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GREENHOUSES MICROCLIMATE REAL-TIME MONITORING BASED ON A WIRELESS SENSOR NETWORK AND GIS

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Abstract: The use of greenhouses with controlled microclimate according to the plants needs is an important way to increase the production of fruits and vegetables and has recently become one of the hottest topics in precision agriculture. In order to know and to control the greenhouse microclimate, smart sensing nodes with wireless communication capabilities are recommended. As one of the promissory protocols associated with wireless sensor networks can be mentioned ZigBee due to its low cost, low power consumption, extended ranges and architecture flexibility. In the present work, a network of sensing and control nodes with ZigBee communication capabilities is considered. The microclimate is monitored using a set of solid state sensors for temperature, relative humidity, light intensity, and CO_2 concentration since these parameters play an important role in plant growing. Every sensor node is autonomous by using energy from a solar cell through a battery charger circuit considering also the powering of the sensing and control node during the night periods. The data from the ZigBee network nodes are sent to a wireless-Ethernet gateway connected to a computer running a LabVIEW application that performs primary processing and to a web geographic information system that provides information about the greenhouse microclimate. Elements related to power harvesting for the implemented wireless sensor network, as well as a set of experimental results are included in the present work.

Keywords: air quality, greenhouse microclimate, ZigBee sensor network, geographic information system, power harvesting

1. INTRODUCTION

One of the most basic and thus critical and priority problems of humankind is food. Water and food shortage affect a huge percentage of the 7 billion people that inhabit Earth in 2011. The intensification of greenhouse horticulture is a commonly occurring trend in many regions around the world, including the Netherlands, Australia, Canada, the Iberian Peninsula, the U.S., and the U.K. The main incentive for this clustering is the reduction of production costs by sharing infrastructure such as energy, water and gas facilities. This intensification leads to increasing greenhouses' scale and to the creation of 'greenhouse parks' where greenhouses are clustered on a single site [1], being technology required to enhance the culture management. While the size of these structures increases, the use of Geographical Information Systems (GIS) [2] brings the ability to visualize and manage all the geo-referenced data produced by wireless sensing nodes, monitoring the greenhouses, materializing the precision agriculture concept. Precision agriculture requires monitoring of air and soil parameters that play an important role in crops growth. Thus, microclimate real-time distributed monitoring systems based on sensor network technology and GIS can be considered as an adequate tool for obtaining the information required for greenhouses' microclimate control and management.

In the present work is described the design and implementation of a wireless sensor network based on IEEE 802.15.4 (ZigBee)to acquire real-time microclimate in a greenhouse, taking into account plants' growth parameters such as relative humidity, temperature, light intensity, and CO_2 concentration. As reported research in the area can be mentioned wireless microclimate sensors for tracking critical environments [3][4] and long range wireless sensor system for long-term microclimate monitoring [5]. Sensor network architectures for air quality and water quality monitoring were reported also by our group and correspond to field measurements of water quality parameters using Wi-Fi networking technology [6][7] including also GIS [8][9] and to the use of wireless networks for indoor air quality monitoring [10][11]. Using a wireless sensor network (WSN)based on National Instruments (NI) technology, including configurable nodes and gateways, and a greenhouse microclimate monitoring software based on different software technologies such as LabVIEW (for WSN acquisition and control), Java, PhP and MySQL (for geographical information system implementation), accurate monitoring and data representation of greenhouse microclimate is carried out. Farmers can access in real-time the data using a browser installed on mobile devices, such as tablet computers, that access the GIS server pages whose sensing nodes data is received through a WSN gateway.

2. WIRELESS SENSOR NETWORK

The use of wireless communication technologies has become an important tool of modern life due to the freedom, distributed capabilities, and cost savings they offer. Wireless sensor networks (WSNs) have emerged as the next wave of wireless technology, highly enabling distributed measurements across vast physical systems including applications for air quality and water quality monitoring, particularly for climate and microclimate monitoring. In the present case, the WSN nodes include solid state sensors that are used to monitor environmental conditions. In addition to many wireless measuring nodes, a WSN system includes a gateway that collects data and provides connectivity back to a host application on a PC server.We considered ZigBee wireless communication protocol in this applicationtaking into account its topology, flexibility, low consumption and long range [12][13]. From different ZigBee possible topologies, such as mesh, star and tree, this last one was employed in this work (Fig. 1). An advantage of this topology is the reduced number of nodes for a specified monitored area.

