

Enhancing Digital Forensic Analysis for Locating Missing Persons: Multimodal Data Integration

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Abstract. This paper presents a framework for enhancing digital forensics to aid a missing person by integrating multimodal data such as location history, social media analysis, eyewitness testimony, mobile phone, and computer data. This approach focuses on creating comprehensive profiling to speed up the search process. Utilising multimodal data integration offers new avenues for enhancing the effectiveness of the investigation process. Through advanced analytical approaches and ethical considerations, this framework seeks to provide safety to the missing persons and closure to their loved ones and law enforcement.

Keywords: Location, social media, eyewitness, aid, records, positioning, missing person, GPS

1 Introduction

The act of aiding a missing person is an emotional task with multifaceted challenge entanglement. It is a heart-wrenching experience for the family who waits for loved ones too. In moments like this, every bit of information becomes a beacon of hope. In the 2019/2020 financial year, police forces in England and Wales received 359,240 calls reporting missing persons cases. This averages almost 1000 a day, which indicates how desperate the situation is (Phoenix and Francis, 2022). Traditional forensic science approaches such as engagement with eyewitnesses and gathering physical evidence have very limited data sources to facilitate the investigation (García, et al, 2022).

The rapid growth of the digital world has opened a significant opportunity for digital forensic analysis in aiding missing persons. By using a multimodal approach, the efficiency and comprehensiveness of digital forensic investigation in aiding missing persons can be achieved (PhD Assistance, 2020). Data including eyewitness accounts, location history, social media analysis, and mobile and computer devices analysis are proposed for integration and enhancement of the investigation process. How the integration of all these available information and technologies contribute to enhancing digital forensics for aiding missing persons, gives prospects in solving missing persons cases (Brown, 2022). However legal and ethical considerations must always be observed (Firdonsyah, et al, 2023).

2 Related Work

Digital forensics has been around as a discipline now for over four decades. The Federal Agency of the United States started digital forensics as a discipline in the mid-1980s. Digital forensics was established after digital crime began to increase, following the introduction of personal computers (Almarzooqi, et al, 2016). The field of Digital Forensics is ever-evolving to the present day. Location information, social media behaviour, eyewitness accounts, and mobile and computer data devices have played significant roles in locating and solving criminal cases. However, this information can also be integrated to analyse missing person cases (Brown, 2022).

In the US about 450,000 young people are reported missing to the police every year. In England and Wales, around 300,000 people are reported missing, and In Canada, it is around 40,000 (Boulton, et al, 2022). Two-thirds of the missing people are under the age of 18, which classifies them as vulnerable (Babuta and Sidebottom, 2020). A website called “*missing people*” which assists in aiding missing persons, states that someone is reported missing every 90 seconds in the United Kingdom (Missing people, 2024). Of course, this is very alerting and needs a radical solution in place. Someone who went missing may not always mean there is a criminal activity involved. However, it is not improbable to be abduction, sexually exploited, and other criminal activities (Phoenix and Francis, 2022). Most people who are reported missing are located safely. However significant number of people

do go through fatal experiences. In aiding missing persons and bringing them to safety, digital forensics plays a vital role. Analysing and integrating all available data speeds up the aiding process.

2.1 Location Information Analysis

Location history is vital information in aiding missing persons. Mobile phones are fitted with GPS chip, which fetches the phone's current location. This works based on position on earth in the form of longitude and altitude (Kini, et al, 2017). Although this technology could pose a threat to privacy, by exposing individuals' home addresses, most visited places, workplaces etc, it could also be used to identify the location of missing individuals. Almost all mobile users use LBS (location-based services).

LBS (Location-based services) are classified into three main categories, position awareness, sporadic queries, and location tracking.

Table 1 Location-Based Services.

Position Awareness	Sporadic Queries	Location Tracking
This type of LBS is used for internal purposes. It is only known to the entity that is making use of it. This can be found in car navigation systems such as calculating the best route and using guidance for local area maps.	This type of LBS is used for making a query. The location is shared once to find accurate responses to POI (point of interest query), such as restaurants, retail, stores etc location.	This type of LBS is used for constantly detecting the whereabouts of the user. Maps such as Google Maps and Waze are the best examples of this.

