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Energy efficient automated control of irrigation in agriculture by using wireless sensor networks

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Many agricultural activities can be highly enhanced by using digital technologies. One of these activities is the regulation of the quantity of water in cultivated fields, a process which is directly interwoven with the sustainability and the productivity of crops, since insufficient or excessive irrigation may not only be obstructive, but also destructive. This paper proposes a scheme based on the collaboration of an integrated system for automated irrigation management with an advanced novel routing protocol for Wireless Sensor Networks (WSNs), named ECHERP (Equalized Cluster Head Election Routing Protocol). At its core, the proposed system aims at efficiently managing water supply in cultivated fields in an automated way. The system takes into consideration the historical data and the change on the climate values to calculate the quantity of water that is needed for irrigation. In case that the change on the collected values is above a threshold more frequent data collection is proposed to minimize the necessary quantity of water. On the other hand, in case that the change of the values is below a preset threshold then the time interval to collect data can increase to save sensor energy, leading to a prolonged sensor lifetime. The results show that network lifetime using ECHERP is improved up to 1825 min and if a round is 110 s the model provides energy efficiency using smaller water quantities.

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1. Introduction

Agriculture plays a vital role in the economy and, in many cases, in the survival of nations, since it provides the basic subsistence for the entire population of a country while at the same time it interacts with several other industries. Especially in rural areas, inhabitants depend on agriculture as it is critical not only for their nutrition but it also constitutes the base of all trade. Moreover, the ever increasing world population demands larger amounts of food which subsequently presupposes a well-managed and cost-effective agriculture.

Throughout the world, irrigation is one of the main water consumers. Almost 60 percent of all the world water, taken from rivers, lakes, reservoirs, and wells, is used for the irrigation of. Without irrigation, crops would never have been grown in the deserts of California and Israel. Irrigation has been around for as long as humans have been cultivating plants. Even though the traditional way of pouring water on fields is still a common irrigation method, other more efficient and mechanized, methods are also used. One of the more popular mechanized methods is the centre-pivot irrigation system, which uses moving spray guns or dripping faucet heads on wheeled tubes that pivot around a central source of water. There are many irrigation techniques farmers use today, since there is always a need to find more efficient ways to use water for irrigation. Producers need to find more effective and efficient use of water resources while maintaining high crop yields. Some efforts to more efficiently utilize water for crop production are examined, Producers has to find more effective and efficient use of water resources while maintaining high crop yields.

While the producers have to apply water to meet the needs of the crop, they must realize that with traditional management practices, yields and returns from the irrigated crop will be reduced as compared to a fully irrigated crop. Moreover, to properly manage the water for the greatest return, producers must have an understanding of how crops respond to water, how crop rotations can enhance irrigation management, and how changes in agronomic practices can influence the water needs.

Water stress during critical times may result in low yields. Crops, such as corn, respond with more yields for every inch of water that the crop consumes as compared to other crops such as winter wheat or soybeans. However, crops, such as corn require more water for development or maintenance before any yield is

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produced. Corn requires approximately 10 in. of water to produce the first increment of yield as compared to 4.5 and 7.5 in. for wheat and soybeans respectively.

The integration of automated procedures in agriculture increases the productivity as well as the quality of the products, thus fulfilling the ever increasing demand for healthy and inexpensive food around the world. However, an efficient automated system has to describe all the main processes that are involved in the agriculture chain. Plant cultivation, which can be considered as the most critical process, is affected by many factors such as the temperature, the humidity and the topography of the surrounding environment. Achieving ideal values for these factors and optimizing their consequences depend on the type of the crops cultivated. Thus, the design of an efficient irrigation system should consider these factors to achieve a successful and high quality harvest. For example, the process of grape maturation is affected by the photo-synthesis that produces the sugar that is stored in the grapes. In grapes, the balance among sugar, acid, pH and potassium is fundamental in determining the quality of the produced wine. This balance depends to a large extent on the frequency of the irrigation of the cultivated fields.

