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# Advanced Control Strategies for Irrigation Systems

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***Abstract*— Water management and irrigation scheduling have become the main subjects of different studies in the last decades, due to their high influence on crop performance indicators. This study presents the most important parameters that have to be monitored in an irrigation management system and the most important ones are synthesized: air moisture and temperature, soil air and moisture, evapotranspiration. Based on the monitoring of these parameters, different control strategies and methods can be applied for optimization and efficiency of irrigation systems. The synthesis in this paper starts with classical control systems and also, advanced methods such as fuzzy concept, decision support systems and model predictive control. Considering the currently necessity of integration into the Cyber-Physical Systems (CPS) concept, the paper finally proposes an irrigation control system for vineyards. The SCADA architecture allows a CPS approach and the fuzzy control strategy is suitable for the Romanian context.**

***Keywords—irrigation, telemetry, control, precision, agriculture***

## I. INTRODUCTION

Irrigation quality is a crop performance indicator, its influence being realized both directly and indirectly. If we refer to the high quantity of water that crops need, we see it as a direct influence factor, as soon as its indirectly role could be seen in the influence on the other nutrients availability and on the timing of cultural operations. Irrigation requirements are very different from a region to another, thus energy efficiency and economic use of water resources depend on a function of soil and crop type, climate and moisture [20].

Many factors influence the potential water-use efficiency. The meaning of the word potential refers to the maximum water-use efficiency that can be achieved when the system is operated properly.

This paper presents an energy efficient proposed system for irrigation management in vineyards. To understand the system structure, they are firstly presented the monitored parameters with a huge influence on crop productivity. It is given an explanation on the advantages of monitoring them, being offered some suggestive examples.

They are also presented the main advanced control methods currently used in irrigation management, due to the fact that it is desired to have an advanced irrigation system able to manage the installation and receive alerts.

Finally, it is presented the integrated automation and telemetry solution for irrigation management in precision agriculture considering criteria to energy efficiency and economics, along with the latest control technologies previously presented.

## II. MONITORED PARAMETERS IN IRRIGATION MANAGEMENT

Precision of measurements is of high importance in vineyards productivity, modern techniques frequently used is focused on the optimization of the oenological potential that vineyards have.

Precision viticulture is characterized by a crop that is dependent of a specific region climate and soil type. This dependence expresses the weather influence in vineyards and some of the arguments that support this idea are:

- Daily temperature trend has a huge influence on the grape quality and, consequently, on wine [15];
- Bunch temperature offers an information related to the phenolic compounds maturation [16];
- Solar radiation has an impact on phenolic compound biosynthesis [18].

### *A. Air moisture and temperature*

Crop is certainly a function of temperature if water is available for optimum satisfaction [1]. Temperature has a great influence on seeds germination. Due to the biochemical processes, the germination phases that include hydration and enzyme activation, its degradation and embryo growth are temperature dependent.

Validated arguments that show the necessity of temperature monitoring are:

- From 5 to 37 [°C], the rate of photosynthesis is doubled at every 10 [°C] increase in temperature;
- The respiration rate becomes double at each 10 °C above the optimum temperature;
- The minimum threshold is the temperature below which no growth is possible.

Global temperature has increased with 0.2 - 0.3 [°C] in the last 30 years and causes are well-known. The growing season in viticulture is more and more influenced by high or low temperatures and, taking account that in the next years the temperature is expected to rise, crop water requirement will increase, due to the direct correspondence with the evaporative demand of the atmosphere. A specific numerical method has shown that for a 1, 2 or 3 [°C] rise of temperature, it will also be a crop water demand increase with 11, 19 and 29 [%], [17].

Relative humidity offers an information regarding the water vapor that is in the air, this parameter being in a strong dependence with temperature. Dew point temperature explains this dependence, because temperature goes down when the relative humidity increases and if the temperature gets cold enough, the air gets to the point in which it holds the highest quantity of water vapors.

Due to these arguments, air moisture and temperature must be monitored in an irrigation management system.

### B. *Soil moisture and temperature*

Soil is also very important in irrigation management as it is a major source of atmospheric CO2 and a storage reservoir for carbon with soil moisture being a driving force. Some advantages of soil moisture monitoring are:

- The influence in temperature and weather forecasting, due to the fact that it has an rise of the evaporation rate that increases the temperature [3];
- The increasement of the humidity caused by the evaporation rate of the soil moisture that increases the dew point;
- The dependence between temperature and precipitation. This is highlighted by the low pressure systems that will condense if air moisture is due to the soil moisture evaporation. The result is precipitation occurrence.

