ON THE USE OF GIS, GNSS AND RFID TECHNOLOGIES IN MODERN IRRIGATION SYSTEMS

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***Abstract**: One of the stringent problems in Europe and worldwide is the moderate use of water resources for irrigation. This communication deals with the use of GIS, GNSS and RFID-UHF technologies to propose an intelligent moisture surveillance system for the agricultural crops. By using such technologies, the objective is to design a tool which can help the end user to decide when the best moment is and where to irrigate its agricultural crop. In this context, the authors are presenting a state-of-the-art of the already existing humidity measurement systems and highlight the advantages and the drawbacks of their proposed one. The correlation between the measured soil humidity and other geospatial attributes such as the topographic slope may be also important for the end user. An example of a humidity distribution map developed with theArcGIS tool will be also presented.*

***Keywords:** GNSS, GIS, RFID-UHF.*

1. Introduction

The United Nations predicts that the world population will surpass 10 billion at the end of the 21st century [1], more than double compared to the 2000s. Together with this populationincrease, the problem of food resources will be more and more stringent. The agriculture is particularly tributary to the weather and to the climatic conditions which is also changing in the wrong direction[2]. In this unfavorable context, it is necessary to scale up the effort toinnovate solutions and technologies in agriculture.

Currently, precision agriculture adopts an engineering approach that involves providing different inputs only when necessary. Recent innovations in electronics and informatics (cheap, lightweight, powerful, and low power consumption computers), geographic information systems, tele detection, localization technologies and the autonomous control of the agricultural machinery facilitates this holistic approach. Precision agriculture is focusing on the management,at a small size level, of the spatial and temporal variation of the agricultural crop's parameters, integrating the above-mentioned technologies.

In agriculture, the crop management suppose the measurement and the surveillance of some parameters like humidity, temperature, etc. More recently, the smart agriculture is integrating the more recent technologies such as the Global Navigation Satellite System (GNSS), Geographic Information Systems (GIS), remote sensing systems, etc., to directly collect data from the agricultural crops[3]. This recent approach related to the use of GNSS and GIS technologies implies a precise localization of the agricultural crops.

Precision agriculture is aware about the impact of various parameters such as the soil resources, weather conditions and the background on the actual agricultural crop. The inherent variability in space and in time of the soil resources and of the meteorologic conditions are leading to a specific, localized, and punctual management of the agricultural crop, thus avoiding a uniform approach. In this way, the efficiency is increased, and the overall environmental impact is reduced.

One of the critical inputs for agriculture is the water resource which deserves to be better managed. Indeed, it is well known that 20 percent of the irrigated cultures supply 40 percent of the world crops[4]. The innovation and the implementation of new and efficient irrigation systems based on modern technologies is of the top priorities of the nowadays academic research and industry.In Romania, the problem of the improvement of the irrigation systems is also of great concern. Indeed, the inherited irrigation system is obsolete and deserves to be updated to cope with nowadays needs and to make a step forward the smart agriculture monitoring[5].

From this perspective, the implementation of modern irrigation systems based on an accurate crop's humidity monitoring is necessary. The soil moisture monitoring needs to be made with a high spatial resolution such that the irrigation to be performed only there is a real need. Moreover, the humidity needs to be monitored "*in-situ*" by the means of communicating sensors having low environmental impact.Looking at the implementation of communicating sensors, IoT technology may provide the most appropriate solutions.

Forecasted to be approximately 30 billion connected devices by 2027 [6], IoT is one of the technologies which is getting evolutions in various application fields like industry, transportation, healthcare, and agriculture. By deploying cheap communicating devices including sensors and actuators, different processes are better understood, and the user may better interact with the containing process.IoT has already been successfully deployed in agriculture, demonstrating increased efficiency in agricultural crop management[7].

One of the challenging aspects of the IoT is the connectivity, generally based on wireless communication protocols. Since the part of the wireless communication in the energy budget of a connected device is the most important, the choice of the communication protocol is done as a compromise between the autonomy of the connected device, its communication range, and the data rate at which the information is conveyed towards the gateway. RFID (Radio Frequency Identification) is a mature communication technology that supports IoT. Initially deployed for identification purposes (traceability, access control, logistics) it is omnipresent in nowadays lives. Recently, this technology started to evolve towards the "augmented RFID" by incorporating sensors and actuators[8], including humidity sensors.

