Satellite GPS Safety Beacon System

Autonomous Localization and Tracking Solution

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Contents

Chapter 1

Project Overview

This project presents the design and implementation of a fully autonomous satellite-based GPS tracking system intended for isolated or emergency environments where GSM and WiFi infrastructures are unavailable.

The objective is to create a compact and energy-efficient safety beacon capable of:

- Acquiring precise GPS coordinates
- Encoding them efficiently for satellite transmission
- Transmitting them via satellite uplink
- Processing and decoding them remotely
- Storing them in a time-series database
- Visualizing them in real time

The complete system forms an end-to-end IoT architecture.

Chapter 2

System Architecture

Figure 2.1: Global system architecture

The system pipeline is structured as follows:

1. GPS module acquisition
2. Microcontroller processing and encoding
3. Satellite uplink transmission
4. MQTT reception
5. Node-RED decoding and processing
6. InfluxDB time-series storage
7. Grafana visualization

Each component has been optimized for energy efficiency and reliability.

Chapter 3

Embedded System Design

The embedded device performs the following operations:

3.1 Coordinate Encoding

GPS coordinates (latitude and longitude) are:

1. Multiplied by 10^6 to preserve microdegree precision
2. Converted to signed 32-bit integers
3. Encoded in Big-Endian format
4. Converted into an 8-byte binary frame
5. Transformed into a 16-character HEX string

Final satellite command:

```
AT+SEND=1,0,16,1,<HEX_PAYLOAD>
```

This method reduces bandwidth usage while maintaining high positional precision.