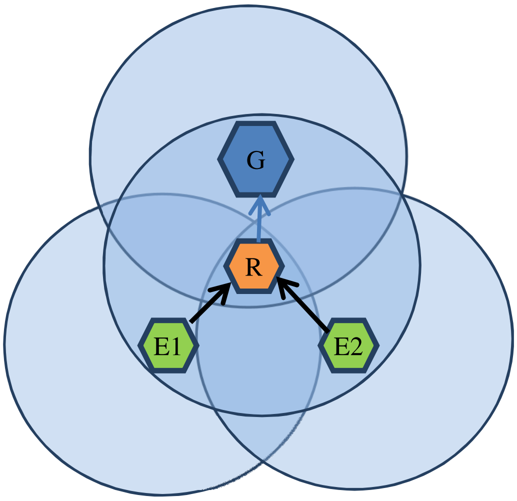

Fig. 1 ZigBee Tree topology for greenhouse microclimate monitoring (G –WSN Ethernet gateway, R- WSN router, E1,E2 – WSN end nodes)

2.1. Wireless nodes

The sensing nodes are based on NI WSN-3202 that is compatible with the ZigBee protocol. This wireless sensing node can be configured as router (R) or as end node (E) using the NI MAX utility. The main specifications of the wireless sensing nodes with multifunction capabilities are: four analogue inputs (±10, ±5, ±2, ±0.5 V range), 16 bit resolution, minimum sample interval 1s, 4 DIO lines. As part of the NI technology, the data management of the microclimate nodes is done using software developed in LabVIEW running in a host computer. The interface between the host computer (network coordinator) and the ZigBee router and the end device is performed through the use of a NI WSN-9791 wireless sensor network Ethernet gateway. Considering the ZigBee limited ranges of this solution (up to 300m), a 2.4GHz high gain antenna was used with the WSN Ethernet gateway, which assures better coverage and permits to increase the distance between the gateway and the router. Because of their low power consumption, NI WSN measurement nodes are also part of an energy harvesting application based on a solar panel. The implemented architecture is presented in Fig.2.

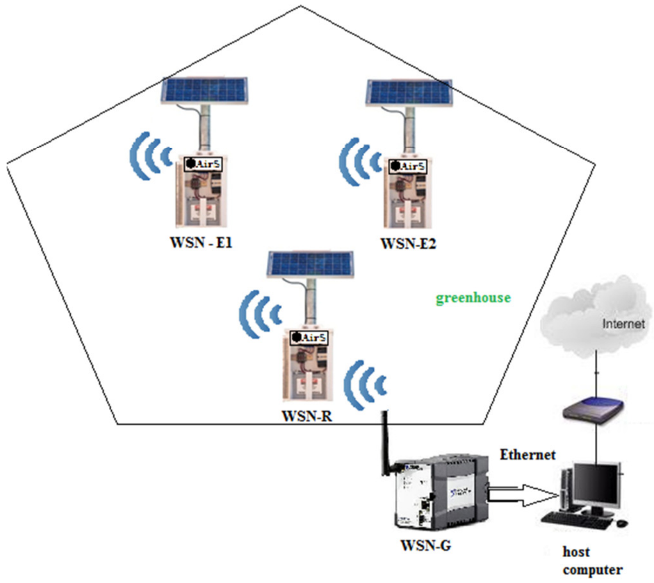

Fig. 2 Hardware diagram of the gateway, router, and end nodes

2.2. Microclimate sensors

The measuring WSN nodes include a set of microclimate sensors that assure the greenhouse microclimate monitoring: temperature sensor (LM-35), relative humidity sensor (HIH-3610), light sensor (TSL250R) and CO2 concentration sensor (TGS4161). Additionally, a charge circuit was used to regulate current from the solar panel (Suntech, modelSTP020S-12/Cb) to a 12V battery that powers the node during its charge.

