

Multi-sensor Integrated System for Wireless Monitoring of Greenhouse Environment

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Abstract—Several parameters contribute to the growth of plants in a commercial greenhouse, namely soil moisture, soil temperature, atmospheric temperature and humidity, carbon dioxide (CO_2) and light intensity. Maintaining optimal levels of these environmental parameters is essential for healthy growth of the plants and to maximise yields in terms of fruits and flowers. Monitoring only a few parameters, such as temperature and humidity, while neglecting others, leads to inaccurate observations and sub-optimal yields. At the same time, increases in greenhouse sizes have forced the growers to increase measurement points (sensor stations) to accurately track changes in the environment. However, increases in measurement points mean increases in installation and maintenance cost of the sensor stations. In this paper, an automated wireless greenhouse climate monitoring system has been detailed with special emphasis on the programming aspects and testing of a temperature and humidity sensor. The proposed system consists of three units- Sensor Station (SS), Coordinator Station (CS) and Central Control Station (CCS). The backbone of the wireless network is based on ZigBee modules for communication between the SS and CS whereas the communication between the CS and CCS uses a XStream proprietary RF modem. Field trials conducted have established the functionality and reliability of the designed wireless sensor network. The overall system architecture shows advantages in cost, size, power, flexibility and distributed sensing.

Keywords- Environmental monitoring, wireless sensor network, greenhouse climate

I. INTRODUCTION

For many decades, plants have been grown in controlled environments, especially in countries where the climate is harsh, either extremely cold or extremely hot. Greenhouses, often called hothouses in cold countries, provide the controlled environment to grow crops which otherwise would not have been possible in the natural environment. Because of the high economic returns on fruits, flowers and vegetables, of late, research into greenhouse climate monitoring and control has attracted the attention of several researchers because environmental factors greatly influence the quality and rate of plant growth. Continuous monitoring of these environmental parameters gives valuable information to the grower to better

understand how each factor affects the quality and the rate of plant growth, and how to maximise crop yield [1-2].

Commercial greenhouses are getting bigger in size to derive the benefits of the economy of scales. Increases in greenhouse sizes have forced the growers to increase measurement points for tracking changes in the environment, thus enabling energy saving and more accurate adjustments. However, increases in measurement points mean increases in installation and maintenance cost. Moreover, once the measurement points have been built and installed, they can be tedious to relocate in the future. With the advent of cheaper wireless communication technology, it is now economically viable to build a network of many wireless sensor nodes to monitor the environmental parameters with greater precision. Several research teams are engaged in greenhouse monitoring using wireless sensor networks [1-5]. Wireless sensor networks have the advantage of low installation cost, improved reliability and huge flexibility in reconfiguring the network to suit different application scenarios.

Work has been undertaken in our laboratories to design and develop a prototype of a wireless sensor network for environmental monitoring and management of a commercial greenhouse [6-7]. Experiments have been conducted in a commercial greenhouse to test the feasibility and reliability of the system. The system is able to monitor up to six environmental parameters, namely atmospheric temperature, humidity, carbon dioxide (CO_2), light intensity, soil moisture and soil temperature.

In this paper we present the design of a multi-sensor integrated system for wireless monitoring of greenhouse environment. The built system has four sensor stations and communicates with the coordinator station using ZigBee RF modules. The long distance communication between the coordinator station and the central control station uses a proprietary RF modem.

The paper is arranged as follows: Section II gives an overview of the hardware of the system. Section III details the software design of the sensor station, coordinator station and the central control station. The experimental results and system integration details are given in Section IV and finally Section V presents the summary and conclusions.

