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Development of a Monitoring System against Illegal Deforestation in the Amazon Rainforest Using Artificial Intelligence Algorithms †

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Abstract: The Amazon Rainforest corresponds to one-third of the world's tropical forest area. This makes it indispensable for maintaining global biodiversity. However, the increasing occurrences of wildfires and deforestation in the region are notorious. In this sense, it is essential to protect forests to ensure the quality of life for future generations and prevent damages that affect the entire planet. In this work, a real-time monitoring device is proposed to identify attempts of deforestation through audio signals from tractors and chainsaws, using embedded artificial intelligence (AI). Additionally, it is capable of communicating with a base station, reaching distances close to 1 km in dense forest, through long range (LoRa) communication. A user interface has also been developed, providing daily alerts such as attack identification, occurrence times, device locations, and battery status. The system has an average power consumption of around 300 nA, employing power management methods defined as ultra-low power mode, sleep mode, prediction mode, and transmission mode. Hence, the device has the potential to promote the sustainable preservation of the Amazon Rainforest, helping to prevent large-scale illegal deforestation.

Keywords: illegal deforestation; Amazon Rainforest; artificial intelligence; LoRa communication; low power system

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1. Introduction

The Amazon Rainforest plays an essential role in climate regulation, capable of controlling precipitation cycles, stabilizing temperatures, and acting as a powerful 'sponge,' capturing a significant amount of Carbon Dioxide, the primary gas responsible for exacerbating global warming [1–4]. The increasing deforestation in the Amazon Rainforest represents one of the greatest threats to biodiversity, global climate balance, and the communities that depend directly on this ecosystem [5–7].

The urgent need to contain and reverse this challenging scenario has driven the development of innovative solutions, among which environmental monitoring devices stand out. In this context, the development of monitoring devices has become a promising strategy for the conservation of the Amazon.

This work aims to present a study on a specific monitoring device that aims to significantly contribute to preventing deforestation in the Amazon Rainforest. The device in question is based on the integration of technologies, including an audio acquisition sensor, LoRa communication networks, and embedded artificial intelligence, in low-power hardware. This information is processed in real-time by advanced algorithms capable of detecting patterns and anomalies, providing immediate alerts to the responsible agencies and relevant authorities.

One of the main advantages of this device is its ability to cover vast and hard-to-reach areas, allowing monitoring not only of areas near urban centers but also of remote and border regions. Furthermore, its energy autonomy and real-time data transmission capability make it a valuable tool for making agile and effective decisions.

The environmental impact of this technology is significant because its effectiveness in monitoring the Amazon Rainforest has the potential to deter illegal deforestation activities and, consequently, significantly reduce the rate of forest degradation. However, it is essential to emphasize that the implementation of this device faces challenges, such as the cost of development, operation, and maintenance.

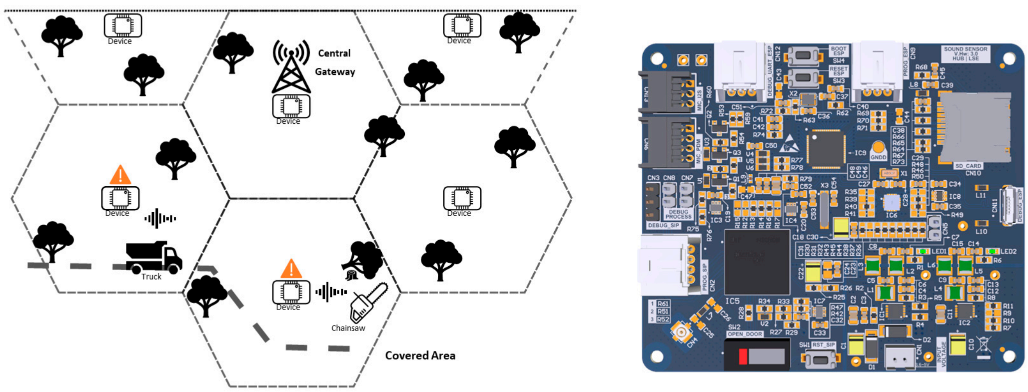
In this context, this work aims to promote a detailed understanding of the proposed monitoring device, highlighting its benefits and limitations as an important tool for the conservation of the Amazon Rainforest. The discussion on the role of technology in environmental preservation is crucial for guiding policies and practices that promote the sustainability of this ecosystem, which is vital for the planet.