Irrigation management is of high importance in a vineyard. In many regions, growers apply irrigations when soil moisture is above an established limit (for example 50 %). Soil moisture is also important because it indirectly influences irrigation (the water application and movement across the field, assuring the intake rate). The application rate depends of sprinkler and low-volume methods such as deep and micro-sprinkles that uses mechanical devices as nozzles [5]. Water that is lost by evaporation could be saved by an efficient irrigation appliance capable of reducing evaporation with 5 to 15 % depending of the frequency that is used.

Irrigation without soil moisture monitoring is not indicated, due to the fact that this parameter has an influence in the balance between canopy size and fruitfulness [19]. The main objective of irrigation is to optimize the plant water stress and this could be done by an efficient soil moisture monitoring. The readings of soil moisture sensor are temperature dependent and field measured resistance needs correction when some differences appear between calibration and field measurements.

Soil temperature monitoring is influenced in an important proportion by solar radiation and humidity. It is considered that soil temperature should be measured by sensors that have no moving parts and that do not need calibration.

### C. *Evapotranspiration*

A very important parameter for crop growth and health is evapotranspiration. This irrigation management variable is computed based on weather information (air temperature and humidity, wind speed etc.).

Explanation of the interdependence existing among evapotranspiration and meteorological data collected from on-site weather stations is offered by using Penman-Monteith method [13].

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (1)$$

$ET_o$ – reference evapotranspiration [mm day$^{-1}$],
$R_n$ – net radiation at crop surface [MJ m$^{-2}$ day$^{-1}$],
$G$ – soil heat flux density [MJ m$^{-2}$ day$^{-1}$],
$T$ – air temperature at 2 m height [ºC],
$u_2$ – wind speed at 2 m height [m s$^{-1}$],
$e_s$ – saturation vapor pressure [kPa],
$e_a$ – actual vapor pressure [kPa],
$e_s$-$e_a$ – saturation vapor pressure deficit [kPa],
$\Delta$ – slope vapor pressure curve [kPa ºC$^{-1}$],
$\gamma$ – psychrometric constant [kPa ºC$^{-1}$].

A more simpler formula is *Priestley-Taylor* equation based on radiation and temperature.

$$ET_o = \alpha \frac{\Delta(R_n - G)}{\Delta + \gamma} + \beta \qquad (2)$$

A simplified formula is Makkink that is based on Priestley-Taylor method. They are two coefficients used in this formula: α ,that has a value of 0.61 and β that is 0.012.

$$ET_o = \alpha \frac{\Delta}{\Delta + \gamma} \frac{R_s}{2{,}45} + \beta \qquad (3)$$

## III. CONTROL STRATEGIES FOR IRRIGATION SYSTEMS

Based on the monitoring of several parameters, as seen in chapter II, different control strategies and methods can be applied for optimization and efficiency of irrigation systems.

Different approaches can be used for designing the control strategy in drip irrigation systems: constant open-loop control, open loop on/off, feedback control, [23].

### *A. Classical PID Control*

Classical control methods such as proportional, integral and derivative methods show good results, Fig. 1.

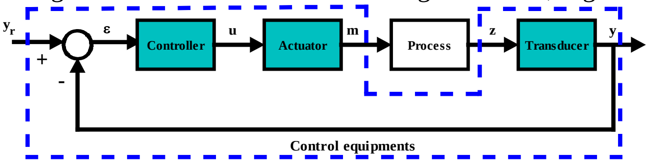


Fig. 1. Classical control system

In [21] a discrete PID controller is used to control an open irrigation channel. The actuator is the opening gate and the controller provides the signal for position of this gate.

PID control is used in [22] in a modified manner, with a constrained integral function, and the goal is supplying the appropriate amount of water to meet the needs of the plant during the diurnal cycle. A diagram of the PID control for soil moisture in dripping irrigation system is presented in Fig. 2.

The controller computes the command signal based on the error between the measured soil moisture from the transducer and the reference one. The actuator is represented by a control relay that acts on the water supply valve. Using this control method, the paper validates the strategy by two settings: a laboratory experiment and a real strawberry crop. Considering the varying solar radiation levels, the controller can still follow the soil moisture reference, which proved this classical method gives good results.

