Design and testing of autonomous irrigation controllers in commercial green houses to control the water consumption

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ABSTRACT

Water management is one of the major challenges while developing sustainable commercial greenhouses. Water is one of the most important resources for crop growth phase along with the nutrition on time. Since current global climatic conditions are not stable, the importance of commercial greenhouses is necessary to meet the pure fruit and vegetable requirements. Underdeveloped irrigation plans are normally leading to water stress, which may result in the decrease in yield and high operations cost to cope up the demand. Maintaining adequate soil water levels is mandatory for all the proper water growth. Automatic irrigation control system can drive an important role in water conservation and at the same time to serve the crop requirement on right time. Atomized irrigation control systems with a well-defined field devise equipped with sensors can maximize the effectiveness of the irrigation water management technology. An experimental setup of the automatic control system has been developed with the help of direct digital control (DDC) technology, and the same has been tested in cucumber greenhouse. This prototype has been developed with the help of a synchronization controller and a communication device to interact with the main climatic control system. A unique converter was developed and tested in cucumber greenhouses. Two algorithms for water control, i.e., a variable frequency drive based (VFD module) on-demand method and a required water calculation method, were programmed. The irrigation controller showed the ability to measure soil demands in real-time and to elicit irrigation at a customary value properly. The system performance for upholding soil rigidities based on this automatic controller was strongly affected by sunlight, whereas the water calculation method is providing a meek irrigation process deprived of recurrent irrigation.

Key Words: Greenhouse, irrigation, control systems, Variable frequency drives.

1. Introduction

Water irrigation has assumed an essential role in the improvement and sustenance of nurseries and greenhouses; the eventual result is the capacity to grow a wide assortment of yields in high volume that can cater for the necessities of the rising populace [1]. The irrigation process is an art that has to be mastered especially when it comes to crops that are growing in a greenhouse because they need just the right amount of water to grow effectively. When over irrigation occurs the majority of plants in the greenhouses usually end up dying due to diseases and the leaching away of nutrients, on the other hand when under irrigation is done the plants will wither off due to lack of moisture [2]. It is essential to understand that water is an element that supports the growth of plants and nutrients transportation when in the right amount, this is why growers are keen to monitor water content in the soil as plants grow. Currently, some irrigations schemes have already been deployed in crop production in greenhouses, and they are controlled by the grower meaning in the absence of supervision the likelihood of over or under-irrigation is plausible [3]. The change in water content affects not only consumers due to lack of products, but the grower faces greater financial challenges because the maintenance of a greenhouse is a financially exhausting job [4]. The main recommendation that most growers are given regarding their
intensity to irrigate is that the frequency of irrigation should be similar to the evaporation rate in the greenhouse. For a grower to manually evaluate the rate of evaporation happening to place the frequency needed for irrigation, it can be a daunting job as well as expensive. This usually leads to yields that are not the most potent for the specific greenhouse.

The creation of an automated system that can control irrigation is the key to ensure efficiency and cut down on the cost of running greenhouses [6]. Automated systems of irrigation work under real-time evaluation of soil content and through that they can sustain the soil with the most appropriate levels of moisture that the plant in the greenhouse. Various example of automated systems are being put into use, but their creation is what differs according to the needs of the particular greenhouse [8]. The automated systems that are being created have to align to two different factors which will be the main basis of creating the system. One factor is by the use of water measurement in the soil indirectly, and this is by measuring elements such as evaporation which directly play a role in the amount of water in the soil and hence determining the intensity of evaporation. The second separate factor is the direct measurement of water content in the soil [14] This paper aims to develop an automated irrigation framework and assess a control system that will have the capacity to perform continuously about the immediate state of the soil. The assessment of the automated system will be able to clearly show if this is the path that growers should be taking to ensure that they have the best yields in their greenhouses and also to be able to cut down on the finances used in operating a greenhouse.

