IoT Based Intelligent Greenhouse Monitoring and Control System

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***Abstract*- Recently, Internet of Thing technology has been used to develop numerous applications, this paper compromising design and implementation of greenhouse prototype that integrated with the IoT to adjust the system's parameters and monitor the system status from any place in this world.**

This system involves three intelligent controllers that designed to stabilize the temperature degree, water level in soil, and light intensity inside the greenhouse prototype structure. These systems have been built by two important parts: the hardware and software.

The hardware part could be achieved by designing and implementing the control circuits, actuators, and install the sensors as well as the devices. The second one is the software part which is involves implementing Fuzzy Inference Engine that represent the system's brain that monitor and manage the entire process in the system to ensure the best performance. This system has been built to contain three control systems that means there are three different Fuzzy controllers. In order to keep the system practicality, the fuzzy controllers should be aggregated in single code that resides in single microcontroller chip with additional codes that perform the IoT duties.

The proposed IoT system provides the ability for specific people to monitor and manage their systems remotely, using a web application with cloud technology.

The major contributions of the proposed system are started by downloading the controller's set-points (the desired environmental conditions) from the web page, transfer the set-points to the controllers, and upload data that read from sensors to the same web page.)

Index Terms— The Greenhouse Technology, IoT Technology, Temperature Control, Fuzzy Controllers.
Introduction

I. Introduction

IoT Technology has been used to reduce the distance between the staff in the article "Things" and its digital impersonation in data frameworks. It's seen as the next-generation network (NGN) of the internet [1].

The IoT is driven by an extension of the Internet through the incorporation of physical articles joined with a capacity to provide more quick-witted administrations to the earth as more information ends up noticeably accessible. Several application areas going from Green-IT and vitality effectiveness to coordination's are now beginning to profit by Internet of Things ideas [2].

A Greenhouse provides basic methods for employment to its proprietor and must be financially pragmatic for the specific atmosphere in which it stands. Also, Greenhouse could be defined as advanced Innovation for Protected

Horticulture addresses the major natural elements of light, temperature, and irrigation [3].

This paper investigates the usefulness of using the IoT based on the greenhouse to utilize low-cost tools and decrease the effort of the Pleasants. This could be implemented by including the automation in irrigation process, conserving temperature, and the degree of brightness inside the greenhouse structure.

More recent attention has been focused on the provision of improvement on the Internet of things (IoT) and how to utilize it with the various applications. The IoT is interesting subject that recently whiteness very large number of papers that aimed to develop this technology. in next paragraphs, several papers about the greenhouse with IoT should be presented.

In 2013, C. wenshun et al. published a paper in which they described the structure of services platform, even operating layer, collecting, and control layer, arrange transport layer and etc. then described the functions of Zhuangluo sunlight greenhouse. Finally, how to run interface and working condition of the system[4].

In 2015, L. Dan et al. presented their paper that centered on using the CC2530 as core chip and introduces a monitoring system design for greenhouse depends on the ZigBee technology. A terminal node sends the temperature to intermediate node by the wireless network, and this node collects all data and sends them to the PC [5].

T. Quynh et al. (2015) suggest an article that analyzes various models of greenhouse in Vietnam and monitoring parameters required and proposes to apply single-path and multiple-path routing protocol in order to improve the IoT monitoring performance[6].

J. Zhao et al. (2010) proposes a paper that studies the integration of control networks and information networks in IoT in practical agriculture production. They also suggest a method that combines the remote monitoring system and wireless communications [7].

This paper has been written to show that IoT save peasants efforts and make the work much easier when the IoT used in Greenhouse applications. Also, this paper tries to provide a solution for some network problems such as dynamic Internet Protocol (IP) and global IP.

The proposed greenhouse has been implemented with three intelligent control systems. These system could be controlled by an intelligent Fuzzy controllers that providing the best performance. The Fuzzy controllers must be resided completely inside Microcontroller chip without require any extra processing. This development feature leads to the more sophisticated improvements of fuzzy systems in practical environments.

II. The Proposed Greenhouse System

Recently, the developments in the field of the IoT technology have led to renewed interest in developing the greenhouse technology. The pleasant was complaints from several things such as keep track the irrigation process and having to do it manually. Also, the plants may suffer from bad circumstances like temperature and light. The major objective of this paper is to develop practical smart greenhouse with three intelligent control systems in order to obtain suitable circumstances. The proposed system has the ability to monitor and control the greenhouse from any place in the world. Fig. 1 depicts the block diagram of the entire system.

The overall designed system could be divided into three important parts; hardware, software, and IoT structure.

A. Hardware Design:

The system compromises numerous tools that are utilized to obtain the desired system. The tools are explained in two sections (Sensing and Actuators):

a) Sensing:

In order to apply the automation process on a given system, sensors are required. The adopted intelligent control system is fed by sensor information. Several types of sensors are used including:

1) *Temperature and Humidity sensor (Htd11):* is new advanced temperature moistness sensor that has many favorable circumstances, for example, small size, basic interface, quick reaction, and inexpensiveness[8].

2) *The Soil humidity Sensor uses capacitance*: measure the water in a soil by computing the dielectric tolerance of the soil, which is a component of the water [9].