Chapter 4

Node-RED Processing

4.1 Flow Overview

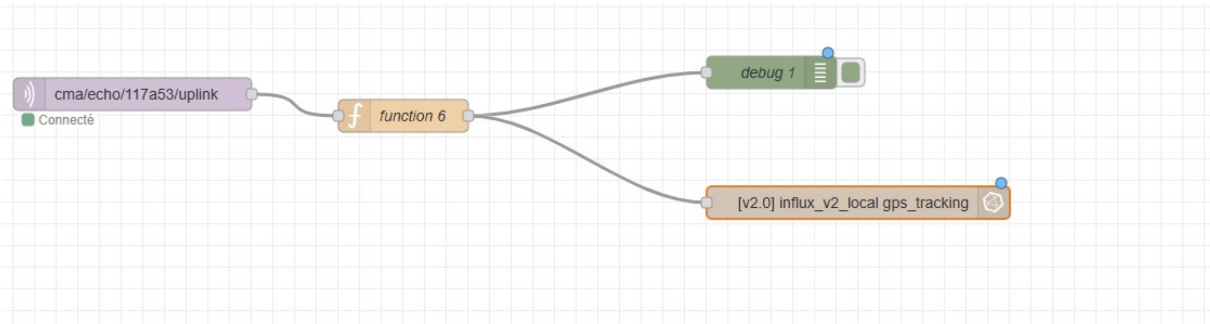
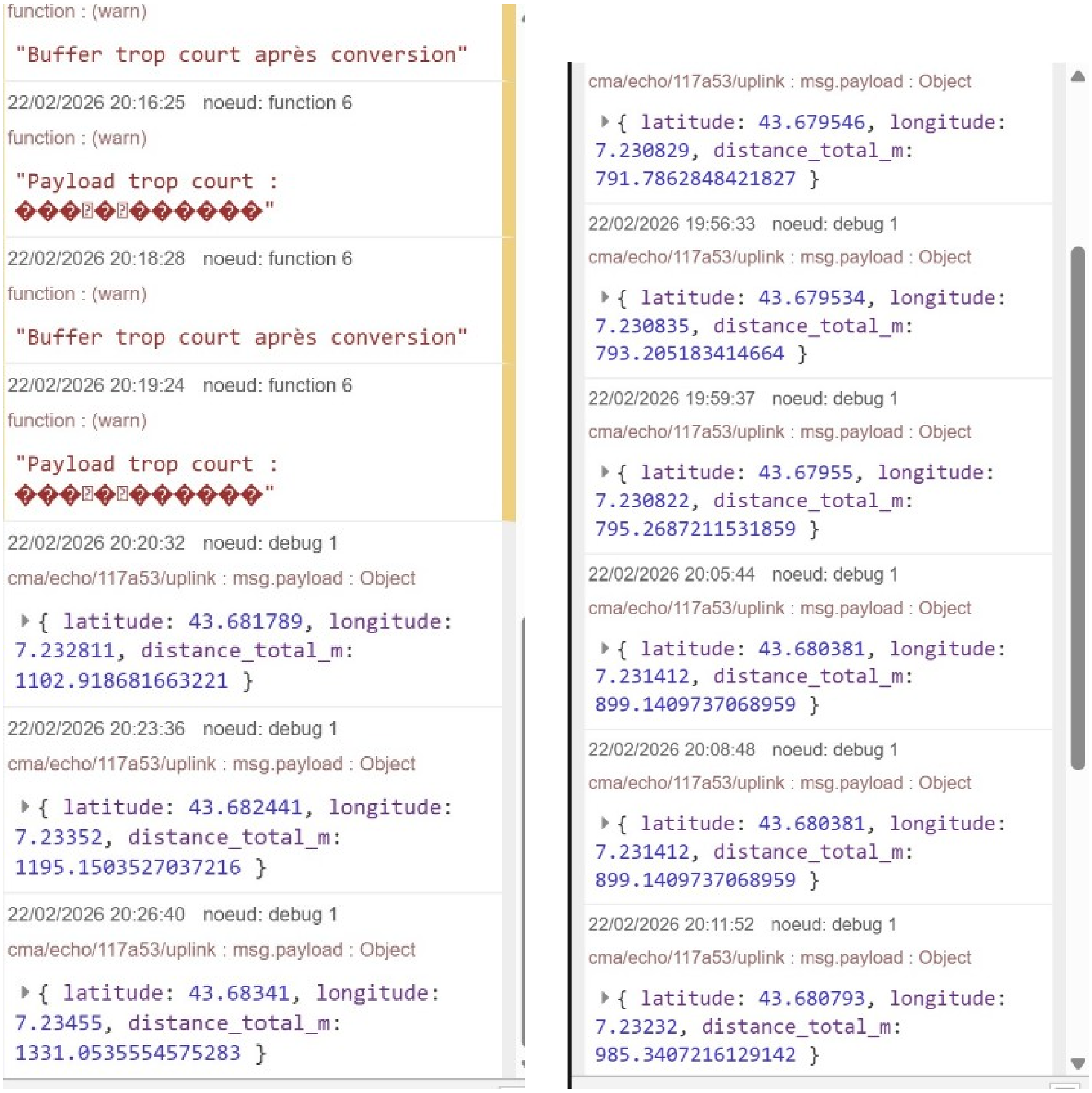


Figure 4.1: Node-RED processing flow

The Node-RED workflow performs:

- MQTT subscription to satellite uplink topic
- Base64 decoding
- HEX to binary conversion
- Big-endian integer extraction
- Distance computation
- Data forwarding to InfluxDB

4.2 Debug Validation



(a) Decoded GPS payload (b) Distance accumulation over time

Figure 4.2: Node-RED decoding and distance computation results

The decoded output confirms:

- Correct latitude extraction
- Correct longitude extraction
- Progressive distance calculation

Chapter 5

Distance Computation

Distance between two consecutive GPS points is computed using the Haversine formula:

$$d = R \cdot 2 \cdot \arctan\left(\sqrt{a}, \sqrt{1-a}\right)$$

with:

$$a = \sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_1)\cos(\phi_2)\sin^2\left(\frac{\Delta\lambda}{2}\right)$$

Where:

- $R = 6,371,000$ meters
- ϕ = latitude
- λ = longitude

The cumulative distance is stored using Node-RED flow context memory.