2. Materials and Methods
An automated irrigation system that can supervise the water content in the soil and be able to initiate irrigation as soon as possible has been developed [7] The system is made up of a variety of factors that can be categorized into two: the hardware and software. The hardware which are physical parts that can visually be assessed and touched include parts such as the sensors, the solenoid valve, the piping to and from the pump, power supply, and a relay board. The software includes the computer systems and interfaces that contains the algorithms than variate the frequency of irrigation. Figures 1 and 2 on the next page show a composition of the hardware that has been used:

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Figure 1- Sensor Kit to be connected to the System

The software includes the computer systems and interfaces that contain the algorithms that variate the frequency of irrigation. Figures 2 below and 3 on the next page show a composition of the hardware that was to be used.

Figure 2- Irrigation System with Moisture Sensor

Figure 3- Water Tank & Irrigation Pump
The sensors are placed in the soil, and they are constructed in such a way that they can monitor the existence of moisture around the soil and be able to send the obtained data to the computer systems where it can be evaluated and the necessary procedure initiated. The solenoid valves are also core parts that are present in the hardware parts of the whole system. This device can be described as an electrical device that functions by the use of magnetic fields to restrict the flow of fluids, and in this case, water is what will be restricted [15]. Once an electric current is imitated from the computerized algorithms the magnetic fields developed will either move in the direction to increase water flow or reduce water flow.

The water pump is a critical part of the system and it where the irrigation water to the greenhouses is collected before being dispersed in the water system. The pipes connect all the different parts that require water to move from place to the other, and the pump is the machine that will produce the kinetic energy to move water through the pipes. The software part of the system is majorly the computer-based elements. The computer where information is being sent to and from can be described as the control center. The processors that are present in the can be able to assess the potential error that has been obtained and provide a solution within seconds.

![Flow Chart](image)

**Figure 4** - Flow Charts of the Algorithms of the Automated System

Figure 4 on the previous page shows a simple tabulation of how the computerized system works. For the system to work algorithms have to be set that can be able to understand and evaluate the
data. The algorithms are set, and thus each action will be dependent on the code written for a specific error [11]. Figure 4 shows how every part of the system is controlled by a particular code. For any changes to occur in the system, the algorithms have to be amended, and as such when created they are developed in relation to specific soil composition and the plant that is to be grown.

![Figure 4- Programming of the System.](image)

The program chart indicated as figure-4 shows how each algorithm performs and is able to provide an outline of what actions are expected. The system uses sensors that have pore conductivity rods, and once they are connected to the electric pathway from the computerized source, the water levels in the soils can be measured by measuring the conductivity (ECP). The more the rods placed in the same type of soil the more reliable reading is obtained and thus having more than one sensor is needed [8]. The power source that I used is the same and does not need to be varied because almost all the products being used have the same central command. Once the pore conductivity is sent to the computer, the algorithms set identify it as an error if the expected conductivity is high or low. If the conductivity is low, the computerized system sends information to the power source of the solenoids, and from there magnetic fields regulates the valve to allow the flow of water and the pump is also initiated. Once the water is introduced into the soil, the sensors make a different reading of conductivity and once the appropriate amount of water is available the flow of water is restricted, and the pump is shut down. The system in totality is made up of various procedures and control actions that produce data and the data obtained becomes the action point for the whole process. Each part of the automated system is dependent on the reading or data obtained and the eventual algorithm present.

3. Test Set Up and Results

It is prudent that the efficiency of the system is tested and this can easily be done by putting the whole structure in a greenhouse and ensuring that the factors are key for the specific plant preset. In this evaluation, the plant in the greenhouse will be tomatoes. These specific plants need a lot of water in the initial stages and thus the algorithm set should include the median data at a high conductivity state.
Looking at the labeled Graph 1 It is clear on how the conductivity of the sensors will work when placed in a greenhouse with young tomatoes. The conductivity level in this particular case will be set at 1200 because the water level expected for this particular plant stands at 0.4 m$^3$. This means that once the algorithm is set to this particular code, it means that the data obtained will revolve around this information. When the evaporation rate increases this is quite bad for young tomatoes and as such this means that the soil is losing water, and the conductivity level will decrease to less than 1200, and this will lead to information being sent to the solenoid valves and water being pumped to the soil in order to attain the required soil content that is efficient for tomatoes. High humidity in the greenhouse will lead to opposite results, and this means that the water levels will increase and as such the conductivity level will also increase and the restriction will be made to the solenoid valve to restrict any flow of water. Once the soil is not watered for a while, the required soil content will be obtained.

