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Original Article

Web application for lightning occurrence visualization: lightspot

Aplicativo web para la visualización de la ocurrencia de descargas eléctricas atmosféricas: lightspot

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Abstract

Introduction: this article presents the development of a web application designed to visualize data related to lightning occurrences, using information provided by the lightning location network World Wide Lightning Location Network (WWLLN)..
Objetive: the aim of this study is to develop a tool that enables the visualization of lightning data, facilitating its analysis through the use of agile methodologies such as extreme programming and Scrum..
Methodology: the development methodology of the application includes the use of extreme programming and Scrum, covering software architecture, interface design, and the execution of functional and integration testing to ensure system performance and functionality.
Results: the application was validated using lightning data from the department of Cundinamarca, Colombia, showing intense electrical activity in the Bajo Magdalena region, particularly in the municipalities of Yacopí and Caparrapí. A peak in activity was observed around 9:00 p.m. local time. The obtained results align with findings from previous studies conducted in broader areas, validating the effectiveness of the application.
Conclusions: the web application demonstrated in this article facilitates the processing and analysis of large volumes of lightning data, confirming its usefulness for studies in different regions and contributing to the monitoring of electrical phenomena.

Keywords: lightning, WWLLN, extreme programing, scrum, web application.

Resumen

Introducción: este artículo presenta el desarrollo de una aplicación web diseñada para visualizar datos relacionados con la ocurrencia de rayos, utilizando la información suministrada por la red de localización de rayos World Wide Lightning Location Network (WWLLN)..
Objetivo: el objetivo de este estudio es desarrollar una herramienta que permita la visualización de datos sobre rayos, facilitando su análisis mediante el uso de metodologías ágiles como programación extrema y Scrum..
Metodología: la metodología de desarrollo de la aplicación incluye el uso de programación extrema y Scrum, abarcando la arquitectura de software, el diseño de interfaces y la ejecución de pruebas funcionales e integración para garantizar el rendimiento y la funcionalidad del sistema.
Resultados: lLa validación de la aplicación se realizó con datos de rayos del departamento de Cundinamarca, Colombia, mostrando una intensa actividad eléctrica en la provincia del Bajo Magdalena, especialmente en los municipios de Yacopí y Caparrapí. Se observó un pico de actividad eléctrica alrededor de las 9:00 p.m. hora local. Los resultados obtenidos coinciden con los hallazgos de estudios previos realizados en áreas más amplias, lo que valida la efectividad de la aplicación.
Conclusiones: la aplicación web demostrada en este artículo facilita el procesamiento y análisis de grandes volúmenes de datos relacionados con la actividad de rayos, confirmando su utilidad para estudios en diversas regiones y contribuyendo al monitoreo de fenómenos eléctricos.

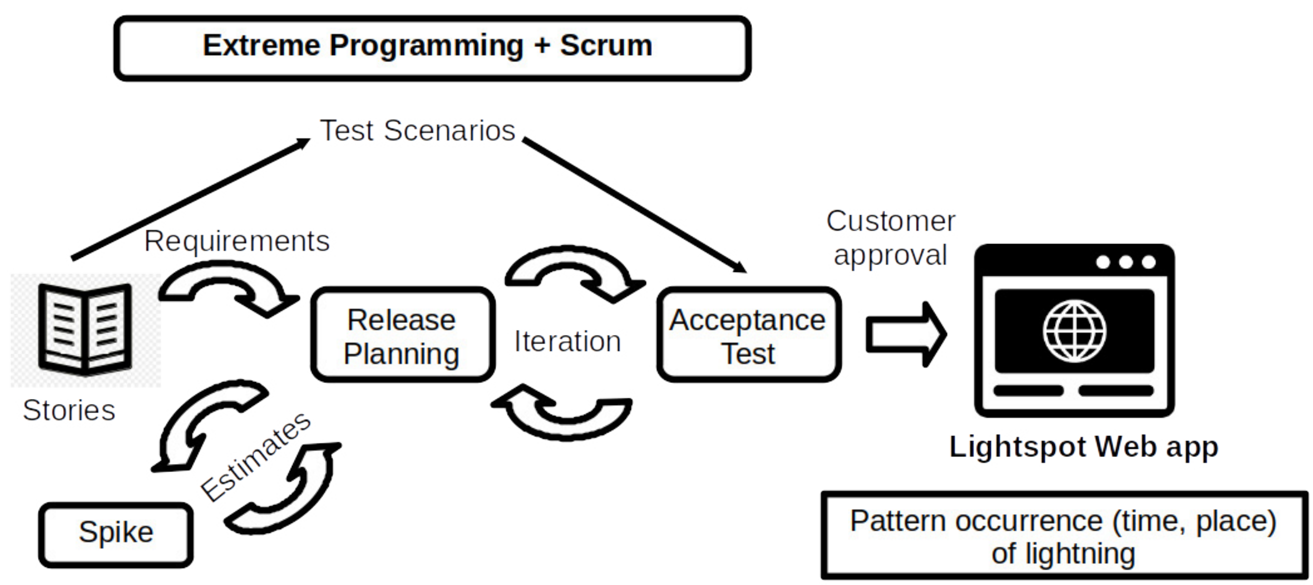
Palabras clave: rayos, WWLLN, programación extrema, scrum, aplicación web

Contribution to the literature

Why was it done?
The web application was developed as a tool to process lightning data and identify occurrence patterns. This capability allows users to determine when and where lightning events occurred, supporting enhanced understanding and planning to mitigate lightning-related risks.

