Monitoring and Controlling of Distributed Modern Greenhouses Using Combined WSN and Mobile Network: Case Study in Jordan

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Abstract – **Automated greenhouse is an emerging technology that aims to control the environmental conditions inside the greenhouse in order to provide the plants with the ideal living conditions, and therefore, the best crops yields are achieved. In this paper, a new automated greenhouse approach is proposed to monitor and control distributed greenhouses. A combined wireless sensor network and cellular mobile network are used in this approach to achieve reliable and secure communications between the farmer and the greenhouses. The experiment was conducted in Jordan over tomato plants. The results show that farmers can monitor and control multiple greenhouses and the plants can live in ideal conditions.**

***Index terms* – Automated greenhouses, Environmental conditions monitoring, Wireless sensor network (WSN), Cellular mobile network.**

I. INTRODUCTION

Protected cultivation or greenhouses was developed to protect crops from adverse weather conditions allowing improved crop yields and effective control over pests and diseases [1]. Greenhouses are now spread throughout the world with large areas. The designs, dimensions, and technologies of greenhouses depend on local weather conditions and the socio-economic environment.

It has been shown, through research, that several factors should be controlled inside greenhouses so that plants will live in their ideal conditions, and therefore, improved quality and productivity of crops are achieved [1]. Such factors are: humidity, temperature, light, irrigation, and carbon dioxide (CO_2) level inside the house. All these factors together are essential for plants life cycle. Monitoring such variables gives an insight to the farmer about the plants and how to manage and adjust these variables to maximize the productivity.

Since it was first established, greenhouses were human-controlled [2]. Controlling living conditions was developed through trial and error. Through practice, controlling became experience. In early years, there were no scientific techniques to measure living conditions [3]. Therefore, the outcomes from using greenhouses were not satisfactory, so finding alternative ways of controlling greenhouses became demanding.

The innovation of modern or automated greenhouses is considered as a breakthrough to agriculture sector [2]. Despite the shapes or the sizes of greenhouses, the principle of using automated greenhouses is to observe the environmental conditions inside the house and take actions if one or more of such conditions drops above or below certain level. Sensors are basically the best choice to provide accurate readings of heat, humidity, light, and carbon dioxide level [3]. Sensors are small in size and consume less power.

First automated greenhouses used distributed sensors that were connected to a central computing unit via cables [3]. This simple approach was acceptable for small-sized greenhouses that require information from one location inside. In modern greenhouses, where the size is much bigger than before, more sensors are required. Wiring between sensors during installation becomes difficult, time consuming, and also costly. Wireless sensors are the suitable alternative [3]. It can be distributed over large areas and connected wirelessly to the central management unit. Moreover, the installation of wireless sensors is simple, it is also cheap, and easy to relocate and maintain.

In this paper, a new automated greenhouse approach is presented and tested to be suitable for agriculture in Jordan. This approach was tested for growing tomato in multiple greenhouses such that distributed wireless sensors, GSM modules, and mobile application facilitate the task of monitoring and controlling such greenhouses. In the following subsections, a brief overview about the agriculture in Jordan is presented. Also, it highlights the distinct weather and the importance of using greenhouses in Jordan.

A. Agriculture in Jordan

The Agricultural Sector in Jordan is one of the most important economic sectors that contributes to employing manpower, and its revenue is the main source of income for people involved in agriculture and their families. It also provides basic products for human consumption [4].

Jordan is a relatively small country with a total land area of about 96000 km^2 [4]. It consists of three distinct climatic zones; the Jordan valley, mountain heights plateau, and the desert region. The last zone constitutes about 75% of the total land area of Jordan. Jordan's weather consists of four seasons: autumn, winter, spring, and summer. It is a very sunny country, with over 310 days of sunshine a year. The weather is almost dry and sunny from May to October, where there is barely any rainfall. Summers are hot with low humidity in the mountain heights with daytime temperatures frequently exceeding 36°C and averaging about 32°C, while nights are almost cool. In the Jordan valley, summers can be very hot with temperatures reaching into the low forties on some occasions.

Most of Jordan's desert receives less than 120 mm of rain a year, while the average rainfall in the mountain heights ranges between 300 to 600 mm a year [5]. The rainy season begins at the end of November and continues till the end of March. The coldest months of the year are December and January, where the temperatures average about 13 degrees Celsius but can drop to around -5 degrees. In areas with an altitude of 1000 meters and above, there is a chance of snowfall in winter.

