APPLIED INFORMATION TECHNOLOGY AND COMPUTER SCIENCE
e-ISSN: 2773-5141

AITCS

Vol. 6 No. 1 (2025) 325-342
https://publisher.uthm.edu.my/periodicals/index.php/aitcs

Chronochat Visualizer: A Forensic Visualization Tool for WhatsApp Chat Data with Timeline Analysis

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DOI: https://doi.org/10.30880/aitcs. 2025.06.01.018

Article Info

Received: 30 July 2024
Accepted: 18 June 2025
Available online: 30 June 2025

Keywords

Data Visualization, Forensic Visualization, Timeline Analysis, WhatsApp Forensics

Abstract

WhatsApp is a well-known instant messaging service that is widely used around the world. However, analysing and visualizing WhatsApp chat data can be challenging task due to increasing crimes cases involving WhatsApp, unstructured raw data and limited features from existing tools. In this study, Chronochat Visualizer, a forensic timeline visualization tool is proposed. Chronochat allows users to import WhatsApp chat data and visualize the timeline of the chat, including the time and frequency of the messages, the contact information, and the number of messages sent and received. The Object-Oriented Programming model was adopted to develop the Chronochat system, which includes modules such as read file module, analysis module and report module. The functional testing result of Chronochat Visualizer confirms that user able to access the tool and all features are function successfully. The user acceptance test shows positive feedback and high satisfaction, confirming the effectiveness of the visualization tool. In conclusion, Chronochat Visualizer able to find and pull-out useful data, trends, anomalies to solve the case.

1. Introduction

WhatsApp is a popular communication tool that allows users share text, image, video, and audio files as well as other types of information that works with Android, iOS, and Windows platforms [1]. With the communication applications are increasingly being adopted, it attracts cybercriminals to exploit the platform to do illicit activities. WhatsApp advanced features (e.g. end-to-end encryption, group chat feature, file sharing feature, voice and video call features, delete message features) allow it to be exploited for criminal purposes, such as fraud, gambling, pornography, corruption, and drug networks [2]. For example, reconnaissance, phishing, catfishing, fake profile, social engineering, hacking, identity theft, scamming, cyberstalking, child pornography, cyberbullying [3]. There are three identified issues motivate this study direction, namely: (1) increasing crimes cases involving WhatsApp, (2) unstructured raw data, and (3) limited timeline analysis features.

WhatsApp chat data typically consists of unstructured raw text messages, multimedia files, and other forms of communication exchanged between users. This unstructured data consists of a wide range of information, including text conversations, timestamps, sender and recipient details, media files such as images and videos, and metadata associated with each message [4]. Shidek et al. [5] highlights a critical need for further research to explore alternative visualization methods. This imperative arises from the identified challenge of enhancing data comprehension, particularly in the context of interpret potential criminal activities within WhatsApp Messenger conversation data.

Therefore, automating forensic analysis techniques to investigate cyber incidents involving WhatsApp application (app) have become critical. An example of the technique is timeline analysis a chronological

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representation of events and activities related to digital artifacts. The proposed tool could use timeline visualization models to illustrate communication patterns over time, allowing users to better understand the dynamics of communication and identify recurring patterns.

In this study, Chronochat Visualizer - A Forensic Visualization Tool for WhatsApp Chat Data with Timeline Analysis - is proposed. This study deployed timeline analysis in enhancing forensic investigations of WhatsApp chat data.

Furthermore, the study aims to improve visualization tools, increase user-friendliness, and overcome these challenged to enhance the analytical potential of WhatsApp communication dynamics.

Three objectives of the study are in three-fold, as follows:

i. To design a tool to visualize WhatsApp Chat metadata to support forensic analysis using timeline analysis approach.
ii. To develop a visualization tool to visualize information from WhatsApp chat data using timeline analysis approach.
iii. To test the tool's functionalities and conduct user testing of the proposed of visualization tool.

The rest of the paper is organized as follows: Section 2 discusses the related work of WhatsApp timeline analysis. Section 3 explains the methodology using the diagram to show all the steps and processes involved in priority during the experiment. Section 4 presents the design and implementation. Lastly, Section 5 concluded the study and the future work.

2. Background of study

This section explains definitions, theoretical background, digital forensic analysis approach and related previous works conducted about the research to understand the literature's landscape and the appropriate methodology.

2.1 Digital Forensics

Digital forensics is a scientific method used to preserve, collect, validate, and interpret digital evidence from digital sources. It aims to reconstruct criminal events or anticipate disruptive unauthorized actions. Despite variations in investigation objectives, evidence sources remain consistent The Digital Forensic Investigation Framework (DFIF) is a five-phase framework: Preparation, Collection and Preservation, Examination and Analysis, Presentation and Reporting, and Dissemination the case [6].

The preparation phase involves monitoring authorization and management support, ensuring the operation and infrastructure are compatible with the investigation, and obtaining necessary information from both inside and outside the investigating organization.

Collection involves gathering digital evidence with strict procedures to ensure authenticity and reliability, including packaging, transport, and preservation. This phase may involve acquiring data from various sources, such as computers, mobile devices, servers, network logs, and cloud services.

The collected evidence undergoes detailed examination and analysis to uncover relevant information. [7] state that the binary data stored on a device is processed to generate corresponding artifacts, such as documents, images, or other types of digital evidence. The analysis phase involves recovering deleted files, examining metadata, reconstructing timelines, and correlating evidence.

The presentation and reporting phase compiles documented evidence into a comprehensive report, including methodology, evidence details, analysis results, and conclusions drawn. The digital evidence identified, preserved, and analysed in the previous phases is presented in court [7], visually represented in charts, graphs, or timelines, and must be clear, concise, and objective.

Disseminating the case is the final phase of the DFIF, where investigators share the findings with relevant stakeholders, ensuring the proper return of physical and digital property.

2.2 Forensic Analysis

Forensics uses digital evidence to address fundamental inquiries about crimes, such as sequence, attribution, source evaluation, and interaction [8]. This data can be used to understand a specific piece of evidence or the crime by utilizing factual observations, formulating and testing theories, and conducting forensic analysis. Digital forensic analysis involves identifying the relevance of each item, isolating it for examination, and considering its fit into the overall body of evidence. Experimentation and study are often part of this process, and new data may be obtained. Forensic professionals may use keywords suggested by analysis to supplement their investigation.

