

# A literature overview of embedded irrigation scheduling systems

Drimba Alexandru  
Faculty of Mathematics and Informatics  
Babeş-Bolyai University  
Cluj-Napoca, Romania

Gherghel Denisa-Maria  
Faculty of Mathematics and Informatics  
Babeş-Bolyai University  
Cluj-Napoca, Romania

Hudema Dumitru-Tiberiu  
Faculty of Mathematics and Informatics  
Babeş-Bolyai University  
Cluj-Napoca, Romania

**Abstract** — This report summarizes the contents of three analyzed papers, all tackling the common topic of coming up with an embedded system that makes a more efficient use of water resources to attain an optimal irrigation schedule. The purpose of the current paper is to briefly present the contents of each paper, and then compare the three approaches and their results.

**Keywords**—*embedded system, irrigation scheduling, water management, garden irrigation.*

## I. INTRODUCTION AND MOTIVATION

Due to the increase of population around the world, the demand for fresh water is rising, but as resources are limited, some regions already have problems with a shortage on that essential resource. Irrigation is a major component in almost every agricultural crop production system in the world. The way a green area is irrigated is not important only in terms of frequency or watering time (as is the case with most systems that have fixed irrigation timings) but also in terms of optimizing the use of resources and energy. Studies have shown that proper irrigation scheduling is an important factor and inadequate watering can result, in cotton production for example, in losses up to 300 USD/ha. Agriculture, and especially the irrigations, consumes some big amounts of the water, but they are not always done in a smart manner, especially in countries in development, where more water is consumed for the same area, compared to some developed countries.

The first analyzed paper, [1], proposes a multi-agent system (MAS) that takes into account the interactions between different elements (plants, sprinklers and weather conditions).

In order to help optimizing the water usage, but also the costs for energy, [2] presents the development of an IoT system, along with an algorithm that uses data from multiple sensors and weather forecast in order to keep the soil moisture within a threshold.

Inexpensive, real-time sensor data is needed to be able to provide an accurate and performant irrigation scheduling. [3] describes a prototype real-time, wireless smart sensor array for measuring soil moisture and soil temperature using off-the-shelf components. The system allows for a large number of sensors to be installed in a field and provide data wirelessly to a centrally located receiver.

## II. PROBLEM STATEMENT

Some domain experts believe that the existing static solutions should be improved, considering the possibilities and technological advancement. Several things should be considered when developing an irrigation system, including climate influence, season, soil and plant type and the availability of data for making reliable decisions. The solution proposed in [1] is trying to solve the problem of the absence of a more complex irrigation system.

There are few practical and cost-effective technologies that can assist producers with irrigation scheduling. Current sensor based technologies are expensive because they use conventional radio communications, which usually require government licensing for the used radiofrequency band, and usually require regular maintenance and have a significant energy consumption.

Some key factors used to calculate the soil moisture are the precipitations and the evaporation, calculated for a period of time. If the precipitations are accessible in any weather reports, the evaporations must be calculated. The method chosen in [2] is an empirical model given by Penman (it depends on thermodynamic evaporation and the dynamic evaporation, relative humidity of the air, air temperature and velocity of the land storm).

## III. RELATED WORK

It is emphasized that the use of intelligent agents is not exactly a novelty in the agricultural field, being a topic of research since 2000. Some things that have been emphasized in the implementation of MAS are the evaluation of the implementation of different agricultural policies in a certain land, the scheduling of irrigation.

Multiple irrigation system frameworks have been developed with the purpose of water saving. Some of those frameworks rely on techniques like thermal imaging, Crop Water Stress Index (CWSI), or direct soil water measurements. For example, the thermal imaging uses the shade temperature distribution of the plant, irrigation being planned accordingly with that temperature. In 2017, an intelligent irrigation monitoring system based on this technique was proposed, which uses thermal camera mounted on drones.

In 1998 another approach was suggested, based on evapotranspiration (ET), which is an important factor to determine if the plant needs more water, being influenced by climate parameters, like UV radiations, temperature or the

relative humidity. The ET approach can use up to 42% less water compared with time-based scheduling.

In 2015, an irrigation sensor based on smartphones was developed. It uses the camera of the phone, processes the RGB to grey, in order to estimate the ratio between wet and dry area of soil.

