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A Novel Approach for Monitoring of Smart Greenhouse and Flowerpot Parameters and Detection of Plant Growth with Sensors

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Abstract: Studies carried out in different parts of the world and in different climatic conditions have made it clear that it is very important to use smart technologies in solving the problems experienced in the field of agriculture globally and locally. Another important aim of the studies is to ensure that agricultural products are grown in smart greenhouse environments outside of arable lands. For this reason, growing agricultural products in greenhouses controlled by smart systems by creating suitable soil and climatic conditions and facilitating people's access to these products has been an important research and application subject. In this paper, the topics of "Smart Agriculture" and "Smart Greenhouse" were worked on. Therefore, a prototype of a smart greenhouse was constructed. Then, it was programmed according to the decided climatic conditions. Consequently, the main aim of this study was to improve the project according to the collected data by the sensors. One of the most important aims of our study was to question the possibility of growing different plants in the same greenhouse. In this context, in our study, a flower and three different vegetables with close growing conditions were grown in the same greenhouse in the same environment. These plants were grown individually both in the smart greenhouse prototype and in the pots outdoors in a natural environment. The differences between the two environments and the differences in the development of the plants were examined and the necessary results were obtained based on the findings. Based on the results obtained, it has been discussed what can be done if the plants grown in the greenhouse, of which we have created a small-scale prototype, are grown in a large-scale smart greenhouse. According to the results obtained, the smart greenhouse made a positive difference in the development of begonia, tomato and pepper. Although, the cucumbers grew more in the pots. In the study, it was observed that the plants were healthier in the smart greenhouse. The cucumbers in the greenhouse grew to 132 mm, the peppers to 61 mm and the tomatoes to 70 mm. The cucumbers in the pot grew to 163 mm, the peppers to 37 mm and the tomatoes to 60 mm. This shows that the yield was positively affected in the smart greenhouse. According to the collected results, the smart greenhouse system saved approximately 16.5% of water compared to the pot. The fact that the system can work both manually and autonomously provides a great convenience for the person controlling the greenhouse.

Keywords: smart greenhouse; smart agriculture; Arduino; sensor; data; plant; flower

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1. Introduction

Over the years, with the rise of smart technology, the need to reduce water resources' consumption and power consumption has increased, both with reducing human efforts in agriculture. In addition, smart irrigation systems and smart greenhouse studies have accelerated in order to meet the increasing food demands with the effect of population growth and to support farmers in order to grow quality products in economic conditions [1].

In order to cope with the food problems in the world, growing enough vegetables and other crops for all households by using artificial greenhouses has been attempted. In the preliminary examination made in this study, it was determined that a smart greenhouse causes more crops to be grown per square meter than crop cultivation in the fields. It has been determined that the reason for this is the continuous analysis and control of the climatic parameters that determine the crop yield in order to grow crops in the most suitable environment. For this reason, it was stated that it should be possible to control the system remotely [2].

In the study, an IoT-based curtain motion simulation for the smart greenhouse was investigated using fuzzy logic control. It was stated that smart greenhouses contribute to finding suitable conditions for the growth of plants by keeping plants away from difficult conditions; these additives positively increase the crop yield and quality. Accordingly, in the study, the design of the ventilation and shutter control of the greenhouse was presented, and the temperature, humidity and light variables in the greenhouse were controlled by using the Arduino UNO kit microcontroller. The louver movement in the greenhouse design was analyzed using the IoT ThingSpeak platform and intervened on a case-by-case basis [3].

In this study, a smart fuzzy logic-based control system was used to provide climate control in the smart greenhouse. Greenhouse climate control, which is a complex process, has been attempted to be controlled with this method. In the study, special measurements were made in order to adjust the temperature and humidity in the most appropriate way with the created microclimate environment. In this context, the proposed control system has been experimentally verified and the efficiency of the system with energy and water savings has been evaluated. The greenhouse method, which is widely used in Tunisia, was used in the study. The designed greenhouse is equipped with a ventilation system, heaters, humidification system, indoor–outdoor climate sensors and a data collection module in order to provide climate control [4].

Sensors are the vital structures of a monitoring and control system. The efficient monitoring and control of the microclimatic environment in a greenhouse is very important for protecting crops from inconvenient environments. Many sensors and actuators are used to control the system in the large-scale greenhouses. The manual monitoring and control of such big systems are very difficult and impractical. Thus, automatic monitoring and control systems in the greenhouses have become more popular. Additionally, the microclimatic parameters of humidity, temperature and solar irradiance in the greenhouse are non-linearly interlinked. They form a non-linear multivariate system. For this reason, a sensor system is required for monitoring and controlling the greenhouse microclimate. Thus, modern sensor devices and systems are carrying the greenhouse monitoring and control system toward a real-time, intelligent, remotely accessible and fully automatic system [5].

In production farming, productivity and profitability are up to providing perfect and timely decisions based on actual factors and historical data. Precision agriculture is an extensive system; it is designed to optimize agricultural production by making a suitable soil and crop management to correspond to the sole circumstances found in every area while also maintaining the environmental quality. The study explained the improvement of a portable and wireless sensor network system to remotely monitor the environmental parameters in an agriculture area. It ensured that field managers received alerts and information regarding actual circumstances while saving the data in a database [6].

In the study, a new optimization scheme was presented. It aimed to achieve a trade-off between energy consumption and the desired climate setting in a greenhouse, such as the CO2 level, temperature and humidity. For a performance evaluation of the presented system, an ad hoc emulator of the greenhouse environment was developed. For the presented model validation and experimental analysis, 15 days of external environmental data collected in Jeju, South Korea were used. Additionally, the presented optimization scheme results were compared with the results of a baseline scheme [7].

Greenhouse systems are utilized in many different areas:

In Nordic countries, natural daylight is limited. For this reason, artificial lighting is a vital factor in industrial plant production. However, the electricity cost of artificial lights becomes too much and accounts for a large percentage of the whole cost of plant production. The use of artificial lighting in plant production is formulated as a multi-objective problem (MOP); optimal plant growth needs to be achieved while simultaneously decreasing the electricity cost. In the previous study, to solve the MOP, a genetic algorithm (GA) was utilized to create a Pareto frontier (PF). It included solutions representing a trade-off for using artificial lighting against the plant production objectives. In the presented study, an alternative evolution strategy was given and compared with the previous GA evolution strategy [8].

The investment in Penaeus (Litopenaeus) vannamei shrimp production in greenhouses utilizing the biofloc technology (BFT) system has been examined. In the study, along with considering the bioeconomic variables, a sensitivity analysis was conducted with the data gained over ten years to evaluate the program's efficiency. The cost of marine shrimp production in greenhouses by the BFT system is expensive when compared to the traditional systems. Although, there is a rise in the biosecurity, productivity, survival, feed conversion ratio and predictability of the harvest. Thus, the improvement of the cultivation management over the cycles provides a decrease in the costs [9].

Digital twins are novel phases in smart and data-driven greenhouses. A digital twin is a digital equivalent to a real-life object. In a virtual space, it mirrors its behavior and states over the course of its lifetime. Thus, they can improve productivity and sustainability. They can also handle the rising scarcity of green labor in greenhouses. The study proposed the results of a literature review on digital twin applications in greenhouses [10].

In the presented chapter, the opinion of transforming idle urban spaces into multi-functional edible urban landscapes was presented. Additionally, the idea was explored as an instrumental one for the cost-effective adaptation and resilience to climate change in cities and towns in sub-Saharan Africa. A multifunctional edible urban landscape was described here as a managed landscape which combines food production and an ornamental design in harmonious coexistence with many urban structures to promote or ensure targeted green spaces for active living, scenic beauty, environmental protection and climate adaptation [11].

The leaf area index (LAI) is used to represent the crop growth characteristics. It is used to calculate canopy photosynthetic rates, set irrigation standards and predict crop growth. The LAI can be estimated utilizing the light-intensity ratio of the upper and lower crop canopy. Additionally, it is affected by the external weather conditions and solar altitude. The main aim of the paper was to present a method to estimate the LAI of bell peppers by utilizing the light-intensity ratio of the upper and lower crop canopy via the solar altitude and weather conditions. Here, the growth stages and weather conditions with the solar altitude were set utilizing 3D-scanned plant models and ray-tracing simulation [12].

Apart from the introduction, this paper is structured as follows: in the "literature review" section, a detailed literature review is presented. The "materials and method" section includes a case study in Turkey with the system modelling and the research methods. In the "results" section, the collected results are presented. The "comparison of the presented study with similar related works in literature" section presents a comparison of this paper with similar related papers. The "conclusion" section concludes the study and explains future work topics.

