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Article

Smart Roots

Raíces Inteligentes

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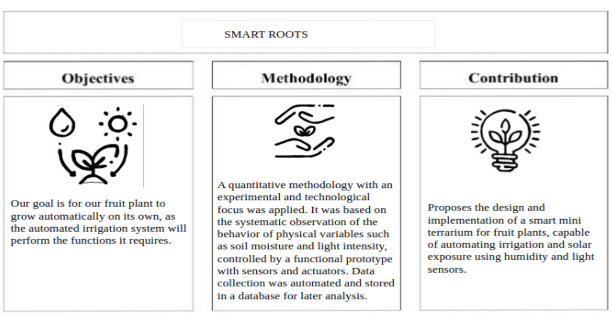
Abstract

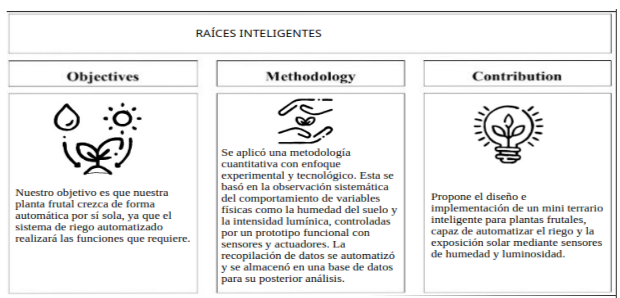
The "Smart Roots" project presents the development of an automated small-scale cultivation system for strawberry plants using a smart mini-terrarium capable of regulating irrigation and sunlight exposure. It uses soil moisture and light sensors connected to a microcontroller that activate a water pump and a motorized cover based on environmental conditions. The system is integrated with a mobile app that allows for remote monitoring, receiving alerts, manual command entry, and viewing historical data. Additionally, a database is implemented to store information such as irrigation events, humidity levels, and sunlight exposure, enabling pattern analysis and system optimization. This project promotes the efficient use of resources, the adoption of emerging technologies, and the development of sustainable plant care solutions. It is especially valuable in urban or educational contexts where smart farming practices are encouraged and where environmental control systems can enhance plant growth and user engagement.



Automated system, Mini Terrarium, Luminica

Resumen

El proyecto "Raices Inteligentes" presenta el desarrollo de un sistema automatizado de cultivo a pequeña escala para plantas de fresa mediante un miniterrario inteligente capaz de regular el riego y la exposición solar. Utiliza sensores de humedad del suelo y luz conectados a un microcontrolador que activan una bomba de agua y una cubierta motorizada según las condiciones ambientales. El sistema está integrado con una aplicación móvil que permite la monitorización remota, la recepción de alertas, la introducción manual de comandos y la consulta de datos históricos. Además, se implementa una base de datos para almacenar información como eventos de riego, niveles de humedad y exposición solar, lo que permite el análisis de patrones y la optimización del sistema. Este proyecto promueve el uso eficiente de los recursos, la adopción de tecnologías emergentes y el desarrollo de soluciones sostenibles para el cuidado de las plantas. Es especialmente valioso en contextos urbanos o educativos donde se fomentan las prácticas agrícolas inteligentes y donde los sistemas de control ambiental pueden mejorar el crecimiento de las plantas y la participación de los usuarios.



Sistema automatizado, Mini Terrario, Luminica

Area: Strengthening the scientific community

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Introduction

Small-scale automated cultivation systems are increasingly relevant for those who want to self-manage their plants in urban environments. This project proposes the design of a single-plant smart mini-terrarium, capable of autonomously regulating irrigation and sunlight exposure using sensors and actuators controlled by a microcontroller. Integration with a mobile app and database for remote monitoring and analysis of water consumption patterns is also planned.

General information

A database is implemented in the cloud [Firebase Realtime Database] or locally [SQLite in the application] with the following records:

- Date and time of irrigation.
- Humidity level before and after irrigation.
- Amount of water used.
- Daily light intensity.
- Sun exposure time.

This data will allow:

- Analyze water consumption patterns.
- Detect variations in irrigation needs.
- Automatically adjust system thresholds through learning.

Unlike other automated cultivation systems, which are limited to passive monitoring or basic irrigation control, this project offers a comprehensive solution that combines environmental sensors, automated actions, mobile connectivity, and cloud data storage.

Its added value lies in the ability to manage plant care in real time, from anywhere, with an intuitive interface and accessible historical data.

This solution not only optimizes resources such as water and electricity, but also promotes technological appropriation and hands-on learning in urban and educational contexts.

Methodology

Box 1

Stages of the Waterfall methodology:

Stage 1: Requirements

Stage 2: Analysis

Stage 3: Design

Stage 4: Programming

Stage 5: Testing

Stage 6: Operations

Figure 1
Diagram of the Methodology

Stage 1: Requirements

The system developed for the project meets several requirements to ensure optimal operation and technical viability. These requirements are divided into functional and non-functional requirements.

