Universitatea Politehnica din Timișoara

PIIRRIGATE: A SMART IRRIGATION SYSTEM

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REZUMAT

Această lucrare descrie proiectarea și realizarea sistemului “PiIrrigate”. Acest sistem are ca scop eficientizarea consumului de apă si optimizarea culturilor agricole sau a grădinilor, prin utilizarea tehnologiilor moderne IoT și a comunicațiilor radio de tip LoRa. Pe măsură ce efectele încălzirii globale se fac din ce în ce mai resimțite, automatizarea si monitorizarea irigațiilor devine o necesitate. Proiectul vizează dezvoltarea unui sistem de monitorizare si control destinat fermierilor care doresc monitorizarea unor suprafețe mari de teren, dar acest sistem poate fi folosit si pentru sere inteligente sau grădinărit normal.

Proiectul utilizează o arhitectură bazată pe microcontrolere Raspberry Pi și T-Beam LILYGO ESP32 LoRa. Aceste componente sunt folosite pentru colectarea si transmiterea datelor in timp real. Sistemul permite monitorizarea parametrilor esențiali (umiditate, temperatură, umiditatea solului și cantitatea de ploaie) prin senzori care sunt conectați la nodurile ESP32. Dupa colectare, datele urmează a fi transmise către un gateway care comunică apoi cu un API web dezvoltat in .NET. Apoi datele urmează a fi stocate într-o baza de date PostgreSQL și trimise folosind SignalR către o aplicație web pentru a fi vizualizate în timp real de către utilizatori.

Utilizatorii au la dispoziție o interfață web care le permite atât vizualizarea datelor în timp real cât și vizualizarea datelor istorice și controlul manual al sistemului. De asemenea, acest sistem implementează un mecanism de înregistrare dinamica a nodurilor în rețea, lucru care permite extinderea facilă a sistemului.

Prin integrarea componentelor hardware și software într-o soluție coerentă, PiIrrigate demonstrează fezabilitatea și eficiența unui sistem IoT dedicat agriculturii inteligente, cu un impact potențial in reducerea consumului de apă și creșterea randamentului agricol.

ABSTRACT

This paper describes the design and implementation of the “PiIrrigate” system. The purpose of this system is to optimize water consumption and improve the management of agricultural crops or gardens by using modern IoT technologies and LoRa radio communications. As the effects of global warming become increasingly evident, the automation and monitoring of irrigation systems is becoming a necessity. The project aims to develop a monitoring and control system intended for farmers who need to oversee large areas of land, but it can also be used for smart greenhouses or regular gardening.

The project uses an architecture based on Raspberry Pi microcontrollers and T-Beam LILYGO ESP32 LoRa modules. These components are used for the real-time collection and transmission of data. The system enables the monitoring of essential parameters (humidity, temperature, soil moisture, and rainfall) through sensors connected to ESP32 nodes. After collection, the data is transmitted to a gateway, which then communicates with a web API developed in .NET. The data is stored in a PostgreSQL database and sent in real time via SignalR to a web application, where it can be viewed by users. Users have access to a web interface that allows them to visualize both real-time and historical data, as well as to manually control the system. Additionally, the system implements a dynamic node registration mechanism, enabling easy expansion of the network. By integrating both hardware and software components into a coherent solution, PiIrrigate demonstrates the feasibility and efficiency of an IoT-based system dedicated to smart agriculture, with the potential to reduce water consumption and increase agricultural productivity.

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1. INTRODUCTION

1.1 CONTEXT

Agriculture is a vital sector that plays a crucial role in sustaining human life and the economy. Agriculture automation and optimization has become a major concern in recent years. As the global population continues to grow, the demand for food is increasing and the developing need for food along with the effect of climate changes are forcing the agricultural industry to adapt and innovate[1].

In the last 35 years, the wold has seen a doubling of the agricultural production. This has been achieved throught the use of different fertilizers, pesticides and herbicides. This doubling was associated with a 6.87-fold increase in nitrogen fertilization, a 3.48-fold increase in phosphorus fertilization and 1.68-fold increase in the amount of irrigated cropland [2]. In addition, the water consumoption is expected to increase by 50% by 2050 [3].

This project aims to address the challenges of water scarcity and the need of efficient irrigation systems by presenting the plan, the implementation, the results and future work of a system that can be used in different scenarios and is meant to help reducing the water consumption and increasing the agricultural productivity. The PiIrrigate project intends achuive this by developing an innovative irrigation system that leverages the power of IoT and LoRa radio communication technologies. The main focus of this project is to create a system that can be easly used in different agricultural settings, starting from small gardens to large farms and even smart greenhouses. Beside this, I wanted to create a system that is easy to use and can be extended with ease.

The ESP32 boards with sensors are responsible for colecting the data. Then data is sent using LoRa to another ESP32 board that acts as a gateway connected to a Raspberry Pi, which is responsible for sending the data to a web API. The web API is developed in .NET and is responsible for storing the data in a PostgreSQL database. The data is then sent to a web application using SignalR, which allows real-time communication between the server and the client. The web application is responsible for displaying the live data and the historical data and also for providing a way to control the system manually and to add new nodes to the system.