3) *A Light Dependent Resistor (LDR) or a photograph resistor:* is a gadget whose resistivity is a component of the occurrence electromagnetic radiation. Subsequently, they are light sensitivity gadgets[10].

b) Actuators:

The actuators could be defined as system that receive control signal that categorized as low power signal usually generated by the microcontroller to operate the devices that require high Energy that may be voltage or currents

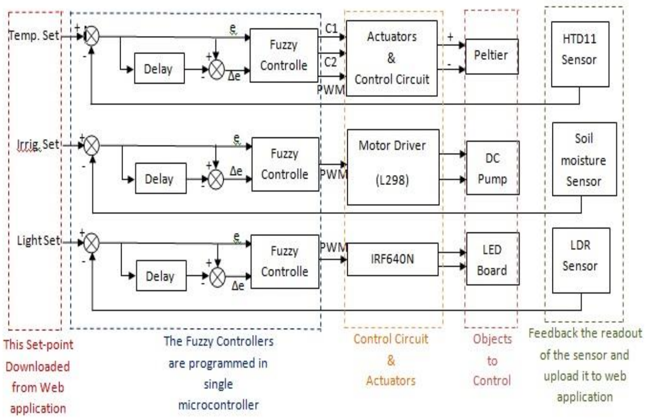

Fig. 1 Block diagram of the Greenhouse system.

The first system is Cooling/Heating system, the device wanted to be controlled is the Thermo-electric cooler (Peltier). This device operates on 12 VDC, the Peltier gives warming in a specific direction of current and in opposite direction gives cooling. The amount of heating or cooling depends on the current value and direction that passes to the Peltier.

In order to satisfy the above conditions a design of control circuit that was shown in Fig.2. This control circuit gives suitable polarity and passing the required amount of current by using Mosfet IRF640N.

The second system is the irrigation system. The DC pump/Motor required to be controlled in this system. The pump operates on 12 VDC, but the difference in this system needs much less current than Peltier. For that purpose, L298 Motor driver are adopted, which provide 2 amperes as a maximum. Fig. 3 shows the circuit that used to control the Pump.

The third system is the Light system. The object should be controlled is LED board, which operate on 5 VDC. In this situation is the same voltage of the microcontroller, but if the LED Board drawing current more than the ability of microcontroller. To protect the microcontroller, a Mosfet IRF640N is utilized to drive the LED board. Fig. 4 clarifies the control circuit for lighting LED board.

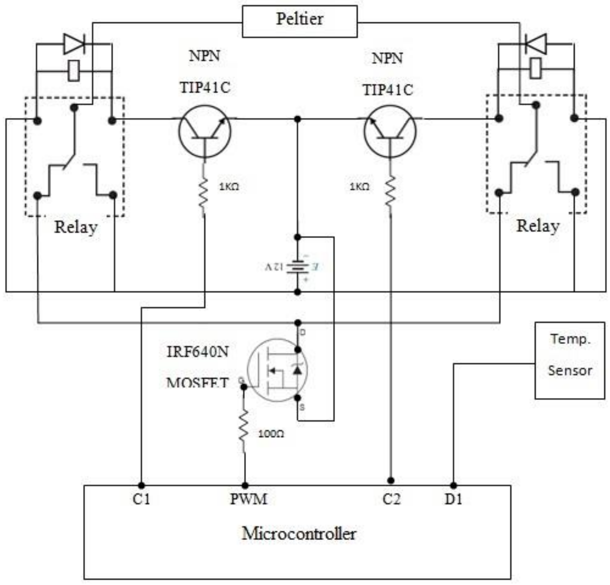

Fig. 2 Peltier's Control Circuit.

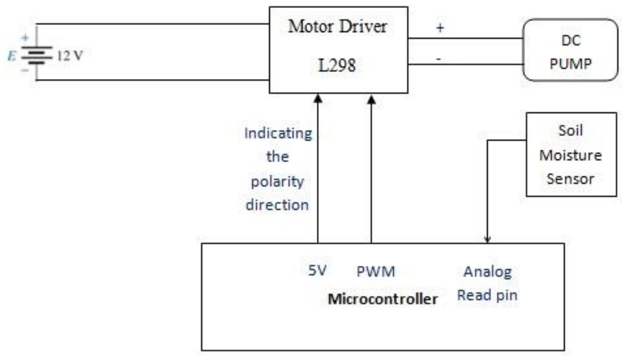

Fig. 3 Pump's Control Circuit.

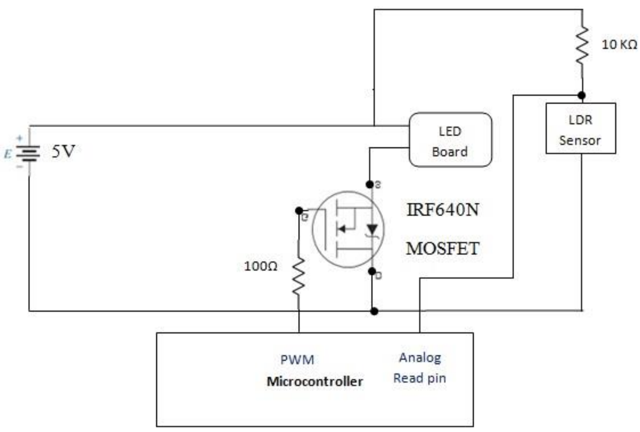

Fig. 4 Light Control Circuit.

The prescribed control circuits have been implemented in real world. Fig.s (5,6, and 7) have been shown the complete hardware system.

The irrigation system has been depicted in Fig. 5. Fig. 6 shows the hardware implementation of the light control system. The temperature control system with actuators and wiring should be illustrated in Fig.7.

