Autonomous Wireless Sensor Network for Greenhouse Environmental Conditions Monitoring

Bartosz Pękosławski, Piotr Krasiński, Michał Siedlecki, Andrzej Napieralski
Department of Microelectronics and Computer Science
Lodz University of Technology
Lodz, Poland
bartoszp@dmcs.pl

Abstract—**The paper describes a prototype of wireless sensor network for monitoring of greenhouse environmental conditions including temperature and soil moisture. The proposed system consists of measurement nodes powered from small-size solar cells and a central node that can be connected to a Personal Computer via USB or work independently. The wireless sensor nodes are responsible for signal acquisition, processing and data transmission via ZigBee radio interface. DC voltage generated by the solar cells is processed by especially designed DC/DC converter and electric energy is stored in a supercapacitor for peak power consumption. Low power solutions are used for minimisation of energy losses. Presented results, conclusions and possible future improvements may be valuable for designers of autonomous habitat monitoring systems.**

Index Terms—**WSN, solar cell, photovoltaic, energy harvesting, greenhouse, habitat, environment, ZigBee, IEEE 802.15.4, low power, DC/DC converter**

I. Introduction

In the recent years, Wireless Sensor Networks (WSN) gain an increasing interest and importance in many applications that involve remote monitoring and control of various parameters. These areas include industrial production lines monitoring, Structural Health Monitoring (SHM) systems and transportation systems. In these cases, the main aim is to increase safety as well as improve efficiency and reliability by measurement of structure mechanical stress and strain, machine vibration frequencies and levels, road traffic, etc. Due to decreasing prices and increasing availability of miniature radio transceivers, WSNs are also applied more and more frequently in home automation, especially in Building Management Systems (BMS), to increase comfort and safety of inhabitants as well as to bring savings resulting from lower energy consumption. The lack of cable connections makes a system installation much easier, more flexible and less expensive.

Another important application for WSNs is monitoring of environmental conditions and parameters such as temperature, air pressure, humidity, gases concentrations, wind speed, wind direction and insolation. Such systems can be used in agriculture to improve plant growth conditions and increase crops. They may be also applied in distributed meteorological stations, solar and wind farms. Large distances between network nodes in these systems make wire connections impractical and often impossible.

A special kind of an environmental condition monitoring system is a measurement network intended for the use in greenhouses. Such systems have been widely studied for several years [1-17]. Various system structures have been proposed, including wire [1], mixed wire and wireless [2, 6, 8, 14] and purely wireless ones [3-7, 9-13, 15-17]. Wire interfaces, which are used in the proposed systems, include: 1-Wire [1], USB [6, 8, 14], I^2C [8] and Ethernet/TCP/IP [1, 2]. The applied wireless technologies include: ZigBee/IEEE802.15.4 [3, 5-9, 12-14, 16, 17], WiFi [3], CyFi [15], GSM/GPRS [4, 9, 11-13] and LonWorks[2]. ZigBee technology is chosen the most frequently because of much lower power consumption comparing to WiFi and Bluetooth [5, 17]. As far as monitored parameters are concerned, most of the authors concentrate on a measurement of: temperature [1-17], humidity [1-17], soil pH factor [9, 15] and light intensity [2, 5, 6, 8, 14, 17]. Moreover, several papers propose the use of actuators to preserve optimal parameter values, including: heaters [1, 5, 7-10], ventilation fans [2, 5, 7, 8], wetting pumps [2, 5, 8-10] and lamps [8-10]. Mobile stations on robot platforms [14] can replace stationary wireless sensor nodes to measure parameters in many locations.

A very important issue related to the use of WSNs is an energy source for wireless sensor nodes. Usually [3-17], battery-based solutions are adopted. This approach has many limitations. First of all, batteries need to be regularly replaced or recharged, which may be very difficult, dangerous or impossible in distant, inaccessible locations. Furthermore, batteries may explode when short-circuited or used at elevated temperatures. Finally, used-up batteries are potentially dangerous for natural environment and they need to be stored and then recycled.

