Opportunities and prospects of IoT application in landscape architecture, design and information and communication technology

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Abstract. Article represents the application of mathematical device for the calculation of irrigation regimes in drip irrigation systems. The accounting of both soil-climatic and physiological parameters of plants has been introduced. An example of calculating the norm of irrigation in the operational planning of drip irrigation modes is given. An option has been developed for introducing intelligent systems for operational planning of irrigation.

1. Introduction

Technological development takes place in many different areas nowadays.

Internet of things (IoT) is the final stage of a long and unfinished revolution in computing and communications. New advances in this field are vital to the extension of the Internet of things.

From the technological point of view Internet of things is a concept that combines wireless sensor network, identification technologies, applications for data processing from sensors and wearable electronics.

IoT helps to create an interface between system and human in internet-based solutions. Different "smart" applications, that are based on Internet of things concept, can be implemented in various areas of human life, including agriculture and forestry.

Many devices connected to the overall network are able to automate routine tasks and allow the possibility for remote control and monitoring of managed “things” in the real time.

This concept allows to create an open and at the same time safe environment from sensor to the cloud. Accessibility and transparency playing critical role in standards development and acceptance. One of the trends noted by many experts is that as the amount of data collected increases, it is advisable to analyze it not somewhere in the remote cloud, but rather as close as possible to the data source. Therefore, regular sensors will be inevitably replaced by more complex and intelligent terminal devices.
that can not only collect data, but also process them, sending only the most important information “up” and, in some cases, make decisions independently. [1]

Internet of things technology provides following features:

• possibility to set up electrical appliances so that they turn on at a specific time (e.g. automated switching on the lights and the heating systems in the greenhouses);
• possibility to configure devices to turn on under certain circumstances (e.g. when the temperature threshold rises, - cooling system turns on);
• control of electrical appliances via voice commands;
• remote control of electricity and electrical appliances;
• irrigation control depending on temperature, time, humidity level and light exposure [2].

Most irrigation systems consist of the following elements:

• source of water supply;
• piping system for delivering of water to the desired points on the site;
• control panel;
• temperature sensors, soil moisture sensors, etc.;
• solenoid valves;
• sprinklers;
• drip pipes with drip irrigation kit;
• water outlets.

Controller integrated into control panel of the automatic irrigation control system is the most important element of the automation system. This automatic irrigation control unit issues commands to turn the system on and off, while controlling the water flow per square meter [2, 3].

The ability to integrate irrigation systems into intelligent systems with unlimited possibilities for managing the irrigation system will allow to:

• have a remote control with smartphone, tablet laptop or computer from any part of the world with internet access;
• organize the access to the system using the built-in web interface, which enables to define required watering program;
• connect unlimited number of different sensors;
• check if the pump actually pump water when it is request. To determine this parameter a water flow sensor is used;
• store system information in the cloud storage;
• inform people about the beginning of irrigation, system failures and critical situations;
• enable a remote forced activation or deactivation of the irrigation;
• deactivate irrigation system if people or animals unexpectedly appear in the irrigated area;
• carry out a statistical analysis of all irrigation parameters over a certain period of time, such as water consumption, amount of irrigated inclusions, state of water moisture, rainfall, etc.

There are several variations of mathematical modeling and data accounting applied for programming and working with such a system as a whole.

2. Calculations
To create an automated irrigation system in agriculture and forestry sector it is important to take into account parameters which will be considered in system’s decision making. Soil moisture is one of the examples of such parameters.[4]

Humidity - is the quantity of water contained in the soil pores, expressed as a percentage of the mass of soil dried to a constant mass at a temperature of 105 ± 2 ° C. defined by the following equation:

$$W = \frac{m_6 - m_7}{m_7 - m_8} \times 100$$

(1)
where, \( m_b \) – weight of containers with moist soil, g; \( m \) – mass of containers with dry soil, that is dried with constant weight, g; \( m_s \) - weight of empty containers.