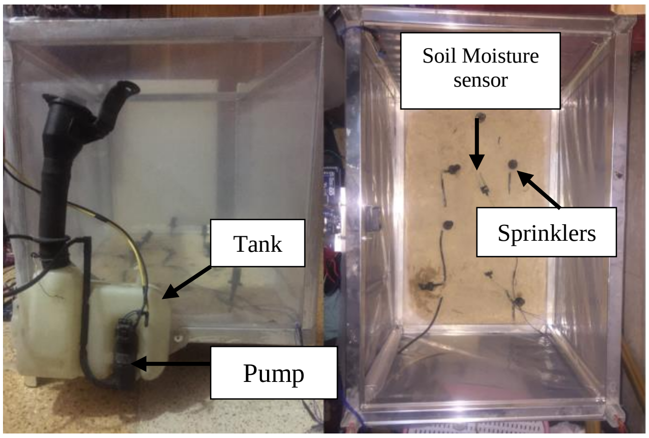

Fig. 5 Irrigation system and sprinklers.

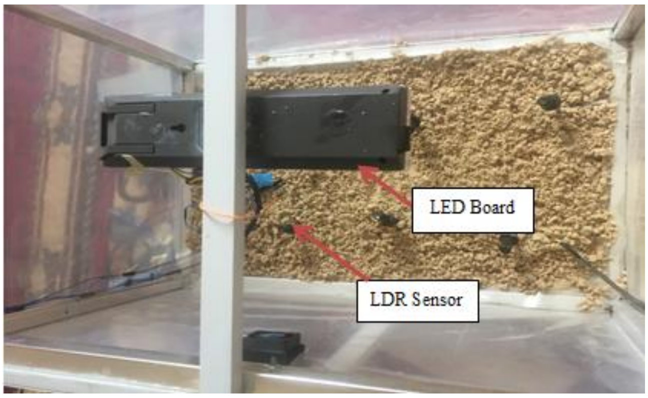

Fig. 6 LED Board and LDR sensor.

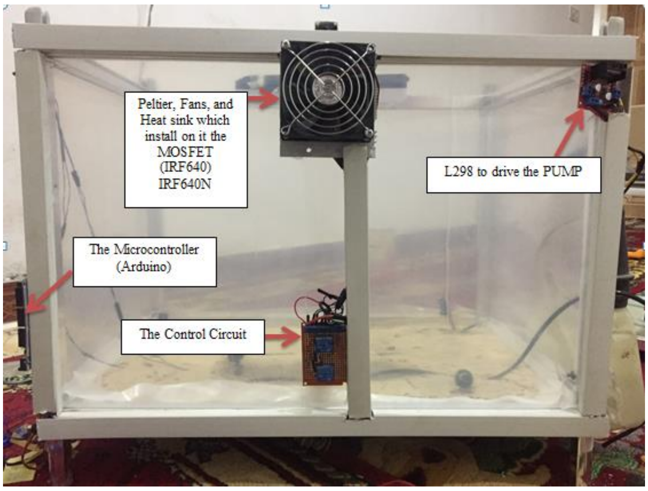

Fig. 7 The Front-side of the implemented system.

B. Software Design (Fuzzy Controllers):

The proposed system uses fuzzy controllers, which is effective in numerous control issues, which may have a problem if managed the system by using direct methods. The fuzzy logic controllers depend on expert's knowledge or trial and error. Because of the linguistic expression of the fuzzy controller, it has not been anything but difficult to ensure the stability and robustness of the fuzzy control frameworks. The Fuzzy controllers are designed and programmed in the single microcontroller, the execution should be sequentially and pass the required information for each fuzzy controller. In this paper, three fuzzy control systems are implemented (Temperature Control System, Irrigation Control System, and Light Control System).

a) Temperature Control System:

The fuzzy controller manages the whole process, to ensure the best performance and stability for the control system. This fuzzy controller is designed to accept two inputs; error (Err) and change in error (ΔErr). The (Err) is generated from the difference between the set-point and the actual temperature. While the change of error (ΔErr), is the difference between the current Err and the previous Err. The Err and ΔErr both have 5 triangle membership functions (NB, NS, Z, PS, PB). And the universe of discourse for Err is (-10 ~ 10) and for ΔErr is (-5 ~ 5). The fuzzy output is the (PWM), that has 5 triangle membership functions (HC, LC, Z, LH, HH). The universe of discourse is (-255 ~ 255). The concluded fuzzy output is produced according to its inputs. When the output is negative, this means cooling is required, otherwise heating is required. The prescribed feature help the system to give suitable polarity which should give the required action (cooling or heating), and the output represents the PWM that control the amount of current should pass to the Peltier. Fig. 8 shows the flowchart of the cooling/heating system.