2. Materials and Methods

2.1. Architecture and Hardware Device

The proposed monitoring system should be capable of covering regions of the Amazon Rainforest and identifying deforestation attempts through the acquisition of sounds from trucks and chainsaws. The system has a Central Gateway responsible for centralized communication of the devices, using LoRa wireless communication. Figure 1a illustrates the architecture of the monitoring system, with devices installed in the forest region, covering areas with a radius of approximately 1 km between the communication nodes and the Central Gateway.

The developed hardware device consists of an embedded electronic system with the main components being an SD Card module, digital microphones, and microcontrollers. One microphone (VM3011-U1) is responsible for waking up the system from low-power mode and energizing the main systems, while the second microphone (SPH0645LM4H-B) is responsible for collecting audio data for artificial intelligence processing. A microcontroller (HTLRBL32L-10) is dedicated to managing the system's power and transmitting LoRa packets. Another microcontroller (ESP32-U4WDH) performs the embedded artificial intelligence processing. Figure 1b illustrates the developed electronic board.



(**a**) (**b**)

Figure 1. Amazon Rainforest Monitoring System: (**a**) System Architecture; (**b**) Developed Monitoring Device.

2.2. Embedded Artificial Intelligence

To perform the processing of the AI model, the TensorFlow Lite library was used, which can execute machine learning models on microcontrollers using very few kilobytes of memory. The primary execution environment fits within 16 KB on an Arm Cortex M3 and can run many basic models. The library has been tested on various Arm Cortex-M Series processors and has also been ported to other architectures, including ESP32 [8].

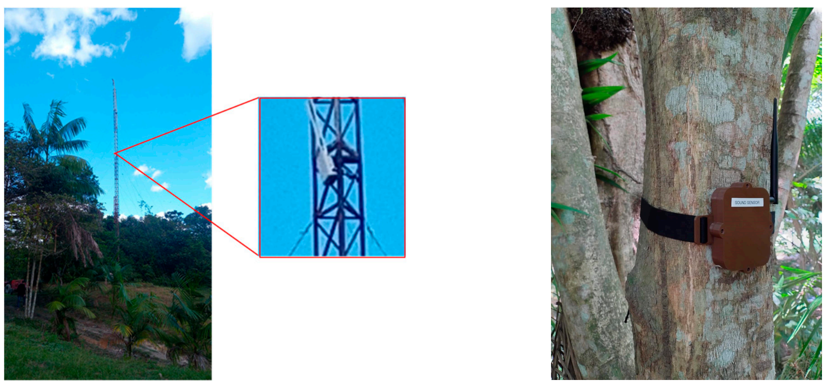
For the development of an artificial intelligence model capable of identifying deforestation attempts, audio recordings of chainsaws and tractors were initially collected in a forest environment under various conditions, including different motor acceleration levels and varying distances between the tools and the audio collection device.

The collected audio data was labeled into two classes: normalcy and deforestation. Subsequently, the audio data was segmented into 1-s samples, each composed of a vector of 16,000 values. After processing the audio, a dataset was obtained, consisting of 50,404 samples. Among these, 88% were categorized as normalcy samples, and 12% as attack samples, indicating deforestation activity.

