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Environmental parameters monitoring in precision agriculture using wireless sensor networks

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ABSTRACT

The 2011 EU Common Agricultural Policy aims to strengthen the competitiveness of the agricultural sector, to promote innovation, contribute to environmental protection and to support jobs and growth in rural areas. The consecutive reforms in agricultural policy have created adequate environment for developing and implementing innovative, environmentally friendly farming methods, allowing the farmers to increase the production and manage the local environment, which is essential for the sustainable development of the agricultural sector.

In this paper, wireless sensor network architecture for vegetable greenhouse is proposed in order to achieve scientific cultivation and lower management costs from the aspect of environmental monitoring. According to the analysis of the features of greenhouse environment, a practical and low-cost greenhouse monitoring system is designed based on wireless sensor network technology in order to monitor key environmental parameters such as the temperature, humidity and illumination.

1. Introduction

Precision agriculture can be defined as the art and science of using advanced technology to enhance crop production. Wireless sensor network (WSN) technologies are the major driver of the development of precision agriculture. Recent advances in wireless communications and electronics have enabled the development and production of low-cost, low-power and multi-functional sensors that are small in size and communicate in short distances. Cheap, smart sensors, networked through wireless links and deployed in large numbers, provide enormous opportunities for monitoring and controlling homes, cities and the environment (Vieira et al., 2003). WSNs as a contemporary technology, integrate the capabilities of sensors, automation control, digital network transmission, information storage and information processing (Yick et al., 2008). The development of WSNs applications in precision agriculture (Brooke et al., 2003) and the system platform for data acquisition, validation, processing and visualization (Cao et al., 2008) makes it possible to increase efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment in many agricultural production systems.

Various measurable physical, chemical and microbiological properties may be collected by a network of spatially distributed devices, available during the entire cropping season. Actually, the use of WSNs provides monitoring, acquisition and storage of various measured parameters. The stored data may be used for developing control and optimization strategies for crop production. Also, the collected data may be used for studying the intertemporal variability of environmental impacts, which is especially important for conversion of conventional towards organic and sustainable crop production (Hokozono et al., 2012). Real time monitoring by implementation of WSNs contributes to minimization of potential production risks, emerging mainly from environmental influences and human actions (Wu et al., 2013). Furthermore, real time data from the fields may be used by farmers to help them adjust their crop production strategies at any time, without the need to use a tractor or any other vehicle to get to each sampling point. Therefore, the implementation of WSNs contributes to some extent to the decrease of energy consumption in agriculture, bearing in mind that the current cropping systems are usually related to high fossil energy input (Di Nasso et al., 2011). The

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effects of increasing energy efficiency in agriculture are investigated by the research on input–output energy balance in greenhouse production (Pahlavan et al., 2011) as well as the research on excessive use of energy and energy consumption optimization in grape production (Khoshroo et al., 2013). Also, the research on energy use efficiency in greenhouse cucumber production using a non-parametric production function (Khoshnevisan et al., 2013) has shown that energy use optimization influences the reduction of CO_2 emission, thus expanding the effects of energy use optimization on increasing the environmental benefits. Actually, the research of energy use in agriculture is mainly related to identification of ineffective energy use by farmers, showing that ineffective use of inputs as diesel, natural gas, electricity, chemical fertilizers or water for irrigation has negative influence on crop production and overall system efficiency. In this context, the collected data from the WSNs may serve as basis for developing strategies for energy use optimization on farms.

