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Greenhouse Monitoring System Based on a Wireless Sensor Network

Ilias Lamprinos *, Marios Charalambides and Michael Chouchoulis

Telco Software Department, INTRACOM TELECOM, 19.7 km Markopoulou Ave, GR-19002, Peania, Greece; E-Mails: mxar@intracom-telecom.com (M.C.); houm@intracom-telecom.com (M.C.)

* Author to whom correspondence should be addressed; E-Mail: labil@ intracom-telecom.com; Tel.: +30-210-667-7953; Fax: +30-210-667-7101.

Abstract: Wireless sensor networks are considered an important dimension of the modern information and communication technology-based solutions for greenhouse monitoring. Several sensing and communication technologies are already available and have been used both in pilot and commercial installations. Their attractiveness is based on their deployment flexibility and low cost. In this paper we present the implementation features of a greenhouse monitoring system that is based on a ZigBee wireless sensor network. The system is composed of various sensor nodes that collect environmental conditions' data and transmit them to a remote database. A web application enables the growers to setup electronic cultivation records and monitor the greenhouse conditions as indicated by the collected WSN data. We also present the outcomes of an experimental study in the context of which the implemented system was deployed and operated in a greenhouse complex with hydroponic cultivation of tomato crops. This experimentation intended to explore the level of heterogeneity of the microclimate conditions in the greenhouse environment. The study revealed non negligible differences on the levels of temperature and humidity even across different sectors of compact greenhouse compartments and highlights the importance of dynamic management of the climate conditions on the basis of real time microclimate observations, with an ultimate objective to achieve greenhouse production of high quality and quantity, while using less input resources.

Keywords: greenhouse monitoring; wireless sensor networks; environmental sensing; ZigBee; smart agriculture; ICT for agriculture

1. Introduction

Agriculture in the European Union faces some serious challenges in the coming years due to water scarcity, rising energy costs, slow transformation of the agricultural productivity model, competition from international markets and uncertainties in the effectiveness of the current European policy [1]. Greenhouse production has the potential to present an alternative approach to some of these challenges. In 2009, the area dedicated to global greenhouse production was about 800,000 ha, of which 20% (160,000 ha) was situated in Europe [1].

All greenhouse cultivation systems, regardless of geographic location, comprise climate control components [2]. Air temperature, solar radiation and air relative humidity are important variables of the greenhouse climate that can be controlled, since they affect crop development and production but also energy expenditure, which can account for up to 40% of the total production cost. The ultimate target of greenhouse climate control is to obtain healthy, well-developed crops with high yield and quality production, while using less resources.

Until recently the business as usual approach in greenhouse climate control was based on the assumption that the climate inside a greenhouse is uniform, without differentiating volume occupied by the crop and the volume above the plants [3]. In addition, so far, greenhouse climate control is based mainly on aerial sensing measured at a single point in the middle of the greenhouse, assuming complete homogeneity of the greenhouse microclimate. Thus, uniform climate set points and water, fertilizer and pesticides dispenses across the entire greenhouse are applied, without accounting for climatic and crop variability within specific sectors of the greenhouse.

The assumption of complete homogeneity of greenhouse microclimate is not valid in the typical modern facilities since greenhouses' size has greatly increased over recent decades [3]. Several studies showed that greenhouse microclimate is highly heterogeneous and large temperature gradients exist even in well-designed greenhouses, with local temperature differences up to about 5 °C [4,5]. These differences vary over different locations in the greenhouse due to varying outside weather conditions and actions like opening or closing the heating and ventilation system. The temperature distribution in greenhouses is one of the factors that influence the uniformity of crop growth. The large differences not only cause non-uniform production and quality, but also problems with pests and diseases [6]. Moreover, this climate heterogeneity increases energy, water, fertilizers and pesticides consumption about 15% [3].

Distributed climate control is not yet standard in the typical greenhouses, but becomes more and more common due to the developments of novel Information and Communication Technologies (ICT), and particularly due to the use of Wireless Sensor Networks (WSN). WSN is a collection of sensors and actuators linked by a wireless medium that performs distributed sensing and acting tasks [7]. Based on the information collected by the sensor nodes in a base station, the latter, if properly programmed, could take decisions that are eventually transformed into appropriate control actions by the actuator nodes.

