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Developing Low-Cost LoRaWAN Internet of Things Devices for Water Resources Monitoring in Bali

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Abstract

In this study, we developed a solar-powered prototype using an ESP-32 MCU, commercially available sensors, and a LoRaWan communication module. The components cost less than $30 USD. The prototype has been running on solar power for two months in room conditions, repeating the sleep-wake cycle and transmitting sensor data - temperature, battery %, light color, and accelerometric data - every ten minutes over LoRaWAN to a cloud data storage. While the data only reflect room settings, and not real environmental data, the operating record demonstrates steady behavior, power autonomy, and data transfer, which is a necessity for IoT devices that monitor water supplies in the field. In the future, the developed devices will be used in Bali, Indonesia, to monitor the hydrological status during an impending water crisis.

Keywords

Internet of Things (IoT), Integrated Water Resources Management (IWRM), LoRaWan, Data driven policy, Sustainable Development Goals (SDG)

Introduction

According to the United Nations (UN) SDGs, water resources must be utilized sustainably so that they are available equally to all humans today and in the future. Integrated water resource management (IWRM) is seen as one method of attaining sustainability. It is also an objective of the United Nations Sustainable Development Goal 7, which focuses on clean water and sanitation.

Monitoring water resources is seen as an important step in developing and implementing suitable policy actions (Abdullaev et al., 2014). Surface freshwater, groundwater, and coastal water are the three types of water resources considered in this study. These resources are especially valuable to people since they are close to human settlements and so are heavily impacted by human activities.

Bali, a tropical island in central Indonesia, is home to 5 million people and a major tourist destination. In the last decade, there have been multiple water crises caused by rising water demand, and land use change (Rosenberg R, 2018). The crises are exemplified by excessive groundwater

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extraction (SISKA et al., 2018; Telegraph, 2019; Wright T., 2020; Yamamoto et al., 2021) which cause land subsidence and flooding (Yastika et al., 2020), coastal pollution (Pramaningsih et al., 2023; Suteja et al., 2024), river and the Subak (traditional irrigation system) pollution (Eryani et al., 2021; Pertiwi et al., 2019; Geria et al., 2023; Aryastana et al., 2020). While these problems are well studied, they do not result in effective policy alleviating them. (Cole, 2012) This applies not only to Bali, but also to other provinces in Indonesia (Widianingsih et al., 2020).

Internet of Things (IoT) devices have already been researched in the context of IWRM (Narendran et al., 2017; Roman et al., 2017; M. Singh et al., 2021), demonstrating their effectiveness in data acquisition and quick response. We contend that establishing a network of sensors that continually monitor basic water resources parameters and provide data that is freely available online to the public and policymakers, would offer a push to implement Integrated Water Resources Management also in Bali.

In this study, we present a prototype of a low-cost IoT device that can be equipped with a variety of commercially available sensors that collect water-related data. When finalized, they will function autonomously, relying on solar power and a battery to interact with the cloud, where data can be saved and analyzed. Such devices will be put in the environment to offer real-time data that may be saved in a database and shown in an easy-to-understand format.

Methodology

To ensure off-grid operation, the prototype was designed with a Lithium Polymer (Li-Po) rechargeable battery a solar array and a power management system. To achieve a long-range data transmission LoRaWAN technology has been selected. Importantly, the device was made from off-the-shelf electronic components, so it could be assembled on a large scale, while keeping the costs low. Some of the important design aspects and challenges have been discussed in a review by (Y. Singh & Walingo, 2024).

Hardware: Based on the objectives stated above, we have chosen the core component of the device as ESP32-based board. The main CPU can be powered off and use the low-power co-processor to constantly monitor the peripherals. The board also includes an integrated RTC (real time clock) that enables the system to wake from deep sleep, and 23 GPIO (General Purpose In Out) pins that allow connection to peripheral devices such as radio communication, battery management, and sensors. Data transmission was achieved by LoRa Module RFM95W (Semtech), which can be tuned based on the region of application, including the 923-925 MHz “AS2” band, used in Indonesia. The hardware schematics is shown in Figure 1.