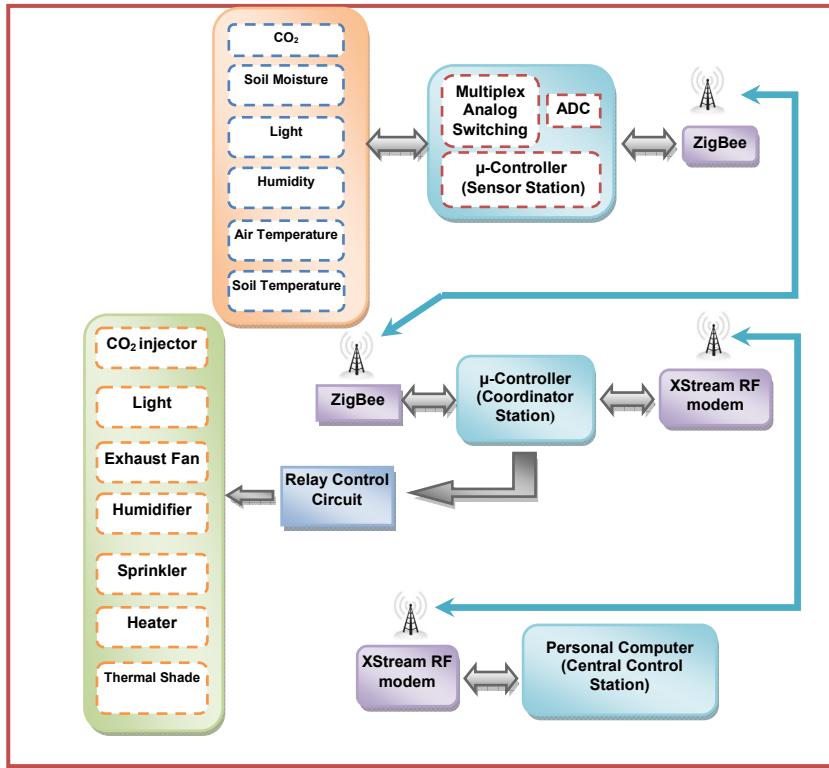


Figure 1. Functional block diagram of the complete system

II. OVERVIEW OF SYSTEM HARDWARE

The proposed system consists of three parts, arranged hierarchically: Sensor Station (SS), Coordinator Station (CS), and Central Control Station (CCS). The overall system is shown in figure 1. The SS and the CS are microcontroller based (Silicon Labs C8051F020 [8]) while the CCS is a personal computer based system. The functions of the three stations are explained in this section.

A. Sensor Station (SS)

The Sensor Station is responsible for the collection of climate measurements data and transmits it to a coordinator station (CS). A detailed review of the various sensors used has been presented in [9]. The SS consists of five commercial sensors:

- Sensirion's SHT75 humidity and temperature sensor integrates the sensor elements and signal-processing in a compact format and provide a fully calibrated digital output [10]. It has humidity operating range from 0 – 100% and temperature operating range from -40 °C – 125 °C.
- CMD7160 CO₂ module uses a compact NDIR (nondispersive infrared) sensor, featuring excellent performance characteristics, including high accuracy and low power consumption [11]. The detection range is 300~5,000 ppm CO₂.
- VG400 soil moisture sensor is a low frequency soil sensor with low power consumption [12]. The output voltage is proportional to the moisture content in the soil.

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- THERM200 soil temperature sensor is similar to VG400 in terms of low power consumption and robust to external interferences [13]. It has a temperature span of -40°C to 85°C. The output voltage is linearly proportional to the changes in the temperature in the soil.
- NORP12 light dependent resistance sensor has spectral response similar to the human eye [14]. The internal resistance increases or decreases depending on the level of light intensity impinging on the surface of the sensor.

Figure 2 shows the assembled sensor stations

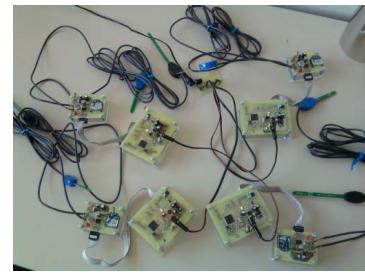


Figure 2. Sensor Stations

B. Coordinator Station (CS)

The Coordinator Station acts as a router that controls the flow of data and instructions between the Sensor Station and the Central Control Station in a pre-programmed manner. It

also manages the local activities such as turning on/off sprinkler, humidifier etc. It communicates with the sensor stations using ZigBee wireless protocol and is thus restricted to short distance links. The ZigBee modules are interfaced to the microcontroller of the coordinator station using UART (universal asynchronous receiver transmitter). It communicates with the central control station using Xstream RF modems which are capable of data transmission up to 5 km using dipole antennas and operating at 2.4 GHz. The modem is interfaced to the microcontroller using another UART channel. Figure 3 shows the prototype of the Coordinator Station.