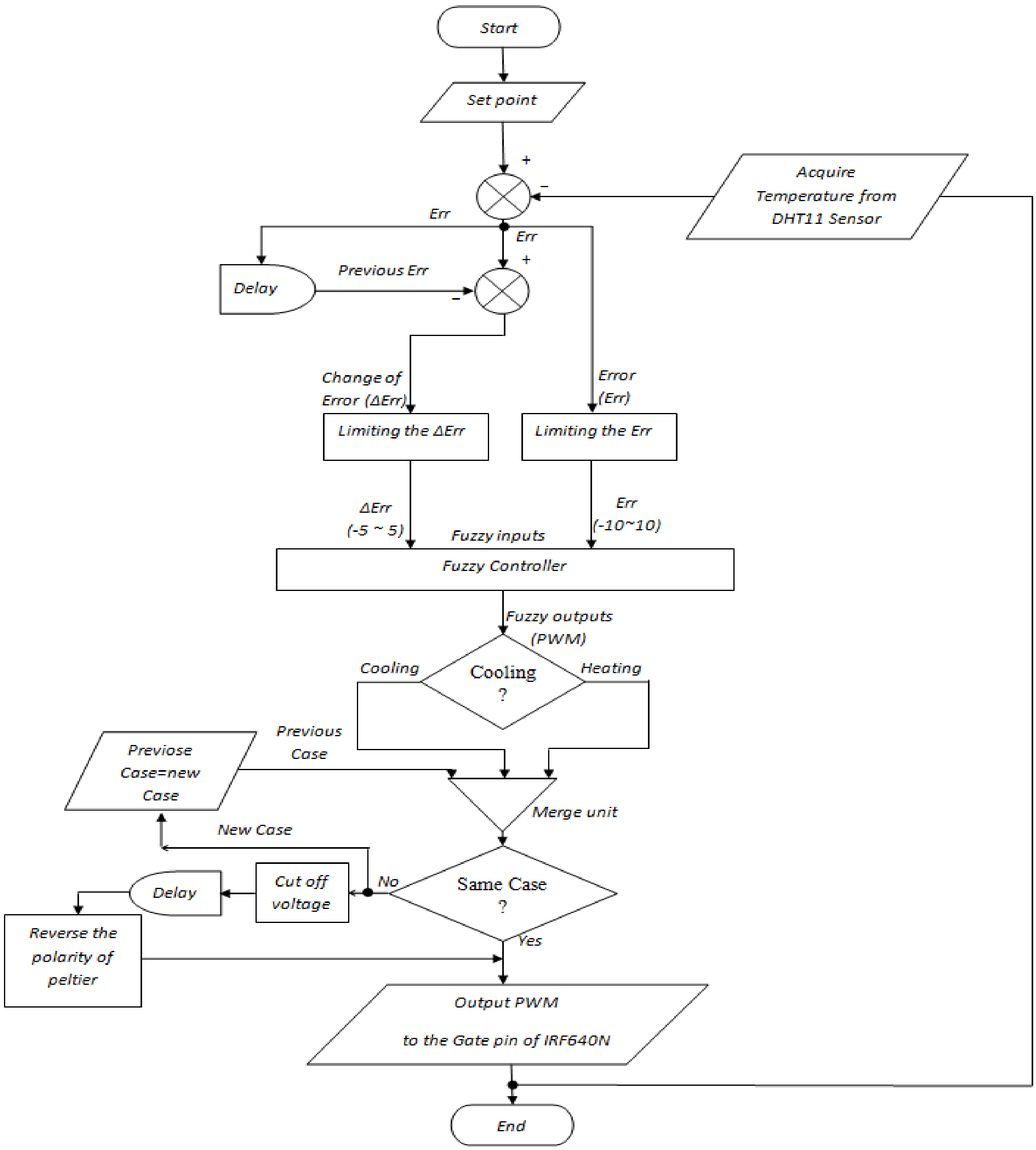

Fig. 8 Flow operation of The Cooling/Heating System.

b) Irrigation Control System:

The aim of the Irrigation control system is to stabilize the humidity of the soil in an efficient way. The hardware managed by the fuzzy controller that has two inputs (Err and ΔErr). Both the Err and ΔErr have 5 triangle membership functions (NB, NS, Z, PS, PB). The universe of discourse for both Err and ΔErr is (-5 ~ 5) and (-2 ~ 2) respectively. The output is (PWM) also represented with 5 membership functions (VL, L, M, H, VH), and the universe of discourse is (0 ~ 255).

At the moment that the fuzzy controller produce value less than 150 V as Pulse Width Modulate (PWM) , Motor Driver (L298) would apply voltage that couldn't operate the Motor (Pump) in appropriate manner to push water. In order to solve that, this problem should be taken in consideration when designing the fuzzy controllers. The fuzzy controllers will produce PWM that equal to 150 or less if the desired water level in soil has been satisfied.

The flow operation of the irrigation control system is illustrated in Fig. 9.