In the paper, the growth rates of plants and a flower were monitored and examined. Additionally, in the presented greenhouse, an irrigation system design was constructed and monitored. The collected results of the greenhouse and the pot were compared. This factor showed that the smart greenhouse system has an important role in terms of saving water. It is thought that this saving will increase as the size of the greenhouse and the measurement time increase. Many important parameters (such as humidity, soil moisture, temperature and light) for a greenhouse were considered in the presented system. In addition, the system can work both manually and autonomously, which provides a great convenience for the person controlling the greenhouse. Additionally, the remote access to the greenhouse provided the opportunity to make any intervention by using a remote control. In this way, a manual use of the greenhouse is possible when the system needs to be controlled outside of a certain routine.

In the study, along with presenting the smart greenhouse, it is aimed to provide suitable conditions for plant breeding by keeping plants away from harsh and severe climate conditions; ensuring better climate conditions will improve the crop yield and quality. Although, greenhouse climate control is a complex process because energy and water savings should also be provided. Thus, a climate monitoring system is implemented along with an irrigation control system. In addition, the presented greenhouse is composed of a shutter control system, a ventilation system, a humidification system, indoor/outdoor sensors and a data collection module to provide climate control. These parameters are considered in the study because they have a direct impact on the crop health and productivity. Furthermore, the manager of the greenhouse can change the system parameters by updating the data. An easy-to-use and install system is aimed to be designed for farmers; it is an important factor for most farmers to have a user friendly and easy-to-use system.

2. Literature Review

This literature review part of the paper is based on articles published from 2013 to 2022 in scientific journals, but mostly 2020–2022 is considered.

The utilized technologies and methods effect the cost of a greenhouse system and the collected product rate. Lately, artificial intelligence usage has increased in greenhouse systems. Climate change is having a big effect on agriculture. A greenhouse system is mostly used in crop production. Additionally, because of the recent technological advancements, it is easy to use automatically in different areas of the greenhouses. Thus, an automated smart greenhouse based on an adaptive neuro fuzzy inference system (ANFIS) and the Internet of things (IoT) is a good solution to boost the crop production inside the greenhouse. Here, four kinds of weather data (the temperature, humidity, sunlight and soil-moisture) were gathered by utilizing sensors in real time. The gained data were sent as input variables to the fuzzy control system. The fuzzy control system manipulated the data and the ANFIS and it provided a prediction for the optimum values of the weather parameters. Thus, farmers monitored all the data and decided on the best value for the temperature and humidity. The study improved the learning efficiency and prediction accuracy. It also proved to be a feasible and effective automated greenhouse maintenance system [13].

A hybrid deep learning model was improved to determine the life and the mechanical performance degradation of greenhouse tri-layer LDPE films. The DL model was good in the training and validation phases. It demonstrated the capability of the prediction of the stress–strain curve of an aged LDPE film in the variable periods. Additionally, the hybrid SVM-CNN model predicted the stress–strain curves as a function of the ageing time. Thus, time and the cost would be saved. This could present easy tools to predict the mechanical properties of greenhouse coverings and their life period under the usage conditions [14].

The number of fruits in a cluster and the K:N ratio in the nutrient solution may affect the yield and quality of greenhouse-grown tomatoes. To avoid the loss of photoassimilates to fruit at the end of clusters that rarely mature and ripen, it is important to know the optimal number of fruit in a cluster under the different nutritional states. The project examined the affects of cluster pruning and the K:N ratio in the nutrient solution on the yield components, yield and quality of tomato fruit grown in a greenhouse [15].

In recent years, there was an adoption of ground and aerial platforms with many sensors for phenotyping many biotic and abiotic stresses over the improvement layers of the crop plant. High throughput phenotyping (HTP) includes the application of these tools to phenotype the plants. Additionally, it varies from ground-based imaging to aerial phenotyping to remote sensing. The presented study examined the latest researches where machine learning and deep learning approaches were utilized for plant stress phenotyping, with the data being collected by using many HTP platforms [16].

Climate control in greenhouses is a difficult task because it has been formed by the strong interaction between the many involved variables, the external disturbances and the time-varying uncertainties that severely effect its internal environment. In the study, a discrete-time fuzzy model predictive control approach of a greenhouse was examined. An interval type-2 (IT2) Takagi–Sugeno fuzzy model was used to present the nonlinear dynamics of the plant subject to the parameter uncertainties that were captured by the interval membership functions [17].

For the optimum crop growth, the management of the temperature and humidity in a greenhouse is important. The status of the temperature and humidity depend on the performance of the dehumidifiers and heaters in the greenhouses. The aim of the study was to monitor the performance of a small-scale suspension-type dehumidifier with a heating module in terms of the temperature and humidity changes over time. Additionally, the monitoring and controlling of the status of the individual actuating components were considered in the summer and winter [18].

Water is very important for farmers, but water costs are high and the availability is limited. Novel technologies are needed to improve crop yields, and efficient irrigation is required to produce more nutritious food with less water. The aim of the work was to use a novel method in irrigation to improve the water use efficiency by using a low-cost wireless communication system and sensors in a Tomato plant drip irrigation in a greenhouse in Palestine [19].

Precision agriculture is used to improve the utilization efficiency of water resources and reduce the environmental impact. Lately, a centralized increase in rice seedlings in greenhouses has been encouraged and applied in variable countries to provide the requirements of large-scale mechanized transplanting for the quality and quantity of rice seedlings. An intelligent raising system that is based on the Internet of things (IoT) cloud platform was proposed for rice seedlings in a greenhouse. The presented system ensured the proper temperature and rice nursery moisture for the rice seedlings according to three different growth levels by using the IoT and intelligent control technology. Thus, the effect of a high temperature or water shortage on the growth of rice seedlings was prevented. To save water resources, an SVR algorithm was used to estimate the operation time of the actuators. Additionally, the given system had many advantages, such as it is easy to operate, it has a low cost, it saves labor and has a short growth cycle of the rice seedlings [20].

In a vegetable greenhouse, the wireless sensor network (WSN) is the vital sensing utility for the Internet of things (IoT). The scope control ensures that the WSN can assure efficient information. Many researches do not consider the object size and provide a lack of attention to the occlusion between targets. There may be many leaves and fruits in vegetables that may lead to a blind area and a low utilization of the directional sensors. The study presented a non-occlusion coverage scheme for the greenhouse IoT, which was based on the geometric relationship between the directional sensors and targets [21].

In this study, the presented review focused to gain an insight into the actual researches and the applications of the operational management in the field of intelligent agriculture, based on the Internet of things (IoT). It identified the existing shortcomings and the potential issues. To analyze the co-citation networks in the literature related to the operational management of the IoT-based intelligent agriculture, the Java application CiteSpace was used. Then, the research was reviewed in the three fields separately in detail [22].

In this study, an IoT-based e-business model of an intelligent vegetable greenhouse was presented based on the main process and key nodes of the e-business model. Information, logistics and capital flows are known in the industry chain to be consisting of the ingredient suppliers, IoT-based e-business platforms, IoT-equipped greenhouses, payment and delivery service providers and end consumers. The value chain was examined according to Michael Porter's value chain model. It is helpful for greenhouses to focus on basic activities in the business model. Many issues, such as the planting structure and time optimization, big data-driven pricing, water and fertilizer integrated control, plant light supplement and order-driven picking and packing, were considered. The IoT techniques brought these characteristics for the operation issues. They were examined and mathematical models were formulated [23].

In this study, an IoT-based smart greenhouse automation using Arduino was presented. The study aimed to increase growth in the greenhouse, analyze the data and control the system accordingly. The Arduino microcontroller and the appropriate software and sensors were used in the system. The design was made using the Arduino Mega card, and it was aimed that the sensors measure the soil moisture and the light intensity of the greenhouse for irrigation purposes. In the study, the Arduino UNO, soil moisture sensor, DHT11 humidity sensor, LDR light sensor and temperature sensor were used. In order to control the system, programming was done with Arduino software. If the temperature rose above the set limit, a fan was automatically actuated as a cooler to lower the temperature. In addition, the use of a web-based IoT had made the system more useful [24].

It was aimed to use various monitoring methods for automation by using temperature, light, soil moisture and carbon dioxide amount measurements in the system that was designed in accordance with Android devices. In addition, the input and output parameters used in the greenhouse control were displayed on the Android device [25].