Chapter 6

InfluxDB Storage

6.1 Database Configuration

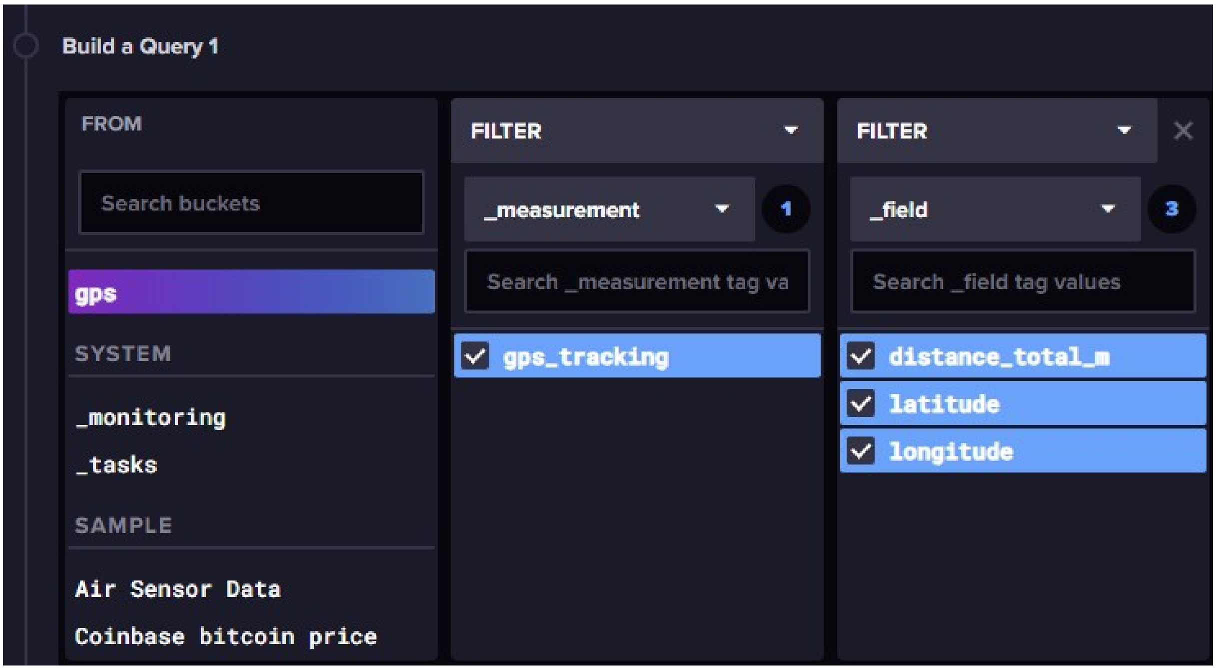


Figure 6.1: InfluxDB bucket configuration

Data structure:

- Bucket: gps
- Measurement: gps_tracking
- Fields:
  - latitude
  - longitude
  - distance_total_m

6.2 Stored Distance Data

2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 19:21:14 GM...	4,77	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 19:53:29 G...	791,79	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 19:56:33 G...	793,21	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 19:59:36 G...	795,27	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:05:44 G...	899,14	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:08:48 G...	899,14	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:11:52 G...	985,34	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:20:32 G...	1 102,92	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:23:36 G...	1 195,15	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:26:40 G...	1 331,05	distance_total_m	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:29:44 G...	1 394,48	distance_total_m	gps_tracking

Figure 6.2: Distance accumulation table

6.3 Longitude Data Example

2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 19:21:14 GM...	7,22	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 19:53:29 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 19:56:33 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 19:59:36 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:05:44 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:08:48 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:11:52 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:20:32 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:23:36 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:26:40 G...	7,23	longitude	gps_tracking
2026-02-22 15:29:56 G...	2026-02-22 21:29:56 G...	2026-02-22 20:29:44 G...	7,23	longitude	gps_tracking