What were the most relevant results?
The two primary outcomes of this project were, first, the development of the web application guided by the combined principles of extreme programming and Scrum methodologies, ensuring an agile and iterative development process. The second significant outcome was the validation of the tool using actual lightning data, which yielded some insights into the lightning activity patterns within the Department of Cundinamarca.

What do these provide results?
The first outcome demonstrates to new researchers how to develop tools for processing lightning data, offering a framework and practical guidance for similar projects. The second outcome highlights the potential of filtering lightning data to identify occurrence patterns, which can play a crucial role in creating effective mitigation and safety plans. These results collectively contribute to advancing both methodological approaches and practical applications in lightning risk management.



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Introduction

Lightning is a natural phenomenon characterized by the transfer of electric charge, typically originating from an electrified cloud (Cumulonimbus) (1), (2). Discharges may occur within a single cloud, between clouds, into the surrounding air, or to the ground. However, under specific conditions, lightning can also accompany volcanic eruptions and firestorms (3), (4).

Most lightning occurs in the troposphere, with only about 25% reaching the ground as cloud-to-ground (CG) discharges (5). These discharges transfer high-intensity currents to the Earth, producing visible flashes and audible thunder. The rapid heating of air along the discharge path ionizes air molecules, emitting photons and generating shockwaves.

Regions with intense lightning activity are typically located in intertropical zones, where topography, rainfall, and wind patterns favor its production (6). Northern South America, consistently ranked as one of the regions with the highest lightning activity, exemplifies this phenomenon (7). Here, lightning poses significant risks to human life, animals, and infrastructure, particularly from CG discharges (8).

A study conducted in Colombia between 1997 and 2014 reported an annual lightning-related mortality rate of 1.78 deaths per million inhabitants, equating to approximately 80 fatalities per year (9). Most incidents occurred in rural areas, where outdoor activities are common. Similarly, an analysis of data from 1997 to 2014 revealed a mortality rate of 1.51 per million annually (10). Both studies rank Colombia among the Latin American countries with the highest mortality rates from lightning strikes.

These findings underscore the need to study lightning in Colombia to understand its characteristics and develop effective mitigation strategies (11). The initial step is identifying when and where lightning occurs. Such information supports the creation of climatological maps illustrating lightning activity, aiding in the development of measures to minimize the impact of CG discharges on people and infrastructure (12).

Detecting the origin of a CG discharge requires a network of sensors to monitor changes in ambient electric and magnetic fields. These networks typically include measurement stations equipped with loop antennas to detect magnetic fields in the VLF band, complemented by additional instrumentation for polarity estimation (13). Data from these stations are combined to estimate discharge origins using methods such as Direction Finding (DF), Time of Arrival (TOA), or Time of Group Arrival (TOGA) (14) (15).

Detection networks provide lightning location data, including latitude, longitude, and the discharge's estimated timestamp (16). Some networks also estimate the peak current and discharge polarity (positive or negative), depending on the available instrumentation. However, georeferenced graphical representations of lightning locations are often missing. Such visualizations enhance data interpretation, making the information more accessible to a wider audience.

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Globally, an estimated 40 to 50 lightning events occur every second, amounting to millions of discharges daily (17). Managing and plotting this massive volume of data is challenging. For example, a dataset from central Colombia contains over 80 million records spanning five years, averaging 16 million events annually or about 40,000 discharges daily. This study sourced lightning data from the first 15 days of October 2022 from the World Wide Lightning Location Network (WWLLN).

While many previous studies have identified lightning patterns, they often lack details on the tools used for data processing and pattern recognition (18), (19), (20). This study addresses this gap by detailing the development and validation of a tool for identifying lightning activity patterns. This contribution fills a critical void in existing research and provides a framework for future studies to publish validated lightning patterns using this tool.

Methodology

The Lightspot web application is designed to be an accessible tool for both the general public and registered users, enabling them to view lightning occurrence data across various regions. Its primary purpose is to provide a platform where users can upload plain text files in WWLLN format containing lightning strike records, thereby facilitating the analysis of lightning activity patterns in specific areas. Currently, the application allows users with administrator roles to upload data, making it accessible to all users. Lightspot is in the functional development stage and is planned to be launched online in the future, offering broader access and the potential for integrating new features based on user needs.

The authors developed a web application called Lightspot using a combination of eXtreme Programming (XP) selected for its emphasis on high-quality software development and Scrum methodologies that provide a collaborative framework for task management. Both methodologies emphasize teamwork, continuous feedback, and delivering software in short development cycles.

The project was organized into five iterative deliveries, or sprints, allowing for incremental progress and the delivery of minimal viable functional products. Figure 1 illustrates the six phases of the XP methodology, integrating artifacts from the Scrum framework to support iterative software development and project organization.

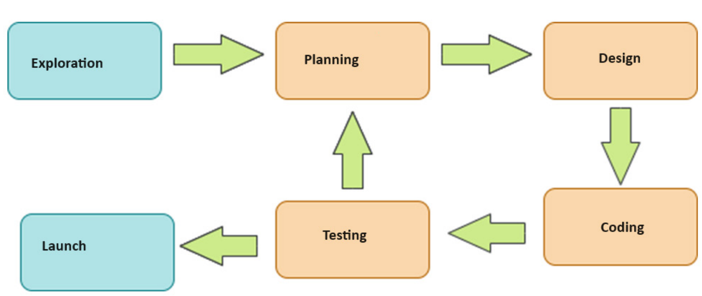

Figure 1. Methodology phases for web application development

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Requirements

Roles for project participants were defined, including product owner, development team, and stakeholders. A literature review was conducted to identify similar software developments focused on visualizing lightning. User stories were created to guide the development team in selecting suitable technologies and exploring potential software architectures. Functional requirements for the web application were gathered following the IEEE 830 standard, as summarized in Table 1.