Power supply in the current prototype was ensured by a 1W polycrystalline silicon solar cell coupled with a charging circuit (Adafruit), a 300 mAh LiPo Battery (3.7-4.2V) and two DC-DC converters for a stable 5V supply to the MCU and 3.3V to the peripheral devices. When the MCU is in deep sleep, the second converter is powered down, which concurrently powers down all the peripherals to save power.

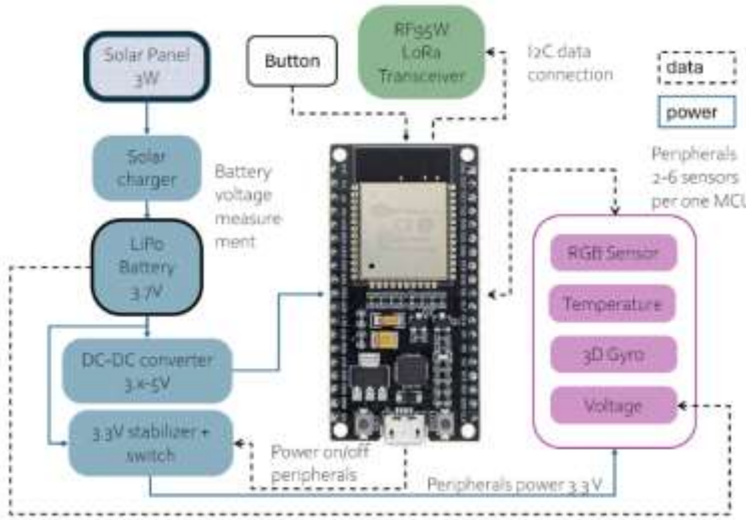

Figure 1. Diagram of the MCU, power management, radio and peripherals.

The acquisition of environmental and diagnostic data was achieved by off-the shelf components that have been procured in an online marketplace. Temperature was measured by DS18B20 (Texas instruments) communicating though the one-wire protocol. Wave intensity will be inferred by a three-axis accelerometer GY-521 (MPU6050). Water quality is to be inferred optically, by TCS34725 RGB Sensor with a CMOS chip and white LEDs by the color and intensity of the scattered light. The higher the level of scattering, the higher is water turbidity. Yellow or green tint suggests contamination with clay or algae respectively. Battery level was determined by a voltage splitter. A device fitted with these sensors can be used for coastal water monitoring – water temperature, waves and water colour and turbidity.

The software has been programmed in C++ in an object-oriented programming fashion (OOP). The code was structured to ensure modularity and ease of maintenance as shown in Table1. Each sensor and functionality are encapsulated in its own class, promoting reusability and scalability, with distinct sections handling different aspects of the device's operation, such as sensor management, data encoding, network communication, and user interaction through a web server.

Table 1. Main loops and subroutines

Function name	Description
setup	Initial system setup, sensor initialization, LoRa configuration.
loop	Continuously monitors input, sensor data and communication.
gotoSleep	Transitions the device into deep sleep mode – save power
blinkLed	Utilized for diagnostic purposes, flashes the onboard LED.
hex2bytes	Converts hexadecimal strings into arrays, for processing network keys.
initDevice	Establishes a WiFi AP and starts a web server for configuration.
dateTime	Provides formatted strings representing the current date and time.

requestNetworkTimeCb	A callback function that synchronizes the device's RTC with network.
ReceiveCallback	Manages incoming LoRaWAN messages, processing received data.
readSensorData	Gathers data from sensors and prepares it for transmission.
sendtoLora	Dispatches formatted sensor data across the LoRaWAN network.

Data relevant to the device's operation, such as network keys and configuration settings, were encapsulated within the Preferences object. This object manages access to persistent storage, ensuring that data integrity and encapsulation are maintained. The software uses open-source libraries, sourced from GitHub. The overview of the utilized libraries is shown in Table 2.