In this paper we present the implementation features of a greenhouse monitoring system that is based on a ZigBee WSN. The system is composed of various sensor nodes that collect environmental conditions' indicators and transmit them to a remote database. A web application enables the growers to setup electronic cultivation records and monitor the greenhouse conditions as indicated by the collected WSN data. We also present the outcomes of an experimental study in the context of which the implemented system was deployed and operated in a greenhouse complex with hydroponic cultivation

of tomato crops. This experimentation intended to explore the level of heterogeneity of the microclimate conditions in the greenhouse environment.

2. Experimental Section

For the needs of studying the variability of climate conditions in greenhouses we deployed a WSN in a greenhouse facility located in central Greece (39°25' latitude and 22°73' longitude). The network was deployed in a greenhouse compartment that was made of a metal frame and plastic sheets of polyethylene film (typical greenhouse construction in the Mediterranean area) and was covering an area of 160 m^2. The network included six nodes (three sensor nodes, a router, a weather station and a coordinating node) and had the topology presented in Figure 1.
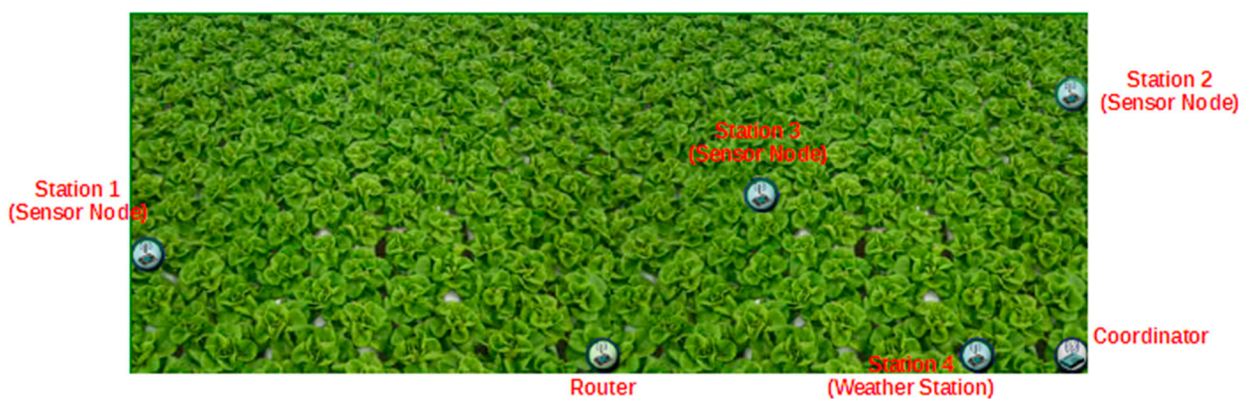

Figure 1. Topology of the experimental WSN.

All the sensor nodes were measuring *temperature* and *humidity*. Moreover one of them was capable of sensing also *solar radiation*. All the sensor nodes where also sending their *battery level* and the *received signal strength indicator (RSSI)*. The sensor nodes were programmed to get measurements every ten minutes and scan for a parent node (either the coordinator or the router node) to transmit their data. Further details about the technical features of the sensor nodes are presented in [8]. The above mentioned infrastructure was deployed in July 2015 and is still under operation. At the time of our study, the greenhouse compartment included hydroponic cultivation of tomato.

The collected measurements were handled by a *greenhouse WSN monitoring and visualization application i.e.*, a native application running in a PC placed in the utility room of the greenhouse. This application has multiple roles: it enables end users to remotely configure the WSN nodes (e.g. the measurements' frequency); it supports virtual representation of the WSN topology and real time presentation of the collected measurements; and it makes use of web services for uploading the measurements to a remote database for integration with a *greenhouse cultivation electronic record application*. Figure 2 provides indicative screenshots of these applications.

3. Results and Discussion

Figure 3 presents the waveforms of temperature within the greenhouse, as captured in the course of a week (a) and a day period (b). Macroscopically, the measurements' waveforms of all the sensor nodes follow the same pattern. However, when considering the data at a higher resolution, e.g. within a day

