Meteorological Data Aggregation System for Application in Agriculture 2.0

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Abstract—**Digital transformation has given numerous new possibilities for improvement of all industries through creation of new business processes or changes to existing ones. Agriculture, specifically, has experienced a "rebirth" through the use of digital technologies such as sensor networks, drones, satellites and similar, which has received a name Agriculture 2.0. Meteorological data management systems found their use in agriculture decision supporting solutions, as well. However, there are some challenges, these solutions are only as good as the data made available to them and implementing a system for acquiring quality data may be very expensive. The research described in this paper aims to solve these issues by using multiple publicly available free weather data sources and analyzing it to get the best possible results. The proposed system builds on acquired and analyzed data to provide users with features such as reliable notifications and machine/equipment automation.**

Index Terms—**agriculture 2.0; data analytics; digital transformation; meteorological data; precision agriculture; weather data aggregation.**

I. INTRODUCTION

Digital transformation is a comprehensive process of using digital technologies to create new or change existing business processes, culture and user experiences and generally change the way of doing business through the use of digital technologies and the improvements they enable [1,2].

The digital transformation began when full advantages of digitalization were recognized and started being used. It can be best seen in the changes of work of customer services - the processes of accepting applications, searching for relevant data/responses and resolving the issues were completely transformed when it was "discovered" that data no longer had to be searched in opaque dusty folders and cabinets, but could be found in a couple of mouse and keyboard clicks. That, basically, represents the digital transformation, it is not a simple improvement in efficiency of existing methods by using digitalization, but it is understanding and using the advantages and potentials of information technology for creating new business methods and processes [3].

By the beginning of the 21st century, most farmers ran their business processes manually, relying primarily on experience and tradition. At the beginning of the century, that began to change. The application of digital technologies has automated a large number of processes, and it has enabled much better monitoring and better decision making for many more [4]. Innovations such as a milking robot, automation of machines for digging the soil, planting, pruning plants, or harvesting enable much easier more productive work for farmers [5].

In the last couple of decades, base (navigation) stations for precise agricultural condition have appeared, which enabled independent navigation for machines in the fields, and along with them, meteorological stations that directly provided meteorological data to the machines started being used. That's when the real digital transformation in agriculture began. With increased precision and the ability to process huge amounts of data, machines were able to take over more sensitive jobs and operate independently of humans [6].

The majority of people know that weather has an important impact on the agricultural industry. Crops need moisture, heat and sun to succeed. What is less obvious is how some weather information can influence farmers' business decisions, helping them plan efficiently, minimize costs and, as a result, increase yields and earnings. Farmers have to make weather-related decisions on a daily basis and there are four basic areas of agriculture where weather conditions are mainly used:

- Crop growth / irrigation,
- Frost prevention,
- Pest and disease control,
- Crop cultivability,
- Fertilization.

During the year, farmers make small but frequent decisions about their crops and the cumulative effect of the financial implications of those decisions can be significant, especially when it comes to producers who have thousands of hectares planted. For them, unforeseen weather conditions represent a much higher risk and cost than the cost of using accurate and reliable weather data [7]. In recent years, digital transformation of agriculture and solutions for precision agriculture are expected to play a key role in developing countries [8]. Additional motivation for this research is that precision agriculture is being explored and evaluated for the use in Montenegro [9,10], and Agriculture and information technology are recognized as strategic priorities in the Smart Specialisation Strategy of Montenegro 2019-2024 [11].

II. BACKGROUND AND APPROACH

The focus of this research is creation of a meteorological data management system capable of providing accurate meteorological data, both current data and forecasts, in a way that enables farmers to make informed decisions, whether they do it themselves, manually, or whether these decisions

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are made automatically by machines. The paper describes the key elements of the information system that provides quality and accurate meteorological data, with the possibility of sending notifications to users and direct connection with agricultural machines in order to automate them.

A. Needs for Precise Meteorological Data

Accurate meteorological data are necessary for any studies related to climate trends and meteorological events. Automatic meteorological stations are one of the best instruments in meteorology today and enable fast and efficient measurements, as well as measurements in remote areas [12]. In addition to using the data itself, the goal of collecting raw, current meteorological data is also to analyze them and make predictions based on them for the near or distant future. Currently, there are a handful of institutions in the world, but also companies that deal with climate forecasts, each using different methods of analysis and forecasting models. Certainly, all of these models also have different levels of precision and companies are competing with each other to create the most accurate model. They are doing this not only out of prestige or scientific curiosity (although yes to a certain extent), but as mentioned earlier, because predictions have a great influence on economic decisions in various industries, and primarily in agriculture [7,8].