The smart greenhouse designed in this study consisted of soil moisture, temperature, humidity and light sensors. These sensors detected various parameters and transmitted them to the Atmega328 MCU microcontroller, which controlled the greenhouse. The program controlling the system has been written for microcontroller-specific environment conditioning. The greenhouse environment was automatically controlled by the system. Actuators such as coolers and pumps were used for the control. It was observed that the efficiency and reliability of the designed smart greenhouse system were higher than the open greenhouses. It has been stated that human errors that can be seen in greenhouses or farms will not be seen in the smart greenhouse. Apart from this, it has been concluded that the system had an environmentally friendly structure and if it can have a wireless structure, its use in large areas can be cost-effective and easily applicable [26].

In this study, the Internet of things (IoT) study was carried out for hydroponic planting in the designed smart farm. In the study, it was emphasized that the effects of global warming make it important to carry out agriculture in a controlled environment. For these reasons, it was stated that the maintenance of smart greenhouses is easy to control factors such as the light, temperature and humidity [27].

In this study, climate monitoring was designed and implemented with an irrigation control system based on wireless sensor network (WSN) technology. The system in the greenhouse was established at Babylon University in Iraq. In addition, the system monitored real-time temperature, humidity and soil moisture, and the tests showed that the system was stable, and no errors were detected [28].

This study discussed the effects of the transition to a modern irrigation technology. The decision to adopt or not to adopt an alternative irrigation technology (sprinklers) is not a random determination. Selection bias may occur and this can lead to biased estimates. The study applied methodological specifications to correct for self-selectivity biases. Then, the technical efficiency scores from the adopters and non-adopters were measured and compared. The empirical application utilized data covering 56 small-scale greenhouse farms in Crete, Greece for the cropping years between 2009 and 2013 [29].

In this study, the water problem in Algeria was discussed. An automatic irrigation system based on cloud technology and an Arduino microcontroller was proposed to optimize water use for farmland and help the farmer to control his field. The system also aimed to control the temperature using data from a weather website [30].

In this study, an Arduino-based smart irrigation system was established. A soil moisture sensor, water flow sensor and temperature sensor were used in the created smart irrigation project [1].

Soil degradation is an important topic for farmers. Thus, soil fertility and water quality should be preserved all over the world. In this study, in five regions of China, a field survey and sampling of greenhouse cultivation soil were managed to examine the accumulation and variation characteristics of soil ion compositions in the field [31].

The presented study determined the influences of vegetable greenhouses in the field of Lhasa on the Tibetan Plateau, using the open field soil as a control. The gained results presented that the soil properties varied depending on the cultivation time and vegetable types [32].

This paper presented a summary about selective harvesting robotics in three different production systems: greenhouse, orchard and open field [33].

In a greenhouse, for automating the harvesting of bunches of tomatoes, the end-effector needed to reach the best cutting point and adjust the pose of the peduncles. To determine the peduncle cutting point localization and pose estimation, a method was proposed in the study [34].

3. Materials and Method

3.1. A Case Study in Turkey

In our study, by constructing a smart greenhouse prototype, we were focused on monitoring the development of the same plants to be grown in the smart greenhouse and the natural environment. Our study was also based on examining the collected outcome and deciding what developments could be made. Furthermore, a case study was worked on to cultivate variable plants in a greenhouse. In the study, the developments of a flower and vegetable plants were followed in the greenhouse.

In the presented study, our proposed idea is given within these steps: indicate the materials to be utilized, construct the prototype of the smart greenhouse, decide the plants and flowers that would be monitored and appropriate the design of the circuit. For the Arduino Uno microcontroller, develop a software with App Inventor, improve a mobile application and monitor the collected results from the greenhouse, examine the data and appraise the results.

In this study, various materials were utilized to construct and manage the smart greenhouse prototype: an Arduino Uno microcontroller board (ATmega328P), which is an electronic hardware and software-based microcontroller. It is utilized as an input/output (I/O) board. There are many digital and analog inputs/outputs on the Arduino board. The program is written in C language. Since it has a very wide library support, the sensors can be easily controlled. Due to all these features, the inexpensiveness and the user friendliness, an Arduino Uno microcontroller was used in our project in order to control our prototype autonomously. For these reasons, Arduino microcontrollers are used on many prototypes and even industrially in some cases [35].

The sensors ensure that name of smart can be applied to the greenhouses. The environment variables of smart appliances are controlled by sensors. The data are collected by the sensors and then they are given to the software. Thus, the pressure, temperature, heat and humidity values of the environment are examined. The DHT11 sensor was utilized to measure the temperature situation in the greenhouse. This sensor produces a voltage value according to the temperature of the environment and the ambient temperature is determined using the relevant libraries over this voltage value [36]. The temperature value was determined according to the planted plants in our project. Additionally, the heat balance in the greenhouse was attempted to be ensured. Another sensor used in the study was the soil moisture sensor. The sensor was driven into the soil inside the greenhouse and, like other sensors, it produced a resistance value between 0 and 1024 according to the soil moisture condition in our study. Two soil moisture sensors were located on the left and right parts of the greenhouse [37].

Bluetooth was utilized for providing the communication of the smart greenhouse prototype with Android-based mobile devices, and also the manual management of the presented smart greenhouse. Therefore, the HC-06 Arduino Bluetooth sensor was utilized in the study [38].

To display the collected data on the greenhouse prototype and to display the interactions performed to the greenhouse over the application, a 16 × 2 LCD panel was utilized in the study.

In the greenhouse, to ensure the air flow, two wired plastic impeller fans were used; one of the fans was big and the other one was small. They were located on the right side and the left side of the greenhouse. The basic duty of the partially larger fan working with 12 V was to cool the air in the greenhouse by expelling the hot air inside the greenhouse. The smaller fan works with 5 V to expel the heat produced by the heater. The basic duty of the fan was to propagate the heat in the greenhouse in a way that did not harm the plants.

In the presented project, a 12 V brushless submersible water pump was utilized in the irrigation system. It was designed in a way that the water rising by this pump would irrigate the whole of the soil areas with the hose.

In our project, a ceramic heater lamp was utilized. Working with 220 V, these heaters are very effective. We decided to use the heaters during a short period of time together with a small fan. Thus, the heater did not send heat to a single area.

The top of the greenhouse prototype was made collapsible. In this way, it was possible to benefit from both sunlight and the ambient temperature by opening the top when necessary. In order to measure the efficiency of the greenhouse prepared within the scope of the smart greenhouse project, an open flowerpot was used next to the greenhouse. So as not to harm the roots of the plants on the greenhouse and pot floor, a floor of pumice stone with the equivalent characteristics was prepared for both environments. The same quality of soil and some vermicompost were added to the prepared floors. According to the provided literature review about the plants and flowers, it was decided to plant pepper, tomato, cucumber plants and begonia flowers because they grow in almost the same circumstances and habitat. The growing conditions and environments of these plants were determined from agricultural websites and MEGEP course module resources [39–43]. Accordingly, it was determined that the temperature in the greenhouse need to be between 20 °C and 30 °C in general, and the soil moisture need to be over 50% to provide enough moisture for the plants to grow.

These plants were planted on the prepared equivalent soils both in the greenhouse and in the pot according to the order seen in Figure 1. The system, which was created in accordance with the prepared prototype, was made controllable with software by adding all the components. Figure 2a–d shows all the components in the smart greenhouse system.

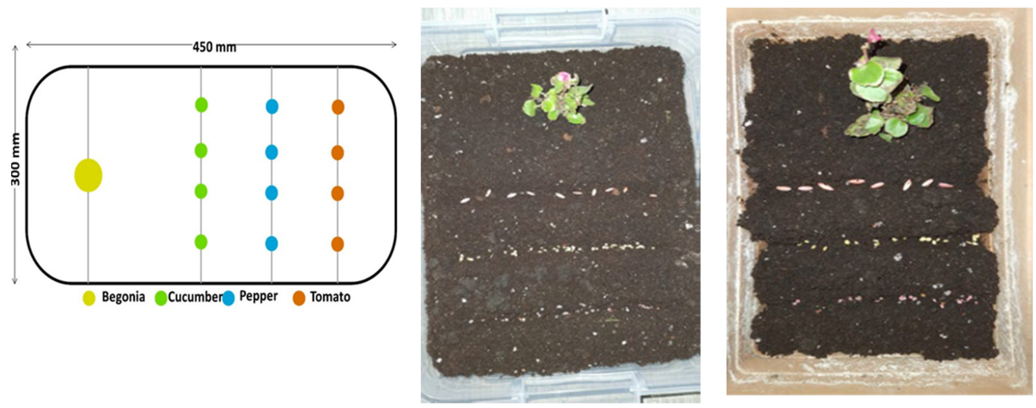


Figure 1. Planting order of begonia and three of the vegetables in the greenhouse and the pot.