Passive and Active Positioning: In the process of tracking individuals or attempting to locate, positioning information is obtained from GPS or mobile network (e.g. 3G or 4G). However, the accuracy of the precise location is insufficient. The position given may be within a perimeter of km to 2km in a built-up area and 4km to 10 km in an open outdoor environment. GPS is more precise; however, it does not work in indoor environments. There are recent developments in indoor positioning, using base stations, and radio waves (Ni, et al, 2003). This development focuses on active indoor positioning. However, this may not help try to aid missing persons in tracing criminals. This is because it requires the willingness of the other side, which is hardly ever feasible. Passive indoor positioning is the only preferred option left. Passive indoor positioning has two types: vision-based and wireless-based (Tsai, et al, 2019).

1. Vision-based positioning is based on making use of cameras, which works by taking photos, and requires no intervention. The photos are then used to determine the precise location of the person by comparing them with photos in the database.
2. Wireless-based positioning based on signal collection from the target to determine the exact whereabouts of the target. This includes.
 - Deploying proximity detection, which determines the principle of closest proximity. This is achieved by using beacons and sensors such as IR (infrared receiver) and RFID (radio frequency identification) are deployed in areas that are designated for observation. The sensor with the strongest signal is the location of the target (Ni, et al, 2003).
 - Deploying Triangulation, which works direction-based approach and distance-passed approach. Ultrasonic, Bluetooth and WIFI access points are used to calculate the strength of the received signal strength, angle of arrival, time of arrival, and difference of arrival are calculated to determine the whereabouts of the target (Rida, et al, 2015)
 - Fingerprinting which is also known as 'scene analysis' is a technique of estimating target locations by using received signal strength-based radio map, which has online and offline phases and Padmanabhan, 2000).

There are various location identification techniques concerning location principles. This includes arrival time, angle of arrival, enhanced observed time and cell identification. Cell Identification is a relatively easier approach

to locate the target by identifying its serving base station (Xu, et al, 2013). Mobile phones are connected to a network, which means that there is an assigned IP address for each mobile, Service providers use database query, that gives them approximate location, and based on the location of the mobile is determined. After determining the location data is transmitted based on the location as illustrated in Figure 1.

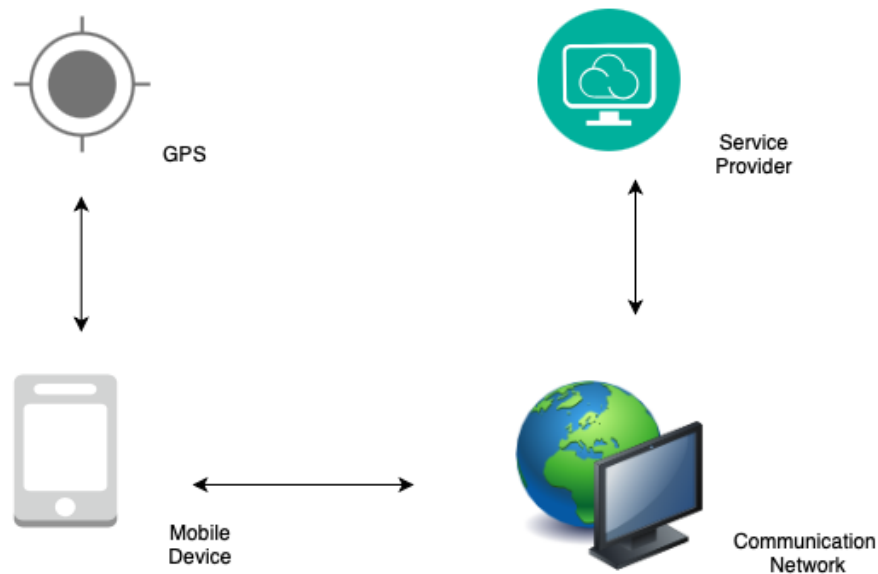


Figure 1 Location Obtaining Process.

The above figure shows how GPS location, mobile devices and communication networks, and service providers share services among themselves.

Location privacy: Location privacy contains two elements: location privacy and query privacy. Location privacy is about identifying where exactly the user is, and query privacy concerns the interest of the user. To protect this privacy invasion individual's location history may be faked and may not be accurate. Algorithms such as k-1 can be used to hide the exact location and produce various fake locations (Kini, et al, 2017). This highlights that unless various approaches are integrated, the aiding process may take longer time than expected.