Another technology which may complement the IoT to provide innovative solutions in precision agriculture is the Geographic Information Systems (GIS). GIS technology represents an information system dedicated to data management and which can analyse various spatial information related to agriculture such as the culture productivity and the agronomic factors as for example soil roughness, NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), etc. GIS technology can handle various types of data and integrate various technologies (e.g., IoT sensors) into the decision-making process.As a main advantage, GIS gives the possibility to provide a user-friendly cartography of the analysed information, facilitating in this way the understanding of the agricultural crop's development and of the interactions between the crop and other "inputs" like fertilizers, pests, weeds, etc. Based on this spatial representation given by GIS, the end-user can take advised decisions.

In this context, this paper describes a humidity monitoring system based on the IoT (Internet of Things) and more specifically on the RFID technology is proposed. The information collected from the different sensors which are geo localized is presented to the end user by using the GIS technology. Based on this information, automatized systems may be imagined which will perform selective irrigation in dry zones.Modern technologies employed in the precision agriculture are covering three main aspects of the production process: i). data collection, ii) data processing and analysis and iii) decision making based on the collected data. The proposed soil moisture measurement system is focusing on the first to ones but a future development which includes the latter one may be relatively easily addressed.

The remainder of the paper follows this structure:after presenting a brief state of the art of existing humidity measurement systems in agriculture, Section 2describes in detail the proposed soil moisture monitoring system focusing on the RFID-UHF communicating sensor specifications. Section 3 is describing the implementation of a GIS tool able to feature the information of the humidity level and an application example is presented. Finally, section 4concludes the paper.

2. Towards a smart moisture monitoring system in agricultural crops

The knowledge about the soil moistureat each step of the plant's development plays a paramount role in the agriculture. Indeed, water allows the nutriment transfer between the plant and the soil through the osmosis process, the runoff, the evapotranspiration, and the vegetation growth. Certainly, there is a close relationship between the soil moisture and the plant's development [9]. Moreover, there is of great importance to measure the soil moisture dynamics because of high temporal and spatial variability even at small surface levels.

a). Brief state of the art of humidity measurement solutions in agriculture

The most used method employed to measure the soil humidity is the gravimetric one (i.e., measuring the mass of water per mass of dry soil). This direct method has good accuracy but because soil samples need to be extracted and then characterized in laboratory conditions, it is relatively difficult to be implemented.

Another way to analyse the soil moisture and its spatial and temporal variation is to analyse previously collected data. For example, based on the geostatic analysis method implemented in ArcGIS, in [10] it is presented the soil's relative humidity form the agricultural crops in China. A similar approach consists in using machine learning algorithms to estimate spatially and temporally the soil moisture distribution with a relatively good precision. For example in [11], data collected from the SMAP (Soil Moisture Active Passive) TB (temperature brightness) observations together with information such as vegetation water content and soil temperature is used in order to extract long-short term memory models.

Time Domain Reflectometry (TDR) together with Frequency Domain Reflectometry (FDR) are another non-destructive method to measure the soil's water content. These methods are based on the variability of the soil's dielectric constant as a function of the water content. The moisture variation is translated into the variation of the travelling time of an electromagnetic wave which is reflected by the soil [12].

The indirect method of Ground Penetrating Radar (GPR) can also be successfully employed, providing a high-resolution representation of soil moisture, especially in non-saline soils. If TDR is giving a good accuracy at 5 cm depth, the GPR method gives good accuracies at depths three times larger [13].Some other indirect methods for humidity measurement are using ionizing radiation: neutron scattering method or gamma ray attenuation. These methods are expensive and are presenting a health risk [14].

Capacitance or resistive sensors may also be employed for soil moisture measurements. They are exploiting the electrical characteristics of the humid soil. These methods are relatively accurate but requires expensive electronics to process and to send the information towards the end user. A comprehensive review of the moisture monitoring approaches can be found in [14].

b). Description of the proposed humidity monitoring solution

To monitor soil moisture, a specific quantity of UHF RFID tags capable of measuring relative humidity will be utilized. An example of such a tag is the one manufactured by the Asygn company[15]. Depending on the type of agricultural crop, the depth at which the tag may be buried may vary between few centimeters and one meter. The deployment may be performed by using a soil sampler embedded on an agricultural rover. The precise position of the rover will be determined by a GNSS receiver and a database with the tag's relative position and their identifiers will be created.

