# Fingerprint Forensics in Crime Scene: A Computer Science Approach

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**Abstract**—Biometry is essential when it comes to personal identification and verification in forensic applications, and the fingerprint is one of the most commonly used biometric features in the field of biometric identification. To detect fingerprints at the crime scene, to collect and transfer fingerprints in a way not to modify its nature, to make appropriate enhancements without causing loss of data on fingerprints, to preserve and store fingerprints are complex processes. Appropriate realization of these processes is essential for crime scene investigation. This study analyses and evaluates the crime scene investigation in a detailed way from a computer science perspective with a special focus on fingerprints, and whole process is divided into three components. In light of the studies conducted in the literature, 14 main problems that are encountered in the realization of these three components have been identified and criticized. Afterwards, the disciplines supported by forensic science, and the components that compose the crime scene are evaluated on the basis of four basic challenges encountered in the processes. Finally, to overcome 14 problems and four challenges, six technology-supported solutions are presented.

**Keywords**—Fingerprint, crime scene investigation, forensic science, evidence, biometrics, computer science approach.

## 1. Introduction

The crime scene is defined as the area where a crime has been committed, continued and spread. In the time interval between the beginning and end of the crime, all the environments in which the suspect and the victim are found are considered crime scenes. For this reason, it contains a lot of forensic data about the crime committed. A crime scene can be depicted as any physical environment that could provide potential evidence to an investigator [1], [2]. The most general definition of crime scene investigation (CSI) can be expressed as the analysis of the relationship between crime scene, affecting people of the incident and people affected by the incident. Forensic data is used for identifying the nature and reason of the incident, the people who affect the incident, people who are affected by the incident, and external factors. These data are collected as a result of CSI.

CSI is based on scientific reasoning. This form of research means that the CSI is systematic, methodological, and logical. The first response to the crime scene, securing the crime scene, documenting the crime scene, packing and preserving the materials obtained from the crime scene, collecting physical evidence, developing hypotheses about the actions taken at the crime scene, and reconstruction of crime are parts of the systematic reasoning process [1], [3].

Forensic sciences have been guiding critical decisions made by governments, law enforcement officers, scientists, lawyers, judges and technicians, insurers, regulators, journalists, and even the public. As well as specialists working in different disciplines of forensics, different segments of society have different perspectives and interpretations about what forensic science can do or cannot do. These perspectives affect the justice systems of societies. The ethical status of forensic science has changed dramatically in recent years. In the 1970s and 1980s, new scientific methods and techniques, devices, tools, technologies, standards, procedures, and methodologies are used to improve the quality of assessments made today to overcome the inaccuracies and deficiencies in evidence analysis.

Over the past twenty-five years, forensic sciences have made a big leap thanks to scientific breakthroughs and the rapid development of technology. However, most of the studies focusing on CSIs have been done about procedures to be applied in the management of the process, staff management, evaluation of biological and biometric evidence, and assessing the compliance of the whole process with legal criteria. There are many comprehensive studies focusing on identification, collection, and evaluation of fingerprint, and the legal validity of these steps. However, there are not many studies in which the development of technological infrastructures used for investigation processes is evaluated from a computer science perspective.

One of the main components of the CSI process is the crime scene. The realization process and components of the crime, the place where the crime took place, the conditions in which the crime was committed and those involved in the crime cannot be determined in advance. Thus, it is necessary to have the capacity to evaluate all kinds of crime scenes. Another component is Forensic Science. Forensic sciences need to be very successful in solving crimes, saving innocent people from the investigation process, and bringing criminals to justice. Some practices in CSI require the collaboration of different areas of expertise.

For this reason, forensic science has a multidisciplinary structure. There is a growing need for mechanisms and forensic science strategies that provide accurate and reliable evidence within minutes. Another important component of CSI is the human factor. Personnel working both at the crime scene and in the laboratory have a direct influence on the CSI process. No matter how major the development in forensic sciences is, the expert factor continues to play an important role in decision-making in most forensic processes. Forensic work often involves interpretation and subjectivity. For this reason, cognitive and human factors are important for making accurate forensic decisions.

