Precision Agriculture for Greenhouses Using a Wireless Sensor Network

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***Abstract*—Agriculture is one of the most crucial needs of the life since it supports human and animals with food supplies and benefits the human employment and the national economy. Wireless Sensor Network (WSN) has recently applied in precision agriculture to improve the crop yields and apply the agricultural resources at right time and place. In this paper, Greenhouse Smart Management System (GSMS) using WSNs is designed and developed to automatically control, manage and monitor the agricultural parameters and activities inside the greenhouses. The ambient relative humidity and temperature of the greenhouse are measured using sensor nodes. When the sensed parameters exceed threshold values, the irrigation and cooling activities are triggered by activating the fan and water pump devices. GSMS includes also an algorithm to compute the period of irrigation and coolingaccording to the measured agricultural parameters. Hardware and software for the proposed GSMS are developed in this paper. The results show that the GSMS can save the agricultural resources and improve the crop yields, compared with other traditional schemes.**

Keywords—wireless sensor networks; precision agriculture; irrigation; microcontroller; greenhouse; Android

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have become an emerging phenomenon in industry, both for civil and military purposes. It consist of hundreds or thousands of small sensor nodes connected to each other using wireless networks systems. Each sensor node consists of processing unit, sensingunit, storage unit, and radio unit. Sensor nodes are low-cost and have limited resources [1][2].Sensor nodes are deployed in the area of interest to sense and monitor physical phenomena such as temperature, pressure and the presence for objectives [3]. WSNs can be deployed in random where for example sensor nodes are dropped from an airplane, or planned fashion such as deployment of WSNs in precision agriculture application [4]. The sensor nodes cooperate [5] together to sense, compute and transmit the information from area of interest to users. Nowadays, commercial and industrial areasuse WSNs for many applications such as healthcare,environmental monitoring, structural monitoring, wildlife habitat monitoring, navigation, smart homes, inventory control and disaster management. WSNs can also be used in military field including intrusion detection, detecting illegal crossings, and surveillance [6].

Precision agriculture (PA) or precision farming (PF) refers to automation in agriculture using information technology. PA is defined as the techniques of applying PA inputs such as farming parameters and resources at the right location and time to optimize the farming production, improve the resource utilization, provide online monitoring for farmers, reduce the agriculture cost and reduce the human power, subject to minimizing the environmental impact [7], [8], [9]. Farming parameters and resources include site-specific application of water, fertilizer doses, pesticide, soil moisture, herbicides, and air temperature [10]. WSNs are employed in PA to monitor, optimize and measure different farming and sowing parameters and resources. These parameters are transmitted wirelessly to farmer so that appropriate actions are taken [11], [12].

Agricultural parameters such as humidity and temperature can be measured either by using direct sensing, or remote sensing. Direct sensing employs large number of sensor nodes placed directly to the land, while remote sensing is performed using aircraft and satellite, based on electromagnetic waves reflection and absorption by the soil, or imagery and maps [13], [14]. However, direct sensing can collect more data that gives more accurate measurements, better resolution, lower cost and better timing compared with remote sensing. In addition, direct sensing does not affect by the weather and field conditions [15]. Moreover, remote sensing is not suitable for indoors such as the green houses. Therefore, direct sensing using WSNs I adopted in this research to monitor and manage the green houses. Irrigation is the process of delivering water to the soil.In traditional irrigation, water irrigation is performed periodically. Farmers irrigates each plant by common-sense without any accurate calculations, which leads to waste the water and unevenly irrigate the plants. The traditional irrigation techniques [16] includes surface, sprinkler, micro-sprinkler and drip systems. Traditional irrigation is performed without precise knowledge about the soil and leads to non-uniform water for the plants, which results in less yields, time consuming, water wastage and more human efforts.

The paper is organized into seven sections including this one. After this introduction, Section 2 browses the related work. Section 3 explores the GSMS framework and algorithms. The GSMS hardware and software developments are described in Section 4 and Section 5, respectively. An

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experimental results evaluation is presented in Section 6 and, finally, Section 7 summarizes the paper.

