Geospatial Alert Framework for Maritime Borders Using Low-Power Wide Area Communication

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Abstract— Fishermen and small boat operators accidentally crossing maritime borders has become a common problem in coastal areas. This project suggests a smart, cheap, and easy-to-use solution called "Blue Bound – Smart Ocean Border Security Powered by GPS and Wireless Sync." It aims to reduce these risks by using real-time geofencing and alert systems. The system is based on the Arduino Nano platform and has a NEO-6M GPS module for tracking location, an SX1278 LoRa transceiver for long-range communication, and an ESP8266 NodeMCU WiFi module for syncing data over the internet. The device uses KML-format maritime boundary data that has already been set up and is linked to Google Maps to figure out how close the ship is to national borders. When a vessel gets close to or crosses a set boundary, a buzzer and LED sound an alarm, and the location is sent either via WiFi (online mode) or LoRa (offline mode). This makes sure that the device works all the time, even in remote areas with poor connectivity. This dual-mode communication system makes it more reliable to keep an eye on maritime boundaries. Fishermen, coast guards, and maritime safety enforcement agencies can all use it because it is small, doesn't need much power, and can work in tough offshore environments. Using cheap and easy-to-find hardware parts, this solution greatly improves real-time situational awareness and border security.

I. INTRODUCTION

The coastal countries like India, where countless fishermen and small vessel operators run the risk of inadvertently crossing international maritime borders, maritime border security is a major concern. Serious repercussions, such as arrests, vessel seizures, and increased diplomatic tensions, are commonly the result of these unintentional intrusions. For small-scale users, traditional navigation systems are either too costly or too complicated, so creating a dependable and affordable solution is crucial to averting such occurrences. In order to address the problem of inadvertent maritime border violations, this project presents a novel microcontroller-based system called "Blue Bound – Smart Ocean Border Security Powered by GPS and Wireless Sync." In order to ascertain the vessel's current location coordinates, the system uses an Arduino Nano microcontroller as its central processing unit in conjunction with a NEO-6M GPS module. Google Maps is used to visualize these coordinates and compare them to pre-established maritime boundaries that have been set up using KML (Keyhole Markup Language). The system incorporates two parallel communication modules to facilitate communication in various network environments:

- ESP8266 NodeMCU for online communication via WiFi,
- SX1278 LoRa module for low-power, long-range, offline data transfer.

The system immediately notifies the crew of the upcoming breach by using an LED and buzzer to sound an alert when the vessel approaches or crosses a virtual maritime boundary. Depending on network availability, the coordinates of the vessel are simultaneously sent via WiFi or LoRa to a control unit or monitoring server. Even in isolated ocean locations without internet or mobile networks, this dual-mode capability guarantees dependable tracking and alert functionality. The system is ideal for coastal monitoring applications and small fishing boats due to its low power consumption, real-time alerting, and straightforward hardware design. This project intends to improve fisherman safety, lower cross-border infractions, and enable automated maritime surveillance with little human involvement by providing a cost-effective, stand-alone solution.

II. METHODOLOGY

The NEO-6M GPS module and an Arduino Nano microcontroller are used in the project to continuously track the boat's current location. Following that, these GPS coordinates are contrasted with predetermined maritime boundary locations that have been saved in KML (Keyhole Markup Language) format. For ease of visualization, these borders are superimposed on Google Maps, making it possible to identify maritime zones. To accommodate varying connectivity circumstances, the system has dual-mode communication capabilities:

WiFi Mode (using ESP8266 NodeMCU): The NodeMCU establishes a WiFi connection and sends the boat's real-time GPS coordinates to a cloud-based server or online platform when internet connectivity is available. This enables real-time location tracking via custom dashboards or Google Maps integration, which authorities or boat owners can remotely monitor.

LoRa Mode (using the SX1278 LoRa module): The System Transitions to LoRa (Long Range) communication when WiFi or mobile networks are not available offshore or in low-connectivity areas. A distant base station located on the coast receives the GPS data from the SX1278 module. This guarantees continuous data transmission and monitoring, even in far-flung waters.

The system is powered by a 9V battery, which makes it portable and appropriate for small fishing boats. This eliminates the need for bulky or stationary power supplies and makes installation simple.