As a result, different ambient energy harvesting technologies [18] have been developed in order to provide battery-less power supply of wireless sensor nodes. The main energy forms harvested by these miniature transducers are: solar energy, mechanical vibrations energy, thermal energy and radio waves energy.

In this paper, the authors propose the use of small-size solar cells as a power source for sensor nodes of a greenhouse environmental conditions monitoring system.

II. Monitoring System

A. Structure

The proposed greenhouse monitoring systems consists of wireless sensor nodes and network coordinator (central node) that can be linked to a PC via USB interface. The WSN applies ZigBee technology and star topology. The use of additional routing devices is unnecessary because of relatively short distances between network nodes in the concerned application.

Fig. 1 presents the system architecture.

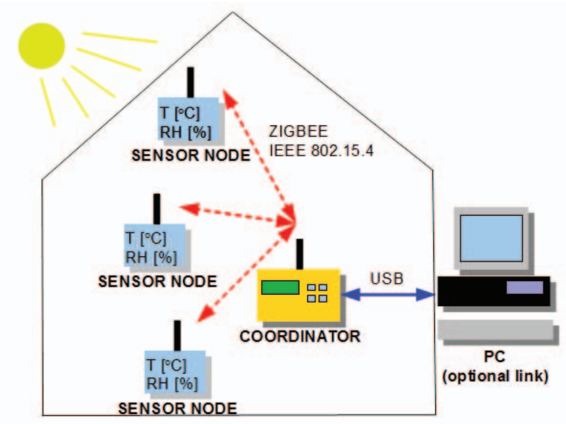

Figure 1. System architecture

B. Network Coordinator

The network coordinator is responsible for reception of measurement data from wireless sensor nodes, data presentation and transmission to a PC. The coordinator consists of Atmel ATZB-24-A2 module of ATmega1281 microcontroller and AT86RF230 ZigBee radio transceiver with integrated chip antenna, text LCD, four switches and FT232BL IC for UART to USB interfaces conversion. The network coordinator is powered from 12V DC power supply connected to internal 3.3V and 5V linear regulators. The 5V supply voltage is required for USB converter and LCD.

The internal structure of the network coordinator is presented in Fig. 2.

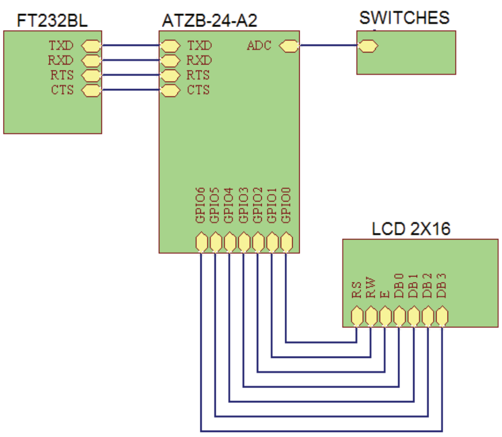

Figure 2. Network coordinator structure

The actual view of the network coordinator circuit is shown in Fig. 3.

Figure 3. View of network coordinator and its display

C. Wireless Sensor Node

The wireless sensor nodes are responsible for a measurement of temperature and soil humidity and sending the acquired data to the network coordinator when the are active. The main parts of sensor node are solar cells, power processing module and measurement data acquisition and transmission module described later in detail.

III. Wireless Sensor Node Solutions

A. Measurement Data Acquisition and Transmission

The measurement data acquisition and transmission block is based on the ATZB-24-A2 module, the same as the one used in the network coordinator. Two sensors are connected to this module: temperature sensor DS1820B20 with digital 1-Wire interface and analog humidity sensor SYH-2R. The humidity sensor is powered using square wave of 1V amplitude and 1kHz frequency produced by 8-bit timer in microcontroller operating in PWM mode. An analog signal from humidity sensor is amplified by INA125 instrumentation amplifier and then converted to digital form by 10-bit A/D converter in ATZB-24-A2. The measurement ranges for the sensors are -55 to +125 °C and 20 to 95% RH respectively. The sensors are placed in narrow aluminum tubes in order to avoid negative influence of soil conditions.