The process may involve assessing the digital object's source, investigating unknown file formats, creating timelines, conducting functional analysis, and using relational analysis to determine the connections and interactions between elements of a crime. Forensic analysts aim to provide answers to basic questions such as what happened, where, when, how, who was involved, and why. They can also be instructed to address specific inquiries or compile a list or compile a list of other probable evidence sources, such as email accounts and portable storage devices.

2.2.1 Timeline Analysis

This project utilized digital forensic techniques, including timeline analysis, which is crucial for investigating digital crimes [5]. Timeline analysis is connected to the date and time of events and can be used to identify the origin of documents. Forensic analysts can reconstruct aspects of a document's generation and change using computer maintenance of distinct date-time stamps. Some file formats, like Microsoft Word, have inbuilt metadata that can help for document authentication [8].

In forensic investigations, timeline analysis helps investigators reconstruct the sequence of activities, interactions, and changes that occurred on a system or within a dataset [9]. For WhatsApp chat data, timeline analysis plays a pivotal role in uncovering the temporal aspects of conversations, user interactions, and media sharing. It helps investigators establish a cohesive narrative of events, understanding the context and identifying patterns.

There are two approaches to timeline analysis: traditional, which relies solely on file system timestamps, and super-timeline, which includes events stored within an operating system and various log files [9][10]. Both approaches contribute to the broader field of digital forensics, where maintaining the integrity of temporal data is essential for reconstructing digital incidents and establishing a coherent narrative.

2.3 Visualization Models

Visualization is a tool that provides a user with an image that aids in understanding the underlying information, using models like bar charts, line charts, and scatter plots.

A bar chart is a data visualization method that accurately represents numerical data, with one axe representing categories and the second representing quantitative data [11]. It can be horizontal or vertical and is suitable for displaying numerical data.

Line charts are visual representations of data points over time, revealing trends, speed fluctuations, and variability levels [12]. To improve readability, limit lines to four or fewer, use intuitive increments, avoid overcrowding with lengthy labels, and position labels directly adjacent to lines. Important lines should be highlighted in dark colours [13], and for more than four data series, use small multiples, a series of small charts using the same graphic for better comparison.

Scatter plots are used to display complex data patterns between two variables but are less commonly used in time series analysis than line graphs. Wang et al. [14] argue that scatter plots offer valuable insights into temporal patterns, especially when data shows nonlinear relationships or irregular fluctuations.

2.4 WhatsApp Forensics

The increasing number of WhatsApp users has led to malicious individuals using the app for illicit actions [15] . Researchers have used technological anti-forensics techniques to record online crimes and demonstrate the potential for cybercrime. Experiments on WhatsApp's effects after the seven-minute delete function were presented [16]. As instant messaging apps evolve, new deletion capabilities should be examined to examine spam messages sent by multiple users. Artefacts stored in different locations or pathways within a device are important to consider. For example, on an Android smartphone, WhatsApp Messenger generated artefacts like names, locations, and contents preserved in files.

2.4.1 WhatsApp Data Structures

Table 1 lists artefacts produced by WhatsApp Messenger on Android smartphones, organized into contacts database wa.db, msgstore.db, chat_list, and sqlite_sequence, with each table storing message attributes, contents, and metadata.

Table 1 *WhatsApp Messenger artifacts* [4]

Content	Directory	File
Contacts database	/data/data/com.whatsapp/databases	wa.db
Chat database	/data/data/com.whatsapp/databases	msgstore.db
Backups of the chat database	/mnt/sdcard/Whatsapp/Databases	msgstore.db.cryptmsgstore-< date>.crypt
Avatars of contacts	/data/data/com.whatsapp/files/Avatars	UID.j, where UID is the identifier of the contact
Copies of contacts avatars	/mnt/sdcard/Whatsapp/ProfilePictures	UID.j, where UID is the identifier of the contact

Table 1 *(cont)*

Content	Directory	Files
Log files	/data/data/com.whatsapp/files/Logs	whatsapp.log, whatsapp-< date>.log
Received files	/mnt/sdcard/Whatsapp/Media	various files
Sent files	/mnt/sdcard/Whatsapp/Media/Sent	various files
User settings and preferences	/data/data/com.whatsapp/files	various files

2.5 Comparison of Existing Study

Three tools are compared to the proposed tool, based on another researcher's development, to assess its limitations and are for improvement. Jadhav et al. [17] have created a WhatsApp chat sentiment analyser that used natural language processing (NLP) to analyse the emotional tone of conversations. The tool categorizes messages into positive, negative, or neutral sentiments, providing users with insights into the overall mood or sentiment in their conservations. Improvements include status display, document sharing, and location sharing. The tool also provides a visualization dashboard, using Python and various libraries like Matplotlib, Seaborn, Streamlit, and Pandas. The timeline method is used to present who, when, where, and how the data is visualized. The goal is to simplify system operation for users with limited computer experience and eliminate the risk of inaccurate data entry due to its validation capabilities.

Farzana et al. [18] developed a tool for analysing WhatsApp chat data, identifying frequently used phrases, message frequency, sentiment, and key topics. The tool uses Python programming and pandas, matplotlib, and seaborn libraries to import data and create visualizations. The Flask web framework allows easy interaction with the tools. The tool uses security measures like HTTPS and encryption to protect user data integrity, ensuring no alteration during the visualization process. The system also uses visualization techniques like word clouds, bar charts, line graphs, and network graphs to make the findings more understandable.

Patka's WhatsApp Activity Analyzer tool [19] provides insights into user engagement, message frequency, and group dynamics. It analysed metrics like message sent, active users, and emojis.

To the extent of our study, no other work has been carried out that uses WhatsApp chat data visualization for digital forensics. Chronochat Visualizer is a timeline analysis tool that demonstrates the relationship between chat data and timestamps. It offers multiple modules and can help resolve issues related to timestamps and message types. Table 2 presents a comparative summary of Chronochat Visualizer with the reviewed work.