II. RELATED WORK

Precision agriculture is deeply considered within greenhouses [17], [18], [19], [20] and [21]. In [19], the A2S approach is developed to monitor and control the environmental conditions and the growing process of cabbages and melons.However, the irrigation system in [19] considers only specific types of plants. In [18], a real time monitoring system is proposedfor greenhouse management to control environmental parameters like temperature and relative humidity using WSNs. The system employs Adaptive On Demand Transmission Power Control (AODTPC) protocol to adjust the transmission power according to the channel states so that the energy consumption of batteries is saved. A Kalman Filter is used to estimate the states of the channel that are exploited to adjust the transmission power.Temperature is controlled to be within a predefined range using refrigerator. Precisionagriculture in greenhouse is developed in [20], [19] and [21] through measuring of temperature, humidity and moisture. When the threshold values of measurements are excited, pumps and valves are activated for irrigation. Intelligent Greenhouse Monitoring System (IGMS) [19] and Greenhouse Monitoring System (GHMS) [20] are developed for monitoring of farming parameters.Greenhouse Irrigation Management System (GIMS) is designed in [21] for automated irrigation. The results shows that automatic irrigation is more efficient than the traditional scheduled irrigation. However, the systems proposed in [20], [19] and [21] consider only one plant rather than the whole area of plants. All the above researches do not consider the period of agricultural activities such as irrigation and in turn the agricultural resources may waste.

In this paper, Greenhouse Smart Management System (GSMS) using WSNs is developed to monitor and control the agricultural parameters in greenhouses. When the sensed agricultural parameters exceed threshold values, specific actions are triggered and activated such as fan, pump and buzzers, for a period of time.

III. GREENHOUSESMART MANAGEMENT SYSTEM

A. GSMS Architecture and Framework

As shown in Fig. 1, WSNs is deployed in planned manner inside the greenhouse. Sensor nodes measure the ambient relative humidity and temperature. The communication among sensor nodes is multi-hop communication where the messages are relayed from sensor node to another sensor node until reach to the sink node. The sink node forwards the messages to the farmervia Bluetooth (BT) connectivity.According to the sensed relative humidity and temperature, the GSMS aims to determine the right time for irrigation to open the irrigation plumb and for cooling to activate the cooler fan.

Fig.2 shows the GSMS sensor node components. The heart of the sensor node is the microcontroller (MC). In this paper, Arduino MC is used. The temperature and humidity sensors are connected to the MC as input devices. On the other hand, the irrigation pump and the cooling fan are connected to the MC as output devices. The farmer controls and monitors the greenhouse using Android mobile application via BT connectivity.

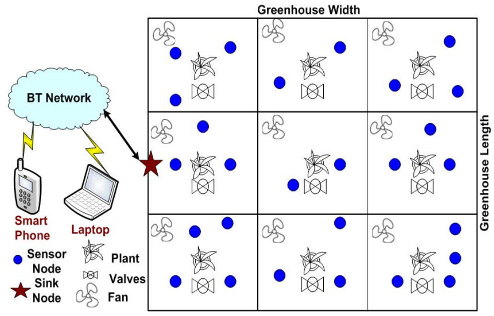

Fig. 1. GSMS Framework

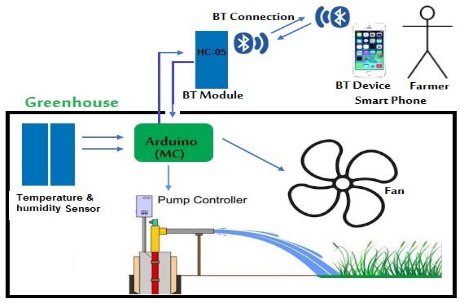

Fig. 2. GSMS Sensor Node Components

The WSNs node architecture is shown in Fig. 3. The MC consists mainly of processing unit, memory unit, storage units, Analog to Digital converter (ADC), output/input ports. The sensors are connected to MC through input ports while the actuators including fans and valves are connected to MC through output ports. Communication unit using BT wireless module is used for communication among sensor nodes and to forward the data to the farmer. DC power supply is also required to deliver energy to sensors, MC and BT module.