The module contains two low-power voltage comparators LTC1540 that sense voltage level at an electric energy storage element. Voltage thresholds are set to 1.6V and 3V, corresponding to placing sensor node in sleep mode and its waking up, respectively. The outputs of the comparators are connected to external interrupt inputs of the microcontroller.

The structure of the module is depicted in Fig. 4.

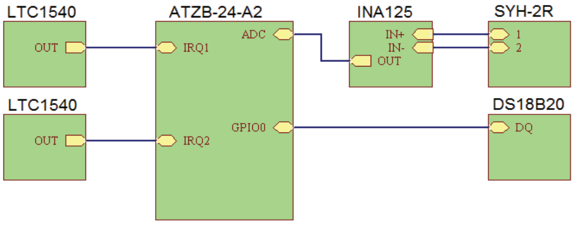

Figure 4. Measurement data acquisition and transmission module structure

Fig. 5 shows the actual view of measurement data acquisition and transmission module. The size of the PCB is 50 x 50 mm.

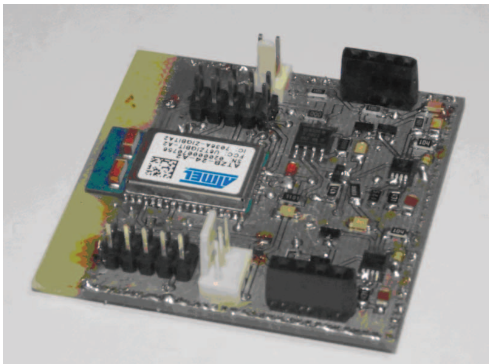

Figure 5. View of measurement data acquisition and transmission module

B. *Power Processing Circuit in Sensor Node*

The first power processing prototype is based on LTC3108 IC. This is a step-up converter with an internal oscillator, charge pump, synchronous rectifier and LDO. DC input voltage is converted to AC one in transformer, whose primary winding is switched by an internal MOSFET.

Schematic drawing of the first DC/DC converter is shown in Fig. 6.

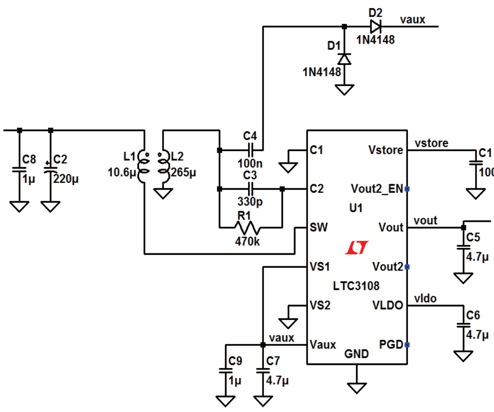

Figure 6. Schematic drawing of DC/DC converter based on LTC3108

VP2-0216H Coiltronics transformer with 1:5 turns ratio is used in the designed converter. Capacitance of C4 needed to be increased to 100nF and external rectifier diodes were necessary to obtain output voltage stability for a wide range of input voltages. Output voltages are 2.2V for digital part (ATZB-24-A2, DS18B20) and 3.3V for analog part (INA125, SYH-2R) of the sensor node. Moreover, 1F supercapacitor is used as an energy storage component connected to VSTORE output, which reaches maximum voltage of 5.25V.

The second constructed prototype of power processing module is based on LTC3105 DC/DC converter. This circuit is less complex than the first one and does not require input transformer. Maximum Power Point Control (MPPC) technique is used to maintain optimal input voltage. The output voltages are the same as in the first circuit but there is no separate output for supercapacitor (it is connected to VOUT output). Fig. 7 presents the schematic drawing of the LTC3105 -based DC/DC converter.