B. Weather Data Collection

The process of analyzing meteorological data begins with the regular collection of current meteorological data for locations in the system. Data is retrieved at regular intervals, every hour, half hour, or more frequently, from several available sources. These sources are defined as publicly available APIs offered by weather data providers that provide weather data for locations based on GPS coordinates. In addition, weather data may be obtained from user owned devices equipped with sensors, either by polling the devices for data or devices sending the data to the system. The data collected from multiple sources is then standardized and formatted according to the structure of the table in the database, and finally entered into the database for aggregation and further processing. Even though sources provide the same data such as temperature, humidity, etc, they differ from each other in several technically important ways. As a rule, the "keys" of the data are always different, the daily temperature can be called *Temperature* by one source and *DailyTemperature* by another. In addition, there are often differences in the units in which values are displayed, precipitation can be displayed in centimeters but also inches, and differences can also be found in the data structure itself. Therefore, a different way of processing (parsing) and formatting data and their standardization is made for each source.

III. IMPLEMENTATION AND DISCUSSION

A. Weather Data Aggregation and Analytics

In parallel with the regular retrieval of current meteorological data, for each location the system is retrieving meteorological forecasts from multiple sources for the next 7 days on a daily basis. It is at this step that it is necessary to perform data analysis. The first part of the process, forecasts collection and formatting, works like the process of collecting current measurement data. The second part of the process, analysis, is the one that differs. After collecting and formatting the data, instead of entering it directly into the database, precision coefficients must be added to the forecasts so that users know how reliable each forecast is.

In order to estimate the coefficient of precision of a forecast, we take the current weather data and compare them with the values that were predicted for this moment in the past (last 7 days). Here, precision analysis is implemented by taking one parameter, the maximum daily temperature, and for even more precise analysis, more or all data can be taken. Figure 1 shows the values taken from the previous 7 forecasts from the database. The precision coefficients and values on the graph are shown only illustratively.

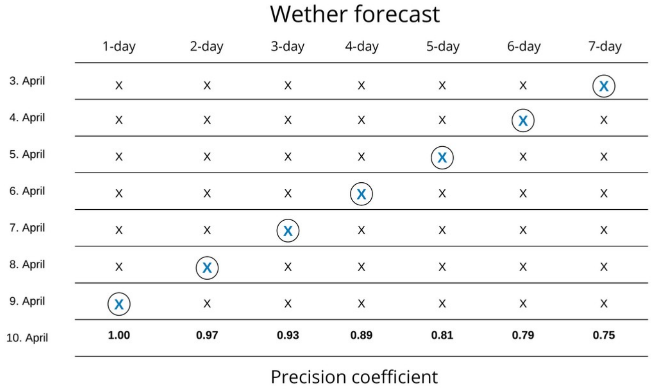


Fig. 1. Analysis of the precision coefficient of a seven-day weather forecast

For each day of the forecast **n** that we want to estimate, we need to compare the present value on today's day **t** with the value that was forecast at time **t - n** for day **t**. So, to get the precision of the 1-day forecast **n = 1**, we need to take the **n**$^{\mathbf{th}}$ value from the forecast series that was recorded on this day - n or **t - 1** and it is **[t - n]**. If we want to estimate the 2-day precision of the weather forecast **n = 2** on April 10, t = 10, we need to take the value **[t - n]**, **[10 - 2] = 8**, ie. in order to evaluate the precision of the forecast for April 12 on April 10 (two day forecast), we need to take the second value from the series of forecasts from April 8, which will be the predicted value for April 10, and compare it with the current measured value. For example, if on April 10 we want to evaluate the two-day precision, for April 12, we will take the current temperature value of 21 degrees Celsius, then, the second value from a series of forecasts from 2 days ago, April 8, which is 20 degrees, compare 20 / 21 and obtain a two-day forecast precision factor of 0.95 or 95%.

As stated, the implemented analysis takes only one parameter, the daily temperature, and for better results another parameter can be taken or even more of them depending on the needs.