The purpose of this paper is multifold:

- To ensure reliable and detailed investigation of the crime scene,
- To maximize the quality of Forensic data collection and recovery procedures,
- To propose a systematic approach to ensure that the collected Forensic data is validated,
- To encourage a more consistent methodology, thus enabling more verifiable results to be produced,
- To facilitate the transfer of valid evidence between crime scene investigator and law enforcement,
- To establish a framework of standards, principles, and approaches for the detection, recording, and recovery of forensic evidence at the scene.

This study focuses on the fingerprint. The CSI process is divided into three components: information acquisition, field expert activity, and technical evaluation. The relationship between each component and their relationship with fingerprint are evaluated. In these components, the difficulties encountered in the process steps applied to the fingerprint and the technical/technological problems are examined from a computer science perspective and solutions are presented. In the second section of the study, CSI components are explained in detail. In the third section, the fingerprint collected from the crime scene is evaluated in terms of crime scene components. In the fourth section, the problems encountered in the crime scene components in terms of fingerprints are determined, and in the fifth section, the approaches that need to be developed as solutions to these problems are presented. In the last section, the results of the study are given.

## 2. Crime Scene Components

CSI requires science, logic, and law to make joint decisions under one roof. The scene should be evaluated in detail with all conditions, and all kinds of physical evidence should be associated with the statements of the suspect and affected people, which turns CSI into a long and exhausting process [4]. Also, since each crime scene has its specific features, the steps taken in assessing a crime scene and collecting evidence cannot be directly adapted to different crime scenes.

The investigation process usually starts at the crime scene. The crime scene is defined as the place where the incident takes place directly, the immediate environment of the crime scene and the remote environment that indirectly affects the crime scene [5]. Actions of the first arriving team, such as the accurate identification of the crime scene and protection, isolation and securing the evidence appropriately have a direct impact on the success of the criminal analysis process. The purpose of the CSI is to analyze and document the crime scene, to collect physical evidence, and ultimately to reconstruct the incident [5]. To carry out the steps above, teamwork must be ensured. For this reason, people who have different expertise should work in sequence or together during these steps. All the forensic data that are found to be suitable for evaluation at the scene are transferred for a holistic analysis to produce a definite result [5].

The CSI process is suitable for classification and analysis with different approaches since it incorporates many components from various disciplines under one roof. Many studies have been carried out so far; crime scenes have been evaluated from the location of the scene, the type of evidence, the size of the crime scene and the type of crime. Special disciplines such as forensics, psychology, sociology, technology, criminology, biology have been used for these evaluations [6]. In this study, the crime scene process is considered from a computer science perspective, and the whole process was divided into information acquisition component, field expert activity component, and technical evaluation component. These components were analyzed using critical key elements shown in Figure 1 [4], [6]–[8].

To enlighten a forensic case successfully, critical key elements need to be provided. These basic elements are as follows [7]–[14]:

- **Validity:** The validity of the outcome of the CSI depends on the information collected by the research specialist about the case, the methods and techniques used in the investigation of the scene, and the results of the analysis in the laboratory. If these processes are considered as a chain of interconnections, one's small carelessness or error can lead to misinterpretation of the case, the misguidance of legal authorities, loss

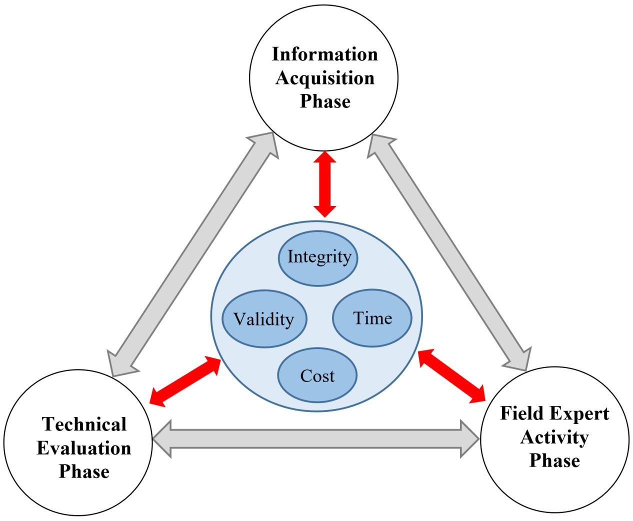


Fig. 1: Key Elements of Crime Scene Component

of evidence, or even closure of the case due to lack of evidence.