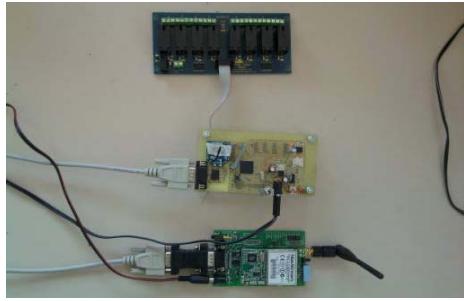


Figure 3. Coordinator Station

C. Central Control Station (CCS)

The Central Control Station is the main controller of the system. The functions of the CCS are-

- Issue instruction to lower computers (Coordinator Station, Greenhouse Station)
- Process incoming data and provide a convenient way that allows the users to easily access and visualise the data
- Provide control commands to adjust the greenhouse climate conditions in accordance with the grower's requirements. Details of the climate control algorithm will appear in another paper.

The CCS is a PC based system. The application running on the CCS was developed in Visual C#. The program has a very user friendly GUI to monitor the Sensor Station data. Various climate parameters are depicted in real-time using graphs. The CCS is connected to the RF modem on the USB port.

III. SOFTWARE DESIGN

This section shows the macro-level software design of the various stations.

The Sensor Station is used for collecting and processing raw data from the sensors and transforms them into a more understandable format. Collected data is encoded into a data packet and is sent to the central control station via the coordinator. Figure 4 shows the flow chart of the software design of the Sensor Station.

Figure 5 shows the flow chart of the software design of the Coordinator Station. The Coordinator Station controls the flow of incoming and outgoing data and instructions from the Sensor Stations and the Central Control Station.

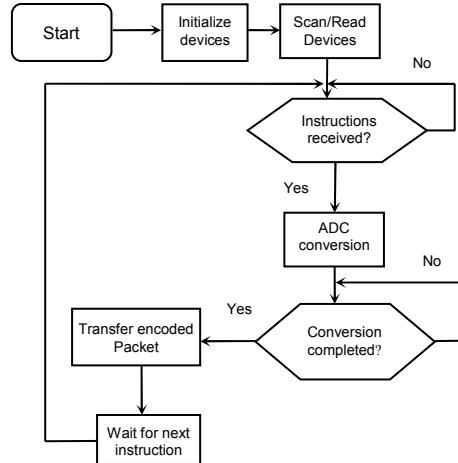


Figure 4. Software design of the Sensor Station

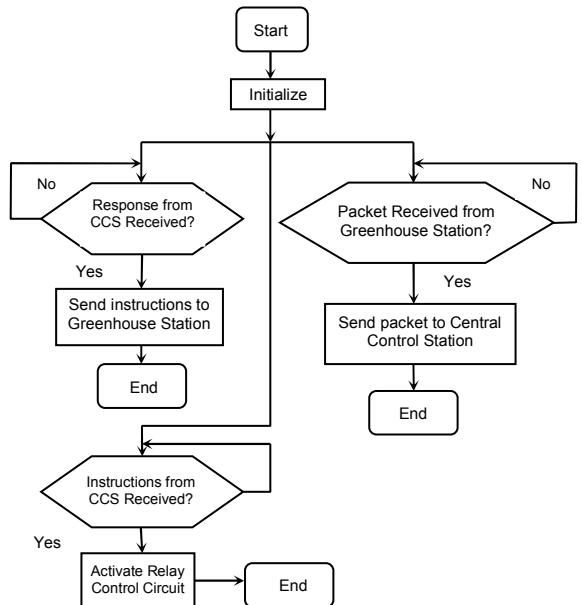


Figure 5. Software design of the Coordinator Station

Figure 6 shows the flow chart of the software design of the Central Control Station. The Central Control Station is the main controller of the system. It can be used for data control and storage as well as providing instructions to lower stations (Sensor Station and Coordinator Station). When environmental parameters such as temperature or humidity become higher or lower than the set thresholds, some corrective actions are needed. The controller station has been specifically designed to tackle this issue. It is able to automatically control the greenhouse climate by sending control commands, in accordance with the requirements, through to the Coordinator Station. Upon receiving the commands, the Coordinator Station immediately controls the electric-relay switches in the greenhouse to activate local activities such as heating, lighting, ventilation etc.