period, we realize that there is a difference in the measured temperature that varies in between fractions of unit and up to 3 °C. The differences tend to zero during the night period and tend to expand in the course of the day. It is worth to note that the herein presented figures pertain to observations that were carried out during late October. When analyzing the data collected during summer period, then the differences where even more significant, exceeding 5 °C in the course of the day. Finally, similar observations were carried out with regards to the relative humidity. An indicative set of humidity related waveforms is presented in Figure 4.
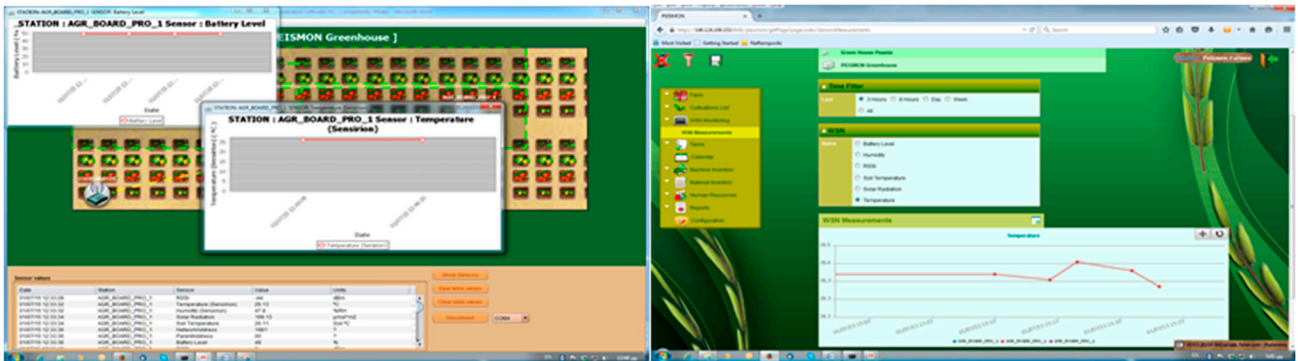

Figure 2. (**a**) Greenhouse WSN monitoring and visualization application. (**b**) Greenhouse cultivation electronic record application.
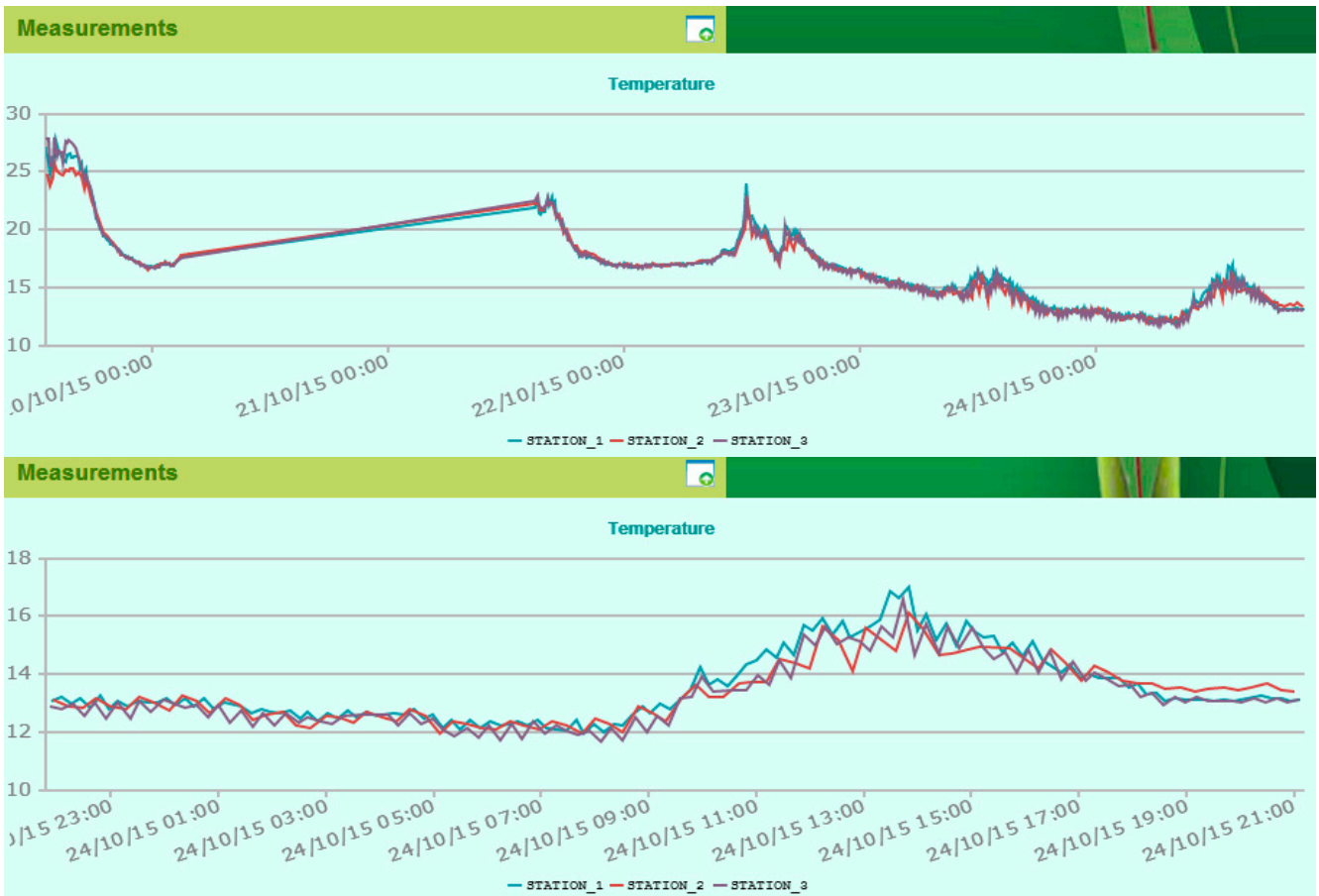

