

Enhancing the Cloud Security through Topic Modelling

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Abstract—Protecting cloud applications is crucial in an age where security constantly threatens the digital world. The inevitable cyber-attacks throughout the CI/CD pipeline make cloud security innovations necessary. This research is motivated by applying Natural Language Processing (NLP) methodologies, such as Topic Modelling, to analyse cloud security data and predict future attacks. This research aims to use topic modelling, specifically Latent Dirichlet Allocation (LDA) and Probabilistic Latent Semantic Analysis (pLSA). Utilising LDA and pLSA, security-related text data, such as reports, logs, and other relevant documents, will be analysed and sorted into relevant topics (such as phishing or encryption). These algorithms may apply through Python using the Gensim framework. The topics shall be utilised to detect vulnerabilities within relevant CI/CD pipeline records or log data. This application of Topic Modelling anticipates providing a new form of vulnerability detection, improving overall security throughout the CI/CD pipeline.

Keywords—Cloud, Security, Topic Modelling, Natural Language Processing, Continuous Integration (CI), Continuous Deployment (CD)

I. INTRODUCTION

In today's rapidly changing digital world, the security of cloud-based applications is a crucial concern for organisations worldwide. With the growth of cloud services and the increasing complexity of software infrastructures, defence against cyber threats becomes increasingly tricky.

One critical area of focus inside this domain is the Continuous Integration and Continuous Deployment (CI/CD) pipeline. To ensure the security of cloud applications, vulnerabilities must be identified and addressed before deployment.

In the current state of software development, continuous integration relates to continuous deployment, which eliminates the discontinuity of development and deployment [1]. So, first comes to build, test, and last comes to deploy. A CI/CD pipeline is simplifying these tasks.

However, the CI/CD pipeline has some security issues (such as data privacy [2], exploited scripts [3], lack of authentication [4], etc.).

Additionally, ensuring security in cloud environments is a continual challenge. Protecting cloud platforms from various security breaches, such as downgrade attacks on Transport Layer Security (TLS), a crypto protocol (e.g., ROBOT,

DROWN, POODLE) [5] and software supply chain attacks (e.g., Log4j, CodeCov, SolarWinds) [6, 7] is crucial. Failure to recognise and manage these risks can have serious consequences.

This study focuses on applying Topic Modelling techniques, such as Latent Dirichlet Allocation (LDA) and Probabilistic Latent Semantic Analysis (pLSA) of Natural Language Processing (NLP), to improve the overall security of cloud-based applications throughout the CI/CD pipeline. By utilising the power of natural language processing and machine learning, the goal is to develop a framework capable of predicting and exposing potential security vulnerabilities in text-based data generated throughout the CI/CD pipeline.

The primary outcome of this study is to develop a novel framework that utilises Topic Modelling, particularly LDA, and cosine similarity techniques to analyse text-based data such as plain text, lack of integration, disorganised contents, lack of contexts, partial incident reports, truncated logs, or isolated pieces of information from the CI/CD pipeline.

By comparing text-based documents against selected datasets containing security-related information, the framework identifies patterns that resemble security vulnerabilities, allowing users to identify and address potential risks before deployment.

Utilising synonyms (for example, protection, risk, threat, virus, spyware, etc.) and associated terminology (such as encryption, phishing, hacking, identity theft, etc.), we seek to uncover hidden and uncovered insights, classify the incidents, and strengthen security intelligence.

The fundamental question driving this research is:

RQ: How can Topic Modelling techniques be effectively applied to analyse fragmented security-related text data and enhance the security of cloud-based applications throughout the CI/CD pipeline?

This research brings a fresh approach by integrating Topic Modelling into the CI/CD pipeline to detect security threats. Its significance lies in connecting natural language processing techniques with cloud security, making it easier to share threat intelligence and identify risks throughout development.

The rest of the paper is as follows:-

II. Background and Related Works: This section covers what we already know about cloud security and Topic Modelling, pointing out the challenges and gaps this study is trying to fill.