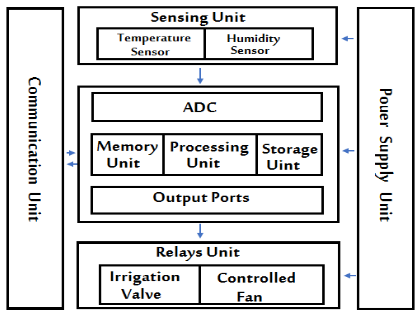

Fig. 3. WSN Node Architecture

B. GSMS Algorithm

The flowchart of GSMS algorithm is shown in Fig. 4. The main purpose of the GSMS algorithm is to compute the period of irrigation and cooling according to the current sensing measurements.

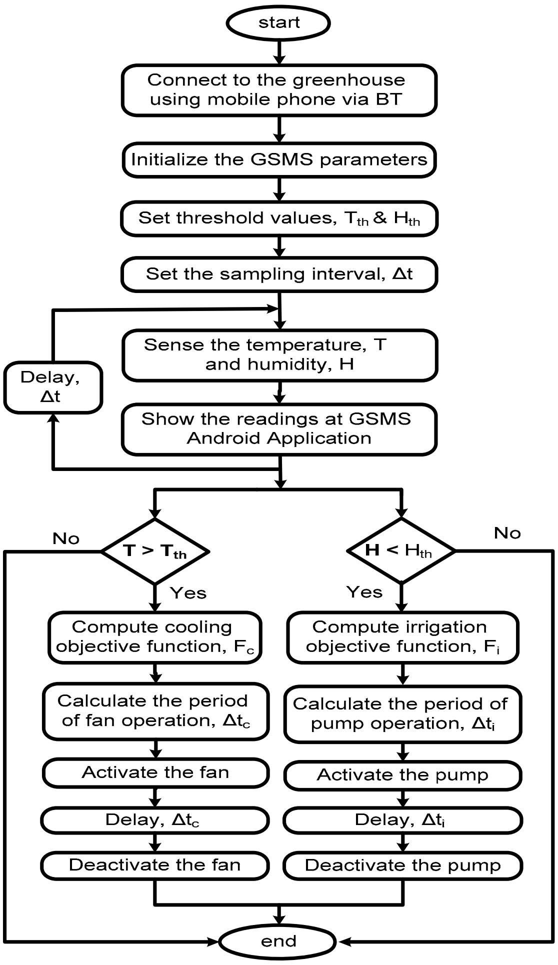

Fig. 4. GSMS Algorithm

At each time, $t_k$when the temperature, $T(k)$ is high and the relative humidity, $H(k)$ is low, the irrigation and cooling periods should be high. Therefore, the objective function todetermine these periods is defined as follows:

$$F_z(k) = \alpha * \left(\frac{T(k)}{T_{max}}\right) + (1-\alpha) * \left(\frac{H_{min}}{H(k)}\right) \quad (1)$$

where, z is replaced by "c" in case of cooling and "i" in case of irrigation, H_{min} is the minimum humidity and T_{max} is the maximum temperature. The objective function, $F_z(k)$ is assumed to be proportionally linear with the periods of cooling or irrigation, $\Delta t_z(k)$ is according to:

$$\Delta t_z(k) = \left(\frac{\Delta t^z_{max} + \Delta t^z_{min}}{F^z_{max} - F^z_{min}}\right)(F_z(k) - F^z_{max}) + \Delta t^z_{max} \quad (2)$$

where, Δt^z_{max}, Δt^z_{min} are the maximum and minimum irrigation or cooling periods respectively, $F^z_{max} = 1$ is the maximum value of the objective function calculated at a maximum temperature, $T(k) = T_{max}$ and a minimum humidity,$H(k) = H_{min}$ and F^z_{min} is the minimum value of the objective function calculated at a minimum temperature, $T(k) = T_{min}$ and a maximum humidity, $H(k) = H_{max}$.

In GSMS algorithm, the farmer initiates BT connection with the WSNs through the sink node. The parameters for the proposed GSMS algorithm are set automatically through the application code or manually by the farmer. These parameters include the sensor calibration constants and parameters controlled the irrigation and cooling periods. Furthermore, farmer can manually set the threshold values for relative humidity, H_{th} and ambient temperature, T_{th} after which the irrigation and cooling are started. The sampling interval, Δt of GSMS which is the time between two successive sensing is set.