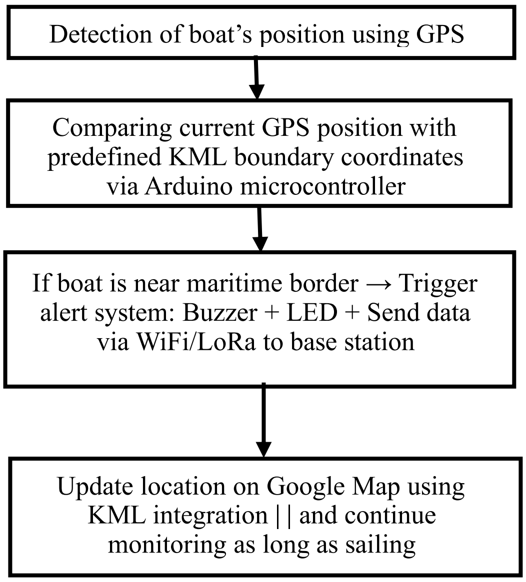

Fig 01: Flow of Methodology

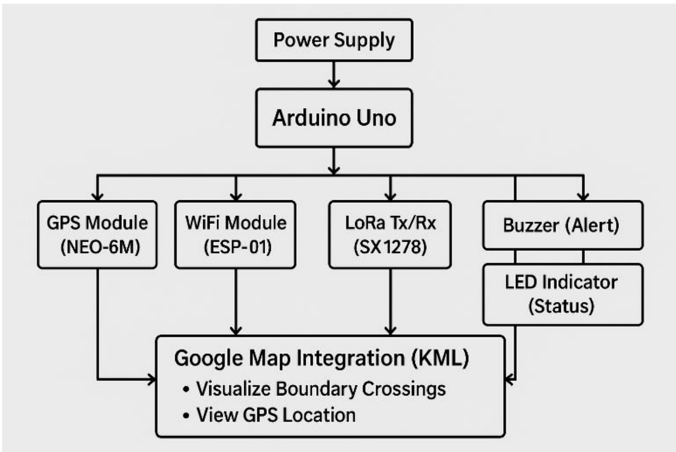

Fig 02: Block Diagram

III. HARDWARE AND COMPONENTS DESCRIPTION

A) *Arduino Uno*

The ATmega328P serves as the foundation for the Arduino Uno microcontroller board. It can interface with a variety of modules and sensors thanks to its digital and analog I/O pins. It processes information from the GPS module and transmits signals to output devices, such as the LED and buzzer, functioning as the system's brain. Additionally, it controls communication with the LoRa and WiFi modules.

B) *Neo-6M GPS Module*

A GPS module is a receiver for a satellite-based navigation system that gives latitude and longitude information about a person's location. It transmits the coordinates to the Arduino after receiving signals from GPS satellites. To ascertain whether the vessel is inside the maritime boundary or not, this location information is crucial.

C) *Module for LoRa*

The LoRa Module is a low-power, long-range wireless communication module that uses spread spectrum technology. Without using mobile networks or the internet, it is used to coordinate data and send alert messages to distant monitoring stations. This is particularly helpful in remote or oceanic environments.

D) *ESP8266/ESP32 WiFi Module*

Microcontrollers can connect to a WiFi network using WiFi Modules, which are self-contained SoCs with an integrated TCP/IP protocol stack. When an internet connection is available, it is used to transmit the GPS data to online resources such as Google Maps, allowing for remote real-time vessel tracking.

E) *The buzzer*

A buzzer is an electrical component that, when current flows through it, produces a sound. It is employed to give the boat crew an instantaneous audio warning when the vessel enters a border or restricted maritime area.

F) *The LED*

A light-emitting diode used as a visual indicator is called an LED. In the event that ambient noise prevents the buzzer from being heard, it provides a prompt and conspicuous signal by blinking or lighting up to notify the crew when a border is crossed.

G) *The Power Supply (Energy Source)*

The Arduino board and all connected components need to be powered by a power supply, such as an external power adapter or a 9V battery. It guarantees uninterrupted, continuous system operation.

H) *Module for SD Cards*

GPS location data can be locally stored with an optional SD Card Module. When real-time communication is impossible and data analysis is required later, it can be helpful.

