IrrigDSS – Decision Support System for Irrigation Scheduling

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***Abstract* — In this paper, we present IrrigDSS, a decision support system for site-specific data-driven irrigation scheduling. The solution enables water consumption optimization in a way that maximizes yields and reduces the overall cost of the crop farming. IrrigDSS uses several data sources for building data warehouse database and decision models. Decision models include descriptive and predictive models developed to help farmers in the decision-making process. An interactive graphical user interface provides an insight to the present state of the crops and offers access to the recommendation system for determining the adequate irrigation schedule.**

I. Introduction

The need for an increase in agricultural production, due to the growth of the global population, causes the need for improved irrigation water use efficiency [1]. Not only is there a need to optimize the overall irrigation water consumption to maximize crop yields, but there is also a need to provide farmers with precise information on plant conditions and daily crop water use, especially at critical plant growth phases. There are various calculation methods for crop water requirements estimation that could be applied by farmers. And, although crop yield is often related to water use, most growers do not use any methods for determining the water requirements of the crops they cultivate. Also, most of the methods that are used are applied in a non-criticized way, which leads to significantly different calculation results for the amounts of water required by the crops [2]. Many of these methods were designed for areas with specific pedological and climatic conditions, and thus their application is very limited. The goal of irrigation scheduling, which should be enabled by the research presented in this paper, is to guarantee an optimum water supply for crops, with soil moisture level being maintained close to the level that is required by the plant [3]. Applications that provide irrigation schedule planning are crucial to help maximize yield potential of crops that are exposed to water deficits.

In the last few years, due to an implementation of Internet of Things (IoT) and Big Data technologies in the domain of agriculture, Precision Agriculture (PA) concept has emerged [4]. PA can be defined as a whole-farm management approach using information technology, remote sensing, and proximal data gathering. The PA is used in order to optimize investments and maximize profits in regard to available resources, which can be supported by implementing a Decision Support Systems (DSS). The Site-Specific Crop Management (SSCM) approach is "a form of PA whereby decisions on resource application and agronomic practices are improved to better match soil and crop requirements as they vary in the field" [5]. In other words, SSCM can be described as an information and technology-based agricultural management system to identify, analyze and manage site soil spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment [6]. SSCM includes various data sources such as sensors, drones, and satellites for gathering all data types related to crops and weather and soil conditions. One of the main advantages of using SCCM in farming is that it can be used to accurately determine the most appropriate irrigation schedule.

In this paper, we present a Decision Support System (DSS) for SSCM, named IrrigDSS. The goal of the presented solution is to utilize the advantages of SSCM in a way that would enable improvement of irrigation process. IrrigDSS comprises of the following modules: (i) data management module, which comprises a Data Warehouse (DW) database with a corresponding Extraction, Transformation, and Loading (ETL) process (ii) decision model management module, which comprises analytic functions and prediction models and (iii) data presentation module, which comprises a dashboard with graphical data representation (GUI).

It is vital for IrrigDSS to reliably indicate when, and with what amount of water should the crops be irrigated. For this reason, the system enables soil moisture level prediction, which can be proven crucial in very large irrigation systems. In these systems, the irrigation process must be initiated early enough for the system to irrigate the whole surface area of the field before the soil moisture level falls beneath the critical point, at which the crops start to wither. The proposed approach also enables complex analysis of gathered data, which enables further improvement of the system, by analyzing correlations between different factors that affect the trends in soil moisture level.

Apart from the Introduction and Conclusion, the paper has three sections. In Section II we present the architecture of the IrrigDSS, along with the three components it comprises. Next, in Section III, we give a brief overview of the functionality provided by the IrrigDSS, and discus the results obtained by applying different predictive and descriptive models on the soil moisture level data gathered during the year 2016 on the several agricultural fields located in Bačka district, Serbia. In Section IV we give an overview of the related work.