At each time step, k the sensors detect the ambient relative humidity and temperate of the greenhouse. The readings are sent via BT to the proposed GSMS Android application installed on the farmer mobile phone/laptop for monitoring purposes. Another sensing activity is scheduled at time step $k+1$ where $t_{k+1} = t_k + \Delta t$. When the relative humidity and temperature exceed H_{th} and T_{th} , the irrigation or cooling activities are triggered for a periods of $\Delta t_i(k)$ or $\Delta t_c(k)$, respectively.

IV. GSMS HARDWATR DEVELOPMENT

A. GSMS Hardware Compnents

*1) Temperature Sensor:*As shownin Fig. 5,NTC thermistor based on LM393 comparator module is adopted to sense the temperture of the greenhouse. The thermistor has three pins which are supplied voltage (Vcc), ground (GND) and digital output (DO). However, DO is not used and instead the output of the temperature sensor in NTC module is directly connected to the microcontroller.


Fig. 5. NTC temperture Sensor

*2) Humidity Sensor:*HR202 humidity sensor is used in this system to detect the ambient relative humidity of greenhouse. It has high linearity, a wide wet range of 20-95%RH, a low power consumption and high stability. The module features output and power LED indicators. The output is available in both analog form and a digital form which is obtained using a LM393 IC comparator. As shown in Fig. 6, HR202 has four pins named analogue output (AO), digital output (DO), ground (GND) and the supplied DC voltage (Vcc). Therefore, using DO, HR202 can connect directly to the microcontroller .

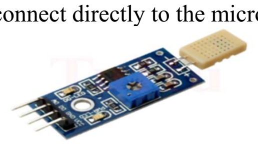
Fig. 6. HR202 Humidity Sensor

*3) Actuators:*The actuators are activated using relays. As shown in Fig. 7, the relay is an electro-mechanical switch that allows to control the conduction of a high voltage/current connection using a low voltage/current connection. The comtrolled actuators used in this research are the water pumb for irrigation and the fan for colling.

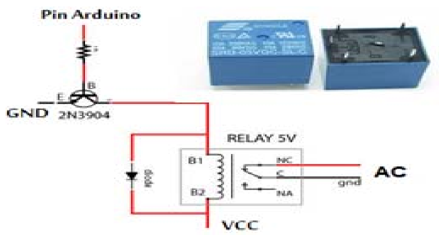

Fig. 7. Relay circuit diagram

*4) Bluetooth Module:*GSMS embraces HC-05 wireless Bluetooth module to allow farmers send the actions and triggers to the greenhouse and receive the monitoring information from the greenhouse. It can be configured as a master or a slave to form the BT piconet. HC-05 uses BT V2.0 protocol standard with default baud rate of 9600 bps and 2.4GHz ISM frequency spectrum. HC-05 consists of integrated antenna, BC417 radio and UART interface with programmable baud rate.It operates in data transfer mode to transmit and receive data to other BTdevices and command mode to send AT commands. As shown in Fig. 8, it has six pins which are a KEY to operate in command mode, supplied voltage (Vcc), ground (GND), transmit serial data (TXD), receive serial data (RXD), and state to show if it is connected.

Fig. 8. HC-05 wireless Bluetooth module

*5) Arduino Uno Microcontroller:*As shown in Fig. 9,Arduino Uno microcontroller has 14 digital input/output pins, 6 analog inputs, a 6 MHz quartz crystal, a USB connection, a power jack and a reset push button. It powers with 5V DC by using the PC directly via USB port, external AC to DC power supply powered via jack, or external batteries powered via jack. It contains 32 KB flash memory, 2 KB SRAM, 1 KB EEPROM and 16 MHz clock speed processor. Arduino Uno can be programmed using Arduino software (IDE) via USB port.

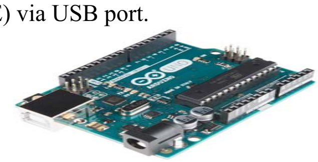

Fig. 9. Arduino Uno

B. GSMS Hardware Circuit Design

Fig. 10, shows the complete circuit design for the GSMS. The Arduino is powered using an external battery of 5V. The HC-05 BT module is connected to the Arduino input ports 0 (RX) and 1 (TX). The HR202 humidity sensor is connected to the Arduino analog port A0 while the NTC temperature sensor is connected to Arduino analog port A1. The first relay which controls the operation of fan is connected to theArduinooutput digital port, D12 while the second relay which controls the operation of irrigation valve is connected to theArduinooutput digital port, D13. The DC power delivered to sensors and BT module is supplied from the Arduino board.