Figure 6.3: Longitude field values in InfluxDB

Chapter 7

Visualization with Grafana

7.1 Trajectory Visualization

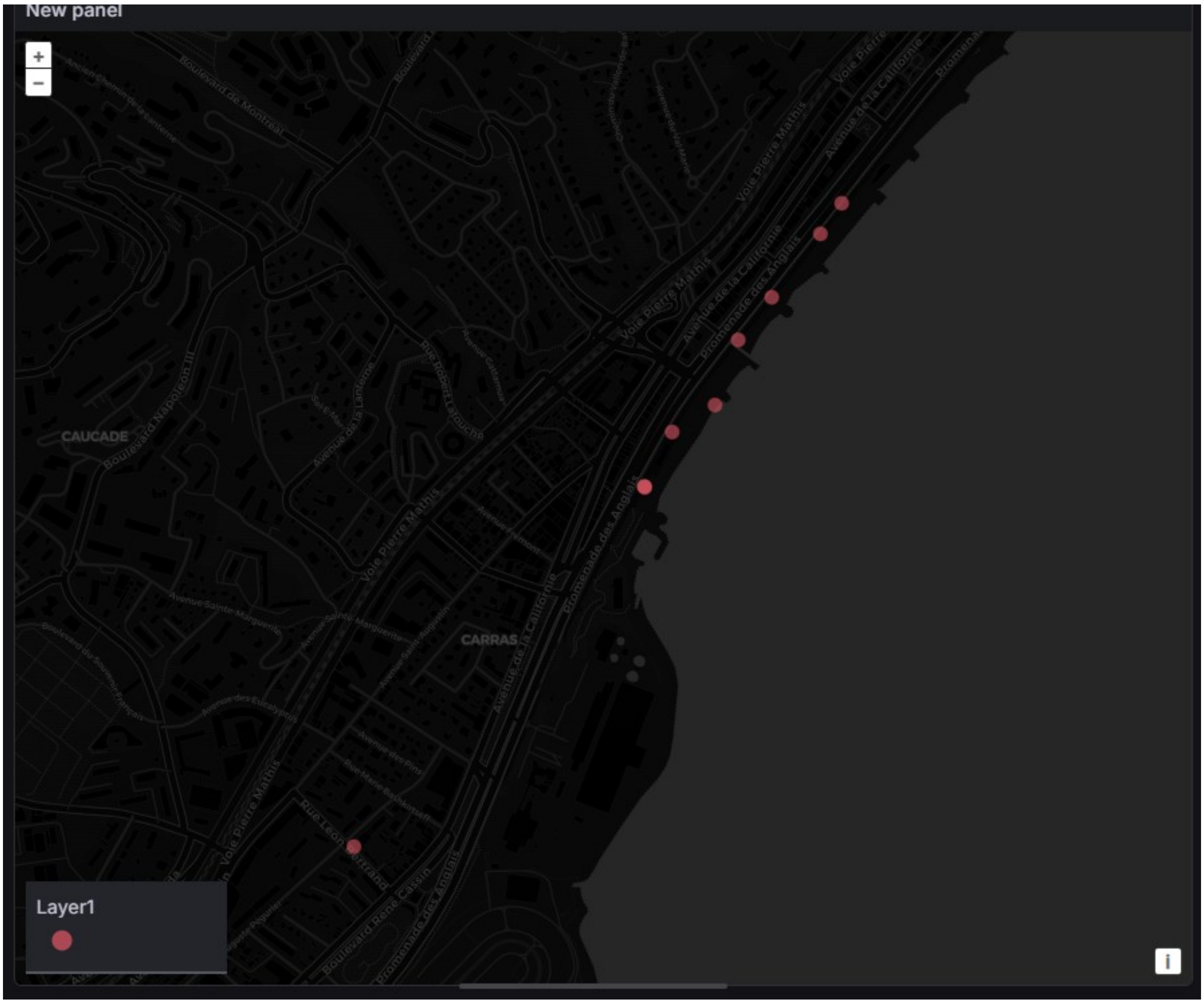