2.2 Social Media Behaviour Analysis

The availability of the Internet and the rapid growth of the smartphone industry have played a significant role in social media advancement. Social media has become an integral part of the norm in the contemporary world. The term 'social media' is broadly used to refer to interactive online platforms, internet forums and chatrooms (Phoenix and Francis, 2022). The heterogeneous nature of social media has always made it difficult to give a precise definition of what it means. A report in 2022 states that there are 4.62 billion social media users. This is 58 % of the entire population. The active users engage in activities such as sharing daily activities (Rich and Aiken, 2024). The use of social media between 2016 and 2022 has doubled as shown in the graph below.

The amount of information available on social media platforms attracts both malicious actors and state intelligence to target individuals and organisations. Due to these reasons, OSN (Online Social Network) crimes are growing rapidly. OSN crime includes terrorism recruitments, illegal campaigning, propaganda campaigns, sexual exploitation etc. Due to this eminent threat, the process of identification, detection, prediction, and mitigation is carried out by SMF (social media Forensics). SMF co-exists with the security of the Social Media ecosystem because the readiness of SMF improves the security level of the social media environment (Basumatary and Kalita, 2022).

2.3 Mobile Device Analysis and Computer Analysis

Mobile and computer devices are used for various purposes daily. This includes shopping, communicating, navigating, transactions and others. These tasks influence users to share different types of data. Retrieving these data gives a comprehensive profile of the behavioural pattern of the target (Rich and Aiken, 2024).

Mobile Phone and Computer Based Investigations: The mobile phone industry is growing rapidly. The growth of the mobile industry plays a vital role in our daily lives. Mobile forensics plays a significant role in locating missing persons or solving crimes. The large data found in the phone gives an immense amount of evidence to establish facts or at least have a hint to determine the whereabouts of the target. Approaches such as HDFI (Harmonious Digital Forensic Investigation), which follows “obtaining authorisation, documentation, information flow, preservation of chain of evidence, and interaction with a physical investigation” constituting part ISO/IEC 27043 gives advantageous direction in aiding missing person (Omeleze and Venter, 2013). Various types of devices and data records can be integrated to analyse behavioural patterns and used as a roadmap for locating the target.

Computers can provide a roadmap for committing crime and solving crime. Computers are also capable of recording activities performed by their means (Shrivastava, et al, 2013). IM (instant message) investigation, which includes applications like WhatsApp and Telegram could be investigated on both computers and phones utilising mobile forensics (Nawaz, et al, 2023). Device records and data records can be found by analysing mobile and computer devices. Table 2 contains a list of possible data found on mobile and computers that could be utilised for analysing behaviour patterns.

Table 2 Mobile and Computer Data

Device Records (active and deleted)	Data Records (active and deleted)
Contact Lists	Contact
SMS message (with photos)	SMS Data
MMS message	SMS Message
Call log data (with time stamps)	Location data
Calendar information (with locations)	Call log data
Picture files	Calendar information
Video files (with sound)	Picture files
Email messages (with attachments)	Video files
(Web browsing history)	Email Message
Application data	Web History
User accounts	Application data
Passwords	
Searched Items	
Installed applications	
Application data	

File system data	
File system status	
Unallocated and deleted spaces	

2.4 Eyewitnesses Data Collection and Analysis

In England, it is a statutory requirement to interview a missing person who is under the age of 18 who returns from a missing episode within 72 hours. The RHI (returning home interview) is undertaken to uncover what insight is found to safeguard them in the future, examine if there is any risk they are revealed to, and what risk factors were at home. However, this only occurs after the target is located. Research on RHI indicates that people involved in missing episodes; have previously been involved in criminal activities, drug problems, conflict at home, behavioural problems, and mental issues (Boulton, et al, 2022). This indicates that it is not always the case that someone who is missing is unaware or involuntary. A missing person may have engaged in criminal activities. This means that the target does all possible to remain hidden, which requires an even tougher approach to the investigation. In some cases, individuals with mental cases may also avoid collaboration in allocating them due to their mental health conditions. This means that gathering information from eyewitnesses and relatives could significantly contribute to aiding missing persons.