This system takes advantage of the LoRa radio communication technology, which allows for long-range communication with low power consumption. Meaning that the system can be used in remote areas and it will work even if the internet connection is not available to all the nodes. The Raspberry Pi is the only component of this system that needs to be connected to the internet. Other components can be scatered on a area of 10km or more, depending on the environment and the node setup (mesh or star topology).

1.2 MOTIVATION

The reason why I choose to create such a system was fulled by my passion for technology and smart agriculture. Besides this, I like to observe the data path, from the moment it is collected by the sensors, to the moment it is displayed in a web application. I have always been intested in pieces of technology that can be used to solve real world problems and now I had the chance to create such a system.

Initially, I wanted to create a system for my own lawn, but as I started working on the project, I realized that the system can be used in many other scenarios, such as smart greenhouses or even large farms or vineyards.

2. STATE OF THE ART

2.1 INTRODUCTION

The state of the art chapter provides an overview of the current state of smart irrigation systems and their applications in agriculture. This chapter will explore the existing technologies, methods, and solutions used in smart irrigation. It will also highlight the gaps and challenges in the current systems, and how the PiIrrigate project aims to address these issues.

2.2 EXISTING SMART IRRIGATION SOLUTIONS

2.2.1 TYPES OF SMART IRRIGATION SYSTEMS

There are several types of smart irrigation systems used in modern agriculture:

- **Weather-Based Controllers**
  These systems use weather data to adjust irrigation schedules based on evapotranspiration rates, ensuring that plants receive the right amount of water.
- **Soil Moisture-Based Controllers**
  These systems rely on data from soil moisture sensors placed in the root zone of the plants. Irrigation cycles are triggered when the soil moisture drops below a predetermined threshold, ensuring plants receive water only when necessary. This method is very precise for specific zones [4].
- **Hybrid Systems**
  Many modern systems utilize a hybrid approach, combining data from both weather feeds and soil moisture sensors for more accurate and resilient irrigation decisions. Some research also explores "hybrid" in terms of integrating different energy sources (e.g., solar and wind) to power the systems or combining various irrigation methods (like drip and sprinkler) under one smart control [5].

3. BODY

3.1 FIGURES AND PHOTOGRAPHS

Figures (including images, graphs and screenshots) are numbered in order of their appearance in the paper. Alternatively, figures may be numbered in order in each chapter, including the chapter number. Each figure has a number and a title, which is mentioned under the figure, centered. Where applicable, the source of the figure shall be indicated in brackets after the title of the figure;

All figures and photographs inserted in the paper must be referenced in the text, numbered and titled.

There will be a blank line (Nimbus Sans 12 pt) between the figure and the text. Figures will be centered.

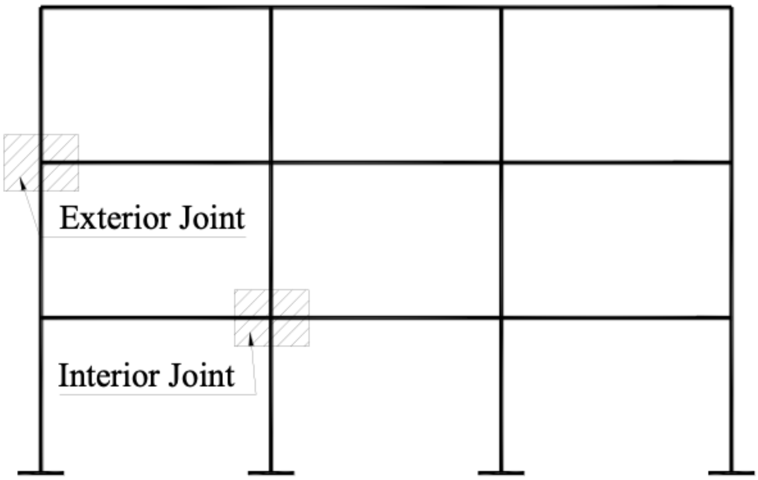

Figure 3.1: Example of a figure (source: The Scientific Bulletin of the UPT – series Building Engineering – Architecture, issue 2/2010)

A reference to a figure can be created: Figure 3.1.

3.2 TABLES

Tables will be numbered in the order in which they appear in the paper. Alternatively, tables can be numbered in order in each chapter, including the chapter number in the numbering. Each table has a number and a title, which is mentioned above the table, in a centered alignment. Where applicable, the data source shall be indicated in brackets after the title of the table.

All tables presented in the paper must be referenced in the text of the paper, must be numbered and accompanied by a title (see example below). If copied figures are used, the source of the photo will be indicated in parenthesis. As far as possible, the usual font (Nimbus Sans 12 pt) will be kept in the table, but there are also accepted ways to highlight important results (Bold, Italics, etc.)

A blank line (Nimbus Sans 12 pt) will be left between the text and the table. Tables will be centered.