III. Research Objectives: This section outlines what to achieve with this study and the specific goals we have in mind.

IV. Methodology: Describes the steps taken to build the framework.

V. Results: Share the key findings and how the framework boosts cloud security.

VI. Discussion: Discuss the findings, including their limitations and broader impact.

VII. Conclusion: Summarizes the main takeaways, highlights contributions and discusses future works.

II. BACKGROUND AND RELATED WORKS

In [8], Jelodar et al. (2019) explored applications of Topic Modelling, specifically LDA, across fields such as, medical science, software engineering, and political science. Reviewing papers from 2003 to 2016 demonstrated how versatile topic modelling can extract meaningful insights across various disciplines. Their work also shows its potential for analysing security-related text data to enhance cloud security.

Paradis et al. (2018) [9] used LDA to classify software vulnerability data from the Common Vulnerabilities and Exposures (CVE) project. Their approach required minimal preprocessing and helped organise complex, noisy data to extract valuable insights, providing a novel method for navigating large amounts of vulnerable information.

Okey et al. (2023) [10] analysed Twitter discussions on ChatGPT and cybersecurity, revealing mixed opinions about its potential benefits and risks. Using LDA, they categorised the discussions under hashtags such as, #chatgptsecurity, demonstrating how topic modelling can be applied to analyse historical security data.

Řehůřek et al. (2010) [11] introduced GENSIM, an NLP framework focused on scalability and ease of use for topic modelling. GENSIM supports Latent Semantic Analysis (LSA) and LDA, regardless of the training corpus size. This framework is essential for our research, offering a scalable and user-friendly platform for applying topic modelling in cloud security.

Roepke (2022) [12] and Ruchirawat (2020) [13] both highlight practical applications of Topic Modelling, emphasising data preparation techniques that enhance dataset coherence and relevance. Their insights support our approach to managing fragmented security-related data, forming a foundation for using Topic Modelling in cloud security enhancement.

A. Analysis

The reviewed literature provides various insights into using Topic Modelling in cybersecurity. Okey et al. (2023) illustrated the effectiveness of LDA in analysing ChatGPT discussions [10]. Paradis et al. (2018) used LDA to classify software vulnerability data, contributing to improved cybersecurity practices [9]. Jelodar et al. (2019) emphasised the value of Topic

Modelling in extracting insights across diverse fields [8]. Furthermore, Řehůřek et al. (2010) developed GENSIM to tackle scalability challenges in NLP [11].

However, a clear gap exists in applying topic modelling directly to cloud security within CI/CD pipelines. Most studies focus on analysing historical data, lacking proactive approaches to predict vulnerabilities in real-time environments. While GENSIM is scalable, its direct application in cloud security is still largely unexplored.

This study aims to bridge that gap by using Topic Modelling to proactively identify security issues throughout the CI/CD pipeline, contributing to improved cloud security practices.

III. RESEARCH OBJECTIVES

O1: Explore the application of Topic Modelling techniques, particularly LDA, in analysing security-related text data.

O2: Investigate the effectiveness of Topic Modelling in predicting potential vulnerabilities in cloud applications.

O3: Provide insights and recommendations for integrating Topic Modelling into the CI/CD pipeline to improve overall cloud security throughout the software development process.

O4: Develop a scalable and user-friendly framework for applying Topic Modelling techniques to enhance cloud security practices throughout the CI/CD pipeline.

IV. RESEARCH METHODOLOGY

In developing our solution, we utilised research methodologies and software development practices. We detailed some of those in Section V-B.

The key to our approach was using topic modelling, specifically LDA and cosine similarity techniques, to analyse data and identify security-related patterns.

LDA is a generative probabilistic model used to discover latent topics within a collection of documents. It works by assuming that each document is a mixture of various topics, and each word is attributed to one of those topics [14].

Cosine similarity measures the similarity between two vectors by calculating the cosine of the angle between them [15]. Its simplicity and efficiency in measuring similarity between documents allow the system to compare documents and datasets effectively.