II. THE ARCHITECTURE OF IRRIGDSS

The main value of the solution described in this work is that it enables site-specific data-driven calculation of the irrigation schedule. With this kind of a solution, it is possible to optimize water consumption in a way that would maximize yields and reduce the overall cost of the crop farming. The proposed solution also enables the increase of knowledge about crops and the conditions they thrive in, which is vital for the further development of the calculation methods used for the irrigation schedule planning. The solution comprises three distinct modules: Data Management Module (DMM), Decision Model Management Module (DMMM), and Data Presentation Module (DPM). Those modules are encapsulated in a single three-layered web application developed by using .NET framework.

We utilized three data sources for building DW database: (i) measurement data gathered from soil moisture sensors placed on the observed fields, (ii) meteorological data from Republic Hydrometeorological Service of Serbia (RHSS) [8], and (iii) farmers' records on their currently used irrigation schedule. In the Figure 1, solid black arrows depict the flow of data from the data source through ETL component to the DW database.

DMMM stores descriptive and predictive models which are used to define next action in irrigation schedule. Decision models were designed to enable both tactical and strategic decisions based on the available historical data from DW database. In other words, the role of decision models is to determine when to perform irrigation and how much water is needed. Descriptive models range from traditional statistical methods, such as summary statistics, time series smoothing and decomposition, to time series regimes detection and pattern recognition models. Predictive models include various solutions, based on different approaches, for soil moisture forecasting for a time period of one, three or five days. All decision models are designed by using R programming language and software environment for statistical computing [10]. Communication between the modules of IggisDSS is depicted by framed directed edges shown in the Figure 1.

