

Remote management and control system for LED based Plant Factory using ZigBee and Internet

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Abstract— Recently, intelligent systems for agricultural production are being developed for safe and low cost food production. Plant factory provide high yield by growing multiple crops and making efficient use of land and resources. Plant growth is facilitated by maintaining humidity, temperature, CO₂ concentration and light intensity and these factors need to be monitored and maintained for an automated system. In this paper, we have proposed a control system for a LED based plant factory consisting of ZigBee wireless mesh network, and remote monitoring via Internet. Field sensors are installed for monitoring environmental conditions and power metering and ZigBee mesh network has been deployed for data acquisition from these sensors. ZigBee nodes transfer the field data to the coordinator node which also serves as a gateway node providing interoperability between TCP/IP network and ZigBee Wireless Sensor Network (WSN). A major novelty of the system is the use of LED lighting instead of fluorescent lighting due to its low power consumption, long life and useful narrow band. LED lighting system provides an efficient and economical lighting system that facilitates plant growth by varying light intensity and frequency according to light conditions and growing requirements and also helps in reducing production costs and speeding growth. Prototype of the proposed system has been installed in a small part of greenhouse. Data acquisition and remote management of the system has shown very satisfactory performance.

Keywords—ZigBee, Plant factory, LED lighting system, Wireless Sensor Network

I. INTRODUCTION

Recently, intelligent environment control systems for production of plants are being developed. Agricultural production is highly dependent on climatic conditions and a plant factory provides an enclosed, controlled environment that ensures stable production throughout the year irrespective of the outside weather and environment. A fully automated plant factory makes efficient use of land and provides controlled physical conditions and proper management for better agricultural yield. This is achieved by proper control of humidity, temperature and CO₂ inside the growing facility. It comes up with a great number of advantages like, freedom of setting up anywhere; giving stable production throughout a

year irrespective of weather, its isolation from outside environment; making it void from insect damage, making safe and green cultivation possible as no pesticides and toxic chemicals are needed and used in it.

An automated plant factory consists of control devices, data acquisition network, and I/O devices. Control devices may include Programmable Logic Controllers, I/O devices like actuators. The control mechanism for data acquisition in plant factory can be based on a wired network or a wireless network. Recently, application of wireless sensor networks has gained a great attention and is being investigated deeply. Sensors are used for monitoring of environmental conditions which are very basic and necessary for agricultural production like light intensity and frequency, humidity, temperature and CO₂ concentration in the air. Having knowledge of these parameters allows performing necessary actions to maintain optimal environment that facilitate plant growth and hence improve yield. The I/O devices are connected to a suitable network for data acquisition for use by a central management system and performing necessary control action based on the gathered data.

A. Related Work

Data acquisition and control network can be developed by using either wired or a wireless system. Most of typical systems are wired in which data acquisition is mostly done by using fieldbus [1]. A fieldbus is a local network which is optimized for short point to point data transfers. Another example of wired system is using power line communications [2] in which data is transmitted over electrical power lines. Wired systems implemented using Controller Area Network CAN [3] have also been built. Wired systems are rigid and put certain constraints like flexibility, maintenance etc. to the network. Installation and extension is not simple and is uneconomical and maintenance costs are much higher. Recent developments in wireless networks [4] have given a stronger alternative as these networks offers greater flexibility, scalability, ease of installation, maintenance and modification.

Reference [5] has presented and implemented a low cost and flexible distributed control system by integrating different communication technologies i.e. CAN, wireless technology and TCP/IP. The use of distributed local networks on smaller

area increases implementation complexity and this network is seen to eliminate cost of wiring only for some part of network. Also security issues of the wireless part of the network have not been discussed. A similar type of system like [5] has been presented in [6] with an extra feature of email support using Simple Mail Transfer Protocol (SMTP). This system also offers low cost and some experimental achievements but shares the drawbacks of complexity and no security features for the wireless network. A distributed control system for greenhouse management based on a programmable logic controller (PLC) connected to a group of sensors and actuators via the field bus PROFIBUS (Process Field BUS) has been presented in [7]. A hybrid wired/wireless network solution has been presented in [8], where CAN and ZigBee network are used discussing the related problems that this integration involves particularly, integration of the wireless and wired network. The system has been tested only for limited functionalities to check for the integration of the hybrid network.