For some activities in agriculture, in addition to temperature, precision in the occurrence and amount of precipitation, primarily rain, is more important. Therefore, along with the existing analysis, countless more analyzes can be created that will reflect the needs of certain users. Accuracy analysis can be created based on air pressure, rainfall precipitations, snow, or any combination thereof, and users would have the option to choose which analysis they want to monitor, or they could choose to track weighted accuracy coefficients based on all analyzes.

In addition to the analysis that can be performed on new data, sufficient data will be collected over time for meaningful analyzes of historical data. Also, adding more sources will increase the amount of available data exponentially and it will be possible to make detailed analyzes and comparisons among the sources themselves, that are much more advanced than precision analysis. Furthermore, this approach could be enhanced by applying artificial intelligence and machine learning to data sets of this size, it is certain that parallels and correlations between certain locations will be drawn as well as many other useful information as well.

B. Micro Level Weather Forecasts

In order to provide the user with the most accurate and high-quality meteorological data, it is necessary to implement the functionality of micro-locations, ie. that users are not limited to weather data for the city or municipality in which they are located, but that they can select the specific location they want on the map. This will allow users to choose, for example, their field or orchard and thus obtain highly localized data, rather than an average for a wider area.

At the beginning of the development of this functionality, a problem was encountered, and it is related to the unlimited number of possible user locations. The process begins with the user adding a location by entering its name and selecting a location on the map. When entering a location in the database, the location from the map is converted to latitude and longitude, which gives the following values - e.g. 42.435363, 19.261012. Each location has a certain latitude and longitude that consists of degrees, hours, minutes and seconds which equals to 2 numbers of 6 decimal places. The number of possible combinations of these two numbers is 32 septillion. In a hypothetical case where there is a database (or more of them) that could support so many locations, the question is whether it makes sense to make so many API requests to sources? The answer is no, and for three important reasons. The first reason is technical in nature, making so many requests would take too much time. The second reason is economical, all sources of meteorological data are services that provide meteorological data through the API for a certain amount of money. The cost of so many calls would simply not be worth the benefits. The third and main reason concerns the very nature of meteorological data. Although previous reasons could ultimately be technically and economically surpassed, the question arises whether they should be at all? Theoretically, it is possible to create millions of locations on one square kilometer, but that area is too small for the data to differ between locations at all. Therefore, it was decided to do a research that will show for which area perimeter the data does not change.

A short research was made with the task of determining the minimum distance between two points on the territory of Montenegro for which the retrieved data will differ.

The research was performed as follows:

- Several random locations on the territory of Montenegro were selected,
- The current measurement data for each of these locations were then retrieved, which is the basis on which the following data was compared.

The following was done for each location:

- Current measurement data 5 kilometers from the baseline was retrieved for each location;
- After that, the data 10 kilometers away from the baseline was retrieved for each location;
- And so it was continued, raising the distance by 5 km up to a distance of 30 kilometers. The following graph shows an example of data retrieval for several locations.

Figure 2 shows three locations marked with blue dots, and locations for which measured values were taken at a distance of 5 kilometers from each other as red dots. It was noticed that the data can differ significantly at the fifth point which is 25 kilometers away from the base location, but it was also noticed that in some cases the data can also differ at the fourth point at the distance of 20 kilometers. Therefore, it was decided to create a new type of data, Aggregate location, to which all User locations within a radius of 20 kilometers will be linked and for which meteorological data of one, aggregate location, will be served.

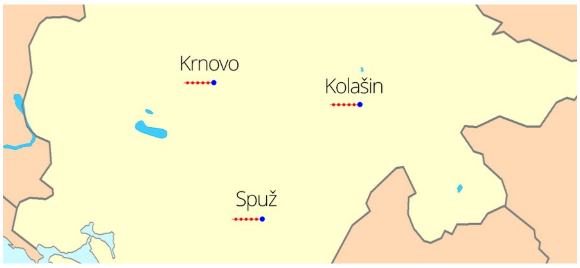


Fig. 2. Investigation of diversity of meteorological data by location

It was first decided to take a circle within a radius of 20 kilometers from the aggregate location as the surface of the aggregate location, but it was later switched into a square in order to be based on latitude and longitude. The final solution is that all user locations that fall under 0.1 degrees distance of latitude and longitude in relation to the aggregate location are to be linked to it. The distance of 0.1 degrees is taken because, calculated in kilometers, it amounts to 11 kilometers and 0.2 degrees diameter approximately fits a chosen distance of 20km.