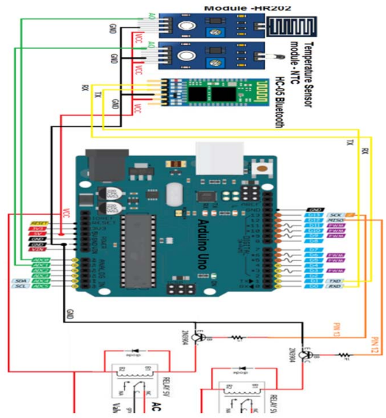

Fig. 10. GSMS Harware Design

Fig. 11 and Fig. 12 show the fabrication and PCB of one sensor node. This sensor node is placed near a plant. The irrigation pump and cooling fan are activated manually or automatically as described in Section II. The sensor node is packaged in a box to save the component form damage.

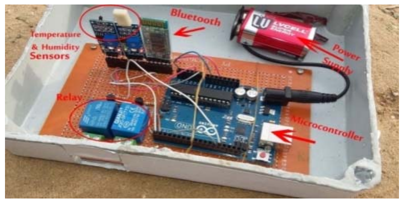

Fig. 11. Sensor Node PCB Package

Fig. 12. WSN node placed near the plant

V. GSMS SOFTWARE DEVELOPMENT

The GSMS software application is developed in Android operating system so that it can operate in smart phones. The main screen of the application is shown in Fig. 13. Farmer initiates the GSMS by connect to greenhouse via BT. As shown in Fig. 13, the HC-05 module is configured as a master and hence, the mobile phone initiates the connection.

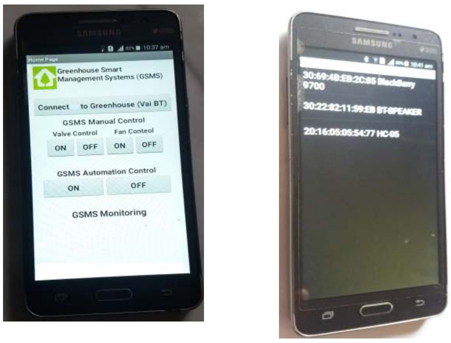

Fig. 13. GSMS Anroid Application – BT Connection Screen

As shown in Fig. 14, the application consists of three parts. The first part is the GSMS manual control by which the farmer can manually activate and deactivate the irrigation valve and cooling fan. If the farm enable the automatic control in the second part of GSMS application, the GSMS operates automatically according to the algorithm shown in Fig. 4. The last part is the GSMS monitoring which enable the farmer to monitor the sensed parameters which is received every sampling interval time.

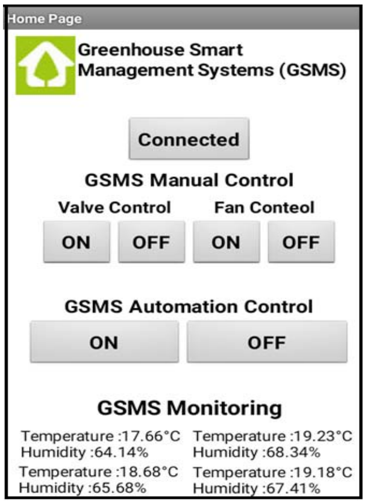

Fig. 14. GSMS Anroid Application – Monitoring, annual control and autmatic control control screen

VI. EXPERIMENTAL RESULTS

In this section, the proposed GSMS is evaluated. The weighting parameter in Equation (1), α is set to 0.5. The sampling interval, Δt is set to 1 second. The minimum and maximum periods are set as follows: $\Delta t_{max}^{z} = 10$ min for "i" and 10 hours for "c" and$\Delta t_{min}^{z} = 5$ min for "i" and 5 hours for "c". The average of historical temperature and relative humidity statistics in Gaza Strip for 12 months are recorded and plotted in Fig. 15 and Fig. 16, respectively[22]. Therefore, the parameters of Equation (2) are set as follows:,$T_{max} = 32$ C°, $T_{min} = 18$ C°, $H_{min} = 63$, $H_{max} = 73$.