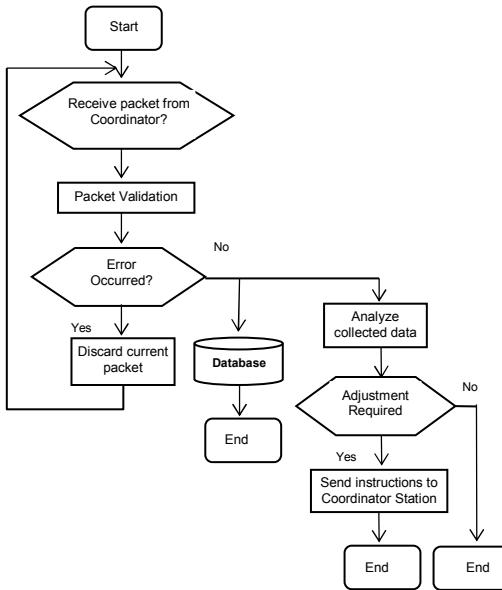


Figure 6. Software design of the Central Control Station

IV. TESTING AND SYSTEMS INTEGRATION

A number of experiments were conducted to test the accuracy and sensitivity of each sensor. These experiments took place in various locations such as process lab, glasshouse and a backyard. A number of calibrated commercial sensing devices were also used as reference standards for each sensor.

A. SHT75 humidity/temperature sensor

The SHT75 has a 2-wire digital interface (SCK and DATA) [9] which are connected to the microcontroller as shown in Figure 7. The serial clock pin on the sensor is used for input signal only. Serial data pin on the other hand is bidirectional.

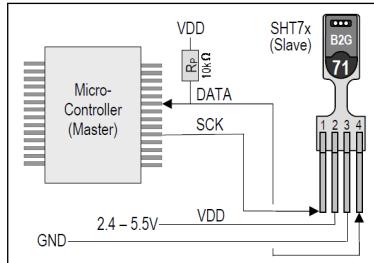


Figure 7. SHT7x connection circuit [9]

B. Testing the temperature and humidity sensor

C8051F020 microcontroller development board was used in this experiment. To initiate a transmission, a special transmission start sequence has to be issued to the sensor which wakes up the sensor and allows the sensor to be ready for any incoming instructions or commands.

The output of the start-up transmission is shown in figure 8. The program lowers the DATA line while the SCK line is high, followed by a low pulse on SCK line and raising DATA line again. The start-up transmission is followed by a series of command bits. The subsequent command consists of three

address bits and five command bits ('00000101' for relative humidity, '00000011' for temperature). Figure 9 and 10 show examples of sending command to the sensor.

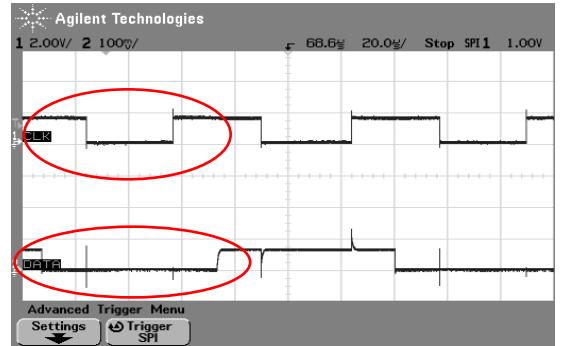


Figure 8. Start-up Transmission

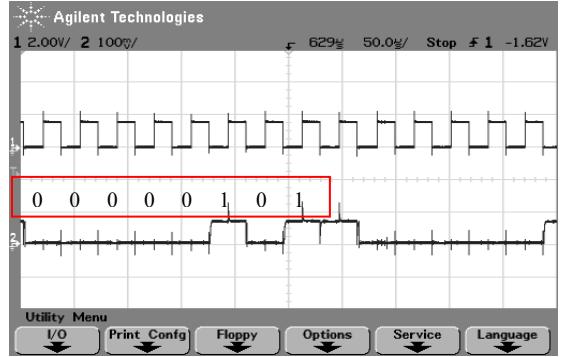


Figure 9. Relative Humidity command (00000101)

