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Automated zone-specific irrigation with wireless sensor/actuator network and adaptable decision support

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ABSTRACT

Precision irrigation based on the "speaking plant" approach can save water and maximize crop yield, but implementing irrigation control can be challenging in system integration and decision making. In this paper we describe the design of an adaptable decision support system and its integration with a wireless sensor/actuator network (WSAN) to implement autonomous closed-loop zone-specific irrigation. Using an ontology for defining the application logic emphasizes system flexibility and adaptability and supports the application of automatic inferential and validation mechanisms. Furthermore, a machine learning process has been applied for inducing new rules by analyzing logged datasets for extracting new knowledge and extending the system ontology in order to cope, for example, with a sensor type failure or to improve the accuracy of a plant state diagnosis. A deployment of the system is presented for zone specific irrigation control in a greenhouse setting. Evaluation of the developed system was performed in terms of derivation of new rules by the machine learning process, WSN performance and mote lifetime. The effectiveness of the developed system was validated by comparing its agronomic performance to traditional agricultural practices.

1. Introduction

Given the advancements in the field of wireless sensor networks (WSNs) as well as in the miniaturization of such sensor systems, new trends have emerged in the field of precision agriculture (Zhang et al., 2002; Srinivasan, 2006). Reviews of wireless sensor technologies and applications in agriculture and food industry have been given by Wang et al. (2006) and by Ruiz-Garcia et al. (2009).Wireless networks allow the deployment of sensing and actuation infrastructure at a much finer granularity than has been available before. Sensors and actuators can be used to precisely and autonomously control, for example, the concentration of fertilizer in the soil, based on information gathered from the soil itself, the ambient temperature, and other relevant environmental factors. Incorporating feedback into the system through the use of sensors and actuators allows for a more fine-grained analysis that can adjust flow rate and duration in a way that is informed by local conditions. Significant economic gains are expected by applying such precise information to control the growth of particularly delicate and high value crops such as wine grapes, citrus fruit and strawberries. Sensors that are able to monitor the crop itself, for example, leaf temperature in strawberries, or sugar-levels in grapes, or the photosynthetic activity of the crop plant, to provide location-specific data could also prove to be very effective.

In particular, the use of WSN technology to optimize irrigation in agriculture is of benefit to both the farmers and the environment. According to recent reports, agriculture irrigation accounts for 50–60% of freshwater usage from sources in the natural environment and up to more than 90% in some developing countries (UNESCO, 2009, pp. 106–115). Given the increasing worldwide shortage of water caused by a combination of a changing climate and pressure resulting from high demand of agricultural products, it is of primary importance to develop new irrigation control strategies that allow the minimization of water wastage while keeping associated costs at an affordable level.

In this paper we describe the design of an intelligent decision support system and its integration with a *wireless sensor/actuator network* (*WSAN*) to implement closed-loop zone specific irrigation control in greenhouses via wireless communication. Our research focuses on the provision of proactive applications by deploying sensor networks and connecting sensor data with actuators

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through an adaptive and able to learn decision-making layer. The system developed provides real-time monitoring and control of both agricultural inputs and outputs (irrigation control). A rule editor with a graphical user interface (GUI) is used by the domain-expert to initialize the knowledge base. The system is optimized to adapt to changes in crop development by configuring the rule parameters in the system ontology. In addition, machine learning is employed to enrich systems' knowledge base.

The remaining of the paper is organized as follows. Section 2 gives an overall description of the developed system. The topics covered in this discussion include the layered modular architecture of the system, the WSAN platform, the supported sensors and their interfacing to the platform, the ontology-based decision making layer and the machine learning process followed to extend system knowledge. Section 3 details the technological and agronomic results. It provides an evaluation of the developed system in terms of a prototype deployment, the derivation of new rules from the machine learning experiments performed, the WSN performance analysis and the mote lifetime estimation by using analytical models, the agronomic impact of the system and also provides a discussion of related work and lessons learnt. Finally, Section 4 presents a summary of this work.

