

Diseño de un dispositivo electrónico para registro y transmisión inalámbrica de variables físicas, en función del buen estado de plantas domésticas, para visualización en tiempo real en aplicativo Android para el Bosque Seco del Parque Biotemático Megua

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Abstract

El artículo a continuación presentado consiste en el diseño e implementación de un dispositivo electrónico para el registro y transmisión inalámbrica de variables físicas, en función del buen estado de plantas domésticas para su visualización en tiempo real en un aplicativo Android para el Parque Biotemático Megua. El aplicativo, llamado aka Caribe Smarts Plants, es un prototipo electrónico desarrollado con el objetivo de mejorar la conservación del ecosistema local, así como también brindar educación ambiental sobre el ciclo de vida de las plantas y recopilar información regional sobre las condiciones climáticas y de cuidado de la flora atlanticense. Es así que se logrará brindar una alternativa viable, funcional y de bajo presupuesto, que guarde la información pertinente de plantas locales y permita la adquisición, monitoreo y procesamiento de los datos de las variables ambientales de temperatura ambiente, humedad del suelo, luminosidad y fertilidad, a través de lecturas periódicas transmitidas sobre redes Wi-Fi (IEEE802-1b/g) en una aplicación Android, con el objetivo de promover la recuperación, preservación y protección del ecosistema de bosques secos.

Keywords: Biodiversidad, Desarrollo de aplicaciones Android, Flora, Procesamiento de datos, Sensado de variables físicas, Transmisión WiFi

INTRODUCTION

The maintenance and healthy development of domestic plants depend strongly on environmental conditions surrounding their root systems and aerial structures. Variables such as soil moisture, ambient temperature, relative humidity, light intensity, and soil temperature influence fundamental physiological processes including photosynthesis, respiration, nutrient uptake, transpiration, water transport, and plant growth. Variations in any of these conditions can negatively influence plant development if they persist outside suitable limits. Conventional plant-care practices often depend on visual inspection, personal experience, and predetermined watering schedules. Although such practices are simple to implement, they frequently fail to reflect the actual environmental conditions experienced by plants. A plant may receive excessive irrigation despite already having sufficient soil moisture, while another plant may experience dehydration before visible symptoms such as leaf wilting become noticeable. Advances in embedded electronics have significantly reduced the cost and complexity of environmental monitoring. Modern microcontrollers can simultaneously obtain measurements from multiple sensors, process those measurements, store information, and transmit data wirelessly through Wi-Fi or Bluetooth technologies. These developments have encouraged the expansion of Internet of Things applications in agriculture, environmental monitoring, domestic automation, and precision irrigation. Instead of treating environmental monitoring as an activity requiring expensive scientific instrumentation,

low-cost embedded platforms have enabled researchers and users to develop portable and scalable systems capable of collecting measurements continuously. Wireless sensor technologies are especially relevant to plant monitoring because environmental variables change dynamically. Soil moisture decreases due to evapotranspiration and plant water consumption, ambient temperature changes according to solar radiation and weather conditions, relative humidity varies throughout the day, and available light changes according to time, vegetation cover, and environmental conditions. Consequently, periodic or real-time monitoring provides a more useful understanding of plant environments than isolated manual measurements. When these measurements are transmitted to mobile devices, users can monitor plants remotely without directly inspecting each individual specimen. The development of Android applications has further increased the accessibility of environmental monitoring technologies. Smartphones provide highly portable computing platforms capable of receiving, processing, storing, and visualizing sensor information. A well-designed mobile interface can translate numerical measurements into meaningful indicators that users can understand rapidly. For example, soil moisture may be displayed not only as a percentage but also through status indicators indicating adequate, moderate, or critical moisture conditions. Similar visualization mechanisms may be used for temperature, humidity, and light intensity. Notifications can additionally inform users when specific variables exceed predefined limits. The dry-forest environment presents particular monitoring challenges because plants may experience periods of elevated temperature, strong solar radiation, reduced atmospheric moisture, and limited water availability. Under these conditions, inappropriate irrigation or insufficient environmental awareness may significantly affect sensitive domestic plants. Therefore, a sensor-based monitoring platform can assist users in understanding how environmental conditions change throughout the day and how those conditions relate to plant requirements. The proposed research focuses on the design of an electronic system capable of acquiring multiple physical variables associated with plant conditions, processing these data through an embedded microcontroller, and transmitting them wirelessly to an Android application. The system is conceptualized for application in Parque Biotemático Megua and emphasizes a combination of affordability, energy efficiency, simplicity, modularity, and reliable real-time visualization. The significance of the proposed device extends beyond domestic plant maintenance. It may also serve as a technological resource for environmental education, allowing students, visitors, and environmental managers to observe the relationship between plant health and microclimatic conditions. Furthermore, the architecture could later be expanded to include automated irrigation, remote cloud storage, predictive analytics, and large-scale sensor networks. The objective of this study is therefore to establish a technically feasible framework for monitoring plant-related physical variables through embedded sensing and wireless communication. The study specifically addresses sensor selection, electronic architecture, communication mechanisms, Android visualization, data-processing procedures, and system-evaluation criteria.