Once everything is set up, and all the elements of the system are in order it is critical that data is analyzed to be able to effectively state whether the system is functional or not. Because what is being measured is a greenhouse, it is important to note that there will be a variety of other factors that will readily affect the way plants behave. Temperature and humidity are the core factors that are variable in the greenhouse, and it is critical that in this experiment they are maintained as constant as possible to get the appropriate readings [13]. The Digital signals of every company should also be addressed, and this can be presented in tabulation form to get great comparison data. At the start of the experiment, the amount of water that is in the tank should also be measured. This is critical because once the data is compared at the end of the experiment, it will be able to provide a conclusive report. The data that was obtained in regards to the conductivity level of the water in the soil as presented in the table below:

| Time   | Conductivity level |
|--------|-------------------|
| 6.am   | 1200              |
| 9.am   | 1000              |
| 12 pm  | 900               |
| 3 pm   | 900               |
| 7 pm   | 1200              |
| 11 pm  | 1300              |
Graph 2 can clearly show the increase and decrease of conductivity in the soil. The dynamic change in conductivity and reading the same results at two different times is also shown. The initial reading on the tank was also taken about the time when the conductivity level was collected. The tank level was taken about meters and was evaluated all through the day till the end of the experiment. This is shown in the table below:

Table 2. Tabulation Showing the Water Level in the Tank While the System Is In Operation

| Time   | Tank Level |
|--------|------------|
| 6 am   | 7.00 m     |
| 9 am   | 6.50 m     |
| 12 pm  | 5.00 m     |
| 3 pm   | 4.00 m     |
| 7 pm   | 4.00 m     |
| 11 pm  | 4.00 m     |

4. Discussion of Results
The findings that were obtained during the experiment needed to be evaluated to state if the system was working or not. In the evaluation of the conductivity level of the soil it was clear that it started at 1200 which was the median expected conductivity and in this case, the amount of water was still the same and had not changed from the initial marking. Three hours later at 9 am, the conductivity level stood at 1000 and the corresponding levels of water at that particular time in the tank had fallen from 700 centimeters to 650 centimeters. This is a notable difference, and it complemented the function of the system. What this change meant is that the system noted that the conductivity level of the soil had reduced and this was not good for the plants because it meant that the plant was missing the essential water required. The algorithms that were in the computerized systems and regulated the flow of water allowed water to be pumped from the tank and that is why the reading reduced because the water was used to bring the water level in the soil back to the required level. The data was analyzed three hours later, and the conductivity level was on the decline, this means other external factors such as heat were affecting the greenhouse. The data notably changes when it reaches 7 pm because the conductivity seems to be on the rise from 900 to 1200. Though there was a change in the conductivity level the amount of water in the tank did not change, and this is because the algorithm at this time restricted the flow of water because the water level in the soil was more than required at that particular time. The restriction will continue till the water levels go down and as such over-irrigation is avoided. The data from the valves also corresponded with the timelines where change was notable. For the solenoid whose
opening is affected by the amount electric-magnetic field, the valves opened when the water levels are down, and they closed when the amount of water was high. The pumping activity also corresponded with the decline of the water level in the tank. Once the valves were open to operate it, the pumps would fire up and vice versa. The data that was obtained was able to show that every part of the system is correlated with the other and as such the systems cannot be described as fully function if one part is amiss. The set algorithms are also key because they can readily be changed in regards to a particular plant. In this case, the tomatoes were the main crops and all through the function of the automated irrigation systems they were growing steadily and healthily.