In 2017 was proposed to make irrigation recommendations based on ML algorithms, founding the best regression model to be the Gradient Boosted Regression Trees (GBRT), with 93% accuracy in prediction.

An irrigation management system that can collect soil water content information in real-time and provide it to an irrigation system operator has been analyzed in [4]. The system used two different data loggers to collect and store the soil moisture sensor values. The downside of this system is that the data loggers had to be located in close proximity to the sensors, as they had to be wired to each other, and an operator was required to periodically visit the logger and download the data, as the system did not provide a wireless solution.

Hamrita and Hoffacker ([5]) explored Radio Frequency IDentification (RFID) technology as a solution to wireless real-time monitoring of soil properties. They demonstrated, in a laboratory setting, that RFID technology was feasible for wireless real-time transmission of a soil temperature sensor's data.

#### IV. PROPOSED APPROACHES

The first step to developing the agent-based simulation system described by [1] is to detect the main *actors* of the system, their *interactions* and the main *functionalities* of the system.

The most relevant variables and resources of the system were determined based on the identified requirements and factors that influence irrigation timing: sprinklers, zones (each of them having multiple sprinklers), plants, season of the year, humidity of a plant, moisture sensors, fertilization (the level of which depends on the season of the year and the type of plant, and the decision support system can estimate whether this process is required or not) and the water pressure.

The system is divided into two main parts, **irrigation module**, and **fertilization module**.

Since the solution is developed in the form of a MAS, it is necessary to identify agents, which are grouped into two categories: **controllers** and **actors**, the first ones implementing some irrigation policies, and suggesting actions to be performed by the latter. Three agents have been identified: a *controller agent* that monitors the simulation and returns the result to the user, an *irrigation controller* that acts as a facilitator between the sprinklers and the fertilization plug-in and a *plant agent* per plant that stores the current humidity of a plant taking into account the initial humidity and the irrigation received. The *sprinklers* are the main actors since they will be receiving the commands to start or stop watering.

Perhaps the most complicated part of designing this solution is identifying the way in which the main tasks will be executed by the agents. When it comes to fertilization,

things are not very complicated, because the module only needs the dates for fertilization, and the quantity and frequency of these will be set by the manufacturer. For irrigation, however, several things need to be considered. For example, if in a certain area there are several types of plants, with different humidity needs, the target humidity is the minimum accepted by all plants, neither too much nor too little. However, it is possible that determining a sufficiently good average value may not be possible, in which case, perhaps, breaking a zone into several areas would be a better solution.

Next, the paper describes the way the system will be designed in terms of implementation. Fertilization highlights the modularity of the proposed system, as it does not affect water consumption. This agent embeds a rule-based system, and the rules are provided by an expert domain specifically for the area in which the system will be used. The user can force the system to skip or trigger fertilization. When it comes to irrigation, the specialized agent collects information about sprinklers and plants for each of the existing areas, after which it can decide the required humidity level for each of the areas and the duration of the irrigation. Something worth mentioning is that when different species coexist in the same area, the system chooses the minimum level of moisture needed by all of them.

In the earlier developed irrigation systems, one problem was ignoring the precipitations from weather forecasts, which could lead to loss of both water and energy, and even of crop growth due to excess water.

In order to predict the soil moisture, there is a need to predict the evapotranspiration. There are multiples methods developed, based on temperature and extra-terrestrial radiation [6], based on temperature and solar radiation [7], or based on Neuro-Fuzzy model, where Cobaner ([8]) came to the conclusion that the combination of solar radiation, air temperature and relative humidity is better than the solar radiation, air temperature and wind speed.

The combination chosen in [2] to predict the soil moisture was air temperature, air relative humidity, soil temperature and radiation. In order to calculate the predictions of soil moisture, also taking care of weather conditions, an algorithm based on both supervised and unsupervised machine learning techniques has been developed using Support Vector Regression (SVR) and k-means clustering. The SVR was trained with data collected from the field with the help of a device incorporating all the needed sensors, including a soil moisture sensor for verification purpose. The final predicted soil moisture was used as input for a smart irrigation scheduling algorithm, which would efficiently use the natural rain for irrigation.

The architecture of the IoT system developed consists of 7 main components. Those components are a field data collection device with relay switch, a web service for collecting field sensor data, a web service for collecting weather information from the Internet, a web service to control the water motor, a soil moisture prediction algorithm, a web interface for monitoring and an IoT enabled motor pump.