As shown in Fig. 3, the process of adding user locations is marked with numbers. Under number 1 the first user location to the system is added. Since there is no location to which it can be linked, the first aggregate location with these coordinates is automatically added. The next is user location number 2 which is too far from aggregate location 1 and an aggregate location is automatically created for it and gets linked to it. After that, user locations 3 and 4 are entered. Since they are less than 0.1 degrees away from the aggregate location 1, they fall within its diameter and are linked to it in the database. These user locations will in future retrieve the meteorological data of the aggregate location 1. User location 5 cannot be linked to any aggregate location because it is too far away from them and an aggregate location is also created for it. Coincidentally, its area overlaps to some extent with aggregate location 1. This does not mean that new user locations that fall under the area that intersects the two locations will be linked to both locations, but they will belong to one of these two locations depending on distance.

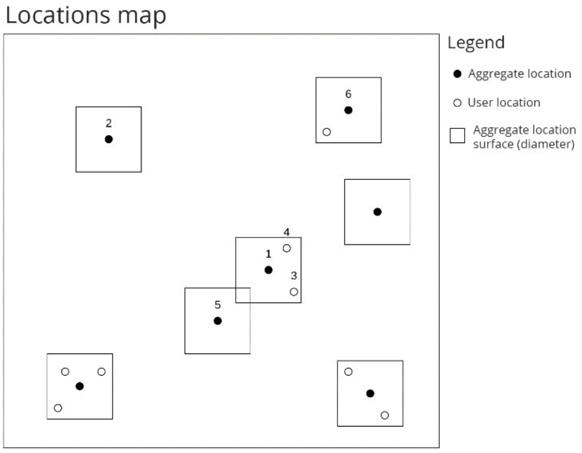


Fig. 3. Creating user defined locations for weather data aggregation

The implementation of this structure of locations enables the provision of quality and accurate meteorological data to end users for any of their micro locations, with a reasonable limitation in the form of aggregate locations.

C. Notification/Alarms

No matter how hard they try to give an accurate and precise weather forecast, meteorologists must always make certain generalizations, either on a spatial or temporal dimension. In addition to spatial differences between data, as happens within the same municipality, data also differs at the same location depending on the time of day. While we can get information on TV about the minimum and maximum daily temperature, or about the morning and evening weather conditions, the conditions may differ even within a time period such as "evening". Although more detailed meteorological data can be found on the Internet, mostly at the level of one hour, even this way of informing has two drawbacks - the first is that the weather can change significantly within one hour, for which the best example is hail that has huge negative consequences in agriculture, and the second is that it is extremely time consuming. It is necessary to check the website or application every hour in order to obtain the latest data. This problem needs to be solved in a different way, that is, instead of the user checking the data himself and informing himself in that way, why wouldn't it be the other way around?

Assuming the wide presence of Internet and Internet of Things (IoT) network of interconnected edge devices, it is possible to implement a notification system that works automatically and notifies the user, by a method that suits him - SMS, Email or API Callback (calling an external URL, described in detail in the next section), when certain conditions are met. Example - the user can choose to be notified via SMS when snow falls on a location, such as a field in the countryside. Each time the data is collected, the system will check whether the conditions are met and, if so, send an SMS to the user that it's snowing at a given location. The user can set up multiple notifications and choose from multiple conditions so this functionality can save users time and prove to be very effective.

Given that for the analysis of meteorological data described earlier, a system of regular retrieval of data from available sources must be created, the notification system would be easy to implement. The system would be activated when entering the retrieved data, it would compare the current weather data for a location with user notifications activated for it, and if they match, it would send a notification in the manner specified by the user. One of the biggest challenges in this case is the user experience, ie. notification management interface. One must enter a large amount of data with different interrelationships (Variable - Temperature, Rain, etc.; Comparison - higher / lower, true / false; Value, etc.), and the process must be easily understood and used.

After certain period and several attempts, a specific design and user experience solution was selected - Conversational User Interface [13]. The interface designed in this way is not an exact example of a conversational user interface, but it is modeled based on it and has several similarities. Its main feature is that notifications can be created and managed through a sentence-like interface whose parts can be changed and ultimately make perfect sense. This is achieved by combining textual elements and inputs with brief instructions designed to understand what to choose as that input.