Two datasets were utilised to validate our model:

Worldwide Software Supply Chain Attacks Tracker (Comparitech) [16] and Breaking Trust: Shades of Crisis across an Insecure Software Supply Chain (Herr, 2021) [17].

These datasets contain weblinks to various cloud security-related webpages (such as attack reports and blogs), providing diverse security-related texts.

V. RESULTS AND ANALYSIS

A. CI/CD Pipeline Integration

The proposed system enhances cloud security practices by analysing text-based data generated throughout the CI/CD

pipeline. It consists of several core components, including a web application for user interaction, a backend server for data processing, a MySQL database for data storage, and algorithms for topic modelling and vulnerability detection.

Users can upload text-based files, e.g., release notes or log files, from the CI/CD pipeline for comprehensive vulnerability analysis. The system interfaces with the CI/CD pipeline before deployment, identifying potential security risks at critical stages of the software development lifecycle (Figure 1).

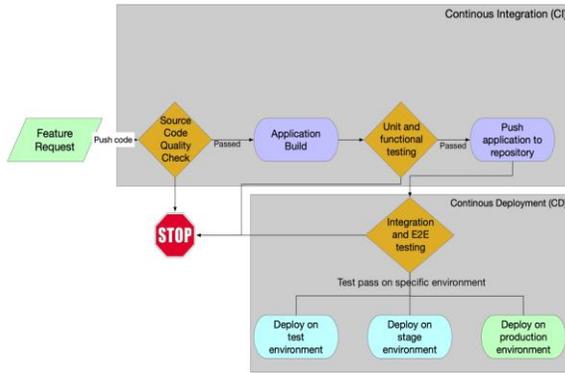


Fig. 1. CI/CD Pipeline Integration

B. System Design and Architecture

The system is built on a client-server architecture, which enhances modularity, scalability, and security. REST APIs facilitate seamless communication between the client and server, ensuring efficient data exchange and smooth operation. This design separates the user interface (client-side) from application logic and data storage (server-side), allowing independent updates and modifications to each component.

The architecture also supports resource distribution across multiple servers, enabling scalability to handle increased loads. Clustering sensitive data and logic on the server side reduces the risk of unauthorised access, further strengthening the system's security.

C. Technical Implementation

- Web Application

The web application serves as the primary user interface, enabling users to:

- Upload files or datasets for analysis.
- Initiate the vulnerability detection process.
- View results in an intuitive and user-friendly format.

- Backend Functionality

The backend server handles all data processing tasks, leveraging Python for its versatility and robust NLP support. Key backend components include:

a) *Topic Modelling*: LDA extracts latent topics from uploaded datasets, enabling the analysis of fragmented security-related text data.

b) *Vulnerability Detection*: The system compares CI/CD pipeline input files to uploaded datasets, identifying related

security incidents. It checks the relevance of databases using topic modelling results and employs cosine similarity to find the top 10 most similar documents.

- Data Management

Data is stored in a MySQL database, chosen for its reliability, efficiency, and robust capabilities. Serialised LDA models are stored to optimise performance, allowing quick retrieval and reuse without repeated topic modelling.

D. Key Features

- Security

User passwords are encrypted to protect credentials and safeguard sensitive information.

Clustering sensitive data on the server minimises the risks of unauthorised access.

- Scalability and Performance

Serialised LDA models reduce processing overhead, improving responsiveness when handling large datasets.

The system architecture supports resource distribution, ensuring scalability as workloads increase.

E. CI/CD Pipeline Integration and Results

The system's integration into the CI/CD pipeline enables the detection of security vulnerabilities before the deployment stage. The system analyses text-based data and exposes potential risks in files such as release notes or logs.

This result validated the system's ability to detect vulnerabilities and share threat intelligence.