(**a**) (**b**) (**c**) (**d**) (**e**) (**f**)

Figure 2. (**a**) Fans, (**b**) soil moisture sensors, (**c**) light and heater, (**d**) irrigation system on prototype (**e**), and (**f**) the view of the smart greenhouse system with all its components and the flower pot.

In order to turn the prepared prototype into a smart greenhouse and operate it, the circuit design was also determined. The Arduino Uno microcontroller and the circuit design that we designed accordingly are shown in Figures 2e,f and 3.

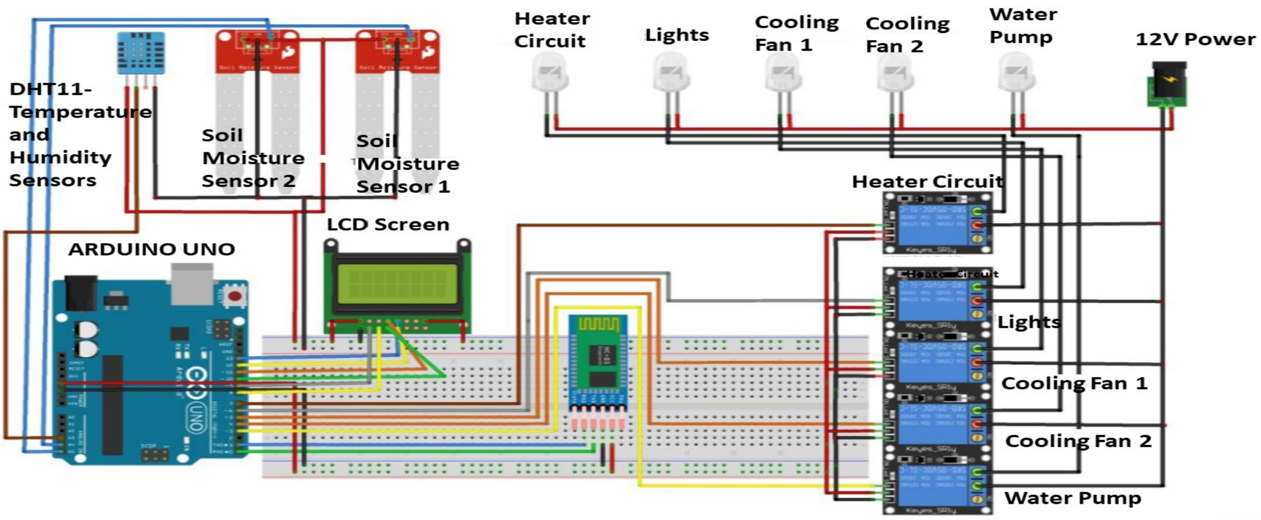


Figure 3. The circuit design.

3.2. Making the Greenhouse Working with Arduino Software

To ensure an operational greenhouse, the software control was achieved with Arduino. While constituting the software, the Arduino IDE interface was utilized. In addition, an interface was constructed. When needed, it allowed the system to perform manually by Android-based mobile devices. The Arduino software was designed to control all the parameters of the system and to produce suitable solutions. Thus, the system became self-controlled. According to the data collected by the sensors, the system operated the heating systems, cooling systems and water pump by turning them on/off when necessary. The collected data were shown on the LCD panel constantly.

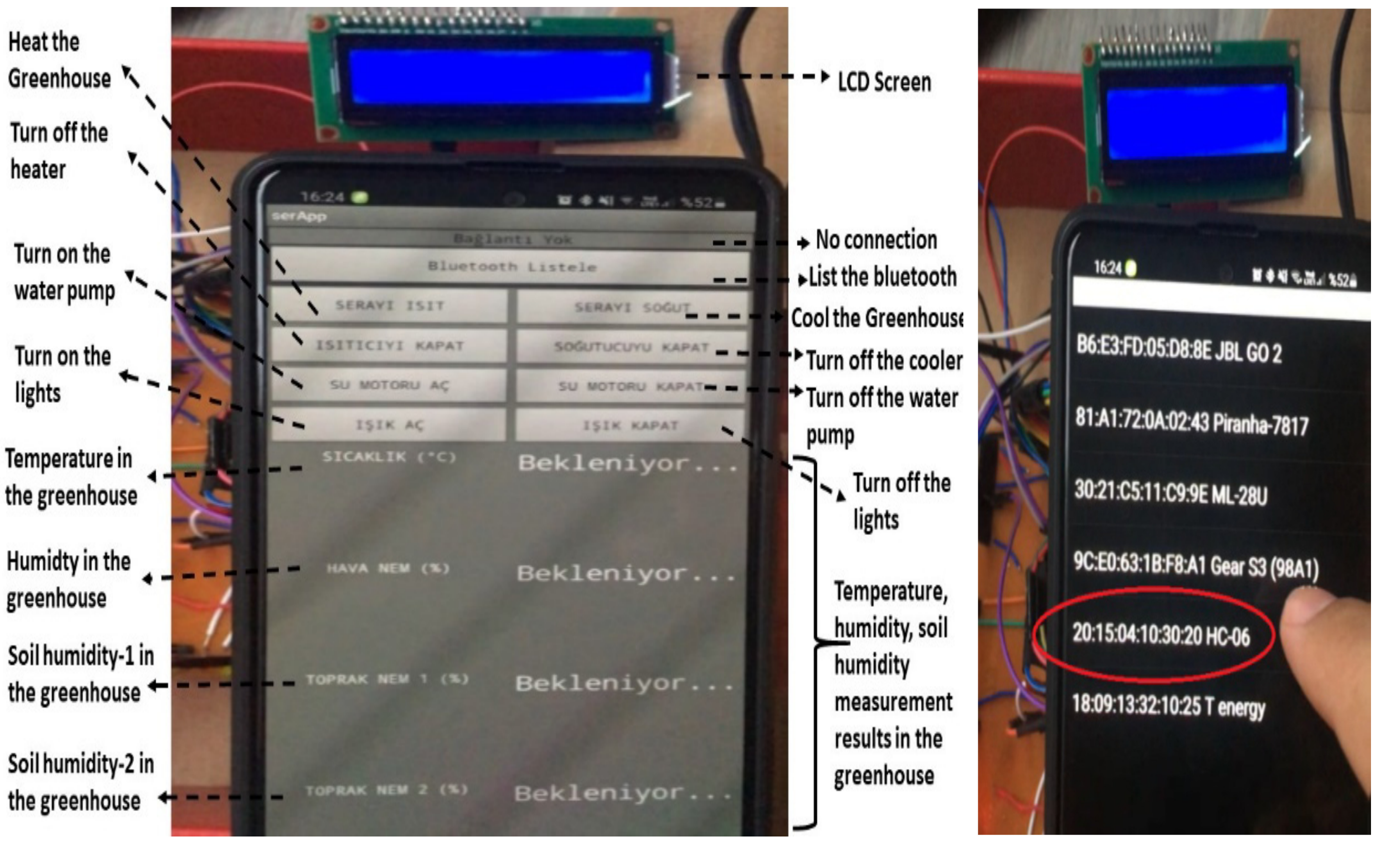
Additionally, the system ensured that the automatic or manual changes were shown on the LCD panel. Separated control mechanisms were established for the water pump, heater, light and fans (fan1 and fan2). The information obtained from the soil moisture sensors and the temperature sensor were continuously analyzed with the program, and the operation of the system was decided when it reached certain values. When the determined temperature and humidity values in the system were reached, the relays activated and operated the appropriate output units. In this way, when the temperature dropped below

20 °C, the heater was activated and turned on, and when the temperature of the greenhouse reached 20 °C again, the heater was disabled and thus the heating process was completed. As soon as the temperature sensor data exceeded 30 °C, the fans on both sides of the system started to cool the system. In this way, when the temperature of the greenhouse dropped to 30 °C again, the fans were disabled and the cooling process was complete. In addition, when the values in the data of one of the two soil moisture sensors in the system fell below 50%, the water pump was activated and water was added to the greenhouse for a certain period of time. In the smart greenhouse system, the values of both soil moisture sensors were expressed separately as S.Humidity1 (soil moisture sensor 1) and S.Humidity2 (soil moisture sensor 2), and the measured moisture amount was showed on the LCD screen. In addition, the temperature value was expressed as Temperature and represented on the LCD screen. In addition, when the water pump, heater and cooling fans were ON/OFF in the system, notifications to express these situations were made on the LCD screen and all the information in the greenhouse was displayed on the screen.

