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Remote Embedded System for Agricultural Field Monitoring: Enhancing Resource Allocation in Agriculture †

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Abstract: This research addresses the need to enhance agricultural management due to rapid population growth in the 20th and 21st centuries. It focuses on integrating sensors and embedded systems to collect data on soil and air conditions, including temperature, humidity, and solar radiation. This information is obtained using ESP32 microcontrollers and stored in a centralised database. The system uses JavaScript and the Leaflet library's Interpolation algorithm to create interactive maps, allowing farmers in the northern region of Paraná, Brazil, to monitor their fields and activate irrigation according to predefined routines. This innovative system offers a data-driven approach to agriculture and automated irrigation, benefiting family farmers.

Keywords: relational database; JavaScript; interpolation; embedded systems; crop cultivation; family farmers

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1. Introduction

Since the late 20th century, the agricultural industry has embraced technological advancements catalyzed by the internet revolution to bolster productivity, sustainability, and resource allocation. Notably, the utilization of remote embedded systems with network connectivity has emerged as a dependable instrument, catalyzing the transformation of agricultural field monitoring. In line with the global population projections of 2019, it is anticipated that the world's population will increase by approximately 26% by 2050. With this impending demographic milestone, it is projected that farmers will face the unprecedented challenge of meeting the world's growing food demand, surpassing all historical production records [1]. This surge in demand necessitates a strategic enhancement of resource allocation. The incorporation of monitoring tools stands as a promising avenue to identify the precise locations, methods, and extent of resource deployment.

Arable land, being a fragile and limited resource, requires careful management to maximise its potential for increased production without the need for expansion. This goal can be a ained through the judicious management of various components within the agricultural environment, including fertilizers, water, and pesticides. Despite notable technological advancements, the average water usage in fields has shown minimal change over the past five decades, resulting in water surplus in specific areas of the plantation while causing shortages in others [2].

This study seeks to design a computerized precision agriculture system employing a microcontroller system with network connectivity. The system will measure key variables, including air temperature, air humidity, and soil moisture, at multiple locations within an agricultural field and transmit this data to a central server. The data will be interpolated to create maps depicting the agricultural environment's status in relation to the variables under analysis. This system aims to provide an automated irrigation tool.

Then, the primary objective of this study is to develop a computerized precision agriculture system capable of employing a network-accessible microcontrolled system to collect measurements of vital variables, such as air temperature, air humidity, and soil moisture at various locations within an agricultural field. These measurements are then transmi ed to a server, and the data is subjected to interpolation techniques to create maps of the agricultural environment, illustrating its condition concerning the analysed variables, both current and historical.

This research is divided into the following structure: (i) Materials and Methods, where it is shown The Theoretical Framework and its selected programming languages for the project, the microcontrollers, and sensors used for measurements, and also introduces the core concepts of network architecture chosen for the project; (ii) Results and Discussion presents the prototype developed in the research; (iv) Conclusions addresses the final reflections, challenges faced, and suggestions for improvements.

2. Materials and Methods

Structured Query Language (SQL) was chosen for the creation of the database due to its versatility, user-friendliness, and ability to handle extensive sets of structured data. MySQL was employed as the Database Management System (DBMS). A DBMS is a suite of software tools that enables the database to be queried and modified through the use of its proprietary communication sockets [3].

In creating the visual part of the website that delivers information to the user, HyperText Markup Language (HTML) was employed to define the elements, and Cascading Style Sheets (CSS) were used for styling and positioning these elements on the page. Additionally, the Bootstrap framework was utilised for interface design. Bootstrap is a robust and extensible frontend toolkit, constructed and customised with Sass, allowing for the use of a pre-programmed grid system [4].

The web service responsible for receiving data and executing operations on the database utilized Hypertext Preprocessor (PHP). PHP, a high-level language, is particularly well-suited for the creation of dynamic web pages. It offers an array of tools for facilitating user interaction through forms, URL parameters, and links. What sets PHP apart from languages like JavaScript and CSS is its server-side execution, delivering pre-processed, pure HTML. This architectural choice enables interactions with databases and server applications without exposing the primary source code of the system, thereby ensuring data security [5]. In the generation of interpolated temperature and humidity maps, the Leaflet library was employed. Leaflet is an open-source tool for rendering interactive maps [6].

The chosen microcontroller was the ESP32 by the manufacturer Espressif. This embedded board comes with built-in Wi-Fi and Bluetooth connectivity, a low-power processor, and provides a robust and highly integrable platform capable of meeting the ongoing demand for energy-efficient consumption. It offers essential tools for ensuring data security due to its ability to operate with encrypted network protocols [7].

To carry out temperature and air humidity measurements on the data collection microcontrollers, the DHT11 sensor was employed. This sensor is capable of measuring both parameters and outpu ing them as a digital signal. It can measure temperatures in the range of 0 °C to 50 °C and humidity in the range of 20% to 80%, which typically covers the measurements within the arable fields of Northern Paraná, with only occasional exceptions. For soil humidity measurements, a corrosion-resistant resistive hygrometer was used.