Table 2 *Comparison of existing tools with the Chronochat Visualizer*

		WhatsApp Chat Sentiment Analyzer [17]	WhatsApp Chat Analysis and Visualization [18]	WhatsApp Activity Analyzer [19]	Chronochat Visualizer
Programming Language		Python	Python	Python	Python
Visualization	Bar chart	Yes	Yes	Yes	Yes
	Line chart	Yes	Yes	Yes	Yes
	Scatter plot	No	No	No	Yes
	Word Cloud	Yes	Yes	Yes	No
WhatsApp metadata	Timeline analysis	Yes	Yes	Yes	Yes
	Contact analysis	Yes	Yes	Yes	Yes
	Message analysis	Yes	Yes	No	Yes
	Group chat analysis	Yes	Yes	No	No
	Location analysis	No	No	No	No
Report generation		No	No	No	Yes

3. Methodology

The project aims to develop a forensic visualization tool for analysing WhatsApp chat data using an object-oriented software development model. Python, an object-oriented programming language, is chosen due to its support for abstraction, encapsulation, inheritance, and polymorphism techniques. Python's libraries include Matplotlib, Seaborn, Bokeh, and Plotly [20]. The project follows Bruegge & Dutoit [21] which includes five phases: requirement elicitation, analysis, design, implementation, and testing. This approach aligns with the complexity of the project requirements and ensures the visualization tool is well-designed and tested. Activities of this study is summarized into Table 3.

Table 3 *Object-oriented software development model*

Phases	Activity	Outcome
Object-oriented requirement elicitation	• Analyse requirement. • Identify functional requirements. • Define non-functional requirements. • Identify software and hardware requirements.	• User requirements • Functional requirements • Non-functional requirements • Hardware and software requirements
Object-oriented analysis	• Verify system specifications using the Unified Modelling Language (UML) to support system and software development. • Create Use Case Diagrams to illustrate system functionality. • Create Class Diagrams to illustrates how classes are arranged and related to one another in a system. • Create Dynamic Modelling to specify and execute a system control mechanism. • Perform data cleaning.	• Case diagram • Sequence diagram • Activity diagram • Class diagram. • A clean data table
Object-oriented design	• Transform the analysis model into a design model. • Implement Object-Oriented Design (OOD) principles. • Present algorithm design. • Design GUI design focuses on creating a user-friendly interface. • Design UML diagrams.	• Interface design • Display messages table • Visualization models.
Object-oriented implementation	• Transforming design models into executable code using a programming language. • Transforming the object model into source code that aligns with the specified requirements. • Develop the graphical user interface (GUI) according to the interface design. • Implementing Python libraries for data visualization, Matplotlib, Streamlit, Arrow, and Pandas	• Source code • Graphical user interface (GUI)

Table 3 *(cont)*

Phases	Activity	Outcome
Object-oriented implementation	• Transforming design models into executable code using a programming language. • Transforming the object model into source code that aligns with the specified requirements. • Develop the graphical user interface (GUI) according to the interface design. • Implementing Python libraries for data visualization, Matplotlib, Streamlit, Arrow, and Pandas	• Source code • Graphical user interface (GUI)
Object oriented testing	• Conducting unit testing • Conducting integration testing • Conducting system testing. • Conducting user acceptance testing.	• User feedback • Improved Chronochat Visualizer

3.1.1 UML Diagram

The use case diagram of Chronochat visualizer in Fig.1 show the three processes involved, upload WhatsApp chat data file, analyse chat data, and view analysis results. As shown in Fig. 2, seven components, including user, Graphical User Interface (GUI), file system, data processing, data analysis, visualization, and dashboard.