- **Integrity:** The boundaries of the crime scene can be of different dimensions depending on the type and progress of the incident. The crime scene shows the way the incident is handled and the relationship between the victim and the perpetrator dynamically. The crime scene contains many traces and evidence about the perpetrator and victim, as well as the evidence of people who are not involved. It can be very difficult to associate the collected data with the crime, especially if the environment is not well isolated during the first intervention to the scene or if the crime occurs in public areas where many people have access. The most important point here is to detect the data related to the crime directly and make accurate inferences from the chain of custody.
- **Time:** CSI is a difficult and time-consuming work, and in many ways, all staff working on the scene are running against time. The content of the evidence may deteriorate in time or may disappear, and the criminal may escape or involve in further actions of crime. Also, the time spent on an investigation is seen as an extra cost for law enforcement officers in terms of the employing expert and shift. However, an inattentive analysis and a wrong result have a devastating effect on the whole process. For this reason, the research specialist should employ a careful and thoughtful approach and produce several different theories of crime based on the information available after the necessary screening. The time taken to produce reasonable conclusions about the action is crucial.
- **Cost:** Forensic analytical procedures applied to the types of physical evidence can be very costly. In a crime scene, evidence that is unrelated to the incident, or the analysis of evidence that becomes unrecognizable even if it is related to the incident reduces the efficiency of the investigation and increases its cost. Also, at some crime scene, specific experts may need to work with specific equipment. Such requirements increase the cost of the investigation process.

All process steps implemented in the crime scene components must be compatible with four key elements. Also, specific criteria have been offered in this study to evaluate each component within itself and to define the relationship between some components. In the third and fourth sections of the study, a detailed explanation is given on these criteria.

### *2.1 Information Acquisition*

CSI is a comprehensive process that requires the simultaneous or sequential implementation of complex assessment mechanisms, the use of a wide range of equipment during the assessment steps, and the expert's work. The main purpose of this process is to collect information to analyze the nature of the crime, the sphere of influence, and

