AI-Based Self-Sufficient System for Optimizing Gardening Conditions

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***Abstract*— Agriculture has been present for many years; it has a long history and continues to be a major source of income and food to this day. However, the production process of the plant is difficult for people who do not have much experience in gardening. Therefore, this project aims to facilitate the cultivation process for home gardeners as a practical and easy-to-use solution. Soil moisture, air temperature, humidity, and soil salinity readings are used by the system to adjust the tomato's environment. The system should monitor the tomato's condition through sensors and make amendments to preserve those conditions, as well as detect tomato diseases through a deep learning model and cure them with the system if possible. All this will be facilitated by a mobile application. To implement the project, the following methods will be utilized: an SDI as the irrigation method, Wi-Fi as the type of communication, TensorFlow as the deep learning framework with transfer learning, and flutter for the app development.**

Keywords— Tomato production, Vapor Pressure Deficit (VPD), Internet of Things (IOT), Surface Drip Irrigation (SDI), Artificial Intelligence (AI), Deep Learning Model, Convolution Neural Network (CNN), Transfer Learning, Tomato Diseases.

I. INTRODUCTION

"Taking root around 12,000 years ago, agriculture triggered such a change in society and the way in which people lived that its development has been dubbed the Neolithic Revolution" [1]. Agriculture has been present for many years, as it was the transition from a nomadic era of instability to the beginning of permanent settlements and civilization. As time advanced and the population grew, not all people were needed for the production of crops; as such, a lack of knowledge in the gardening process was established. In recent years, gardening has been increasing in popularity among the general population, and as such, more and more crops are being produced in natural conditions. These conditions, however, may cause harm to the gardening process, especially in arid or semiarid regions. Furthermore, fruits and vegetables are known to be more sensitive to these conditions. As seen in [2], tomatoes are amongst the most important crops worldwide and are being grown increasingly more each year in regions such as Saudi Arabia. Because of the harsh conditions of the climate, it is paramount to study the effects seen on tomatoes and methods that can reduce these effects. As seen in [3], [4], and [5], tomatoes were greatly affected by temperature level, humidity level, salinity level, irrigation system, and rate of irrigation. A discrepancy between these factors can cause some diseases to develop on the tomato. A possible optimizer to the production of tomatoes that may reduce the discussed problems is an "**AI-Based Self-Sufficient System for Optimizing Gardening Conditions**." This system would automatically irrigate the tomatoes, use sensors to monitor the garden's condition, display those measurements on an application, alert the user to undesired measurements and possible solution, adjust the irrigation amount based on the readings, and detect tomato's disease by the phone camara through a deep learning model.

II. LITERATURE REVIEW

A. Vapor Pressure Deficit (VPD)

As shown in [3], Vapor Pressure Deficit (VPD) are increasingly influencing plant survival. VPD measures how much water exists in the air compared to the maximum amount of moisture the air can contain, known as the Saturation Vapor Pressure (SVP). Plant transpiration rates are closely linked to a plant's water conditions, which are affected by VPD. Plants need nutrients to survive, and the nutrients' absorption is limited by the VPD. When VPD is high, transpiration is high, which can lead to the plant losing the water containing nutrients that it desperately needs. In the case of a low VPD, the opposite occurs. As a result, plant growth and productivity can be improved through VPD regulation.

SVP indicates how much water vapor can be held by an atmosphere at a specific temperature. Water vapor can only be held at a specific temperature up to a certain amount. In order to determine the SVP, the air temperature (T) has to be taken into account. Based on paper [3], the following equations were used. Equation (1) can be used to calculate the SVP.

$$SVP = 0.6108 \exp(\frac{17.27\,T}{T+237..3}) \qquad (1)$$

On the other hand, Active Vapor Pressure (AVP) is the actual amount of water vapor held at a given temperature. Equation (2) determines the AVP at a given relative humidity (RH).

$$AVP = SVP\ \frac{RH}{100} \qquad (2)$$

Equation (3) can be used to calculate the VPD using the SVP and AVP. This equation is important for understanding how much evaporation or condensation will occur in an area, as well as for calculating transpiration rates of plants.

$$VPD = SVP - AVP \tag{3}$$

It was reported by H. Noh [3] that plants grow best at 0.5 to 1.5 kPa (kilopascals), and a VPD of 2.2 kPa could cause plant stress and fruit cracking. Nevertheless, plants are affected by VPD in five major ways: pore opening, CO2 absorption, transpiration, nutrient uptake at the roots, and crop stress. It was also seen that temperature and humidity can be used to adjust the VPD. Previous studies showed that regulation of VPD can be accomplished using modern technologies. Whenever the VPD departed from the recommended range, fogging water was automatically injected into the treated zone. There were no notable differences in the height of the crops, fruit setting, leaf development, and phenological stages; however, the number of total yields, the total commercial yield, and the total fruits showed significant differences with the treated tomato crops.