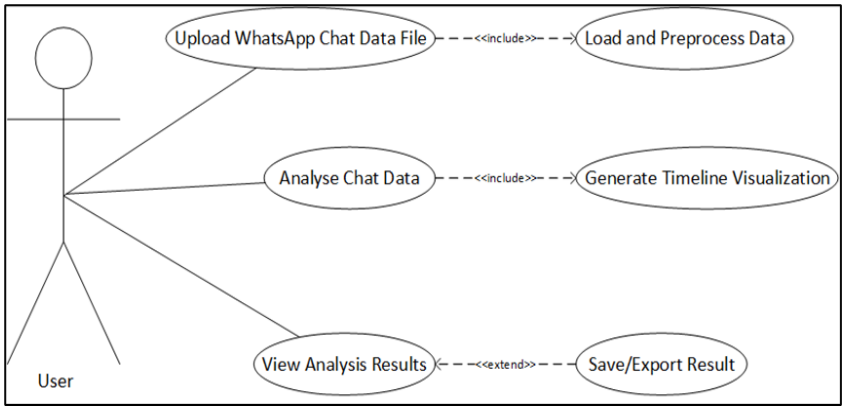

Fig.1 *Use case diagram of Chronochat Visualizer*

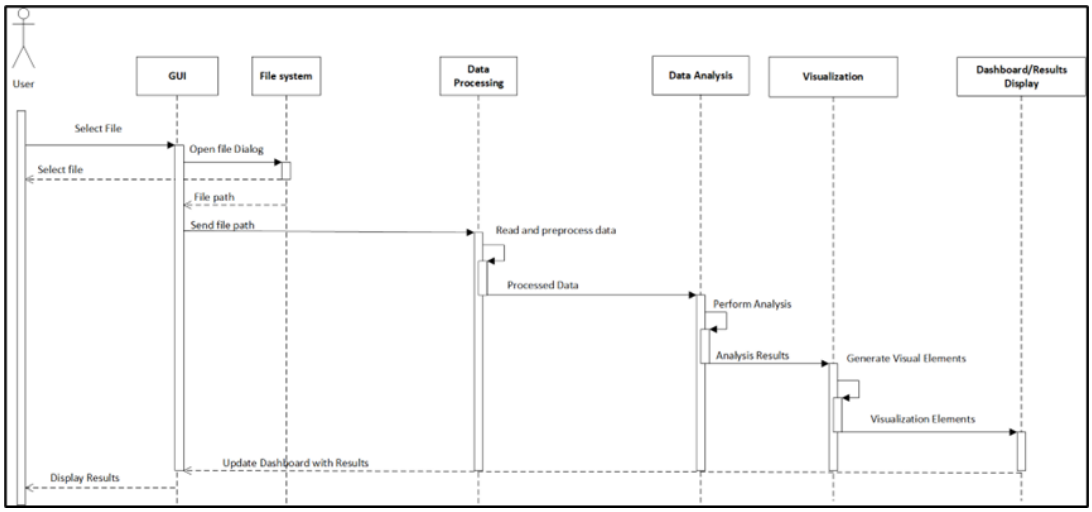

Fig. 2 *Sequence diagram of Chronochat Visualizer*

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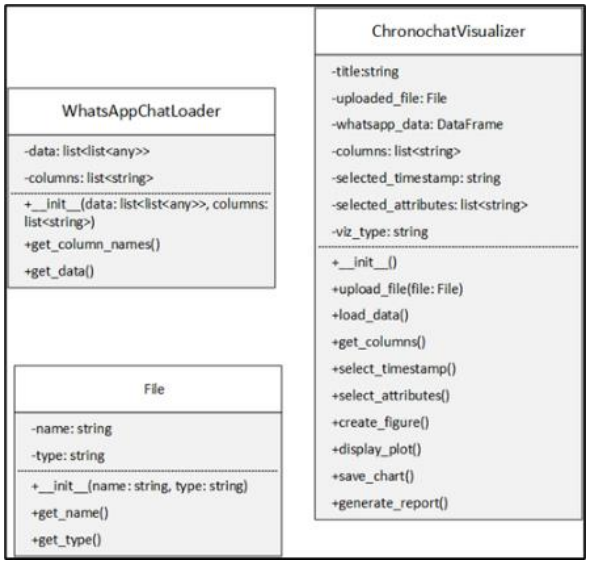

Fig. 3 *Class diagram of Chronochat Visualizer*

Fig. 3 shows three main classes involve in Chronochat Visualizer, the main class, Chronochat Visualizer represent the tool. Second class, DataFrame, represents a Pandas DataFrame. The third class is File that represents file.

3.1.2 Chronochat Visualizer Architecture

Three modules include to develop the Chronochat system, such as read file module, analysis module and report module.

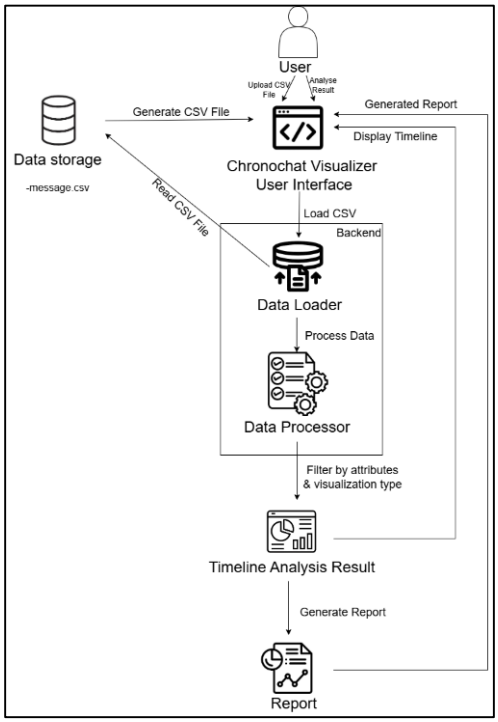

Fig. 4 *Chronochat Visualizer Architecture*

The WhatsApp conversation timeline analysis tool in Fig. 4 is designed for easy uploading, processing, displaying and reporting of chat data. Streamlit supports the frontend with an easy-to-use interface for uploading CSV files and showcasing visualizations. The backend consists of a Data Loader, Data Processor, Visualization Generator, and Report Generator. The Data Loader loads the CSV files, the Data Processor converts timestamp data, filters out irrelevant data, and sends the data to the Visualization Generator for various charts. The Report Generator creates a PDF report for users.

Table 4 *The Chronochat Visualizer modules*

Module	Description
Read file module	The Chronochat Visualizer have a browse file button that open dialog box to select CSV file.
Analysis module	In the analysis module, the attributes are chosen then the analysis result display in visualization chart.
Report module	The result can save and export in PNG and PDF.

PyCharm is chosen for the Chronochat Visualizer, offering dynamic features, code completion, real-time error checking, and integrated Python debugger, alongside Streamlit framework and libraries like Matplotlib and Pandas.

4. Results and Discussion

4.1 Timeline analysis module

This section presents the implementation of Chronochat Visualizer. Furthermore, results of tool's testing and user acceptance testing are included. The Chronochat Visualizer interface is a crucial aspect of software development, enhancing user experience by providing seamless and intuitive interface (see Fig. 5).

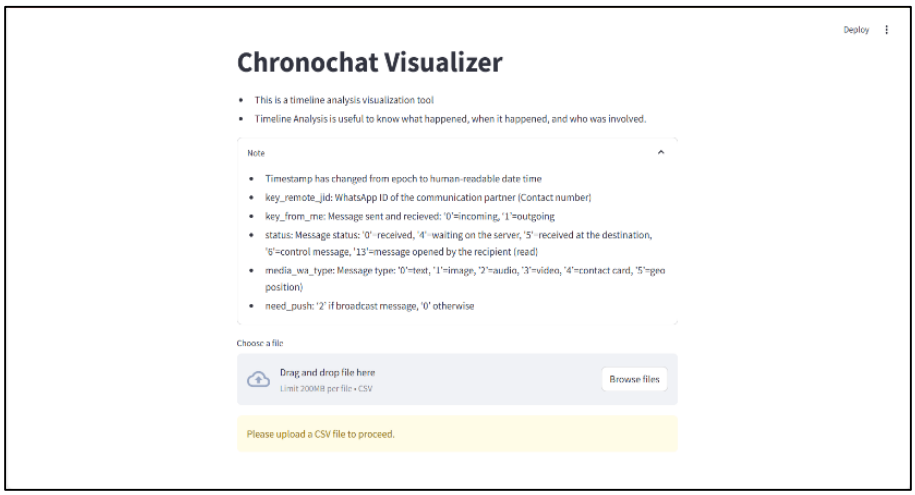

Fig. 5 *The main window interface*

The Chronochat Visualizer application features a clear, logical layout, allowing users to easily navigate and perform actions, including uploading CSV files and selecting visualization options. A "Note" for attributes, and an input widget for uploading CSV files containing WhatsApp chat data. Chronochat Visualizer restricts file type to prevent malicious uploads uses Streamlit's file uploader function and input validation.