Figure 7.1: Grafana real-time trajectory

7.2 Detailed Map View

Figure 7.2: Detailed trajectory path

7.3 Data Inspection

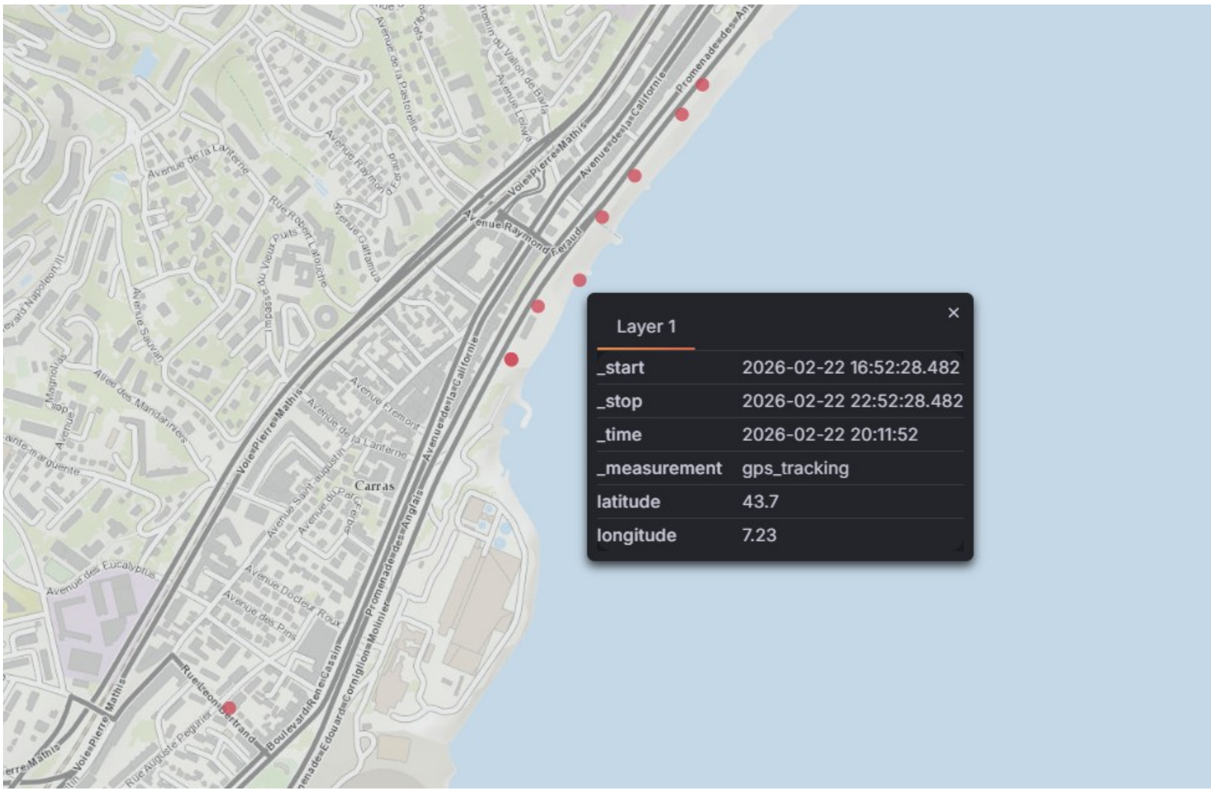