2. Materials and methods

The overall goal of the research and development work described in this paper is to design a new plant growth monitoring and control system comprising:

- a distributed network of sensors for accurately sensing the plant growth activity and environmental conditions, and plant growth control actuators;
- ontology-based decision support mechanisms that associate sensor data with actuator commands;
- a machine learning process for enhancing plant state diagnosis based on logged data; and
- a set of tools that facilitate the specification of applications and the visualization of measuring parameters and assessed states.

As an application example of the above system we have considered an intelligent irrigation control strategy applied to protected agricultural crops that can improve the environmental and economic sustainability of the greenhouse sector.

2.1. System overview

The system is organized in a layered modular approach to allow flexibility and extensibility. A layered system architecture decouples the low-level sensory communication from the application business logic; the former gathers raw data from sensors, while the latter can be captured as an hierarchy of rules (Goumopoulos et al., 2007). In this way, applications do not depend on a specific sensor or a protocol that this sensor uses to transfer data values. Therefore, new sensor devices that emerge for a selected plant parameter can be integrated to the system without disturbing the other modules. Similarly, a different wireless communication protocol can be used without affecting the application business logic. This approach allowed us to develop and evaluate precision agriculture applications with diverse system and technology configurations (Goumopoulos et al., 2007, 2009; Goumopoulos, 2012).

Fig. 1 illustrates the system architecture in a high level view. In yellow color are shown the components that are discussed in this paper. In the lower layer various sensors/actuators that can collectively form composite WSANs, provide the raw data and the means to activate devices associated with agricultural inputs (e.g., irrigation). In the driver's layer, a specific driver is designed and implemented for each WSAN implementing the hardware communication protocol. The coordinator of the WSAN is connected to the corresponding gateway at the backend system which collects all sensor measurements before forwarding them to populate a relational database. The system architecture embraces the use of standalone devices that communicate directly with a driver through a device-specific communication protocol. These devices are usually complex sensors such as an infrared (IR) imaging system, and the PAM meter. The latter which is used in our prototype employs the so-called Pulse-Amplitude-Modulation (PAM) measuring principle to provide a selective measure of the relative chlorophyll fluorescence quantum yield for determining the photosynthetic efficiency of the plant. This parameter acts as a general plant health indicator and provides a reference for the classification process of the machine learning algorithm applied.

The functionality of the backend system is supported by the following main components: *Ontology*, *Decision Support System* (*DSS*), and *Machine Learning* (*ML*). The ontology specifies all the rules that support the decision-making process in the form of a knowledge base. The DSS provides all the synthetic information, acquired from the analysis of the stored data, needed to make operative decisions for the plant growth management. The purpose of the ML

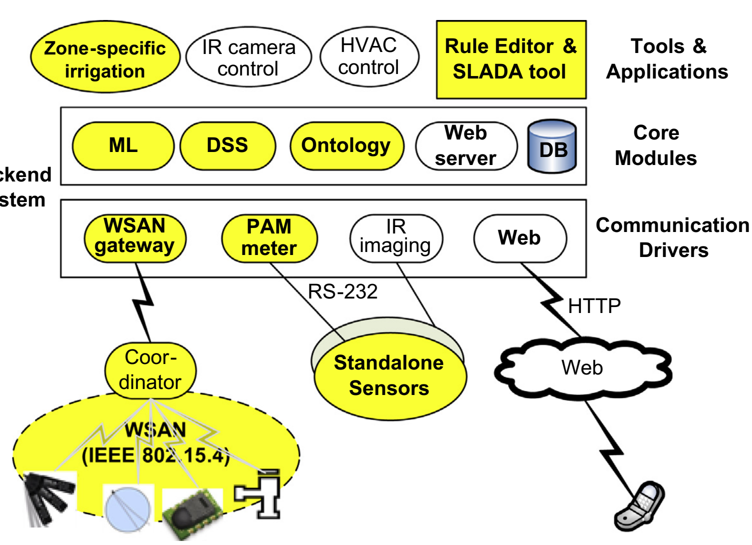

Fig. 1. High-level system architecture.