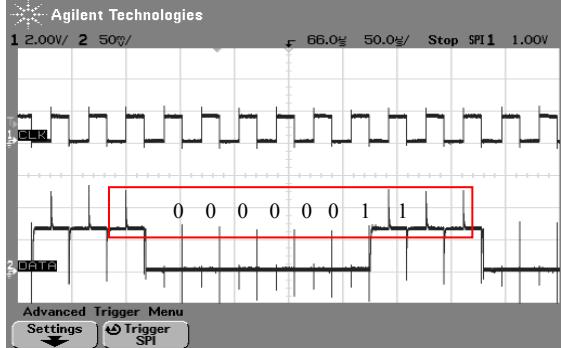


Figure 10. Temperature command (00000011)

Data was collected for 1 hour at intervals of 10 minutes. The 1-hour tests were performed several times at different times of the day. The results for one such 1-hour test are shown in Table 1. The results were compared with those obtained from another temperature and humidity measurement device namely Fluke 975 Air Meter. Similar tests were performed for all the other sensors, namely the CO₂, soil moisture, soil temperature and light.

The test results for SHT75 show that the measured temperature is within ± 1.3 °C and humidity within $\pm 2.3\%$ of those measured by Fluke 975. These differences are very small for the intended application.

TABLE I. TEMPERATURE AND HUMIDITY MEASUREMENT RESULTS

Time (min)	SHT75		Fluke 975	
	Temp (°C)	Humidity (%)	Temp (°C)	Humidity (%)
0	22.3	47.5	22.7	50.2
10	22.6	46.2	23.1	48.5
20	21.8	47.1	22.9	50.1
30	22.1	46.5	23.5	48.9
40	20.8	48.1	23.2	48.5
50	22.2	46.6	23.7	49.5
60	22.3	47.8	24.1	49.3

C. Systems integration and testing of the wireless communication network

The system was tested using the connection setup shown in figure 11.