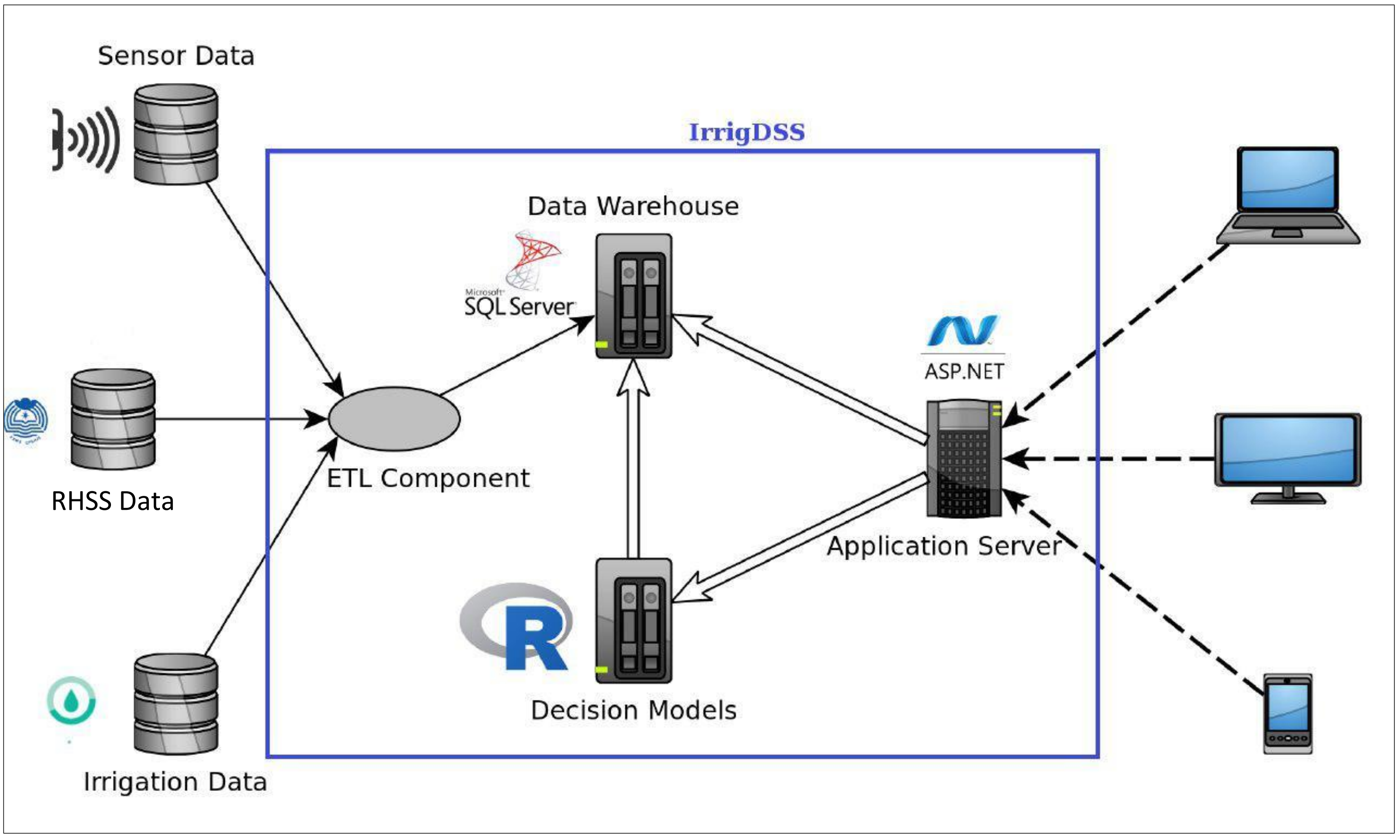

Figure 1 – Overview of the IrrigDSS architecture

DMM contains DW database, in which data gathered from sensors and other sources are stored, along with a corresponding ETL process. The building of the data warehouse included some typical actions: inspecting available data sources, designing the data warehouse schema according to Kimball's dimensional modeling methodology [7] by using identified dimensions and facts, and preparing data for the data warehouse. The data preparation required modeling of the process for extracting, transforming and loading data (ETL). ETL process is designed in MS SQL Server Integration Services and DW database is implemented in MS SQL Server [9].

DPM represents a graphical user interface with an interactive access to DW database content and decision models. The graphical user interface was developed to provide the overview of the current state of the crops and their environment to the user, as well as to help in decision-making process regarding recommendations on when, and with what amount of water should the crops be irrigated. Dashed directed edges in the Figure 1 illustrate remote access to the DPM using desktop and handheld user interface devices. The main part of DPM is the user dashboard with the following functionalities: (i) querying the DW database with standard Online Analytical Processing (OLAP) operations, such as slicing and dicing, (ii) diagram representation of results obtained by using descriptive models, and (iii) recommendation of the irrigation schedule for a required period according to the results of predictive models and user-defined rules.

III. SOIL MOISTURE FORECASTING AND ANALYSIS USING IRRIGDSS

In this Section, we give a brief overview of the functionality provided by the IrrigDSS. Time series forecasting and exploratory data analysis, described in the corresponding subsections of this section, are performed on the soil moisture level data gathered on several agricultural fields located in Feketić, Srpski Miletić and Futog, Bačka discrict, Serbia. Three different crop types were planted at those locations – corn, sugar beet and soybean. The measurements were gathered during the vegetation period of July-September of the year 2016, with sensors periodically reading the values on every 2-10 minutes. Sensors were installed on three depths: 10, 30 and 60 cm.