With the dataset in hand, the training phase proceeded. In this phase, the dataset was split into two subsets: the training set with 80% of the samples and the test set with 20%. It's worth noting that this split was done in a stratified manner to ensure representative proportions of both classes in both subsets. The architecture of the neural network consists of 5 one-dimensional convolutional layers, interspersed with pooling layers. Next, a 1D Global Max Pooling layer is applied to reduce the dimensions and a dropout layer with a rate of 20% is inserted. In the last layer, a fully connected layer is applied, using softmax activation. The Nadam optimizer is used, the cost function adopted is categorical cross entropy, and the evaluation metric chosen is F1-Score. The learning rate is set to 0.001, and a mini-batch containing 256 samples is applied in the training process.

2.3. LoRa Communication and Web Application

The LoRa communication gateway was installed on a 15-m communication tower in the Ecoforest Adventure Park, located in a rural area of the Amazon region. Its purpose is to establish communication with the Sound Sensor boards installed in dense forest areas, with a maximum distance of up to 1100 m between them. Figure 2a shows the LoRa gateway installed on the Ecoforest Adventure telecommunication tower, and Figure 2b presents the device installed on a tree in the Amazon Rainforest, with its respective protective case and antenna operating at a frequency of 915 MHz and a gain of 5dBi.



(**a**) (**b**)

Figure 2. Installation of the Monitoring System: (**a**) Communication Tower; (**b**) Prototype Installed on a Tree in the Amazon Rainforest.

To visualize the monitoring data from the Amazon Rainforest processed by each Sound Sensor device, a web application was developed using the frameworks NestJS for creating the Sound Sensor API and ReactJS for creating the project's web page. The API comprises two databases, PostgreSQL (a relational database) and InfluxDB (a time-series database). It also integrates with ChirpStack, an open-source LoRaWAN server, which registers the Sound Sensor devices and receives their information via uplink.

3. Results

3.1. Energy Management

With the implementations of the device's operating modes, it was possible to measure the device's energy consumption at each stage. The average time of operation for each of the modes was also established. Table 1 presents these measured parameters.

Table 1. Measured Current Values of the System's Operation Modes.

Operation Mode	Period	Consumption
Ultra-Low Power	10 minutos	300 nA
Sleep	2 segundos	200 uA
Prediction	1 segundo	50 mA
Transmission	300 milisegundos	130 mA

3.2. AI Performance

After the completion of training, it was possible to evaluate the performance of the proposed model. The results and performance metrics achieved on the test dataset are described in Table 2, and the confusion matrix is shown in Figure 3.

Table 2. Results of the Proposed Model on the Test Dataset.

Metric	Value
Accuracy	99.6%
F1-Score	99%
Loss	0.052

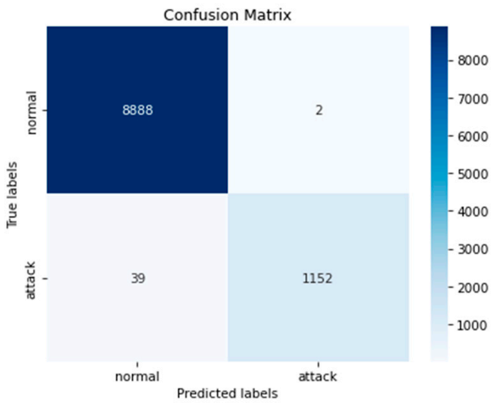


Figure 3. Matriz de confusão do modelo proposto.

3.3. LoRa Distance

The maximum message reception distance was validated through a route in the Ecoforest Adventure park. The monitoring device was programmed to send LoRa messages with 1 byte of information in the payload every 10 s during the forest journey, with the geographic coordinates of the location being recorded every 1 min. Simultaneously, the uplinks sent by the device were monitored on the developed dashboard, allowing real-time observation of received data. The coordinates were synchronized with the uplink transmission times in a .csv file. This file was loaded into the Google Earth Pro software, where it was possible to visualize the traveled path as well as the terrain elevation profile of the forest. Figure 4 shows the achieved distance of approximately 1023 m from the gateway installation point to the device and the elevation profile of the terrain along the route in Google Earth Pro.

