WSN Application for Sustainable Water Management in Irrigation Systems

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Abstract—This paper introduces a new way of maintaining a sustainable irrigation system, applied to gardens or agricultural fields, replacing human intervention with Wireless Sensor Networks, in order to achieve a better efficiency in the process that can lead to savings for the final user, not only monetary but also in natural resources, such as water and energy, leading to a more sustainable environment. The system can retrieve real time data and use them to determinate the correct amount of water to be used in the garden in order to keep it healthy. Besides the system architecture, this paper includes a real case scenario implementation and result discussions.

Index Terms—Internet of Things, Wireless Sensor Networks, Sustainability, LoRa, ESP32, Water Savings

I. INTRODUCTION

Internet of Things (IoT) research and implementation has been growing in the last years, focusing in topics such as Transportation, Smart Cities, Retail, Agriculture, Smart Factories, Healthcare, Culture and Tourism [1]. Connecting real world elements and adding intelligence and communications for smart process and autonomous decisions, IoT is enabling different types of beneficial applications and services that can sustain our day-by-day in ways that we never expected before [2]. For this, IoT monitors and automate through the use of sensors and actuators networks and intelligent processing units, that share informations between devices and allows them to work together to improve user experience.

In a world where natural resources, such as water, are starting to vanish and material goods prices, like energy, are in all times highs, the need to create more efficient processes is a must in order to improve sustainability. To achieve this, innovations in a large scale are required and IoT can take a major role. Combining IoT, sustainability and Machine Learning (ML) algorithms is possible to achieve a disruptive innovation capable of saving energy, cutting costs, fewer fuels, waste reduction and time saving.

All around the world, water shortage is becoming a bigger issue and with a big amount of fresh water being used in agriculture or related activities, the need to control the amount of water in those activities is essential. An irrigation system wastes on average 30% of water due to environmental conditions [3] or from the cycles not being optimized for the types of plants.

Using a Wireless Sensor Network (WSN) in the fields, that analyze temperature, humidity and soil moisture, combined with the location, weather forecast and type of plants, the system will be able to automatically and dynamically predict the real amount of water to be applied in order to keep the fields healthy and obtain the best automatized and sustainable (economic, social and environment) decision.

In this paper, a system based on WSN for retrieving real time environmental data in order to optimize irrigation timings is explained. The test case, followed by its experimental results and comparison with a traditional irrigation system, are also represented. Finally, the main conclusions and future work are also presented.

II. RELATED WORK

The literature shows a variety of projects [4]–[7] implementing IoT systems for irrigation control, using single nodes with Arduinos, combined with a set of environmental data sensors, using large amounts of wire to spread them across the fields, in which data is used to increase the garden or agricultural fields efficiency, including user comfort and water savings. Also, some full WSN projects were found, such as Maksudjon Usmonov, who developed a low-cost WSN based on LoRa [8], capable of controlling an existing drip irrigation system with the aim of improving it in order to automate it by totally or partially eliminating human interaction, or Dr. M. N. Rajkumar et al. who develop a smart irrigation system [9] that automatically turn on or off the valves based on soil moisture sensor data. Our proposal stands out from the others by the use of algorithms capable of analyzing the environmental data and understand the correct amount of water needed for the field, instead of watering only when moisture is low. Also a more reliable WSN, based on modular nodes using LoRa, allows the ability to perform in any conditions or specifications without the need of wires, spreading multiple sensor nodes within the environment.

III. SYSTEM ARCHITECTURE

The system architecture consists on a WSN composed by a set of nodes with different features. The network is controlled by a single gateway, the broker, that is in constant communication with an online server, using Message Queuing...
Telemetry Transport (MQTT), a messaging protocol suitable for small, low-power, low-bandwidth devices [10], via a WiFi connection, making it responsible for exchanging the messages between the server and the multiple nodes in the network, that communicate with the broker using a LoRa peer-to-peer connection.