	A	B	C	D
1		Yes	No	Unknown
2	Known to Children,Ãs Services	82 (73%)	7 (6%)	24 (21%)
3	Has an active key worker	61 (54%)	2 (2%)	50 (44%)
4	Engaged in crime	46 (41%)	-	67 (59%)
5	Conflict at home	40 (35%)	12 (11%)	61 (54%)
6	Behavioural problems	36 (32%)	3 (3%)	74 (66%)
7	Used drugs	36 (32%)	3 (3%)	74 (66%)
8	Has mental health issues	23 (20%)	3 (3%)	87 (77%)
9	Association with older peers	19 (17%)	1 (1%)	93 (82%)
10	Drank alcohol	11 (10%)	5 (4%)	97 (86%)
11	Subject to a Child in Need Plan	10 (9%)	12 (11%)	91 (81%)
12	Been a victim of a crime	9 (8%)	1 (1%)	103 (91%)
13	Has a disability	9 (8%)	6 (5%)	98 (87%)
14	Arrested, charged or prosecuted	9 (8%)	1 (1%)	103 (91%)
15	Subject to a Child Protection Plan	8 (7%)	12 (11%)	93 (82%)
16	Has learning difficulties	5 (4%)	6 (5%)	102 (90%)
17	Previous neglect	4 (3.5%)	-	109 (97%)
18	Been homeless	3 (3%)	-	110 (97%)
19	Has physical health issues	3 (3%)	5 (4%)	105 (93%)
20				

Figure 2 Background of Missing Young Persons, (Adapted from (Boulton L. et al, 2022))

Table 2 highlights the situation of young people before they are announced missing. There is various information highlighted in the table that give insight into what could be the leading cause.

2.5 Automated Investigation

Digital forensic analysts have historically investigated digital evidence manually (Du, 2020). However, the recent development of automated tools that can be used to analyse raw data is a significant improvement in the field. This progress however faces issues in the court of law concerning its accuracy and legality. BPF (Push button forensics) known as highly automated digital forensics is criticized at least for two reasons; firstly, some consider it to be a means of knowledge deterioration, which causes over-reliance on artificial intelligence (Wang, et al, 2024). Others think that it provides a low-quality investigation, due to the nature of the tool being dependent only

on training previous data, and not good judgment (Gladyshev, et al, 2013). However, these concerns could be eliminated by feeding accurate data sources, which helps in enhancing comprehensive investigation. The process of developing automated tools include researching on various automated solutions, developing the desired solution and testing the tool. As highlighted in Figure 3, the research can be conducted by using Continuous Integration and Continuous Deployment (CI/CD) approach, which is continuously researching concurrently with tool development, and integrating testing process into the innovation process. This simultaneous approach streamlines the development lifecycle, ensuring the effectiveness and reliability of automated forensic tools (IBM, 2021).

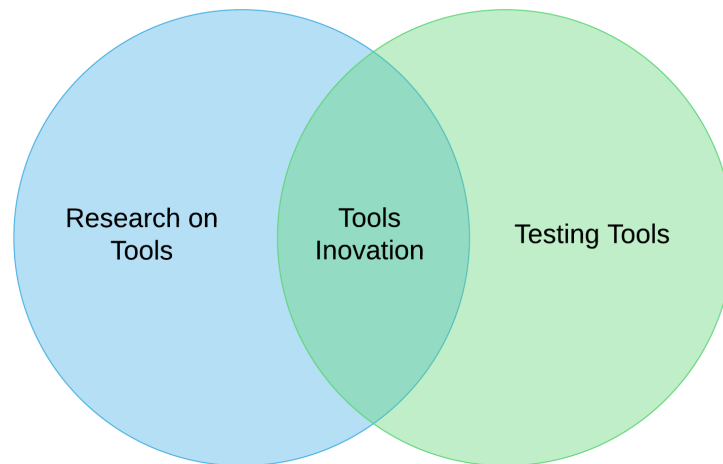


Figure 3 Research and Innovation of Automated Tools.