Environmental Variables Associated with Domestic Plant Health:

Plant development represents the result of complex interactions between biological processes and environmental conditions. Although many variables contribute to plant health, soil water availability, temperature, relative humidity, and solar radiation are among the most influential parameters that can be practically monitored using low-cost sensors. A monitoring device designed for domestic plants should therefore combine several sensor types rather than relying exclusively on a single environmental measurement. Soil moisture is one of the most important parameters because water availability directly influences nutrient transport, cellular turgor, photosynthetic performance, and overall plant development. Plants obtain most of their water through their roots, making the moisture condition of the substrate particularly important. Excessively dry soil can result in water stress, stomatal closure, reduced photosynthesis, and eventual wilting. Conversely, excessive moisture can reduce oxygen availability around roots and create conditions favorable to root diseases. Traditional assessment of soil moisture often depends on manual contact with the soil or subjective visual inspection. Electronic monitoring can improve this process by supplying quantitative information. A capacitive soil-moisture sensor is generally more appropriate for long-term monitoring than simple resistive probes because capacitive sensors do not expose measurement electrodes directly to the soil in the same manner, thereby reducing corrosion and extending operational life. Ambient temperature also plays an important role in plant metabolism. Temperature influences enzyme activity, photosynthesis, respiration, evaporation, and transpiration. High temperatures can increase water demand and intensify moisture loss from both soil and leaves. Extremely low temperatures can similarly inhibit metabolic activity. Continuous temperature monitoring therefore helps users understand whether observed changes in plant condition correspond to thermal stress. Relative humidity describes the amount of atmospheric moisture relative to the maximum amount of moisture air can hold at a particular temperature. Low relative humidity can increase transpiration and accelerate water loss, whereas excessively high humidity may reduce transpiration and potentially create favorable conditions for fungal development. Combined temperature and humidity sensors provide a convenient and inexpensive method for monitoring both variables.

Light intensity is essential because plants depend on solar or artificial radiation for photosynthesis. Insufficient light may cause weak development, elongated growth, and reduced photosynthetic activity. Excessive radiation may increase

leaf temperature, accelerate water loss, and cause damage in species adapted to shaded environments. Monitoring light intensity allows users to determine whether plants are positioned appropriately throughout the day. Soil temperature is another useful variable because root systems depend on appropriate thermal conditions for nutrient absorption and metabolic activity. The temperature of soil may differ from ambient air temperature because soil retains and releases heat at different rates. An optional waterproof temperature sensor installed near the root zone can therefore enhance understanding of the plant microenvironment. The integration of these measurements establishes a multidimensional description of environmental conditions affecting domestic plants. Instead of indicating only whether the substrate is dry, the system can show whether dryness is accompanied by high temperature, low humidity, or excessive light intensity. This combined interpretation can support better plant-care decisions.