The chosen communication standard to connect the WSN was LoRa, since it is a long range low power wireless technology that uses unlicensed radio spectrum [11] and aims to eliminate repeaters, reduce device cost, increase battery lifetime on devices, improve network capacity and support a large number of devices. All these features, when compared to other major communication protocols in IoT systems [12]–[16], as can be seen in Table I, make LoRa the ideal solution to connect our WSN.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Wi-Fi</th>
<th>Bluetooth</th>
<th>ZigBee</th>
<th>LoRa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate [kbps]</td>
<td>11 x 10^3</td>
<td>1 x 10^3</td>
<td>250</td>
<td>110</td>
</tr>
<tr>
<td>Frequency [GHz]</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>0.868</td>
</tr>
<tr>
<td>Range [m]</td>
<td>1-100</td>
<td>10-100</td>
<td>10-100</td>
<td>2000</td>
</tr>
<tr>
<td>Nodes/Master</td>
<td>32</td>
<td>7</td>
<td>65540</td>
<td>15000</td>
</tr>
<tr>
<td>Power Consumption [mA]</td>
<td>100-350</td>
<td>1-35</td>
<td>1-10</td>
<td>1-10</td>
</tr>
<tr>
<td>Security</td>
<td>WPA/WPA2</td>
<td>128 bit</td>
<td>128 bit</td>
<td>128 bit</td>
</tr>
</tbody>
</table>

In order to gather information from the environment the network is complemented with sensor nodes. A high level view of the system architecture can be seen in Figure 1.

Each node is composed by two main elements, an ESP32 chip, a dual core 32bit ultra-low-power consumption microcontroller with built-in WiFi and BLE and 34 programmable GPIOs, including 18 12-bit Analogic Digital Converters (ADCs) for Analog Sensors [17], and a RFM95W, a transceiver LoRa radio module capable of creating multi-point network, with individual node addresses and encryption, in a range of approx 2000 meters [18]. Despite of the same hardware, each node has different characteristics. The broker makes use of the on-chip WiFi connection, while the sensor node has this feature turn-off as well as uses the deep-sleep functionality in order to be a low-power device, allowing it to run on batteries. Also an array of sensors are attached to the sensor node, composed by:

- DHT22, a low cost temperature and humidity sensor that allow temperature readings between -40 to +80 degrees Celsius and humidity between 0 to 100%, with a precision of 0.5°C and 2-5% for temperature and humidity respectively [19];
- Soil moisture sensor, a simple breakout, composed by two pads that work like probes, that uses the conductivity between them for measuring the moisture in soil and similar materials [20].

The proposed system is capable of sustain up to 250 nodes without compromising the system efficiency. Creating a bigger network does not involve extra work for the users, since the nodes are configured automatically inside the network when booting for the first time.

In terms of security, all the messages are encrypted using a private key. This includes the radio messages, as well as the MQTT messages. Also each user has a private MQTT topic, that only we can listen to, so no other user can receive or send those messages.

IV. Results and Discussions

In order to test the proposed solution, there was a need to choose a garden with a conventional irrigation system already implemented. A small garden in AUDAX-ISCTE - Entrepreneurship & Innovation Centre of ISCTE - Instituto Universitario de Lisboa, was chosen due to known irrigation characteristics as well as the possibility to keep track of the system implementation. The garden, as seen in Figure 2, has 3 irrigation zones so, to achieve the proposed goal, a network of 3 sensor nodes, each one in a irrigation zone, plus a broker were included in the garden.

The proposed scenario does not replace the conventional irrigation system, being the goal only to retrieve environmental data in order to comprehend the efficiency of the current system and how, with this data, will be possible to improve it.

Therefore each sensor node was running for a week, retrieving air temperature and relative humidity and soil moisture every 10 minutes and sending the data to the servers via the broker. The first thing in order to prove our system is reliable was to guarantee that the sensor data is correct. For this, the retrieved data was compared with daily data from the national Portuguese weather institute - IPMA - that through their API [21] provide hourly temperature and the higher and lowest values for relative humidity for each day in the garden location.
Figure 3 shows that the retrieved temperature information from the sensor network follows the online temperature for that region, with some variations.

To further evaluate the reliability of the sensor information, the margin of error between the obtained sensor data and the IPMA API data for the hourly temperature, maximum and minimum day temperature and relative humidity were calculated, as can be seen in Table II.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Error margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Temp [°C]</td>
<td>± 0.77</td>
</tr>
<tr>
<td>Max Temp [°C]</td>
<td>± 0.57</td>
</tr>
<tr>
<td>Min Temp [°C]</td>
<td>± 1.14</td>
</tr>
<tr>
<td>Max Hum [%]</td>
<td>± 6.85</td>
</tr>
<tr>
<td>Min Hum [%]</td>
<td>± 1</td>
</tr>
</tbody>
</table>

Regarding the temperature parameters is possible to see an average margin of error of about 0.82°C and for humidity of about 4%. This is justified by the sensor precision, as described before, of 0.5°C and 2-5% for temperature and humidity respectively.

Knowing that the retrieved data is reliable is now possible to understand if the current system is efficient. For this, the air relative humidity, soil moisture, rain and irrigation times were compared, as can be seen in Figure 4.

