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Design of A Low-Cost Smart Irrigation System using LoRa wireless RF technology

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Abstract

Water is essential for ensuring food security in the world, and agriculture is by far the largest consumer of the earth's available freshwater. Food demand and world's population are expected to increase over the next years. However, climate change will continue to affect water resources and make the problem of food security more complex. Therefore, agriculture must be smarter and agricultural water management must be more efficient and sustainable. This paper presents a low-cost and smart irrigation system based on LoRa technology to better manage irrigation water at field scale. The system essentially consists of a set of nodes distributed on the field for irrigation control and monitoring of soil parameters, a complete weather station for measuring climate data and a remote server for remote decision-making support. The weather station is connected to the internet via a gateway and the measured climatic data are collected and stored regularly on a server, where access to data is provided by a confidential service. The remote server allows the user to select the irrigation mode and method and to store the soil condition variables collected by the wireless sensor network in order to process them for a more optimal management of irrigation. The irrigation system also allows to compute the Penman–Monteith reference evapotranspiration (ET0) on the daily scale, turn on or off the pump remotely, and automatically fill the water tank. Based on our experimental tests, the low investment cost and the high energy autonomy make the proposed irrigation system more suitable for off grid areas with limited water resources.

Keywords: Smart Irrigation, Internet of Things, Wireless Sensor Network, LoRa, LoRaWAN, Irrigation Water Management

Système d'irrigation intelligent à faible coût utilisant la technologie RF sans fil LoRa

Résumé

L'eau est essentielle pour assurer la sécurité alimentaire d'une population mondiale croissante, et l'agriculture est de loin le plus grand consommateur d'eau douce disponible sur terre. La demande en produits alimentaire et la population mondiale augmenteront au cours des années à venir, et le changement climatique continuera à affecter les ressources en eau, déjà limitées, et rendra le problème de la sécurité alimentaire plus complexe. Par conséquent, l'agriculture doit être intelligente et la gestion de l'eau d'irrigation doit être plus raisonnée et plus durable. Cet article présente un système d'irrigation intelligent à faible coût, basé sur la technologie de communication sans fil LoRa, pour la gestion des eaux d'irrigation de manière plus efficace et précise à l'échelle de la parcelle. Le système comprend essentiellement un ensemble de nœuds distribués au niveau de la parcelle pour le pilotage d'irrigation et la surveillance des paramètres du sol, une station météorologique complète pour la mesure des données climatiques en temps réel et un serveur distant pour l'aide à la prise de décisions à distance. La station météorologique est connectée à internet via une passerelle et les données climatiques mesurées sont collectées et stockées régulièrement sur un serveur, dont l'accès aux données est assuré par un service confidentiel. Le serveur distant permet à l'utilisateur de sélectionner le mode et la méthode d'irrigation et de stocker les variables d'état du sol collectées par le réseau de capteurs sans fil afin de les traiter pour une gestion plus optimale de l'irrigation. Le système d'irrigation permet également le calcul de l'évapotranspiration de référence ET0 journalière selon le modèle de Penman-Monteith, la commande à distance pour la mise en marche ou l'arrêt de la pompe et le control automatique du niveau d'eau dans le réservoir. Le faible coût d'investissement et la grande autonomie énergétique du système d'irrigation proposé le rendent plus approprié pour les zones isolées et limitées en ressources d'eau.

Mots clés : Irrigation intelligente, Internet des objets, Réseau de capteurs sans fil, LoRa, LoRaWAN, Gestion de l'eau d'irrigation

تصميم نظام ري ذكي منخفض التكلفة وقائم على تقنية LoRa

حمزة الطاوس، رشيد حضرية، علي الموساتي

ملخص

يعد الماء ضروريا لتوفير الأمن الغذائي لعدد متزايد من سكان العالم، وتعتبر الزراعة وبفارق كبير أكبر مستهلك للمياه العذبة الموجودة على الأرض. من المتوقع أن يزداد عدد سكان العالم وكذلك الطلب على الغذاء خلال السنوات القادمة، وسيستمر التغير المناخي أيضا في تأثيره على مصادر المياه وبذلك يؤدي إلى تفاقم المشكلة وصعوبة حلها. نظرا لكل ما سبق، لا بد أن تتغير الزراعة لتصبح أكثر استدامة وإنتاجية. يقدم هذا المقال نظام ري ذكي منخفض التكلفة ويعتمد على تقنية التواصل اللاسلكي لإدارة عملية الري الزراعي بطريقة أكثر نجاعة ودقة. يتكون هذا النظام أساسا من مجموعة عقد موزعة في الحقل بهدف التحكم في الري ومراقبة متغيرات التربة، محطة رصد جوي كاملة لقياس متغيرات حالة الطقس وخادم بعيد لدعم اتخاذ القرار عن بعد. محطة الرصد الجوي متصلة بالإنترنت عبر بوابة من أجل إرسال كل القياسات إلى خادم معين ومن ثم تخزينها في قاعدة البيانات مع إمكانية التوصل بها عن طريق خدمة سرية. يتيح الخادم البعيد للمستخدم إمكانية تحديد نمط وطريقة الري وكذلك تخزين متغيرات حالة التربة التي تجميعها بواسطة شبكة الاستشعار اللاسلكية بهدف الاعتماد عليها فيما بعد لغرض إدارة الري بشكل أفضل. يعمل نظام الري أيضا على تقدير قيمة التبخر نتح المرجعي اليومي باستعمال نموذج Penman-Monteith، كما يسمح للمستعمل بتشغيل وإيقاف المضخة عن بعد مع ضمان ملء خزان الماء بشكل تلقائي ودائم. تكلفة الاستثمار المنخفضة والاستقلالية الطاقية العالية يجعلان من نظام الري المقترح أكثر ملائمة للمناطق المعزولة وذات الموارد المائية المحدودة، وذلك بناء على الاختبارات التجريبية التي تم إجراؤها.