The following algorithm (Figure 2 presents the pseudocode) was designed to efficiently identify security vulnerabilities by analysing the similarity between the input file and existing datasets.

```

Algorithm Topic_Modeling_and_Similarity_Analysis
Input: filename
Output: Topics, Tokenized Data, LDA Model

1. Load the Excel file (filename) containing References and Metadata
foreach row in filename:
    a. Retrieve webpage content from the URL.
    b. Clean and preprocess text:
        i. Remove punctuation, numbers, and stopwords.
        ii. Convert text to lowercase.
        iii. Apply lemmatization to retain nouns and adjectives.
    c. Store the cleaned text in the column "Summary".
2. Tokenize the cleaned text and store it in "Tokens".
3. Create a dictionary of tokens and a document-term matrix.
4. Apply LDA to the document-term matrix to discover latent topics
    a. Define num_topics (e.g., 10).
    b. Train LDA with the tokens.
5. Save the trained LDA model and results to a file.

End

```

Fig. 2. Pseudocode Representation of the Algorithm

This system's development involved several libraries and tools, each chosen to fulfil a specific function and optimise performance. Table 1 lists these technologies, describing their purposes and benefits to the system. The tools range from backend frameworks such as, Flask and SQLAlchemy to data processing libraries such as Pandas and Gensim and frontend

technologies such as, TypeScript and React. These components played a vital role in creating a robust, scalable, and efficient platform.

TABLE I. LIBRARIES AND TOOLS USED

Technology	Purpose	Features/Benefits
Flask [18]	Web framework for building RESTful APIs and handling HTTP requests efficiently.	Lightweight and flexible, suitable for RESTful API development.
SQLAlchemy [19]	ORM tool for database management.	High-level interface for interacting with the MySQL database.
Gensim [11]	Topic modelling tasks and text analysis.	Efficient implementations of LDA and other algorithms; scalable and user-friendly.
Pandas [20]	Data preprocessing and dataset formatting.	Versatile in data manipulation and preprocessing; enables efficient dataset handling.
Sci-kit-learn (sklearn) [21]	Machine learning tasks and cosine similarity calculations.	Robust ML functionalities ensure accurate document and dataset comparisons.
NLTK [22]	Text processing tasks such as tokenisation and stop word removal.	Enhances accuracy and effectiveness of text analysis.
TypeScript [23]	The primary language for frontend implementation.	Strong typing and scalability for easy codebase maintenance and development.
React [24]	Frontend framework for building user interfaces.	Component-based architecture offers a wide range of reusable UI components.
Material UI [25]	React component library for frontend design and styling.	Provides a modern and visually appealing user interface.
MySQL [26]	Database management system for data storage.	Reliable, scalable, and widely used; ensures data integrity and consistency.
Redis [27]	Session token storage for server-sided sessions.	Fast and scalable session management capabilities.

- System Testing

Multiple testing methodologies were utilised to ensure the system's reliability, functionality, and performance across various use cases. Table 2 lists those.

TABLE II. TESTING METHODOLOGIES AND THEIR PURPOSES

Testing Methodology	Purpose	Key Features/Benefits
Unit Testing	Verifies that individual backend components operate correctly and meet specifications.	Ensures correctness and reliability of isolated functionalities.
Integration Testing	Ensures the system functions seamlessly when new features are integrated.	Validates interactions between different components of the system.
Acceptance Testing	Assesses the system against initial requirements and expectations.	Confirms that the final system meets user needs and design goals.
API Testing with Postman	Tests API endpoints to ensure correct responses to various inputs and scenarios.	Validates API functionality and identifies potential issues in communication layers.

F. System Validation

The implemented system was validated to ensure its effectiveness and reliability in detecting security vulnerabilities throughout the CI/CD pipeline.

To test its performance, a case study was conducted using GitHub's latest release notes (Enterprise Server 3.10.9). A text document containing the release notes was uploaded to the system and compared against its datasets using the built-in algorithm.

The analysis identified websites associated with security attacks, with a similarity score exceeding 60%, demonstrating the system's capability to expose potential security risks in newly released software updates.