Figure 7.3: Detailed point information

Chapter 8

Node-RED Dashboard Interface

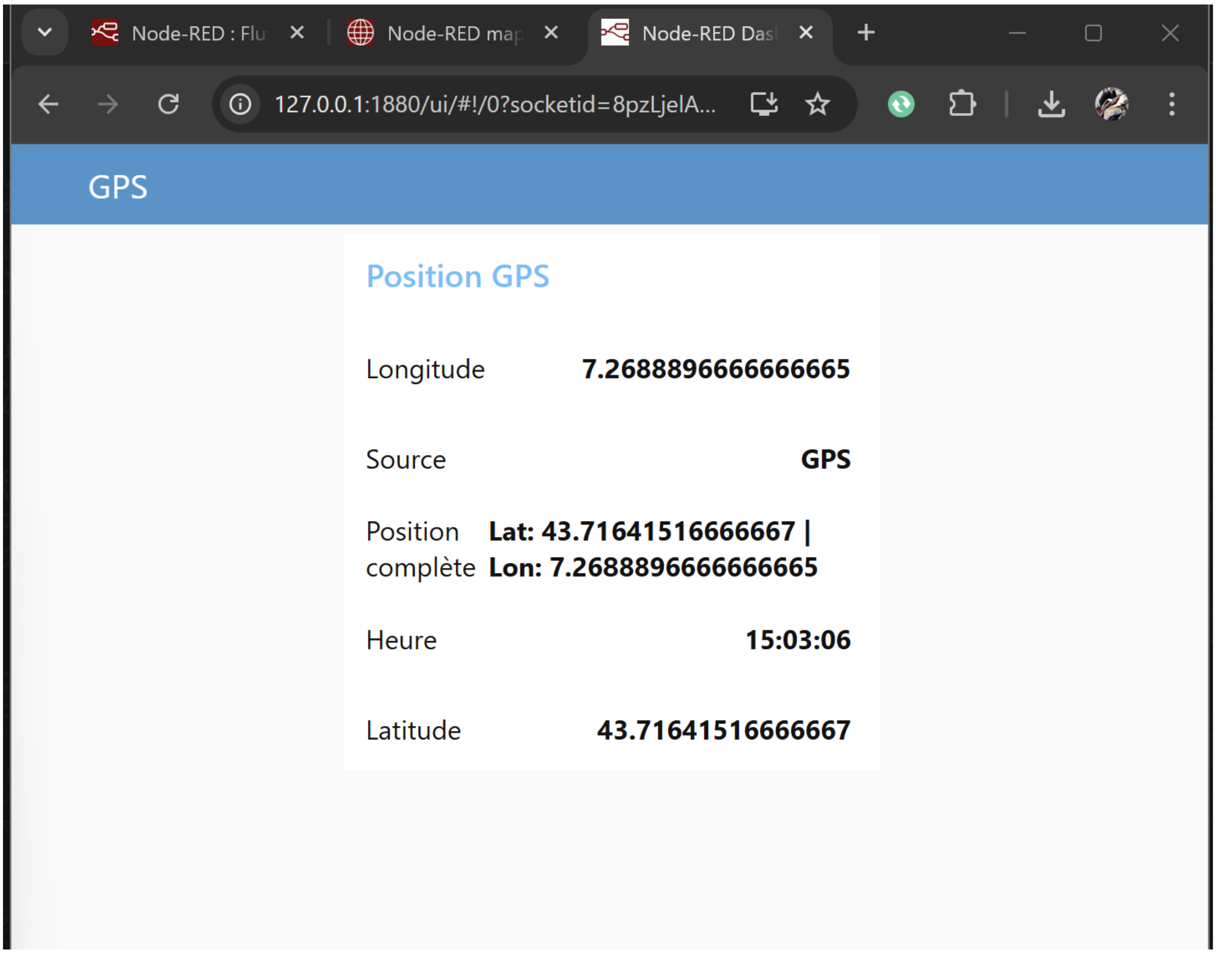