A. Time series forecasting

Forecasting of the changes in the soil moisture level is used to estimate when the crops should be irrigated. One of the techniques provided by the IrrigDSS solution for this purpose is the ARIMA model [11]. ARIMA models represent one of the most frequently used techniques for forecasting the future values of the time series data, such as measurements gathered from the soil moisture level sensors. They are used to describe the autocorrelation, i.e. the linear dependence that exists in the time series data. One major convenience that ARIMA models offer is that they provide the means to assess the prediction intervals of the forecast. With this, it is possible to expand the forecast with a range of values that a dependent variable could occupy with a certain probability, which enables us to express the uncertainty of the forecast. An example of the use of this functionality of the IrrigDSS is presented on the chart displayed on Figure 2. The chart shows a five-day forecast, marked with a blue line, based on the data points collected after the last rainfall, along with 80% and 95% prediction intervals (darker and lighter shade of gray, respectively). Relatively narrow prediction intervals indicate that the forecast has a pretty high certainty of turning out to be true. Red line shows the actual values of the soil moisture for the forecasted period. Based on this kind of a forecast, it is possible to predict when the soil moisture level is going to drop beneath the critical level, at which the crops start to whiter. This enables IrrigDSS to warn the crop grower that the irrigation process should be started. It is crucial that the grower receives the warning early enough in order for the irrigation process to be completed before the soil moisture level drops beneath the critical point on any part of the field.

B. Exploratory analysis

For exploratory data analysis purposes, traditional diagrams and techniques are utilized, such as scatter plot, box plot, time series decomposition, and hierarchical clustering of soil moisture content measurements aggregated by crop type, sensor depth, and location.

Scatter plots

Based on line diagrams, shown in the Figure 3, it appears that the moisture content is reduced with an increase in the