3.3. Monitoring Greenhouse Data by a Mobile Application with Appinvertor

App Invertor [44] is a beneficial platform. It allows users to develop block-based mobile application over web address. The mobile control of the presented project was determined to be constituted on the corresponding platform. The program was planned to ensure the automatic and manual management of the presented greenhouse.

The system was used remotely via the mobile application with a Bluetooth connection. The presented mobile application interface was created with App Invertor. The interface is illustrated in Figure 4a. The working steps of the prepared Android application: as seen in Figure 4a, the HC-06 Bluetooth module was used to provide the Arduino connection by pressing the "Bluetooth List" button on the top line of the application.



(**a**) (**b**)

Figure 4. (**a**) Presented Android application, (**b**) The list of Bluetooth devices in the application.

After clicking on the HC-06 module from the devices listed in Figure 4b, the connection was made. As seen in Figure 5, at the underside of the presented page, the collected data from the sensors could be updated consistently, after the "Connection Established" message was displayed at the top of the page. The temperature, air humidity, soil moisture 1 and soil moisture 2 data were collected from the sensors; they were continuously displayed on the LCD screen and in the application. The air humidity value reading from the sensor was shown in Figure 5a and the humidity value reading from the soil moisture 2 sensor was regularly displayed both in the application and on the LCD screen, as seen in Figure 5b.

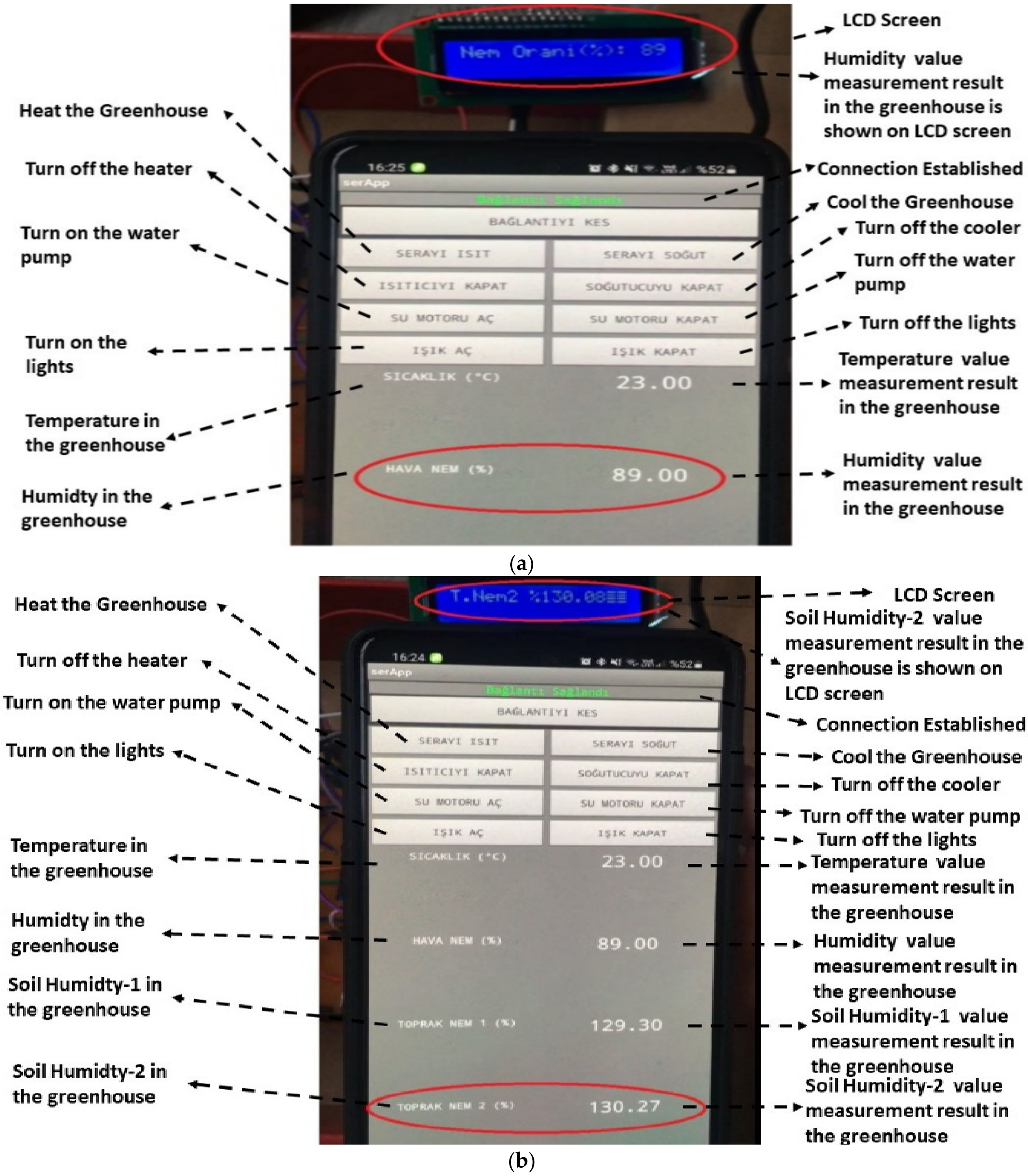


Figure 5. (**a**) Air humidity and (**b**) soil moisture 2 in the application and on the LCD screen.

3.4. Monitoring of the Prepared Smart Greenhouse System

The smart greenhouse work commenced by planting the begonia, tomato, pepper and cucumber plants in the greenhouse prototype and pot. The greenhouse and potted plants were positioned side-by-side in order to benefit from the same amount of sunlight. In this way, the effect of the sunlight was ensured to be the same for both environments. The same type of soil was used in both environments and an equivalent amount of worm manure was given. The water used for the irrigation was the same type in both environments. All interventions in the pot were done manually. The plants were examined between 2 December 2020 and 11 January 2021. The first irrigation process of the plants was done manually. In the first irrigation, 750 mL of water was given to both environments. Afterwards, the smart greenhouse took its own water from the water pump with the help of a motor when it was needed, and 200 mL of water was given to the flowerpot every three days. The height of the begonia plants in seedling form were measured. About 5 days after the start of the observation, on 7 December 2020, the first sprouts took place in the area where the cucumber seeds were planted in the pot. Two days later, on 9 December 2020, the first sprouts were seen in the area where the cucumber seeds were planted in the greenhouse. In this way, the vegetables and flowers were monitored in the greenhouse with the sensors and in the pot, and the data concerning them were constantly collected. All operations in the greenhouse were carried out by the Arduino supported system. In the pot, the irrigation was carried out in accordance with the growing conditions. The amount of water given to the pot and the greenhouse was monitored. Additionally, the data concerning other changes in the plants were collected. In the smart greenhouse system, the light, temperature and humidity values were constantly controlled, and all interventions were made automatically or manually when it was necessary. The development stages of the plants grown in the smart greenhouse during the whole experiment are shown in Figure 6a,b.

(**a**) (**b**) (**c**) (**d**)

Figure 6. Developmental process of plants grown in the greenhouse (**a**,**b**) and in pots (**c**,**d**).

The development stages of pot-grown plants during the entire study period are shown in Figure 6c,d.

3.5. Situations in the Smart Greenhouse—The Heating System

With the program presented in the smart greenhouse, the greenhouse interior temperature would not be lower than 20 °C. In one of the measurements, the outdoor temperature was measured as 13.3 °C, as seen in Figure 7, and the greenhouse interior temperature was measured as 19 °C by the sensor, as also seen in Figure 7.