1. Check Data Type and Format
    a. Retrieve the first element of the 'selected_timestamp' column
    b. Check if this element is of type 'int' or 'float'
2. Epoch Format Verification
    a. Convert the first element to an integer
    b. Convert this integer to a string.
    c. Check if the length of this string is exactly 10 (indicating epoch format)
3. Apply conversion based on format
    a. If Epoch format
        i. Use 'apply' to iterate over each element in the 'selected_timestamp' column
        ii. Convert each element from epoch format to datetime using 'arrow.get(x).datetime'
    b. If not epoch format
        i. Use 'apply' to iterate over each element in the 'selected_timestamp' column.
        ii. If an element is of type 'int' or 'float', convert it using 'arrow.get(x).datetime'

Otherwise, convert the element to datetime using 'pd.to_datetime(x)'

Fig. 6 *Algorithm of date conversion from Epoch format to human readable*

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WhatsApp chat database uses epoch time format, requiring data conversion to ensure readable timestamps as in Fig. 6. Chronochat Visualizer uses Arrow library to convert epoch timestamps to human-readable DateTime format, improving data accuracy and interpretability. Epoch time allows forensic analysts to recreate user actions, create timelines, and uncover crucial evidence for investigations, ultimately contributing to justice defence [22].

4.1.1 Contact Number over Timestamp

Fig. 7 to Fig. 9 is the analysis of contact number over timestamp in line chart, scatter plot and bar chart. In forensic analysis, analysing contact number over timestamp can provide valuable insight into the communication patterns and relationship between individuals [23]. In WhatsApp context, by analysing contact numbers, investigators can identify communication patterns, including who communicated with whom, how often, and at what times. Therefore, this will increase the detection on communication patterns. Moreover, the analysis can lead to identification of potential evidence.

Fig. 7 *Line chart of Contact number over timestamp*

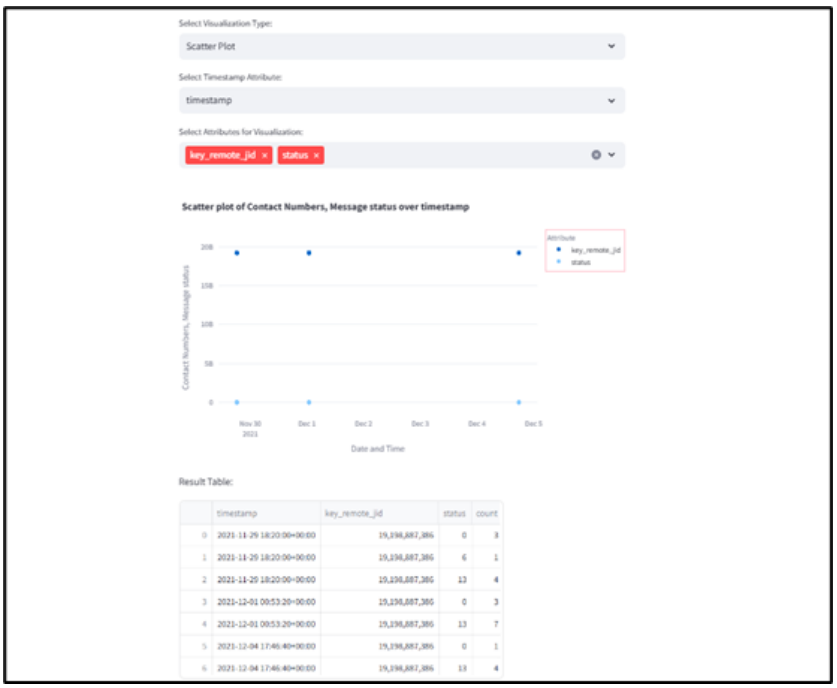

Fig. 8 *Scatter plot of Contact number and status over timestamp*

Fig. 9 *Bar chart of Contact number over timestamp*

4.1.2 Message Incoming or Outgoing over Timestamp

Fig. 10 to Fig. 12 provide a timeline analysis for WhatsApp messages incoming or outgoing over timestamp. WhatsApp messages can provide context to the communication, allowing investigators to understand the direction of communication, which can be crucial in establishing roles of individuals in a criminal investigation [24]. Moreover, the analysis can provide digital footprint of an individual's activities, which can be used to track movements and activities.