Regarding the functional requirements, the system must be able to automatically detect soil moisture levels and activate the irrigation pump when they fall below a set threshold. It must also measure sunlight intensity to manage the opening or closing of the terrarium lid, depending on environmental conditions. Furthermore, it is essential that the system log each event and send the data to a database, allowing it to be consulted through a mobile application from which manual commands can also be issued.

Regarding the non-functional requirements, it is stipulated that the system must be compact, have low energy consumption, be easy to maintain, and be compatible with Android mobile devices. Its design must be intuitive to facilitate use by non-technical users, while ensuring the integrity and availability of the stored data.

Stage 2: Analysis

It arises from the need to implement accessible and sustainable technological solutions for automated plant care, especially in urban environments where time, space, and technical expertise may be limited.

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The system analysis demonstrates that its modular design allows for future adaptations, such as the inclusion of additional sensors [temperature, soil pH] or the use of learning algorithms to optimize decision-making. It also demonstrates that the solution is replicable, cost-effective, and functional for domestic, educational, or experimental purposes.

Stage 3: Design

The system was developed using a modular and functional approach, integrating electronic and structural components that automate the care of a strawberry plant inside a mini terrarium. The system is composed of three main blocks: sensing, processing, and actuation. The sensing block uses a capacitive soil moisture sensor and an LDR or BH1750 ambient light sensor. These sensors capture environmental conditions in real time. Data processing is performed by an ESP32 microcontroller, selected for its wireless connectivity [WiFi/Bluetooth], low power consumption, and ease of programming. This device interprets the signals received by the sensors and activates the corresponding actuators.

The actuation block includes a water pump that turns on when soil moisture is low, and a servomotor that opens or closes a top cover that regulates the entry of sunlight. All events are logged in a database [Firebase or SQLite] and viewed using a mobile app developed with Blynk or Flutter. The terrarium's physical design includes a transparent container that allows natural light to enter, a water reservoir connected to the pump, and a stable structure that supports all the electronic components. Accessibility to the elements was prioritized to facilitate maintenance and possible upgrades. This design favors the system's scalability, allowing for adaptation to different types of plants or environments, and the future integration of new sensors or artificial intelligence algorithms to optimize plant care.

Box 2

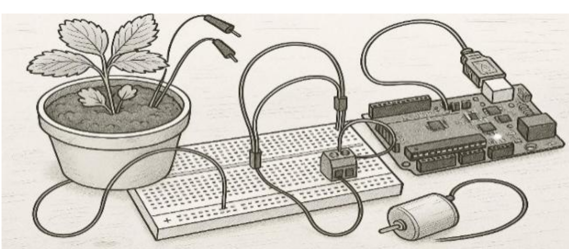

Figure 2

Armed project design.

Stage 4: Programming

The programming we used for the system was developed in Arduino C/C++, using the Arduino IDE development environment. The code was loaded onto an ESP32 microcontroller, selected for its compatibility with digital sensors and its Wi-Fi connectivity, ideal for integration with cloud databases and mobile applications.

The main algorithm is based on a periodic cycle that runs every five minutes, during which the values from the soil moisture sensor and the ambient light sensor are read. If the moisture value is below a predefined threshold [for example, 30%], the irrigation pump is activated for a specified time, and this event is logged in the database. Likewise, if the light intensity is very low [less than 200 lux], the servomotor is activated to open the lid; if it is too high [more than 800 lux], or if the temperature exceeds a certain limit, the lid is closed to prevent overexposure.

Box 3

```
CÓDIGO DE MINI TERRARIO INTELIGENTE
#include <WiFi.h>
#include <HTTPClient.h>
#include <Servo.h>

// Pines
const int pinHumedad = 34;   // Entrada analógica (sensor de humedad)
const int pinLuz = 35;       // Entrada analógica (sensor de luz)
const int pinBomba = 26;     // Control bomba de agua (rele o transistor)
const int pinServo = 13;     // Servo motor (para tapa)

Servo servoTapa;

// WiFi
const char* ssid = "TU_SSID";          // Tu red WiFi
const char* password = "TU_PASSWORD";  // Contraseña WiFi

// Firebase
const String firebase_host = "https://TU_PROYECTO.firebaseio.com/";

// Umbrales configurables
int humedadMin = 30;       // % mínimo de humedad
int luzMax = 800;          // Valor máximo para cerrar tapa
int luzMin = 200;          // Valor mínimo para abrir tapa

void setup() {
  Serial.begin(115200);

  pinMode(pinBomba, OUTPUT);
  digitalWrite(pinBomba, LOW);
  servoTapa.attach(pinServo);
  servoTapa.write(0); // Tapa cerrada al inicio

  // Conectar a WiFi
  WiFi.begin(ssid, password);
  Serial.print("Conectando a WiFi");
  while (WiFi.status() != WL_CONNECTED) {
```

Figure 3

Arduino programming code

Stage 5: Testing

Individual and integrated tests were conducted. Individual tests focused on verifying the response of each component: the humidity sensor, the light sensor, the water pump, the servomotor, and the connection to the database.