G. System Walkthrough

The system offers a streamlined, user-friendly interface designed to assist in identifying potential security vulnerabilities efficiently. Users can upload text-based files or datasets for analysis upon logging in or registering. The system allows users to define specific comparison parameters, such as selecting relevant datasets or setting similarity thresholds, to tailor the analysis to their needs. Once the analysis is complete, the system generates a detailed report highlighting potential vulnerabilities and providing links to related documents and websites. This intuitive process ensures that users can effectively uncover security risks in files and datasets, enhancing the security of CI/CD pipelines.

The first step in using the system involves uploading files or datasets for analysis. Users can click the "Upload Files" button to select relevant CI/CD pipeline documents or choose the "Upload Datasets" button to upload entire datasets for comparison. As illustrated in Figure 3, this step allows users to provide input data efficiently for security analysis.

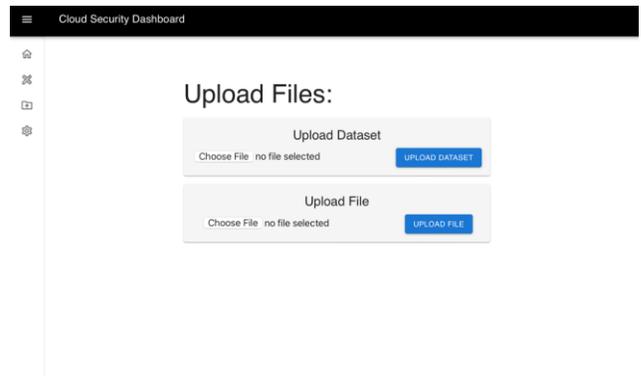


Fig. 3. File Upload in the system.

Users navigate to the Comparison page once the files or datasets are uploaded. Here, they select a file from the uploaded list and choose one or more datasets to compare against the selected file. Users initiate the analysis process by clicking the "Run Model" button, shown in Figure 4, enables the system to analyse and compare the documents, facilitating the identification of potential security vulnerabilities.

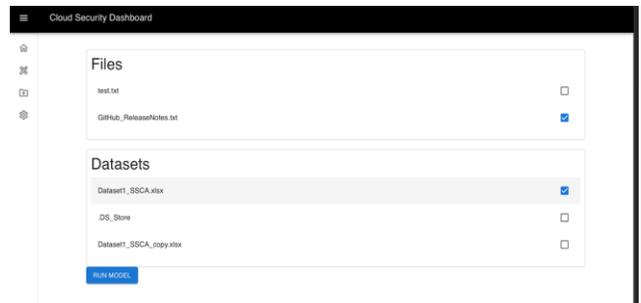


Fig. 4. Comparison Selection and Run Model Step

In the final step, users are directed to the Results page, where the system displays the top 10 most similarities from the selected datasets. Each result includes key details such as the dataset

name, document link, and similarity percentage. These insights allow users to perform in-depth analysis and take appropriate actions based on the findings. This step is illustrated in Figure 5.

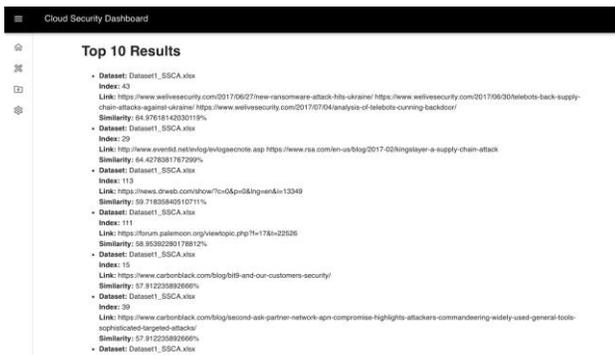


Fig. 5. Comparison Results

H. Novelty of Results

This study takes a fresh approach to improving cloud application security by focusing on analyzing text-based data within the CI/CD pipeline.

A vital feature of this method is the proactive use of topic modelling, which helps uncover security vulnerabilities before deployment.

The platform analyses fragmented security-related text data from multiple datasets through Topic Modelling, uncovering similarities and potential risks in documents like release notes and logs. This integration enables the platform to share actionable threat intelligence with users effectively.