Constant mass — mass of the soil sample that changes in two control weighings on less than 0.02 g. Drying of the samples before the first weighing continues for 3 hours for sandy soils and for 5 hours for the other soil types; before new weighing, additionally for sandy soils - 1 hour, for the other soil types - 2 hours (accruing to Russian Governmental Standard 5180-84). Moisture determined in this way is called weighted moisture, and the applicable method called thermogravimetric method of moisture content determination.

The total soil moisture in natural conditions is called natural soil moisture. Under normal conditions, natural moisture does not correspond to total moisture. Therefore, in order to characterize the physical state of the soil, in addition to absolute moisture, it is necessary to know the degree of filling of pores with water. To do this, determine the degree of moisture (water saturation coefficient), equal to the ratio between the natural content of water in the soil and its full moisture capacity, corresponding to the full filling of the soil pores with water. Soil moisture content can be determined by using one of the following equations, depending on the input data accessibility:

\[
S_T = \frac{W}{W_{max}}; \ S_T = \frac{W\rho_S}{\rho_{W}}; \ S_T = \frac{W\rho_S(1-n)}{n}
\]  

(2)

where, \( W \) – natural soil moisture, %; \( W_{max} \) – full moisture capacity, %; \( n \) – soil porosity, %; \( \rho_S \) – density of the soil particles, g/cm\(^3\); \( e \) – porosity coefficient; \( \rho_W \) – density of water, g/cm\(^3\).

Coarse-grained and sandy soils are subdivided according to its moisture degree as:

- soils with low humidity level, \( 0 < S_T < 0.5 \);
- wet soils, \( 0.5 < S_T < 0.8 \);
- water-saturated soils, \( 0.8 < S_T < 1.0 \).

Hygroscopic humidity — is a soil moisture content in a dry state or equilibrium with humidity and ambient temperature, this is percentage share. This share is defined in the same way as natural humidity.

Optimum moisture content — the moisture degree at which the maximum density of dry soil is achieved, determined by filling samples with a constant expenditure of labor for their compaction in a standard sealing apparatus. Optimum moisture content is determined based on the graph that shows the dependence of dry soils density on moisture by standard compaction method (table 1). [5, 6]

For cohesive soils, the standard compaction graph has a pronounced inflection in the dependency curve for density of dry soil on moisture, and for unbound soils this graph may not have a pronounced maximum. In this case optimum moisture content is considered to be 1.0... 1.5 % lower than the moisture content corresponding to the starting point of the compression fittings. At the same time, 1.0% is taken for gravelly, large and medium sized sands, 1.5% for small and dusty sands (figure 1) [6].

Moisture content at the rolling boundary — it is the amount of moisture at which the soil is presented in between solid and plastic states. This type of moisture content is determined by the gravimetric soil water content method, the plasticity of which corresponds to the rolling boundary, and is calculated by moisture content determination equation.

Moisture content on the tensile strength — certain level of humidity at which the soil is on the borderline between plastic and fluid states. This level is defined by the gravimetric method on the soil, the plasticity of which corresponds to the yield strength and is calculated by the formula for determining moisture.
Figure 1. Dependence of the density of dry soil on moisture: a – for bounded soils; b – for unbounded soils.

Table 1. Optimal moisture content.

| Soils                  | Optimum soil moisture, g/cm³ |
|------------------------|-------------------------------|
| Large-block soils:     |                               |
| Gravel                 | 3…5                           |
| Grus                   | 5…7                           |
| Sand:                  |                               |
| semi-gravel            | 4…6                           |
| Coarse                 | 6…8                           |
| medium                 | 7…9                           |
| fine and very fine sand| 10…23                         |
| Loamy sand             | 8…14                          |
| Light loams            | 12…16                         |
| Heavy loams            | 16…22                         |
| Clays                  | 18…26                         |
According to the degree of moisture content soils divided into varieties given in table 2.