First, the humidity sensor was verified to correctly detect changes in soil water content using different types of substrate [dry, wet, soaked]. Subsequently, the operation of the light sensor was evaluated, simulating different lighting levels with a flashlight and natural light. The water pump was then activated manually and automatically, verifying that it responded to the programmed threshold.

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Likewise, the servomotor's movements were tested, verifying the opening and closing of the lid depending on the light intensity. Finally, integration tests were conducted, with the entire system operating for several 5-minute cycles. During these tests, the records in the database were monitored and displayed on the mobile app. The results demonstrated that the system responds appropriately to environmental conditions and performs its function autonomously and reliably.

Box 4

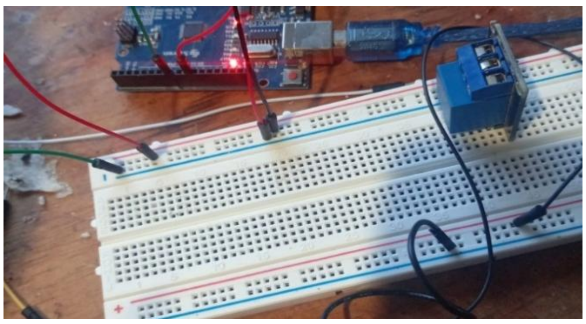

Figure 4
Image of the test that was performed at the time of connection

Stage 6: Operations

The system operates autonomously through a continuous cycle that runs every five minutes. During each cycle, the microcontroller reads the values from the soil moisture sensor and the ambient light sensor. If it detects low humidity, it activates the water pump; if the light is insufficient or excessive, it automatically regulates the opening or closing of the lid. All events are recorded in a database and can be accessed through a mobile app, which also allows manual commands to be sent. The system is designed to operate 24 hours a day, with minimal user intervention, maintaining optimal conditions for plant care.

Box 5

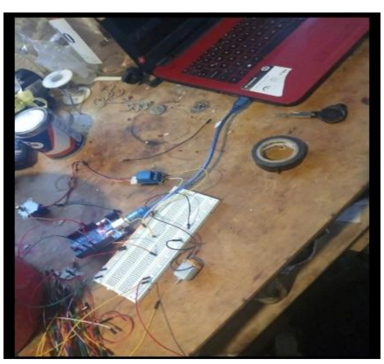

Figure 5
Operation of how the project was set up

Materials to implement

The following materials are the primary ones that will be implemented and used in the creation of the prototype. Some materials and implementations are subject to change. The following table is a guide to the components that will be used.

Box 6
Table 1
Materials Table

Componente	Descripcion	Cantidad
Microcontrolador	ESP32 [WiFi + Bluetooth] o Arduino + módulo WiFi	1
Sensor de humedad del suelo	Capacitivo	1
Sensor de luz	Fotocelula [LDR] o sensor BH1750	1
Mini Bomba de agua	SV DC o sumergible USB	1
Rele de transistor	Control de bomba	1
Servomotor o motor	Para tapa movil	1
Deposito de agua	Recipiente de plastico pequeño	1
Tuvo de agua	Conduccion de agua	1
Cables y protoboard	Conexiones	Variado
Fuente de Energia	Bateria Li-ion o fuente USB	1
Contenedor del terrario	Vidrio/Plastico transparente	1
App movil	Interaz de control [personalizada].	-
Base de datos	Firebase Realtime DB o SQLite en la app	-

Source: Prepared by the authors with data obtained

Conclusions

This project demonstrates that it is possible to automate plant care through the use of accessible technologies. Its efficient, autonomous, and replicable design offers a functional solution for monitoring and controlling irrigation and lighting, optimizing resources and promoting the use of technology in urban agriculture. This system not only facilitates plant care but also represents an educational tool with great potential for growth and innovation.

Declarations

Conflict of interest

The authors declare that there are no financial, personal, or academic conflicts of interest that could have influenced the development of this project.

The research was conducted for educational purposes and without external funding.

Author contribution

Anaya-Aguilar, Romina Suleima: Contributed to the preparation and execution of the research project documentation.

Barriga-Cortes, Alexander: He contributed to the structure of the Arduino code and researched information for the documentation and is the project leader.

Perez-Hernandez, Agnes Ludwika: He contributed to the search for information and provided materials

Hidalgo Baeza, Maria del Carmen: I contribute with the review of the documentation.

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Abbreviations

DB: Database.
ESP32: Microcontroller with WiFi/Bluetooth connectivity.
IoT: Internet of Things.
LDR: Light-dependent resistor [light sensor]

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Antecedents

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