The temperature information is provided by a LM35 integrated temperature sensor characterized by linear relation between the measured temperature and voltage output v_T:,

$$v_T = \gamma \cdot T \tag{1}$$

whereγ=10mV/°C. In order to assure appropriate signal for WSN measurement nodes an amplification scheme based on a LM324 single supply operational amplifier was designed and implemented.

The specifications of the relative humidity sensor are: 2%RH accuracy, 0.5%RH repeatability, 0.5%RH linearity, voltage supply 5 VDC, current supply 200uA and the output voltage signal, VRH, according to the RH sensed values in the 0.8 - 3.9 V voltage interval. The RH=RH (V_{RH}) inverse model is implemented on the host computer LabVIEW software and is based on the manufacturer specification using a linear relation between the acquired voltage (V_{RH}) and the relative humidity (RH),

$$RH[\%] = \alpha \cdot G_2 \cdot V_{RH} - \beta \tag{2}$$

where G_2=1.5 is the gain, α=32.25 V^{-1}, and β=-25.80 are constants for the used sensor. To improve the accuracy of the RH measurement temperature information is used and an extended inverse model RH=RH(V_{RH}, V_T) is used.

Considering the importance of light intensity in photosynthesis, each node includes a low cost light to voltage converter TSL250R. The TSL250R includes a photodiode and atrans-impedance amplifier and the output voltage $V_{light}$is directly proportional to the light intensity (irradiance) on the photodiode. Considering the manufacturer output voltage vs irradiance characteristics, the output of the used light sensor is:

$$v_{light} = a \cdot E + b \qquad (3)$$

where a=0.082 V/uW/cm^2 and b=0.008V. In order to evaluate the capability of the low cost solution to extract accurate information about daily light cycle, a reference CMP pyranometer was employed. The signal provided by the pyranometer, which is characterized by 13.6 uV/W/m^2, was amplified using an INA122 instrumentation amplifier and the resulting signal, v_{pyra} was applied together with the v_{light} to the analogue inputs of the WSN measurement node.
The measurement of CO_2 was done using a solid electrolyte sensor TGS4161 characterized by low power consumption and a 350-10000 ppm measurement range. The performance of this sensor is influenced namely by humidity, CO, H_2andr ethanol vapours. Additionally a broadband gas sensor,NAP-11AS,characterized by high sensitivity for different gases, including smells estimation, was included in one of the WSN nodes. The information delivered by this sensor can be also used for TGS4161 data validation. An inverse model CO_2conc=CO_2conc (VCO_2) was implemented on the software associated withthe WSN coordinator (host computer) using LabVIEW. Several modelling techniques including neural network were considered [11].
The localization of the WSN nodes is calculated through the GPS coordinates of the WSN Ethernet gateway provided by a Garmin GPS system, Foretrex 201 RS232 connected to the WSN coordinator, which is a PC that also runs the GIS application.

3. SYSTEM SOFTWARE

The system software has two components, a wireless sensor network control and acquisition and data processing (WSN-CAS), and a web-based geographic information system (WebGIS). The development of the first component was done using LabVIEW Wireless Sensor Module Pioneer that permits to configure the wireless sensor network and also to perform the sensor data management through the use of shared variables associated with the analogue input channels (AI0, AI1, AI2, AI3). The data from the sensors is processed using a set of polynomial and/or neural network inverse modelling software modules that perform the voltage-to-physical quantity conversion (e.g. voltage to temperature expressed in ºC; voltage to CO_2 concentration in ppm)
A particular implementation associated with WSN-CAS is presented in Fig. 3. In the figure can be observed that for the particular case of RH and CO_2, two inputs – one output sensor inverse modelling modules were considered taking into account the influence of temperature of the RH and CO_2 sensor characteristics.