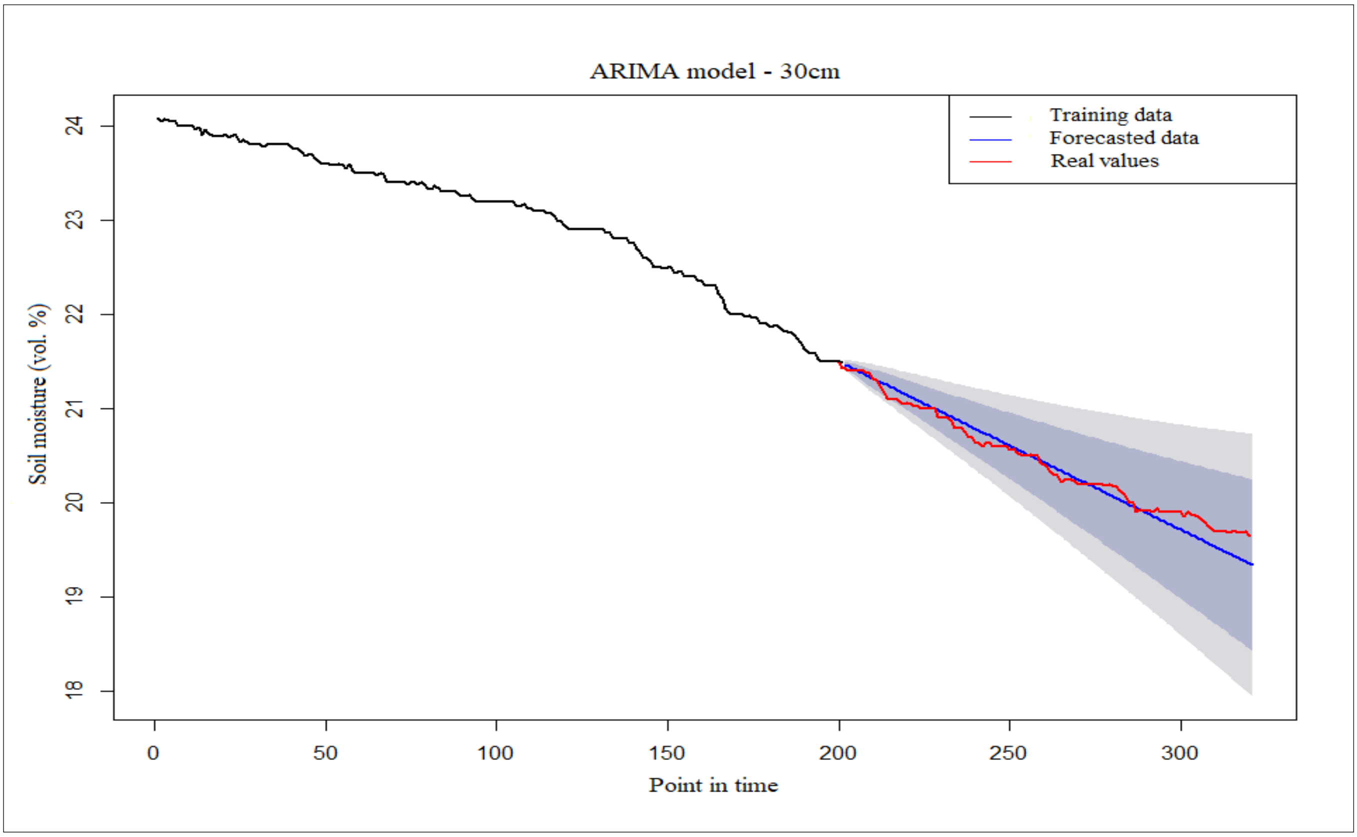

Figure 2 - Time series forecasting example

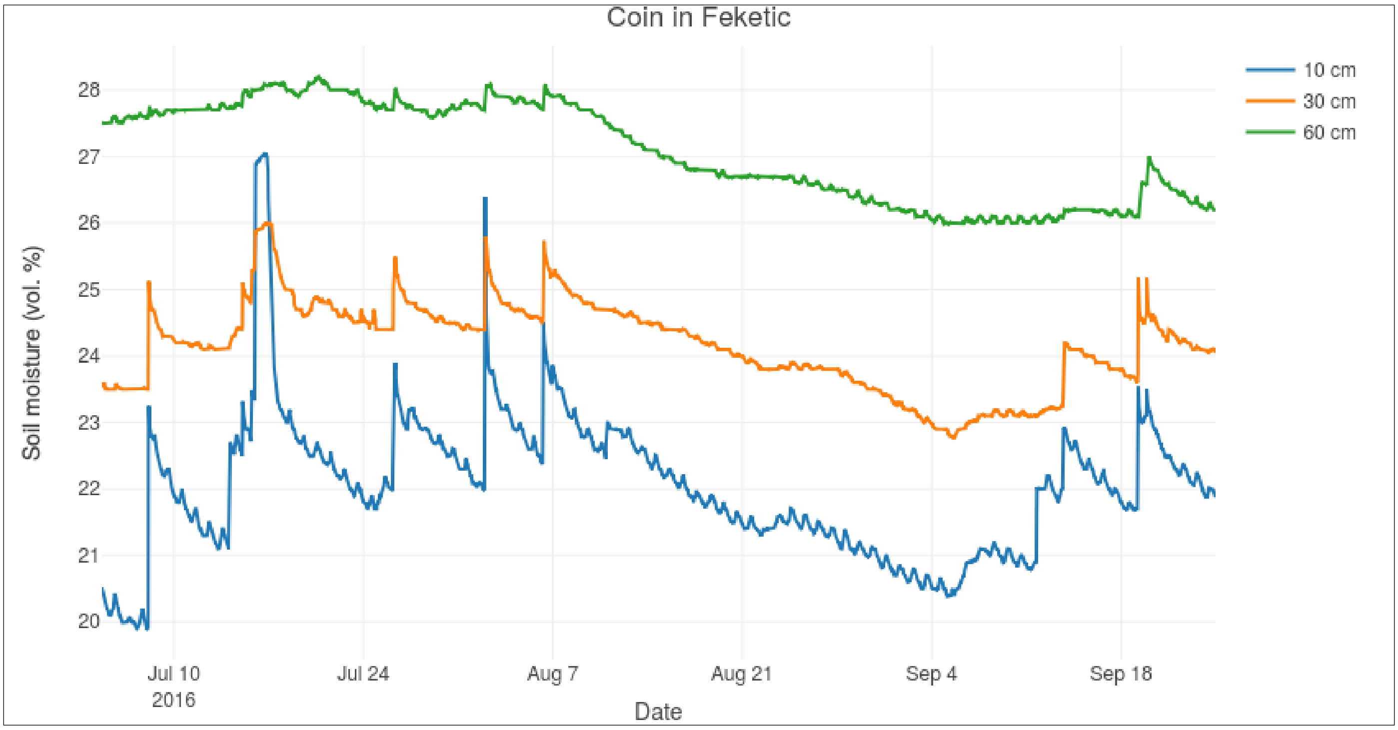

Figure 3- Scatter plot example

depth. Therefore, fluctuation in the moisture content over time is largest at the depth of 10 cm. Also, by observing scatter plots, it is noteworthy that extreme values of soil-moisture content at different depths occur at the same time but differ in intensity and shape.

Box plots

Observing the box plot in Miletić, shown in the Figure 4, it is noticeable that, in the case of corn, the moisture content increases with increasing depth of installed sensors, while the variance of soil moisture content decreases. In case of soybean, a box plot is significantly different, the maximum variance and the smallest amount of moisture content are at the mean depth. This behavior can be explained by the fact that the root of the soybean is at a depth of about 30 cm, so it takes the largest amount of water at the mean depth. Box plots, generated for different crop types at the same location with almost identical soil quality, have significant similarities only at a depth of 10 cm. Therefore, it can be deduced that the influence of crop type properties at depths of 30 cm and 60 cm is more significant than the impact of soil characteristics. Also, there are significant differences between boxplots based on measurements