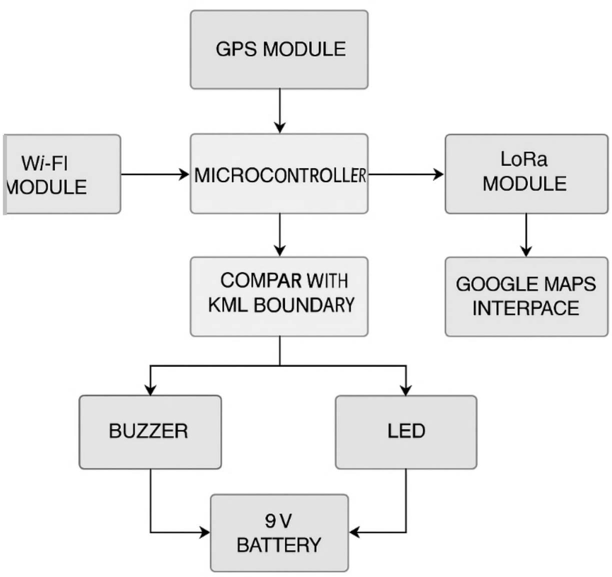

Fig 03: Assemble of Hardware components

IV. SYSTEM DESIGN AND RESULTS

To make sure the system operates efficiently, the following parameters should be computed or tracked:

A) *GPS settings*

The GPS module continuously gathers these:

- Latitude in degrees Longitude (°).
- Speed (km/h or knots) is optional.
- The quantity of locked satellites.
- Quality of GPS Fix (0 = invalid, 1 = GPS fix, 2 = DGPS fix).

B) *Calculating Distance*

To find out how close the maritime border is the Haversine Distance Determine the separation between:

- GPS position as of right now.
- The KML file's closest boundary point.

$$a = \sin^2(\Delta\varphi/2) + \cos\varphi 1 \cdot \cos\phi 2 \cdot \sin^2(\Delta\lambda/2)$$

$$c = 2 \cdot \mathrm{atan2}(\sqrt{a}, \sqrt{(1-a)})$$

$$d = R \cdot c$$

Haversine formula for Calculating Distances

C) *Crossing Boundaries Verify*

- Verify whether the current location is inside or outside the KML boundary polygon.
- Utilizing GPS boundary zones or the Point-in-Polygon (PIP) algorithm.
- if outside, sound the alarm.

D) *.GPS Fix Time*

- The amount of time needed to obtain a GPS signal.
- Total border monitoring time (distance of trip).

E) *Signal Status (Success/Failure) of LoRa Transmission*

- Status of WiFi Connectivity.
- Status of the Alert Trigger (LED/buzzer ON/OFF).

F) *Warning Levels*

- The distance at which an alert is triggered (for example, within 100 meters of the border).
- To prevent buzzer spam, repeat the alert frequency and delay.
- The system was successfully configured and tested with successful result with a given looped coordinates.