The first thing to notice is that some irrigation times occur during rain moments or in situations were the soil moisture was above 65%. These situations are the main responsible for the waste of water in irrigation systems. It is also possible to retain that when the air humidity is higher the soil humidity decreases more slowly.

These results shows that the real time information obtained from the environment can help improve the efficiency of the irrigation system. To calculate the ideal amount of water is necessary to take into consideration the type of plants, the evapotranspiration, garden area, type of valves and tubing, distance between valves and the number of irrigation’s per day. All of these parameters go along as displayed in Equation 1

\[
T = \frac{A \times [7.2 \times A \times (ET \times 0.001)] \times 60}{V \times N \times 1000} / P
\]

where T is the irrigation time, V is the volume of water per valve, N the number of valves, P is the number of irrigation periods, A is the garden area, given by Equation 2

\[
A = [(0.5 \times N) - 1] \times D^2
\]

and ET is the evapotranspiration, given by Equation 3

\[
ET = 0.0023 \times (T_{med} + 17.78)R_0 \times (T_{max} - T_{min}) \times 0.5
\]

where \(T_{med}\) is the average temperature, \(T_{max}\) is the maximum temperature, \(T_{min}\) is the minimum temperature and \(R_0\) is the incident solar radiation which, based on latitude and time of the year, for Lisbon is about 17.5 mm/day. These temperature values can be the maximum and minimum retrieved from IPMA for that day or those values adapted from the retrieved sensor data, changing the values if any higher or lower values exists.

To have a more efficient system and use as much sensor data as possible, the irrigation times formula (Equation 1), was adapted to take in consideration the last air humidity and soil moisture values. With this is possible to obtain a more reliable irrigation time, taking into consideration all the environmental data.

Table III shows the irrigation times for each of the following scenarios: a) Irrigation without controller, the one already applied to the garden; b) Irrigation system controlled by our solution while using Equation 1 to calculate the irrigation times; c) Irrigation system controlled by our solution while using the optimized Equation 1 to calculate the irrigation times. Both solutions b) and c) are prediction based on the sensor values retrieved from the environment.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Irrigation Time [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>10</td>
</tr>
<tr>
<td>b)</td>
<td>8.20</td>
</tr>
<tr>
<td>c)</td>
<td>7.49</td>
</tr>
</tbody>
</table>

Is possible to verify that by applying a solution based on the sensor data retrieved from the environment the amount of time...
the valves are open are reduced meaning that he amount of water used will be lower while maintaining the garden healthy.

Considering the Equation 4 the amount of water used by the system can be calculated based on the time the irrigation system is turned on, allowing to compare the consumption’s of the normal irrigation system and a system based on our solution.

\[ C = \frac{(V \times N \times 1000) \times T}{60} \]  

(4)

Table IV shows the amount of water used in the scenarios described above.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Water used [L/h]</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>1890</td>
<td>-</td>
</tr>
<tr>
<td>b)</td>
<td>1550</td>
<td>17.9%</td>
</tr>
<tr>
<td>c)</td>
<td>1415</td>
<td>25.1%</td>
</tr>
</tbody>
</table>

Using only temperature data is possible to achieve a 18% improvement in the water used in the system whereas when the humidity is taken into consideration a 25% improvement is achievable.

Watering at exactly the same times, but with the ideal amount of water, we get identical results in terms of soil moisture and garden health, but with a much lower water consumption.

V. CONCLUSIONS AND FUTURE WORK

In this article, a system based on WSN for retrieving real time environmental data in order to optimize irrigation timings as well as the results from a real case implementation, were presented.

It is possible to conclude that the retrieved data was reliable and capable of being introduced in an intelligent and efficient algorithm in order to predict a more accurate irrigation timing. Also possible to understand that by keeping track of environmental status, such as rain or high humidity values, it is possible to detect if it is really necessary to irrigate.

The real case scenario results show that a reduction of 25% can be achieved with the application of a WSN in an already existing environment. Although the theoretical value is 30%, this can be achieved and even improved with some modifications to the irrigation system, namely the valves and tubing used as well as the application layout.

By combining the sensor data gathered by the WSN with AI algorithms it is possible to configure, in real time, the WSN to adapt to new conditions or specifications, but also achieve a better efficiency in the process leading to savings for the final user, not only monetary but also in natural resources, such as water and energy, leading to a more sustainable environment.

In order to further test the system, in the future we will implement the system in a larger garden, with at least 20 irrigation zones. Also an application for agriculture, where a big amount of crops exists, each with different water needs, that affect the irrigation times.

REFERENCES