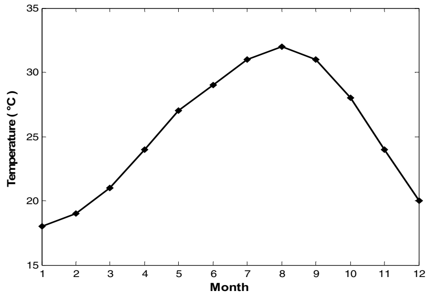

Fig. 15. Average monthly temperature in Gaza Strip during one year

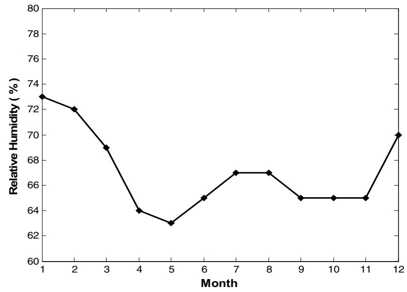

Fig. 16. Average monthly relative humidity in Gaza Strip during one year

The GSMS is operated for one day dated 25th January, 2017 and the temperature and relative humidity for both indoor and outdoor are recorded and plotted in Fig. 17 and Fig. 18, respectively.As expected, the temperature and relative humidityare higher in indoor compared withoutdoor.

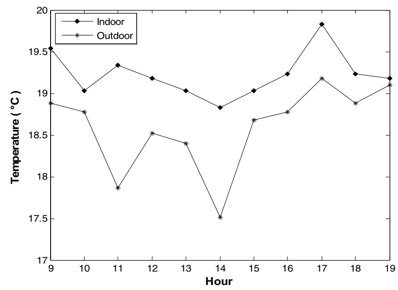

Fig. 17. GSMS one-day operation – The temperature indoor and outdoor

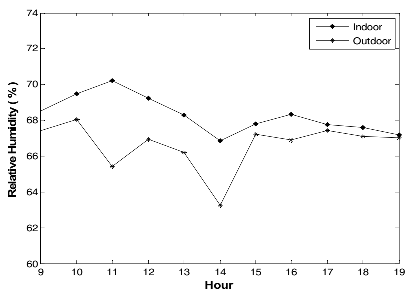

Fig. 18. GSMS one-day operation – The reletive humidity indoor and outdoor

Using the historical temperature and humiditydata plotted in Fig. 15 and Fig. 16, the irrigation and cooling periods of the GSMS and traditional approachesare plotted inFig. 19. The periods of traditionalapproachesare assumed to be fixed and equal to the average period of GSMS approach. As shown in Fig. 19, in case of traditional approach, five of irrigation and cooling activities areperformed for a long time which leads to use much water and blocking off the crop breathing, weakening the plants roots and increasing the insect damage of crops. On the other hand, six of irrigation and cooling activities areperformed for a short time which leads to use less water and wither the plants, affect adversely the photosynthesis, and in turn reduce the drop production.

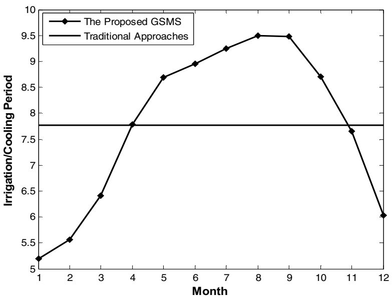

Fig. 19. The irrigation &cooling periods of GSMS and traditional approaches

VII. CONCLUSION

In this paper, GSMS is developed to monitor the agricultural parameters including the temperature and relative humidity, and automatically manage and control the irrigation and cooling of greenhouses. Hardware and software implementation for GSMS are designed, developed and evaluated. The GSMS aims to active the irrigation pump and the cooling fan when the sensed relative humidity and temperature exceed a predefined threshold value. Arduino microcontroller is adopted to develop the sensor node. In addition, Android software application is also developed to connect, monitor and control the greenhouse via BT connectivity. Future work includes the monitoring of other parameters such as CO2 level. The results show that the proposed GSMS improves the crop yields and decreases the agricultural resources wastage by applying the cooling and irrigation activities for well-calculated period of time.

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