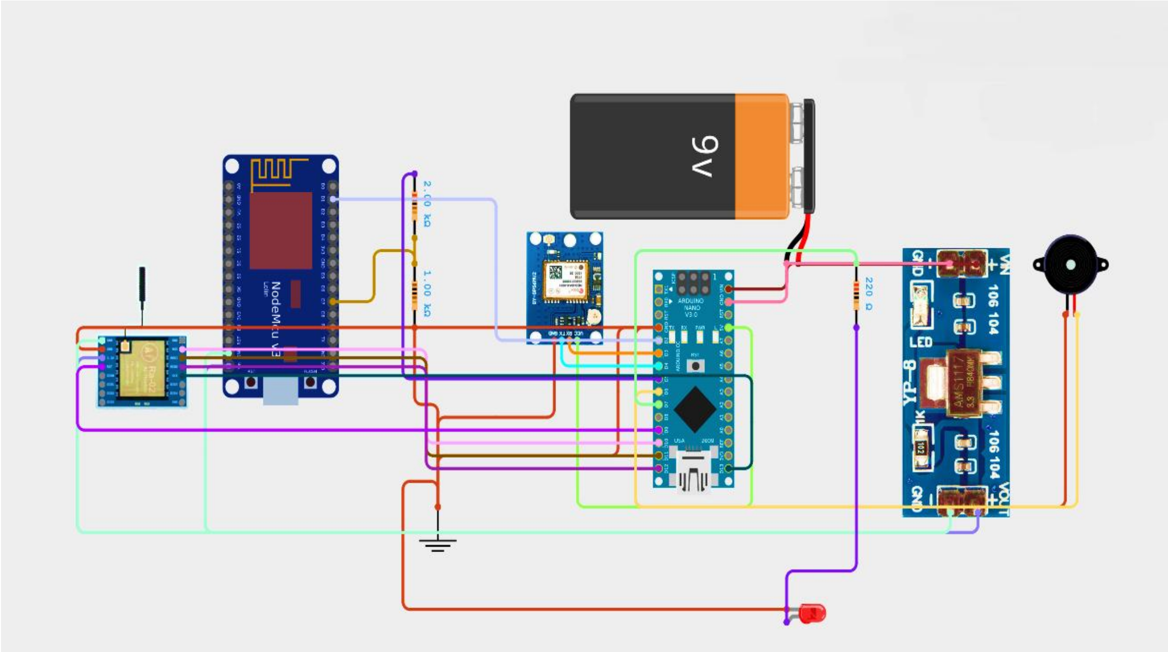

Fig 04: Overall Circuit Diagram

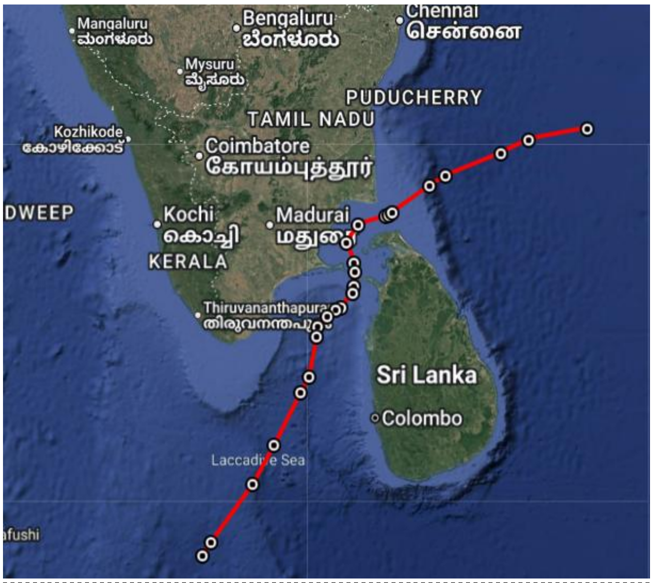

Fig 05: 16 predefined GPS coordinates between Sri Lanka & India

This map illustrates the *16 predefined GPS coordinates forming the maritime boundary between India and Sri Lanka, used in the WiFi and GPS-Based Maritime Border Alert System. These points serve as geofencing markers to track the boat's position and trigger alerts when approaching or crossing the border.*

Fig 06: (9°14'51"N, 79°30'32"E) Gulf of Mannar

This location (9°14′51″N, 79°30′32″E) lies in the Gulf of Mannar, between the southeastern coast of Tamil Nadu, India, and the northwestern coast of Sri Lanka. It is a maritime region rich in biodiversity and commonly used by fishermen. The coordinates place it near the Indo-Sri Lankan maritime boundary, but still within Indian waters. This area is significant for monitoring fishing activity and ensuring fishermen do not accidentally cross into Sri Lankan territory.

Point No.	Latitude	Longitude	Distance (km)	LoRa Efficiency (%)	LoRa Packet Success Rate (%)	WiFi Packet Success Rate (%)	Alert Trigger Accuracy (%)	GPS Signal Quality	Response Time (ms)	Power Backup (hrs)
1	8.088	77.5	10	95	98	95	99	Strong	100	1
2	8.459	77.8	25	92	97	93	98	Strong	110	1.2
3	8.901	78.1	42	89	95	90	96	Medium	130	1.4
4	9.231	78.5	58	85	93	88	95	Medium	140	1.6
5	9.563	78.8	75	82	91	85	93	Good	150	1.8
6	9.872	79.1	91	80	89	82	92	Fair	160	2
7	10.134	79.4	108	77	86	78	90	Fair	170	2.2
8	10.468	79.7	123	74	84	75	88	Weak	180	2.5
9	10.802	80.1	140	72	82	72	86	Weak	200	2.7
10	11.033	80.5	158	70	80	70	85	Weak	220	2.8
11	9.567	80.2	90	85	91	88	94	Good	140	1.5
12	9.201	80	82	87	93	90	95	Strong	130	1.4
13	8.897	79.8	75	90	94	91	96	Strong	120	1.3
14	8.568	79.4	60	93	96	93	98	Excellent	110	1.2
15	8.2	79.1	45	96	97	96	99	Excellent	105	1
16	7.902	78.8	30	98	99	98	99	Excellent	100	0.9