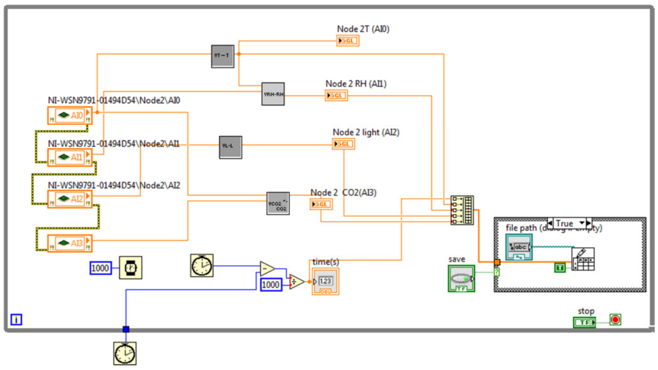

Fig. 3WSN-CAS LabVIEW primary implementation of data acquisition, processing, and logging of the T, RH, light and CO_2 measuring channels

The WSN nodes produce large amounts of data that require management and analysis. To provide support for visualization and querying of the data produced by the sensors' networks in greenhouses cluster a framework was built. The platform allows for structuring, browsing, querying, and managing the data through the Internet.
The system, built upon MySQL, Google Map technologies, PHP and java programming languages, delivers dynamic maps and GIS data along with GIS services via the Web. [14].The architecture associated with GIS is presented in Fig. 4.

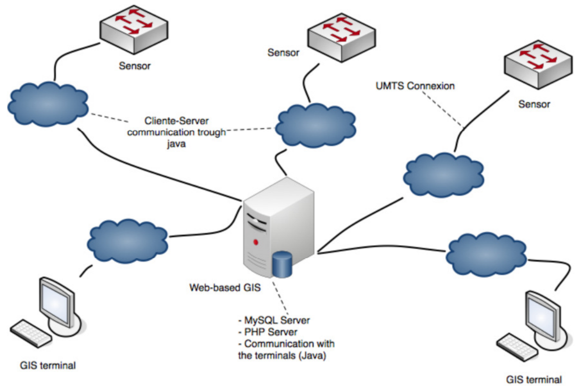

Fig. 4 Architecture of the Web-based GIS application

System users can create new sensors networks using the WebGIS and then access the WSN nodes'geographic localization (Fig.5).

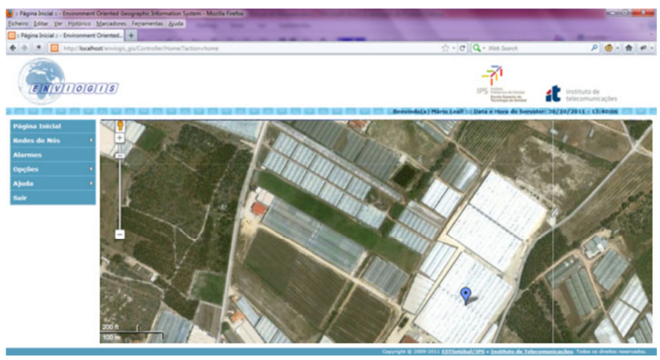

Fig. 5 The WebGIS panel for network and nodes management

When creating new nodes, the user specifies the type of information measured at each node (unit, time step, etc) and the structure of the database is automatically created in the server side of the system. Sensors' measurements are stored into the system database and can be displayed in real time in the WebGIS or queried to produce reports.

4. RESULTS AND DISCUSSION

Using the implemented wireless sensor network and the software components that were described before, different laboratory and field tests were performed. Thus, three sensor nodes configured as one router node (WSN-R) and two end nodes (WSN-E1, WSN-E2) were connected to the network coordinator through the WSN Ethernet gateway. In order to tests the reliability and the power consumption of the system, the first tests of the implemented network were done in laboratory, the indoor air quality conditions being measured. The evolution of some measured parameters during the whole day, where the sensors were attached to a plant, is presented in Fig. 6.

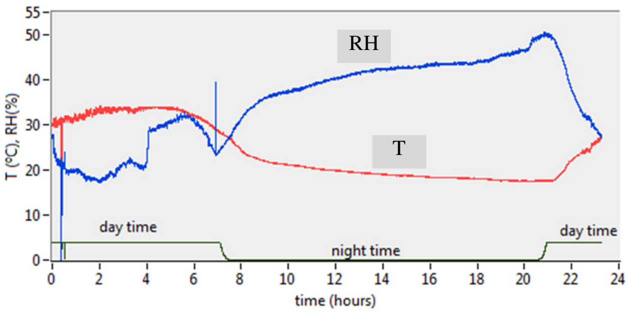

Fig. 6 The evolution of T and RH for a 24 hours period (day time and night time periods)