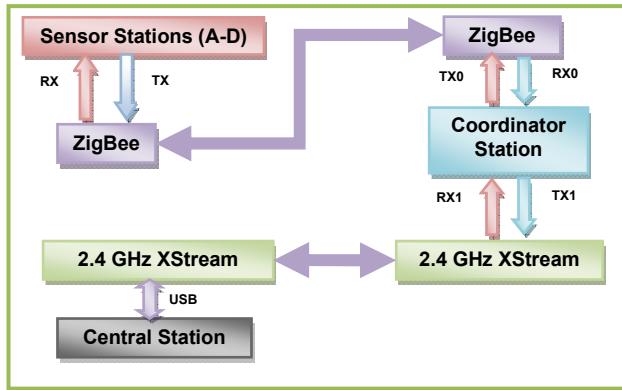
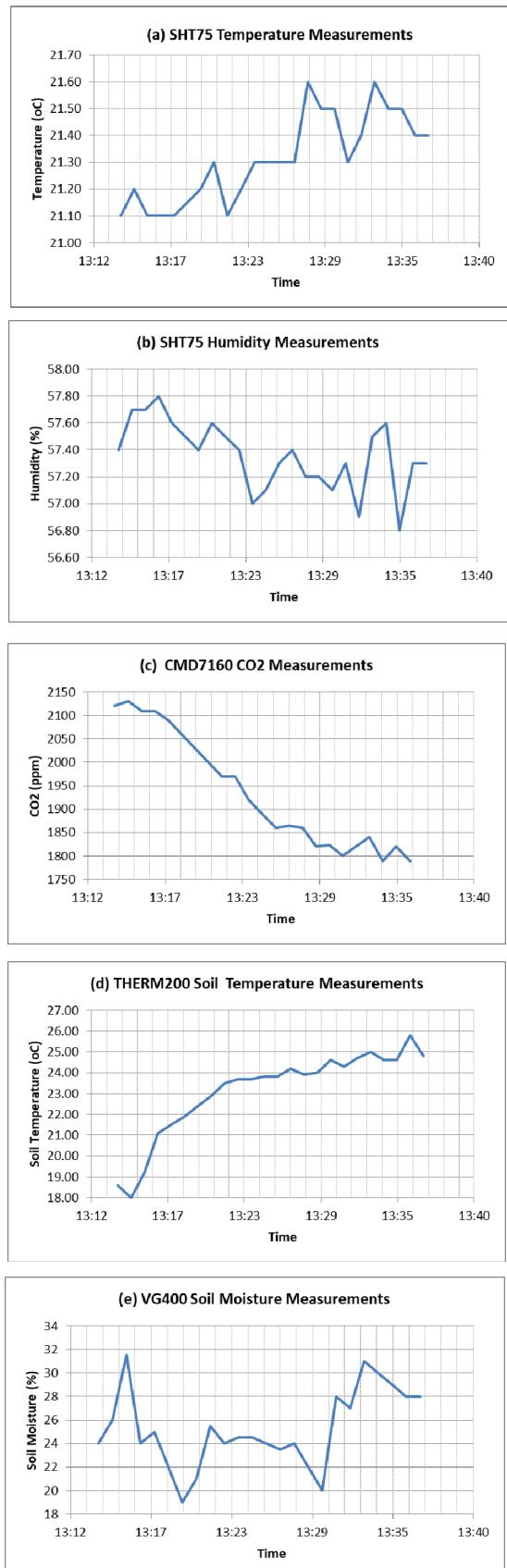


Figure 11. Wireless communication setup for testing

Four Sensor Stations (A – D) were installed in a medium sized greenhouse together with a Coordinator Station and a Central Control Station. The distance between the Sensor Stations and the Coordinator Station varied from 20 m to 56 m. The distance between the Coordinator Station and the Central Control Station was 300 m. The laptop PC based Central Controller Station, running the application software, is shown in figure 12. The XStream RF modem is connected to the PC on the USB port. Data was gathered and logged from all the Sensor Stations over an extended period of time. The plot of the data gathered from Sensor Station A is shown in figure 13.



Figure 12. Central Control Station with XStream transmitter



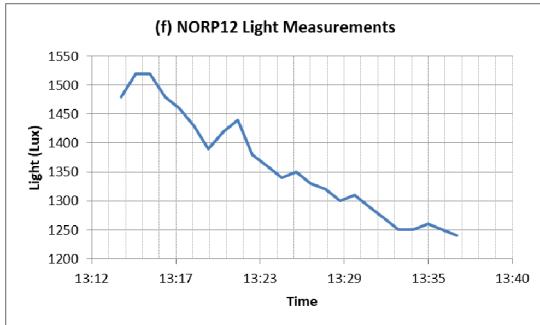


Figure 13. Plots of Sensor Station data (a) Air temperature (b) Humidity (c) CO₂ (d) Soil Temperature (e) Soil Moisture (f) Light intensity

V. SUMMARY AND CONCLUSIONS

Greenhouses are getting bigger in size to maximise returns through economies of scales. This has made the task of monitoring the greenhouse climate accurately and controlling the environmental parameters precisely a very challenging task. With the advent of low-cost sensors and wireless communication hardware which is reliable and easy to install, deployment of wireless sensor network is an attractive solution.

In this paper the design of a wireless climate monitoring system has been presented which is hierarchically organised as three stations – sensor station, coordinator station and the central control station. Each station has a predefined role. A large greenhouse will typically have several sensor stations. Each sensor station is equipped with sensors to monitor the vital environmental parameters such as temperature, humidity, soil moisture etc. The data from the sensors is collected and sent to the coordinator station using ZibBee wireless modules. The coordinator station acts as a conduit between the sensor station and the central control station. It is also responsible for the actuation of heaters, sprinklers etc to control the greenhouse climate. The central control station is a PC based system which runs the application software. The user can enter control parameters using the software. The central control station also logs the sensor date into a database and depicts the sensor data graphically. Data can be plotted in real-time mode or archival mode. In archival mode, historical data can be retrieved and plotted. This allows past data to be analysed to study the trend of the measured data.