Table 2. Soil type by degree of moisture content (TCEP 45-3.03-19-2006).

| Soil moisture content          | Humidity, g/cm³ |
|--------------------------------|----------------|
| Moisture deficiency Normal     | less than 0.9 $W_0$ |
| Extensive Moisture Content     | from 0.9 $W_0$ to $W_{\text{permissible}}$ inclusively |
| Waterlogged soils              | from $W_{\text{permissible}}$ to $W_{\text{max}}$ inclusively |
|                                | more than $W_{\text{max}}$ |

where, $W_0$ – optimum soil moisture; $W_{\text{permissible}}$ – permissible humidity; $W_{\text{max}}$ – full moisture capacity.

Permissible moisture content – it is amount of acceptable moisture level that will allow the soil to be compacted to the point regulated by the required compaction coefficient (table 3). It is presented as a share from the optimum moisture content.

Table 3. Permissible soil moisture during compaction (TCEP 313-2006).

| Soils                              | $W$, optimal in shares $P_{\text{optimal}}$ including soil compaction factor $K_{\text{compaction}}$ |
|------------------------------------|-----------------------------------------------|
|                                    | more than 1                                      | 1…0.98                          | 0.95            | 0.90            |
| Very fine sands, loamy sand light  | 0.85…1.30                                      | 0.80…1.35                      | 0.75…1.60 |
| and coarse                         |                                               |                                 |                 |
| Light and dusty sandy loam         | 0.85…1.20                                      | 0.80…1.25                      | 0.75…1.35 |
| Heavy loamy sand dusty, light      | 0.90…1.10                                      | 0.85…1.15                      | 0.80…1.30 |
| loam and light dusty loam          |                                               |                                 |                 |
| Heavy loam and heavy dusty clay    | 0.90…1.00                                      | 0.90…1.05                      | 0.85…1.20 |
|                                    |                                               |                                 | 0.80…1.30 |

Soil compaction coefficient is the most important characteristic that is carefully monitored. This coefficient helps to determine density of dry soil in its foundation structure as well as its maximum standard density. The actual values of soil compaction coefficient are determined by the ratio of the density of dry soil $\rho_d$ to its maximum standard density obtained in the laboratory device of the standard compaction Soyuzdor Research Institute - $\rho_d$ (max), i.e. soil compaction coefficient is determined by following formula:

$$K_y = \frac{\rho_d}{\rho_d(\text{max})}$$

Moisture swelling —is the moisture content obtained after completion of a soil sample swelling, this soil sample is compressed by a given pressure under conditions that exclude the possibility of lateral expansion. Moisture swelling is determined at each stage of filler application. Completion of the swelling can be observed by the strain increment which should be not more than 0.01 mm and held at least for 16 hours. After the swelling is done sample moisture is measured by weight method and calculated by the moisture content equation [7, 8].

Shrinkage limit – a soil moisture with a sharp decrease in shrinkage, determined by the inflection point of the curve in a graph that shows the dependence of the soil samples volume on changes in moisture during drying process (figure 2).
3. Methods and Materials

Operational planning of drip irrigation regimes for agricultural and landscape crops provides for the determination of science-based conditions and norms of irrigation depending on soil, physiological, climatic and technical irrigation. In modern drip irrigation systems, the parameters of irrigation regimes are calculated similarly to traditional methods but taking into account the part of the site that needs watering. In this case, the irrigation flow is determined by the following formula [9, 10]:

\[
    m = 100\gamma h S (\beta_{HB} - \beta_{min})
\]

where \(\gamma\) – density of the lower soil layer (g/cm\(^3\)); \(h\) – depth of the calculated active soil layer (m); \(\beta_{HB}\) and \(\beta_{min}\) – soil moisture, respectively, with the smallest moisture capacity (HB) and lower limit of allowable soil drying, % to the mass of an absolutely dry soil; \(S\) – the ratio of the wetted area to the moistened area, represented in fraction of a unit. In addition, soil moisture content \(\beta_{min}\) is determined depending on the mechanical composition of the soil, agricultural crop type and the phase of its development as a percentage of \(\beta_{HB}\). Depth of the calculated soil layer \(h\) differentially varies according to the phases of plant development in different periods of vegetation. Thus, when determining the rate of irrigation according to the formula (4), additional accounting of quantitative and qualitative information is necessary.