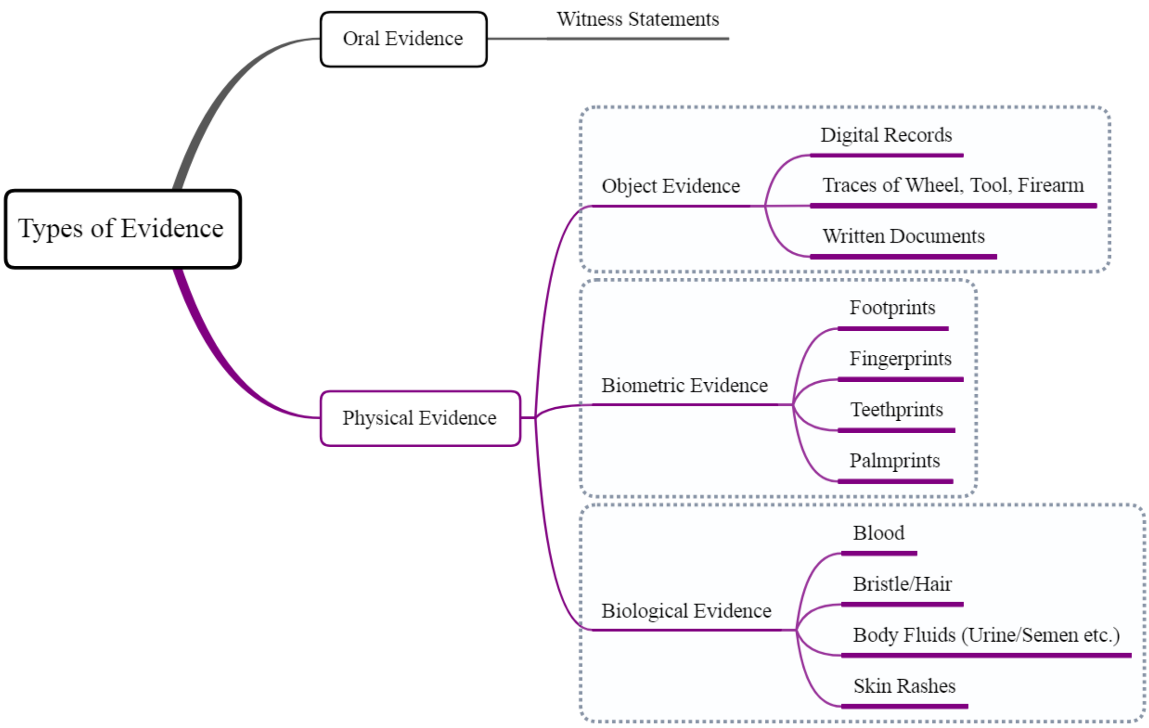


Fig. 2: Evidence collected during the CSI process [15], [16]

form a hypothesis that can revitalize the incident. For this reason, all the steps in the CSI, from the reconstruction of the incident to the outcome of the court, must be directly related to the information collected from the scene.

All the statements, comments, documents, and marks that come from different sources and anything containing information are called evidence. Any material or physical object that can be touched, alive or inanimate is called physical evidence. After being processed in laboratories, it can be used as evidence in court for the reconstruction of the crime. The statements of witnesses and accomplices are called oral evidence. In addition to this, digital or concrete documents gathered from the scene are expressed as documentary evidence. This evidence serves useful in making sense of the incident. Specialized staff and disciplines have to ensure the effective collection, preservation, packaging, and transport of evidence. After the data collection process, different experts and disciplines are used to determine the procedures to be applied for the collected evidence and to evaluate the quality of the evidence [17].

## 2.2 Field Expert Activity

CSI has been considered as the most important aspect of a criminal investigation by many people. High-quality and valid evidence for accurate and fair results can only be obtained if the incident is examined professionally and effectively. During the investigation of the crime, many different units can work simultaneously.

A team leader is assigned to each scene in order to direct and manage the investigation, to distribute the tasks to the units and ensure the correlation of the units working with each other to investigate the incident. The team leader cannot leave the scene from the beginning to the end of the incident. The leader's main task is to manage and coordinate the entire process [18].

The staff who are assigned to detect the incident is defined as the initial responding officers. They arrive at the scene first and ensure the safety of the environment. This team consists of people working in law enforcement officers and they are specialized in the type of incident such as narcotics, counter-terrorism, etc. Their mission is to maintain the original state of the scene, protect the evidence, and to provide information flow to the next teams [18].

Depending on the location and type of incident, some people who have proven expertise such as anthropologists, blood pattern analysts, bomb technicians, criminalists, fingerprint analysts, engineers, entomologists, autopsy specialists, and odontologists can work in the criminal investigation process together or respectively [18], [19]. These team members work on evidence for making them visible and collecting them from different places and surfaces. Also, it is the task of this expert group to protect the collected evidence and to conduct a preliminary examination [18], [19].

The investigation team works to collect the necessary information from eyewitnesses, examines the immediate surroundings of the scene, and assist the other teams and experts with the information they collect. The investigation team works to link the crime scene data with each other and with the incident and synthesize the collected data to create a scenario that revives the incident [18].