الكلمات المفتاحية : الري الذكي، إنترنت الأشياء، شبكة الاستشعار اللاسلكية، LoRa، LoRaWAN ، إدارة مياه الري

Introduction

Agriculture is the most water consuming sector, responsible for around 70% of annual consumption in most countries of the world, and up to 95 % in developing countries (Goelnitz and Al-Saidi, 2020). This is why water use in agriculture is at the core of any discussion of water and global food security (Flynn, 2019). Despite the many initiatives taken to raise awareness about the growing risk of water scarcity, many farmers still use traditional irrigation methods or don’t master the use of modern irrigation methods, resulting in low water use efficiency. The demand for food will increase in the coming years, driven by many factors like population growth, urbanization, industrialization, rising per capita incomes and changing lifestyles (Keating et al., 2014). As a result, farmers all over the world are under pressure to produce more and optimize their water use, especially in countries most threatened by water stress in the years to come (Mekonnen and Hoekstra, 2016). The situation is particularly worrying under arid and semi-arid climates, where the negative effect of climate change on water resources (Bates et al., 2008) is exacerbating a highly unfavorable scenario. Therefore, the use of water in agricultural irrigation must meet the challenges of food security and "more crop per drop" (Luquet et al., 2005) needs to be produced. Smart irrigation (SI), which is based on the integration of information and communication technologies for the estimation of crop water requirements, seems to be a promising solution for improving agricultural productivity and the rational management of water resources.

With the development of network information technology (NIT), wireless sensor network (WSN) for irrigation management has been proven useful for water saving. In this regard, a central pivot irrigation system with wireless underground sensor networks (WUSN) (Dong et al., 2013), was previously presented for the autonomous management of irrigation based on the monitoring of real-time soil conditions. The results showed that the wireless communication channel between soil and air is significantly affected by many spatio-temporal aspects, such as the location and burial depth of the sensors, soil texture and physical properties of the soil, soil moisture, and the vegetation canopy height. Also, an automated irrigation system (Gutiérrez et al., 2014) has been designed and implemented to use irrigation water efficiently. In this, sensors have been placed in the root zone of the crops in order to measure the moisture level and temperature of the soil, and a wireless information unit was used to transmit the measured data to the web server via the network public mobile. This work uses an algorithm that has been developed with predefined threshold values of soil temperature and humidity to manage irrigation. Similar work using the WSN has been presented by authors in (Emharraf et al., 2020) for controlled irrigation and monitoring. In addition, Savić and Radonjić (2018), have proposed an architecture for an intelligent irrigation system based on a ZigBee wireless sensor network. The ZigBee technology adopted in this work can only provide a shorter range, while our work uses LoRa which provides a long range, making it more suitable for agricultural use.

The adoption of internet of things (IoT) in agriculture was triggered in order to reduce the need for manual labor and manage irrigation water in a sustainable manner (Tzounis et al., 2017). There are already many initiatives that have developed IoT systems for irrigation management, based on data collected from a variety of connected sensors. Within the framework of the SWAMP project (Kamienski et al., 2018), the global architecture of an IoT-based platform for intelligent irrigation in agriculture, was presented in (Kamienski et al., 2019) with a practical approach based on four pilots across Brazil and Europe. A solution combining IoT and fuzzy logic (FL) for decision support, has been proposed by Munir et al. (2018), for intelligent irrigation in tunnel greenhouses. Similar work has been presented in (Krishnan et al., 2020), with a comparison between IoT based irrigation system, conventional micro irrigation and manual flood irrigation. The results of the comparison proved that there is reduction in power and water consumption when using the proposed system. Irrigation methods using fuzzy logic use parameter thresholds followed to control the irrigation process, and they do not form a simple relationship with the water requirements of the crops.

Today, many platforms exist on the market to sustainably manage irrigation water. However, small and medium scale farming systems are not practically ready for adopting these IoT platforms according to importance of initial cost, operation and maintenance. Furthermore, most of the adult farmers are socio psychologically opposed to introduce such a new technology. In this context, this research work aims to develop a low-cost smart irrigation system based on LoRa wireless communication technology, by combining the technologies of wireless sensor network (WSN) and internet of things (IoT). The paper is organized as follows: the layout of irrigation system, an overview of the technology used, the different modules that compose the system and the irrigation management methods are presented in Section 2. The results of an experimental field test, have been discussed in Section 3. Finally, the paper is concluded in Section 4.

Material and methods

Layout of the proposed smart irrigation system

The proposed smart irrigation system is designed to optimize water use for irrigation and to help the farmer monitor his field in real-time. The system can independently decide when to activate and deactivate solenoid valves to supply water to crops depending on the availability of water in the soil. Also, the user can manage the irrigation of his agricultural field remotely by determining the mode and method of irrigation to adopt. The proposed irrigation system is the combination of a set of hardware and software components, and its overall architecture is shown in Figure 1.