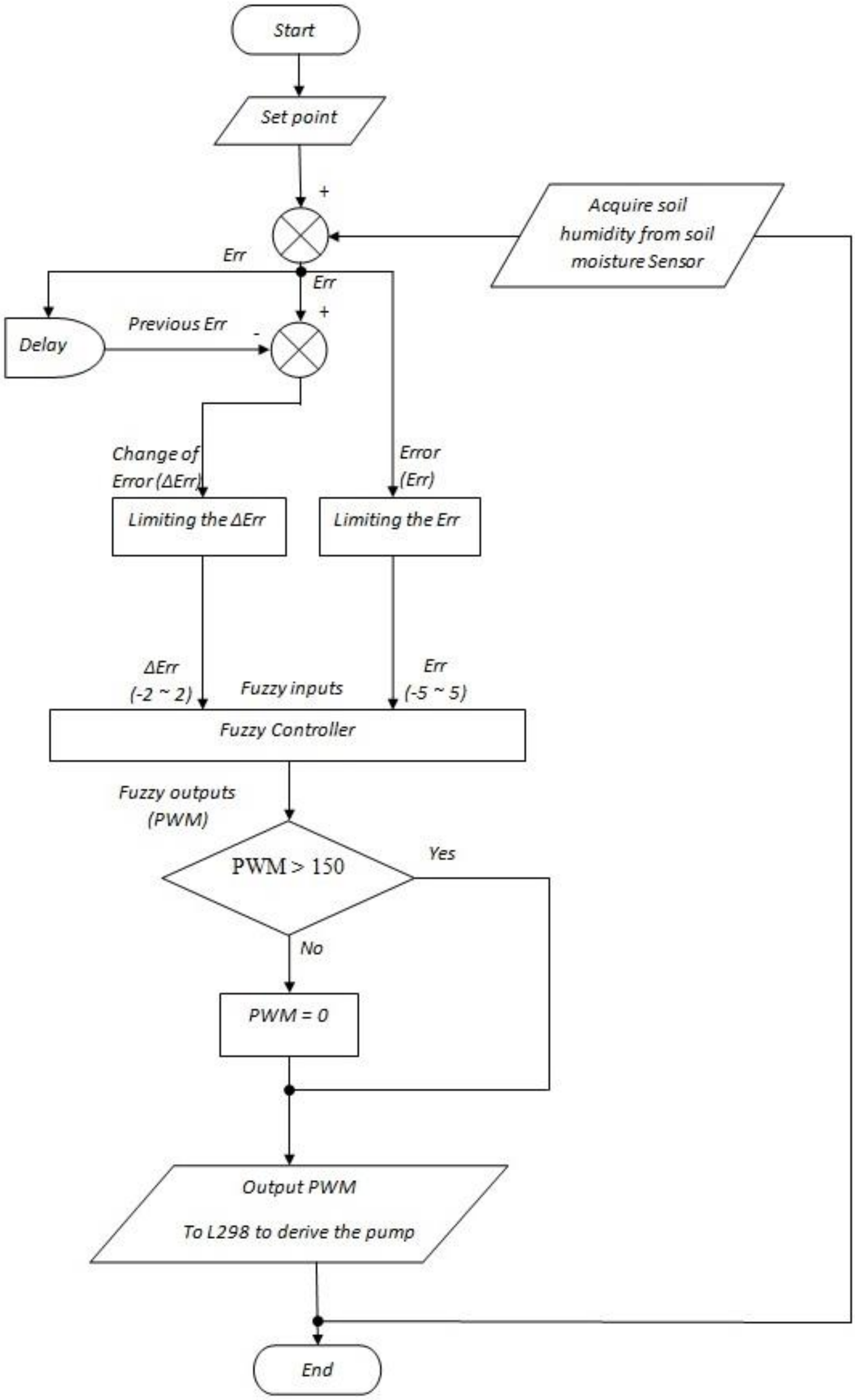

Fig. 9 Flow operation of Irrigation control system.

c) Light Control System:

The aim of the Light control system is to establish the intended brightness in a specific range, which helps the plants in the photosynthesis. The Fuzzy controller is managing the entire process in order to get the best performance, high efficiency, and stable system. The Fuzzy controller has two inputs (Err and ΔErr), the Err and ΔErr both have 5 triangle membership functions (VL, L, M, D, VD) and (NB, NS, Z, PS, PB) respectively. The universe of discourses for both the Err and ΔErr is (-1023 ~ 1023) and (-200 ~ 200) respectively, while the output has 3 membership functions (L, M, H) and the universe of discourse is (0 ~ 255). This output represents the PWM signal to drive the LED Board to obtain the required illumination. Fig. 10 shows the flow operation of the light control system.