### 2.3 Technical Evaluation

Assessing the crime scene requires an action plan. After the scene is described and protected from external influences, it is depicted using sketching or photography to evaluate the incident before specialized analysis begins. Subsequently, the visible evidence such as blood is collected directly and the non-visible ones such as latent fingerprint are tried to be made visible by expert intervention and technical infrastructure support. Finally, once the evidence has been made visible, if necessary, it is moved from the scene to the laboratory for examination. For the collected evidence, a more detailed examination is carried out in the laboratory. These examinations are mostly chemical and computer-aided applications to understand the content of the evidence or to make sense from the evidence. Due to scenarios such as re-examination of evidence by the court or objection to a court decision, all evidence must be stored. For this reason, many technical infrastructures are needed to collect, transfer, evaluate, match and even store data. In the process of gathering evidence at a crime scene, some equipment such as support tools designed for specific purposes, mobile phone/ cameras/ computers, tele-forensic and telecommunication technologies, hand tools, forensic light sources, metal detectors, latent print kits, light sources and tools, and software/hardware-assisted systems for data enhancing and matching are used [11], [21].

The data with biological and biometric content from the collected evidence is transferred to the laboratory for detailed examination. Detailed laboratory examination also requires a series of procedures and different equipment to perform these procedures. With the infiltration of technology into all areas of life, it is not surprising that the techniques and methods used to resolve crimes are futuristic. From retinal scanning to evidence chemistry monitoring, new forensic technologies can be far more advanced than the methods used to solve crimes in science fiction films. Nowadays, biometric recognition systems using video and audio recordings, fingerprint identification using AFIS technologies, detection systems using DNA found in body fluids such as saliva, sweat, and different technology-

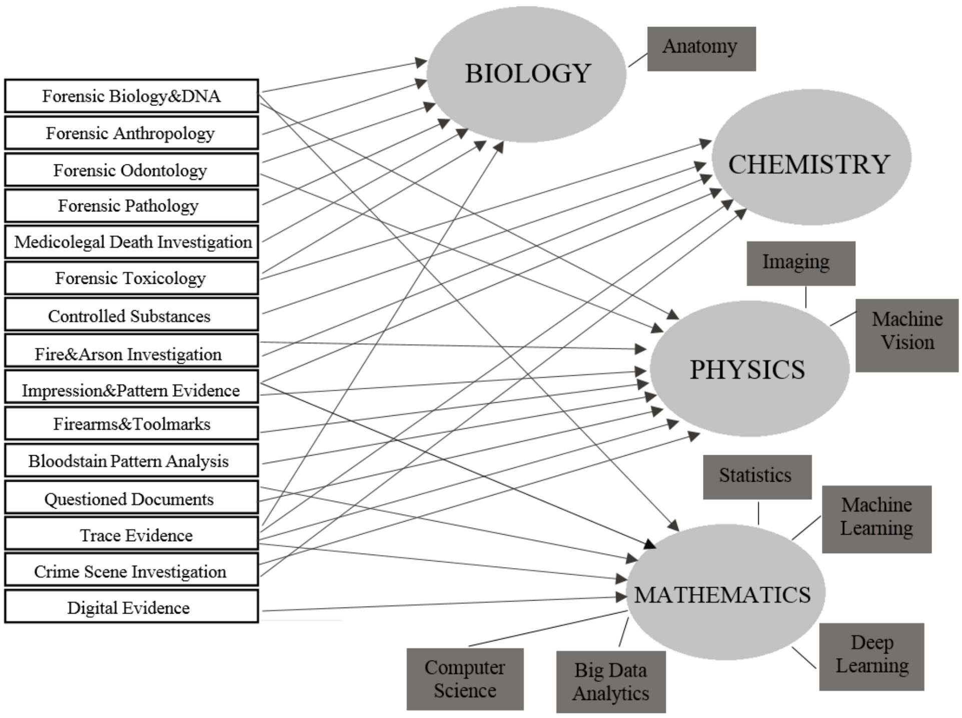


Fig. 3: Most Common Forensic Disciplines [20]

supported designs are used in all in many CSIs.

## 3. Evaluation of Crime Scene Components in Terms of Fingerprint

CSI requires a multidisciplinary study. While CSI is a process that should be examined from a sociological and psychological point of view in terms of murderer-victim-cause, it can be considered as a criminal case with the point of reconstruction of the crime and going from evidence to the offender. Therefore, the crime scene can be classified through different perspectives considering the type/ effect of the crime, the status of the killer/ victim, the type of data containing the evidence, the type of methodology/ method planned to be used in the analysis process, and the type of investigation.