Then, when necessary, an UAV (Unmanned Aerial Vehicle) equipped with an RFID receiver fly over the agricultural crop and reads the humidity values given by the buried sensor tags. Through a high data ratewireless communication link, the UAV sends to the end-user the database containing the humidity values and the corresponding RFID tags' identifiers. By the means of the GIS technology, the relative humidity values are represented on a map displayed on a tablet PC. The end user is deciding which zones need to be irrigated in priority. An automated decision system which controls the irrigation system may also be imagined. The synoptic of the proposed humidity monitoring system is given in Figure 1.

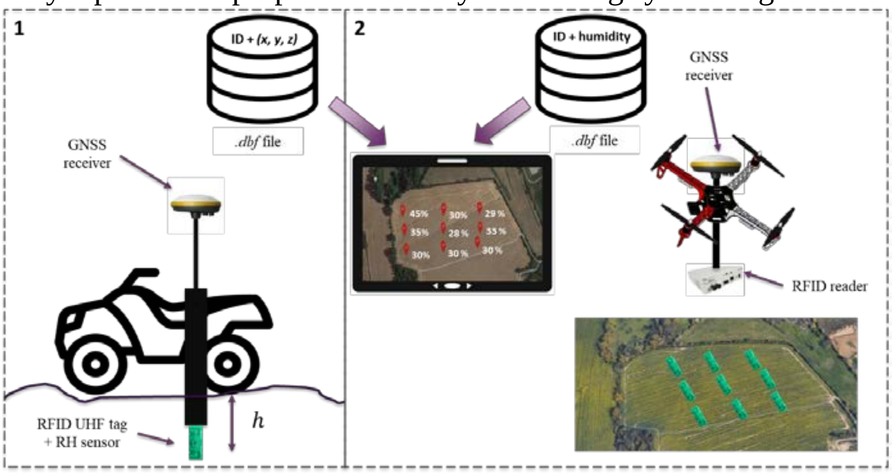

Fig. 1 Synoptic of the proposed soil moisture monitoring system

In RFID, the communication occurs between an active device called reader and a transponder (tag). The reader in emission mode provides the communication support by generating towards the tag an electromagnetic wave at a certain frequency and having a constant amplitude. By the retro modulation principle, the tag varies the characteristics of the incoming wave and sends back to the reader the contained information. Different frequencies are employed, from classical low frequency RFID (125 kHz - 134 kHz), to high frequency (13.56 MHz) up to ultra-high frequency (868 MHz) and even higher ($60\ GHz$).

Various criteria need to be considered when selecting the operating frequency, with the primary factors being communication range (i.e., the distance between the reader and the tag) and the tag's dimensions. In the given application scenario, RFID-UHF is the most suitable choice, as with current technology, it provides a communication range on the order of tenths of meters [16].

In the proposed scenario, the use of RFID-UHF passive tags is also of great importance since no conventional power supply (battery) is needed. Indeed, passive tags are power supplied by the incoming electromagnetic wave coming from the reader and no other power source is needed. This particularity of the RFID-UHF technology allows to design "*deploy and forget*" sensors, i.e., sensors which are buried into soil and are performing the humidity monitoring only in the presence of the reader. The drawback of this approach is that the soil moisture monitoring will be performed only when the RFID tags will be read.

Another advantage of the RFID technology is the low cost of a classic passive tag which is less than 20 eurocents. In this way, a large-scale deployment of such passive tags may be envisaged. At last, modern technology allow the fabrication of tags on environmentally friendly substrates. For example, in [17], the authors are presenting of chipless humidity sensors tags designed on a paper substrate and using a commercial desktop printer and silver ink which reduces even more the manufacturing complexity and cost.

One of the main challenges when employing RFID technology in the proposed soil moisture measurement scenario is to accurately locate the sensors which may be buried. Localization solutions based on the RFID technologies are already existing for other applicative contexts. For example, in [18] the authors are proposing the precise localization of a robot, by combining the RSSI (received strength signal indicator) and the phase difference obtained when receiving the RFID signal. In their scenario, the localization occurs in a relative coordinate system and in a confined environment.