Table 1: Physical variables proposed for plant-condition monitoring

Physical Variable	Proposed Sensor	Unit	Purpose in Plant Monitoring	Typical System Function
Soil moisture	Capacitive soil-moisture sensor	%	Determines water availability around roots	Generates irrigation warning when moisture falls below threshold
Ambient temperature	Digital temperature sensor	°C	Identifies thermal conditions surrounding plants	Detects excessive heat or unsuitable temperature
Relative humidity	Digital humidity sensor	%	Measures atmospheric moisture	Supports interpretation of transpiration and water demand
Light intensity	Digital light sensor	lux	Measures available illumination	Identifies inadequate or excessive light exposure
Soil temperature	Waterproof digital probe	°C	Measures root-zone temperature	Detects unfavorable thermal conditions in substrate

Each parameter should be calibrated according to its measurement characteristics. Particularly in the case of soil moisture, raw sensor readings cannot automatically represent universal percentages because soil composition, salinity, compactness, and sensor placement influence capacitance. Therefore, calibration should be conducted using dry and fully saturated reference conditions appropriate to the substrate used with the monitored plant.

Electronic Device Architecture and Hardware Design:

The proposed electronic device consists of five major technological components: environmental sensors, a central microcontroller, a wireless communication subsystem, a power-management system, and a protective enclosure. The central objective of the hardware design is to maintain adequate measurement capability while minimizing cost, power consumption, and physical complexity. A microcontroller based on the ESP32 architecture represents an appropriate processing platform because it combines computational capacity, analog and digital interfaces, integrated Wi-Fi, Bluetooth connectivity, and low-power operating modes. Its integrated wireless capabilities reduce the requirement for additional communication hardware and simplify the overall circuit architecture. Environmental sensors are connected to the microcontroller through analog inputs or digital communication buses. Capacitive soil-moisture sensors commonly provide analog voltage outputs proportional to soil conditions. Temperature, humidity, and light sensors can communicate digitally, reducing susceptibility to analog noise and simplifying calibration. The microcontroller periodically activates the sensing modules, obtains multiple readings, filters temporary variations, and converts raw measurements into standardized values. Instead of collecting measurements continuously, the system may operate according to programmable intervals. For example, measurements may be collected every two minutes under normal monitoring conditions. More frequent measurements increase temporal resolution but also increase power consumption and network traffic. Data-processing routines within the microcontroller can include moving averages, range verification, and invalid-reading rejection. If a temperature sensor produces a physically impossible reading, the system should reject the measurement rather than transmit misleading information. Similarly, multiple soil-moisture measurements can be averaged before transmission to reduce fluctuations caused by electrical noise. Power management represents an essential consideration for portable monitoring systems. The proposed prototype may operate through a rechargeable lithium battery or regulated external power source. A photovoltaic panel could also be integrated for installations where access to electrical infrastructure is limited. The microcontroller can enter a low-power mode between measurements to extend battery life.

The physical enclosure should protect the electronic components against dust, accidental water exposure, and direct sunlight while maintaining appropriate ventilation for temperature and humidity measurements. Sensors intended for

direct contact with soil should remain external to the enclosure and connect through sealed terminals or cables.

The following conceptual sequence illustrates operation of the electronic device:

Environmental Sensors → Signal Acquisition → ESP32 Microcontroller → Data Filtering and Calibration → Wireless Communication → Mobile/Cloud Database → Android Application

During each sensing cycle, the microcontroller activates relevant sensors, records measurements, evaluates whether values fall within valid operational ranges, and prepares a digital data package. Each package may contain a unique device identifier, time stamp, soil-moisture level, ambient temperature, relative humidity, light intensity, soil temperature, battery status, and communication status. The device architecture should remain modular so additional sensors can be introduced without redesigning the complete system. Future versions could incorporate electrical conductivity sensors for nutrient monitoring, pH sensors, carbon dioxide sensors, rainfall sensors, or leaf-wetness sensors. Another important feature is local data buffering. Wireless connectivity may occasionally become unavailable. Instead of losing environmental data during such interruptions, the microcontroller can temporarily save recent measurements in local memory. Once communication is restored, buffered measurements can be transmitted to the database. Hardware modularity also facilitates maintenance. When individual sensors fail, they can be replaced independently without replacing the central processing unit. This increases the long-term sustainability of the system and reduces maintenance costs.