Table 3.1: Example of a table

	Yield stress, fy [N/mm2]		Tensile strength, fu [N/mm2]	
Element	Mill certificate	Coupon tests	Mill certificate	Coupon tests
Beam IPE360	285.0	329.8 flange 348.4 web	427.0	463.2 flange 464.0 web
Column HEB300	311.3	313.0 flange 341.8 web	446.0	449.8 flange 464.4 web
End plate	281.0	248.3	424.7	416.0
Cover plate	296.0	273.2	443.0	436.7

A reference to a table can be created: Table 3.1. To create a table, one can use `https://www.tablesgenerator.com/latex_tables`.

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$$A = \pi r^2 \tag{3.1}$$

A reference to an equation can be created: (3.1).

3.4 CODE

```
1 public class Client {
2     public static void main(String[] args) {
3         Animal tiger = new Tiger();
4         Animal parrot = new Parrot();
5         tiger.breed(parrot);
6     }
7 }
```

Snippet 3.1: Subtype polymorphism example Snippet 3.1

Flexibility introduced by polymorphism can be seen in Snippet 3.1, lines *(3)*, *(4)*. Variables, `tiger` and `parrot`, being of type `Animal`, can refer to `Tiger`, or `Parrot` objects. Still, this flexibility becomes a problem when dealing with call such as that in line *(5)*, since „breeding" makes sense only between objects having the same type.

```java
public class Client {
        public static void main(String[] args) {
                Animal tiger = new Tiger();
                Animal parrot = new Parrot();
                tiger.breed(parrot);
        }
}
```

Snippet 3.2: Subtype polymorphism example Snippet 3.1

4. CONCLUSIONS

```java
public class Client {
        public static void main(String[] args) {
                Animal tiger = new Tiger();
                Animal parrot = new Parrot();
                tiger.breed(parrot);
        }
}
```

Snippet 4.1: Subtype polymorphism example
Snippet 3.2

The paper will end with a chapter of conclusions. It will contain the main results of the work and their practical implications. In the case of diploma projects, the main synthetic data obtained from the design process will be mentioned.

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At the end of the paper will be given a list of references for the scientific texts consulted during the work. All sources will be listed, including those on the internet. These will be referenced in the text and listed in alphabetical order, as in the examples below.

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b. The title of the article, the patent, the conference paper, etc., in quotation marks.
c. The title of the magazine or book in italics. How the reference is written depends on the type of publication, please follow the instructions at the link above carefully.

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Each reference number must be enclosed in square brackets on the same line as the text, before any punctuation mark, with a space before the parentheses.

Examples:

a. ". . .the end of my research [13]."

b. "The theory was first introduced in 1987 [1]."

The list of references in the bibliography is composed of all the sources used to document the paper and is made in the numerical order of the citation in the text and not in alphabetical order of the authors.

The identical insertion of a sentence or paragraph shall be made by including the page from the source used, but also by quotation marks and the use of Italics; for sources taken from the Internet, the page addresses shall be included; in the final bibliographic list the works shall be entered in the alphabetical order of the authors' names. For collective works, the rule of alphabetical order applies to the first author.

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The bibliographical sources the author of which cannot be mentioned should be specified as "***" followed by the name of the article and/or book, the publishing house and the place of appearance (for books), the volume, the issue, the first and last page of the quoted work, and the year of appearance.

*** https://ro.wikipedia.org/wiki/Motor accessed February 2022

Example: Einstein **einstein**, mentioning “The intuitive mind is a sacred gift.”

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5. BIBLIOGRAPHY

[1] K. Obaideen et al., "An overview of smart irrigation systems using iot," *Energy Nexus*, vol. 7, p. 100 124, 2022, ISSN: 2772-4271. DOI: `https://doi.org/10.1016/j.nexus.2022.100124`. [Online]. Available: `https://www.sciencedirect.com/science/article/pii/S2772427122000791`.

[2] D. Tilman, "Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices," *Proceedings of the National Academy of Sciences*, vol. 96, no. 11, pp. 5995–6000, 1999. DOI: `10.1073/pnas.96.11.5995`. eprint: `https://www.pnas.org/doi/pdf/10.1073/pnas.96.11.5995`. [Online]. Available: `https://www.pnas.org/doi/abs/10.1073/pnas.96.11.5995`.

[3] I. Froiz-Míguez et al., "Design, implementation, and empirical validation of an iot smart irrigation system for fog computing applications based on lora and lorawan sensor nodes," *Sensors*, vol. 20, no. 23, 2020, ISSN: 1424-8220. DOI: `10.3390/s20236865`. [Online]. Available: `https://www.mdpi.com/1424-8220/20/23/6865`.

[4] J. Q. M. Malarie Gotcher Saleh Taghvaeian, "Smart irrigation technology: Controllers and sensors," [Online]. Available: `https://extension.okstate.edu/fact-sheets/smart-irrigation-technology-controllers-and-sensors.html`.

[5] U. S. E. P. Agency, "Soil moisture-based irrigation controllers," [Online]. Available: `https://www.epa.gov/watersense/soil-moisture-based-irrigation-controllers`.

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