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Intelligent multi-agent system for water reduction in automotive irrigation processes

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Abstract

This paper deals with a multi-agent system (MAS) to automate the gathering and managing of information from potato crops in order to provide a precision irrigation system. The proposal and development of a novel MAS is presented based on different agent subsystems with specific objectives to meet the main objective of the global MAS. The proposed MAS has been developed on the Cloud Computing paradigm and is able to gather data from wireless sensor networks (WSNs) located in potato crops for knowledge discovery and decision making. According to the collected information as historical data by the MAS, it can make decision on an actuator set that modify the irrigation system by updating the areas of the crop with most irrigation needs. The use of these intelligent technologies in rural areas provides a considerable saving of resources and improves the efficiency and effectiveness of agricultural production systems. The architecture has been tested in an agricultural environment in order to optimize irrigation in a potato crop. The results showed a significant reduction in comparison to traditional automotive irrigation.

Keywords: Multi-agent system; smart sprinkling; CBR system; RFID; pivot irrigation

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1. Introduction

Intelligent systems learn from the environment in order to make decisions and discover knowledge through the analysis of their surroundings. The goal of this approach is to provide an intelligent environment capable of making decisions and managing resources efficiently. In addition, the use the historical data achieved to transform it into

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knowledge in the process of decision making according to the requirements and needs of the system at that time. As a result of applying the so-called intelligent systems to rural environments, smart environments emerge with de ability to measure and analyse their own environment and responding to certain stimuli automatically. These environments are WSNs that they use to collect the information they need from the outside and launch the actions they need to respond, automatically and by means of actuator networks, to certain situations. Examples of these intelligent environments exist in urban and rural construction, so-called intelligent cities, home and building automation, automation of industrial applications in smart industries and intelligent hospitals. The wireless technologies allow us the deployment of such networks avoiding the need to wire buildings while reducing the costs and inconveniences of the configuration phase. WSNs support the necessary communication needs between network devices, in a flexible way in time, space and autonomy, without requiring a fixed structure. WSNs allow the construction of a wide range of applications, such as control of energy costs, monitoring of environmental data, security and control of access to environments, industrial and domestic automation. In this sense, tele-monitoring (or detection) makes it possible to obtain information about users and their environment. In this sense it is also possible to offer users personalized online services, taking into account the state of their environment and their interactions with it. The aim of this paper is the design and development of a MAS leading to data collection and automation of decision making in potato crops and in general, within rural environments. The proposal will also allow the subsequent knowledge discovery from the historical data obtained in a cloud system. The proposed MAS consists of subsystems of agents responsible for performing tasks coupled with the general objectives, providing intelligence to the platform, real-time response and adaptation to the needs of the application problem. The final goal of this MAS is to automate the irrigation system in potato crops. The MAS applies Artificial Intelligence (AI) techniques to classify the crop into different areas according to the indicator values such as, precipitation, level of water or moisture in the soil, use of pesticides and fertilizers, among others. All the parameters above, allow us to establish a classification of the crop into different types of areas according to its needs. This way, areas of the crop with similar environmental conditions will have similar needs of resources and so, these can be grouped in a same category. Hence, we identify the areas with grater irrigation needs from those with lesser water needs.

2. Multi-Agent system for Crop Irrigation

In order to perform a precision agriculture over a very large area, it is needed to divide it into smaller areas. Each one of these areas will indicate its resource needs. This will help the control system to being able to identify the needs of each area and respond to them accordingly and in an automatic manner. The factors that affect the harvest can be: the level of humidity of the earth and air or the level of fertilizers present in the soil. Thanks to the division of the land, it is possible to make a local control of these factors, irrigating or fertilizing when and where is necessary. This approach will improve crop production in each area of the field while optimizing the consumption of resources (water or fertilizers) [4]. Normally, there is a pivot in charge of irrigating each area of the field. It has to identify each defined area of the crop automatically in order to irrigate it. That is why, in the development of the system, we have used one of the most promising technologies in automatic identification and data capture (AIDC): RFID technology. The main objective of RFID technology in this system is to collect data through a transponder (tag) so that they can be transmitted and received by a transceiver in the pivot, all through a wireless communication channel. In order to locating and identifying assets, works like [11],[13] use RFID technology to access the information without the need for a direct line of sight. Such capacity is also relevant in food tracking and tracing systems, through the identification of batches of individual products. Other use cases of this technology that go beyond identification are shown in [7],[10],[9], where it is integrated with other technologies such as sensor technology, for the development of new functionalities. In this work, RFID technology has been adapted to face the challenge of optimize water consumption using knowledge of weather conditions and soil moisture. The data collected by each sensor is transmitted by a cryptochip that sends such information encrypted using Blockchain technology [3],[2]. To address such problems, it is necessary to leverage AI techniques (such as multi-agent systems, MAS), allowing us to automate the analysis of heterogeneous data that come from different sources. There are works like [9],[5],[8] that show how AI improves the decision-making process in agriculture by obtain knowledge from the data collected through heterogeneous data sources and act automatically and accordingly on the basis of that knowledge. We propose a multi-agent system (MAS) in order to control the irrigation process of the crop. The Real-World Manager Subsystem is the one responsible to

