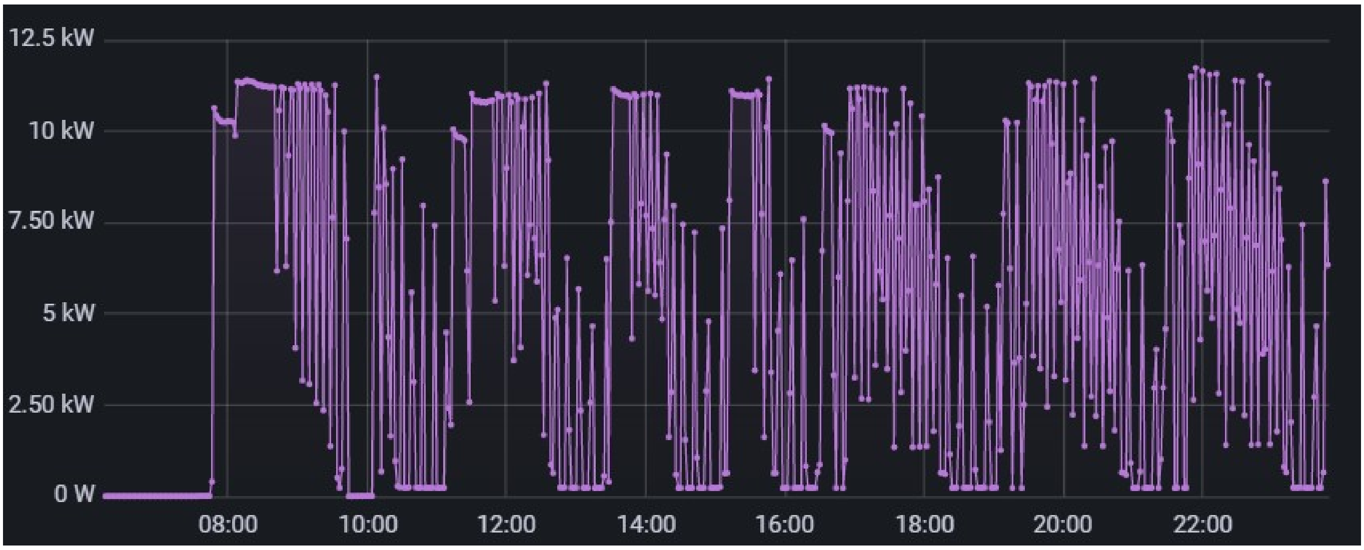


Figure 10: Electrical active power

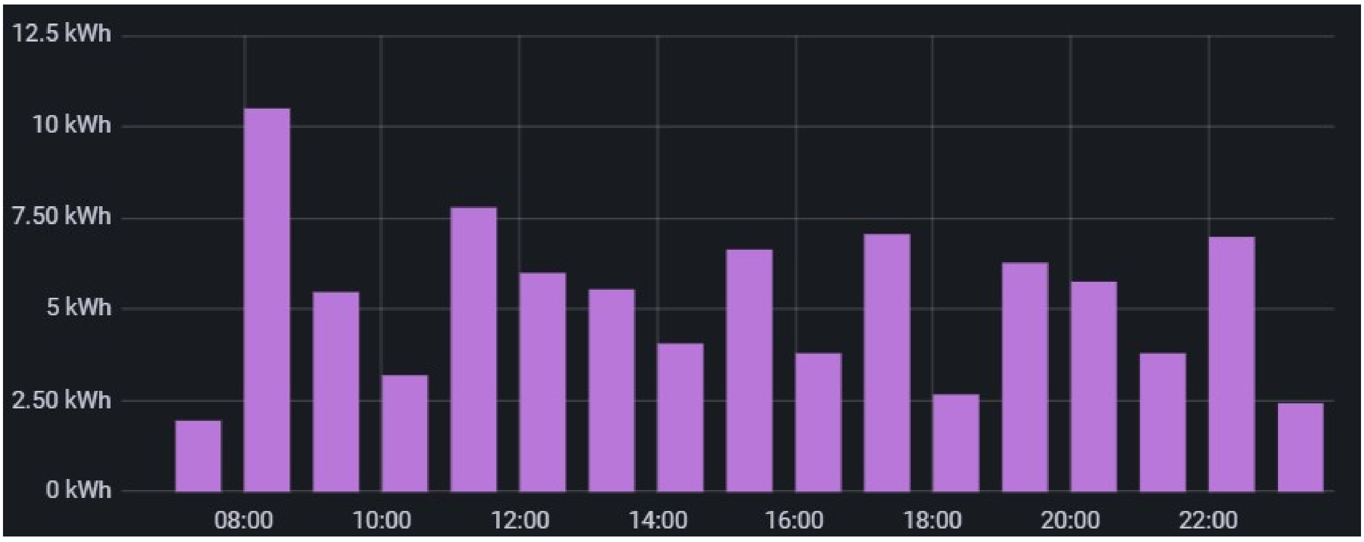


Figure 11: Electrical energy consumption

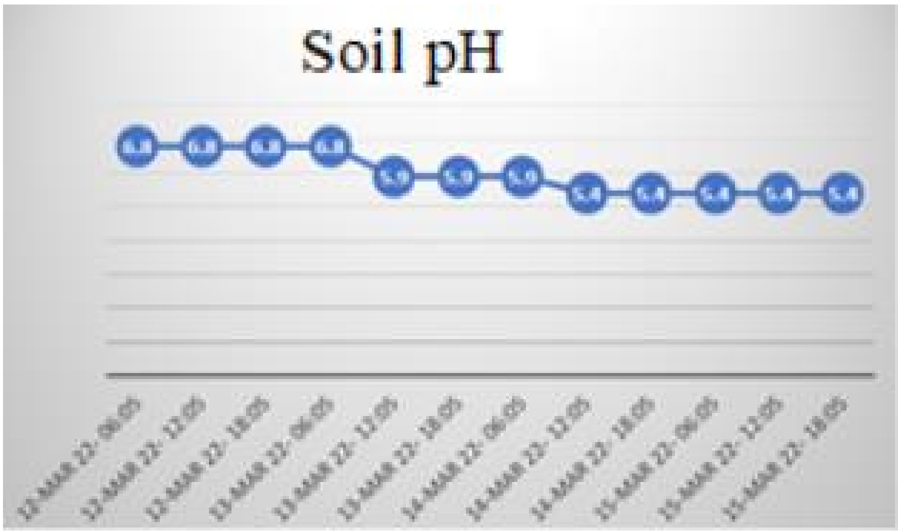


Figure 12: Soil pH measurements

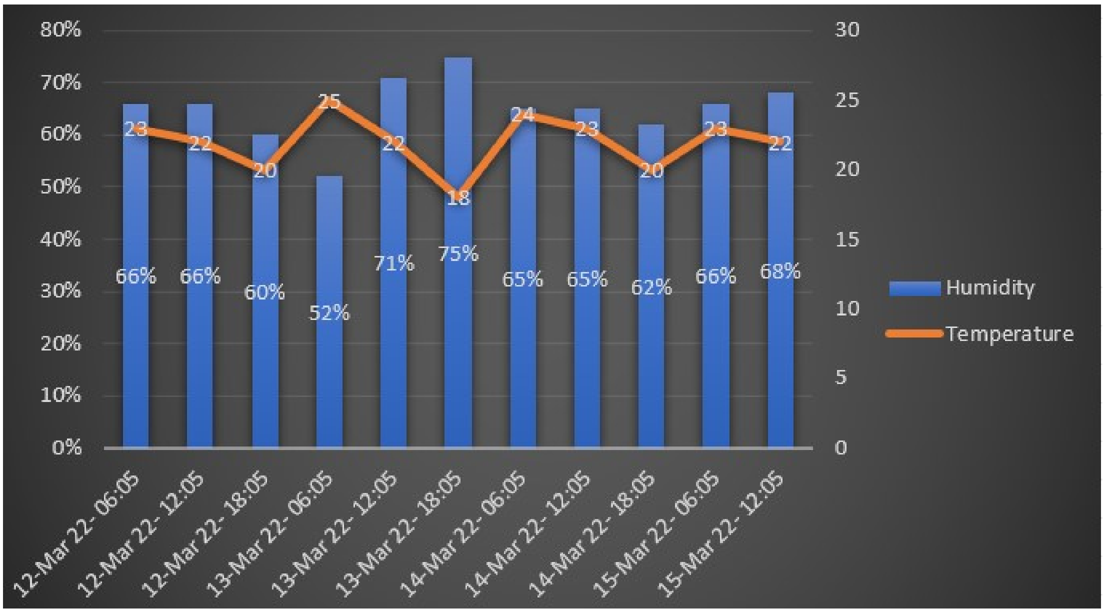


Figure 13: Humidity and temperature measurements

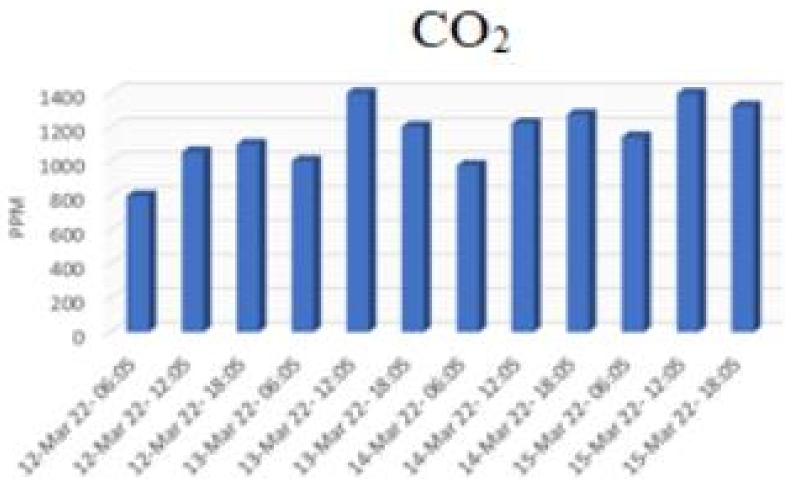


Figure 14: CO_2 concentration measurements

No.	Components	Quantity
1.	Developing board with ATmega328P	1
2.	ESP8266	1
3.	ZMPT101B AC Voltage Sensor Module	1
4.	SCT-013-030 Non-invasive AC Current Sensor	1
5.	Power supply	1
6.	Bidirectional BUS Logic converter	1
7.	Resistor 10K	2
8.	Resistor 100ohm	1
9.	Capacitor 10uF	1
10.	Connecting Wires	22
11.	Breadboard	1
	Total	147 €

Table 2: Electrical quantities monitoring device components and device final price

No.	Components	Quantity
1.	Developing board with ATmega328P	1
2.	ESP8266	1
3.	Soil pH Sensor	1
4.	BH1750 Ambient Light Sensor	1
5.	SHT31 Humidity Temperature Sensor	1
6.	CCS811 Air Quality Gas Sensor	1
7.	Connecting Wires	16
8.	Breadboard	1
	Total	178 €

Table 3: Environment parameters monitoring device components and device final price

As the results show, the data recorded by the devices are fine for extensive analysis and to make optimizations and improvements in the processes; and regarding the price of the devices, we believe that it is an affordable price for smaller farmers as well.