In Fig. 6,one can observe the day/night evolution of temperature and relative humidity in the air.
Taking into account that the system is powered using a battery charged by a solar panel, different tests were done considering values of current consumption up to 140mA, which corresponds to the maximum current consumption associated with a WSN node including the NAP-11AS that is characterized by intensive power consumption. The evolution of the current delivered by the solar panel and charging current provided by the charger circuit attached to the solar panel when a 140mA current consumer is attached to the system is presented in Fig. 7.

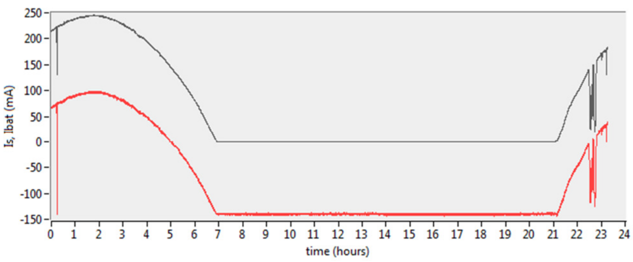

Fig. 7 The evolution of currents provided by the solar panel and battery charger during the whole day considering also a 140mA current consumption associated with the wireless node (Is – solar panel current (red line), Ibat- battery charging current (black line))

Fig. 7 shows the positive Ibat current values during the day when the injected current by the solar panel, Is, is up to 246mA. During the night, negative values of Ibat are registered considering the powering of the 140mAh consumer. In order to compensate the reduced daytime (less than 10h), the use of two solar panels is considered for each node.
Additional tests were done to measure a greenhouse microclimate when the sensors where distributed inside the greenhouse materializing different WSN architectures - mesh and tree - and taking into account that each of the WSN components presents four sensing channels that work independently of WSN configuration(as router of end node). Thus considering the geometry of the greenhouse, a *Gateway-Router1-Router2-End Node* tree distribution was considered in a first experimental approach. The distance between wireless network nodes was 200m.Considering the GPS coordinates provided by the GPS systems attached to the WSN Ethernet gateways and the node line direction, the individual WSN nodes GPS coordinates are calculated and used to actualize the greenhouse microclimate condition on the WebGIS. Figure 8 presents two of the different ways of displaying experimental measured data for a tested relative humidity sensor channel. The figure shows the graphical visualization of the information captured by the sensor along several days of measurement.

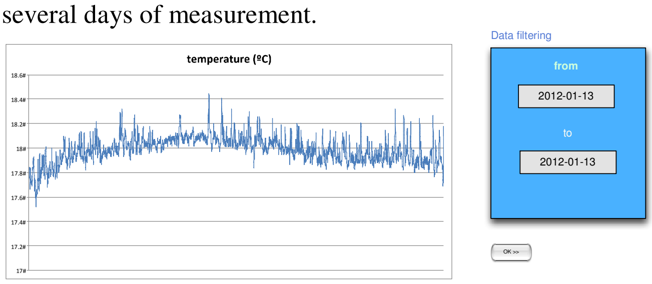

Fig. 8 Graphical visualization of the information captured by a sensor along a certain period of time

For each sensor and each greenhouse measured field, the user can also set alarms to prevent specific situations inside the greenhouses. When the value read by the sensor and stored in the database is outside the limits defined by the user, the alarm triggers.

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5. CONCLUSIONS AND FUTURE WORK

This paper presents the design and implementation of greenhouse microclimate real-time monitoring based on a ZigBee wireless sensing network and on a geographic information system. The system was installed and tested in laboratory indoor conditions but also in a greenhouse. The laboratory tests were necessary in order to estimate the reliability of the system including the solar panel and battery circuit charger associated to each node. Elements of intelligent modelling of multivariable characteristics were included in the work considering the necessity to improve the accuracy of the RH and CO_2 measurement channels whose characteristics are dependent on temperature.Regarding the software, the work presents a web based geographic information system design and implementation, which is characterized by high flexibility and the capacity to be adapted to new monitoring scenarios. As the future work we are planning to include in the WSN nodes other measurement channels such as soil moisture and soil temperature to control irrigation and to evaluate if the light sensor information can be replaced by the information that is associated with the output current delivered by the solar panel. We also consider implementing spatial statistics functionalities in the Web-based GIS in order to generate maps showing the distribution of data inside the greenhouses, by interpolating data measured at each node.