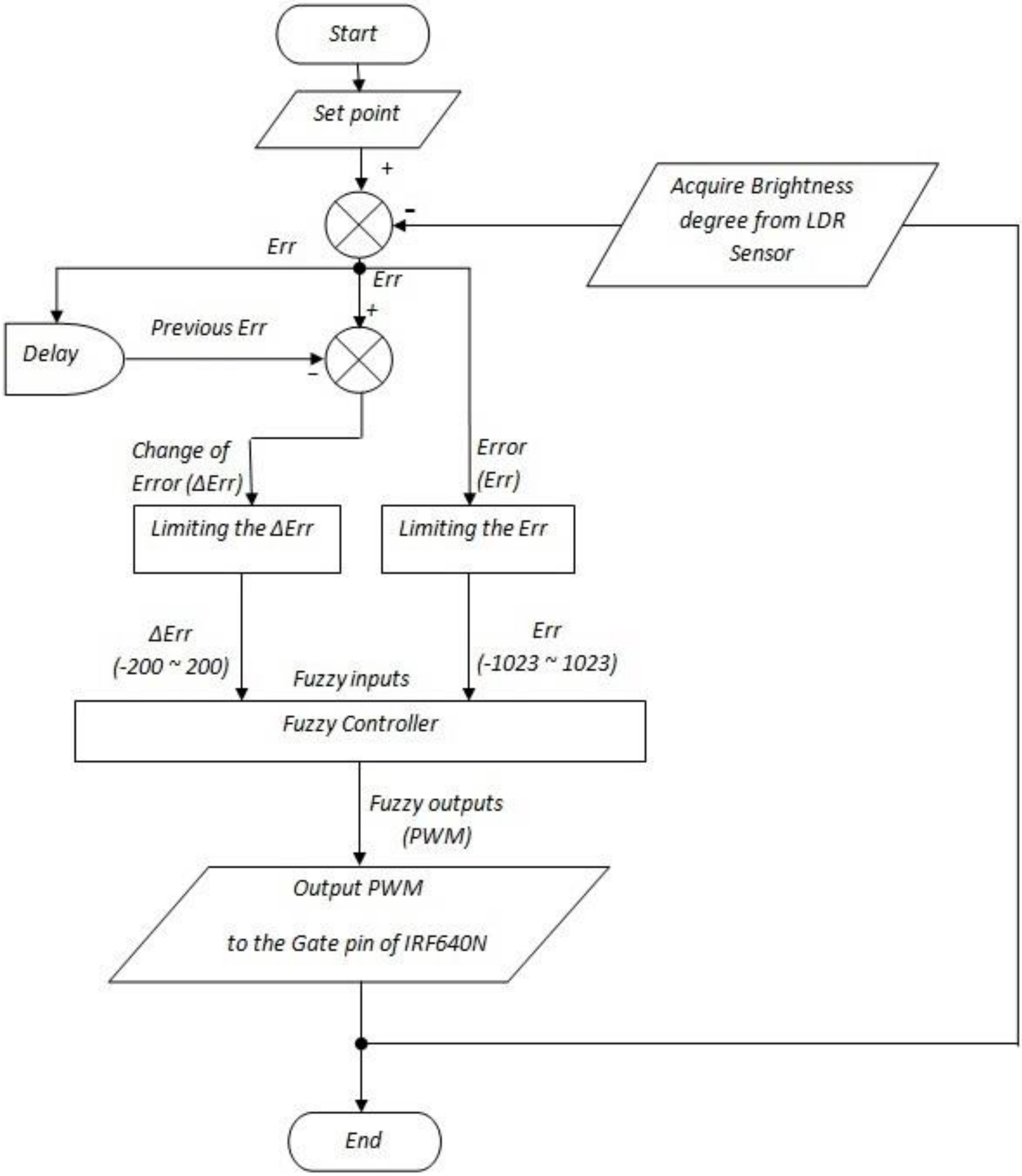

Fig. 10 The flow operation of the Light control system.

C. The IoT Structure:

In recent years, a large number of IoT interest papers have been published. IoT acts as the main role in technology development. The IoT introduces numerous facilities in any field that may use it. This paper focusing on using IoT in the greenhouse as previously explained, the proposed greenhouse had three intelligent systems. The function of IoT in this work gives the pleasant the ability to monitor and control their greenhouses remotely.

To make the work of IoT easy to understand, Fig. 11 provide an imagination about how the IoT work in upload and download data and deliver it to the control systems.

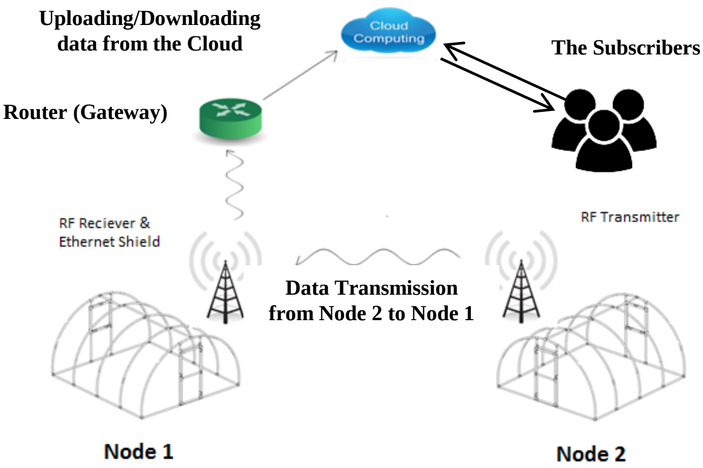

Fig. 11 The upload and download data operation.

To achieve the IoT system that could perform the functions that has been illustrated in Fig. 11, there are some programs and techniques should be employed:

a) Design a web application:

The First step was designing a web page to display the information for the user. The web page should be easy to use, attractive, and has a simple HTML code in order to speed up the execution of functions of the web page.

The designed web application is important to be secured with Username and password for each user. Also, the permissions of each member are different, a part of members are authorized to access, monitor, and control the systems as shown in Fig. 12.

While the other part has the ability to access and monitor the state of the systems as shown in Fig. 13.

a) The cloud technology:

The real problem faced in this project as especial case and in IoT as general case is centered on the public Internet address (IP). This is a big problem facing the developers of IoT. However, there are several solutions; one of them is the use of cloud technology.

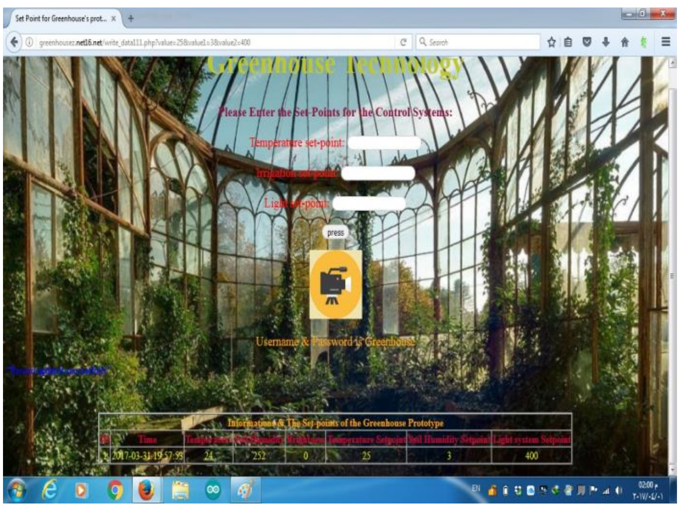

Fig. 12 The web application: control and monitor.