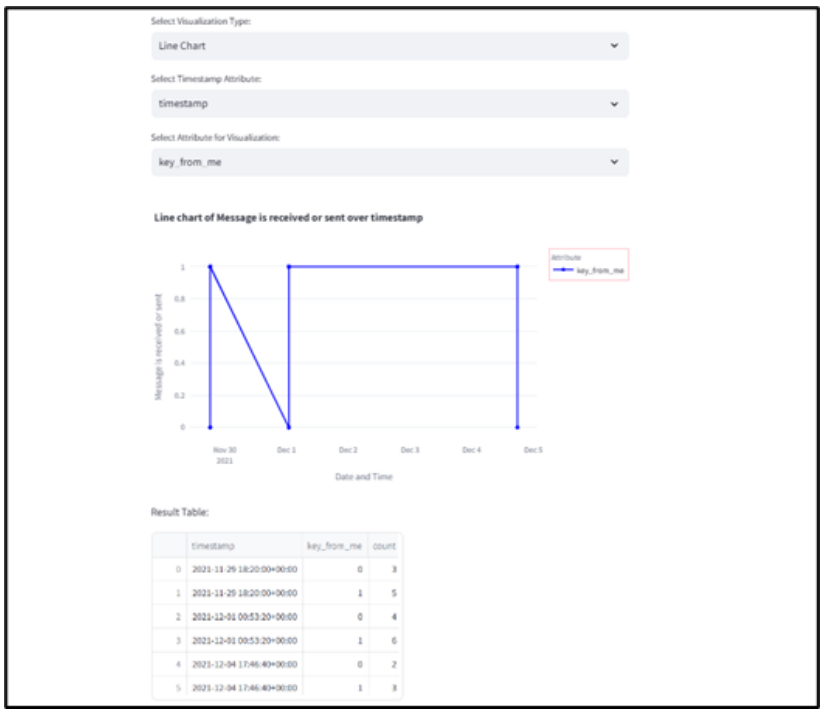

Fig. 10 *Line chart of Message incoming or outgoing over timestamp*

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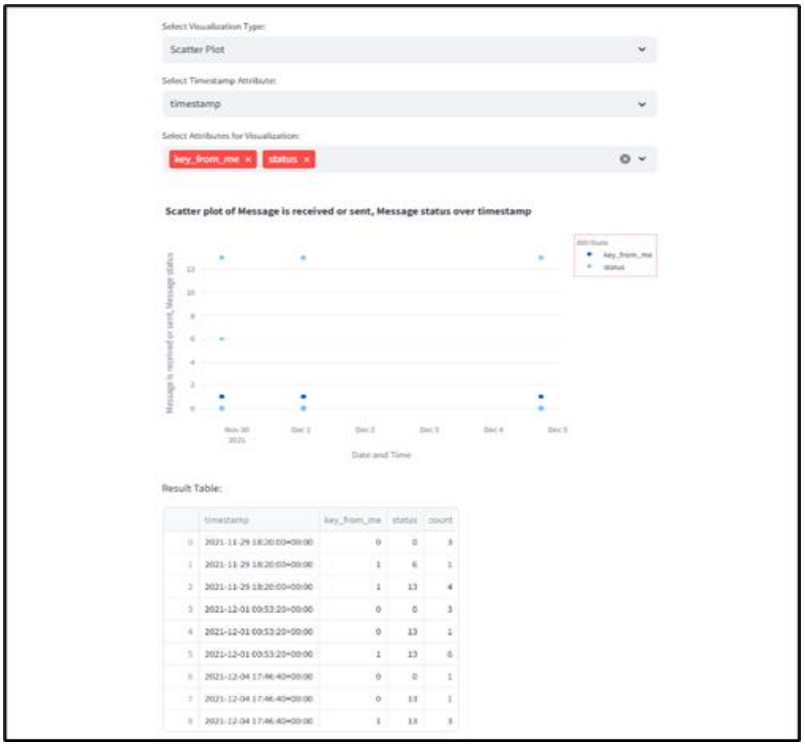

Fig. 11 *Scatter plot of Message incoming or outgoing and status over timestamp*

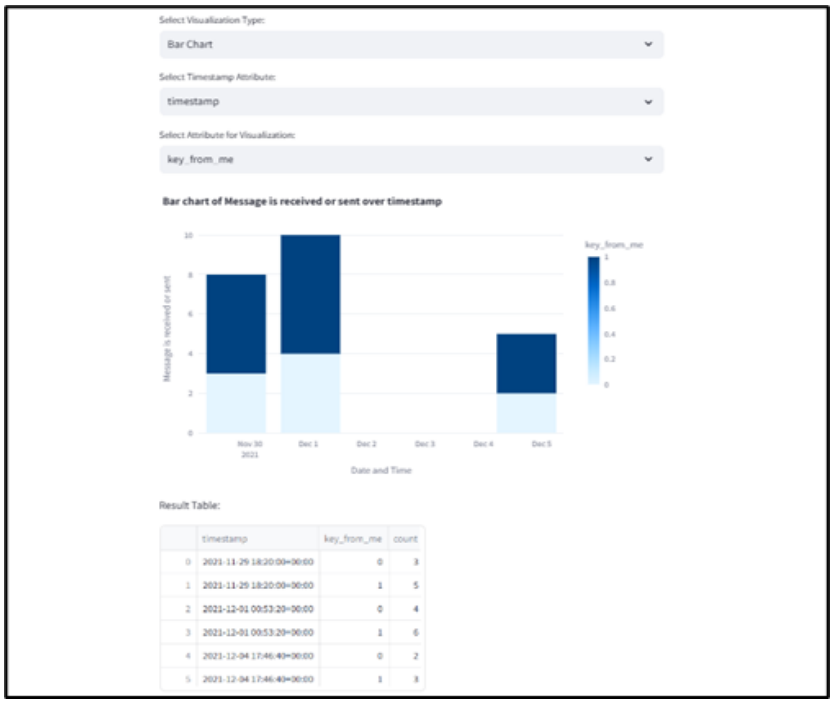

Fig. 12 *Bar chart of Message incoming or outgoing over timestamp*

4.1.3 Message status over Timestamp

Fig. 13 to Fig. 15 shows the analysis of message status over timestamp. In WhatsApp, “status” (i.e. ‘0’ = received, ‘4’ = waiting on the central server, ‘5’ = received by the destination, ‘6’ = control message, ‘13’=message opened by the recipient (read)) is indicated whether a message was delivered, read, or not delivered. This information relevant in indicating suspect had knowledge of a particular event or communication because if a message sent but not delivered, it may indicate the communication were trying to be conceal by enable disappearing message [25]. Additionally, in accordance with section 233 of the Malaysia Communication and Multimedia Act (CMA) 1998 [27], "status" can serve as a hint to identify any message receipt, such as received or read, in cases of communication misbehaviour.