Table 1 Web application functional requirements

Module	Cod.	Requirement
Variable Measurement	RF-1	Load text file with lightning occurrence records
	RF-2	Delete last lightning record
	RF-3	Display geographical location of lightning records
Data Visualization	RF-4	Filter map by location
	RF-5	Filter map by time
	RF-6	Display lightning record statistics in charts
	RF-7	Filter charts by time
	RF-8	Filter charts by location
Report Generation	RF-9	Generate lightning record reports
	RF-10	Filter reports by time
	RF-11	Filter reports by location
User Management	RF-12	Authenticate user
	RF-13	Register user
	RF-14	Activate user account via email
	RF-15	List registered users

The ISO/IEC 25010 standard was used as a reference for non-functional requirements, focusing on performance efficiency, resource usage, storage capacity, usability aligned with user experience guidelines, and maintainability.

Table 2 Web application non-functional requeriments

Feature	Code	Requirement
Performance Efficiency	RNF-1	Resource Utilization
	RNF-2	Capacity
Usability	RNF-3	Operability
	RNF-4	User Interface Aesthetics
Maintainability	RNF-5	Modularity

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Visual Studio Code was used for frontend development, while PyCharm was employed for backend construction. Version control was managed through a GitHub repository. MongoDB Compass facilitated database management, and Postman was utilized to send HTTP requests for validating API behavior.

Planning

In this phase, the iterative sprint process began with user stories prioritized from the product backlog. A Kanban board tool was used to manage and visualize the team's workflow across three columns: pending work, work in progress, and completed work. The development of the web application was organized into five sprints based on complexity:

First sprint: Developed user authentication, record loading from a text file, and information display on a geographic map.

Second sprint: Implemented filters on the geographic map by location (department and municipality) and time (hours and dates). Developed an interface for deleting loaded records using a drop-down list.

Third sprint: Created a dashboard with descriptive graphs of the records, enabling data synthesis for areas of interest using applied filters.

Fourth sprint: Added report generation functionality to summarize filtered information, including a table of database records.

Fifth sprint: Enabled registration of additional users and account activation via confirmation email.

Additionally, user stories were visualized using a Visual Story Mapping tool, illustrating the requirements established by the product owner.

Design

The software structure was designed to ensure a simple and adaptable data model capable of accommodating potential changes during implementation. The development team created an architecture model to visually represent the required functionalities, employing use case diagrams and mockups to illustrate user interactions with the application.

A NoSQL database was selected to efficiently manage the large volume of data provided by the WWLLN network. Additionally, a distributed software architecture was designed to support horizontal scaling in future versions, enabling the addition of nodes as data volume grows. Figure 2 presents the structure of the three database collections, with their properties detailed in JSON format.

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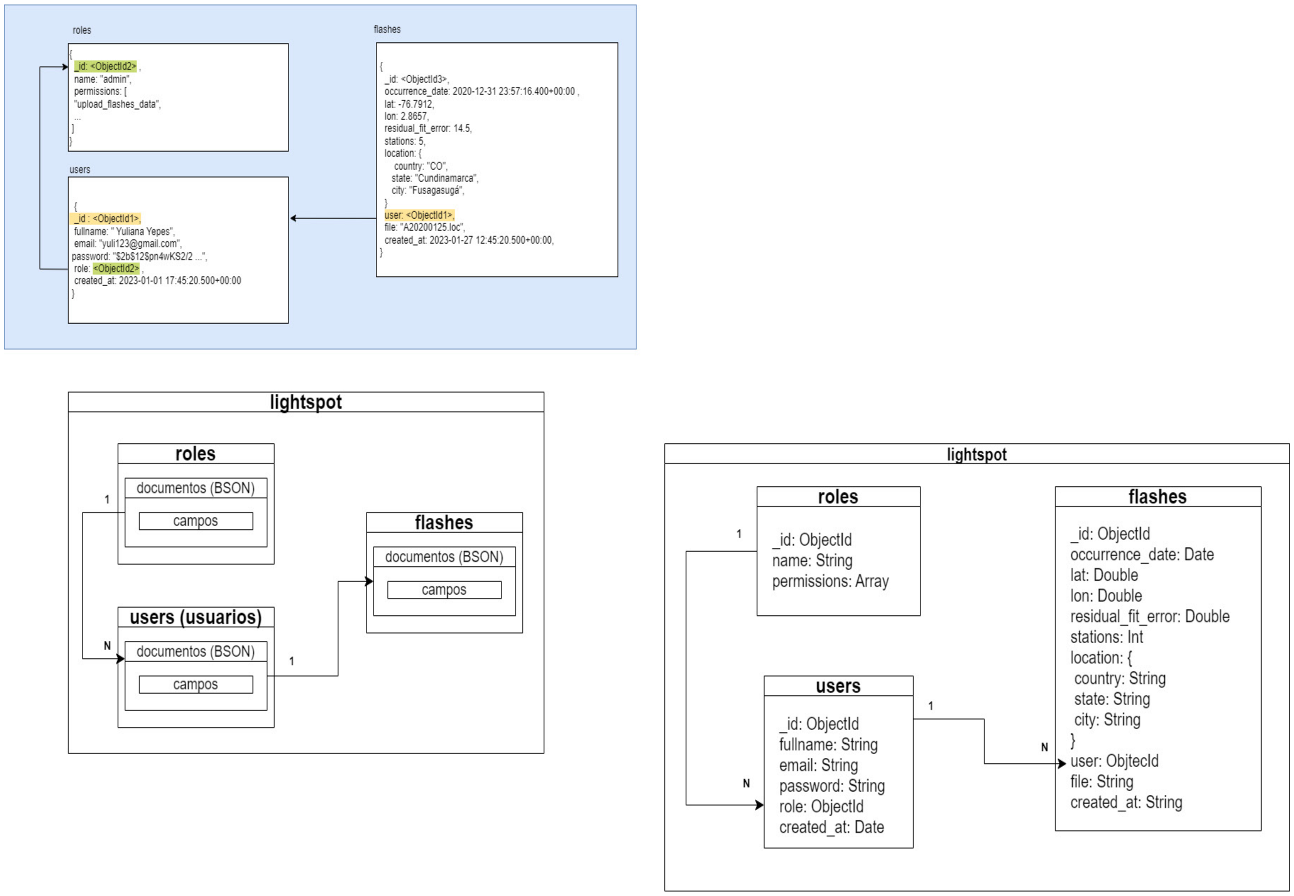

