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The Use of ZigBee Wireless Network for Monitoring and Controlling Greenhouse Climate

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Abstract: The increasing demands for crop production and quality have significantly increased the utilization of high quality and productivity green houses. Modern greenhouses are nowadays having great sizes and they are equipped with sophisticated monitoring and controlled actuation systems to assure maximum productivity and provide value-added quality. Increases in greenhouse sizes has increased the demand in increasing the monitoring points in order to provide real-time precise measurement of some important parameters and hence to avoid unnecessary exposure to unhealthy ambient conditions. The increase of monitoring points is certainly leads to increase the complexity of managing and maintaining them efficiently.

The aim of this paper is to present a novel wireless sensor network based ZigBee technology for monitoring and controlling greenhouse climate. The system consists of a number of local stations and a central station. The local stations are used to measure the environmental parameters and to control the operation of controlled actuators to maintain climate parameters at predefined set points. For each local station a PIC Microcontroller is used to store the instant values of the environmental parameters, send them to the central station and receive the control signals that are required for the operation of the actuators. The communication between the local stations and the central station is achieved via ZigBee wireless modules.

Index Terms— Greenhouse monitoring and control, Wireless network, ZigBee.

I. INTRODUCTION

The increased demand for high quality products, the increased concern about food security, and the impact of climate changes are some of the factors that have contributed to the rapid development of the greenhouse industry in the past four decades across the world [1]. In general greenhouses are structures that are designed to provide a climate-controlled environment for plants that are not in season to be cultivated indoors where a controlled environment can mean a higher survival rate. The target of the commercial purpose greenhouses, like in any other business, is to maximize profit, which depends directly on the yield grown. It is well known that, plant species perform their best while being in the most suitable environment through maintaining the temperature, light and humidity at the optimal level for photosynthesis. Beside the commercial purpose greenhouses, there are a number of facilities for performing experiments related to plant growth research, where a high degree of the climate control is needed, too. Consequently, greenhouse climate control requires real-time precise measurement of some important parameters in order to avoid unnecessary exposure to unhealthy ambient conditions [2]. Computerized environmental control systems were found to be the most reliable solution in providing the ability to integrate the control of all systems involved in manipulating the growing environment, thus improving the crop development and reducing the production costs [3].

Nowadays there are numerous greenhouse environmental control systems presented on the market, offering as much or as little of the control as may be feasible. In the past generation of greenhouses it was enough to have one cabled measurement point in the middle to provide the information to the greenhouse automation system. The system itself was usually simple without opportunities to control locally heating, lights, ventilation or some other activities, which was affecting the greenhouse interior climate [2].

In modern greenhouses, facilities are required to provide several options to make local adjustments to the artificial climate and other greenhouse support systems easier and more reliable. Moreover, with the increase of greenhouses size, more measurement data is also needed to make this kind of the systems work properly. Increased number of measurement points should not dramatically increase the automation system cost. It should also be possible to easily change the location of the measurement points according to the particular needs, which depend on the specific plant, on the possible changes in the external weather or greenhouse structure and on the plant placement in the greenhouse [4].

Wireless sensor network (WSN) can form a useful part of the automation system architecture in modern greenhouses. Wireless communication can be used to collect the measurements and to communicate between the centralized control unit and the actuators located at the different parts of the greenhouse. Compared to the cabled systems, the installation of WSN is fast, cheap and easy. Moreover, it is easy to relocate the measurement points when needed by just moving sensor nodes from one location to another within a communication range of the coordinator device. Furthermore, if the greenhouse flora is high and dense the small and light weight nodes can even be hanged up to the plants' branches. WSN maintenance is also relatively cheap and easy. The only additional costs occur when the sensor nodes run out of batteries and the batteries need to be charged or replaced, but the lifespan of the battery can be several years if an efficient power saving algorithm is applied [5-8]. As an open and global standard for WSN, ZigBee shows advantages on low-cost, low power consumption and self-forming. The current researches of ZigBee wireless sensor network on industrial automation, electronic products, smart buildings and medical care were presented and, as an explorative application of ZigBee wireless sensor network in protected agriculture overcoming the limits of wire connection, its applied design for greenhouse management was proposed by introducing both the hardware and software architectures.

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II. GREENHOUSE CONTROL SYSTEM

The control system for the greenhouse includes the following components:

- Data acquisition of the environmental parameters through sensors;
- The processing of data, comparing it with desired states, and finally deciding what must be done to change the state of the system;
- The actuation component carrying the necessary actions.