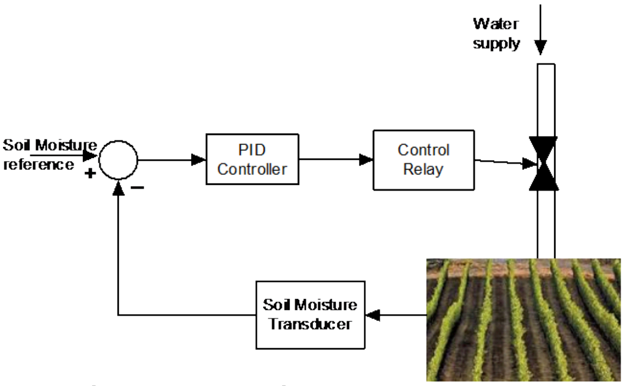


Fig. 2. Soil moisture PID Control

### *B. Fuzzy control systems*

Fuzzy control is a strategy used for irrigation management considering several controlled parameters: soil moisture, water supply, loss minimization etc.

The general architecture for fuzzy control of soil humidity is presented in [24], Fig. 3. The water supply is assured through a reservoir house height acts as actuating variable *h*. The soil moisture error is the difference between measured soil moisture and the reference one. The system has a variable reference depending on the stage of growth of the plant.

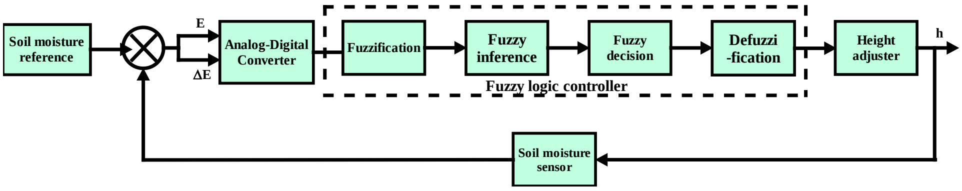


Fig. 3. Fuzzy control architecture

The soil humidity error's membership function assignment, which is of high importance in fuzzy control, is based on the rule that the higher sensitivity membership for little error and the fine stability membership for larger error. Totally, there were 16 fuzzy rules in this system.

### *C. Decision support systems*

In [6], a decision support system (DSS) is proposed for water supply prediction and control. This system collects data from a specific weather station. Then, collected data and weather predictions from three different sources are analyzed and the result is an evapotranspiration prediction and an estimation of plant daily development forecast for the next 10 days.

Information regarding soil moisture is collected from 375 sensors. It is very important to have more than 80 % of the soil moisture in the plant root region to get an economical optimum.

A water distribution planning solution is proposed in [8] for irrigation in an arid district. Optimal water delivery scheduling for irrigation canals is implemented through a DSS system.

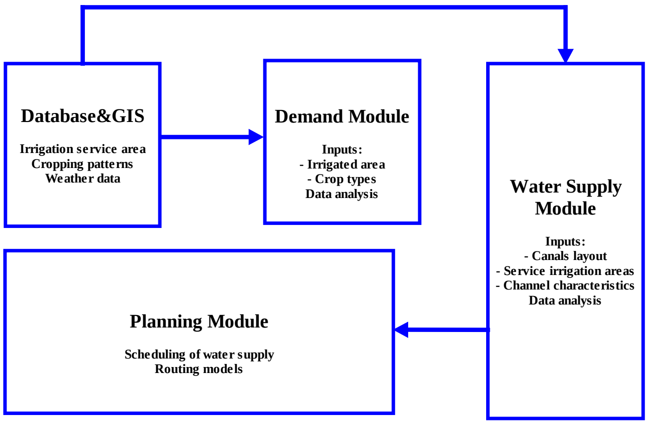


Fig. 4. DSS architecture for water supply scheduling, [8]

The DSS structure consists of a water demand module, a supply module and a planning module, Fig. 4.

Water supply necessity must be permanently correlated with water mass balance that uses the following concepts:

1. Frequency of irrigation
2. Irrigation duration
3. Irrigation timing

### D. Model Predictive Control

Model predictive control (MPC) approach is common used in industry offering a number of features:

1) is robust against uncertainty
2) system constraints can be handled
3) is easy to accomplish tuning
4) is used in multivariable control applications

In MPC control strategy the future evolution control sequence of the system is determined based on system model by minimizing a cost function. The cost function is obtained by minimizing the deviation from set points over the prediction horizon, Fig. 5.