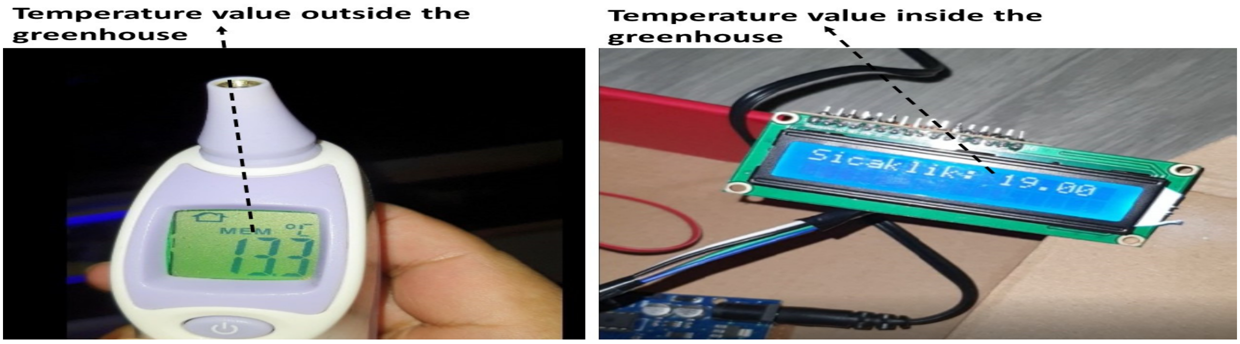
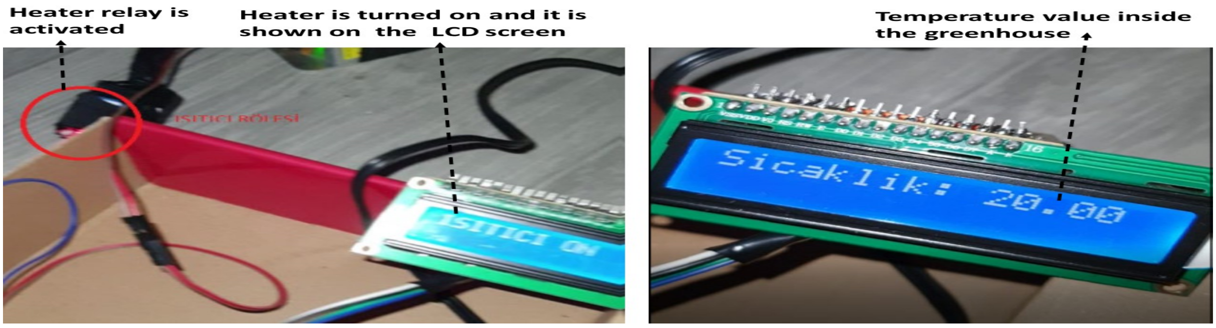


Figure 7. Temperature measurements at outdoor and in greenhouse.

In the Arduino application, a signal was sent to the relay output, called "heater", when the greenhouse interior temperature dropped below 20 °C. As soon as the signal was sent to the tip named "heater", the relay would be activated, as seen in Figure 8a. The ceramic heater bulb inside the greenhouse would also be activated and it would increase the greenhouse interior temperature. After a while, the value showing the greenhouse interior temperature was displayed on the LCD screen, as seen in Figure 8b.



(**a**) (**b**)

Figure 8. (**a**) Activation of the heater relay and (**b**) display of the temperature on the LCD screen.

By the help of the Android application, the presented smart greenhouse could be intervened any moment, independently of the automation criteria. For example, even if the temperature was 23 °C, the cooler could be operated, as seen in Figure 9. Additionally, the heater could be turned off and on.

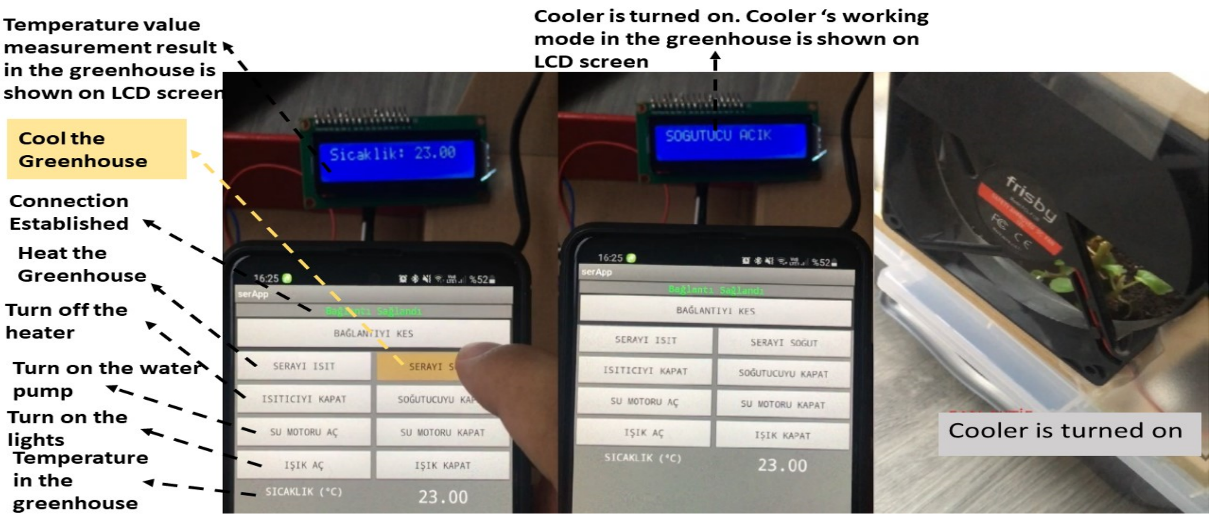


Figure 9. Operating the cooler with the app.

3.6. Situations in the Smart Greenhouse—The Irrigation System

In the presented smart greenhouse system, there were two soil moisture sensors embedded in the soil. With the Arduino application, the sensor values were checked at fixed intervals and displayed on the LCD screen, as seen in Figure 10a,b.

(**a**) (**b**) (**c**) (**d**) (**e**)

Figure 10. Displaying the values taken from soil moisture sensors on the LCD screen (**a**,**b**). Activated irrigation system (**c**) and values on soil moisture sensors as a result of irrigation (**d**,**e**).

In the prepared program, there was a function that evaluates the data coming from the soil moisture sensor. With the function, the water pump seen in Figure 10c was activated when both sensor values fell below 50%. After a delay of 5000 ms, the water pump was turned off again. As a result of these processes, the irrigation system activated along with the activation of the water pump relay that is seen in Figure 10c. The values read from the soil moisture sensors as a result of the irrigation process were also shown on the LCD screen, as seen in Figure 10d,e.

3.7. Turning Greenhouse Lights on and off

The lights of the prepared smart greenhouse could be turned on and off with the help of the Android application. After the light was turned on with the "Light On" button, seen in Figure 11a, on the application, the notification of this situation was seen on the LCD screen, as seen in Figure 11b. The image inside the greenhouse when the lights were turned on is shown in Figure 11c.

(**a**) (**b**) (**c**)

Figure 11. (**a**) "Light On" button on the Android application. (**b**) Displaying the status on the LCD screen after the lights were turned on. (**c**) The view of the lights in the greenhouse.

4. Results

The productivity test of the prototype, which was the final stage, was carried out. The plants were examined between 2 December 2020 and 11 January 2021. In the first irrigation, 750 mL of water was given to both environments. Five days later, on 7 December 2020, the first sprouts took place in the area where the cucumber seeds were planted in the pot. Two days later, on 9 December 2020, the first sprouts were seen in the area where the cucumber seeds were planted on the smart greenhouse. The development of the plants on the smart greenhouse and pot were monitored and their progress was followed. The data on the height of the plants and the amount of water they consumed were collected. The water consumption values of the plants grown in the smart greenhouse and in the pot are given in Figure 12.

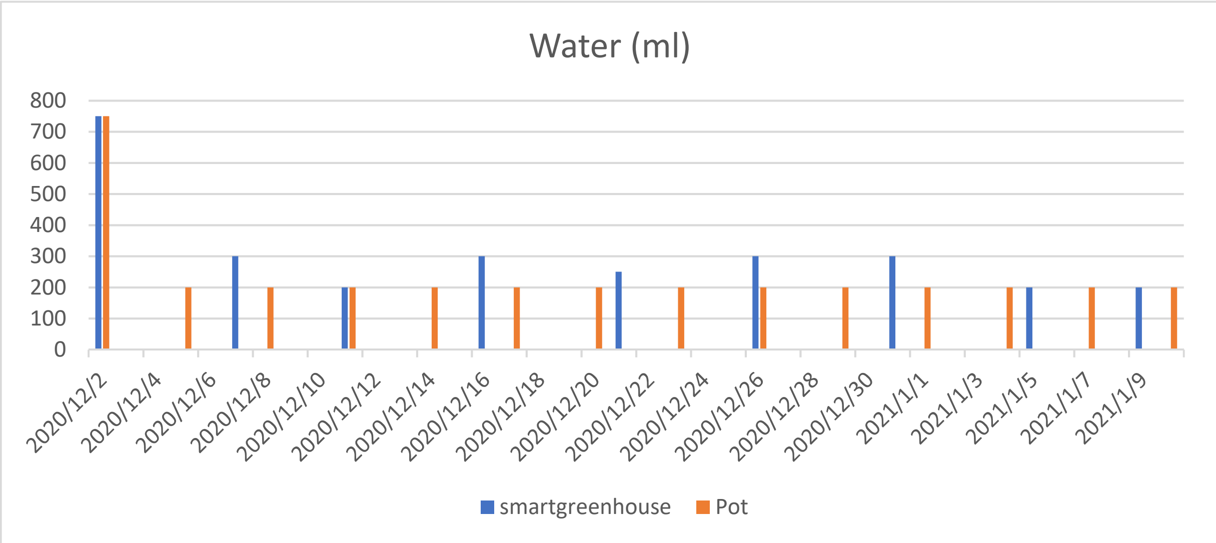


Figure 12. The amount of water the plants consumed in smart greenhouse and pot.