The control of the greenhouse investigated in this paper consists of several distributed local stations and one central station. Each local station is responsible for obtaining the greenhouse climate parameters by three sensors for the temperature, humidity and light. These sensors are connected to a PIC16F877A microcontroller which consists of embedded ADCs. A ZigBee transceiver is directly connected to the microcontroller to provide a wireless connection with a central station. A PC was used to implement the central station at which the set value for each parameter is declared and compared to those received from each local station. Based on the measure and set values of the parameters the central station provides the required control action at each location. These control actions are sent back to the local stations via ZigBee module. Finally, when the control actions received by the local station, the microcontroller will provide the necessary control signals to the actuators and coordinate their operation. Figure 1, shows the schematic diagram of a local station, and figure 2 shows a block diagram for the system architecture.

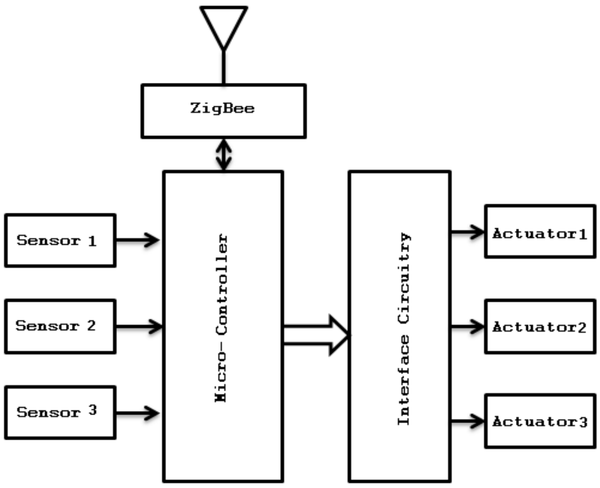

Figure 1: Local wireless station.

A. *Sensory System*

Sensors provide input information for the automation system by measuring the climate variables of the greenhouse. Sensor-generated signals are acquired and conditioned by a PIC16F877A microcontroller. Three parameters are monitored in this study namely; temperature, humidity and light or solar radiation.

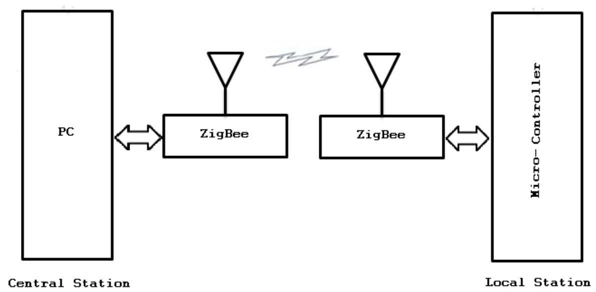

Figure 2: System architecture

Five different families of temperature sensors are available on the market. Each family of temperature sensors has its advantages and disadvantages. Depending on the application, one sensor may be more suitable than the other. In this study, thermistors are used to measure the temperature in the greenhouse. Thermistors are temperature dependent resistor devices, they are easier to wire, cost less and almost all automation panels accept them directly. Thermistors are made of semiconductor materials with a resistivity that is especially sensitive to temperature.

When it comes to humidity sensing technology, there are three types of humidity sensors: capacitive, resistive and thermal conductivity humidity sensors. We used Capacitive Humidity Sensors (CHSs) which are widely used in industrial, commercial, and weather telemetry applications. CHSs consist of a substrate on which a thin film of polymer or metal oxide is deposited between two conductive electrodes. The sensing surface is coated with a porous metal electrode to protect it from contamination and exposure to condensation. The substrate is typically glass, ceramic, or silicon. The changes in the dielectric constant of a CHS are nearly directly proportional to the relative humidity of the surrounding environment. CHS are able to function in high temperature environments (up to 200°C), near linear voltage output, wide RH (Relative Humidity) range, high condensation tolerance, reasonable resistance to chemical vapors and contaminants, minimal long-term drift, high accuracy, small size and low cost.

Light from the sun is responsible for nearly all life on the earth. Sunlight fuels the process of photosynthesis where plants convert carbon dioxide and water into carbohydrates. Plants use light in the range of 400 to 700 nanometres. This range is most commonly referred to as PAR (photosynthetically active radiation). Monitoring PAR is important to ensure that plants are receiving adequate light for photosynthesis. Typical applications include forest canopies, greenhouse monitoring etc. PAR is also measured to estimate evaporation in bodies of water, as it plays a key role in surface water temperature. This sub-section will present some of the popular light sensors on the market that can be used for environmental monitoring applications. Here, Light Dependent Resistor (LDR) Similar to photometric sensors, LDRs measure visible light as seen by the human eye. A LDR is basically a resistor; the internal resistance increases or decreases dependent on the level of light intensity impinging on the surface of the sensor.