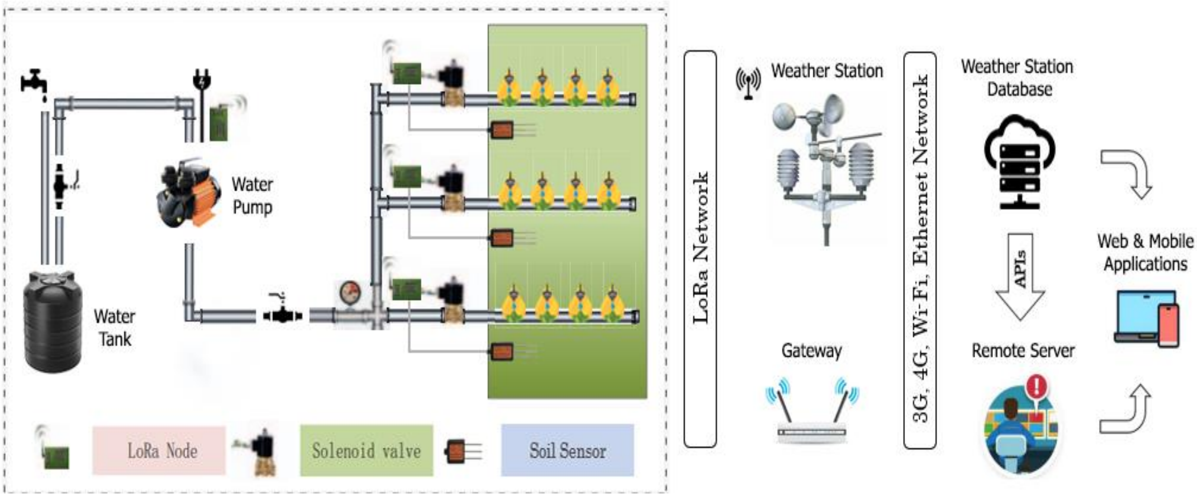


Figure 1. Illustration of the proposed irrigation system architecture.

The wireless sensor network aims to regularly monitor the water status of the soil and control irrigation by maintaining the soil water content at a level sufficient to satisfy crops water requirements. The connected weather station takes readings, at regular intervals, of temperature, relative humidity of the air, wind speed, solar radiation and level of precipitation. Finally, the remote server is dedicated to centralize all the information necessary to support remote decision-making. The irrigation technique chosen is drip irrigation, to provide water to the roots efficiently and avoid wasting a lot of water through deep percolation. The proposed irrigation system uses LoRa wireless communication technology due to its great compatibility with the goals of our research.

LoRa technology overview

The present work uses LoRa wireless communication technology for data transmission and communication management between the different modules of the irrigation system. This technology is widely used in the world of internet of things (IoT). Smart cities, smart homes and buildings, smart industrial control, smart healthcare, smart agriculture are the main application areas of the internet of things in which LoRa technology is used. In addition, and in the face of the exceptional circumstances related to the COVID-19 pandemic which has presented the world with unprecedented challenges in the history of mankind, LoRa technology is playing a key role in the fight against the coronavirus disease by implementing public safety solutions to help with contact tracing, ensure compliance with health regulations in the workplace and meet the needs of healthcare professionals. LoRa is a proprietary, patented radio technology owned by Semtech Corporation for low power wide area network (LPWAN) applications and operates on ISM frequency bands that are not subject to regulations and that can be used freely (free of charge and without authorization). The LoRaWAN communication protocol uses chirp spread spectrum (CSS) modulation which allows on average a communication distance between a gateway and a device of up to 5 km in urban areas and 15 km in rural areas. The target of this protocol is clearly low-cost, low-power and long-range communications, and this combination limits the maximum data rate to 50 kilobits per second (Kbps). Indeed, LoRa technology has revolutionized the internet of things by using very little energy and enabling data communication over a long range. The emergence of LoRa technology has helped fill a technological gap in Wi-Fi / BLE and cellular networks, which require either high power or high bandwidth and have the inability to penetrate shielded indoor environments or have a limited range. Also, the combination of LoRa technology and other expensive technologies, reduces the cost of deploying the IoT system. IoT applications like remote data acquisition, weather monitoring and smart agriculture set a set of different priorities, each have a different set of priorities. The quantities being measured or controlled in these applications such as weather conditions or soil moisture levels, all change very slowly over an extended period of time. Moreover, the nodes are often several kilometers apart and are battery powered. This is why the network protocol used must send small data packets efficiently over long distances while limiting power consumption. LoRa technology is designed to be tailored to these requirements, and that is why it sees itself as an innovative and comfortable solution to help in the digital transformation of agriculture and its change for the better.

System design and implementation

Irrigation equipment

The experimental plot was provided by the Regional Center for Agronomic Research of Oujda, for implementation of the research work. In this plot, we installed all the necessary equipment for irrigation: a water pump with adjustable pressure, a water tank with a float valve at the top to ensure autonomous filling and a network of irrigation pipes (Figure 2). These last are accompanied by in-line drippers, which allows us to distribute the water under low pressure, bringing the water precisely to an immediate vicinity of the crops, and it is enough to cut the pipe each time we want to add a dripper.

Figure 2. Installation of irrigation equipment.

Weather station

Agricultural activities are generally sensitive to climate conditions and most tasks are directly governed by the weather. In the context of irrigation management, the impact of weather on the water needs of crops is crucial. Monitoring weather conditions is therefore an essential element to meet the needs of a crop for intelligent and sustainable management of irrigation water. That's why we installed a complete weather station to monitor the climatic conditions near the experimental site (Figure 3).

Figure 3. Installation site of the weather station.

This weather station has a set of sensors to regularly measure temperature, relative humidity, wind speed, level of precipitation and solar radiation. Also, it has the advantage of visualizing climate data in real-time and from anywhere, via a web or mobile application. In terms of cost, the weather station used is inexpensive and has a built-in battery which ensures the supply of electrical energy and thus achieves a minimum autonomy of 5 years with very little maintenance.