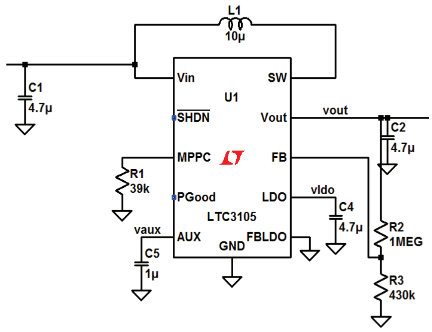

Figure 7. Schematic drawing of DC/DC converter based on LTC3105

PCBs of both DC/DC converters have the size of 25x50 mm and are mounted on the top of the data acquisition and transmission module.

Fig. 8 presents the actual view of the sensor node with the LTC3108-based power processing module.

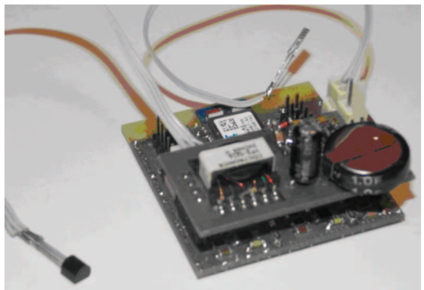

Figure 8. View of sensor node with power processing module and sensors

C. *Control Program Algorithms*

The network coordinator operates in continuous manner. After initialization, network status is checked and nodes are added. Then the coordinator waits for measurement data from active nodes. In meanwhile, the coordinator can perform tasks related to user interface. After reception, data are transmitted to a PC.

Fig. 9 presents the flowchart diagram of the network coordinator control program algorithm.

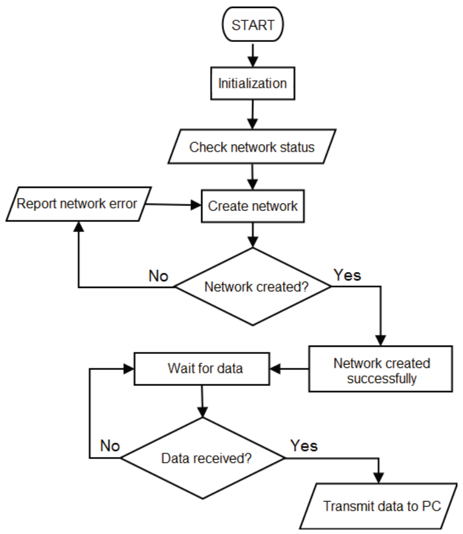

Figure 9. Network coordinator control program algorithm

The sensor node operates in cyclic way. It stays in sleep mode for most of time until supercapacitor voltage reaches required level. In active mode, connection with network is established, measurement data is acquired and sent to the coordinator. Then the node enters sleep mode for the preset time or until enough energy is accumulated for the next measurement and transmission. When supercapacitor voltage becomes insufficient, measurement and transmission procedure can be safely intercepted and sleep time may be prolonged.

The flowchart diagram of the sensor node control program algorithm is depicted in Fig. 10.

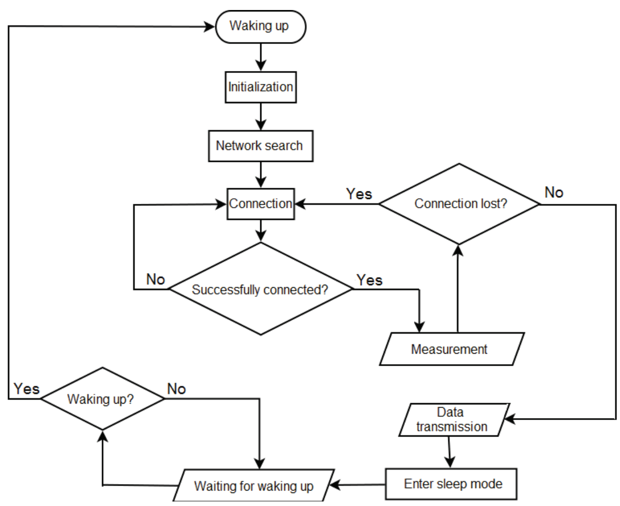

Figure 10. Wireless sensor node control program algorithm

IV. Tests and Results

Performed tests consisted of three main parts: sensor tests, power supply tests and communication tests.