Finally, a greenhouse sensor station has been designed and fabricated which is part of a complete greenhouse management system. The local station takes charge of collecting climate measurements data in a greenhouse (temperature, humidity and light) and transmits the data to the central station. Figure 3, shows the practical local station.

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Figure 3: ZigBee based wireless local station

B. *Actuation System*

An actuator is a piece of equipment that produces movement when given a signal. Actuators are used in the computer control of an environment, industrial automation and in robotics or, more generally, actuators are the machines used for output in control applications. For the situation in a computer controlled greenhouse, the actuators receive their control signal from the microcontroller to control the inside climate variables of the greenhouse. The designed system includes the following actuators:

- A ventilation fan, its speed determines the exchange between inside and outside air, thus causing natural ventilation.
- Heating system consists of a number of heaters distributed along the greenhouse.
- Thermal/shade screen, which is picked up or extended along the roof of the greenhouse. In the first case, it prevents the loss of heat acquired during the day (for cold months). Whereas, as shade screen, it protects the crop from excess of solar radiation and reduces the increasing temperature (for hot months).
- Evaporative cooling system consists of an exhaust fan at one end of the greenhouse and a pump circulating water through and over a cellulose pad installed at the opposite end. When the fan operates, negative pressure is created inside, causing external air to be drawn through the wetted pad. Evaporation results from contact between water and air, getting a lower inside temperature in the greenhouse.
- Irrigation system, water is pumped through polyethylene tubes to apply drip irrigation.
- Artificial lighting lamps, apply light radiation over plants to lengthen the photoperiod.

III. COMPARISON BETWEEN WIRELESS SENSOR NETWORK STANDARDS

A wireless sensor network (WSN) is a computer network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. The development of wireless sensor networks was originally motivated by military applications such as battlefield surveillance [5]. During the last decade wireless sensor networks are utilized in many civilian applications, including environment and habitat monitoring, healthcare applications, home automation, and traffic control.

Several standards are currently either ratified or under development by organizations. Standards are used far less in WSNs than in other computing systems which make most systems incapable of direct communication between different systems. The predominant standards commonly used in WSN communications are:

1- Wi-Fi
2- Bluetooth
3- ZigBee

All the above mentioned technologies work at similar RF frequencies, and their applications sometimes overlap [6]. In the current study, we chose the following five main factors of greenhouse networks to compare: cost, data rate, number of nodes, current consumption and battery life.

From cost point of view, ZigBee chip is US$ 1 or less, the lowest; Wi-Fi and Bluetooth chips are $ 4 and $ 3, respectively. The overall system cost can be significantly reduced by the employment of ZigBee chip.

Regarding data rate, ZigBee is 250 kbps, while Wi-Fi and Bluetooth are 54 Mbps and 1~2 Mbps, respectively. Despite the lowest data rate, ZigBee is sufficient for a greenhouse. Generally, data traffic in a greenhouse is low—usually small messages such as the change of temperature or a command from the controller to an actuator. And also, low data rate helps to prolong the battery life.

As it is well known, the capacity of network is determined by the number of nodes, and ZigBee has up to 254 nodes, the largest among the three. It meets the application demand of more and more sensors and actuators in a greenhouse.

The power and current consumption, ZigBee has the lowest current consumption, 30 mA, while Wi-Fi, 350 mA, and Bluetooth, 65~170 mA. It also greatly helps to prolong the battery life.

Finally the battery life of a ZigBee chip has the longest battery life, a few months or even years.

As a whole, ZigBee technology offers long battery life, small size, high reliability, automatic or semi-automatic installation, and, particularly, a low system cost. Therefore, it is a better choice for greenhouse monitoring and control than other wireless protocols [7-8].

IV. APPLICATION OF ZIGBEE WIRELESS SENSOR NETWORKS IN GREENHOUSE CLIMATE

ZigBee based wireless networks have three types of topologies namely: star topology, peer-to-peer topology and cluster tree topology [9]. The first topology is called Personal Area Network (PAN). The central station plays the role of the network coordinator and it is responsible for establishing the communication between it and the local units. Each local unit chooses a PAN identifier, which is not currently used by any other station within the radio sphere of influence. This allows each star network to operate independently. Figure (4) shows the actual distribution of the local stations within the greenhouse.