Fig. 13 The web page: monitor.

There are several companies offer to the developers a space on their servers and give them a domain name. This domain name gives the ability to the developers to access their server from anywhere in the world. In this work, the 000webhost is selected, in which the website code and additional files of PHP and MySQL are uploaded by Filezilla program to a 000webhost server.

b) Local communications of nodes:

In order to make several nodes capable to connect to internet and download the set-points and upload their system status, the master-slave technique could be used. The master would be defined as node that has the ability to connect to the public internet by the Ethernet to download/upload the nodes data. Also, the master node communicate locally with others node by using the RF Transmitter. While, the slave node is only communicate with slave node to send their status and receive the set-point that specified for its control system.

c) Remotely Management and Monitor the system's status:

In this article, attempt to construct a prototype IoT, using simple, cheap, and available tools. To apply the IoT in a practical application, there are many tools should be employed like Ethernet Arduino Shield and Arduino microcontroller.

The Ethernet plays as the main tool which makes a connection between the greenhouse and the router that acts as a gateway. The first step was programming the microcontroller to make a link between the greenhouse and the server, to be more accurate with the PHP files that should be resided on the server. The PHP file function fetches the data send through the link from the greenhouse and store it in MySQL table. The link established by HTTP request, which is issued by the microcontrollers.

The download data is accomplished by multiple HTTP requests from the greenhouse to the server. The response of the server has returned the code to the source (microcontroller) of the request. The microcontroller will receive the server's response and store it in buffers, then start to looking for the intended parameters that used for managing. In this project is considered as set-points whose utilize to drive the intelligent control systems that explained previously.

The last feature in this IoT system is the utilization of the IP camera to offer an online monitoring for the greenhouses, there is an icon in Fig. 12 and Fig. 13 referred to the camera which enables the pleasant to watch their plants online.

The problem faced the developers is the dynamic IP that changes every time after the router reboot. In order to solve that, NO-IP website could be used to obtain a dynamic domain name. This domain name should be set-up in the router, after that the domain name will hold the public IP of user router even if it changed (dynamic IP).

III. Results

After completing the prescribed work and make sure of the correct execution in acceptable time. The implementation is divided into several parts:

The first part was building the control systems (Hardware implementation and Fuzzy controller), the execution of the fuzzy controllers and managed the control systems was completely inside the microcontroller. The next section will present some result of an experiment on the control systems. The results of the cooling/heating system are depicted in Fig. 14.

The set-point is 25° C and the starting temperature is 35° C. The case here is cooling, then put the appropriate polarity on the terminals of the Peltier, then output the PWM signal on Mosfet 640N to control the amount of current in result control on the heating produced and reaches the desired temperature in acceptable time.

The result in Fig. 15 shows the response of the irrigation control system. The result in Fig. 16 illustrates the response of the system and how the system reaches the desired brightness degree in specific time.

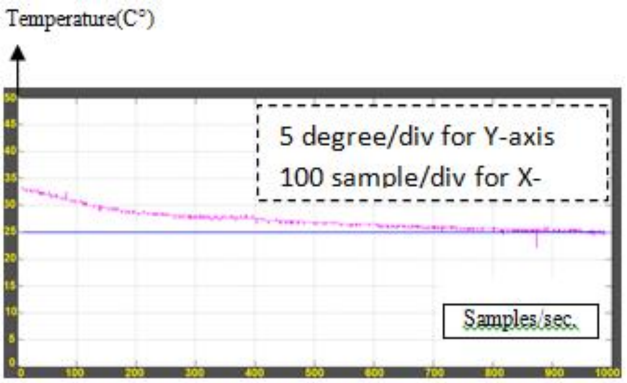

Fig. 14 Set-Point is 25° and the initial value is 35°

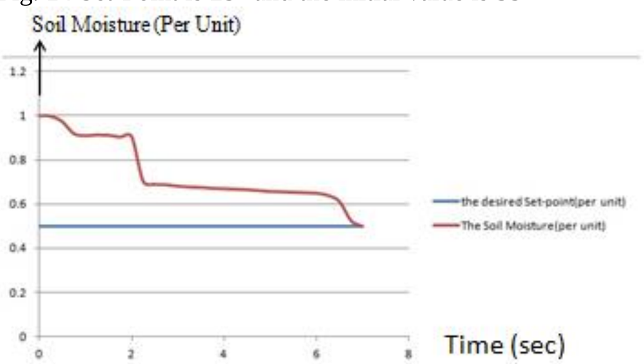

Fig. 15 The set-point is 0.5 and system response.

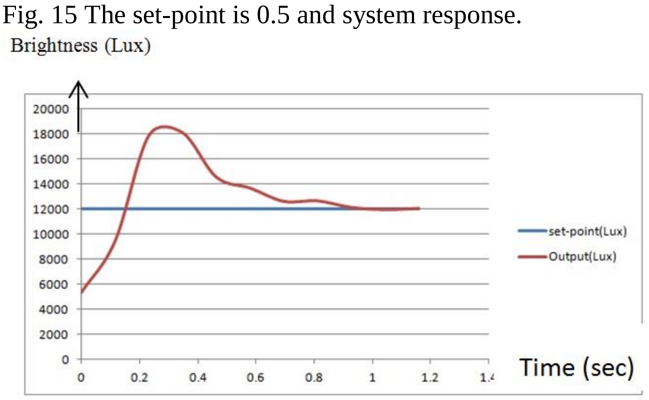

Fig. 16 the system response of light system control.