Figure 3. (**a**) Temperature waveform as captured by the WSN in the course of a week. (**b**) Temperature waveform as captured by the WSN in the course of a 24h period.
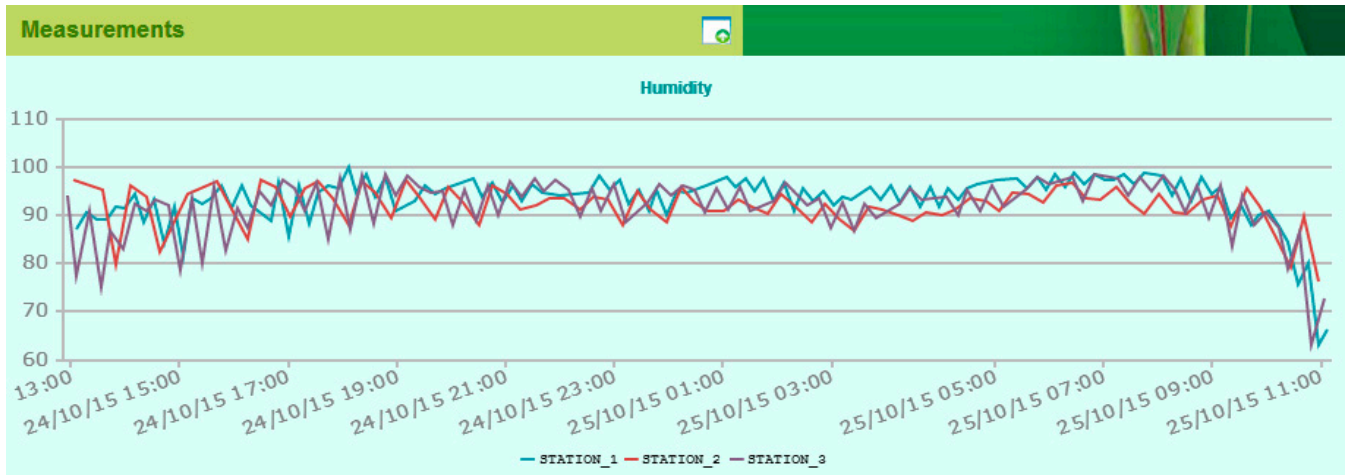
Figure 4. Humidity waveform as captured by the WSN in the course of a 24 h period.

4. Conclusions

This paper addresses an important issue related to greenhouse operation, that of climate control. In particular it focuses on the assessment of the assumption of homogenous climate conditions throughout the greenhouse. Our experimental study confirmed the findings of several studies which claim that greenhouse microclimate is highly heterogeneous and big temperature differences exist in the modern greenhouses that typically occupy large areas. The original contribution of this study pertains to the fact that it extends this observation also to more compact greenhouses. The extensive data collected in the course of a pilot study that lasted several months during summer and autumn period revealed non negligible differences on the levels of temperature and humidity, even across different sectors of the same greenhouse compartment. These findings make even more notable the need for dynamic management of the climate conditions on the basis of the real time microclimate observations. The significance of this approach is dictated by the fact that the optimum management of the greenhouse microclimate is key for achieving greenhouse production of high quality and quantity, while using less input resources in terms of energy, water, fertilizers and pesticides.

Acknowledgments

Author Contributions

I. Lamprinos designed the system architecture and drafted the manuscript. M. Charalambides led the implementation of the WSN monitoring and visualization application. M. Chouchoulis led the cultivation electronic record application. All authors interpreted the results and were involved on revising the final draft.

Conflicts of Interest

The authors declare no conflict of interest.

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