2.6 Digital Forensic Ethics and Legal Considerations

When conducting forensic analysis, it is important to consider that the laws and morals surrounding data collection are observed. The Fourth Amendment of the US Constitution states that arbitrary searches and seizures are forbidden. Therefore, the data collection process must adhere to the legal procedure to get acceptance in court (Lucifer Insider, 2023). In the process of locating a missing person, it is possible to get hold of sensitive data of the target, however, whenever processing or storing the data gathered, it is crucial to ensure that the GDPR and other local applicable laws are observed. It is also unprofessional and unethical to expose individuals' sensitive data that are collected during the aiding episode (Firdonsyah, et al, 2023).

3 Methodology

The method used in this research aims to enhance the process of aiding missing persons using various technologies and available data. The data integration approach encompasses eyewitness accounts, social media behaviour, location data, mobile data, and computer data. The methodology is outlined below.

Social Media Analysis Techniques

- Document relevant information found on Facebook, TikTok, Twitter, Instagram YouTube and other platforms that could help to gain insights into a behavioural pattern of the target.
- Analyse the target's social media to understand the behavioural pattern.
- Utilise a range of social media types including content-sharing sites, blogging, online social network sites and others.

Social media plays a significant role in aiding missing persons. This is due to its fast-growing nature and the amount of valuable data made available by users. Between 2018 and 2022, the number of social media users has increased in millions as highlighted in Figure 4. Therefore, it must be considered as one of the significant venues in an episode of aiding missing persons.

Number of Social Media Users Over Time in Billions

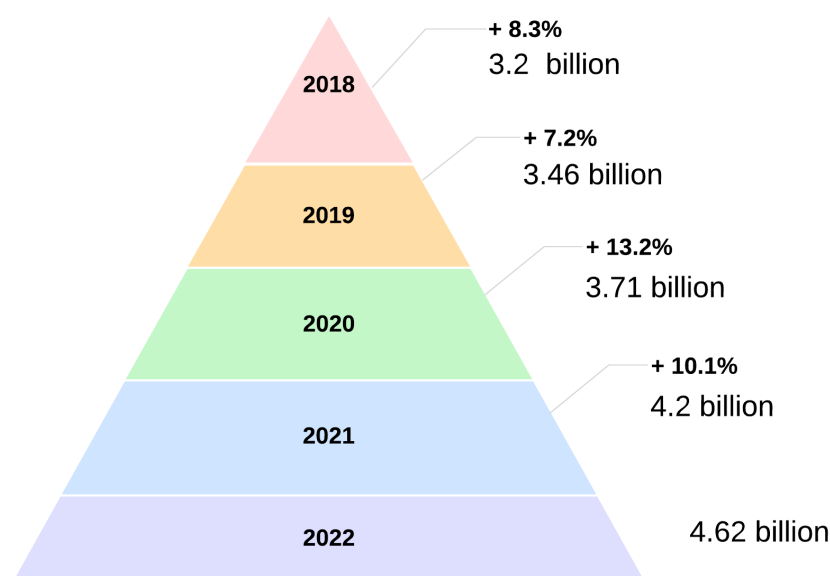


Figure 4 Social Media Users Annual Growth.

The investigation into targets' social media behavioural patterns, significantly contributes to the process of determining their whereabouts. For a single target, various social media platforms can be analysed to better determine the behavioural pattern of the target (Rich and Aiken, 2024). Popular social media platforms are listed in Table 3. These platforms could potentially hold large amounts of data that could help in building a profile.

Table 3 Social Media Platforms and Their Popular Services

Social Media Characteristics	Most Popular Services
Micro-Blogging	Twitter, Tumblr
Blogging	HuffPost, Business Insider, WordPress
Online Social Networking Site	Facebook, Snapchat, Instagram
Social News	Reddit
Collaborative Project (Wikis)	Wikipedia, Wikitravel, wikiHow
Social Bookmarking	Pinterest, Delicious
Community QandA	Quora, Stack Overflow, Yahoo Answers
Media-content Sharing sites	YouTube, TikTok, SlideShare
Opinion-Review-Rating sites	Tripadvisor

The above table contains a list of social media platforms that can be analysed to add behavioural patterns to the target's profile.

Location Analysis Techniques

It is vital to integrate various techniques to enhance the process of analysing locations for aiding missing persons.