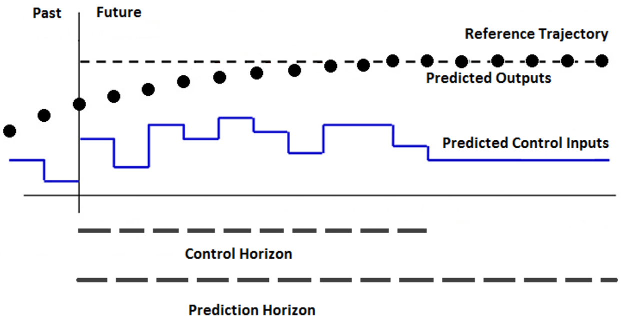


Fig. 5. MPC control

In [25] a Model Predictive Control framework for real-time irrigation scheduling is developed. A state space formulation of the water balance model is developed. The accuracy of the water balance approach is affected by uncertain measurements, such as evapotranspiration and precipitation and constraints such as limited water. The soil moisture deficit set-point tracking is accomplish by the MPC controller. The MPC controler also incorporates input and output constraints. The controller successfully tracks the commanded set-point as well as meets the constraints.

## IV. Proposed System for Irrigation Control in Vineyards

Irrigation control strategies should be integrated in complex automation and telemetry systems. There are several such systems in the world, adapted on specific crops and weather. Two of the implemented irrigation management systems are presented further.

The *Advanced Scientific Irrigation Management* application is a complex SCADA systems used for optimization irrigation in an arid district in USA, [6].

In order to implement the irrigation program, it is used a 6 six days sample code for each of the 369 parcels. Then, code is transferred to the SCADA master system which controls the 93 RTU stations by radio communications. Irrigation channels are controlled by a Decision Support System (DSS), as described in section III.

Advantages of this system should be summarized as the overcome of water infiltrations, water costs, water-supply shortages, some specific irrigation issues.

In [7] an implementation of an automated irrigation system, installed in Australia is presented. Efficiency of the irrigation system can be improved by an information infrastructure including sensors, actuators and supervisory control and data acquisition communication network. The task of the supervisory control is to ensure that the physical flow capacities are not exceeded. An irrigation system model is constructed based on the interconnection of the individual pool models. In order to achieve an entire irrigation system under closed loop control where water orders are met in real time on demand, the research and development effort has focused on controlling water quantity and quality in open channels.

Due to knowledge and existing technologies in the third wave of the information processing, communication and computing, a new telemetry system for precision agriculture should be integrated into the Cyber - Physical System (CPS) concept. The CPS paradigm has two connotations. On the one hand, it solves the issues related to the way in which inquiry is done, whereas the second one is a model that underpins all specific states of the components of the process [4].

Considering the synthesis on the control systems implemented over the world and the specific conditions in the Romanian context, an energy efficient irrigation system for water supply control in vineyards is proposed, Fig. 6. The irrigation management system for the precision agriculture could be seen as a MIMO system.

The control strategy follows a fuzzy approach and it considers soil moisture control and the disturbances can be air temperature and evapotranspiration, as it is a plant disease indictor.