Several sensors were evaluated for the system and calibrated against standard instruments. The detailed test result for one of the sensors, namely the STH75 humidity and temperature sensor, has been presented. The system was integrated with 4 sensor stations and tested in a greenhouse. Each sensor station had 6 sensors, one each for air temperature, humidity, CO₂, soil temperature, soil moisture and light

intensity. So the overall testing involved 24 sensors. The wireless network was reliable and performed satisfactorily.

The novelty of the reported work is in its 3-tier structure which enables an implementation with distributed hardware architecture. It also makes the system modular for fault isolation and is highly scalable which makes it adaptable for greenhouses of various sizes.

REFERENCES

- [1] Dae-Heon Park and Jang-Woo Park, Wireless Sensor Network-Based Greenhouse Environment Monitoring and Automatic Control System for Dew Condensation Prevention, Sensors 2011, 11(4), 3640-3651; doi:10.3390/s110403640
- [2] Ahonen, T., Virrankoski, R., Elmusrati, M., Greenhouse Monitoring with Wireless Sensor Network. Proceeding of Mechtronic and Embedded Systems and Applications, 2008. MESA 2008. IEEE/ASME International Conference, pp. 403 – 408.
- [3] Mohd Fauzi Othmana, Khairunnisa Shazalib, Wireless Sensor Network Applications: A Study in Environment Monitoring System, Procedia Engineering, Elsevier, Volume 41, 2012, Pages 1204-1210
- [4] BeomJin, K., DaeHeon, P., KyungRyung, C., ChangSun, S., SungEon, C., JangWoo, P., A Study on the Greenhouse Auto Control System Based on Wireless Sensor Network. Proceeding of Security Technology, 2008. SECTECH '08, pp. 41–44.
- [5] S.Othman. "Preliminary Infrastructure Development for Greenhouse Accounting of Malaysian Rainforest using Wireless Sensor Network", European Journal of Scientific Research, Vol.33, No.2, pp. 249-260, 2009.
- [6] Yang, S., Zhang, Y. Wireless Measurement and Control System for Environmental Parameters in Greenhouse. Proceedings of the Measuring Technology and Mechatronics Automation (ICMTMA), 2010, Vol 2, pp. 1099 – 1102.
- [7] K.Anuj et al., "Prototype Greenhouse Environment Monitoring System," Proceedings of the International Multi Conference of Engineering and Computer Scientist, March 2010, Vol 2, pp.17-19
- [8] Silicon Laboratories Inc. C8051F020 Development Kit. [online]. Available: http://www.silabs.com/Support/Documents/TechnicalDocs/C8051F020_Short.pdf
- [9] Vu Minh Quan, Gourab Sen Gupta, Subhas Mukhopadhyay, Review of sensors for greenhouse climate monitoring, Proceedings of Sensor Application Symposium (SAS 2011), 22-23 February, 2011, San Antonio, USA, pp. 112-118
- [10] Sensirion Inc. SHT7x – Humidity & Temperature Sensor. [online]. Available: <https://www.sensirion.com/en/environmental-sensors/humidity-sensors/pintype-digital-humidity-sensors/>
- [11] Figaro Sensors, TGS4161 – CO₂ sensor. [online]. Available: <http://www.figarosensor.com/products/docs/CDM7160%280417%29.pdf>
- [12] Vegetronix, VG400 – Soil moisture sensor. [online]. Available: <http://www.vegetronix.com/Products/VG400/>
- [13] Vegetronix, VG400 – Soil temperature sensor. [online]. Available: <http://www.vegetronix.com/Products/THERM200/>
- [14] Silonex, NORP12 LDR. [online]. Available: <http://www.datasheetarchive.com/NORP12-datasheet.html>