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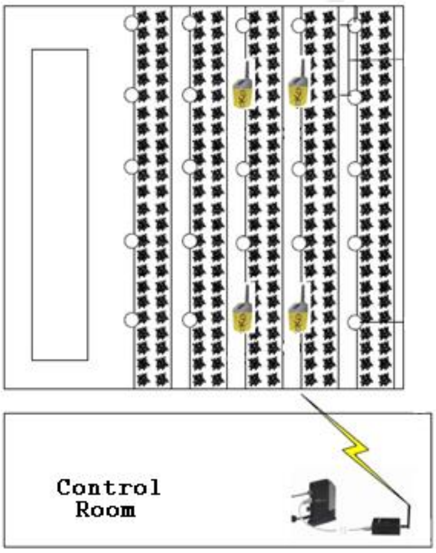

Figure 4: Location of ZigBee Wireless sensor Stations.

In this paper, we established the network according to the star topology. As shown in figure 5, once the central station is activated for the first time, it establishes its own network and becomes the network coordinator. The central station then initializes its hardware, stack and application variables, chooses an unused PAN identifier of zero, and broadcasts beacon frames to the local stations. When the local stations receive the beacon frame then they will send a request to join the network. Upon the receiving of the request by the central station, it will add them as a child device in its neighbor list and return a response. The local stations will add the central station as its parent in their neighbor list and return an acknowledgement. The central station then monitors all network nodes in real-time, maintaining the network information database.

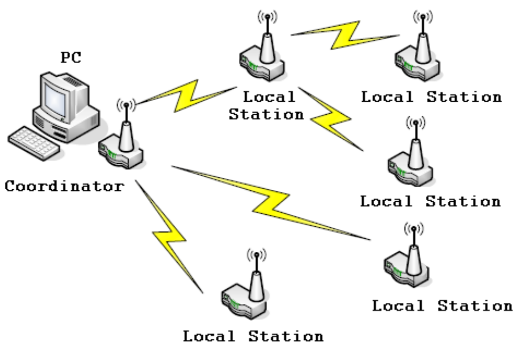

Figure 5: network topology architecture

Software algorithms for the local station microcontroller and the central station PC were developed. The software developed for the local station microcontroller includes data acquisition, data processing and data transmission through the Zigbee module.

A. Sensory System

The local station is designed to collect the greenhouse environmental data and to send them to the central station. Figure (6) shows the software flow chart for the local station.

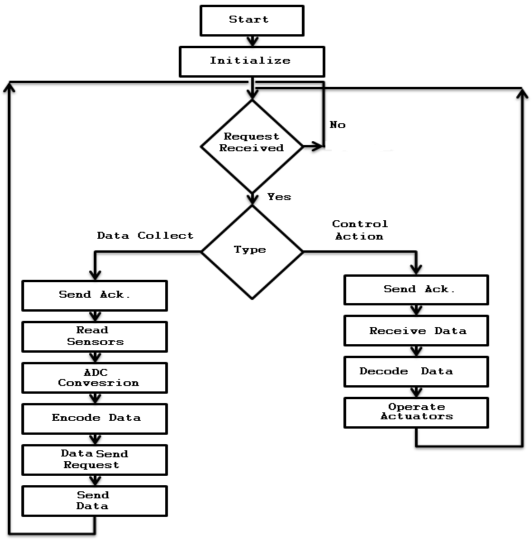

Figure 6: Local Station Data Flow.

At the initialization stage, the microcontroller performs two operations; the ADC initialization and the UART initialization. When the initialization process is completed, the microcontroller goes into a wait state and waits for data request or control action request from the central station. By receiving the data request, the microcontroller generates and send acknowledgement signal through the ZigBee module, enables the sensors connected to it, read the sensors' output signals and performs an analog to digital conversion on the collected data. Upon the completion of the conversion process, the data is encoded into data packet and sent to the central station. On the other hand when the microcontroller receives a control action request, it sends an acknowledgement signal to the central station and wait for the control data packet. Once the data is received it will be decoded and analyzed to find out the required action to be taken for each actuator.

B. Central Station Software System

The central station is designed to perform the following tasks:

1- Network coordination.
2- Collect data from local stations.
3- Data analysis and decision making by generating the necessary control actions.
4- Sending control actions to the local stations.

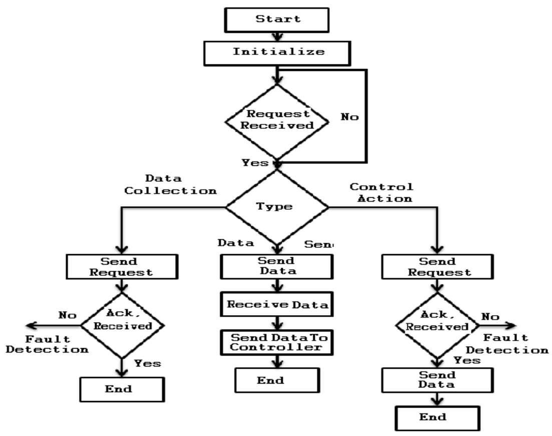

Figure 7: Coordinator Agent Software Flow.