Below are two types of sentences that can be used to create notifications (the underlined part of the text is input):

```
-----------------------------------------------
Notify me when SELECT MEASUREMENT UNIT SELECT
COMPARISON ENTER VALUE at location, SELECT LOCATION,
notify me via SELECT METHOD on phone number /
email / callback URL _______________.

Notify me when SELECT PRECIPITATION at location,
SELECT LOCATION, notify me via SELECT METHOD on
phone number / email / callback URL _______________.
-----------------------------------------------
```

By selecting the inputs in the given sentences, the following sentences can be obtained:

```
-----------------------------------------------
Notify me when the temperature rises above 40 at
location Greenhouse, notify me via SMS at 069 123
456

Notify me when it rains at location Orchard, notify
me via Callback (URL) at callback URL
http://server.automation.control/device/1/activate.
-----------------------------------------------
```

This method of notification management enables the best user experience and easy data management for end users, which is farmers in our case.

D. Machine/Equipment Automation

The functionality that shows a great potential is sending notifications via the Callback API. It builds on the notification system described in the previous section and is a method by which users can be notified in case the conditions for notification for a location are met. The Callback API in the world of programming is a way to get feedback to your software/hardware after something happens in an external IT system. In this case, for the end user, this information system represents an external system, and the programs and devices used by the user represent its software and hardware.

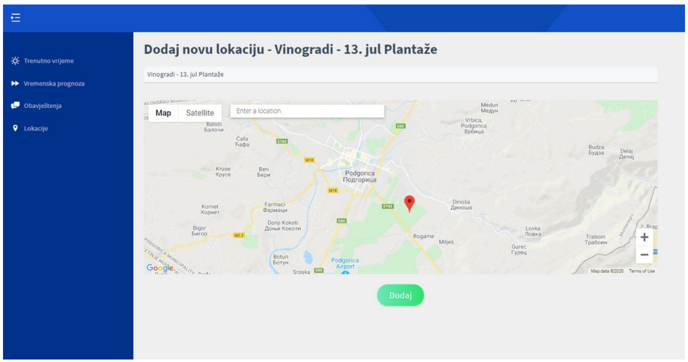
For example, user can set to receive a notification when hail starts to fall at one of its locations. The user may specify that he should be notified not via SMS or Email but via the Callback API, where it will provide an URL to its smart device server, which will, when it receives the notification, for example, automatically raise the cover to protect the plants from the hail. This method of communication with other systems is part of the IoT paradigm and opens up great possibilities for the automation of processes in agriculture [14, 15]. Irrigation control depending on air humidity and rainfall amount, raising and lowering the sun protection depending on temperature, activating anti frost systems, and much more can be automated, even systems that do not yet exist on the market, because this method allows a great possibility for interoperability with third-party and future systems.

E. Proof of Concept: A Prototype

All of the functionalities described in this paper were implemented as initial prototype system that served as a proof of concept [16]. The solution was implemented as a web-based service using Javascript programming language. Javascript was a language of choice, both on backend and frontend, with the exception of some processes that were developed with Python. The backend was done on Node.js, using the Strapi framework for developing data management system [17,18]. Frontend was developed using open-source framework Vue.js [19]. Finally, the data analysis and notifications system was developed purely in Python.

The system works as a web portal that is accessible via mobile device or personal computers. Registered users can specify several locations of interests and for each location weather data is collected, aggregated and processed as described in previous sections. Adding a new user defined location is illustrated in Fig. 4. The user can pick a location using a map based user interface. Each user can define several locations of interests and the data are kept and displayed in dedicated user space.