Irrigation nodes and remote control system

The irrigation nodes are distributed in the experimental plot to monitor soil moisture and trigger crop irrigation, depending on the method chosen by the user (Figure 4). Each node basically consists of a development board with an ESP32 microcontroller and an SX1276 LoRa transceiver operating at 868 MHz frequency, a soil sensor to measure soil volumetric water content (VWC), soil temperature, soil electrical conductivity and soil salinity, an RS485-UART converter for ensuring the communication between the microcontroller and the soil sensor, a low consumption bistable solenoid valve controlled just by an electric impulse, two relays, a lithium battery and a breakout board (RTC) to turn the power line on and off periodically while reducing the standby current of the overall system considerably. The parameters acquired by the soil sensor are processed by the microcontroller and transmitted to the remote server via the LoRaWAN network. The threshold values of the volumetric water content are defined in the code uploaded to the microcontroller according to the crops to be irrigated and their resistance to water stress. Additionally, the microcontroller processes control actions taken by the remote server to control irrigation.

Figure 4. Prototype of the irrigation node. equipment.

The remote server is specially dedicated to communicate remotely with the nodes of the irrigation network and provide the user with decision support tools. It mainly includes a computer with an application developed in Python using the Django framework, a gateway (ESP32 board) and a Wi-Fi router (Figure 5). The Python application allows the user to view data in real-time, choose the irrigation methods to adopt and send commands to remotely control the system. The purpose of the gateway is to transmit data and action messages between the server and the nodes of the irrigation system. The Wi-Fi router allows the creation of a local network and the connection to internet. The internet connection is essential to retrieve the daily readings of the weather station in the local database. In addition, an algorithm was developed in Python language for the estimation of the daily reference evapotranspiration rate (ET0), at each midnight based on the daily readings of the weather station. All measurements made or collected from nodes are stored in a MySQL database for future use.

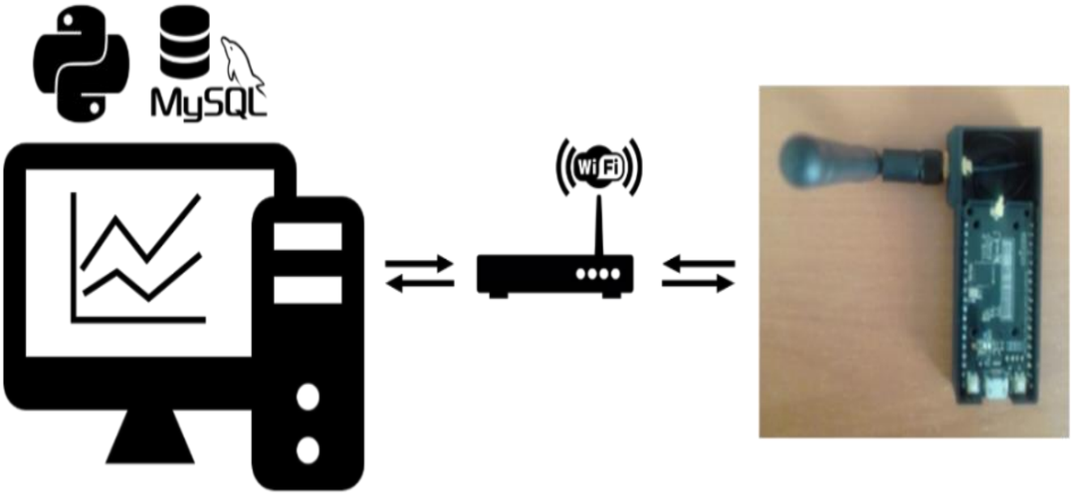


Figure 5. Illustration of the structure of the remote server.

Water pump control

The control of turning on and off the water pump is essential and must be ensured at all times. To this end, a prototype remote control of the pump was designed to control the irrigation water source (Figure 6). This prototype consists of a LoRa32u4 board which is a combination of an ATmega32u4 microcontroller and a LoRa radio frequency module operating at 868 MHz frequency, and a relay to turn on or off power to the pump. Starting and stopping the pump can also be done manually, using a switch provided for this purpose.

Figure 6. Remote control prototype of the water pump.

Irrigation management methods

Method based on soil water reserve

The soil water reserve (SWR) is the amount of water in the soil at any given time. It is generally expressed in millimeters of water, easily comparable to that of precipitation and evapotranspiration. It is a dynamic variable that changes over time, influenced jointly by precipitation and evapotranspiration. However, not all the water in the soil is available for use by plants, either because the roots have not colonized the entire volume of the soil or because the water is strongly retained by the soil to be extracted by the roots. The soil water available to the plant, that which can be extracted through root suction, is called the available water content (AWC) and consists of a readily available water (RAW) which is in practice 1/2 to 2/3 of the available water content. In other words, it is the difference between the moisture at field capacity (MFC) and at wilting point (MWP). The available water content is a state variable which depends on the physicochemical properties of the soil, its particle size, the arrangement of particles and the distribution of porosity. When the force exerted by the soil becomes greater than that of the roots, the wilting point is reached and the roots can no longer absorb water (Figure 7).