B. Soil Salinity

"Salinity is a major problem affecting crop production all over the world: 20% of cultivated land in the world and 33% of irrigated land are salt-affected and degraded" [4]. This shows that one of the many factors that most affects a crop's growth, health, and productivity is soil salinity, as restated in [6]. Different crops react differently to salinity levels; however, it was found that vegetables react more severely as most of them are sensitive to moderately sensitive to high salinity levels, as seen in [4] and [6].

Tomatoes, in particular, are moderately sensitive; as such, it is important to maintain their salinity levels. This impact is shown through certain characteristics of the fruit: growth of the plant, plant's water absorption rate, photosynthetic quality of the plant, and germination and the speed of germination.

As soil salinity has such an adverse impact on the plants it is essential to find practices that maintain its level. The methods to minimize salinity are soil reclamation, fertilization, irrigation, and leeching. Soil reclamation is a process of removing salt from the soil by using gypsum or calcium carbonate. Fertilization is a process of adding organic matter to the soil to reduce salinity. Irrigation is a process of flushing out the salt from the soil with fresh water. Leeching is a process of removing salts from the soil by applying water and letting it drain away. All these practices are important for maintaining soil salinity; however, irrigation is considered to be the most effective practice as it helps in flushing out salts from the root zone and also helps in maintaining an optimum moisture level in the soil. Therefore, irrigation is considered to be the best practice for maintaining soil salinity [4].

C. Irrigation

"The continuous decrease in water resources in the world in general and in arid regions such as Saudi Arabia in particular has forced farmers to use low-quality water and to alter their irrigation practices" [5]. This is important as water is a fundamental need for the plants' health and survival. As the sources of water are limited, it is of paramount importance to use it effectively and efficiently to produce the most productive yield with the best quality of the fruit, while maintaining water use efficiency (WEU) and irrigation water use efficiency (IWUE) as seen in [5] and [7]. Irrigation is also important in maintaining some of the issues that developed in the plants as a result of climate conditions, such as soil salinity levels and the evapotranspiration rate of the plant.

As [5] shows, the method of drip irrigation was shown to be more productive than other traditional methods often used in agriculture. However, drip irrigation has two types, surface drip irrigation (SDI) and subsurface drip irrigation (SSDI). The drip irrigation method was said to be appropriate for arid climates; however, there is another method called deficit irrigation that has even more potential for water productivity. Deficit irrigation is not a new method of irrigation; it is the same drip irrigation method as before but with a reduced amount of water. There are two types for this method, regulated deficit irrigation (RDI) and partial root drying irrigation (PRD). The benefit of these methods is that they maintain water reduction while hardly affecting the yield of the crop [8].

D. Tomato Disease Detection Based on AI Technologies

Table I. Accuracy comparison for ML methods used to detect tomato disease.

Classification Method	**Number of leaf Images**	**Number of fruit Images**	**Number of classes**	**Accuracy (%)**	**Ref**
SVM Cauchy kernel	200	-	2	100%	[9]
SVM Laplacian kernel				98%	
SVM Invmult kernel				78%	
Decision Tree	1,000	-	5	96%	[10]
K-NN	16,012	-	10	94% - 96%	[11]
CNN (Customized)	16,012	-	10	98.4%	[12]
CNN (VGG6)	16,012	-	10	93.5%	[12]
CNN (Inception V3)	16,012	-	10	77.5%	[12]
CNN (MobileNet)	16,012	-	10	82.6%	[12]
CNN (GoogleNet)	16,012	-	10	99.72%	[13]
CNN (ShallowNet)	22,369	1,347	24	78%	[14]
CNN (DenseNet)	22,369	1,347	24	95.31%	[14]

Through the last decade, many researchers have been enhancing the process of detecting disease using AI technology. Regarding Rajasekaran Thangaraj et al.'s paper, which analyzed 44 research, deep learning has given a great result. The deep learning model outstrips the other machine learning methods for tomato disease detection. Note that deep learning with hyperspectral imaging has an advantage compared to the other methods in detecting early tomato diseases. Furthermore, deep learning modules detected the plant disease efficiently even with regular images [14]. Convolutional Neural Network

CNN is the most common deep learning method for classification and computer vision tasks. CNN is a neural network that has at least one convolutional layer. In [12], Mohit Agarwal et al. proposed a CNN model using the Plant Village Public Dataset. The model consists of three convolution layers, three Maxpool layers, and a dropout rate of 0.5. In order to increase the model's accuracy, the researchers applied simple augmentation and varied the leaves' backgrounds. Moreover, to reflect the field condition, the images' brightness was increased by 20-30% on a width between 20% and 80%.