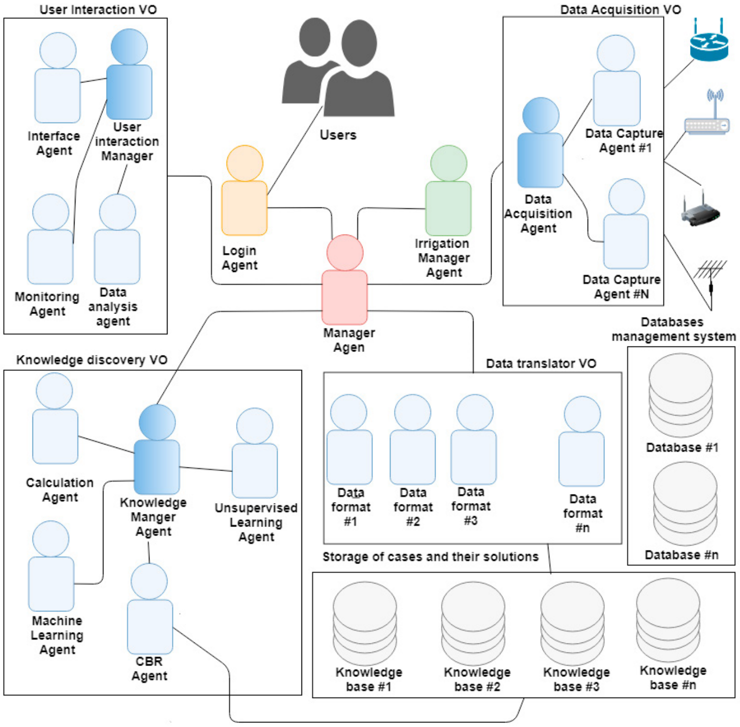

Fig. 1. Multi-agent architecture for water reduction in automotive irrigation processes.

receive the data from the sensors and to give orders to the actuators of the platform. The Sensor Manager Agent obtains information on the conditions of the crop from wireless sensors positioned throughout the field. Such sensors measure different indicators like precipitation, level of moisture in soil, use of pesticides and fertilizers. All the information recollected by the Sensor Manager Agent is sent to the Data Persistence Subsystem in order to store it in logs for further analysis of the conditions of the soil. The actuator Manager Agent, thanks to the knowledge extracted from the historical data recollected by the sensors, knows when and where to irrigate in order to fill the needs of the crop in each area. Each area is virtually represented by its binary state, which indicate if the area needs to be watered or if it has enough water. When an area needs to be watered the Actuator Manager Agent sends water by opening the corresponding electrovalve of the pivot after detecting the area by its RFID tag. The Data Persistence Subsystem manage the access to historical logs of the data the MAS work with. The Data Fusion Agent fuse the information recollected by the network of sensors in a determined time-stamp and stores it in the Database. The Data Formatter Agent formats the data in order to let the agents of the MAS to work with it in a manner that they can understand it. The Artificial Intelligence Subsystem represents the intelligence of the whole MAS and this is where data are analyzed. This subsystem is represented by two agents, the knowledge extraction agent which applies unsupervised learning techniques (such as data clustering) when data are not labeled and the CBR agent (case-based reasoning agent) which generate a solution from the stored cases in the CBR database. In the presented case study, the knowledge extraction agent uses a clustering method in order to group similar areas.