The microcontroller network features autonomous power supply through photovoltaic cells. To maintain compactness, prismatic lithium-polymer ba eries were employed, along with a protection circuit for charging and discharging. Typically, these ba eries provide the highest energy density available in the market.

Methods

The development methodology employed for this project was the Waterfall model, one of the most traditional approaches to software management. It follows a linear sequence of stages, where each phase of the project must be completed before the next one can begin. In the initial stage, system requirements are defined. In the second stage, the project is developed, with the aid of UML diagrams. Upon completion of this phase, the implementation begins, involving the writing of program code and the development of functionalities. Subsequently, the unit testing phase is undertaken to ensure that each component of the system functions correctly.

For system requirements definition, a literature review was conducted within the scientific literature on the use of resources in agricultural fields in the Paraná state's Northern Pioneer region. Subsequently, the Entity-Relationship Diagram (ERD), as depicted in Figure 1, was created to understand how the entities in the system's database should relate to one another. The ERD is one of the key diagrams in UML. MySQL Workbench, a tool for database creation and management, was employed to construct the research diagram.

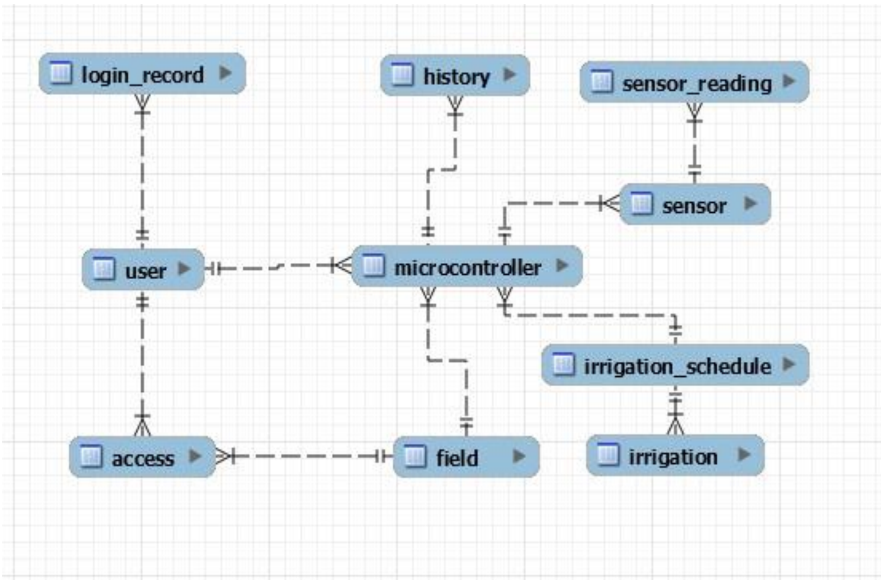

Figure 1. Entity-Relationship Diagram (ERD) of the system.

In the diagram depicted in Figure 1, the "user" table holds information about the system maintainers. This table exhibits a one-to-many (1:N) relationship with the "microcontroller" table, signifying that a single user can register multiple microcontrollers, while each microcontroller can be registered by only one user. Additionally, the "user" table maintains one-to-many (1:N) relationships with two other tables: "login_record," which stores user log entries, and "access," which records the agricultural fields that a user is authorized to manage.

The "microcontroller" table is related to four other tables in the following manner: it exhibits a one-to-many (1:N) relationship with the "field" table, representing arable fields. This signifies that one microcontroller can belong to only one arable field, while a single arable field can be associated with multiple microcontrollers; it maintains a one-to-many relationship with the "history" table, which is used to store data every time the irrigation actuators are triggered; there is a connection with the "sensor" table, facilitating the link between each microcontroller and its respective sensors; it is associated with the "irrigation_schedule" table, where the irrigation routines to be followed by that microcontroller are stored. Additionally, each microcontroller is uniquely identified by a Media Access Control (MAC) physical address, as denoted by the unique constraint.

The "irrigation" table specifies the soil moisture threshold at which irrigation should stay active and the time for its activation. It is connected to the "irrigation_schedule" table in a many-to-one (N:1) relationship. This means that one irrigation can be associated with only one irrigation routine, and an irrigation routine generally encompasses multiple irrigation actions.

The "sensor" table contains data regarding latitude and the type of sensor. It is related to the "microcontrolador" table in a one-to-many (1:N) relationship. This means one sensor can be linked to only one microcontroller, but a single microcontroller can be associated with numerous sensors.

The "sensor_reading" table stores the values recorded by the microcontrollers, and it is related in a one-to-many (1:N) manner with the "sensor" table. This data from the "sensor_reading" table is used to generate maps.