TABLE 1: AVERAGE TEMPERTURE, PRECIPITATION, AND HUMIDITY FOR THE YEAR IN JORDAN. [5]

Month	*Average Temperature* [°C]	*Average Precipitation* [mm]	*Relative Humidity* [%]
January	8.8	21.7	69.8
February	1.3	19.2	66.4
March	13.8	14.1	51.4
April	18.7	6	45.2
May	23.1	2.7	35.3
June	26.3	0.5	35.1
July	28.1	0.7	37.5
August	28.3	0.7	38.7
September	25.8	0.2	42.8
October	22	3.8	42.7
November	15.4	8.3	56.1
December	10.6	15.3	66.1

The Department of Statistics (DoS) in Jordan implemented several agricultural surveys to obtain basic information on all-seasons crops, planted areas, quantities of products, and other valuable information. According to the DoS and the most recent General Agricultural Census 2007 (GAC 2007) [5], 23.4% of agricultural products is vegetables, which occupies 18.2% of the total area of land used for planting. Since the average precipitation in Jordan is low, and it is unlikely to rain between May and October, 95.2% of the total vegetables product depends on irrigation from natural water resources. The most popular crop in Jordan is tomato. The percentage of the area that is exploited to grow tomato to other vegetables is 31.1%.

The GAC 2007 also shows that the number of greenhouses in Jordan is 46522, which occupies 7.6% of the total area of agriculture. Also, 5.7% of these greenhouses are used to grow tomato.

B. Related Works

Recent researches that concern automated greenhouses have adopted several modern techniques in order to achieve optimum environmental conditions and therefore, higher crops productivity.

Regarding the position of sensors in modern greenhouses, Lin et al [6] use CFD simulator to find the optimal place of temperature sensor. They generalized their work to the rest of environmental sensors.

Teemu et al [7] developed a wireless sensor node for greenhouse monitoring by integrating a sensor platform with three commercial sensors capable to measure four climate variables. The sensors were connected to a gateway node, which was connected to a central computer via USB cable. The feasibility of the approach was tested by deploying a simple sensor measurement points. Wiemin et al [8] designed intelligent greenhouse environment monitoring control system which is based on ZigBee and embedded technologies. The real-time data from the greenhouse can be viewed at a central computer.

Eredics et al [9] developed neural model for intelligent greenhouse based on deployed wireless sensors. Zhao et al [10] proposed a solution to remote greenhouse environmental monitoring which is based on GSM technology and RF. The system constitutes the regional environmental information monitoring network and close communication platform based on radio frequency. Combined with the remote communication technology based on GSM networks, the system implements small and medium-sized greenhouse environmental monitoring.

Most research has common approach of acquiring data from wireless sensors, collecting it through a gateway, and finally sending it to a central computing unit.

In this research, a new automated greenhouse approach is presented. This approach was applied for two greenhouses and can be generalized to more than two. Farmers can monitor and control the greenhouse inside environment using distributed wireless sensors, controllers, GSM module, and a mobile application. In this approach, the farmer has the choice to control the greenhouse automatically or manually. In the following section, the system model for the new approach is described in details.

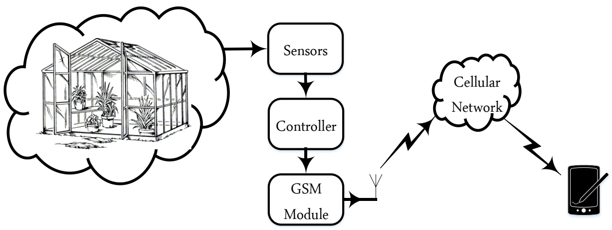
II. SYSTEM MODEL

This approach consists of three main processes: data acquisition, monitoring, and controlling, as shown in Figure 1.

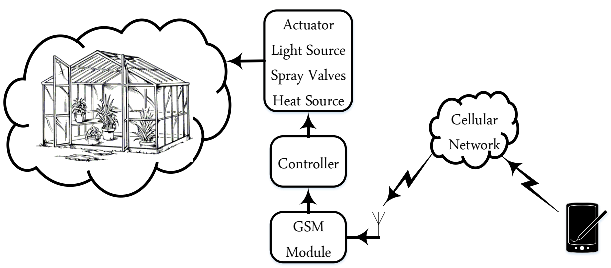
A. Data Acquisition

The data acquisition process of the environmental conditions inside the house (i.e. humidity, temperature, light intensity, irrigation, and CO_2 level) is achieved using distributed wireless sensors. The readings for each environmental condition are taken from three sensors at three different locations inside the greenhouse and averaged to ensure that more accurate readings are obtained. Moreover, the real-time data are taken every 10 minutes period to save the power of the sensors. The readings can also be taken anytime upon the user request.