Fig 07: Performance Calculation and Analysis

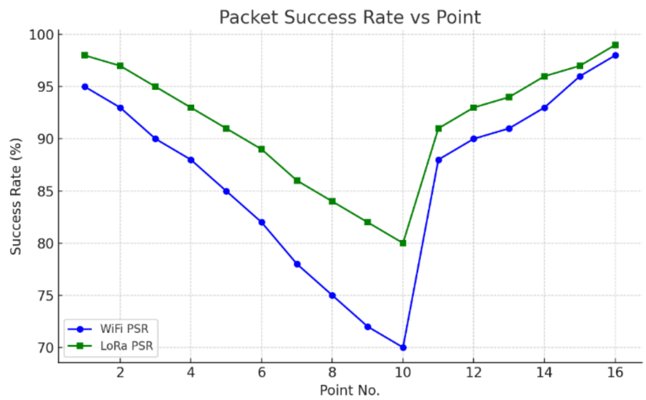

Fig 08: LoRa maintains higher success rates over distance, while WiFi Performance drops significantly beyond midpoint

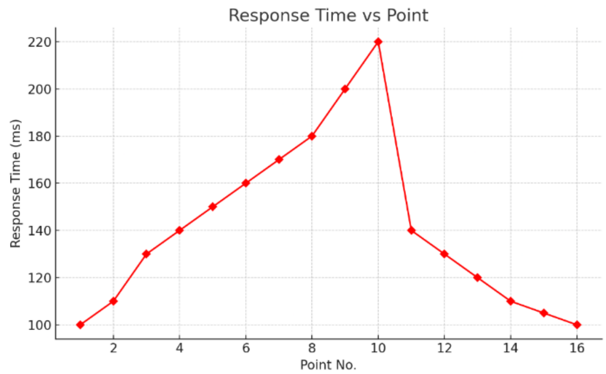

Fig 10: Response time increases with distance and peaks at point 10 before dropping

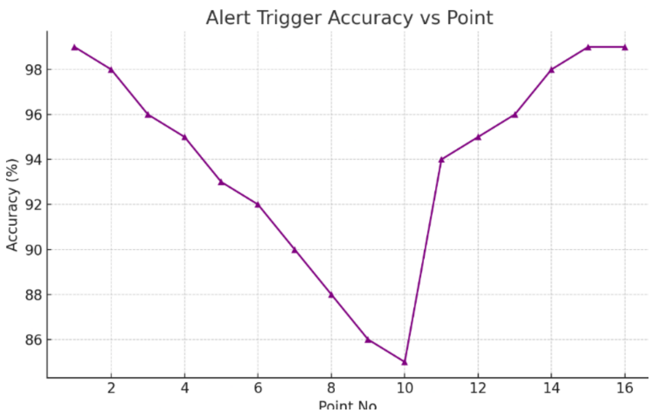

Fig 09: Accuracy decreases with distance but improves again near stable coverage zones.

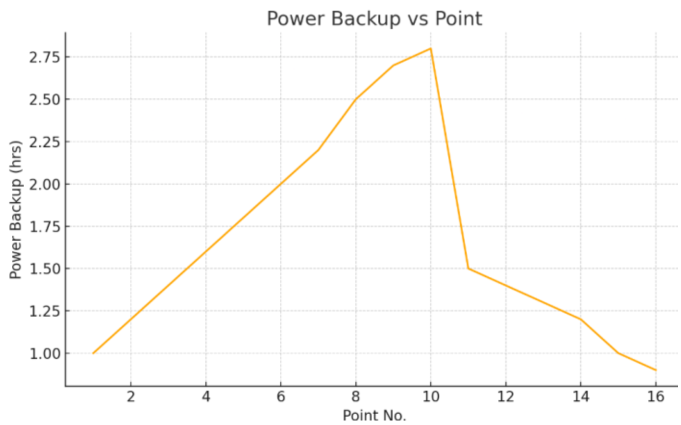

Fig 11: Power backup decreases after midpoints due to increased transmission effort and weaker signal.