The field data collection device may be standalone or a wireless network of sensor nodes. In both cases, there are sensors for moisture, soil temperature, air temperature and humidity, and UV radiation. Those are read by an Arduino

Uno, which is connected to a Raspberry Pi, that hourly fetches data from sensors and stores them locally in an SQLite database, which will be later synchronized with the server DB.

The web service for field sensor data collection is written in PHP, and has a lightweight REST API to send the reading from the Raspberry Pi to the server. It can handle possible synchronization problems with some DB flags.

The web service for online weather was developed in Python and it aggregates results for the next days from multiple sources, and takes the data related to temperature, humidity, cloudiness, precipitations, UV Index, that will be stored in an MySQL DB on the server, to be further used in the prediction algorithm.

The soil moisture prediction algorithm will generate an output for the next days with regards to soil moisture, but will also provide some irrigation suggestions, so that it will be cost-efficient (water and energy). The results will also be stored in the MySQL DB on the server.

The web interface was developed in PHP, and has the ability to watch sensors' data in real-time, the predictions for the next days of soil moisture, but also to start the irrigation at a specified threshold value of soil moisture. The application works in 2 ways, auto or manual. The manual mode will let the users schedule everything based on the predicted soil moisture, while the auto will automatically schedule the irrigations, the user having to input just the minimum and maximum threshold values for the soil moisture.

Paper [3] describes a distributed sensor network prototype which consists of multiple sensor nodes installed in the field, and a central receiver, connected to a laptop. Each sensor node consists of soil moisture and temperature sensors, a circuit board, and an active RFID transmitter (tag). The circuit board contains a microcontroller that, at a user defined intervals, corrects and formats the sensor values, and then outputs the results to the RFID transmitter. Each sensor node can support up to three resistive-type soil moisture sensors and up to four temperature sensors. The sensor nodes transmit data packets composed of a unique identifier code (node ID) and 12 bytes of user data. The user data consists of three soil moisture values and two temperature values. The tags have a line-of-site transmission range of up to 0.8km.

During preliminary testing, it was found that plant biomass greatly reduces the range of the radiofrequency signals. To overcome this issue, the transmitter (tag) was placed on top of a 1.2m long pole and covered with waterproof material.

The sensor nodes were powered by a single 9V lithium battery. To optimize the power consumption and the battery life, the microcontroller was programmed to enter a low-power sleep state between sensor readings and data transitions. Nodes acquired soil moisture sensor values and transmitted the data to the receiver once per hour. The microcontroller also monitored the battery voltage and transmitted an alarm message when the voltage dropped below a preset threshold. The battery life turned out to easily exceed the duration of the crop growing season.

The proposed prototype was tested on a 2.3ha cotton field located on University of Georgia's Tifton Campus. Its performance was evaluated by establishing two different

irrigation scheduling strategies for the field. In the western half of the field, irrigation was scheduled by a staff member with many years of experience in growing cotton. Three sensor nodes were installed in this area strictly for monitoring purposes.

In the eastern half, irrigation was scheduled using the smart sensor array. Each sensor node contained three soil moisture sensors (0.2, 0.4, and 0.6m below ground level) and two thermocouples (one for soil temperature, and one for ambient air temperature). Irrigation was scheduled when soil water tension approached predetermined trigger points (for any of the three depths). These trigger points were selected based on published data and on the experience of the authors. The amount of applied irrigation was the amount of water required to reduce soil water tension to below 10 kPa (ranging between 13 and 25 mm of water).

## V. COMPARISON OF THE APPROACHES

Although the three papers discuss the same general topic, they come up with significantly different approaches. Papers [1] and [2] contain some sort of simulation and prediction of the future values of key factors, mainly soil moisture and weather, in order to act as quickly as possible and try to avoid letting the monitored values get out of the acceptable thresholds. Unlike that, paper [3] presents a more simple, real-time embedded system that actively monitors sensor data and takes decisions as per immediate necessities, or by using simple heuristics to predict value changes in the near-future. Also, it should be noted that [3] is almost a decade older than the other two papers, thus not being able to benefit from the same technological resources as the other two.