As such, the spatial representation of the soil humidity based on RFID technology does not impose a precise localization of the buried sensors. However, if there is a need to extract the sensors to be further reused, then the precision needs to be on the order of centimetres (geodetic one).From this perspective, "*deploy and forget*" RFID tags may release the constraint of the location precision.

Classical geodetic methods based on Total Station Theodolites (TST) are difficult to be implemented in our proposed monitoring system because of the high number of sensors which are envisaged to be deployed. Consequently, such technique wouldrequire a high data collection and processing time. Because the sensors will be deployed in agricultural areas, the localization of the humidity sensors based on RFID tags may be performed in an efficient manner based on the GNSS technology.

Among others, particularly, the RTK (Real Time Kinematics) technology has proven its efficiency and reliability, especially in open areas[19].Indeed, the RTK technology offers the best spatial precision when Internet connectivity is guaranteed since RTCM (Radio Technical Commission for Maritime Services) corrections may be sent. In this case, a network of GNSS permanent stations is employed and, through the NTRIP (Networked Transport of RTCM via Internet Protocol), the corrections are sent such that the agricultural rover burying the RFIDtags obtains its location at geodetic precision, as in [20].

Moreover, in the proposed application, the integration of GIS technology brings a significant contribution to improve the efficiency, to promote the sustainability, and to facilitate the process of taking informed decisions in themanagement of water resources and in the implementation of agricultural practices.

3. Obtained results

To take a step forward toward the implementation of the proposed system and especially to build the GIS system's architecture, a series of humidity measurements, based on the existing commercial sensors, were undertaken. The employed moisture sensor was Spectrum Field Scout SMEC 300 from Spectrum Technologies and, as can be remarked from

Fig. 2 to the sensor, a GNSS receiver was mechanically attached to have the precise localization of the humidity measurement.

The measurement campaign was performed at the Ezăreni pedagogical facility of the "Ion Ionescu de la Brad" University of Life Sciences,Iaşi, Romania. This facility is located 2.5 km south-west from Iaşi, in the south-western extremity of the Moldavian Plane, known also as “*Câmpia Jijiei inferioare şi Bahluiului*”, see Fig 3 for details.

From the geographical point of view, the Ezăreni facility is located between the coordinates 47°5’- 47°10’ N latitude and 27°28’- 27°33’E longitude. The structural relief is represented by interfluvial erosion surfaces with fragmentation, which is the dominant relief of the pedagogical facility.These surfaces were formed on a clay-marly complex, strongly fragmented by the hydrographic network.Slopes are impacted by current geomorphological processes (washouts, linear erosion in different stages, landslides).

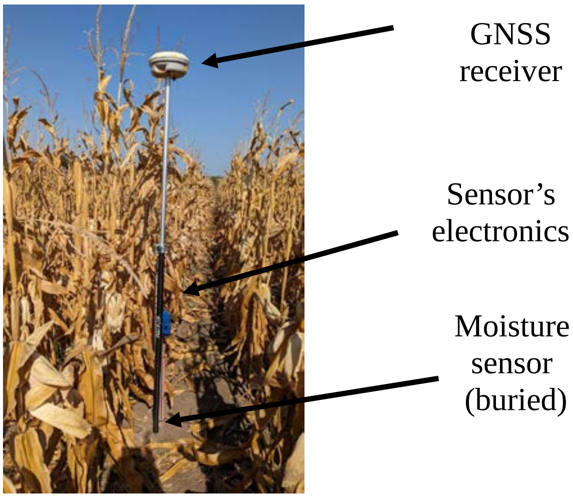

Fig. 2 Moisture sensor attached to a GNSS receiver for localization purposes

The current relief is integrated into the general geomorphological aspect of the Moldavian Plateau.Most of the pedagogical facilities’ surface includes wide plateaus, with average altitudes of 100-130 meters and slopes of 2-4%.The highest altitude is 170 m (*DealulNucului*), and the lowest height (60 m) belongs to the valley of the Ezărenistream.