The development of greenhouses was to increase efficiency in the growing of crops, and the implementation of irrigation was to boost yields even further. The concept of irrigation enabled growers to farm over large tracks of land, but the creation of an automated system is to introduce efficiency. The advantages of automated systems are great, and they can be seen in some ways: In the past growers were had to manually assess the water content in the soil and not every farmer is knowledgeable about such aspects, and their actions might lead to the destruction of crops. The automated system does not require a grower to continuously assess the state of the soil, but once the system is activated, it will operate in regards to the algorithms that have been set. Another key advantage is moderate use of water sources. During manual irrigation or natural irrigation, most growers would use water without a care in the world of whether it will end or not, but the automated irrigation system has changed that. It enables growers only to irrigate their farms when there is need to do so rather than spoiling water. A final critical advantage is that it can be used by any crop and implemented in any region. The core factors that allows this system to be able to be used in different crops is because of the use of different codes to assess the different conductivity level of the soil that the plant will be growing in. This also means that the system can also be used to monitor different crops in the same greenhouse to assess different crops one at a time the only variable that will need change is the algorithms.

There are two recommendations that I would like to pass along that will certainly make this automated systems to be more effective. The first recommendation is the inclusion of an alert system that can be able to communicate with the grower on what is happening even when the grower is away from the greenhouse through the use of texts or email. This will be able to enlighten the grower of the processes that are happening and can easily help one to realize when something is wrong. For example when the solenoid valve malfunctions and the grower is notified he can be able to respond as soon as possible and prevent the loss of the crops in the greenhouse. Another recommendation that I would pass along is the use of solar as the source of power and integrating it into the system. The use of electricity is quite a burdening financial activity which many growers cannot be able to maintain. The use of solar power to provide electricity can be helpful because it will ensure that many growers take up the system and cut down on financial expenditure. The automated irrigation system is quite an effective one, and I would encourage people who are in the greenhouse business to take it up and implement it. The future of this irrigation system is quite great.

5. Conclusion

In conclusion, the evidence that has been obtained supports that the use of automated systems is effective and can greatly lead to efficiency in the growing of crops in greenhouses. The constant prerequisite for nourishment in the ever-rising human population needs the quick change in sustenance, and this has come in the form of the automated irrigation systems that is to ease the stresses of growing different crops. The economy of scales in regards to being able to nourish the population is for the most part subject to agribusiness and the climate conditions. The main reason as to why the climate has changed and the natural lands cannot support the existence of man is because of the changes that man is making to the environment and as such the creation of different food production systems has become the main goal of growers. The automated systems of irrigation is a concept that cannot readily be under looked because it has clearly shown that it brings about more positive results than expected. In the past man had to evaluate the water content manually and this was not always effective, but such an automated system can give reliable results.
There are two recommendations that I would like to pass along that will certainly make this automated system to be more effective. The first recommendation is the inclusion of an alert system that can be able to communicate with the grower on what is happening even when the grower is away from the greenhouse through the use of texts or email. This will be able to enlighten the grower of the processes that are happening and can easily help one to realize when something is wrong. For example when the solenoid valve malfunctions and the grower is notified he can be able to respond as soon as possible and prevent the loss of the crops in the greenhouse. Another recommendation that I would pass along is the use of solar as the source of power and integrating it into the system. The use of electricity is quite a burdening financial activity which many growers cannot be able to maintain. The use of solar power to provide electricity can be helpful because it will ensure that many growers take up the system and cut down on financial expenditure. The automated irrigation system is quite an effective one, and I would encourage people who are in the greenhouse business to take it up and implement it.

The future of this irrigation system is quite great by obtaining methods to demonstrate humidity variations within the climate control designed model and with more pronounced control effects through improved field devices optimization.

6. Acknowledgment
I would sincerely like to thank the faculty of the Department of Mechanical Engineering at BITS Pilani Dubai Campus for their guidance and support that was instrumental in the presentation of this report.

7. Nomenclature
  - PAR Photosynthetically Active Radiation
  - HVAC Heating, Ventilation and Air Conditioning
  - DDC-Direct digital contro

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