for the same crop type on different locations. In case of corn in Feketić, a slight decrease in the value of the median moisture content with a depth increase is noticeable, while the variance at 10 cm and 30 cm is approximately equal and greater than the variance at 60 cm depth. The decrease in variance and the increase in the median of moisture content with an increase in depth are present in case of soybean. In Feketić, the similarities between the two observed crop types are present only at a depth of 60 cm and reflected in the same intensity of variance.

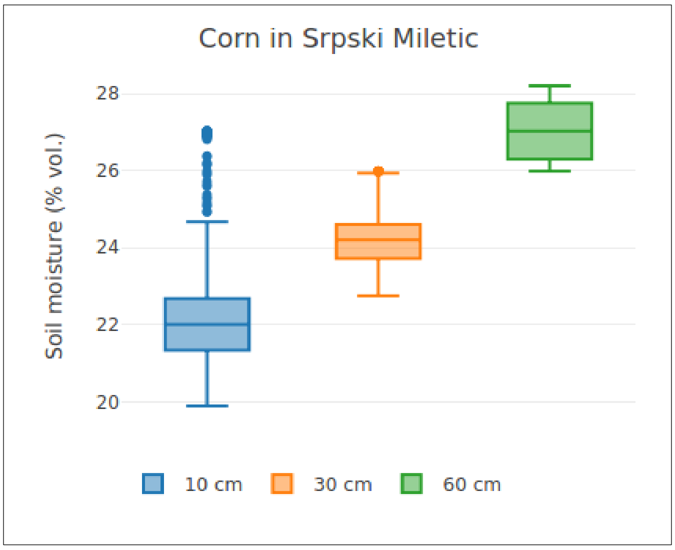

Figure 4 - Box plot example

Time series decomposition

Seasonal patterns on daily basis are discovered in observed time series data by applying Seasonal and Trend decomposition using Loess (STL). STL decomposition is shown in the Figure 5. Discovered patterns indicate the presence of regular oscillations in the soil moisture content regardless of the precipitation. It is noticeable that there is a greater regularity of the seasonal component during the dry periods. These daily oscillations explained as a result of several factors. The first is an appearance of dew in the morning, which the soil partially adopts by noon during most of the summer days. The second factor is the fact that plants use more water by their root system at night than during the