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In this paper we used intelligent system based on the fuzzy logic for the data analysis and control action generation. This task is beyond the scope of this paper, were only the network coordination and communication will be discussed.

The coordination task is performed by a software agent or subsystem, its function is similar to router operation that controls the flow of data between the central station and the local stations. Figure 7 shows the flow diagram for the coordination agent. When the system is started the central station initializes its hardware, the application parameters and initializes the network as been mentioned previously. By the end of the initialization process, the coordination agent will transmit and receive data packets and request signals. There are three request signals; data collection request and control action request from the central station controller subsystem and data sending request from the local stations. When the coordinator agent is instructed to request data from local stations it will forward this signal to the specified local station and wait acknowledgment from the local station. If the agent did not receive any acknowledgement from the local station it will retransmit the request for three times. If the coordinator agent didn't receive any acknowledgment then it will inform the controller agent about fault possibility in the local station. On the other hand, if the local station responds to the data collection request, the data collected will be received by the coordination agent and sent to the controller agent. If the coordination agent receives control action instruction, it will send a request signal to a local station. If the local station didn't respond to this request, the agent will perform fault diagnose procedure. If the coordination agent receives an acknowledgement signal from the local station it will send the control action packet. Finally, when the coordination agent receives data sending request from a local station, it will respond to it by an acknowledgement signal and wait to for the data packet. The received data packet will be then transferred to the controller agent for data analysis and decision making.

The second function for the central station is main controller of the system, where it is used to analyze the data from local stations and generate the required control action. Figure 8, shows the software flow diagram for the control agent. The controller agent software is developed by using VB.NET. It consists of three main modules; namely data validation and identification module, controller module and data handling module.

The data validation and identification module allows the system to determine the status of sent and received data packets and the identity of the local station that will send or receive the data packet. Each data packet consists of at least two bytes depending on the operation to be performed. The first and the second byte are common to all the three operational modes, the first byte contains a Unicode character that is used to specify the mode of operation, while the second byte is used to provide the PAN of the local station. For the data send mode and control action mode, an (n+1) bytes are generated where n represents the number of sensors or actuators and the extra byte is used to declare the value of n. For each sensor or actuator a single byte is used to store the data collected from a sensor or the state of the actuator.

The data handling module is designed to perform four functions. The first function is to handles the information that are extracted from the received data packets and send them to the controller. It encodes the control action data into packets and send them to the coordinator agent, run the control algorithm and finally displays the environmental data and the state of the actuators in real-time.

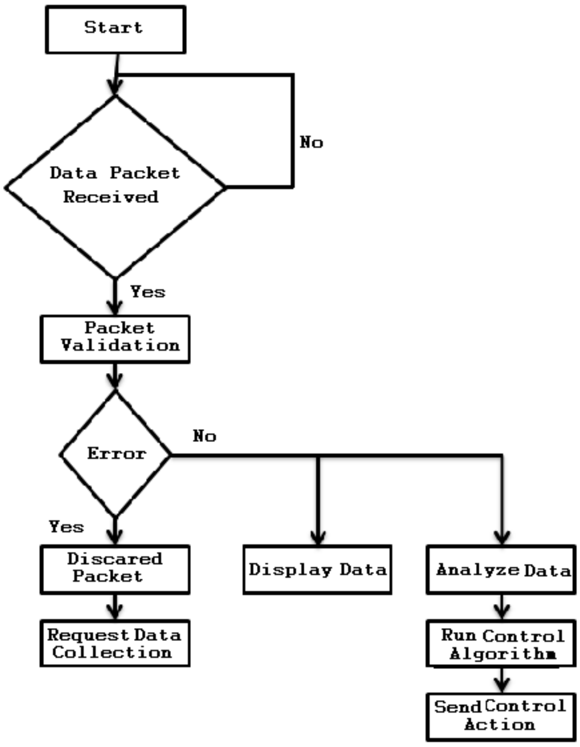

Figure 8: Control Agent Software Flow Diagram.

V. CONCLUSIONS

In this paper, we discussed the wireless solution of greenhouse monitoring and control system based on ZigBee technology, and designed the wireless nodes, network establishment and software system. With the capabilities of self-organizing, self-configuring, self-diagnosing and self-healing, the ZigBee based monitoring and control system provides nearly unlimited installation flexibility for sensors, increases network robustness, and considerably reduces costs. The system has been smoothly running in the modern greenhouse. We, therefore, conclude that the ZigBee-based monitoring and control system can be a good solution for greenhouse monitoring and control.

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