The wireless sensors used in this paper are made by Monnet Company [11]. They are: light intensity sensor, temperature sensor, humidity sensor, irrigation sensor, and CO_2 sensor. All sensors have wireless capability to forward the readings to the gateway (i.e. the controller) wirelessly. The wireless light intensity detector measures the light intensity inside the greenhouse. The sensor has ±1% accuracy. The wireless humidity sensor allows monitoring the relative humidity of the air within the greenhouse with ±3% accuracy. The wireless temperature sensor is placed inside the green house to measure the temperature. The sensor has accuracy of ±1°C. The irrigation sensor, wireless water rope, measures the amount of water in the soil of at the greenhouse. Finally, the CO_2 sensor measures the concentration of CO_2 gas inside the house. All sensors operate at 868MHz, and the range of transmission of each sensor is between 75 – 90 m non-line-of-sight.



(a)



(b)

Figure 1: (a) Data acquisition and monitoring processes (b) Controlling process

B. Monitoring

When the real-time readings from the distributed sensors are obtained, it is then collected via a centralized controller that forwards such readings to a GSM module. The GSM module works as a bidirectional gateway between the greenhouse and the farmer. It ensures that the communications is made properly and remotely between the farmer and a particular greenhouse.

The microcontroller used in this paper is based on the ATmega1280. It has 54 digital input/output pins of which 14 can be used as PWM outputs, 16 analog inputs, 4 hardware serial ports UARTs, and a 16 MHz crystal oscillator.

Moreover, the GSM module used in this paper is SIM908 module. It is a complete Quad-Band GSM/GPRS module (850/900/1800/1900 MHz) that combines GPS technology for satellite navigation. The module can be controlled via AT commands, and can be operated at temperature from -40°C to +85 °C.

C. Controlling

The readings from the greenhouse allow the farmer to monitor and overcome any undesired changes in the environmental conditions by controlling; light sources, heat sources, customized windows and doors, and finally, water spays around the plants.

In this approach, controlling the greenhouse can be made either manually or automatically. Manual controlling is made when the farmer chooses to overcome any undesired changes in the houses based on the readings from the distributed sensors. He may choose not to change the inside environment. Automatic controlling, on the other hand, is achieved by programming the controller to handle any undesired changes and the farmer is just monitoring the environmental conditions.

D. Mobile Application

Both monitoring and controlling is initiated using mobile application. This application is developed under Android environment. The access to the greenhouse controller is made through the GSM module that is connected to the greenhouse. The application starts by asking for the phone number for that particular GSM module as shown in Figure 2.

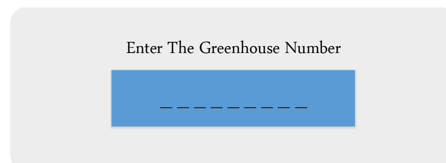


Figure 2: The mobile application requests the desired greenhouse number.

When the phone number is entered, the mobile application asks the user to choose either to control the greenhouse manually or automatically.

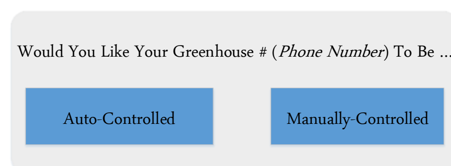


Figure 3: The mobile application asks for manual or automatic control of the greenhouse.

If “manually-controlled” option is selected, an SMS will be sent to the controller to proceed with the associated algorithm as follows:

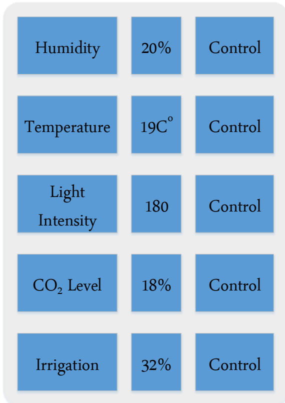


Figure 4: The screen of manual control.

The controller starts acquiring data from the sensors attached to greenhouse and prepares it to be sent as an SMS through the GSM module to the application.

If the readings of the variables at the greenhouse are within the normal range, the controller takes no action but still sends such values to the application. If one or more variables drop above or below customized thresholds, the user can control the greenhouse. Each "Control" button next to each variable is translated into a certain control action that is send as an SMS. So, the application user can monitor and control the greenhouse. The screen of manual control is shown in Figure 4.