Sensor tests confirmed the assumed measurement ranges and satisfactory measurement accuracies (±0.5 °C in -10 to 85 °C range and ±3% RH in 60 to 70% RH range).

The DC/DC converters were studied in computer simulation in LTSpice software and then in reality. In the real tests, two solar cells with nominal output voltage of 0.55V and output current of 3.6A were used. The two cells were connected in series to supply sensor node. Fig. 11 presents the obtained current-voltage and power-voltage characteristics of the two connected cells at full sunlight intensity, at 15 °C ambient temperature. Tests at different light intensities (partly clouded, fully clouded, sunset, artificial light) revealed significant power decreases - even 3 to 10 times lower generated electric power.

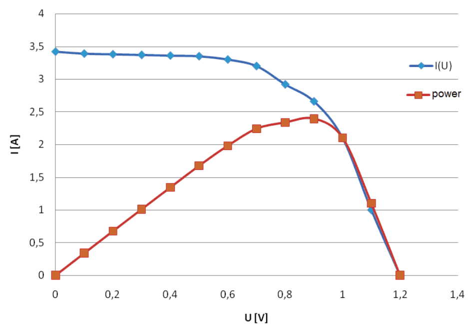

Figure 11. Solar cell I(V) and P(V) characteristics

The two DC/DC converters operate correctly provided that the input voltage is high enough. The first converter can operate with input voltages as low as 0.3 - 0.4V (Fig. 12). The second converter requires higher input voltages but it offers much higher output current capability (over 15 mA as compared to 4mA for LTC3108). The problem related to both converters is their low efficiency for very small currents (several µA as in sensor node sleep mode), which drops from over 60% at several mA down to efficiency below 30%.

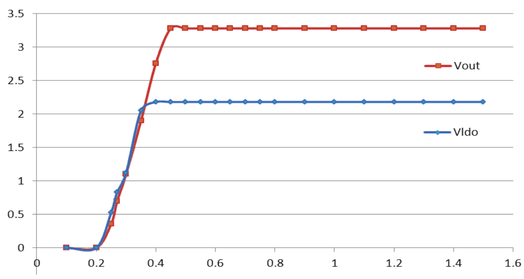

Figure 12. Output voltage versus input voltage characteristics of LTC3108-based DC/DC converter

Communication tests has shown the maximum range of about 100m for 3dBm output power of radio transceiver and 250kb/s transmission rate. The supply current is about 15 mA during transmission. When this current cannot be supplied, the module enters sleep mode until the next waking-up. Networks established by the coordinator functioned correctly and new sensor nodes can be added not only during initialization.

V. Conclusions

In conclusion, a prototype of wireless sensor network for monitoring of environmental conditions inside a greenhouse was proposed and studied. The proposed solution applies powering of wireless sensor nodes from miniature solar cells instead of electrochemical batteries. System structure, network coordinator and sensor node design were described. The results of initial tests confirm possible usefulness of the solution but further modifications are planned.

Future work should concentrate on further power consumption minimisation, power processing efficiency improvement and solar cell replacement with a more efficient one. These steps are aimed to make sensor nodes less vulnerable to light intensity changes. The functionality of the network coordinator can be improved by addition of a flash card slot and a real time clock. Furthermore, more environmental parameters, such as sunlight intensity and soil pH factor, should be possible to measured by the sensor node.

References

[1] D. Stipanicev, J. Marasovic, “Networked Embedded Greenhouse Monitoring and Control,” Proceedings of the 2003 IEEE International Conference on Control Applications, Istanbul, Turkey, pp. 1350-1355, 23–25 June 2003

[2] G. A. Pereira, C. E. Cugnasca, "Application of LonWorks Technology Distributed Control in Greenhouses", Proceedings of 2005 EFITA/WCCA Joint Congress on IT in Agriculture, Vol. 1, pp. 1349-1354, Vila Real, Portugal, 2005

[3] M. Mancuso, F. Bustaffa, "A Wireless Sensors Network for Monitoring Environmental Variables in a Tomato Greenhouse", Proceedings of the IEEE International Workshop on Factory Communication Systems, Torino, Italy, pp. 107–110, 27–30 June 2006