Determination of irrigation regimes in drip irrigation systems according to dependence (4) does not allow to take into account physiological characteristics of the plant state, which indicate the presence of water stress [11]. In practice, there can be cases where soil moisture is higher than its critical point and there is no need in irrigation but at the same time plant, in terms of changing the diameter of the stem and, if the diameter of the fruit, indicates a lack of water.

Due to the inability to identify causality between different parameters of irrigation regimes and the sum of characteristics of the irrigated area by conventional methods, there is currently no analytical relationship, which, in combination with the physiological parameters of the plant, introduces
scientifically based technologies for operational planning of irrigation. The model for operational planning of irrigation for automated drip irrigation systems is considered as a functional mapping:

\[ X = \{x_1, x_2, \ldots, x_n\} \rightarrow d \in D = \{d_1, d_2, \ldots, d_m\} \]

where, \(X\) – variety of the plant characteristics and the plot of the irrigated area; \(D\) - classes variety of the variable solutions. \(m\) – irrigation rate. Difficulties in approximating of this dependence occurred due to the presence of quantitative and qualitative information that represents physical and linguistic uncertainty. In addition, among the qualitative variables there are binary variables ("method of growing \(=\) (seedling, non-seedling)).

This problem could be partly solved if there would be a larger number of qualified specialists who would be able to determine the optimum time and speed of irrigation, considering the linguistic nature of the variables, methods and granulating their experience without building dependencies. Nowadays, in the absence of such reference experts, mathematical models that are based on soft calculations should be in the basis of intelligent systems applicable for operational planning of irrigation. In this case, the first stage of building the model involves structural identification by adding the model to the experimental data of the training sample using genetic algorithms (GA) or artificial neural networks (ANN),[10]

The hierarchical classification of plant state parameters and the area of the irrigated network is represented by a hierarchical fuzzy inference tree, the root of which are decision classes

\[ D = \{d_1, d_2, \ldots, d_7\} \]

where \(d_1\) – watering is not required, diagnostics during the next day; \(d_2\) – watering is not required, diagnostics is done throughout the day; \(d_3\) – watering is required at the rate of 50-60 m\(^3\)/ha; \(d_4\) – watering is required at the rate of 60-70 m\(^3\)/ha; \(d_5\) – watering is required at the rate of 70-90 m\(^3\)/ha; \(d_6\) – watering is required at the rate of 90-110 m\(^3\)/ha; \(d_7\) – watering is required at the rate of 110-140 m\(^3\)/ha \([11, 12]\).

Figure 3. Hierarchical inference tree.
From the figure 3 following parameters can be observed:

- \( W \) – water stress level of the plant, according to its physiology \([\text{is}, \text{vd}, \text{pt}, \text{ir}]\);
- \( S_m \) – soil moisture level \([\text{ltcr}, \text{cr}, \text{htcr}, \text{h}]\);
- \( A \) – favorable climate level for crops growth \([\text{mf}, \text{m}, \text{f}]\);
- \( x_1 \) – increment of stem diameter \([a, \text{but}, \text{no}, \text{sp}, \text{p}]\);
- \( x_2 \) – increment of fruit diameter \([a, \text{but}, \text{absent (not)}], \text{slightly positive (sm)}, \text{positive (p)}\);
- \( x_3 \) – leaf temperature \([\text{low (l)}, \text{lower than average (lt)}, \text{average (a)}, \text{higher than average (hta)}, \text{[high (h)]}\);
- \( x_4 \) – juice movement intensity \([\text{low (l)}, \text{lower than average (lt)}, \text{[average (a)]}, \text{higher than average (hta)}, \text{[high (h)]}\);
- \( x_5 \) – times of day \([\text{morning (m)}, \text{day (d)}, \text{closer to the evening (cte)}, \text{evening (e)}, \text{[night (n)]}]\);
- \( x_6 \) – soil texture \([\text{loamy sand (ls)}, \text{light loamy (ll)}, \text{medium loamy (ml)}, \text{heavy loamy (hl)}, \text{clay (c)}]\);
- \( x_7 \) – method of growing \([\text{seedlings (s)}, \text{[non-seedlings (ns)]}\);
- \( x_8 \) – vegetation phase \([\text{planting-flowering (pf)}, \text{[beginning of fruit-bearing (bofb)]}, \text{[ripening-gathering (rg)]}]\);
- \( x_9 \) – soil moisture \([\text{low (l)}, \text{lower than critical (ltc)}, \text{critical (cr)}, \text{higher than critical (htcr)}, \text{[high (h)]}]\);
- \( x_{10} \) – air temperature \([\text{low (l)}, \text{lower than average (lt)}, \text{[average (a)]}, \text{higher than average (hta)}, \text{[high (h)]}]\);
- \( x_{11} \) – precipitation forecast \([\text{no}, \text{low rainfall (lr)}, \text{[sufficient rainfall (sr)]}, \text{[heavy rainfall (hr)]}]\);
- \( x_{12} \) – relative humidity \([\text{low (l)}, \text{[medium (m)]}, \text{[high (h)]}]\);
- \( x_{13} \) – wind speed \([\text{low (l)}, \text{[medium (m)]}, \text{[high (h)]}]\);
- \( x_{14} \) – depth of the lower soil layer \([\text{low (l)}, \text{[medium (m)]}, \text{[high (h)]}]\);
- \( x_{15} \) – part of the humidification area \([\text{low (l)}, \text{[medium (m)]}, \text{[high (h)]}]\);
- \( x_{16} \) – soil type again \([\text{chestnut (c)}, \text{[southern chernozem (sch)]}, \text{[regular chernozem (cch)]}]\).

Terminal set of peak labels – input quantities by which irrigation modes are determined; Non-terminal set of peak labels – convolutions of these factors into aggregated ones.

Mathematical Model:

\[
X = \{x_1, x_2, \ldots, x_{16}\} \rightarrow d \in D = \{d_1, d_2, \ldots, d_7\} \quad (7)
\]

 defining modes of drip irrigation, we will present in the form of a combination of ratios:

\[
m = f_m(W_s, S_m, A, x_{6}, x_{14}, x_{15}, x_{16}) \\
W_s = f_{W_s}(x_1, x_2, x_3, x_4, x_5) \quad (9) \\
S_m = f_{S_m}(x_6, x_7, x_8, x_9) \\
A = f_A(x_{10}, x_{11}, x_{12}, x_{13}) \quad (11)
\]

The set of relations (2) - (5) is formalized by four Mamdani fuzzy knowledge-based systems, which act as granules of expert information in the form of rule sets as "If - Then" type:

IF \( S_m \) = «high» AND \( W_s \) = «normal development» AND IF \( A \) = «favorable» AND \( S_m \) = «above critical» AND \( W_s \) = «positive trend» THEN \( d_2 \) – watering is not required, diagnostics during the next day.

Each of the input quantities \( X = \{x_1, x_2, \ldots, x_{16}\} \) is represented as a linguistic variable whose values are terms from the corresponding term – sets. Linguistic terms are defined by fuzzy sets using triangular membership functions \( \mu_i(x_i) \) input variables \( x_i \), \( i = 1, 16 \) to their qualitative linguistic assessments. Selection of this type of the membership fractions is based on certain limitations when setting up the model by artificial neural networks (ANN). Bundles, corresponding to relations (8–11), are performed
by Mamdani fuzzy inference [12] according to the hierarchical system of embedded fuzzy knowledge bases.

4. Conclusion

In this study a newly developed mathematical model was described. The model allows to calculate irrigation regimes in drip irrigation systems by considering sixteen influence factors, which makes it possible, unlike conventional approaches, to take into account soil, climatic and physiological parameters of the plant in the consortium. A comprehensive accounting of these parameters allows to make scientifically based decisions on the timing and norms of crops irrigation during the operational planning of drip irrigation regimes. Development of an expert system that is based on the resulted fuzzy model will reduce the need for special training required to solve operational irrigation planning problems in drip irrigation systems using phytosanitary monitoring equipment and meteorological stations.

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