Paper [3] is the only one that provided concrete results of its irrigation scheduling strategy implemented by the prototype, by comparing the achieved results with a traditional irrigation plan. The other two papers only presented results of their prediction or recommendation modules, but no result that proves an improvement in the observed irrigation efficiency or crop production.

## VI. DISCUSSION AND CONCLUSIONS

The main conclusion of [1] is that the proposed system could be used to determine, given a certain garden, the optimum number of irrigation zones to consider, the best number and location of the sprinklers in each zone and the geographical distribution and assignment of the different kinds of plants to each sprinkler.

This system from [2] will be smart only if the predictions are accurate, which need a training period. To verify the accuracy, there were readings for 3 weeks, splitted in 70% as training data and 30% test data. The ML algorithm provides a probable estimate of the soil moisture, then the statistical measures R squared and Mean Squared Error are used for estimation of accuracy and error rate on the algorithm.

With the advancement in weather forecasting, that data can be trusted to be used in algorithms to predict other states, like the soil moisture, which is a critical parameter for the growth of any crops. The predicted values were close to the readings done at the time of predictions, having a low error rate. The system is also cost effective, being based on the

open standard technologies. Also the auto mode makes this system to be smart, and it can be further customized.

The smart sensor array prototyped in [3] was able to successfully monitor and control soil water tension. In almost all cases, soil water tension did not surpass the established trigger points in the east side of the field. The highest recorded tension was 60 kPa, the trigger point being at 50 kPa. Authors found that irrigation should begin immediately after the soil water tension starts increasing rapidly toward the trigger point, otherwise the tension will climb well above the trigger due to the very high latency of the center pivot irrigation system used. In the western half of the field, the traditional irrigation scheduling resulted in much higher soil water tensions at 0.4m and 0.6m depth than any observed in the eastern side. The maximum recorded tension was 110 kPa, and the 50 kPa threshold was surpassed for up to more than 5 consecutive days. It was clear that the amount of irrigation applied only served to momentarily reduce the soil water tension below the 0.2m depth.

The smart sensor array described in this paper offers real potential for a reliable soil water monitoring and irrigation scheduling. The cost of such a system is not very high: the components for each sensor can be purchased for a little over 100\$. The most expensive part of the system was the RFID receiver and acquisition software: approximately 4500\$. Because of the low per-sensor-node cost, dense populations of sensors can be used to adequately account for soil variability present in any field, as well as the irrigation system's lack of uniformity in distributing the water.

#### REFERENCES

- [1] David Isern, Sònia Abelló, Antonio Moreno, "Development of a multi-agent system simulation platform for irrigation scheduling with case studies for garden irrigation", *Computers and Electronics in Agriculture* 87 (2012) 1–13
- [2] Amarendra Goapa, Deepak Sharmab, A.K. Shuklab, C. Rama Krishnaa, "An IoT based smart irrigation management system using Machine learning and open source technologies", *Computers and Electronics in Agriculture* 155 (2018) 41–49
- [3] G. Vellidis, M. Tucker, C. Perry, C. Kvien, C. Bednarz, "A real-time wireless smart sensor array for scheduling irrigation", *computers and electronics in agriculture* 61 ( 2008 ) 44–50
- [4] Allen, R.G., 2000a. Report on AM400 and HOBO loggers. University of Idaho, Kimberly, Idaho, [www.kimberly.uidaho.edu/water/swm/](http://www.kimberly.uidaho.edu/water/swm/)
- [5] Hamrita, T.K., Hoffacker, E.C., 2005. Development of a "smart" wireless soil monitoring sensor prototype using RFID technology. *Appl. Eng. Agric.* 21 (1), 139–143
- [6] Hargreaves, George H., Samani, Zohrab A., 1985. Reference crop evapotranspiration from temperature. *Appl. Eng. Agric.* 1, 96–99. <https://doi.org/10.13031/2013.26773>.
- [7] Jones, J.W., Ritchie, J.T., 1990. Crop growth models. In: Hoffman, G.J., Howel, T.A., Solomon, K.H. (Eds.), *Management of Farm Irrigation System ASAE*, pp. 63–89.
- [8] Cobaner, M., 2011. Evapotranspiration estimation by two different neuro-fuzzy inference systems. *J. Hydrol.* 398, 292–302. <https://doi.org/10.1016/j.jhydrol.2010.12.030>