Wireless Data Transmission and Android Application:

Wireless communication transforms the electronic device from a standalone measurement instrument into a connected environmental-monitoring platform. The proposed system may support Wi-Fi for internet-connected operation and Bluetooth Low Energy for local communication when internet infrastructure is unavailable. Under Wi-Fi operation, the microcontroller can send sensor information to a remote or local server using a lightweight protocol such as MQTT. MQTT is particularly useful in Internet of Things applications because it is designed for efficient communication between resource-constrained devices. The sensing device can publish measurements under defined topics, while the mobile application or cloud service subscribes to those topics. An alternative approach involves transmitting measurements through HTTP-based requests to a web service or database. Although HTTP generally requires greater communication overhead than MQTT, its widespread compatibility can simplify integration with web and mobile services. Bluetooth Low Energy provides another communication mechanism when the monitoring device and smartphone are physically close. The smartphone can directly retrieve measurements without requiring internet connectivity. Such functionality may be particularly valuable in natural or recreational areas where Wi-Fi coverage is inconsistent. The Android application represents the primary user interface of the proposed system. Its design should emphasize simplicity and immediate interpretation. Users should not need specialized knowledge of electronics or plant physiology to understand measurements. The application dashboard may contain five principal environmental indicators:

Soil Moisture: Displays moisture percentage and irrigation status.

Ambient Temperature: Displays current temperature and potential thermal stress.

Relative Humidity: Displays atmospheric moisture conditions.

Light Intensity: Shows current illumination and whether exposure is low, moderate, or high.

Soil Temperature: Displays the thermal condition surrounding the root system.

Visual indicators may classify measurements into normal, warning, and critical categories according to predefined thresholds. The thresholds should remain configurable because different plant species require different environmental conditions. The mobile application should also display historical measurements through graphs. Historical visualization provides greater analytical value than isolated measurements because it allows users to identify patterns. For example, users can observe how quickly soil moisture decreases after irrigation, whether daily temperature peaks correspond with rapid moisture loss, or whether plants receive adequate light only during certain hours. Notifications are another valuable feature. When environmental conditions remain outside recommended ranges for a predetermined period, the application can alert users. A delay mechanism is desirable because temporary fluctuations should not automatically generate notifications. For example, brief direct sunlight may increase temperature momentarily without creating meaningful plant stress. The system can additionally provide general recommendations based on observed conditions. If soil moisture becomes critically low, the application may display a recommendation to inspect irrigation requirements. If light remains excessively low, it may suggest repositioning the plant. These recommendations should remain advisory rather than diagnostic because actual plant requirements vary considerably across species. Data security and communication reliability should also be considered. Wireless connections should use authentication mechanisms, and sensitive configuration data should not be stored as plain text. Device identifiers should help prevent data from multiple monitoring nodes from becoming confused.

A multi-device configuration could allow users to register several plants within the Android application. Each plant may have an individual profile containing species name, location, sensor-node identifier, measurement thresholds, and

historical records. Such functionality would enable the architecture to expand from a single domestic plant to a larger botanical collection.

Data Processing, Prototype Performance, and Graphical Interpretation:

Sensor data require systematic processing before they can provide meaningful information. Raw electronic measurements frequently contain temporary noise, fluctuations, or errors resulting from environmental interference. The proposed system therefore incorporates several stages of data processing. The first stage involves measurement acquisition. Each sensor may be read several times within a brief period. The system can calculate the average or median of these readings to reduce random variations. Values outside physically realistic limits are automatically rejected. The second stage consists of calibration. Soil-moisture readings are calibrated between dry and saturated substrate conditions. Temperature and humidity sensors can be compared against calibrated reference instruments to identify systematic error. Light measurements may similarly be validated using a commercial lux meter. The third stage involves normalization and interpretation. Environmental variables are converted into formats suitable for mobile presentation. Soil moisture may be normalized between 0 and 100 percent, while light intensity remains expressed in lux. Threshold algorithms classify values according to user-defined environmental ranges. The fourth stage involves storage and transmission. Measurements are time stamped and transferred to the communication module. Successfully transmitted information is stored within a database from which the Android application can retrieve historical records. A prototype evaluation should assess five fundamental aspects: measurement accuracy, data reliability, communication latency, power efficiency, and interface usability. Measurement accuracy can be evaluated by comparing electronic sensor values against reference instruments. The mean absolute error may be calculated for each parameter. Repeated tests at different environmental conditions can determine whether the sensor maintains stable performance. Communication reliability may be evaluated through packet-delivery ratio. If the device attempts to transmit 1,000 measurement packets and 980 successfully reach the receiving system, the packet-delivery ratio would be 98 percent. Communication tests should be conducted at different distances and under different obstruction conditions. Latency measures the delay between sensor measurement and visualization in the Android application. Excessive latency would reduce the value of real-time monitoring. However, plant environmental variables generally change gradually, meaning that extremely low millisecond-level latency is unnecessary. A delay of several seconds may remain acceptable for this application. Power efficiency should be evaluated by recording battery consumption under different sensing and transmission intervals. Increasing the interval between transmissions generally extends battery life. Consequently, system designers should establish a balance between measurement frequency and energy efficiency. The graph associated with this study may illustrate a hypothetical 24-hour monitoring cycle. The graph should not be interpreted as actual measurements collected from Parque Biotemático Megua unless field validation has been conducted.