Fig. 13 *Line chart of Message status over timestamp*

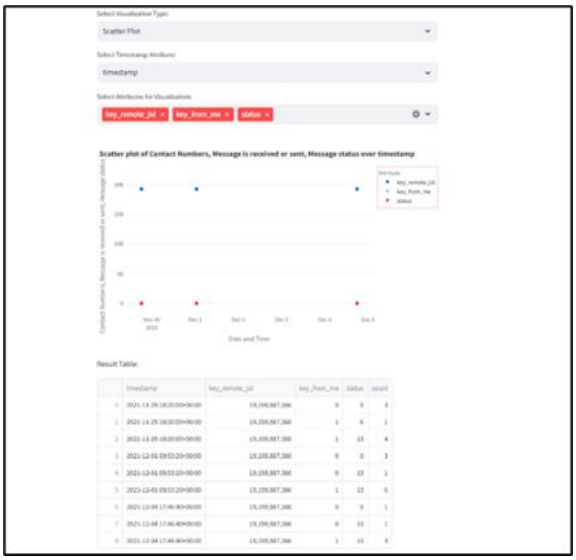

Fig. 14 *Scatter plot of Message status, contact number, and message incoming or outgoing over timestamp*

Fig. 15 *Bar chart of Message status over timestamp*

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4.1.4 Message type over timestamp

Fig. 16 to Fig. 18 shows analysis of message type over timestamp. Message type such as text, image, video, audio. In the analysis, message type can reveal patterns of communication, whether it was primarily text-based or involved sharing of multimedia files. Investigators may identify clues of a suspect's interactions pattern by analysing the type of message sent. A suspect may have been attempting to give evidence a complex message by sending video messages.

Fig. 16 *Line chart of Message type over timestamp*

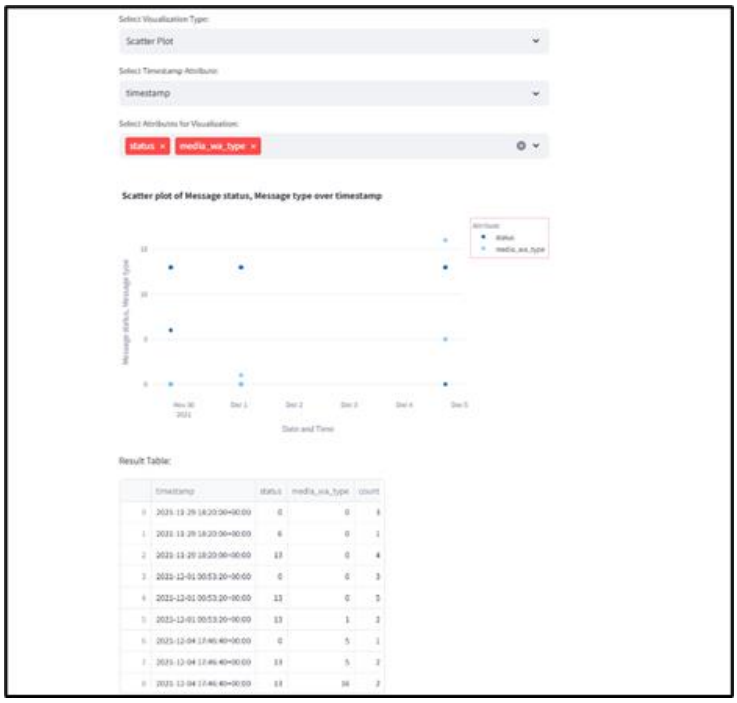

Fig. 17 *Scatter plot of Message type over timestamp*

Fig. 18 *Bar chart of Message type over timestamp*

4.2 Functional testing

Table 5 summarized the functional testing. It indicts that Chronochat Visualizer has successfully passed the test plan scenario, specifically for its visualization features. More importantly, the visualization result can be a potential investigation tool to facilitate events reconstruction based on timeline process. A similar approach was demonstrated by [5] and [26].

Table 5 *Results of functional testing*

No	Test Case	Expected Output	Actual Output
1	Access to Chronochat Visualizer	Able to open Chronochat Visualizer.	Able to open Chronochat Visualizer.
2	Browser file button able to function	Able to open dialog box.	Able to open dialog box.
3	Insert CSV file	Insert successful	Insert successful
4	Table selection	Able to select and display the tables.	Able to select and display the tables.
5	Visualization method selection	Able to trigger different conditions based on the visualization method that is selected.	Able to trigger different conditions based on the visualization method that is selected.
6	Attributes selection	Able to select attributes from the selected tables.	Able to select attributes from the selected tables.
7	Human-readable timestamp	Able to convert epoch timestamp into human-readable timestamps.	Able to convert epoch timestamp into human-readable timestamps.
8	Display data	Able to display data accurately.	Able to display data accurately
9	Export the report	Able to export and save as PDF.	Able to export and save as PDF.
10	Export the chart	Able to export and save as image PNG.	Able to export and save as image PNG.

4.3 Forensic Analysis Scenario Testing

Table 6 forensic analysis scenario testing simulates scenarios that could be analysed forensically to ensure the system captures and retains necessary information. We applied completeness and accuracy metric to test the ability of Chronochat in generating significant outputs to forensic investigations.

Table 6 *Forensic Analysis Scenario Testing*

No	Test Case	Expected Output	Actual Output
Completeness			
1	Shared media type analysis	Able to display complete shared media types from dataset.	Able to display complete shared media types from dataset.
2	WhatsApp contact number and timestamp	Able to display complete WhatsApp contact number and timestamp.	Able to display complete WhatsApp contact number and timestamp.
3	Interaction of incoming and outgoing message pattern over time	Able to display complete incoming and outgoing message pattern over time.	Able to display complete incoming and outgoing message pattern over time.
4	Message status and timestamp	Able to display complete message status and timestamp.	Able to display complete message status and timestamp.
Accuracy			
1	Message timestamp	Able to display correct timestamp.	Able to display correct timestamp.
2	Shared media type analysis	Able to display correct shared media types from dataset.	Able to display correct shared media types from dataset.
3	WhatsApp contact number and timestamp	Able to display correct WhatsApp contact number and related timestamp.	Able to display correct WhatsApp contact number and related timestamp.
4	Interaction of incoming and outgoing message pattern over time	Able to display correct incoming and outgoing message pattern over time.	Able to display correct incoming and outgoing message pattern over time.
5	Message status and timestamp	Able to display correct message status and related timestamp.	Able to display correct message status and related timestamp.

4.4 User Acceptance Testing

The user acceptance testing was conducted with a sample of 35 respondents consisting of final year Computer Science students with knowledge in digital forensics. Respondents were selected based on more than two years of experience in this field. Fig. 19 shows the result of user acceptance testing on functionality of the system. Most user votes pass as the system well-functioning.