Figure 2. Collection framework representation of the web application

Figure 3 presents the case use diagram depicting the system's functionalities from the end user's perspective. The diagram identifies the actors involved and illustrates the relationships between them within the system.

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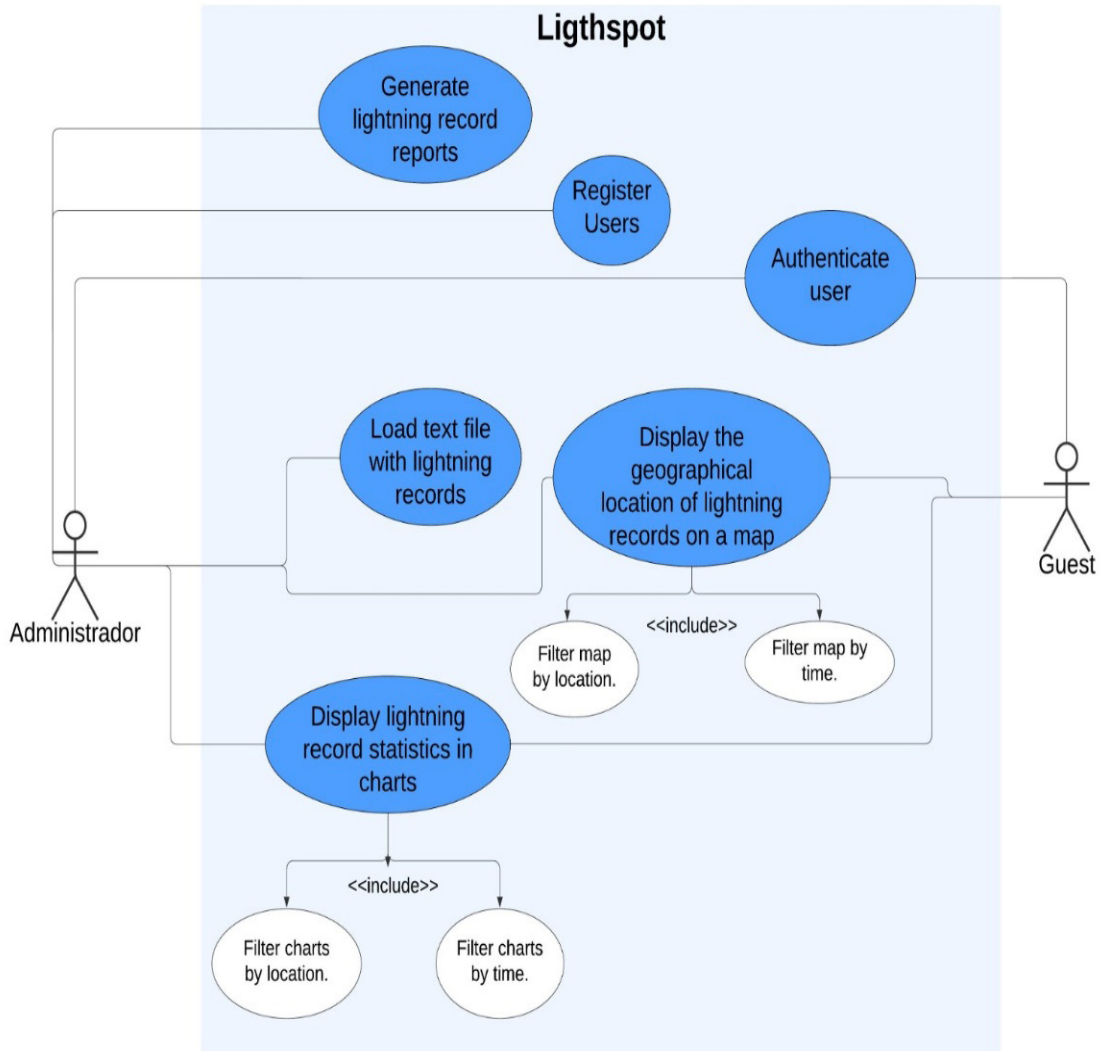

Figure 3. Use case diagram of the web application.

Model C4 was chosen as the architectural framework for the system because it effectively communicates the software structure to stakeholders, promoting product quality and scalability. Figure 4 presents the context diagram, offering an overview of the software and its environment. It identifies the relationships and actors involved in the system, as well as external systems that interact with Lightspot. Additionally, Figure 4 illustrates the software's functionalities and its communication with external services, such as OpenStreetMap.