The scientific discipline of Wireless Sensor Networks (WSNs) has reached a point of maturity that it can provide accurate and highly effective services to farmers. Thus, WSNs should monitor the above described factors to achieve an improved harvest (Shu-ming et al., 2009). WSNs are able to rapidly capture process and transmit critical data in real time. The real-time data collected by sensors located in the cultivated fields may be used by experts or by automated systems to make decisions, such as which irrigation policy should be applied. Additionally, since a WSN does not require the deployment of wires, the need for human intervention is minimized. For these reasons, it is expected that WSNs will become a low cost yet effective approach for the monitoring of fields in the near future.

Additionally, WSNs can be combined with a system that manages the water applied to each field based on the environmental conditions and on the feedback sent by the individual sensors. There are several advantages in using WSNs and automated decision systems in agriculture:

- Improved estimation and planning of field irrigation based on the available water supply.
- Minimization of the required human resources, time, and effort in the agricultural production.
- Early detection of possible floods in the field that could be destructive for the crops and proper pumping of the water to mitigate such cases.
- Better coordination between different working groups, i.e. farmers and technical assistants thanks to a clear division of responsibilities.
- Creation of knowledge gathered from the deployed sensor networks for future applications in the agriculture domain.

All the irrigation models that have been proposed so far do not use an agriculture model to calculate the quantity of water for irrigation. Moreover, they use WSNs to collect data from the area without considering the routing of data from the sensors to the base station, a technique that could provide improved energy efficiency. In this paper, we propose a system that takes into consideration the historical data and the change of the climate values to calculate the quantity of water that is needed for irrigation. In case that the change of the collected values is above a threshold more frequent data collection is proposed to be performed to minimize the necessary quantity of water. On the other hand, in case that the change of the values is below a preset threshold then the time interval to collect the data can increase to save sensor energy, leading to a prolonged sensor lifetime.

In this paper an integrated architecture, based on the use of WSNs, for automated irrigation management is proposed that aims to achieve effective and prompt irrigation of parcels with great energy efficiency due to the utilization of a novel routing protocol.

The paper is organized as follows. In Section 2, the related work is presented. Section 3, describes the structure of the proposed system. Section 4, presents the performance evaluation. In Section 5, the paper is concluded and areas of future work are presented.

2. Related work

The work in the area of WSNs in agriculture is composed of two parts. The first part deals with the routing protocol used to minimize the energy consumption in WSNs, while the second part addresses the development of irrigation systems in agriculture that manage the water used for irrigation.

2.1. Energy efficient routing algorithms in WSNs

There exist several proposals to develop protocols that consider the energy efficiency of sensors in their routing activities. In hierarchical networks, nodes are organized in clusters in which a node plays the role of a cluster head. The cluster head is responsible for coordinating activities within the cluster and for forwarding information between clusters. Clustering has the potential to reduce energy consumption and to extend the lifetime of the network, by achieving a high delivery ratio in a scalable manner. In agriculture, the network used may be rather large since it needs to cover the entire cultivated fields. Therefore, the hierarchical protocols may be suitable and beneficial for precision agriculture.

In (Heinzelman et al., 2000) LEACH, a hierarchical protocol in which most nodes transmit to cluster heads, is presented. The operation of LEACH consists of two phases:

- *The Setup Phase*. In the setup phase, the clusters are organized and the cluster heads are selected. Each node determines whether it will become a cluster head in this round by using a stochastic algorithm at each round. If a node becomes a cluster head once, it cannot become cluster head again after P rounds, where P is the desired percentage of cluster heads.
- *The Steady State Phase*. In the steady state phase, the data is sent to the base station. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize overhead.

LEACH is a wireless distributed protocol that helps WSNs to use less energy. However, LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not recommended for networks that are deployed in large regions.

PEGASIS is an energy efficient protocol (Lindsey and Raghavendra, 2002) using a chain-based protocol and providing an improvement over LEACH. In PEGASIS each node communicates only with a nearby neighbour in order to send and receive data. It also takes turns (cluster head transmit after collecting data from all the nodes) transmitting to the base station, thus reducing the amount of energy spent per round. The nodes are organized in such a way as to form a chain, which can either be accomplished by the sensor nodes themselves, using a greedy algorithm starting from a certain node, or the Base Station (BS) can compute this chain and broadcast it to all the sensor nodes.

TEEN is a hierarchical protocol designed for sudden changes in the sensed attributes, such as sudden drops in temperature due to frost (Manjeshwar and Agrawal, 2009). Responsiveness is an important attribute of time-critical applications, in which the

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