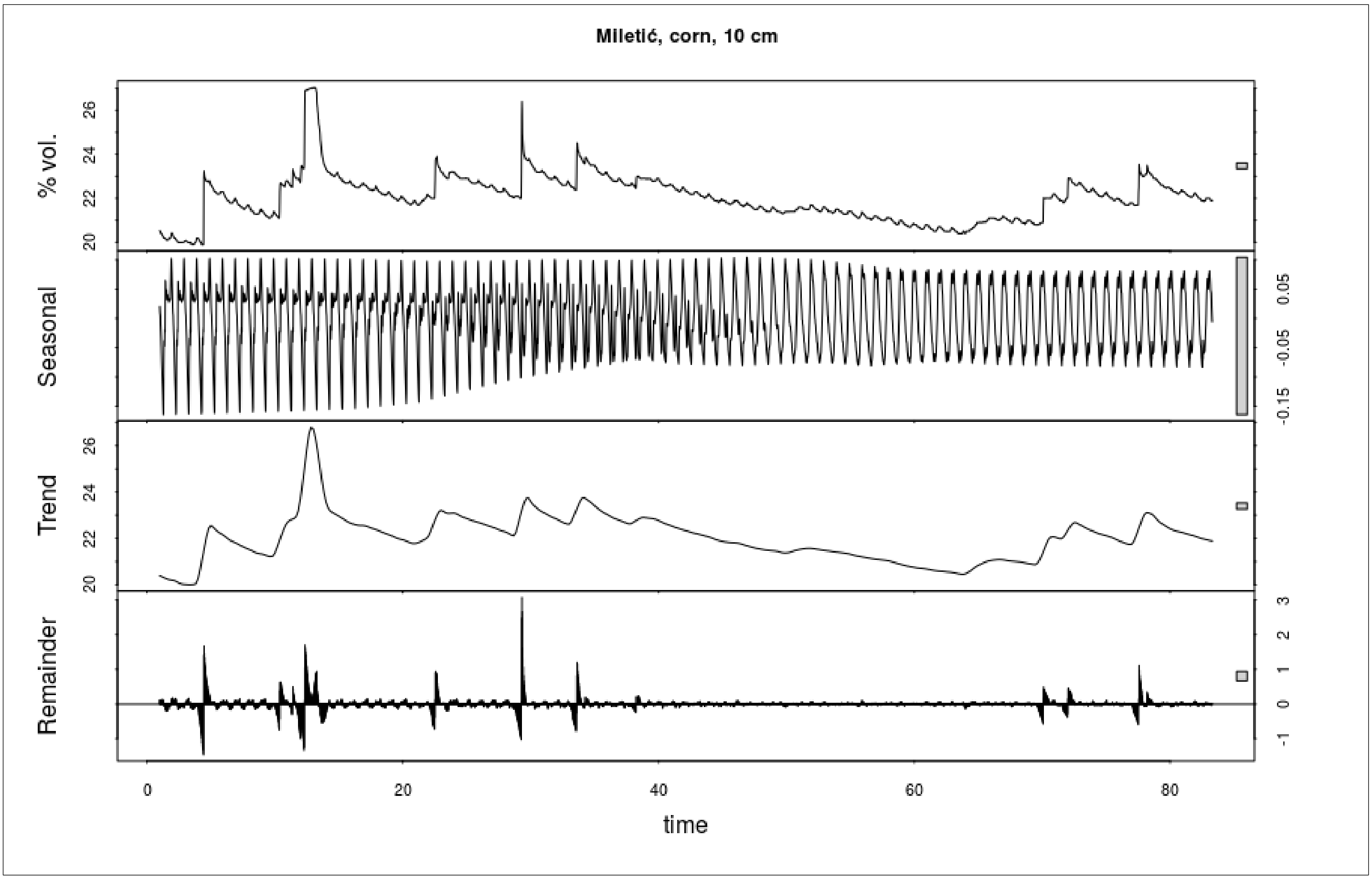

Figure 5 - Time series decomposition example

day. Also, the condensation of water vapor present in the soil, as a consequence of the daily temperature changes, can influence the moisture content. The daily maximum moisture level in the soil is in the interval from 12:30 PM to 01:30 PM, while the daily minimum is usually in the interval from 03:30 AM to 05:00 AM. This arrangement of extreme values of the soil moisture content during the day indicates the connection with daily air temperature fluctuations since maximum and minimum daily temperature mostly occurs in the same parts of the day.