[4] X. Li, Z. Sun, T. Huang, K. Du, Q. Wang, Y. Wang, "Embedded Wireless Network Control System: An Application of Remote Monitoring System for Greenhouse Environment", Proceedings of the IMACS Multiconference on Computational Engineering in Systems Applications, Beijing, China, pp. 1719–1722, 4–6 October 2006

[5] Y. Zhou, X. Yang, X. Guo, M. Zhou, L. Wang, "A Design of Greenhouse Monitoring & Control System Based on ZigBee Wireless Sensor Network", Proceedings of the International Conference on Wireless Communications, Networking and Mobile Computing, Shanghai, China, pp. 2563–2567, 21–25 September 2007

[6] T. Ahonen, R. Virrankoski, M. Elmusrati, "Greenhouse Monitoring with Wireless Sensor Network", Proceedings of the IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications", Beijing, China, pp. 403–408, 12–15 October 2008

[7] B. J. Kang, D. H. Park, K. R. Cho, C. S. Shin, S. E. Cho, J. W. Park, "A Study on the Greenhouse Auto Control System Based on Wireless Sensor Network", Proceedings of the International Conference on Security Technology, Sanya, China, pp. 41–44, 13–15 December 2008

[8] A. Cenedese, L. Schenato, S. Vitturi, "Wireless Sensor/Actor Networks for Real–Time Climate Control and Monitoring of Greenhouses", 2008

[9] G. Qiang, C. Ming, "Research and Design of Web-based Wireless Sensor Network Management System for Greenhouse", International Conference on Computer and Electrical Engineering, pp. 657-661, 2008

[10] S. János, I. Matijevics, “Distant Monitoring And Control For Greenhouse Systems Via Internet”, Zbornik radova konferencije Yuinfo 2009, pp. 1-3, Kopaonik, Serbia, 2009

[11] A. A. Izzatdin, H. H. Mohd, J. I. Mohd, M. Mazlina, S. H. Nazleeni, "Remote Monitoring in Agricultural Greenhouse Using Wireless Sensor and Short Message Service (SMS)", International Journal of Engineering & Technology IJET, Vol. 9, No. 9, pp. 1-12, 2009

[12] Y. Chengbo, C. Yanzhe, Z. Lian, Y. Shuqiang, "ZigBee Wireless Sensor Network in Environmental Monitoring Applications", 5th International Conference on Wireless Communications, Networking and Mobile Computing, WiCom '09, pp. 1-5, 2009

[13] H. Yong, "Design and Realization of Wireless Sensor Network for Vegetable Greenhouse Information Acquisition", 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM), pp. 1-4, 2010

[14] S. János, G. Martinović, I. Matijevics, "WSN Implementation in the Greenhouse Environment Using Mobile Measuring Station", International Journal of Electrical and Computer Engineering Systems, Vol. 1, No 1, pp. 37-44, June 2010

[15] D.D. Chaudhary, S.P. Nayse, L.M. Waghmare, "Application of Wireless Sensor Networks for Greenhouse Parameter Control In Precision Agriculture", International Journal of Wireless & Mobile Networks (IJWMN) Vol. 3, No. 1, pp. 140-149, February 2011

[16] D.-H. Park, J.-W. Park, "Wireless Sensor Network-Based Greenhouse Environment Monitoring and Automatic Control System for Dew Condensation Prevention", Sensors, Vol. 11, pp. 3640-3651, 2011

[17] I. Al-Adwan, M. S. N. Al-D, "The Use of ZigBee Wireless Network for Monitoring and Controlling Greenhouse Climate", International Journal of Engineering and Advanced Technology (IJEAT), Vol. 2, Issue 1, pp. 35-39, October 2012

[18] J. M. Gilbert, F. Balouchi, "Comparison of Energy Harvesting Systems for Wireless Sensor Networks", International Journal of Automation and Computing, Vol. 05(4), pp. 334-347, October 2008