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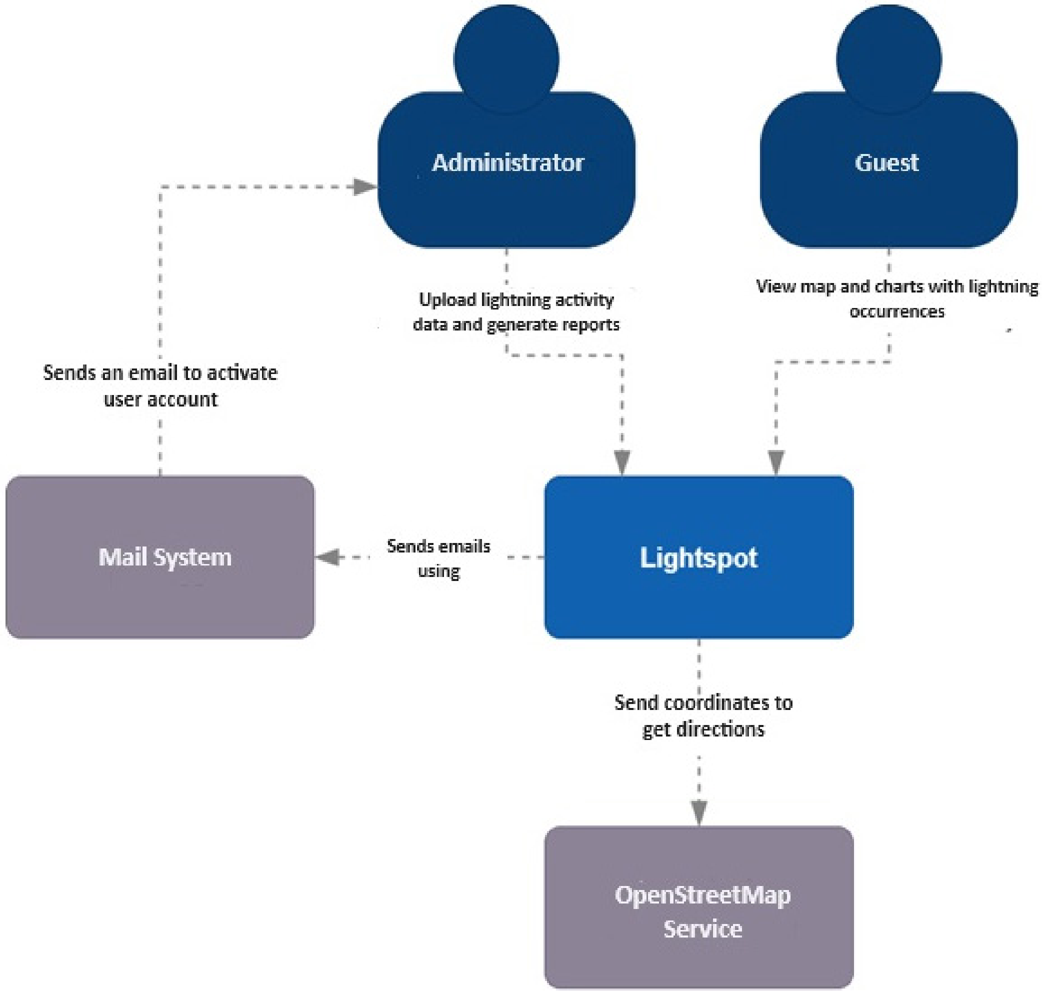

Figure 4. Context diagram showing the interactions between system and external entities.

Figure 5 describes the system components, including applications, databases, and web services. Each container is identified along with its functions and the interfaces used for communication between them. The identified containers are:

Flashes: Manages the service for uploading files, querying logs using filters, and deleting logs.

User: Handles services for the registration and listing of new users.

Role: Manages and queries roles.

Auth: Handles user authentication and permission authorization according to roles.

Report: Generates reports in PDF format.

Email sender: Sends emails using the SMTP protocol.

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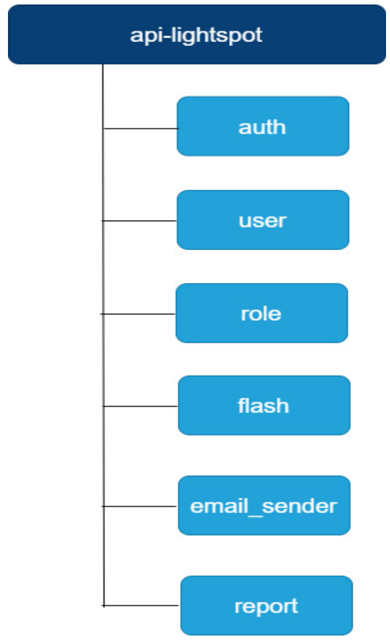

Figure 5. Container architecture of the web application.

The next development phase focused on creating a component diagram that outlines the functionalities of each container. Each container follows a layered architecture with three main components: the router, which manages the endpoints; the service, which contains the business logic for its domain; and the repository, which handles data access. In addition, visual prototypes (mockups) were created to illustrate potential interfaces for the application using the MockFlow tool.

Coding

In this phase, the development team defined the technologies and frameworks to ensure the creation of reliable, maintainable code while simplifying the incremental development of the project. The functional interfaces developed during the sprints were presented. For the frontend, Vue.js was chosen for its ability to execute JavaScript through Node.js, with Vuetify serving as the framework. Vuetify provides pre-designed components that facilitate the development of intuitive interfaces that adhere to user experience guidelines. The application includes features such as loading text files, viewing records on a geographic map with specific markers, and visualizing information through graphics.

The Upload File interface allows users to select a file from their computer or drag it into a designated area. The server validates the file format, checking size and extension restrictions. If the file meets the requirements, the system filters data for Colombia and allows users to preview up to ten records to verify the format. If the format is correct, the upload button is activated, triggering a progress bar that displays the estimated loading time to store the records in the MongoDB database.