Greenhouse data acquisition system based on Bluetooth has been proposed in [9]. The proposed system consists of Bluetooth wireless sensor, data acquisition module and monitoring centre for monitoring information of temperature and relative humidity. [10] Presents a remote monitoring system for greenhouse using Lon works technology. The sensor and actuator network has been implemented using Lon works technology and this network is integrated to IP network for enabling remote monitoring of the system. Reference's [11-13] have discussed and summarised many applications of wireless sensor networks in agriculture showing trend of how fast WSN are getting in agricultural applications.

Among WSN's, the most popular technology is ZigBee [14] due to its very low cost, low power consumption, long network life and security. Due to these advantages, in our proposed system, we have used ZigBee WSN. The system consists of ZigBee sensor, metering and dimming nodes and LED lighting system for plants. The communication between LED's and dimming nodes is the wired part which uses a serial communication protocol.

This paper is organized as follows: In section II, wireless sensor networks and ZigBee are discussed; the system architecture is explained in Section III. In section IV, implementation of the system has been discussed. Finally we conclude the paper in section V.

II. WIRELESS NETWORKS AND ZIGBEE

Wireless Sensor Networks (WSNs) [15] which were initially developed for military applications, now find a much higher application area which includes home automation, surveillance systems, environmental & health monitoring and also in agriculture. Metrics for WSNs include energy efficiency, small size, flexibility, reusability, data rate and unit cost. Design of a WSN depends mainly on the application area of the sensor network. Requirement for Plant Factory is an economical and reliable control network and the market category that ideally serves this purpose is ZigBee. ZigBee is an open global standard which provides long network life

extending up to years and higher reliability and security with low power consumption at low cost. Achieving low cost and low power comes up with a constraint of lower data rate. For monitoring and control purpose, the data set is not very large and ZigBee supports it quite efficiently. Furthermore, open standard architecture offered by ZigBee has many advantages like it provides interoperability between different systems, reduces implementation costs and manufacturing costs tend to be lower.

ZigBee defines a set of communication protocol built on IEEE 802.14 [16] low rate wireless pan standard that defines physical (PHY) and medium access layer (MAC) of low power wireless personal area networks (LoWPAN) and uses a combination of two technologies, Offset-Quadrature Phase-Shift Keying (O-QPSK) and Direct Sequence Spread Spectrum (DSSS). ZigBee specifies [14] network (NWK) layer and application layer that includes Application support (APS) sub-Layer, ZigBee device object (ZDO), Application Framework (AF) and the ZigBee security. It uses Carrier Sense Multiple Access Collision Avoidance (CSMA/CA) for medium access, ensures data packet delivery by providing mesh networking and specifies application to application interoperability. The IEEE 802.14 transceivers operate in unlicensed 2.4 GHz band at a theoretical data rate of 250 kb/s offering 16 communication channels with each channel separated by 5 MHz. There are three types of nodes in a ZigBee network that include a ZigBee Coordinator (ZC), ZigBee Routers (ZR), or ZigBee End-Devices (ZED). ZC and ZR are full function device while ZED is reduced function device. Different network topologies that ZigBee supports are star, mesh and cluster tree. In our application, we employ mesh networking topology with acknowledgements to increase reliability. AODV routing algorithm is used for mesh networking.

ZC is usually mains powered, always on and starts the ZigBee network with a unique network identifier, a PAN ID and chooses one of sixteen channels for operating the network. ZR and ZED request ZC for joining process. Every ZigBee node has a unique 64 bit address assigned to it during manufacturing. Of these 64 bits, top 24 bits are called Organizational Unique Identifier (OUI) and bottom 40 bits are managed by Original Equipment Manufacturer (OEM) making a node unique from any other node in the world. During network formation, a 16 bit address is assigned to each node. In order to find the least noisy channel, ZigBee calls MAC layer to perform two scans: energy scan is performed while to determine the uniqueness of PAN ID in the vicinity, active scan is performed. On the information acquired by these scans, the coordinator starts ZigBee network on a PAN ID and starts the joining process. To start joining process, ZC has permit join enabled and it receives joining requests and next is the authentication process. If authentication is successful, a node becomes part of the network and in the other case, ZC will tell that node to leave and its address is marked to be available for use by another node that wishes to join. If permit join is disabled at ZC, the network is closed and no node can join the network. Routing starts after successful

network formation. We have implemented our network on ZigBee mesh networking topology that used Ad-hoc On Demand Distance vectoring (AODV). Mesh routing is very efficient in terms of bandwidth, time and memory resources offering acknowledged transmissions and delivering packet transmissions up to 30 hops.