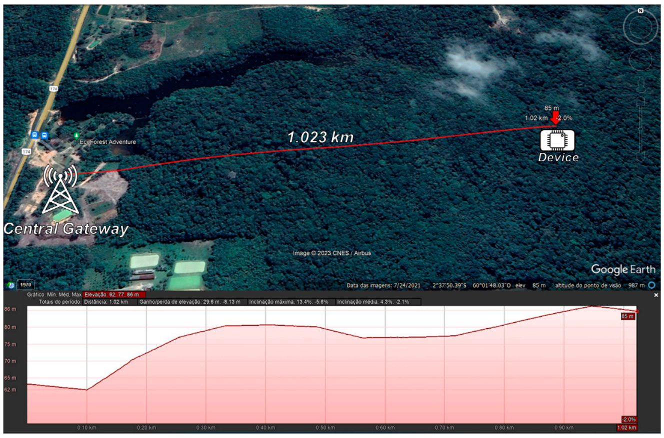


Figure 4. Validation Route for LoRa Communication Distance Between Gateway and Device, and Terrain Elevation Profile.

3.4. Data Visualization

Figure 5 depicts the web application developed, where users can view real-time data from the devices, including installation points on a map, battery levels, the last sent sample, reference point, latitude and longitude, city/state information, and predictions from the device indicating whether it is in normal operation or in alert mode. This application enables users to take preventive and protective actions for the Amazon Rainforest against deforestation.

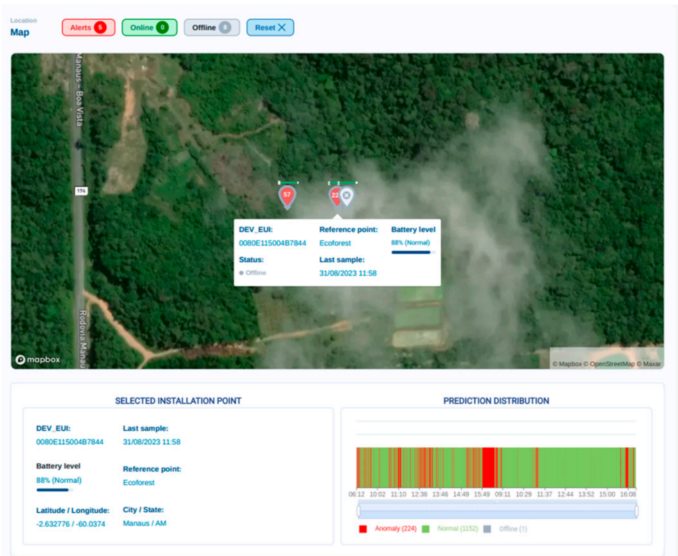


Figure 5. Real-time Web Application for Monitoring the Amazon Rainforest.

4. Conclusions

The illegal deforestation monitoring system for the Amazon involved the development of an embedded electronic device, composed of digital microphones capable of capturing the ambient sounds of the Amazon Rainforest. Through an artificial intelligence model, it identifies the sounds of chainsaws or tractors. The results of this pattern recognition are transmitted via the LoRa network, reaching approximately 1023 km, and can be viewed through a web application. The energy management system achieved ultra-low power consumption, reaching approximately 300 nA of minimum current. The developed neural network was able to accurately identify attacks with an accuracy of 99.6%, with no occurrence of false positives.

In this way, this system has proven to be an efficient means of combating the imminent illegal deforestation of the forest because it enables real-time analysis and detection of attacks. It helps maintain biodiversity, the water cycle, and carbon stocks, preserving these natural processes. Furthermore, public policies can be implemented and better managed, even allowing for the recovery of deforested areas. In this sense, this system has the potential for monitoring not only the Amazon Rainforest but also other interconnected ecosystems, promoting environmental preservation in a sustainable manner.

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