The development of the plants in the smart greenhouse and the pot are shown in Figures 13–16.

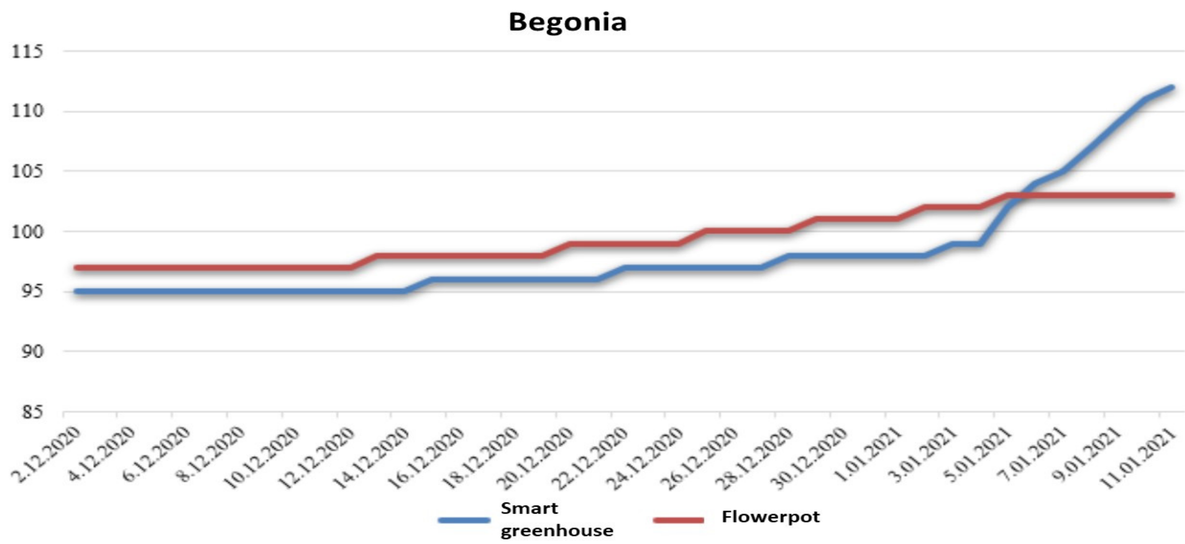


Figure 13. Development graph of begonia flower in smart greenhouse and pot.

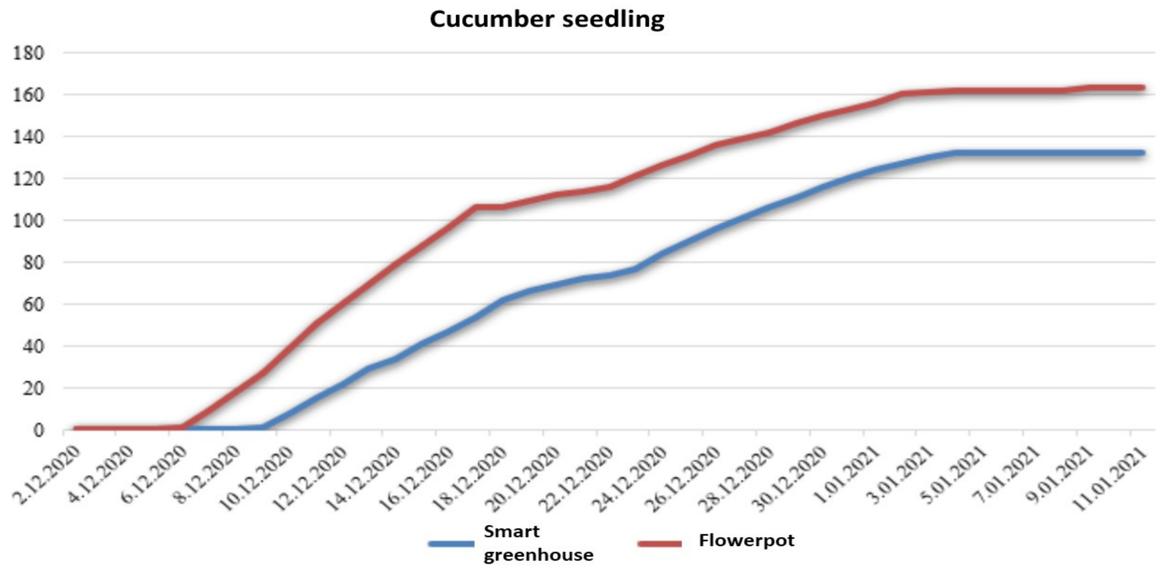


Figure 14. Development graph of cucumber in smart greenhouse and pot.

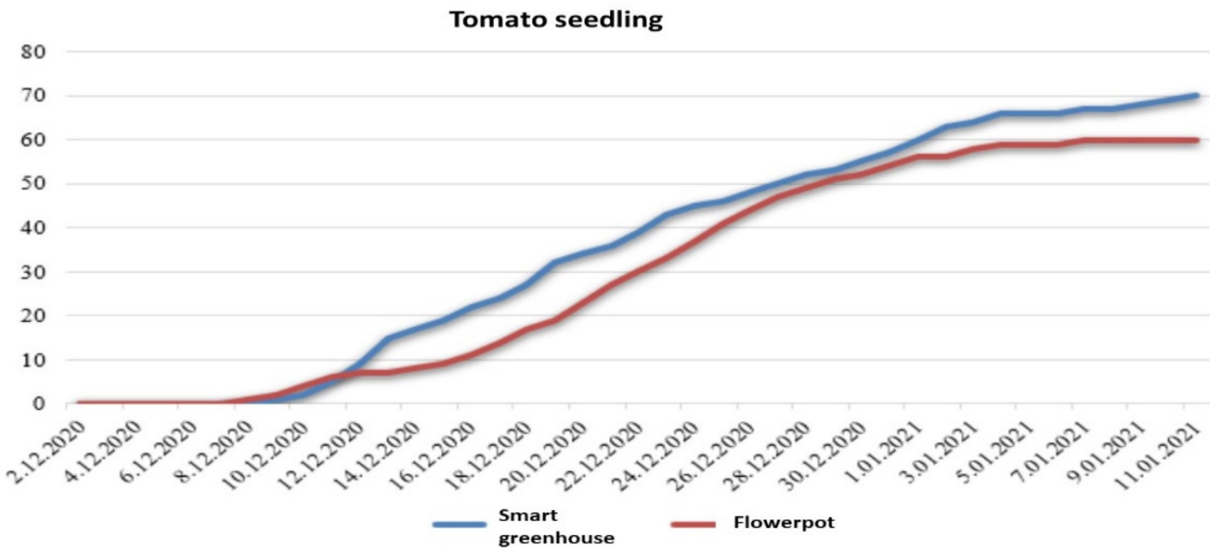


Figure 15. Development graph of tomato in smart greenhouse and pot.

When the collected data were examined, it was seen that all of the plants except for the cucumbers grew more in the greenhouse. During the observation, the begonia flower grew more in height and it had a significantly healthier growth in the greenhouse, as given in Figure 17a,b.