The model's performance was good, reaching an accuracy of 98.4% after 500 epochs. It is essential to point out the importance of image processing before inputting it into the AI model as it increased the accuracy of the results from 91.2% to 98.4%. The above model in the research is compared to other CNN architectures, such as VGG, Inception V3, and MobileNet. The researchers used the transfer learning technique by freezing the pre-trained layers and adding several layers for each model. The VGG6, with an accuracy of 93.5%, does not perform as well as the customized model with the same dataset. The performance of the Inspection V3 model was even worse; with an accuracy of 77.5%, it showed an overfitting behavior. The performance of MobileNet was not great either, but the accuracy, in the end, was 82.6%. The poor performance of the previous models is due to the small number of classes on the dataset. compared to the number of layers on the models. Despite that, it can be noticed that most researchers working on the disease identification of plants have been using transfer learning to enhance the learning ability of the models.

E. Related Projects

The following table shows projects that employed the methods mentioned above for a field related to agriculture.

Table II. Related Projects

Project title	**Project domain**	**Technologies**	**Ref**
Fog Microsystem	Control greenhouses environment	Sensors are used to measure the VPD in the greenhouse, and a pump and small nozzles are used to regulate it.	[15]
IoT Based Plant Health Monitoring	House gardens	Uses sensors to monitor the environment around the plant and provide the necessary amount of water. Arduino is used to control the systems and send data via the internet.	[16]
Computer Vision-Based Fruit Grading System	Processing Lines	Classifies tomatoes as defective or non-defective, ripe, or unripe with machine learning.	[17]
Automatic Image Capturing Box Prototype	Agriculture	The CNN model is used to classify three tomato leaf diseases using the AlexNet model. All sides of the tomato plant are captured automatically.	[18]

III. BLOCK DIAGRAM

The AI-Based Self-Sufficient System for Optimizing Gardening Conditions block diagram is shown in Fig. 1. The connections are clearly illustrated to explain the relationship between the system's blocks. There are four main blocks in this project's system which can be classified as a hardware system, a plant disease detection model, a backend software system, and a frontend software system. The inputs to the system are taken from sensors that measure temperature, humidity, soil moisture, soil salinity, and water level in the water tank. In addition, the outputs of the system are drip irrigation, a VPD controller for the fogging water system, and plant disease detection for tomato plants. For drip irrigation to succeed efficiently, it's important to define the type and age of the plant to assign the exact amount of water the plant needs. Moreover, temperature and humidity values are necessary for the VPD controller to function, as stated in the Vapor Pressure Deficit section. The microcontroller used in this structure is the Arduino Uno which acts as the brain of the hardware system. It is programmed to send and receive data between the hardware and software blocks. There will be wireless communication between the main blocks which can be achieved with the Wi-Fi network since it is compatible with Firebase, which provides documentation to help build the Fasela application. With the aid of TensorFlow and the CNN transfer learning model, a deep learning model will be designed to classify tomato diseases. This model will be interfaced with Flutter so the user will be able to identify diseases by uploading or taking a plant's image. Finally, with the power of Dart and Flutter, an application will be developed under the name of Fasela that can be run on any platform. Users of the application will have access to several features, including the garden's measurements, alerts, and the ability to identify tomato plant diseases.

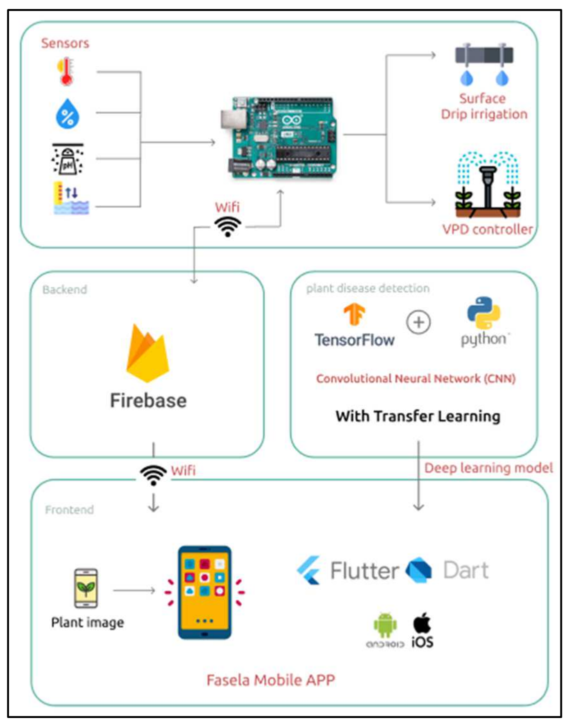

Fig. 1. AI-Based Self-Sufficient System for Optimizing Gardening Conditions Block Diagram