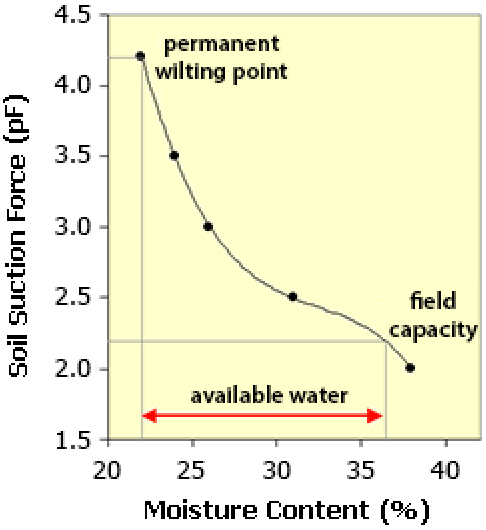


Figure 7. An example of a clay-silt horizon water-retention curve. (https://appgeodb.nancy.inra.fr/biljou/en/fiche/reserve-en-eau-du-sol)

The calculation of the available water content requires an intermediate phase to determine the necessary characteristics of the soil and is done using equation (1):

$$\mathrm{AWC} = (\mathrm{MFC} - \mathrm{MWP}) * \mathrm{AD} * \mathrm{RD} \qquad (1)$$

Where MFC is the moisture at field capacity (%), MWP is the moisture at wilting point (%), AD is the apparent soil density (g/m^3), and RD is the rooting depth (mm).

The available water content can be calculated based on the texture of the soil. Approximately, the average value of the available water content is 0.9 to 1.2 mm/cm of soil for a sand, 1.3 to 1.6 of mm/cm soil for a clay loam, 1.8 to 2 mm/cm of soil for a clay soil, silty clay and sandy clay. Soil samples were taken at different depths (10, 40, 60 and 100 cm) for laboratory analysis, and the results showed that the soil in the experimental plot is silty in texture at all depths considered.

Method based on ET0 estimation

The reference evapotranspiration (ET0) is an essential component of the water balance and its quantification is an important step in irrigation planning. It is defined as the potential amount of water transferred to the atmosphere through direct evaporation from the soil surface and transpiration from a reference well developed and no stressed crop (generally grass or alfalfa). The calculation of the reference evapotranspiration can be performed by several equations/models, but the performance and accuracy of the estimates vary and it all depends on the metrological parameters required for the estimate. The FAO Penman-Monteith reference evapotranspiration (ET0-PM) is the most accurate and recommended model to estimate daily ET0, which can be calculated using equation (2) (Allen et al., 1998):

$$\mathrm{ET0-PM} = \frac{0.408\,\Delta\,(R_n - \mathrm{G}) + \gamma\,\frac{900}{T_{avg} + 273}\,\mathrm{U}_2\,(e_a - e_d)}{\Delta + \gamma\,(1 + 0.34\,\mathrm{U}_2)} \qquad (2)$$

Where Rn is the solar net radiation (MJ/m^2/day), G is the soil heat flux in (MJ/m^2/day), T_{avg} is the average air temperature in (°C), U_2 is the average wind speed measured at 2m height in (m/sec), (e_a-e_d) is the vapour pressure deficit in (kPa), Δ is the slope of the vapour pressure curve (kPa/°C), γ is the psychrometric constant (kPa/°C) which is equal to 0.66. The vapour pressure and the slope of vapour pressure were calculated based following the formulas suggested by (Allen et al. 1998), and G may be ignored for daily time step computation.

The large number of variables and climatic parameters required represents the main limitation of the FAO Penman-Monteith model. In the absence of the requested data for the execution of Penman model, the simple model proposed by Hadria et al. (2021) was integrated in the system to estimate ET0 only from air temperature data. Proposed irrigation system is programmed to calculate ET0-PM automatically and with a daily time step by the data received from the weather station via a confidential service (APIs), and then store it in the MySQL database.

Control of the irrigation system

The remote server allows the user to control the irrigation system remotely as shown in Figure 8. It allows him to choose the irrigation plan to be adopted, to manage the irrigation automatically or manually and to determine the threshold of soil moisture below which irrigation should be started. Moisture thresholds depend on the physical characteristics of the soil and the crop, and can be changed by the user at any time. All the actions corresponding to the decisions taken remotely are carried out by the nodes of the irrigation network. In contrast, all measurements made by the wireless sensor network are sent to the server for monitoring and storage. Also, the battery voltage is measured in real time and sent to the server to find out how much it is charged. The irrigation nodes all have an algorithm that aims to read the soil moisture values, so that they are able to irrigate or not based on the threshold value defined previously. Finally, these nodes can easily switch to irrigation mode based on compensation of daily evapotranspiration losses once they receive the required message from on high.