If "automatic-controlled" option is selected, an SMS will be sent to the controller to proceed with the associated code as follows:

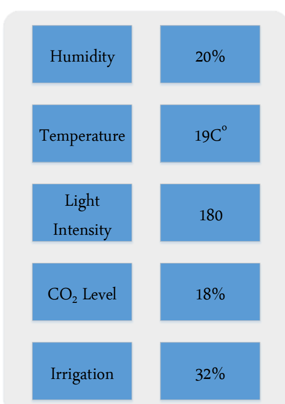


Figure 5: The screen of automatic control.

The controller starts acquiring data from the sensors attached to greenhouse and prepares it to be sent as an SMS through the GSM module to the application.

If the readings of the variables at the greenhouse are within the normal range, the controller takes no action but still sends such values to the application. If one or more variables drop above or below customized thresholds, a certain action or actions are made depending on the changed variable(s). Therefore, the application user is only monitoring and not controlling the greenhouse.

III. RESULTS

The experiment is conducted for two identical greenhouses; each has a unique phone number attached to the GSM module. The user of this approach is able to monitor and control any particular greenhouse or switch to other greenhouses by just entering the phone number of the desired greenhouse. The results are taken for a 24-hour period such that the readings for each environmental sensor are taken from three distributed sensors at three different locations to guarantee average environmental measures inside the greenhouse. The controller as well as the sensors are triggered to take the readings every 10 minutes period. Tomato crop greenhouse is used in when collecting the results.

Figure 6 shows the temperature inside the greenhouse versus time. The figure shows that when the temperature is within the threshold, 25°C, no actions are made. However, when the temperature rises above the threshold, the system triggers the actuators for doors and windows that allow air to pass through the greenhouse to reduce the temperature.

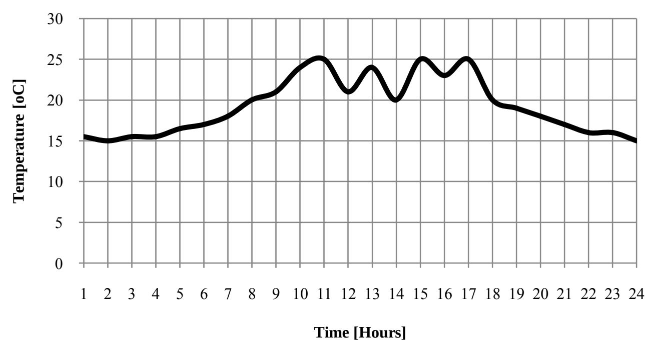


Figure 6: Temperature versus time.

Figure 7 shows the relative humidity inside the greenhouse over 24-hour period when auto-controlled mechanism is applied. The figure shows that when the humidity reaches the threshold, 40%, the curves drops down because the system triggers the actuators for doors and windows that allow air to pass through the greenhouse to reduce the relative humidity.

Figure 8 shows the light intensity inside the greenhouse over 24-hour period. The figure shows the response of the sensor to the light intensity. It shows that for periods 1 – 5 and 19 – 24, it records low values for low light intensity. For the period between 5 – 19, the curve starts to increase to reach its peak at 13 hour and then decays. In case of a cloudy day, when the light intensity reaches below the threshold, 200, the curve is expected to increase due to an operated external light source that provides light to the plants. Turning on or off the light source is made by the controller for day times only.

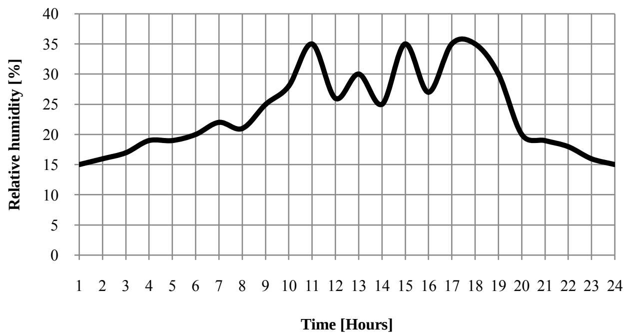


Figure 7: Relative humidity versus time.

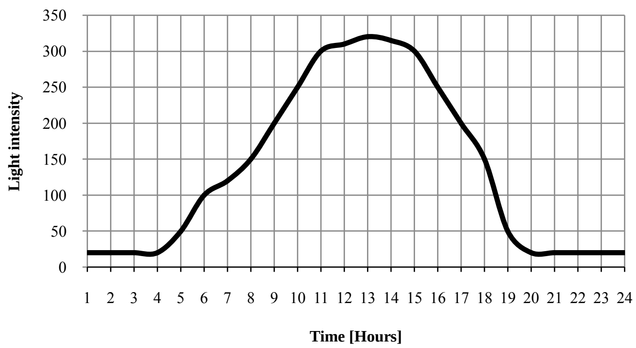


Figure 8: Light intensity versus time.