As shown in Figure 6, data visualization on the Map feature enables users to view records stored in the database on an interactive map. Users can apply location or time filters to narrow the data and

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focus on areas of interest. The visualization displays markers at the locations where lightning strikes occurred (latitude, longitude), with data processed on the OpenStreetMap server.

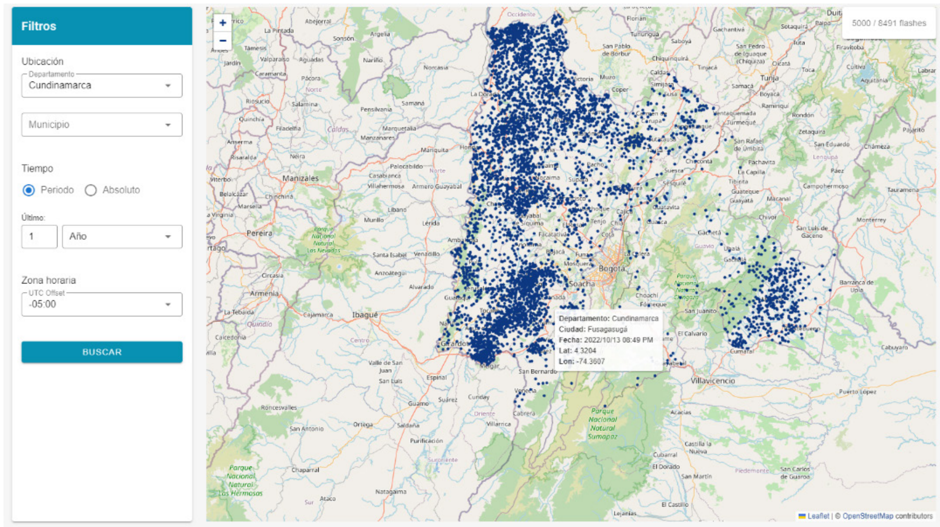

Figure 6. User interface displaying lightning strikes that occurred the first two weeks of October 2022 in the department of Cundinamarca.

The sidebar displays the available filters that can be applied on data. One filter is based on location, offering a list of departments and allowing users to select a municipality. Another filter is by time, where users can choose a time range or specific date. This is achieved using a numerical field to adjust the value and a drop-down list to select the time unit: hour, day, week, month, or year. Another visual elements, such as vertical and horizontal bar charts, as well as pie charts, were created to summarize the data and highlight the locations and times with the highest lightning activity. KPI cards were designed to display key metrics for decision-making.

Additional functionalities developed in the application included user registration, account activation via email, user authentication through login, report generation, and the deletion of files uploaded within the last 24 hours.

The backend was implemented in Python, using FastAPI to build the gateway API, which facilitated the creation of endpoints for the proposed functionalities. The database was built with MongoDB, offering fast data retrieval, making it suitable for handling the thousands of requests the server processes for lightning information. Version control was managed using Git. A clean architecture approach was applied to separate the responsibilities of data access, business logic, and infrastructure. For this purpose, the dependency container was used with the dependency_ injector library. The endpoints were tested using the Postman tool to simulate requests from the application interfaces. FastAPI generated automatic documentation for the endpoints.

Testing

Functional tests verified compliance with requirements and completion of proposed user stories, while integration tests ensured proper interaction among all external components of the application. Sprint reviews highlighted minimum viable products, with detailed explanations of

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functionalities validated by the tests provided to stakeholders. The development team conducted manual tests, evaluating the application's use cases based on the following formula:

$$m = \frac{Numberofapprovedtests}{Numberofperformedtests}$$

Based on the previous metric, the value of m was determined under the following conditions:

If m = 1, software fullfil client expectations.

If 0,8 ≤ m ≤ 1 there are some aspects to improved.

If m ≤ 0,79 iteraction must be rejected.

A total of twenty tests were conducted, each corresponding to a scenario where the expected results were achieved. Detailed test cases are documented in the application evaluation report.

Launching

After completing all user stories and successfully developing the required functionalities, the application development concluded with the creation of a delivery document. This final phase included deploying the application on two cloud platforms, Vercel and Render, chosen for their compatibility with JavaScript and Python and their seamless integration with Git, enabling efficient source code transfer to the production environment.

Results

Performance evaluation of the web application focuses on several key aspects regarding its usability and efficiency. The time required to process lightning data files ranges from 5 to 15 minutes, depending on the number of records. For instance, a test with over 30,000 records had a loading time of approximately 6 minutes.

To evaluate the functionality of the web application, more than 20 functional tests were planned, including listing users, registering users, activating user accounts, loading files, filtering data, and visualizing data. Each test included a clear description of the activity, a step-by-step procedure, and the expected results. Additionally, integration tests were conducted with several external modules, such as OpenStreetMap. Table 3 presents an example of a functional test performed.

Table 3. Example of functional test used to evaluate the performance of the web application

Module	User's account activation	
ID	20	
Description	Create a user's password using a link.	
	Step	Operation
	1	Open link receive by email
	2	Enter a new password
	3	Re-enter password in confirmation camp
	4	Click Save button
	5	Platform automatically logs the new account
Expected results	Create a new password and startas a new user's session	

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The final functionality test used data from the WWLLN to identify occurrence patterns in lightning activity. The test employed a data file containing records from the first fifteen days of October 2022, with over one million lightning events across a wide area including Colombia. Each record file contained a tuple with information about a lightning event, including latitude, longitude, timestamp, polarity, estimated peak current, and the number of stations that detected the event. The filtering capabilities of the application reduced the dataset to 8,510 lightning events within the borders of the department of Cundinamarca. Further filtering revealed the top five municipalities with the highest lightning activity during this period: Yacopí (946 events), Caparrapí (942 events), Puerto Salgar (481 events), Guaduas (473 events), and Medina (459 flashes). The patterns indicate that approximately 62% of the lightning activity occurred at night, with about 5,200 events, peaking around 9:00 p.m. local time.