Table 2. Libraries utilized in the code

Library name	Description
CayenneLPP	Facilitates data formatting for efficient transmission.
WiFi	Manages wireless network connections.
ESPmDNS	Provides multicast DNS capabilities.
AsyncTCP	Supports asynchronous TCP communications.
ESPAsyncWebServer	Enables the creation of asynchronous web servers.
ESP32Time	Manages real-time clock functionalities.
Preferences	Handles persistent storage of configuration settings.

Data processing and transmission: After the data was collected from the sensors and stored in the flash memory, it was converted into a low volume payload using the Cayenne LPP. This encoding has been chosen, since it is able to compress data from four peripherals into a payload of only 17 bytes. The data was relayed over LoRaWAN to the gateway. Currently in the prototyping phase, the IoT device was connected to a Sensecap M2 multiplatform gateway (Seeed Technology Co.Ltd.). The gateway was registered on The Things Network (TTN, The Things Industries), a LoRaWAN network server provider. Each packet of data was processed on the server and relayed to ThingSpeak (Mathworks Inc), where it was aggregated and displayed. The whole chain is shown in Figure 2.

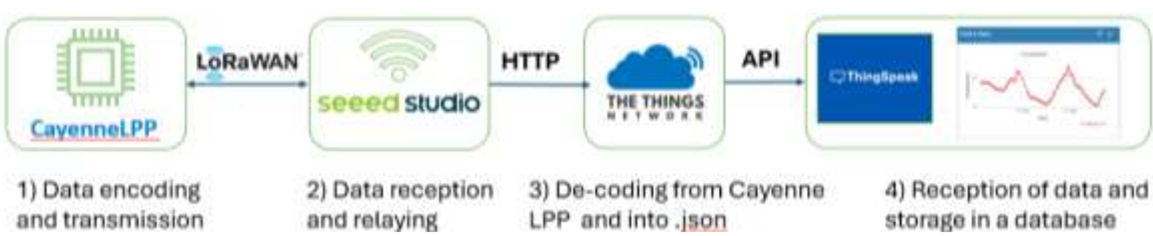

Figure 2. Schematic representation of data transfer and storage

Results and discussion

The prototype hardware has been assembled on a breadboard, allowing for flexibility in the initial stages of development. The device has been operational on solar power for two months, with the battery percentage usually staying between 60-100% charge level, leveling off in the final weeks, due to cloudy weather. The device has been only operating in room conditions to allow for long term software and hardware monitoring and power management and the data do not represent any real field conditions. So far, the hardware and software has proven a robust operating record, with good battery management, data transmission and storage, which are essential prerequisites for autonomous field operation. See the prototype and data in Figure 3. Wave intensity is currently displayed as a dimensionless index, just as is the light quality. These indices will be translated to data after device calibration in the later stages of development. The range of successful data transmission from the gateway to the device has been tested to be 5 kilometers in a rural area.