The development of cleaner crop production procedures, as presented in the work of Kubota et al. would increase energy efficiency in agriculture and enable sustainable development (Kubota et al., 2013). Furthermore, the use of renewable technologies on farms is considered as essential, but not single factor to influence modern and energy efficient agriculture (Bardi et al., 2013). In fact, cleaner production procedures and renewable energy technologies along with reliable real time monitoring systems based on WSNs would contribute in creating the adequate conditions for development of sustainable agriculture. At present, the increased need for food production and the economic pressure of stakeholders enables the use of conventional and even aggressive farming methods which yield to higher short term production at the cause of natural resources depletion. The transition towards sustainable agriculture is strongly influenced by the cooperation between all stakeholders in the sector (farmers, industries, financial institutions, policy and decision makers, non-governmental associations, etc.) as well as of the use of new technologies. In a highly dynamic social and economic environment, the evolution towards sustainable development is based on group or pair-wise interactions of all stakeholders and it should analyzed using methods such as co-evolutionary games (Perc et al., 2010). The interdisciplinary approach would provide solutions for conflicts and defection, thus providing enabling conditions for sustainable development (Perc et al., 2013). Additionally, poor utilization of new technologies such as WSN or renewable energy sources technologies and sophisticated farming methods based on precision agriculture, are mainly related to unfavourable decision making and lack of investments. The unfavourable decision making is usually caused by lack of information, low awareness and reluctance to use new technologies, while lack of investments is mostly related to economic pressure for fast return of investments, increase of profits and lack of support by financial institutions. The identification of these problems and their solution may be analyzed by making use of the problem and objective tree method (Markovska et al., 2013). In fact, by developing low-cost, user friendly systems for environmental monitoring and efficient systems for optimization, some of these problems may be solved, which has been the essential motivation for our research.

2. Related work

The demand for environmental monitoring design and testing of distributed WSNs (Keshtgary and Deljoo, 2012), remote control in agriculture (Mancuso et al., 2006) is rapidly growing in many countries. Although, the topic of precision agriculture has been researched since the 1990s, it is beginning to draw greater attention in the past few years. Blackmore (1994a, b) defined it as a comprehensive system designed to optimize agricultural production by carefully tailoring soil and crop management to correspond to the unique condition found in each field while maintaining environmental quality. Langendoen et al. (2006) made the first large-scale experiment in precision agriculture in the Netherlands (LOFAR-agro). This work is related to the protection of potato crop against disease like phytophthora. Kumar et al., implemented environmental monitoring system which is capable of measuring temperature, humidity, illumination, soil moisture, CO_2 concentration of greenhouse using a sensor array and the digital signal processing (DSP) board (Kumar et al., 2010a,b). Vieira et al. presented a comprehensive comparative study of sensor node platforms, energy management techniques, off-the-shelf microcontrollers, battery types and radio devices (Vieira et al., 2003). Brooke and Burrel described the use of networked sensors in a vineyard (Brooke et al., 2003). Wang et al. investigated the potential for utilization of wireless sensors for increasing productivity in agriculture and livestock production (Wang et al., 2006). Kang et al. proposed an automatic greenhouse environment monitoring and control system by making use of environmental monitoring sensor nodes and adequate monitoring system in greenhouses (Kang et al., 2008). Li et al. designed a remote monitoring system for the greenhouse environment (Li et al., 2006). Their work is related to software development of the embedded web remote monitoring system for greenhouse environments. The Rinnovando group has been working with agricultural experts on a short-term deployment of a wireless sensor network in a tomato greenhouse in the South of Italy (Mancuso et al., 2006). Keshtgary et al. investigate sensor network topologies for precision agriculture (Keshtgary and Deljoo, 2012). They propose two different topologies: in the first topology each sensor node is placed at the corner of each grid and the server node is located in the middle of area and in the second scenario, the sensor nodes are placed at random positions. They compare the two proposed topologies and choose the appropriate topology.

One of the aims in sensor networks research is to reduce the amount of energy consumed by sensor nodes by reducing the communication in the network. The radio is the most energy consuming component on a sensor node and sensor nodes are battery operated. Therefore, reducing the amount of communication (Schurgers et al., 2001) is one of the main factors for extending the lifetime of the network, which is an important requirement of environmental monitoring applications where sensor deployments are expected to work for months or years (Shih et al., 2001). This paper investigates the possibilities of using WSNs and communication algorithms for data monitoring and analyses for the purposes of precision control of production environment. By making use of the experimental results, our aim is to develop a robust, low maintenance and low cost WSN system which would be used for control and optimization of greenhouse crop production.

3. Wireless sensor network for precision agriculture application

Sensors are the essential components of the WSNs, and therefore, of the overall system for environmental monitoring and control. As the crop conditions inside greenhouses are moderate and do not depend strongly on natural agents, implementation of wireless sensor technologies is easier than in outdoor applications. The deployment of WSNs in precision agriculture actually refers to deployment of sensor nodes located in greenhouses or gardens (Baggio, 2005) to provide information of environmental parameters that influence the development of the agricultural crops. Measured data obtained from the sensor nodes are wirelessly transmitted to a central base station for data collection. The base station makes a