3. Case Study

To evaluate the system, it is necessary to develop a scenario based on real data that allows to simulate the behaviour of the system. A potato crop has been carried out on this area, on which the efficiency of the system will be tested in order to reduce water consumption in irrigation processes. The area on which the simulations have been carried out has 20ha of Sandy Loam land with an apparent density of 1.50g/cm^3. The cultivation of the potato has an optimal growth between 13 and 18°C. When planting the soil temperature should be above 7°C. It is a crop quite sensitive to late frost, as it produces a delay and decrease in production. If the temperature is of O°C the plant freezes, ends up dying although it can get to resprout. The tubers suffer the risk of freezing when temperatures are below -2 °C. The moderate relative humidity is a very important factor for the success of the crop. an excessively high environmental humidity favors the attack of mildew, so this circumstance is also taken into account by the sensors managed by the system. Pivot sprinkler irrigation is the most suitable for uniform irrigation. In warmer places, irrigation when the tubers are developed should be minimal, as an excess of water will rot the new potatoes. Soils with excessive humidity are too watery, not very tasty and conservable and not very rich in starch, which affects the tubers. To promote root development, a small water deficit before tubing is very useful. The achievement of dry seasons and wet seasons alternatively, alters the rate of thickening of the tubers. The vegetative cycle of the potato oscillates between 3 and 6 months, depending on the time of planting and the climate. Traditionally, potato cultivation has been irrigated by means of a linear pivot movement, as it fits better than central pivots to the way in which the potatoes are cultivated (row cultivation). In addition, this type of pivot is very effective at the level of uniform distribution of the amount of water. The way in which the irrigation is carried out, as well as the simulation of the behaviour of the pivot has been recreated through the development of a pivot agent. In this case study, the recreated pivot is composed of three 55-meter towers and a 14-meter cantilever with a rotation motor of 1.5CV of 86rpm to 60Hz, which moves at a velocity of 2.3m/min. The canyon is located at the tip of the cantilever with a section of 127 and rotator-type sprinklers with a ground clearance of 4.40m. The simulation recreates the movements made by the pivot according to the irrigation needs of the crop, calculated by the system from the needs of the crop and climatic factors (air humidity, wind, height and sunlight collected through the Gateway HUB (Raspberry Pi 3) which receives weather data from sensors deployed (ElkoEp Weather Station Climate Sensor D WTF). Machine Learning layer agents calculate water loss due to potato evapotranspiration (ETc) based on weather conditions. Water lost by evapotranspiration must be replenished by irrigation and are the minimum water requirements of the crop. Agent Knowledge Extraction calculates water loss by ET evapotranspiration, using climatic parameters. The net evapotranspiration ET$_o$ (Eq 1) is calculated with the equation of Penman Monteith [1].

$$ET_c = ET_0 * K_c \tag{1}$$

ETc is the Evapotranspiration of the crop (in mm/day), ET$_o$ is the Evapotranspiration of the reference crop (in mm/day) and Kc is the coefficient of the crop (The coefficient of potato is 0.45 in initial period (25-30 days), 1.15 in mid-season (30-50 days) and 0.85 in final-season (40 days) [6]). (Eq 2)

$$ET_0 = K_p * E_{pan} \tag{2}$$

ET$_o$ is the reference evapotranspiration (in mm/day) and Epan is the evaporation of Class A Pan, (in mm/day) [12]. It is also necessary to calculate the net water requirements of the crop (Nn). The system calculates the irrigation level taking into account the precipitation prediction that is estimated for the irrigation day, using the following formula (Eq 3), where EP is effective precipitation; the architecture has estimated that 75% of precipitation is effective precipitation (Eq 3):

$$Nn = ET_0 * daysofthemonth - P_e \tag{3}$$

The minimum necessary flow (Q) required by the pivot is calculated from the net water requirements of the crop (Nt) which Nt is calculated considering an efficiency of 85%., the area irrigated by the pivot (m^2) and the time available for watering (tfw) (Eq 4).

$$Q = \frac{Nt * surface}{tfw} \tag{4}$$

The frequency is obtained by dividing the hours that are available for irrigation each month by the time needed to proceed (pivot speed) (Eq 5).

$$Frecuency = \frac{daysofthemonth * hoursofirrigation}{Time} \tag{5}$$

Formula (Eq 6) calculates the puviometry that the pivot provides in each irrigation. Where Q is the minimum flow in l/s and Time in s. This allows to find out about waterlogging problems.

$$Pluviometrics = \frac{Q * Time}{Surface} \tag{6}$$

4. Results

The potato crop data have been obtained from a semi-late cycle of 150 days potato crop in the province of Salamanca (Spain). Semi-late sowing avoids frost and produces a higher production. The simulations were carried out using real meteorological data from April to September 2017. In order to know when the irrigation process should be carried out, it is necessary to calculate the values of the evapotranspiration rate (T).