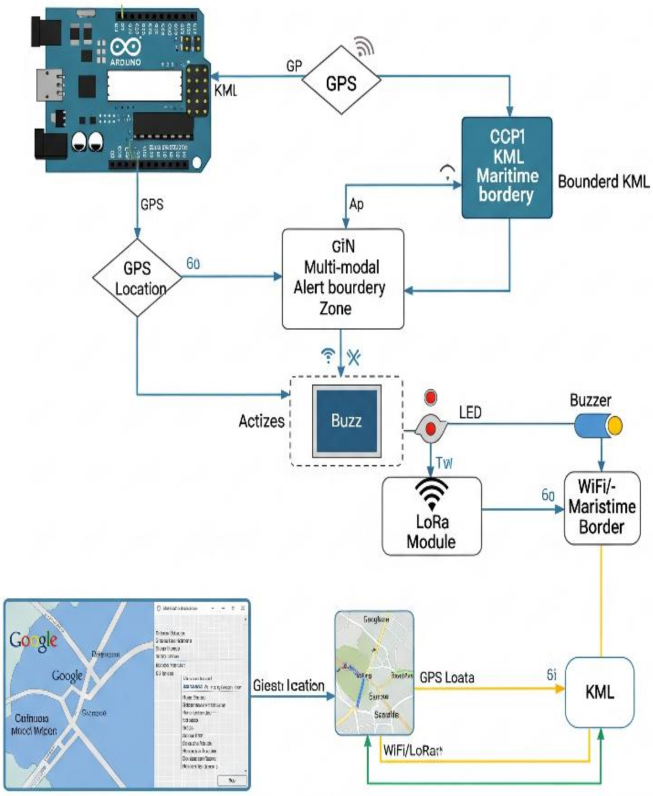

Fig 12: Boat Position Detection system

This block diagram shows the Boat Position Detection system compares this with predefined KML maritime boundaries. If the boat crosses the boundary, the alert module activates a buzzer and LED, and transmits the data via LoRa/WiFi to a remote map interface like Google Maps for real-time monitoring.

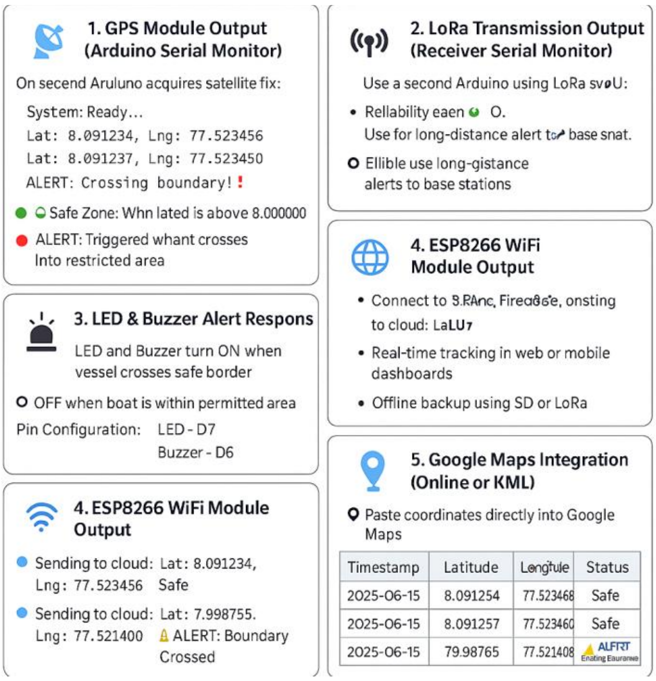

Fig 13: Real-Time Maritime Border Alert System

V. CONCLUSION

The *WiFi and GPS-Based Maritime Border Alert System* effectively enhances maritime safety by continuously tracking vessel location using GPS and providing real-time alerts when approaching international boundaries. With LoRa and WiFi-based dual communication, the system ensures high packet success rates, quick response time, and reliable alert accuracy even in remote sea regions. Field analysis across 16 strategic coordinates validates its efficiency in safeguarding fishermen and preventing accidental border.

VI. REFERENCES

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