- GPS chip utilization: Despite potential privacy issues, mobile phone chips provide substantial information on longitude and altitude data that could be used for location tracking.
- LBS analysis. Location-based services, such as position awareness, sporadic queries and location tracking provide information on precise location.
- Passive and active positioning: Passive methods such as vision-based, and wireless-based positioning can be used. Wireless-based positioning such as proximity detection and triangulation enhance the accuracy of the location.
- Employ location identification based on principles such as angle of arrival, arrival time, and cell identification. (Xu, et al, 2013).

Mobile Phone and Computer Analysis Techniques

- Follow the standardized and general pattern employed in the private corporate sector.
- Upon notification from the management team, request for disk image or terminals of the target machine.
- Conduct comprehensive digital investigation involving high-tech tools.
- Provide detailed investigation results for further actions and decisions (Shrivastava, et al, 2013).
- Look for device and data recordings in both passive and active models.
- Conduct IM (instant message) investigation (Nawaz, et al, 2023).

Eyewitness Data Collection and Analysis Techniques

- Gather information from eyewitnesses, friends, and families of the missing person.
- Analyse data collected from eyewitnesses to identify risk factors, behavioural patterns, and potential indications in aiding the missing person.
- Consume statutory requirements such as RHI to gain insight into what could happen. The below example highlights information found in RHI data.

Automated Tools Techniques

- Select the type of tool.
- Integrate the tool into the existing framework.
- Use the tool for acquisition and analysis.
- Validate the tool.
- Create a report automatically.
- Continuously train and improve the tool (Kamble and Salunke, 2024).

4 Results

This session focuses on presenting the preliminary outcomes of this proposed methodology in locating missing persons by enhanced digital forensic tools. However, it is imperative to note that the experiment is in its early stages and further examination needs to be undertaken. The provided outcomes are hypothetical scenarios, based on the proposed method. More comprehensive analysis is needed to reach definitive solutions. The integration of various technologies in digital forensics is promising, however, extensive validation and refinement are indispensable (Brown, 2022). Social Media platforms are invaluable in the process of data integration, considering the amount of data they contain as illustrated in Figure 5. Social media platforms like Facebook have 3,065 active users on a monthly basis, this platform holds various information including texts, images, videos, and geolocation which could be utilised in the process of aiding missing persons.

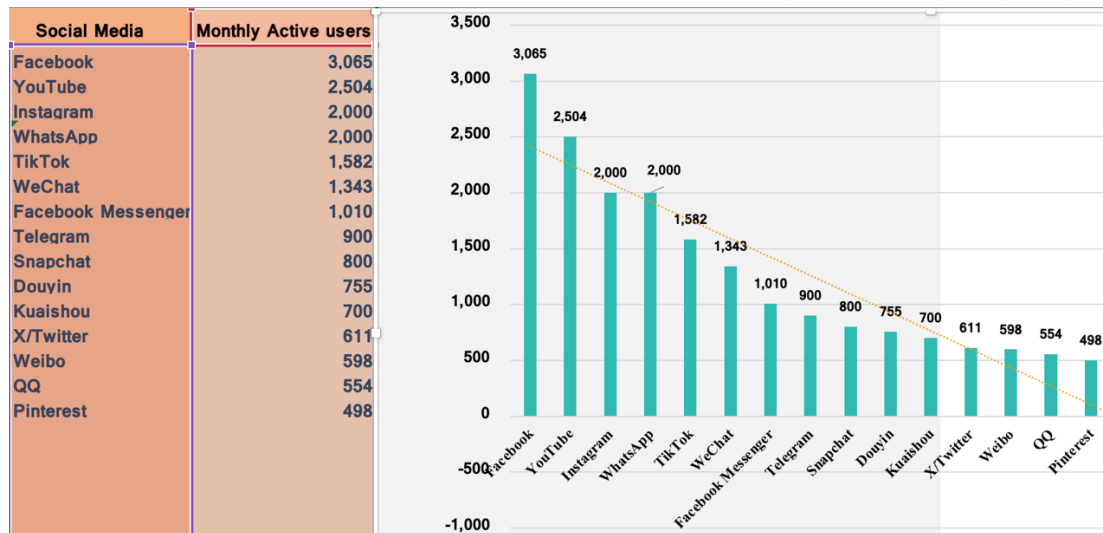


Figure 5 Social Media Platforms, and their Monthly Active users in Millions.