Figure 9 shows the CO_2 level inside the greenhouse versus time. The figure shows that when the level is above the threshold, 20%, no actions are made. However, when the level reduces above the threshold, the system triggers the actuators for doors and windows that allow air to pass through the greenhouse to increase the CO_2 level.

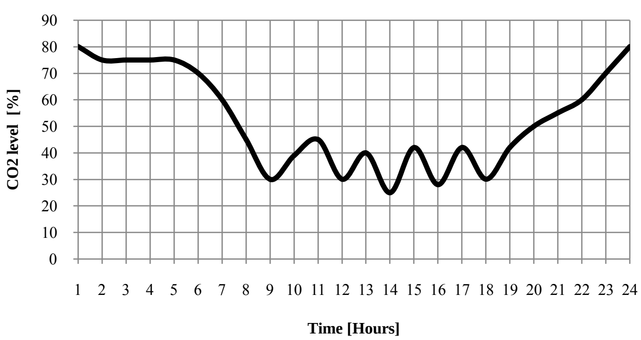


Figure 9: CO_2 level versus time.

Finally, Figure 10 shows the water level inside the soil where the plant is grown. When the irrigation level is low, the controller sends to water valves sprays to supply the plants with the accurate amount of water.

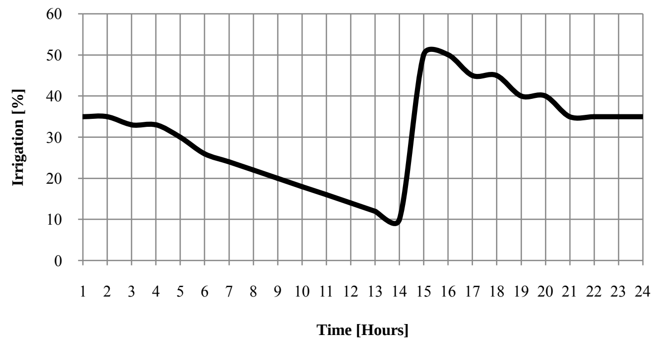


Figure 10: Irrigation level versus time.

IV. CONCULSIONS

In this paper a new approach for monitoring and controlling distributed greenhouses is proposed. The system shows several advantages over traditional techniques. It offers the accessibility to be used in-site or remotely by experienced or non-experienced farmers, it is easy to install and maintain in terms of software or hardware, and can be used to monitor and control small or large-sized greenhouses. Moreover, the system can be used to monitor single or multiple greenhouses. It can save money since less labor is required. Finally, the system provides accurate growing conditions measures, and therefore, the plants live in ideal growing conditions.

REFERENCES

[1] Food and Agriculture Organization of The United Nations, “Protected Cultivation in the Mediterranean Climate” FAO, 1990.

[2] Joe J. Hanan, “Greenhouses: Advanced Technology for Protected Horticulture”, CRC Press 1997.

[3] Francisco Rodríguez, Manuel Berenguel, Jose Luis Guzman, Armando Ramírez-Arias, “Modeling and Control of Greenhouse Crop Growth”, Springer 2015

[4] National Agricultural Information System http://www.nais-jordan.gov.jo/

[5] Department of Statistics in Jordan www.dos.gov.jo

[6] F. Lin; L. Hui; Z. Yuee, "Greenhouse CFD simulation for searching the sensors optimal placements”, Second International Conference on Agro – Geoinformatics, pp. 504 – 507, 2013.

[7] Ahonen, T.; Virrankoski, R.; Elmusrati, M. “Greenhouse Monitoring with Wireless Sensor Network”, IEEE / ASME International Conference on Mechatronic and Embedded Systems and Applications, pp.403 – 408, 2008.

[8] Q. Weimin; D. Linxi; W. Fei; Y. Haixia, “Design of intelligent greenhouse environment monitoring system based on ZigBee and embedded technology”, IEEE International Conference on Consumer Electronics, pp. 1 - 3, 2014.

[9] P. Eredics; K. Gati; T.P. Dobrowiecki; G. Horvath, “Neural models for an intelligent greenhouse - A CMAC global greenhouse model”, IEEE 12th International Symposium on

Computational Intelligence and Informatics (CINTI), pp. 177 – 182, 2011.
[10] X. Zhao; X. Zheng; C. Duan; Z. Chen; S. Sang; Z. Zhang, "The design and implementation of the greenhouse monitoring system based on GSM and RF technologies", International Conference on Computational Problem-solving (ICCP), pp. 32 – 35, 2013.
[11] http://www.monnit.com/

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