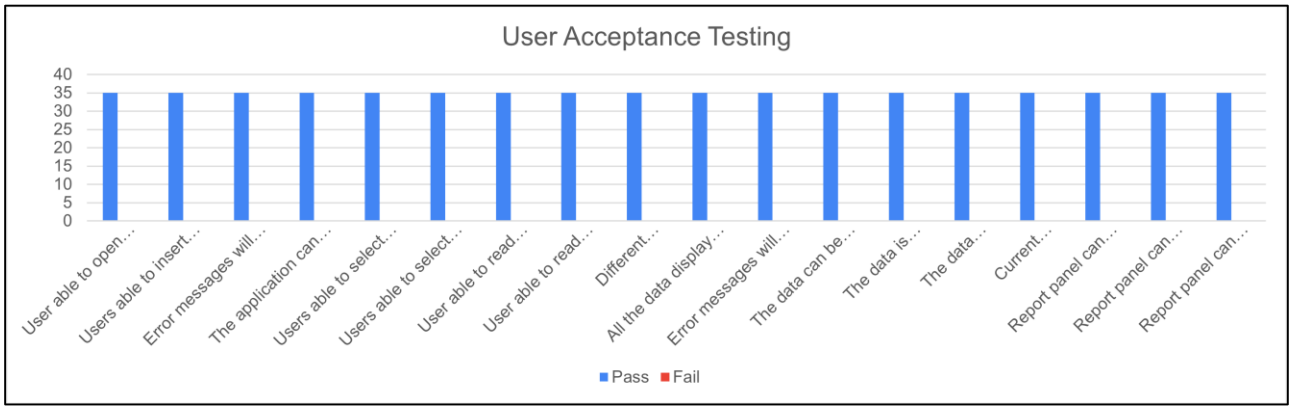

Fig. 19 *Result of user acceptance testing*

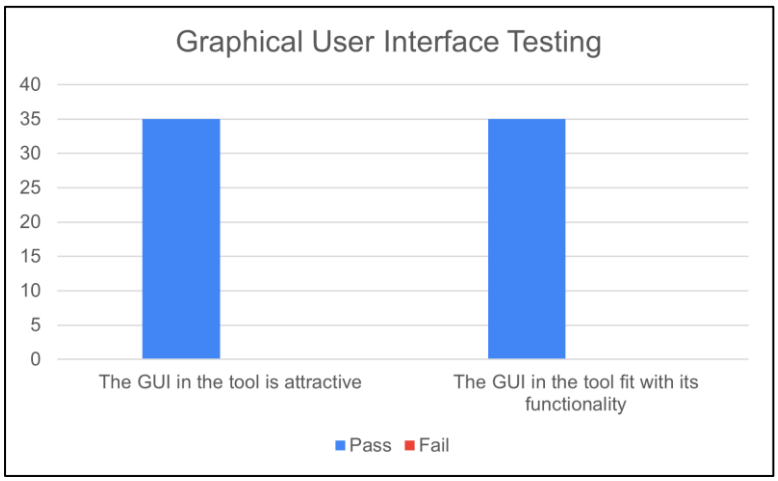

Fig. 20 *Result of graphical user interface testing*

Fig. 20 shows the result of graphical user interface testing. A simple GUI is used for this system and user votes pass or attractive GUI.

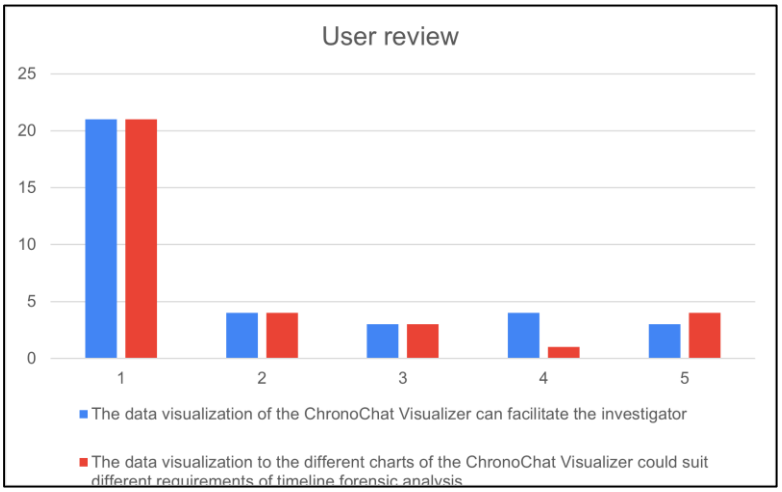

Fig. 21 *Result of User Review*

Fig. 21 shows the user review and feedback are essential in improving Chronochat Visualizer for better quality. A valuable insight into the system's usability, functionality, and overall user experience

5. Conclusion

The Chronochat Visualizer, a WhatsApp Chat forensic visualization tool, has successfully met the objectives, demonstrating its functionality and user testing capabilities. The Chronochat Visualizer has the potential to significantly enhance the efficiency and effectiveness of forensic investigations, allowing analyst to quickly identify key events, relationships, and patterns in large datasets. The advantages would support activities related to events reconstruction.

The project has limitations such as limited chart visualization, limited detail display when hovering over charts, and a lack of an appealing GUI. The system needs improvements to enhance investigator benefits, including a variety of visualization models, tooltips for guidelines, an interactive GUI, and more respondents, particularly digital forensics partitioners.

Acknowledgement

This research was supported by the Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS/1/2020/ICT07/UTHM/03/1). The authors would like to thank the Faculty of Computer Science and Information Technology, Universiti Tun Hussein Onn Malaysia for its support and encouragement throughout the process of conducting this research.

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *N. H. Hassan, N. H. Ab Rahman;* ***data collection:*** *N. H. Hassan, N. H. Ab Rahman;* ***analysis and interpretation of results:*** *N. H. Hassan, N. H. Ab Rahman;* ***draft manuscript preparation:*** *N. H. Hassan, N. H. Ab Rahman. All authors reviewed the results and approved the final version of the manuscript.*

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