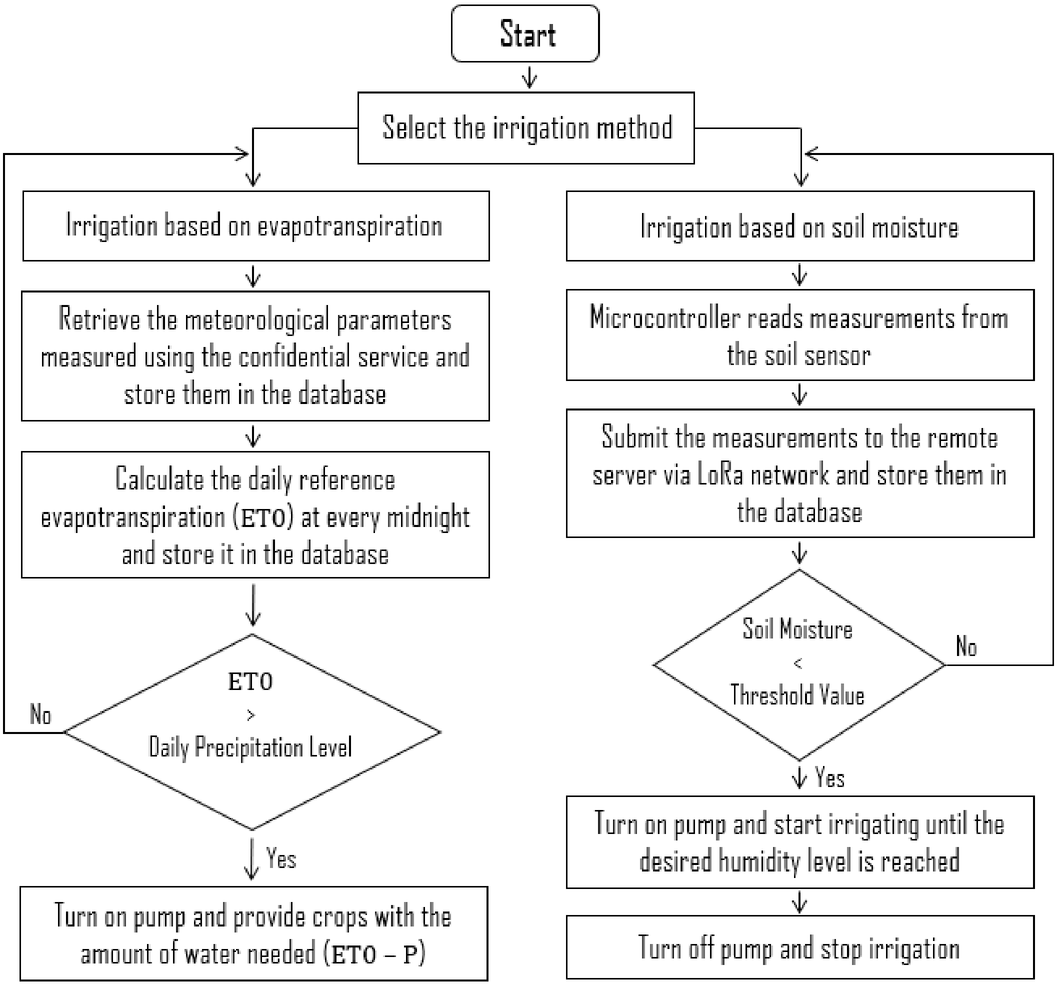
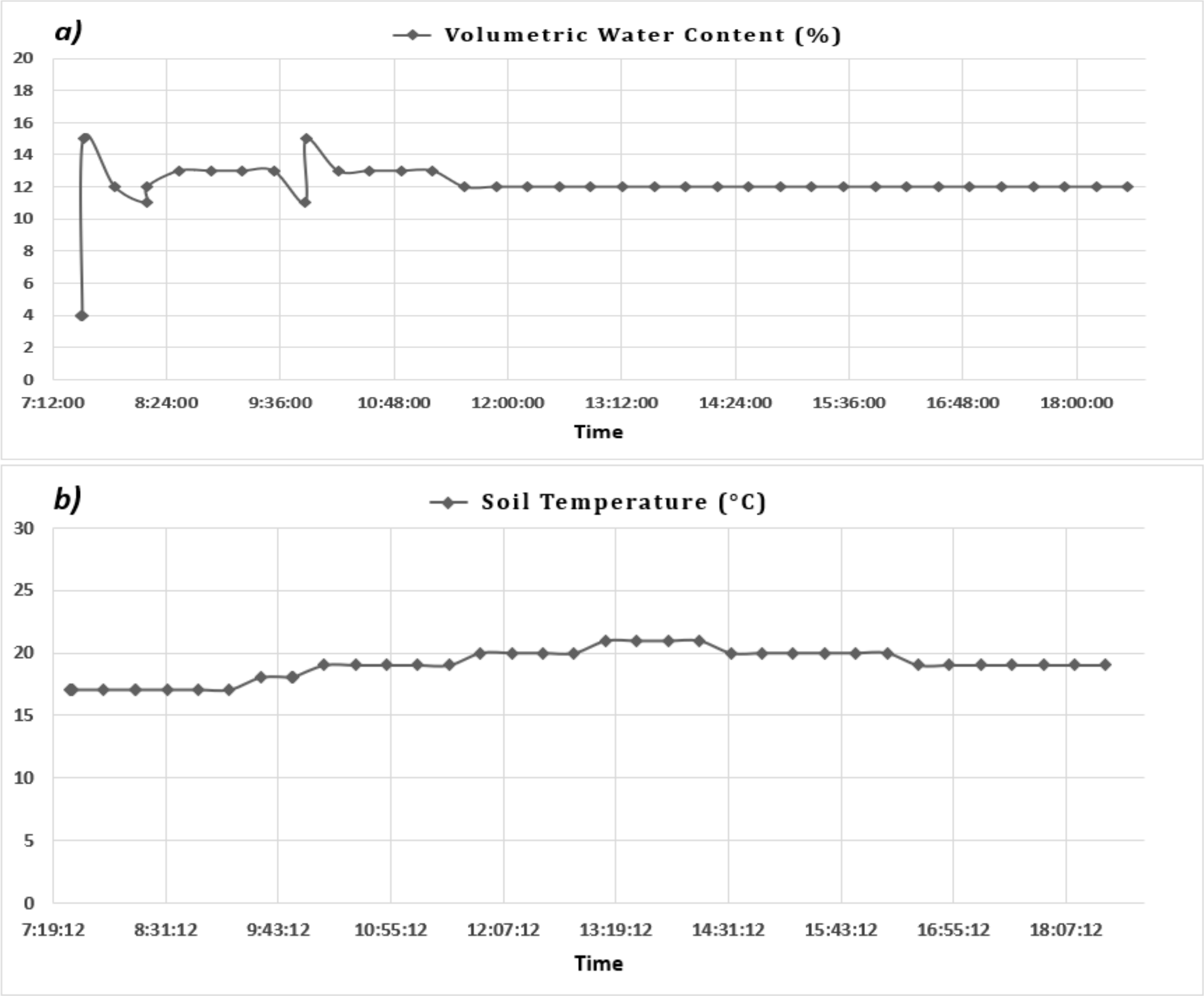


Figure 8. Irrigation control flowchart.