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REFERENCES

[1] Elke Rogge, Frank Nevens, Hubert Gulinck, Reducing the visual impact of ‘greenhouse parks’ in rural landscapes, Landscape and Urban Planning, Volume 87, Issue 1, 3 July, pp. 76-83, 2008.

[2] M.A. Labrador, A.J. Perez, P. M. Wightman, Location-Based Information Systems: Developing Real-Time Tracking Applications, Chapman & Hall/CRC Computer &Information Science Series, October, 2010.

[3] David Grant and Adam Al-Anbuky, “Wireless MicroclimateSensor", ISSNIP 20073rd International Conference on Intelligent Sensors, Sensor Networks and Information", Volume, Issue, 3-6, pp. 1-19, December, 2007.

[4] Xia Ming, Dong Yabo, Lu Dongming, Xue Ping, Liu Gang, "A Wireless Sensor System for Long-Term Microclimate Monitoring in Wildland Cultural Heritage Sites,"2008 IEEE International Symposium on Parallel and Distributed Processing with Applications, pp.207-214, 2008.

[5] J.Sheng Lin and C.Zu Liu, “A Monitoring System Based on Wireless Sensor Network and an SoC Platform in Precision Agriculture,” Proc. 11th IEEE Conference on Industrial Communication Technology, 2008.

[6] P. Girão, O. Postolache, J. Dias Pereira, H. Ramos, "Distributed Measurement Systems and Intelligent Processing for Water Quality Assessment", Sensors &Transducers Magazine, Vol. 38, No. 12, pp. 74-85, December, 2003.

[7] O. Postolache, P. Girão, J.M. Dias Pereira, H.G. Ramos,"Self-organizing Maps Application in a Remote Water Quality Monitoring System", IEEE Trans. on Instrumentation and Measurement, Vol. 54 , No. 1, pp. 322-329, February, 2005.

[8] O. Postolache, P. Girão, G.P. Patrício, J.S. Sacramento, P.M. Macedo, J.M. Dias Pereira, "Distributed Instrumentation andGeographic Information System for Dolphins’ EnvironmentAssessment",Proc. IEEE International Instrumentation and Technology Conf., Victoria, Canada, Vol. I, pp. 1777-1782, May, 2008.

[9] O. Postolache, P. Girão, J.A. Apolonia, N.B. Beirante, P.M. Macedo, J.M. Dias Pereira, "Dolphins’ Environment Assessment and Knowledge Management Using a Distributed Instrumentation and Geographic Information System", Proc IMEKO TC4 Symp., Florence, Italy, Vol. I, pp. 454-459, September, 2008.

[10] O. Postolache, P. Girão, G.F. Ferraria, N. Barroso, J.M. Dias Pereira, G. Postolache, "Indoor Monitoring of Respiratory Distress Triggering Factors Using a Wireless Sensing Network and a Smart Phone", Proc. IEEE Instrumentation and Measurement Technology Conf., Singapore, Singapore, Vol. 1, pp. 451-456, May, 2009.

[11] O. Postolache, J.M. Dias Pereira, P. Girão, "Smart Sensors Network for Air Quality Monitoring Applications", IEEE Trans. on Instrumentation and Measurement, Vol. 58, No. 9, pp. 3253-3261, September, 2009.

[12] ZigBee Alliance, Control your world, on-line atwww.ZigBee.org

[13] J.M. Dias Pereira, O. Postolache, P. Girão, "Spread Spectrum Techniques in Wireless Communication", IEEE Instrumentation and Measurement Magazine, Vol. 12, No. 6, pp. 21-24, December, 2009.

[14] H. Teixeira, M. Leal, Environment Oriented Geographic Information System Project, Technical Report for Computer Engineer Graduation, Escola Superior de Tecnologia de Setúbal, Portugal, September, 2011.