Table 1. Data on the climate of the surface area under potato cultivation.

	April	May	June	July	August
Max. Avg. Temp (°C)	21	24	31	31	31
Min. Avg. Temp (°C)	3	9	13	11	11
RH (%)	62	59	52	47	51
Wind (km/day)	264	240	192	192	168
Avg. Precipitation (mm)	38	47	29	11	12
Solar radiation (MJ/m^2/day)	27.1	29.4	31.5	29.6	27.8
ET_0	4.39	5.34	6.80	6.69	6.00

The amount of water used by the pivot also depends on the rate of precipitation, which allows to reduce the consumption of water. The system uses a correction factor of 0.85 effective precipitation (P_e) since part of the water is lost due to evaporation. In calculating net requirements, it was considered that the case study uses a central pivot irrigation system, which has an efficiency ratio of 85% (Pivot efficiency).

Table 2. Evapotranspiration rate (ET_o) values according to the Penman Monteith Method for Table 4 values.

	April	May	June	July	August
ET_0	4.39	5.34	6.80	6.69	6.00
P_e	32.3	39.95	24.65	9.35	10.2
K_c	0.45	0.75	1.15	1.15	0.85
Nn	99.4	125.59	179.35	198.04	169.8
Nt	116.94	147.75	211	232.98	199.76

Linear pivots do not need to calculate the minimum number of irrigations since due to their characteristics of automation of linear irrigations it allows us a greater frequency of irrigation. However, this is a fundamental parameter to increase the amount of water saved. The characteristics of the pivot used in the simulations require 5 hours (Time=18000s) to irrigate the crop area (16 hours available to irrigate the entire surface). This value is used to obtain the frequency of the minimum irrigation rate with which to irrigate the area monthly. To calculate the minimum flow required by the pivot with the formula (4), the needs of the potato crop, the crop area and the time available for irrigation (value set at 16h for pivot irrigation) are taken into account. The pivot has used 905.01mm without using the system and with the system 768.63mm with a reduction percentage of 15.06%, as shown in Table 4. In Table 4 We can see how the surface whose irrigation is simulated by the system (System Irrigation pluviometric) requires less irrigation needs than the surface that is irrigated without the system.

5. Conclusions

This novel approach combines the advantages of localized irrigation (lower water consumption) and eliminates the disadvantages of pivot irrigation (high water consumption), using a more economic option and shorter time of use (pivot irrigation). The use of a multi-agent system allows managing all the simulation processes, data acquisition, crop monitoring and user interaction. This research puts forward a hypothesis which states that it is possible to use a similar amount of water that localized irrigation requires using automotive irrigation. The results obtained in the case study are clearly indicative of the system's effectiveness, reducing water consumption by 15.06% in the area in which

Table 3. Evapotranspiration rate (ET_o) values according to the Penman Monteith Method for Table 1 values.

	April	May	June	July	August
Q (l/s)	6.76	8.27	12.21	13.04	11.5
Frequency of irrigations	96	99.2	96	99.2	96
Pluviometric values per irrigation (mm)	1.21	1.48	2.19	2.34	2.08
Pluviometric values per month (mm)	116.16	146.81	210.24	232.12	199.68
System frequency of irrigations	100.3	83.5	97.02	90.71	82.47
System pluviometric values per irrigation (mm)	0.95	1.52	1.86	1.88	2.37
System pluviometric values per month (mm)	95.28	126.92	180.45	170.53	195.45

the case study was carried out. The reviewed literature shows that automotive irrigation consumes around 11% more than localized irrigation. The percentage achieved is higher than 11% so we can determine that the use of the proposed system achieves a reduction in water consumption used in the irrigation process.

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