The second part was making the system able to download the set-points from the website; this could be accomplished by utilizing the microcontroller plus Ethernet shield. The third part provided a feature of upload the system's data on the website. Also, this function used the microcontroller and the Ethernet shield. Then should collect all the parts in one system, and employ a principle of execution technique to ensure high-performance and efficient system and no conflict in execution that may lead to deadlock. Fig. 17 had shown the entire result of the system.

As illustrated in Fig. 17, the system starts to work by downloading the set-points from the web application. After that, operate the cooling/heating system, the irrigation system, and the lighting system depending on the set-points. Finally, upload the readout of the sensor to the web application.

In order to calculate the system sampling time, each system should be determined individually. The temperature control system, irrigation control system, and light intensity control system are take 308, 259, and 115 msec respectively as shown in Fig. 17.

While, the IoT could be determined according the results that depicted in Table 1.

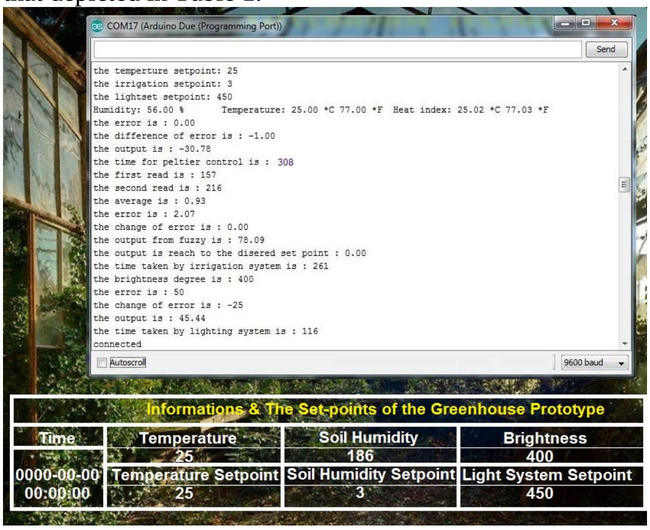

Fig. 17 The entire performance of the system.

TABLE1 The IoT's Time calculations

No.	Time of Action	Time to Downloading Set-points	Time To Uploading the System Status
1	10:32 PM	220 msec.	1178 msec.
2	12:06 AM	357 msec.	1572 msec.
3	08:31 PM	188 msec.	1152 msec.

The time average to download set-points is 255 msec, and the time's average for upload system's status is 1300 msec.

The overall system sampling time could be calculated as (308+259+115+255+1300) which is approximately equal to 2237 msec.

In order to integrate the IP Camera within the web-application that has been designed, this technique could be accomplished by employing the dynamic domain name that hold the public IP of the gateway (Router), which is connected to the IP Camera physically. This dynamic domain name should be configured in the router. In order to redirect the requests to the IP Camera port by use the forwarding ports. As a result, the peasant will be able to monitor the status of the plants inside the greenhouse in real time. Fig. 18 displays the result of employ the IP Camera.

IV. Conclusion

After completing the implementation (Hardware and Software) of the intelligent greenhouse, the resulting prototype has numerous advantages like employing three intelligent control systems (Cooling/Heating System, Irrigation Control System, Light Control System).

These control systems are managed by Fuzzy controllers which designed and programmed inside the microcontroller (standalone) without requiring any external processing, this provides the ability to describe the system as practical system. Also, the IoT provide features that may make the works of the peasant much easier by enable them to monitor their plants and make a suitable decision by

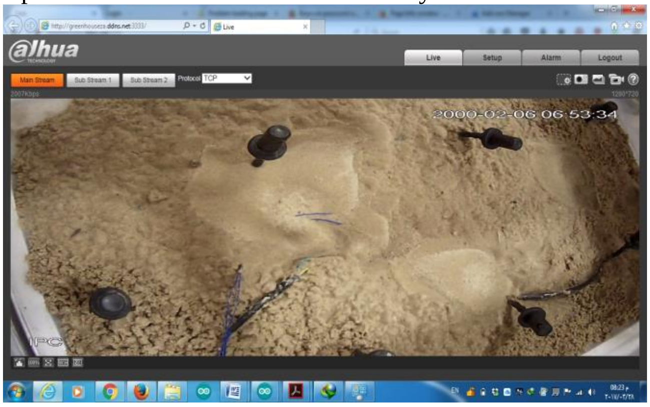

Fig. 18 IP Camera's display the internal view of the greenhouse.

Adjusting the set-points to accommodate any changes may effect on growing the plants. This work compromised attempts to found solutions for the Global IP, Dynamic IP, and blocking ports by ISP companies. The Global IP can come over it when using cloud technology, the dynamic IP can solve by using NO-IP or DDNS, etc.

The weak points in this works could be described as follow:

The IoT depend on the public internet to deliver its data, so that it could be effected directly by the internet problems such congestion.

Also, the LDR has been used as light intensity sensor. This tool may produce unprecise result and that may effect on the overall system performance such as the overshot that appear in Fig.16.

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