Although social media offers significant amount of data in developing multimodal data integration solution for finding missing persons. Various methods and tools are implemented to validate the proposed method as shown in Table 4. These validation techniques encompass a range of approaches and solutions, along with their advantages disadvantages.

Table 4 Comparison of Approaches and Tools for Aiding Missing Persons.

Tool/Method	Description	Advantages	Disadvantages
Social Media Analysis	Investigates for clues of previous communications and behavioural patterns.	It can give an idea of what could happen and uncover information.	Privacy concerns
Geographic Profiling	Utilises spatial data and movement of the target.	It enables to prediction target's location.	Relays on the accuracy of data and invades privacy.
Mobile and Computer Device Forensics	Extract data from the device.	Provides access to communication history and other activities.	Requires skills and tools.
Automated solutions, e.g. image and face recognition	Identifies individuals' images and videos.	Automates identification.	Accuracy may not be reliable and dependent on image quality.
Eyewitnesses Data	Ask Eyewitness for what they have witnessed or know about the target.	Gives detailed information that may not be discovered using other techniques.	It may be misleading and inaccurate

Discussion of Findings: The table above outlines diverse approaches and tools for aiding missing persons. Each method and each tool have their advantages in aiding missing persons (Brown, 2022). Future research shall involve the evaluation and experimentation of these methods and tools highlighting the complex nature of the field, to determine their efficiency. Other methods and tools shall also be explored to refine and enhance the multimodal data integration approach (Rich and Aiken, 2024).

5 Discussion and Conclusion

Digital forensics is becoming increasingly ubiquitous. Enhancing digital forensic analysis for aiding missing persons through the integration of diverse technologies presents both prospects and trials. However, one of the significant challenges in using multimodal data integration is the potential loss of privacy whose data is collected and analysed for these purposes (Kamble and Salunke, 2024). In the process of collecting sensitive data including extensive use of location information, mobile and computer data, and social media behavioural analysis, critical information of the target that is not related to the search may be exposed. This raises ethical and professional issues regarding the misuse of personal data and privacy (Firdonsyah, et al, 2023).

Using automated tools speeds up the analysis of missing persons' cases. The automated investigation approach introduces complexities concerning the legality and accuracy of the results. These tools need to be validated and tested, to the level by which they are approved in legal proceedings (Kamble and Salunke, 2024). Notwithstanding the challenges, multimodal data integration data analysis offers immense opportunity in locating missing persons cases. By leveraging social media behavioural analysis, mobile and computer data and location information comprehensive data can be accessed to create a profile of a missing person's whereabouts (Brown, 2022).

Integrating various information and technologies in digital forensics analysis is a promising avenue for enhancing the process of aiding a missing person. Although there are concerns about the privacy of the targets and the reliability of automated investigation, the advantages offset the risks. The process of binding social media behaviour analysis, location data mobile and computer data advance the efficiency of digital forensics in aiding missing persons. It is imperative to stress that legal and ethical considerations need to be prioritised in carrying out the investigations (Firdonsyah, et al, 2023). This protects individuals' privacy and upholds the process of investigation. Continuous investigation and improvement in digital forensic analysis methods advance the capability of the field in aiding missing persons and bringing rest to their families (Brown, 2022).

6 Recommendations

Moving forward, more experiments shall be undertaken to validate the proposed approach further and enhance the computational techniques employed. In addition, the paper will incorporate a deeper exploration of relevant literature on detailed solutions, laws, data protection, and ethical considerations in aiding missing persons' cases (Firdonsyah, et al, 2023). This involves analysing existing literature and incorporating findings to enhance a comprehensive overview of the field.

While the initial results are promising, further investigation and enhancement are necessary for the full realization of the potential of digital forensics analysis in aiding missing persons. By addressing the challenge of the reliability of automated solutions, privacy concerns and ethical considerations, the effectiveness and integrity of future works can be ensured (Firdonsyah, et al, 2023). Through continued innovation and collaboration, it is feasible to enhance our capabilities in aiding missing persons (Brown, 2022).

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M.A. Selected and analysed methods that would enhance the process of aiding missing persons. M.A. compared and analysed tools and methods that are employed in this process. M.A. documented research results with explanations. S.A. A.C. supervised the research and documentation undertaken by M.A.

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