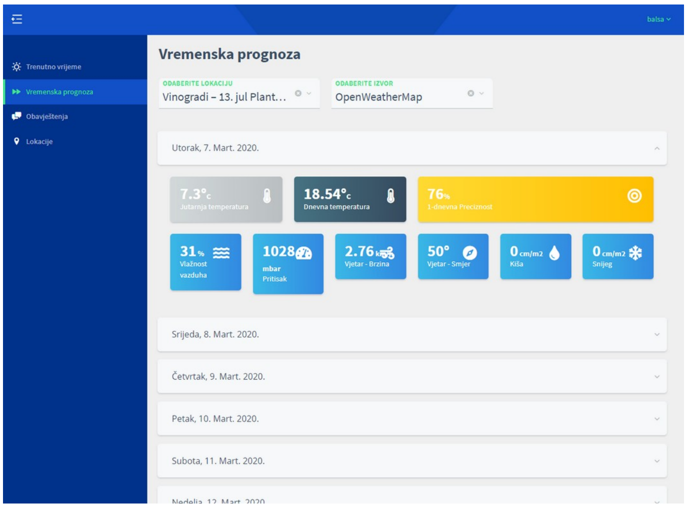
Once configured, the user access the data via user dashboard, where she or he can select the location of interest, data sources, type of data (current or forecast), etc. User dashboard of the prototype system is illustrated in Fig. 5. In addition to accessing data via dashboard, the user can specify notification/alarms conditions in order to be notified via SMS and/or email. Finally, the prototype allowed for communication with IoT edge actuators capable of receiving commands via URL using the Callback API.



Dodaj novu lokaciju - Vinogradi - 13. jul Plantaže

Vinogradi - 13. jul Plantaže

Fig. 4. Creating a user defined location for meteorological data aggregation and analytics - vineyard at 13. jul Plantaže, Podgorica, Montenegro



Vremenska prognoza

ODABERITE LOKACIJU Vinogradi – 13. jul Plant…

ODABERITE IZVOR OpenWeatherMap

Utorak, 7. Mart. 2020.

7.3°c Jutarnja temperatura

18.54°c Dnevna temperatura

76% 1-dnevna Preciznost

31% Vlažnost vazduha

1028 mbar Pritisak

2.76 km/h Vjetar - Brzina

50° Vjetar - Smjer

0 cm/m2 Kiša

0 cm/m2 Snijeg

Srijeda, 8. Mart. 2020.

Četvrtak, 9. Mart. 2020.

Petak, 10. Mart. 2020.

Subota, 11. Mart. 2020.

Nedelja, 12. Mart. 2020.

Fig. 5. User dashboard showing the weather forecast for the selected location

Configuring of an alarm for one of the selected locations is illustrated in Fig. 6. The user selects the location, provides a name for the alarm and defines conditions, i.e. notify me when the temperature rises over 40 degrees.

Dodaj novo obavještenje - Temperatura iznad 40 stepeni - Kuća

Temperatura iznad 40 stepeni - Kuća

Obavijesti me kada: ODABERITE MJERNU JEDINICU Temperatura

-: ODABERITE POREĐENJE Poraste iznad

-: 40

na lokaciji: ODABERITE LOKACIJU Mokri Do

obavijesti me putem: ODABERITE METOD Callback-a (URL)

na callback URL: https://server.automation.control/device/1/activate

Fig. 6. Configuring an alarm for high temperature for the selected location

IV. CONCLUSION

One of the decisive factors in agriculture is the weather and it's impact on crop growth and their yields. Having precise information on the expected amount of precipitation, farmers can optimize crop irrigation and thus increase yields while reducing costs, knowing wind speed in the coming period they can plan soil pollination, knowing temperature and humidity of the soil they can estimate the best time for fertilization. These examples illustrate the importance of predicting weather conditions for the success of farmers' yields.

This paper describes an information system whose functions are aimed at providing reliable meteorological data to farmers, improving the efficiency of their work through notifications and through the automation of their mechanization. In order to obtain the most accurate meteorological data, users have the option of creating micro locations, as well as creating condition based notifications, which are sent either to the user, or directly to his devices (via API callback) in case that conditions are met at a specific location defined by the user. For example, an increase in temperature above 40 degrees Celsius, or a decrease in humidity below 20% and the like.

The information system is designed in such a way that it can be developed and expanded in several ways. It is possible to add more data sources, add new analyzes and thus further "enrich" raw data, and it is possible to expand the system by adding new users' sensors and devices.

New features and protocols will be developed in the future, but certainly all the data from this information system, both raw and derived through the processing, can be exported for further analysis. The main purpose of the system is to provide timely and accurate meteorological data to farmers and the system can easily be interfaced and integrated with other tools from Agriculture 2.0 ecosystem. The system is open for adding new data analytics and future work may include the use of machine learning and creation of new decision support functions.

ACKNOWLEDGMENT

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