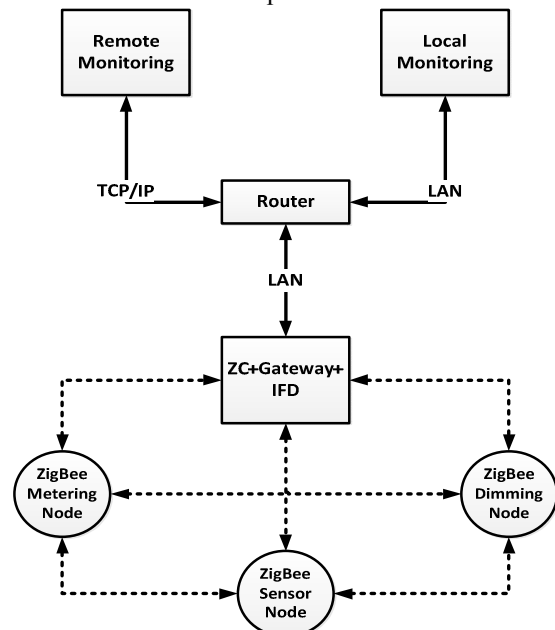


Figure 1: Block Diagram of System Architecture

III.SYSTEM ARCHITECTURE

Research has shown that growth of plants depends mainly on the environmental conditions that include humidity, temperature, CO₂ concentration and light intensity and frequency. Both high and low humidity are abnormal conditions for plant growth so its proper monitoring at all time is important. CO₂ is also an important greenhouse gas and it is also used by plants for their growth. Light is required for photosynthesis, a chemical process through which plants get energy. As proper measurement of these factors is necessary, our proposed system consists of sensors for the measurement of temperature, humidity, CO₂ and light intensity. First three factors can be managed by controlling ventilation manually by the person on field or by employing automatic control. Management of light intensity is needed during night time and is controlled by LED lighting system deployed in the plant factory. Lighting system for the plant factory is based on LED system which provides energy conservation as in traditional lighting systems; a lot of energy is wasted by continuous and over illumination, saving a lot of energy and in turn contributes to lower production costs.

The network consists of dimming, metering and sensor nodes and data transfer is performed using wireless sensor network. The wireless network consists of ZigBee wireless mesh network in which each node can communicate with the other node. Mesh network[17] increases flexibility and robustness and lowers latency. Network consists of one sink node i.e. co-coordinator and all other nodes are routers. Sink node is responsible for network management and also it also

performs data translation, connecting it to TCP/IP network outside for remote monitoring. It is also connected In Factory Display placed inside the factory. As Shown in **Error! Reference source not found.**, the local monitoring centre and the remote monitoring centre. Nodes in the network are discussed in detail below.

A. Sensor node

Sensor node consists of ZigBee radio communication module (RCM), temperature & humidity sensor, CO₂ sensor, colour light sensor and light intensity sensor. Data of each sensor is transmitted using RCM.

1) Temperature & Humidity sensor

SHT7, a single chip relative humidity & temperature sensor module is used communicating with ZigBee module via bidirectional 2-wire serial interface.

2) Colour value sensor

LED's consisting of RGB colours and in order to maintain consistency of RGB as per requirements, TCS3414CS, a digital ambient light sensor with 16 bit digital output is used. It also uses I²C protocol to communicate with ZigBee RCM.

3) CO₂ sensor

Telaire 6613 CO₂ module, a calibrated Non-Dispersive Infrared CO₂ sensor for measuring CO₂ concentration is installed having measurement range from 400 ppm to 2000 ppm. It communicates with EM357 serially via UART.

4) Light Intensity sensor

BH1710FVC, a 16 bit serial output light intensity sensor is used and it uses I²C bus interface for communication with ZigBee RCM.

B. Gateway Node

In order to monitor and control system remotely, a gateway has been implemented to bridge two networks i.e. ZigBee and TCP/IP network. This node does the translation work between the networks in order to monitor sensor data and perform control action accordingly from remote monitoring centre.