The influence of precipitation on the soil moisture level

Correlation, between the change of soil moisture content and precipitation, is calculated on daily basis. According to obtained correlation coefficients, it is noticeable that precipitation and irrigation are losing influence with increasing depth where soil moisture level measurements performed. It is also noteworthy that the effects of adding water are not the same during the vegetation period. During the warm summer months, July and August, when the upper layers of the soil are significantly drier, the precipitation and irrigation influence less on the lower layer of soil (60 cm), since the upper layers absorb most of the added water. This is especially happening in situations when the rain comes after several days without precipitation, and at high air temperatures. Then, the soil moisture sensors at 10 cm and 30 cm react in an expected manner, while the sensor at 60 cm shows very little or no change in the level of moisture.

Comparison between expected evapotranspiration (RHSS) and soil moisture changes

Expected evapotranspiration for Bačka district was retrieved from RHSS website. The expected values of monthly evapotranspiration were compared with the aggregated monthly values of water content losses obtained using soil moisture measurements. It concluded that the results of that comparison are approximately proportional. The highest values are in July, the values in August are 50-60% of July values, while the values in September are 40-50% of August values. The largest deviation from the expected evapotranspiration is in the case of corn in Miletić, where water content losses in August and September are approximately equal. Although the water content loss rates in the soil are generally proportional to the expected evapotranspiration, the absolute values of water losses differ depending on the location. It is noticeable that the total value of losses in Feketić is almost double the value in Miletić. Such a situation may be due to various factors, among which the specific hydrological characteristics of the soil and sensitivity of the sensor.

IV. Related work

There are several existing decision support systems for irrigation scheduling, such as WISHCE (Spain) [12], IRRINET (Italy) [13] and IrriSatSMS (Australia) [14]. The existing solutions address the problem of calculating an optimum water supply for crops in a wide variety of ways. To the best of our knowledge, none of them uses IoT as a core concept for gathering site-specific sensor data. It is worth mentioning that there are some irrigation scheduling software solutions that do take sensor data into consideration when creating an irrigation schedule, such as IrrigNet (Serbia) [15]. However, unlike IrrigDSS, these solutions do not enable complex analysis of different factors that affect the trends in the soil moisture level, mainly because they are not built with DW database as a core part of their architecture. For this reason, they cannot be considered to be fully developed DSSs.

V. Conclusion

The presented solution enables water consumption optimization in a way that maximizes yields and reduces the overall cost of the crop farming, with a potential for the full utilization of the advantages that SCCM approach offers. Furthermore, the approach that was shown enables an in-depth analysis of the acquired data, as shown in the Section 3, which is vital for further improvement of the IrrigDSS solution. We can conclude that the solution presented in this paper proves that it is possible to implement a solution that takes an advantage of the benefits that the SCCM concept offers, in order to optimize the irrigation scheduling and the overall irrigation water consumption.

In our future research we plan to collect data from additional data sources like air humidity, atmospheric pressure, wind speed and solar irradiance sensors, which would provide a greater insight into the soil moisture level variability, different factors that affect it and correlations between those factors. We also plan to improve the Data Model Management Module to support additional descriptive models and more precise predictive models. The detail analyses of our approach will be investigated and presented in detail in a case study.

Acknowledgment

Research presented in this paper was supported by Ministry of Education, Science and Technological Development of Republic of Serbia, Grant III-44010, Title: Intelligent Systems for Software Product Development and Business Support based on Models.

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