VI. DISCUSSION

A. Threats to the validity of results

Several factors may affect the validity of the results, including the quality of datasets, which could suffer from broken links, outdated information, or irrelevant content. Uploaded files might also contain noise, such as unnecessary details or duplicates, skewing the analysis. Documents returned during file comparisons may sometimes fail to align with the intended research goals, which could lead to misleading conclusions.

To address these issues, preprocessing methods such as text cleaning, removing stop words, and lemmatization are applied to improve data quality by reducing noise. Despite these efforts, some risks remain, particularly regarding the relevance of the results. Regular manual review and ongoing algorithm refinements are essential to ensure the system's reliability. Continuous enhancements will further improve the accuracy and consistency of the findings.

B. Implication of the results

This study contributes to both research and practice in cloud security by introducing a novel approach to detecting vulnerabilities through text-based data analysis in the CI/CD pipeline.

The integration of topic modelling offers fresh insights into threat detection, advances theoretical understanding, and encourages future research.

Before deployment, organisations can use the platform to identify and manage security risks in documents like release notes and logs.

This practical approach helps link research insights to real-world applications, providing a strong basis for improving cloud security practices and protecting applications from new and evolving threats.

C. Limitations of results

While the developed system demonstrates significant potential for enhancing cloud security practices, certain limitations must be addressed to realise its capabilities fully:

Scope and Coverage:

The system's ability to perform effectively depends on having a broad and reliable range of security-related data sources. If the datasets are outdated or limited, important threats might be missed. To address this, it's crucial to expand the variety of data sources and keep the repository updated regularly, ensuring better detection and management of security risks.

Resource Limitations:

Another challenge is the impact of limited computational resources on scalability and performance, especially when handling large volumes of text data. These constraints can affect efficiency under heavy workloads. Enhancing the system's architecture and investing in advanced infrastructure, such as distributed computing, can help overcome these limitations and improve processing capabilities.

To minimise the impact of these limitations, the following measures are recommended:

Enhanced Data Coverage:

Broadening data coverage and regularly refreshing datasets can provide a more accurate and up-to-date analysis of security threats. These improvements are critical for ensuring effective risk detection and mitigation.

Resource Allocation:

Investing in better computational resources and leveraging advanced infrastructure, such as cloud-based solutions or distributed computing platforms, can alleviate resource constraints. These improvements will optimise performance, enabling the system to process large-scale datasets and deliver reliable results efficiently.

D. Generalisability of results

The system's generalizability stems from using unsupervised machine learning, allowing it to adapt to various contexts. The nature of the datasets influences results; for example, analysing cloud security datasets yields insights specific to cloud security. This adaptability ensures the system's findings remain relevant and applicable across diverse scenarios, enhancing the overall utility of the results.

VII. CONCLUSIONS AND FUTURE WORKS

With the growing need for better cloud security in CI/CD pipelines, we built a framework using Topic Modeling. By

including natural language processing, this tool helps spot potential vulnerabilities in the text data produced during the CI/CD process.

In short, this work contributes to cloud security by introducing a new way to identify threats in CI/CD pipelines. Users can protect their applications from emerging risks.

This study also provides a solid base for future research, highlighting the importance of incorporating advanced technologies into existing software development practices.

Several routes of future work can be explored to enhance the described system and extend its capabilities:

A future step can integrate the system with CI/CD tools like Jenkins, automating deployment and making it more accessible as part of existing workflows.

Creating an algorithm to filter out irrelevant but similar documents would enhance document comparison accuracy, reduce false positives, and improve overall vulnerability detection.

Enhancing pre-processing techniques to filter out noise and irrelevant information better may help improve the quality and reliability of the data used for analysis.

This would involve refining existing pre-processing algorithms and incorporating advanced text-cleaning methods to improve the data quality used for analysis.

Extending the system to accept a wider range of file types and dataset formats would make it more versatile. By expanding compatibility to accommodate diverse data sources, the system can handle a broader range of security-related text data.

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