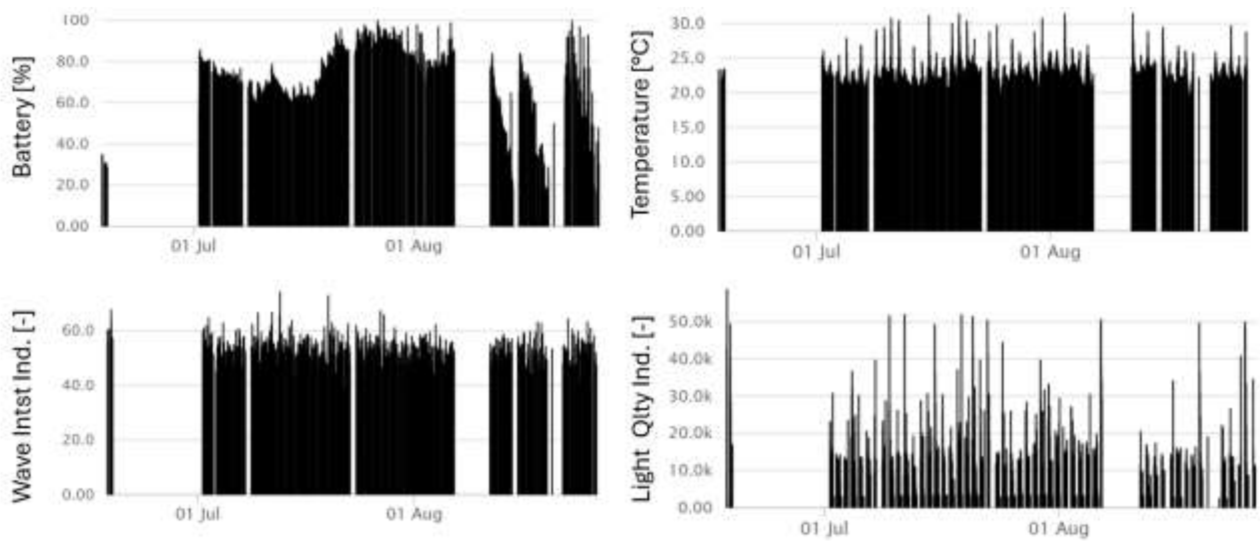

Figure 3. The data from the two months of operation are shown.

As the device is intended to be low-cost and scalable, it uses commercially available components. The cumulative price of the electronic components, sourced from an online marketplace in mainland China, used in this prototype was 400 000 IDR, around 26 USD.

While the sole price of the components does not fairly represent the total price of the device, since the price of the assembly, wiring, encapsulating and programming has not been added, it gives a general indication that the final devices can be constructed for a price of well below USD 100, while commercial IoT LoRaWAN devices monitoring a single parameter usually range in the 100-200 USD per item.

Compared to other IoT sensors, such as proposed by (Alam et al., 2021; Almojela et al., 2020; Bogdan et al., 2023) using ArduinoUNO or (R. Singh et al., 2021) that rely on ESP 8266, The ESP 32 infrastructure used in this research offers more computing power as well as more peripheral options on a compact footprint. While many IoT devices rely on WiFi or Bluetooth for data transmission, the range is not sufficient for a distributed network. Alternatively, a solution proposed by (Aarti Rao Jaladi et al., 2017) used GSM, which offers a good range and coverage, however, is energy demanding and costly for scaling. While LoRaWAN only offers a limited payload size, in the range of tens of bytes, it offers an unparalleled performance in terms of energy and range, which is the reason why it was chosen for this application. Finally, while many IoT devices presented in the literature require a power source, by careful design of hardware and software architecture, we have achieved true autonomy and off-grid operation.

Conclusion

The prototype device, powered by solar energy and equipped with sensors, has demonstrated robust performance in controlled conditions and data transfer up to several kilometers, while costing less than 30 USD in material costs, laying the groundwork for future field deployments. In the following development, the device will be created in a more compact form factor on a PCB, that can be embedded in a waterproof and transparent casing, that allows solar panel charging, but also prevents water intrusion and damage to the sensors.

The remaining number of available GPIOs on the MCU enable a simultaneous connection of 3-4 additional other sensors communication over an I2C, such as conductimetric TDS (Total dissolved solids) or ultrasound sonar for water level measurement in a well or a river. The OOP enables a quick modification of the code. The ultimate target is to create a family of three devices with suitable peripherals – to measure coastal water, surface fresh water and well/ground water.

When each of these sensors are developed and tested in the field, they can be reproduced and distributed, to form a real distributed-sensor network. The data these sensors generate will have to be interpreted in context, where the trends will be a more important indicator than the absolute value. In this regard, correlation of the acquired data with other environmental variables- such as season and rainfall, may provide useful insights into the hydrological properties of the monitored environment in Bali. The integration of this device into a broader network of sensors will enable comprehensive monitoring of water quality and availability, providing the necessary data to support IWRM in Bali and beyond. As the development progresses, the device will be refined and adapted for different water environments, ultimately contributing to a scalable and effective solution for data drive policy measures.

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