5 Conclusions

IoT is a revolutionary technical development that has energized business. It paves the way for brand new chances and challenges across a variety of economic domains. The Internet of Things is an exciting new technology that enables the growing of plants in greenhouses to access many new opportunities.

IoT makes it easier to transition from traditional greenhouses to smart solutions, such as an intelligent greenhouse that is equipped to track indoor factors and connect with the farmer. This allows the farmer to make decisions that automatically protect crops and increase production. IoT for smart greenhouses consists of a wide variety of devices, each of which is outfitted with sensors and actuators. These devices are connected to one another and communicate with one another over the internet, which results in increased osmosis between the digital and physical worlds. In the Internet of Things, sensors and actuators are fundamental components that monitor the system's state as well as environmental conditions. This includes obtaining data on temperature, humidity, CO_2, pH, water and energy consumption, movement, position, and other aspects, as well as managing the system's dynamics.

In addition, the capability to control the aforementioned indoor values within set reference ranges

allows for a reduction in the use of pesticides to protect crops from the most prevalent diseases. The ability to monitor and control optimal crop conditions in a protected environment helps to reduce crop damage that is caused by climate change or any other weather condition. It also enables the farmer to intervene by irrigating, heating, and fertilizing only to the extent that is necessary to achieve the pre-established objectives, which helps to effectively avoid waste and implement approaches that save water and energy.
The goal of the work is to determine whether or not it is possible to create green-house environment and energy consumption monitoring devices for small farmers. These devices would provide a means by which data could be digitized and collected with the intention of increasing production while simultaneously decreasing the amount of electrical energy consumed. The results show that such devices can be developed, at a low cost and with good results regarding the digitization of the data of interest.

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Author contributions

The authors contributed equally to this work.

Conflict of interest

The authors declare no conflict of interest.

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