Illustrative 24-hour environmental monitoring pattern

The conceptual monitoring profile shows soil moisture gradually decreasing during daylight hours, accompanied by an increase in light intensity and ambient temperature. Relative humidity remains comparatively lower during the warmest period and increases slightly during evening conditions. Following irrigation, soil moisture increases rapidly before gradually declining again as water is absorbed by plants and lost through evaporation. This pattern demonstrates why integrated monitoring is preferable to reliance on a single sensor. A low soil-moisture measurement occurring simultaneously with high temperature and intense illumination may indicate a stronger risk of water stress than the same moisture level observed under cooler, humid conditions. The interpretation algorithm may therefore incorporate several variables when producing notifications. Instead of considering soil moisture independently, future versions of the system could use decision rules or machine-learning models incorporating multiple environmental variables.

The application should clearly label historical graphs with measurement units and time stamps. Users should be able to select periods such as six hours, twenty-four hours, seven days, or thirty days. The inclusion of minimum, maximum, and average values may further support interpretation. System performance also depends heavily on sensor placement. A soil-moisture probe positioned too close to an irrigation point may provide measurements that do not represent the entire root zone. Similarly, direct solar exposure to an air-temperature sensor may artificially increase measured temperature. Proper placement guidelines should therefore accompany the system.

Application to the Dry Forest of Parque Biotemático Megua, Validation, and Future Development:

The proposed monitoring system has particular relevance for environments characterized by variable water availability and strong climatic exposure. Dry-forest ecosystems frequently experience seasonal differences in precipitation, prolonged dry periods, high solar radiation, and elevated daytime temperatures. Plants maintained within such environments can experience considerable variation in local microclimatic conditions. Although the system is primarily designed for domestic plants, its potential application within Parque Biotemático Megua provides important environmental and educational opportunities. Monitoring devices could be installed alongside selected plants in demonstration areas, allowing visitors to observe real-time environmental conditions through mobile devices or fixed information displays. Such implementation could transform plant monitoring into an interactive educational experience.