A. Circuit Schematics

Fig. 2 shows a first draft of the 3D view of the project prototype. Drip irrigation and VPD control systems are at the core of the project's hardware design. It will begin with a DIY drip system that will be supplied with water from a water pump. A VPD control system will then be located at the end of the pipe. This system will be responsible for activating the sprinkler to wet the surrounding area and irrigate the plant with the lost water caused by high VPD values. VPDs are equipped with a solenoid valve that is opened or closed based on temperature and humidity.

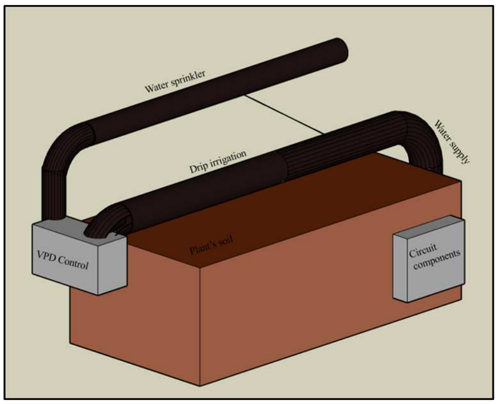

Fig. 2. A 3D view of the prototype design

The detailed connections between the system's components are shown in Fig. 3 and Fig. 4. This system consists of an Arduino Uno, a Wi-Fi esp8266, a DHT22 for measuring temperature and humidity, a soil EC meter for measuring soil salinity, a soil moister sensor, an ultrasonic sensor, a 24V water pump, a 24V solenoid valve, two 24V relays, two 24V adapters, and one 9V battery.

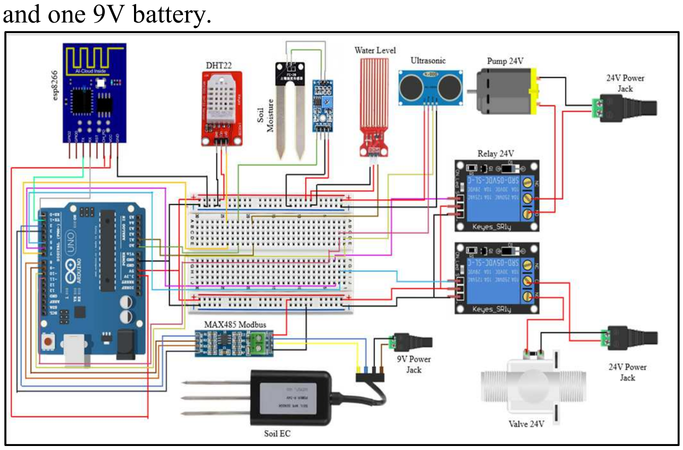

Fig. 3. Circuit schematics 1

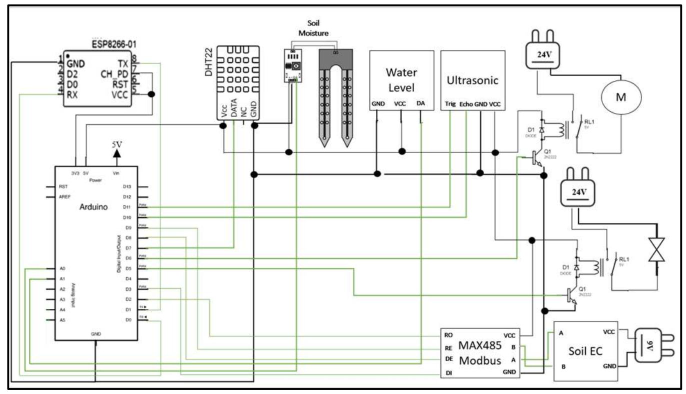

Fig. 4. Circuit schematics 2

B. Flowcharts for Process Flow

According to Fig. 5, the proposed solution follows the following operation sequence. The system starts by looking for exciting plants. If one is found, the system reads plant parameters such as temperature, humidity, soil moisture, soil salinity, and water level. There will be the option for the user to detect diseases and to see the results displayed as healthy or unhealthy with suggested remedies. In terms of the system processes, there are three main operations: notifications, irrigation, and fogging water via VPD. While notifications are specified for soil salinity and water availability in the tank, irrigation is begun by measuring soil moisture and then watering the plant. This is until the soil moisture sensor readings are at the required amount. Based on temperature and humidity values, VPD control will be activated or deactivated. Throughout the day, these operations are running. And in case of the absence of an exciting plant, the user needs to specify the type and age of the plant; otherwise, no operation will take place.