3. Results and Discussion

The project in question comprises a structure divided into three parts, each playing a fundamental role in the system's operation. The first part consists of the data processing and visualization server, which serves as a central hub for interactions with users and microcontrollers. This server hosts user interface screens, providing a platform for user interactions. Additionally, it is equipped with an Application Programming Interface (API) that acts as a receiver for the data collected by access clients. This API is crucial for ensuring seamless communication among the various system components.

The second phase of the project entails the deployment of the microcontrollers. These components are tasked with sending HTTP requests to the primary server. Upon receiving these requests, the microcontrollers orchestrate the execution of designated assignments, such as activating the irrigation valve when the soil moisture level falls below the threshold specified in the "irrigation" table.

In conclusion, the third part of the project focuses on creating clients that facilitate the interconnection between the database server and the microcontrollers. By bridging centralized data storage and distributed processing devices, clients play a crucial role in the integrity and smooth operation of the project as a whole. The diagram shown in Figure 2 illustrates the communication between the entities within the system. The only part with direct access to the Database Management System (DBMS) is the PHP Web Server, which serves as the core of the system. This is important to ensure the integrity of the information stored in the database and prevent SQL injection a acks.

To access the information, the user first logs in on the system's homepage and is then redirected to the interactive maps page. This page features four selection fields, allowing the user to choose the specific measurement period they wish to view. The PHP system conducts a database search for records collected by the microcontrollers during that period, calculates averages, and generates an interactive map using JavaScript, displaying the calculated measurement averages. Subsequently, a second layer is added to the map to showcase data interpolation, improving the user's ability to visualize the field's status.

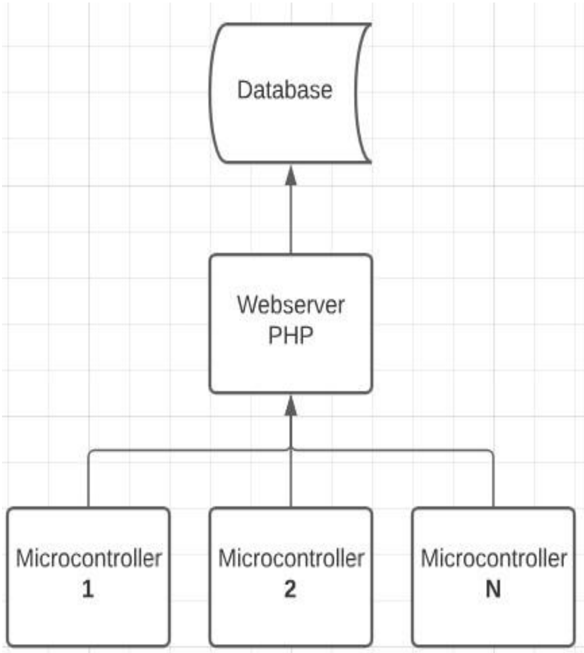

Figure 2. Diagram illustrating the network architecture of the developed system.

Figure 3 illustrates a temperature map generated using data collected by three microcontrollers on 29 August 2023. The microcontroller positioned outside the "IFPR Bloco Administrativo" recorded an average temperature of 28.4 °C during the one-hour interval when the map was generated. The one located underneath the "IFPR Bloco dos Estudantes" registered 28.8 °C, while the microcontroller inside the "IFPR Bloco de Alimentos" measured 21.8 °C. The system calculates an average of the values recorded within a specific time frame and performs data interpolation. Users can explore different positions by interacting with the map, clicking and dragging on the screen. To obtain temperature readings, they simply click on the microcontroller icons. The initial position has been set to the location of IFPR—Campus Jacarezinho.

Figure 3. Map generated by the research.

4. Conclusions

Throughout this paper, strategic choices have been made that have shaped the infrastructure and operation of the project. The careful selection of programming languages, frameworks, and devices, combined with the Waterfall development methodology, has led to a prototype that encompasses data collection, processing, and visual representation. The proposed network architecture and the interaction among system entities have resulted in an agricultural monitoring system capable of performing fundamental high-level operations, such as data storage and retrieval.

The objectives have been partially achieved. The developed system is currently capable of performing tasks such as:

1. registering, deleting, and modifying microcontrollers;
2. listing registered arable fields and microcontrollers;
3. sending and receiving messages from embedded systems that conduct measurements;
4. generating interactive maps with average values within a user-defined time interval;
5. conducting measurements of air temperature, air humidity, and soil humidity;
6. executing data interpolation for the information presented on the maps;
7. performing irrigation through irrigation routines or manually.

To assess whether user needs have been adequately addressed, testing in agricultural environments will be essential. For future implementations, there is a plan to replace the current method of communication between the embedded systems and the PHP server. Instead of using a direct HTTP connection, each ESP module would be equipped with a radio communication module. These devices would send their requests to a central microcontroller Gateway, which would then forward them to the server. This approach would enhance the system's robustness, allowing sensor-equipped modules to operate at greater distances from points with internet connectivity.

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