Results and discussions

Experimental tests were carried out with the aim of testing the proposed system and finding out how well it works. The soil sensor was calibrated and the irrigation node prototype was placed at the experimental plot, where the goal was to maintain a volumetric water content equal to or greater than 12% while monitoring all soil parameters. The calibration of the soil sensor used can be done by software for a few types of soil (mineral soil, sandy soil, clay soil and organic soil), which allows factory calibrations to be automatically applied to the sensor output data. If the soil type is not predefined, specific soil calibrations must be performed for more precision in the measurements. The soil sensor was inserted horizontally into undisturbed soil for more accurate results. The sensor can be oriented in any direction and measures the average volumetric water content along its length, so a vertical installation will integrate VWC over a 10cm depth while a horizontal orientation will measure VWC at a more discrete depth. In addition, it should not be installed within 5cm of the soil surface, otherwise the sensing volume can extend out of the soil and reduce accuracy. Because the soil sensor has gaps between its prongs, it is also important to consider the particle size of the medium. It is possible to get sticks, bark, roots or other material stuck between the sensor prongs, which will negatively affect the readings. Also, the sensor should not be installed near large metal objects such as metal poles or stakes, as this can attenuate the sensor's electromagnetic field and adversely affect readings and, furthermore, it should be inserted into dense soil because the prongs can break if excessive sideways force is used when pushing it in. The soil adjacent to the sensor surface has the strongest influence on the sensor reading, and therefore any air space or excessive soil compaction around the sensor and in between the sensor prongs can profoundly influence the readings. For this reason, it is imperative to maximize the contact between the sensor and the soil during the installation, the sensor body needs to be completely covered by soil.

Every 20 minutes, the node should wake up to read data from the soil sensor and measure the battery voltage, and then send all these measurements to the remote server. If the volumetric water content is below the threshold value, irrigation must be provided regularly until a value greater than or equal to that of the predefined humidity level is reached. On each wakeup, the node must also establish a communication via the LoRaWAN network with the remote server, to know if there are new actions to perform. After all of the above are completed, the microcontroller sends a digital signal (rising edge) to a specific pin of the breakout board to cut off power supply and optimize the power consumption of the node for 20 minutes before restoring the power supply again, and so forth. The breakout board consumes only 25nA when the node is off. Through the analysis of the curves of variation of all the parameters collected, we can clearly see that the proposed irrigation system is functioning properly (Figure 8).