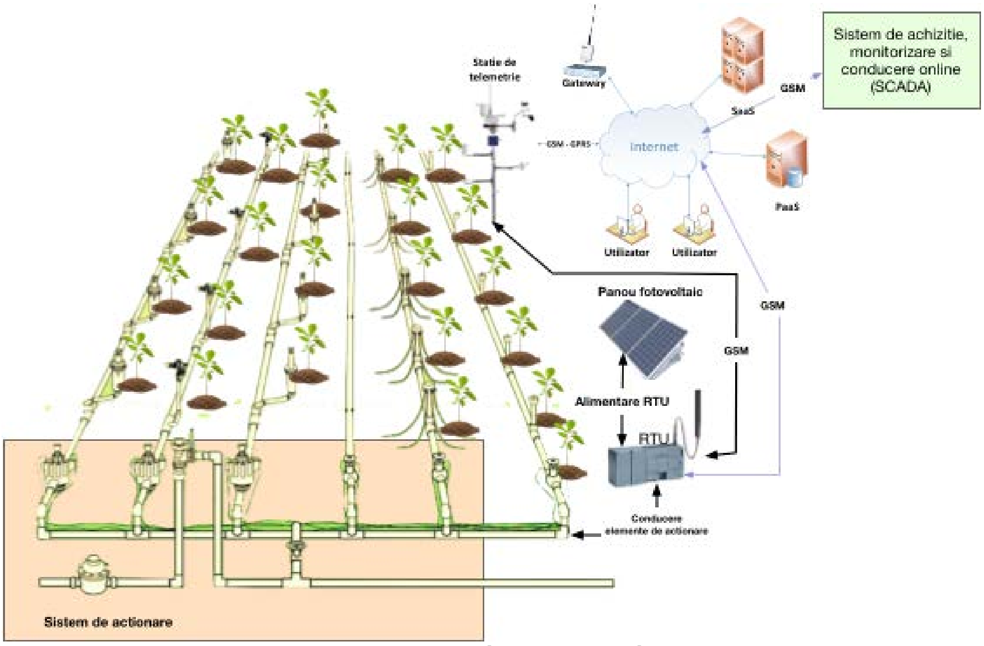


Fig. 6- Proposed irrigation control system

Thus, the system must be fully interconnected and decentralized, being equipped with the following:

- ***One or more telemetry stations*** that establish the irrigation necessity. Taking into account the arguments exposed in the 2nd paragraph, it is of highly importance to have sensors that measure:
  1. The air and soil temperature
  2. The air and soil humidity
  3. The evapotranspiration.

With these parameters, they could be calculated the precipitations necessity and the irrigations efficiency.

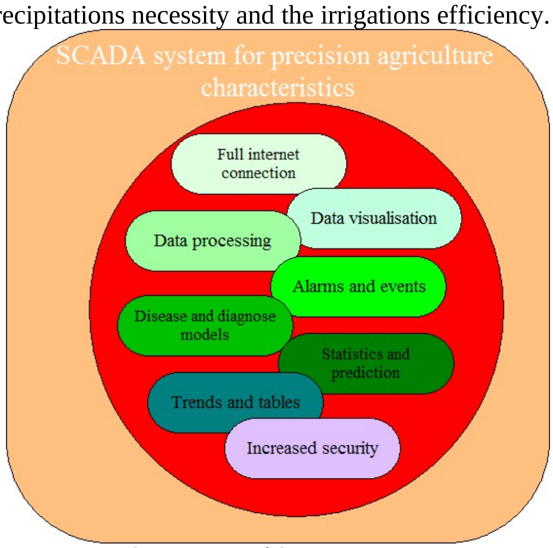


Fig. 7 - Main characteristics of the SCADA system in irrigation management

- ***A SCADA system*** (a SCADA master and a PLC) that receives all information from process and, using some specific decision algorithms, sends commands to actuators. It must be done a software application that collects and processes data from sensors and that has the capability of displaying it in a logical format. The main characteristics that a SCADA system for irrigation management must have are presented in Fig. 7;
- ***A RTU (Remote Terminal Unit)*** that includes solar panels and batteries for independent operation (aquisition of other field parameters and actuators control). Sensors and solar panels have to be connected by simply screwing in a connector. RTU should support analog and digital sensors, pulse counters and even TTL (Transistor Transistor Logic) outputs. It must also have a processor with software and logic control to execute simple programs autonomously (it is not necessary to be connected all the time to a host computer of the SCADA system).

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## V. CONCLUSIONS

Irrigation management systems should be focused on the adequate supply of water in order to increase crop productivity. Due to the fact that soil's rate of water intake depends on the soil conditions or on the applied control method, this study firstly focuses on the main parameters that must be monitored in an irrigation management system in order to discover their high importance, the advantages and effects of their control.

For both soil and air moisture and temperature they could be used specific measurement probes, as well as evapotranspiration could be calculated using Penman-Monteith, Priestley-Taylor or Makkink method.

The control strategies for irrigation systems are classified into 4 categories. It is firstly described a classical approach with PID controllers. The study also focuses on the architecture of fuzzy control systems for soil moisture. More decision support system for water supply prediction and control are studied and the important function are depicted. Model predictive control algorithms are used for high precision control.

Taking into account the new trends in the Cyber-Physical Systems era, the paper proposes an irrigation control system for vineyards in the last chapter. The SCADA architecture allows a CPS approach and the fuzzy control strategy is suitable for the Romanian context. Based on the high quality of measurements, the system computes the water supply necessity based on a fuzzy approach.

The proposed system has an architecture which presents many benefits such as low energy consumption, low administration costs and forecasting functionality.

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