Apart from this, there are many factors to be considered while growing different plants in the same greenhouse. In our study, these factors were mostly considered. In addition, the fact that the system software could be controlled via the mobile interface when requested was one of the most important advantages. The plants tend to grow towards light due to their structural feature. For this reason, it was an expected result that the plants which grew outside the greenhouse would be taller due to their desire to extend their height in the direction of the light. The sunlight coming to the plants inside the greenhouse spread homogeneously with the coating outside the greenhouse. Therefore, the plants did not tend to extend in any particular direction; in fact, the plants grew towards the root, showing a healthier development process. This situation is shown in Figure 17c,d. In Figure 17c, there was a window on the right side of the plants and the plants tended to grow in this direction. This trend was not observed in the plants in the greenhouse, as given in Figure 17d. In addition, the humidity rate in the greenhouse was higher in all measurements. As a result of this, during the development of the begonia flower in the greenhouse, its leaves appeared more lively and stronger. The high humidity created an extremely favorable environment for the reproduction of harmful insects. Unfortunately, the development of some of the plants in the greenhouse was adversely affected by insects and some of them died since spraying was not done on time.

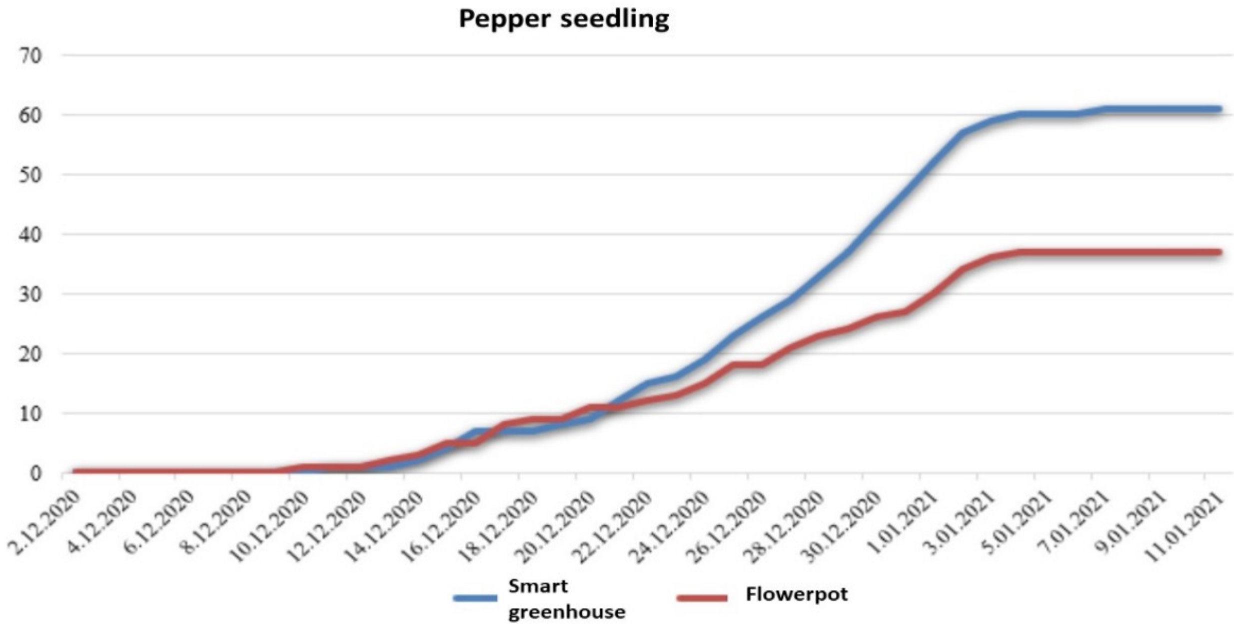


Figure 16. Development graph of pepper seedling in smart greenhouse and pot.

(**a**) (**b**) (**c**) (**d**)

Figure 17. Final status of the begonia flower (**a**) in the smart greenhouse (**b**) in the pot and the sun-related changes of plants (**c**) in the pot and (**d**) in the smart greenhouse.

5. Comparison of the Presented Study with Similar Related Works in Literature

In the study performed in [45], an Arduino uno microcontroller, sensors, a fan, an LED light strip and a water pump were used. When the results obtained in the study were examined, and it was seen that the DHT11 sensor module had an average error value of 2.64% for the temperature. This margin of error is close to the margin of error specified in the technical specifications of the sensor. When comparing the study in [45] with our presented study, an average of a 2–3% error margin was observed in the temperature sensor which we used in the measurements. This result was similar to the predicted margin of error of the sensor's data and previous studies.

In the study in [4], a prototype similar to the one we made in our study was created on a larger scale. A smart fuzzy logic-based control system was given. In the study, it was observed that water use was reduced by 33%. It was also observed that the prototype in the study presented in [4] provided more water savings due to its large scale. When compared to the study in [4], in our presented study, it was observed that an approximately 16.5% water saving was achieved in the smart greenhouse compared to the plants grown in the flowerpot. It is predicted that this savings will increase even more when our presented study is applied to larger greenhouses and when the duration of the examination is extended.

In the study given in [26], a similar study to our presented study was carried out using Arduino, sensors and actuators. In the study, an Atmega328 microcontroller, which we also used, was used. It was observed that the efficiency and reliability of the designed smart greenhouse system were higher than that of the open greenhouses. This result was also seen in our study. It was also noted that human errors that can be seen in open greenhouses will be less common in smart greenhouses. In the study conducted in [1], a remote-controlled smart greenhouse prototype was created. In this way, a system that works autonomously or manually when requested has been created.

In our presented study, a system that can be controlled remotely with an Android application was created. In this way, in our study, a prototype was created that works autonomously when requested, but which can also be controlled remotely via the Android application. This provides a great convenience to the user or the producer as it is a smart greenhouse system that can be easily controlled 24 h a day, 7 days a week.

6. Conclusions

These are the evaluations which have been made according to the results that we obtained from our observations: in both setups, the fastest growing vegetable was the cucumber. In the pot, cucumbers developed earlier and faster than those in the greenhouse. There was no significant difference between the tomato seeds. However, although their development in the pot was fast in the first period, it was observed that the tomatoes were healthier in the greenhouse at the end of the third week. In the pepper seeds, only one seed sprouted, and there was no remarkable improvement in both mechanisms. There were differences in the developments of the plants in greenhouse and in the pots due to the weather conditions and irrigation amounts. It was noted that the begonia flower showed a much healthier growth in the greenhouse, with an obvious height difference in the greenhouse throughout the entire observation. Additionally, it was observed that the leaves were more lively. The cucumbers in the greenhouse grew to 132 mm, the peppers to 61 mm and the tomatoes to 70 mm. The cucumbers in the pot grew to 163 mm, the peppers to 37 mm and the tomatoes to 60 mm. During the observed period, the smart greenhouse used a total of 2800 mL of water as a result of the operation of the system when it was needed. Meanwhile, 3350 mL of water was manually poured into the flowerpot. According to this result, the smart greenhouse system saved approximately 16.5% of water compared to the pot. This factor shows that the smart greenhouse system has an important place in terms of saving water. It is thought that this saving will increase as the size of the greenhouse and the measurement time increases.

The longest leaves of the begonia flower grown in the pot fell off after a while. Therefore, measurements were made with smaller leaves. The graph shows the highest length that was reached. When measuring the existing leaves of the potted begonia plant, the leaf size was measured to be approximately 100 mm. According to the results obtained, the smart greenhouse made a positive difference in the development of begonia, tomato and pepper. Although, the cucumbers grew more in the pots. In the study, it was observed that the plants were more alive in the smart greenhouse; this shows that the yield will be positively affected in the smart greenhouse. In addition, it is thought that the presented smart greenhouse system will be a useful study in terms of both the controllability and usefulness when it is improved in the future. The fact that the system can work both manually and autonomously provides a great convenience for the person controlling the greenhouse. Additionally, the remote access to the greenhouse provided the opportunity to make any intervention by using a remote control. In this way, a manual use of the greenhouse is also possible when the system needs to be controlled outside of a certain routine. The use of greenhouse systems has an increasingly important place in order to overcome the problems that may be experienced in accessing agricultural products due to problems such as the effects of the COVID-19 pandemic, global warming and climate changes. Smart greenhouses also have advantages in preventing the consumption of resources by using them in the most appropriate way.

The presented study is a prototype, but it is possible to adapt this study to a large-scale smart greenhouse system. This is because the presented greenhouse has the smart greenhouse qualification, and it is capable of responding to the needs of agricultural production. The large-scale smart greenhouse system can easily be adapted for plants in the greenhouse with determining the parameters of the system according to the plants. Thus, the plants grown in the greenhouse of a small-scale prototype can be grown in a large-scale smart greenhouse.

Additionally, most of the aforementioned papers focus on a specific problem. In the presented study, there were multiple issues being considered: the water problem, energy problem, management problem, control problem and monitoring problem.

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