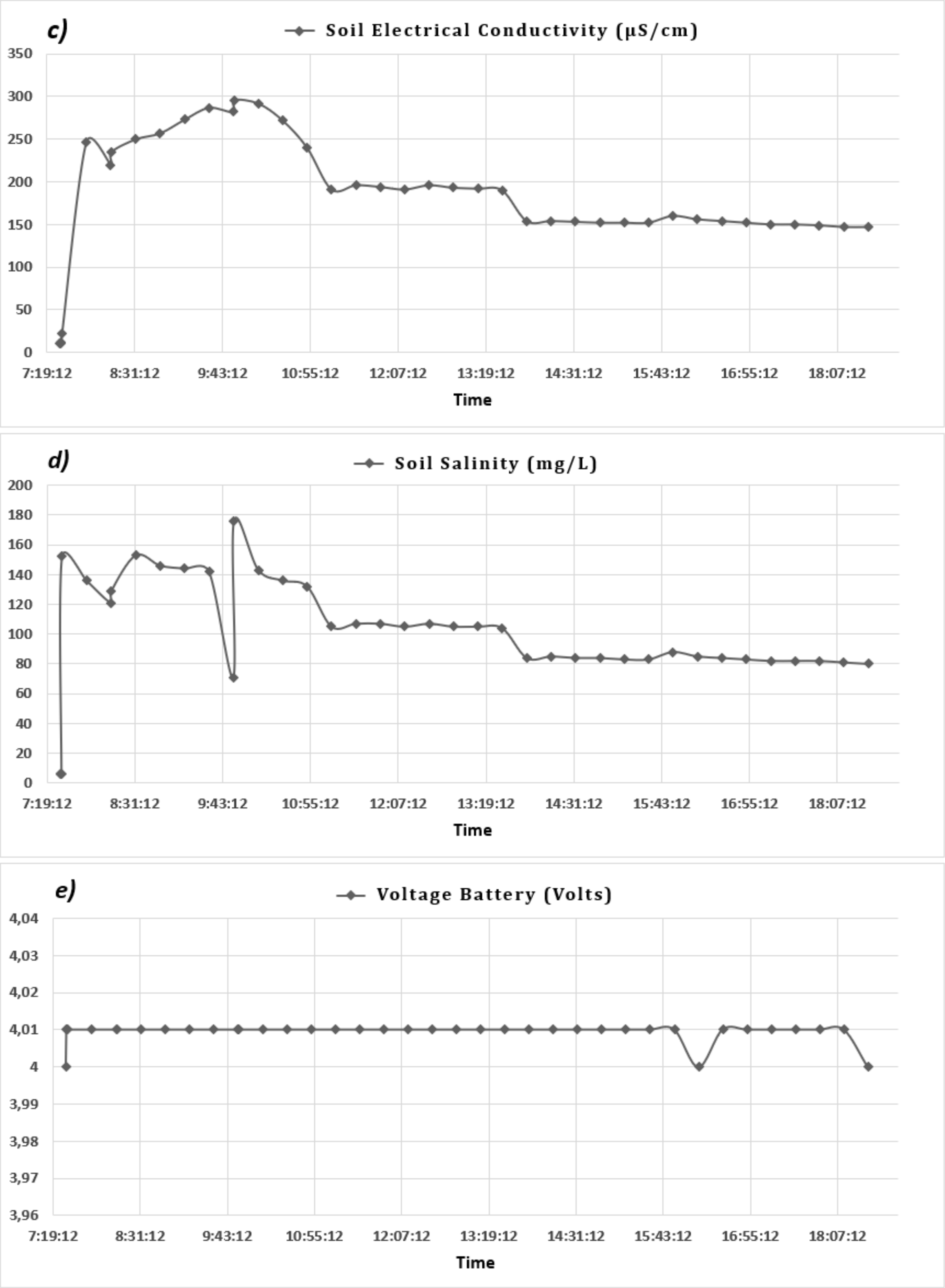


Figure 8. The variation curves of different parameters during the experimental test: (a) Volumetric Water Content, (b) Soil Temperature, (c) Soil Electrical Conductivity, (d) Soil Salinity, (e) Voltage Battery.

The evolution of the volumetric water content shows that the node always provides irrigation when the humidity level is below 12% (Figure 8a). At the beginning, the curve also shows that it is necessary to irrigate 4 times for the water to reach the depth where the soil sensor is located and for the volumetric water content to be above the threshold. The initial fluctuations in the volumetric water content are explained by the flow of water in the soil and the final stabilization at the value of 12% gives proof that there is no runoff due to irrigation at an inconvenient time. Monitoring of the soil temperature indicates that it varies between 17°C and 21°C throughout the period of the experimental test (Figure 8b). This slight variation is mainly linked to the temperature of the irrigation water. On the other hand, there is a significant increase in the soil electrical conductivity after irrigation, followed by a gradual drop (Figure 8c). This increase is clearly linked to the irrigation water, the wetting of the soil leads to an increase in its electrical conductivity. Also, the soil salinity increases considerably after irrigation, and afterwards it drops as does electrical conductivity (Figure 8d). The increase in soil salinity is related to the salt concentration in the water, and its drop after irrigation is caused by the leaching of salt when the water is drained into the soil by gravity. Salinity is one of the main quality parameters for irrigation water. Excessive salinity can alter soil properties, damage plants or reduce crop yields (Asano and Levine, 1998). The method of irrigation also has a direct influence on how salts accumulate in the soil (Malash et al., 2008). The variations in soil salinity and soil electrical conductivity clearly show that these two physical quantities are strongly related (Figure 8c and Figure 8d). Actually, electrical conductivity has been used for several years to determine soil salinity and by several methods (Rhoades, 1990; Rhoades et al., 1990; Malicki and Walczak, 1999). Soils are generally considered saline when the electrical conductivity exceeds 4 dS/m at a temperature of 25°C (Abrol et al., 1988), the electrical conductivity of the soil reaches a maximum value of 0.296 dS/m (Figure 8d), an indicator of the good quality of the water used for irrigation. On the other side, almost no decrease in the battery voltage level is observed, which confirms the very low energy consumption using the breakout board which cuts power to the microcontroller between two uses. Additionally, all the parameters have been collected by the remote server as previously planned and none of them are missed during the entire test period, and this is an important indicator of the reliability of wireless communications established between all the components of the irrigation network. Finally, the system switches to the irrigation method based on evapotranspiration without any technical problems.

Conclusion and perspectives

This study introduces a prototype of a smart irrigation system which aims to better monitor and plan the irrigation of crops in real time, to improve yields and optimize the amount of water used in irrigation. The proposed system uses innovative and efficient technologies, and on the other hand, it is low-cost and economical in terms of energy consumption compared to existing models on the market. The fact that the system is developed by national competences allows us full access and control of the system, a major and advantage for its maintenance and for its improvement in the future.

Based on the experimental test performed, the irrigation system presented in this work has been found to be more viable and can manage irrigation more efficiently. In perspective, the prototype of the new system will be tested on real cases in order to verify its flaws and limits.

Conflicts of interest

The authors declare that they have no competing interests or personal relationships that could have appeared to influence the work reported in this paper.

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Glossary

SI : Smart Irrigation
NIT : Networked Information Technology
WSN : Wireless Sensor Network
WUSN : Wireless Underground Sensor Network
IoT : Internet of Things
SWAMP : Smart Water Management Platform
FL : Fuzzy Logic
LoRa : Long Range
LPWAN : Low Power Wide Area Network
ISM : Industrial, Scientific and Medical
LoRaWAN : Long Range Wide Area Network
CSS : Chirp Spread Spectrum
Wi-Fi : Wireless Fidelity
BLE : Bluetooth Low Energy
VWC : Volumetric Water Content
UART : Universal Asynchronous Receiver Transmitter
RTC : Real-Time Clock
ET0 : Reference Evapotranspiration
SWR : Soil Water Reserve
AWC : Available Water Content
RAW : Readily Available Water
MFC : Moisture at Field Capacity
MWP : Moisture at Wilting Point
FAO : Food and Agriculture Organization
ET0-PM : Reference Evapotranspiration Penman-Monteith
API : Application Programming Interface