Visitors could examine how soil moisture changes after irrigation, compare shaded and exposed locations, or observe relationships between temperature and relative humidity. This would demonstrate that environmental conditions are dynamic and that appropriate plant management depends on quantitative understanding rather than visual observation alone. The device may also support environmental personnel responsible for maintaining ornamental or educational plant collections. Instead of manually examining multiple plants several times each day, staff could review measurements through a centralized mobile interface and prioritize attention according to environmental alerts. A systematic validation process should occur before widespread deployment. The first stage should involve laboratory testing of individual sensors. Each sensor should be compared against reference instruments under controlled conditions. Calibration coefficients can then be developed. The second stage should involve controlled plant testing. Monitoring devices may be installed in several plant containers maintained under different irrigation conditions. The system should demonstrate its capacity to distinguish adequately hydrated, moderately dry, and severely dry substrates. The third stage should involve semi-outdoor testing. Devices should be exposed to realistic fluctuations in temperature, humidity, and light while remaining protected from direct rainfall or extreme environmental damage. Communication performance and power consumption should be monitored. The fourth stage should involve user evaluation. Participants may be asked to install the application, connect with a monitoring device, interpret current measurements, identify a warning condition, and review historical data. User feedback should address clarity, ease of navigation, perceived usefulness, and notification effectiveness. System validation can therefore combine technical and human-centered measures. A technically accurate device may still be ineffective if users cannot interpret its output. Conversely, an attractive mobile interface cannot compensate for inaccurate sensors. Successful deployment depends on both components functioning appropriately. Future development could incorporate automated irrigation. A relay or electronic valve could allow the monitoring node to activate a small water pump when soil moisture falls below a predefined threshold. However, automated irrigation requires additional safeguards because sensor failures could potentially cause excessive watering. Another possible development involves machine learning. Historical environmental measurements could be analyzed to identify patterns preceding visible plant stress. Predictive models could eventually estimate when irrigation will be required rather than waiting for moisture to decline below a fixed threshold. Cloud storage represents another expansion opportunity. Measurements from multiple monitoring nodes could be transmitted to a centralized database, enabling comparative analysis across different plants or locations. Such a system could support environmental research and long-term ecological observation. Solar energy can further improve field suitability. A small photovoltaic panel connected to a rechargeable battery could maintain the monitoring device for extended periods, particularly in locations receiving substantial solar exposure. The proposed architecture may also support additional environmental sensors. Electrical conductivity could provide information related to dissolved nutrients, pH sensing could support soil-condition analysis, rainfall sensors could identify precipitation events, and carbon dioxide sensors could provide additional atmospheric measurements. Overall, the proposed system represents a scalable foundation rather than a fixed final product. Its modular hardware and software architecture allows future improvements without requiring complete redesign.

Summary

This study developed a comprehensive conceptual design for an electronic device capable of recording and wirelessly transmitting physical variables associated with domestic plant health for real-time visualization through an Android application. The system was designed with particular consideration of environmental monitoring within the dry-forest context of Parque Biotemático Megua. The proposed platform integrates soil-moisture, ambient-temperature, relative-humidity, light-intensity, and soil-temperature sensors with an embedded microcontroller featuring wireless communication. These measurements collectively provide a more complete representation of plant environmental conditions than visual observation or single-variable monitoring. The ESP32-based architecture provides a suitable balance between processing capability, wireless communication, energy efficiency, and affordability. Sensors can be periodically activated to obtain environmental measurements, after which readings are validated, calibrated, processed, and transmitted to a mobile application. Wireless communication can occur through Wi-Fi using MQTT or HTTP protocols, while Bluetooth Low Energy can provide local communication when internet access is unavailable. This hybrid structure increases flexibility for domestic, educational, and semi-outdoor applications. The Android application represents the principal interaction layer between the sensing device and users. It can display current environmental conditions, historical trends, plant-specific thresholds, device status, and warning notifications. By translating numerical measurements into understandable indicators, the application supports practical plant-management decisions. The proposed system also emphasizes reliable data processing. Raw measurements require calibration, filtering, normalization, and validation before interpretation. Local data buffering protects against temporary communication failures, while historical data allow users to identify daily and long-term environmental patterns. The conceptual performance framework includes measurement accuracy, packet-delivery reliability, communication latency, energy consumption, and usability. These criteria acknowledge that successful environmental monitoring depends on both

technical performance and user interaction. Within Parque Biotemático Megua, the system could provide additional value as an environmental-education platform. Visitors and students could observe relationships between soil moisture, temperature, atmospheric humidity, light, and plant conditions in real time. Environmental personnel could similarly use the platform to supervise multiple plants and identify locations requiring attention. The modular architecture also supports future technological development. Potential extensions include automated irrigation, photovoltaic power, cloud-based data storage, machine-learning prediction, and additional environmental sensors. These improvements could gradually transform the proposed domestic plant-monitoring device into a broader smart environmental observation platform. The study therefore demonstrates that combining low-cost sensors, embedded electronics, wireless communication, and Android-based visualization provides a practical approach for improving plant monitoring. Rather than replacing human judgment, the technology supplies quantitative information that can support more informed decisions regarding irrigation, positioning, environmental conditions, and plant maintenance. Its affordability, modularity, and adaptability make it potentially useful for domestic plant owners, educational facilities, botanical environments, and environmentally sensitive recreational spaces.

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