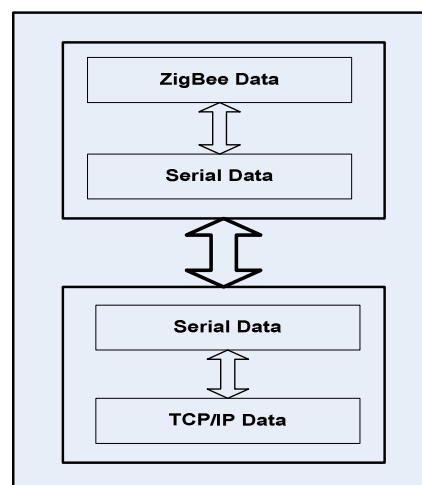


Figure 2: Gateway Node Block Diagram



Figure 3: System prototype installation at a local Greenhouse using RGB LED's

C. Dimming Node

Dimming nodes are used to monitor the faults of LED driver and has a temperature sensor for measuring board temperature for board safety. Clocking is provided by a real time clock device which uses a 2 wire serial interface, I²C.

D. Metering Node

Power metering node consists of ZigBee RCM and power metering sensor ADE7753, communicating via SPI.

IV. IMPLEMENTATION

The proposed system is implemented using ZigBee based metering, dimming and sensor nodes which form ZigBee mesh network and lighting system consists of LED driver controlling the operation of lighting system through serial communication. The coordinator node of the ZigBee network additionally serves the purpose of a gateway node meant for translation of data between two different types of networks i.e. TCP/IP and ZigBee. This gateway node also communicates to In-Factory display (IFD). The ZigBee wireless nodes consist of ember EM357 module which combines a 2.4 GHz IEEE 802.15.4 radio transceiver with 32-bit ARM Cortex-M3 microcontroller having 12kB internal RAM and 192kB flash memory. These devices come with the advantages of highly reliable communication, simplicity in implementation and low cost modules working in 2.4GHz band.

Power consumption is measured by the metering node that consists of power metering sensor, electrically erasable programmable read only memory (EEPROM) and temperature sensor communicating with ZigBee RCM via serial



Figure 4 : Status of sensor data on GUI

communication. Gateway node allows interoperability between the ZigBee network and the TCP/IP network for data acquisition and control from remote site. We have implemented this gateway on the sink node and it converts ZigBee data to serial data and also the other way round. This gateway node is also connected to the IFD on the field display

Data monitoring on the local and remote monitoring centres is done using a graphical user interface (GUI) as shown in Fig.4. Live status of all sensors is shown on this GUI and intensity of RGB LED's can also be varied as per requirements through it remotely.

A. Prototype Installation

Prototype of the system was installed at a small part of a local greenhouse where lettuce plant was grown under RGB LED's shown in Fig.3. Plant growth was monitored using proposed system and LED's intensity and colour was controlled as per requirements through GUI shown in Fig 3. Results of growth of plant are shown in graph in Fig. 5

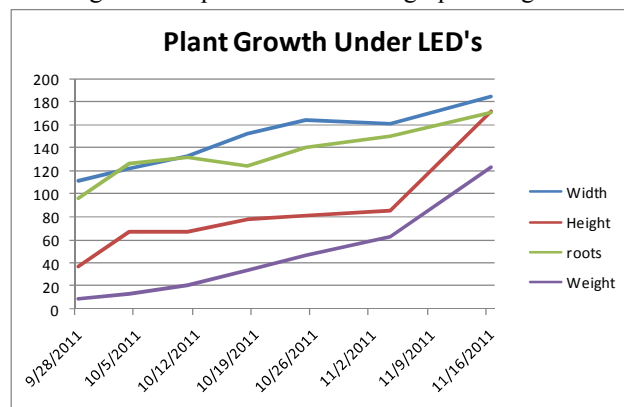


Figure 5 : Average Plant Growth under RGB LED's

V. CONCLUSION/FUTURE WORK

In this paper, we have built a communication system for control and management of Plant Factory by exploiting the advantages of ZigBee technology like low cost, low power consumption, long network life, to design a low cost control system. We have used mesh network which itself has many benefits. Along with that, in order to rapid plant growth, we have used LED based lighting system which adds to the energy conservation of the system, enabling to produce plants

at optimal cost. We have connected this system to remote monitoring centre via internet where we can monitor and control physical conditions as per requirements. An In-Factory display has been installed on field which is a touch screen through which on filed person can also monitor and control the system. The prototype of the proposed system has been installed for experimentation at a local agricultural production area. The use of control algorithms used in intelligent agricultural system is an attractive consideration for future work to be implemented on this existing system.

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