Figure 8.1: Live GPS dashboard interface

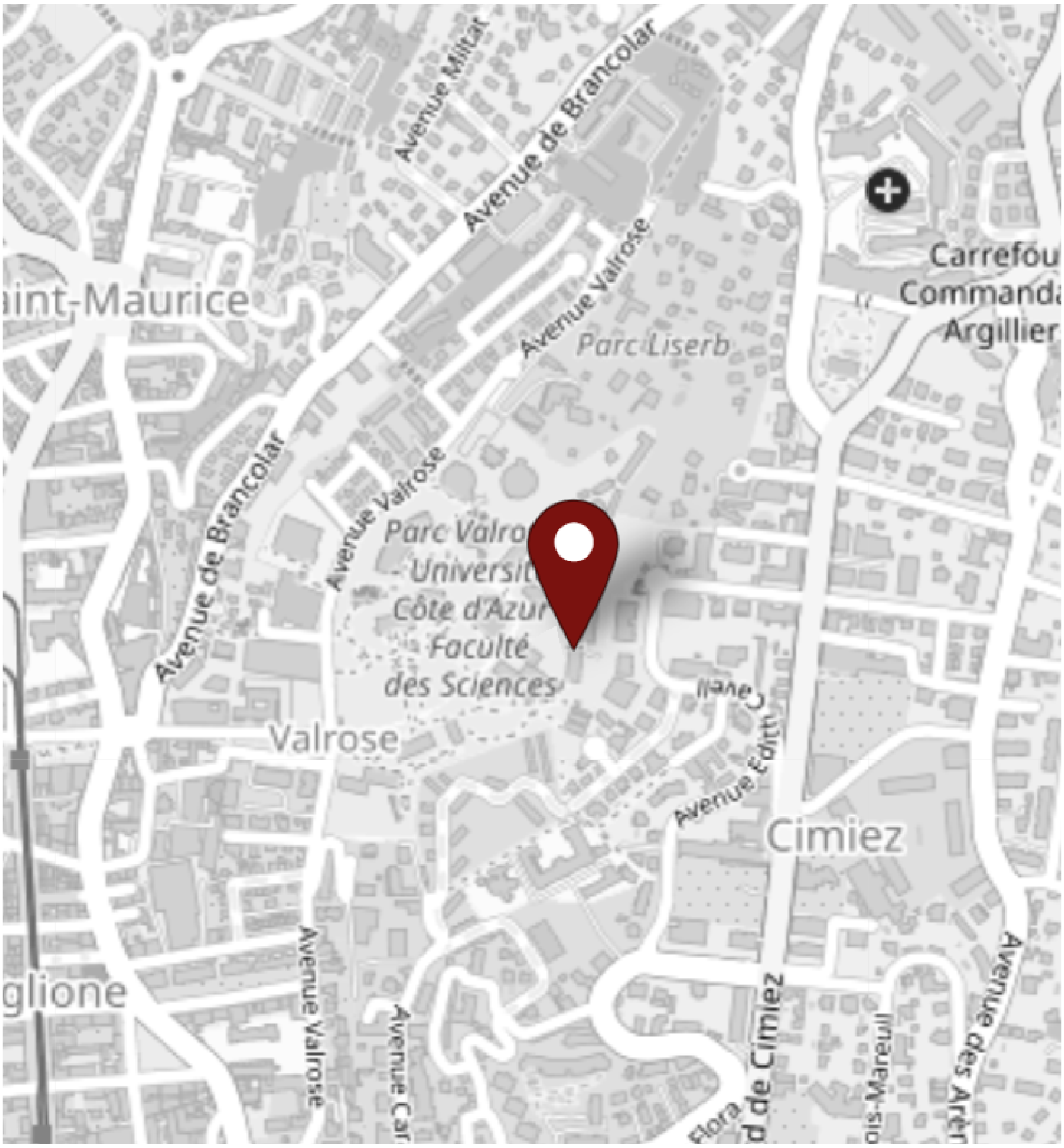


Figure 8.2: Position displayed on interactive map

The dashboard displays:

- Latitude
- Longitude
- Timestamp
- Source

Chapter 9

Energy Consumption Analysis

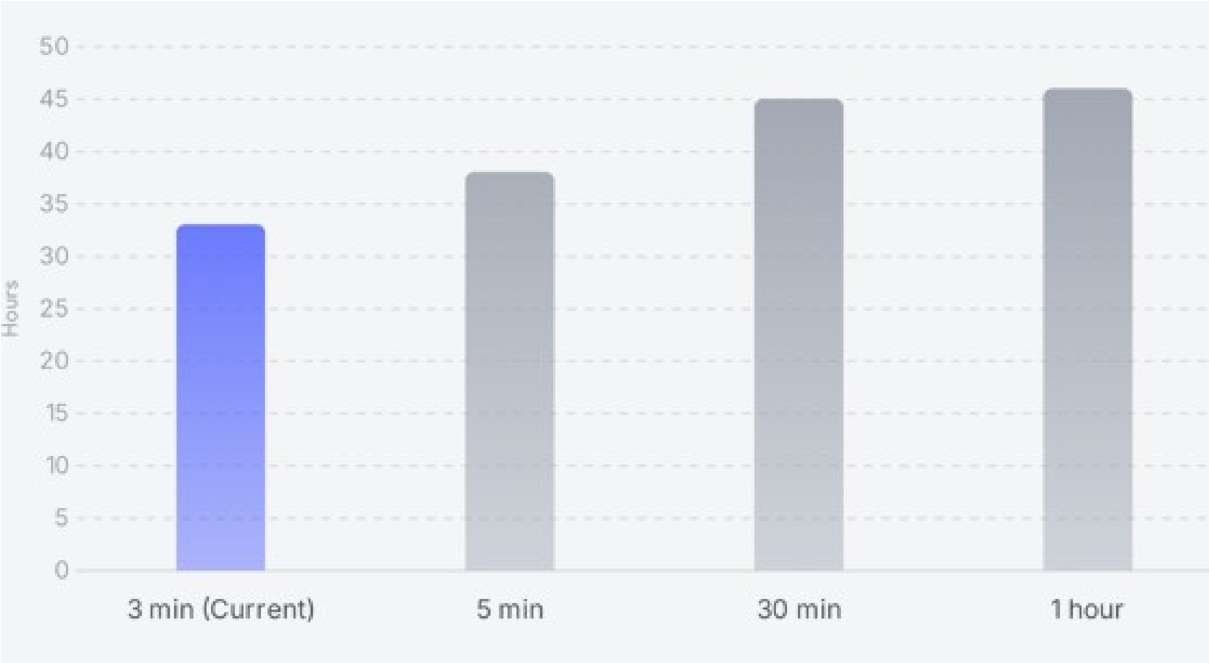


Figure 9.1: Battery autonomy depending on transmission interval

Battery characteristics:

- Capacity: 10,000 mAh
- Voltage: 3.7 V
- Total energy: 37 Wh

Measured autonomy:

- 3-minute interval: 33 hours
- 5-minute interval: 38 hours
- 30-minute interval: 45 hours
- 1-hour interval: 46 hours

Increasing the transmission interval significantly improves autonomy.

Chapter 10

Experimental Results

Field testing demonstrated:

- Reliable satellite transmission
- Accurate GPS precision
- Stable MQTT communication
- Correct database storage
- Real-time visualization

End-to-end chain validated:

$$Satellite \rightarrow MQTT \rightarrow Node - RED \rightarrow InfluxDB \rightarrow Grafana$$

Chapter 11

Limitations and Improvements

11.1 Current Limitations

- Satellite latency
- Energy consumption during frequent transmissions
- No emergency auto-trigger detection

11.2 Future Improvements

- SOS emergency button
- Accelerometer-based fall detection
- Adaptive transmission rate
- Compact PCB design
- Waterproof casing

Chapter 12

Conclusion

This project demonstrates a complete autonomous satellite GPS tracking solution combining:

- Embedded systems
- Efficient binary encoding
- IoT backend processing
- Time-series database management
- Real-time visualization

The system is suitable for rescue operations, remote monitoring, and extreme environment tracking applications.