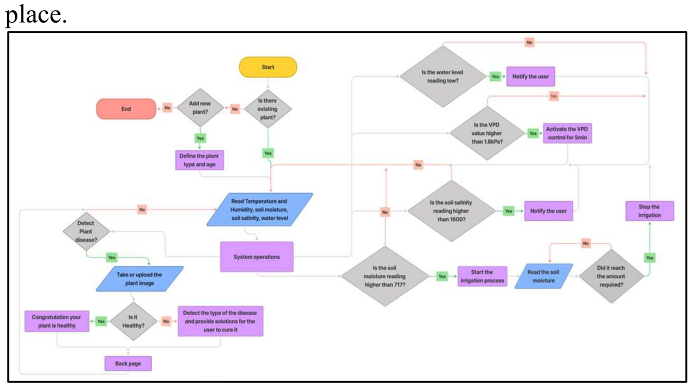

Fig. 5. Flowcharts for process flow

IV. Implementation

In this part of the project, the implementation of the ideas is discussed. This implementation consists of three parts, the hardware, the application development, and the disease detection model. All three parts are further connected by the firebase as a backend. In the hardware, the components shown in the circuit schematics of Fig. 3 were connected. The readings were then sent to firebase to be used by the developed application which was named "Fasela." In the application development, the Fasela application was developed through the use of flutter, and through a connection to firebase, the hardware reading was displayed as seen in Fig. 6. As for the deep learning model, three different models were used to compare which produces the highest accuracy. These models were the DenseNet model, the Resnet model, and the EfficientNet Model. Out of all these models, the EfficientNet produced the best result with the highest accuracy and correct prediction. The worst performance was seen in the ResNet with low accuracy and wrong predictions as seen in Table III. As the dataset was not provided in the literature of Table II, the results of the AI implementation in this section are enough to see which model is the best to use. The dataset used for this implementation is from Kaggle as seen in [19]. Finally, the AI model was downloaded and installed in the Fasela application to make disease prediction through the phone. By these methods, the idea of the "**AI-Based Self-Sufficient System for Optimizing Gardening Conditions**" was implemented.

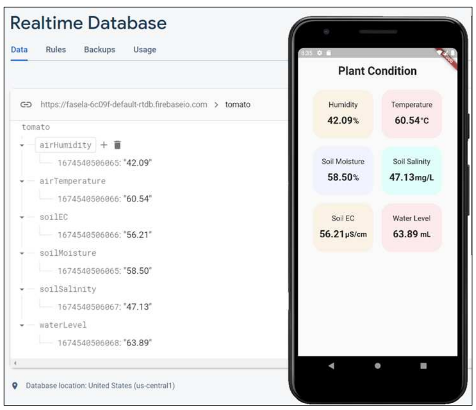

Fig. 6: Hardware Readings Through Fasela Application

Table III. Different accuracy of used models

No.	Pretrained Model	Training Accuracy	Training Loss	Test Accuracy	Predictions
1	ResNet152	56%	1.56	52.37%	Incorrect Predictions
2	DenseNet201	93.6%	1.2	90.59%	Incorrect Predictions
3	EfficientNetB1	99.49%	0.216	97.05%	Correct Predictions

V. CONCLUSTION

This project was aimed to optimize the conditions for growing tomato crops. Tomatoes were chosen as the crop of interest because of their delicacy to harsh condition and because of their importance in agriculture. The factors that impact tomatoes most were studied and their optimum value for healthy crops were analyzed. Keeping these factors along their desired range is important for the survival of the tomatoes; as such, a system was proposed to measure these values and make sure that they are as desired. Furthermore, even with these precautions, some of the crops may get infected with some illness. The deep learning model incorporated with the system can be used to detect and mayhap solve the infection. The development of the mobile application will connect all these aspects to produce one coherent "**AI-Based Self-Sufficient System for Optimizing Gardening Conditions**." The design of the project implements SDI as the irrigation method, Wi-Fi as the type of communication, TensorFlow as the deep learning framework with transfer learning, and flutter for the app development. Furthermore, for the hardware components, multiple sensors will be used for the desired parameters, temperature, humidity, soil moisture, soil salinity, and water level. These components, along with other hardware components, are connected with the Arduino for control and communication. This proposed design of the project will hopefully achieve the aim of optimizing gardening conditions for the average user.

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