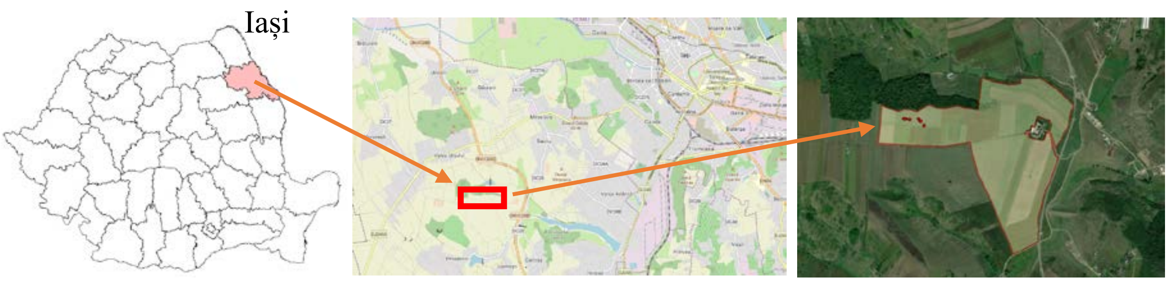

Fig. 3 Location of the study area: regional context and Ezăreni educational farm

The position measurements were performed with a South S82-T GNSS receiver and based on the real time GNSS positioning service ROMPOS (RTK method). The planimeter transformation was performed by using the TransDatRO software [21] and the altitude transformation was performed through the Romanian_ETRS89v1.gsf geoid and the option NTRIP VRS_3.1 since the study area is located at more than 3 km far away from the Iaşi GNSS permanent station (included in the Romanian’s National Geodetic Network)[22].

To represent the collected data, ArcGIS software platform was employed. More precisely, the shapefile containing the information about the soil moisture, the geographical coordinates of each measurement and the projection system were exploited. The obtained results are depicted in Fig.4.

In this figure, the information about the relative humidity is visible at the precise location (Fig. 4 left). Other information such as the crop's location slope can be represented. (Fig 4 right).

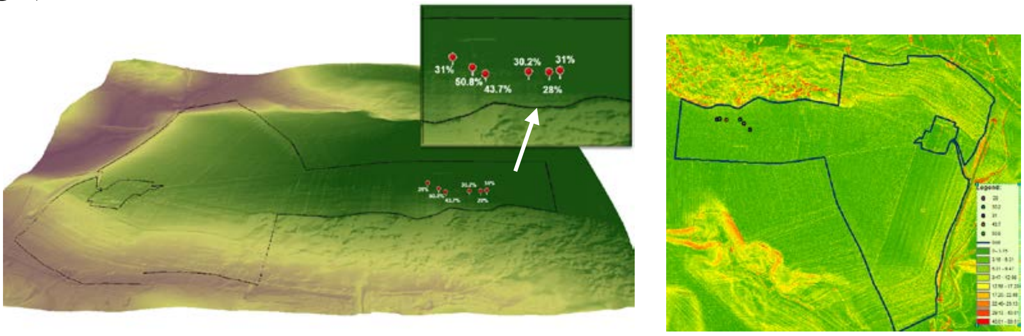

Fig. 4 Moisture measurements reported a 3D map through ArcGIS software.

4. Conclusion and future work

This paper presents a new moisture monitoring system for intelligent agriculture. The proposed system is based on RFID UHF communicating sensors for the humidity measurement. The system is also based on the GNSS technology to have the precise localization of the sensors. The system is based also on the GIS technology to represent the collected data in a user-friendly manner. As a step forward in the implementation of the proposed system, soil moisture measurements based on existing humidity sensors were performed and their precise position was also measured. The obtained results were visualized with the ArcGIS software, to validate this approach and to demonstrate the potential capabilities of the proposed soil moisture monitoring tool. To thoroughly validate the proposed approach, the implementation of this moisture monitoring tool with existing RFID technology is envisioned.

5. Acknowledgements

This work was supported by a mobility project of the Romanian Ministry of Research, Innovation and Digitization, CNCS-UEFISCDI, project number PN-IV-P2-2.2-MCD-2023-0084, within PNCDI III. The authors wish to thank professors Daniel Bucur and Radu Bozomitu for fruitful discussions.

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