Discussion

This project developed a tool using agile methodologies aim to analyze extensive collections of lightning data, emphasizing two key aspects: the web application's ability to handle large data files and its analytical tools for identifying temporal and spatial lightning patterns. The web application was validated using lightning data from Cundinamarca, Colombia, demonstrating the tool's effectiveness in addressing data file size and format, and enabling a graphical identification of patterns as well as the visualization of particular lightning hotspots. As demonstrated for similar works in different context, this type of approach proves to be a valuable to address demands of real world challenges (21), (22).

The XP methodology and Scrum framework proved to be a rapid and flexible approach to software development, because it showed an easy adaptability to changing project requirements while maintaining momentum in the development team. A structured organization rooted in initial specifications ensured efficient decision-making and provided a clear framework throughout the project's lifecycle.

The use of C4 model graphical notation for software architecture offered accessible insights into system structure and functionality. This visualization fostered collaboration between the development team and stakeholders by establishing a shared understanding of the application's components, their relationships, and interactions. This approach streamlined problem-solving and aligned the system with technical and business needs helping to keep the schedule activities plan.

The use of open-source tools were instrumental in addressing development challenges, particularly in managing the complexities of large datasets and high request volumes. Although these tools imposed some limitations, their strategic application mitigated key obstacles. However, it is quite clear that at some point some important decisions must be taken around the web application, specially regarding data storage and GIS functionalities because during the development some challenges appear related to handling large datasets within a web environment constrained by the limitations of free services. Segmenting data provided a practical workaround, but a local server

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deployment is planned to overcome this limitation. Further enhancements include integrating open-source geographic tools like OpenStreetMap and developing an API to fetch real-time data from the World Wide Lightning Location Network.

In its current form, the web application is well-suited for lightning data analysis and aligns with broader software developments in data mining, pattern recognition, and early warning systems for natural phenomena like tornadoes and earthquakes. These capabilities position the tool as a valuable asset for advancing lightning-related research and contributing to predictive and risk mitigation systems that was proved and validated by functional and integration tests aim to ensured quality and performance.

The developed tool is highly relevant for authorities responsible for risk assessment, as it enables the identification of areas with elevated lightning activity and, consequently, locations at higher risk of lightning impacts on people, animals, and infrastructure. While lightning strikes cannot be avoided, implementing protective measures, such as lightning protection systems in schools, sports venues, and other facilities with large gatherings, is a viable strategy. Additionally, identifying specific months and hours with intense lightning activity aids in creating safety protocols for outdoor activities, effectively reducing associated risks. From this perspective, the tool provides critical information for strategic planning and educational initiatives. By offering foundational knowledge about lightning and recommended safety procedures, it empowers local communities to adopt proactive measures, enhancing their safety and resilience.

Conclusions

The web application's capability to map lightning events facilitates the graphical identification of hotspots. This feature is crucial for assessing risks to infrastructure, human lives, and animals in lightning-prone areas. Identifying patterns is valuable for planning more effective risk mitigation strategies. Furthermore, this development establishes a foundation for advancing research into detailed lightning climatology, complementing existing global and regional studies. The approach presented in this paper documents the process of creating software-based tools for lightning research, offering significant benefits for those interested in entering this field of study.

CRediT authorship contribution statement

Conceptualization - Ideas: Fernando Augusto Díaz Ortiz. Data Curation: Johan Romero Romero, Karen Yepes Chala. Formal analysis: Fernando Augusto Díaz Ortiz. Acquisition of funding: Fernando Augusto Díaz Ortiz. Investigation: Fernando Augusto Díaz Ortiz. Methodology: Johan Romero Romero, Karen Yepes Chala. Project Management: Pedro Luis Cifuentes Guerrero. Resources: Johan Romero Romero, Karen Yepes Chala. Software: Johan Romero Romero, Karen Yepes Chala. Supervision: Pedro Luis Cifuentes Guerrero. Validation: Fernando Augusto Díaz Ortiz, Pedro Luis, Cifuentes Guerrero. Visualization - Preparation: Johan Romero Romero, Karen Yepes Chala. Writing - original draft - Preparation: Johan Romero Romero, Karen Yepes Chala. Writing - revision and editing - Preparation: Fernando Augusto Díaz Ortiz.

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References

(1) V. Cooray, An Introduction to Lightning. Springer, 2015. doi: 10.1007/978-94-017-8938-7.

(2) V. Rakov and M. a. Uman, Lightning: Physics and Effects. Cambridge University Press, 2007.

(3) C. Cimarelli and K. Genareau, "A review of volcanic electrification of the atmosphere and volcanic lightning," Journal of Volcanology and Geothermal Research, vol. 422, p. 107449, Feb. 2022, doi: 10.1016/j.jvolgeores.2021.107449.

(4) B. Vonnegut, D. J. Latham, C. B. Moore, and S. J. Hunyady, "An explanation for anomalous lightning from forest fire clouds," J. Geophys. Res., vol. 100, no. D3, pp. 5037–5050, Mar. 1995, doi: 10.1029/94JD02956.

(5) T. J. Lang et al., "WMO world record lightning extremes: Longest reported flash distance and longest reported flash duration," Bulletin of the American Meteorological Society, vol. 98, no. 6, pp. 1153–1168, 2017, doi: 10.1175/BAMS-D-16-0061.1.

(6) R. Albrecht, S. Goodman, D. Buechler, R. Blakeslee, and H. Christian, "Where are the lightning hotspots on Earth?," Builletin America Meteorological Society, vol. 97, no. November, pp. 2051–2068, 2016, doi: 10.1175/BAMS-D-14-00193.1.

(7) D. J. Cecil, D. E. Buechler, and R. J. Blakeslee, "TRMM LIS climatology of thunderstorm occurrence and conditional lightning flash rates," Journal of Climate, vol. 28, no. 16, pp. 6536–6547, 2015, doi: 10.1175/JCLI-D-15-0124.1.

(8) D. E. Villamil, H. E. Rojas, F. Santamaria, and W. Diaz, "Lightning Risk and Disaster Risk Management at the beginning of the 2020s," in 2021 35th International Conference on Lightning Protection (ICLP) and XVI International Symposium on Lightning Protection (SIPDA), Colombo, Sri Lanka: IEEE, Sep. 2021, pp. 01–05. doi: 10.1109/ICLPandSIPDA54065.2021.9627393.

(9) A. S. Cruz-Bernal, H. Torres-Sánchez, H. Aranguren-Fino, and J. C. Inampués-Borda, "Lightning mortality rate in Colombia for the period 1997 – 2014," Revista UIS Ingenierías, vol. 17, no. 2, Art. no. 2, Jun. 2018, doi: 10.18273/revuin.v17n2-2018006.

(10) A. S. Cruz-Bernal, "Evaluación del riesgo por rayos para Colombia (Universidad Nacional de Colombia)," Universidad Nacional de Colombia, Bogotá. Recuperado de https://repositorio. unal. edu. co/bitstream/handle/unal/75636/ASCB_Evaluaci% C3% B3n% 20del% 20riesgo% 20por% 20rayos% 20para% 20Colombia. pdf, 2019.

doi: 10.25100/iyc.v27i1.14326

(11) D. Aranguren, J. Lopez, J. Montanyà, and H. Torres, “Natural observatories for lightning research in Colombia,” in 2018 International Conference on Electromagnetics in Advanced Applications (ICEAA), Cartagena, Colombia, 2018, pp. 279–283. doi: 10.1109/ICEAA.2018.8520371.

(12) A. Rousseau, “Risk Assessment for Lightning Protection,” in Lightning: Science, Engineering, and Economic Implications for Developing Countries, C. Gomes, Ed., Singapore: Springer, 2021, pp. 79–113. doi: 10.1007/978-981-16-3440-6_3.

(13) X. Qie et al., “A review of atmospheric electricity research in China,” Advances in Atmospheric Sciences, vol. 32, no. 2, pp. 169–191, 2015, doi: 10.1007/s00376-014-0003-z.

(14) A. Alammari et al., “Lightning Mapping: Techniques, Challenges, and Opportunities,” IEEE Access, vol. 8, pp. 190064–190082, 2020, doi: 10.1109/ACCESS.2020.3031810.

(15) F. Lyu et al., “A low-frequency near-field interferometric-TOA 3-D Lightning Mapping Array,” Geophysical Research Letters, vol. 41, no. 22, pp. 7777–7784, 2014, doi: 10.1002/2014GL061963.

(16) M. W. Onah, J. A. Adéchinan, F. K. Guédjé, H. Kougbéagbédé, and E. B. Houngninou, “Evaluation of the performance of the World Wide Lightning Location Network (WWLLN) using the lightning detection network (LINET) as a truth,” Bull. of Atmos. Sci.& Technol., vol. 4, no. 1, p. 7, Jul. 2023, doi: 10.1007/s42865-023-00060-9.

(17) J. O. Kaplan and K. H.-K. Lau, “World Wide Lightning Location Network (WWLLN) Global Lightning Climatology (WGLC) and time series, 2022 update,” Earth System Science Data, vol. 14, no. 12, pp. 5665–5670, 2022.

(18) C. Plaisant and B. Shneiderman, “Lightning and Thunder: The Early Days of Interactive Information Visualization at the University of Maryland,” IEEE Computer Graphics and Applications, vol. 42, no. 4, pp. 103–113, Jul. 2022, doi: 10.1109/MCG.2022.3180012.

(19) M. Falco, M. G. Nicora, D. Baissac, M. F. Barle, M. Salaberri, and G. Robiolo, “GeoRayos, a Web and Mobile App to Increase Awareness on Lightning Strikes,” in 2021 XLVII Latin American Computing Conference (CLEI), Oct. 2021, pp. 1–9. doi: 10.1109/CLEI53233.2021.9640001.

(20) F. Ahmed, S. Hasan, I. M. Mahbubul, M. Abul Kalam Mallik, and M. Nafiz Hossen, “GIS-based spatial analysis for lightning scenario in Bangladesh,” Heliyon, vol. 10, no. 7, p. e28708, Apr. 2024, doi: 10.1016/j.heliyon.2024.e28708.

(21) R. Buitrago, J. C. Rodríguez, C. Obando, and H. F. Hernández, “Desarrollo de un APP informativo para situaciones de riesgos sismológico para la ciudad de Bogotá,” Ingeniería y Competitividad, vol. 21, no. 2, Art. no. 2, Jul. 2019, doi: 10.25100/iyc.v21i2.7179.

(22) R. D. B. Contreras Manrique, L. Contreras Manrique, and A. M. Figueroa Hernández, “Inclusión de estudiantes con discapacidad diferencial auditiva a través de la aplicación móvil ListenApp,” inycomp, vol. 24, no. 1, Oct. 2021, doi: 10.25100/iyc.v24i1.11070.