Each type of data at the scene has different characteristics. These differences make it necessary to use different procedures in the process of data

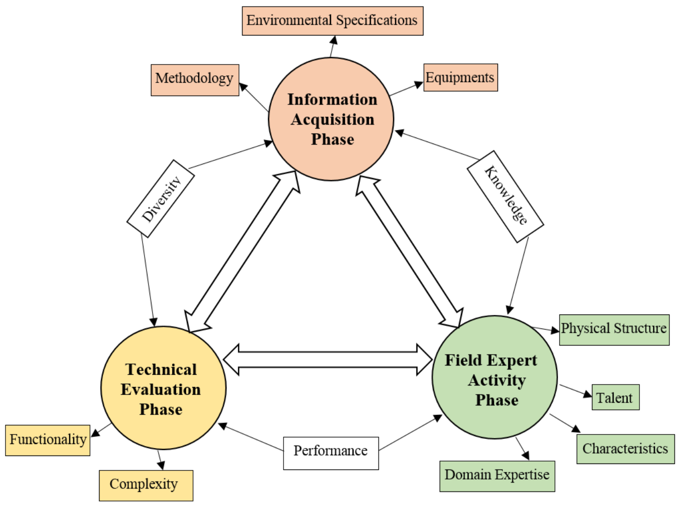


Fig. 4: Evaluation criteria of crime scene components

collection and analysis. In addition, each scene has its characteristics, and the characteristics of the incident and the environment should be taken into consideration during the investigation process. Due to the variations arising from the evidence, environment, and incident, the approaches to be proposed to improve and facilitate the CSI process should focus solely on solving a particular problem. Within the scope of this study:

- Considering the scenarios in which different actions take place at different crime scenes, the difficulties encountered in the process of collecting and analyzing fingerprints from the scene were identified and these difficulties were dealt with a computer science perspective.
- The CSI process was divided into components: the acquisition of fingerprint evidence, the experts involved in the collection of the fingerprint, and the management of the technical process.
- In order to ensure an objective evaluation of the process steps performed by each component and during the interaction of the components, criteria were developed in light of the previous studies in literature, as seen in Figure 4.

### 3.1 Fingerprint Detection at Crime Scene

The methods that are planned to be used in the process of detecting and collecting the fingerprint are selected by considering the characteristics of the surface and environment where the fingerprint is located. In this case, a general classification of fingerprints is mandatory. Fingerprints are basically classified into three main groups as patent, latent, and plastic [22]. A patent fingerprint is formed by transferring a material containing color such as blood, paint, and dirt from the finger to the surface. Such marks can be seen with the naked eye without the need for external assistance. The plastic fingerprint is a three-dimensional pattern on a soft surface. These marks are collected from surfaces such as soap, mud, wax, paste. Latent fingerprints are patterns that are not easily visible to the naked eye. Even if the finger touches a soft surface without any coloring agent, it leaves a mark on the surface thanks to the liquid secreted from the pores on it [22]. This type of marks, which is not seen directly, is made visible by various physical and chemical methods and used for culprit detection.

Plastic and patent fingerprints are easily visible without the need for an external process. External components such as dust, sprays, reflective light sources, or chemicals are used to detect and make latent fingerprints visible [23], [77]. If the fingerprint is detected on the surface of a portable object, it is collected as evidence and examined in the laboratory. If fingerprints are detected on surfaces that are unlikely to be moved, such as doors or walls, the data collection procedure is terminated by viewing these marks with standardized apparatuses for digital imaging (cameras, scanners), or using different methods such as taping.

The photographing of mark evaluated within the scope of the study is called technical photographing. Patent fingerprints can be photographed directly. Latent fingerprints are made visible by using special filters, lighting techniques or chemical enhancements and recorded with technical photographic method [4], [21], [24].

### 3.2 Experts Working in Fingerprint Collection Process

Police officers and detectives do not have the special skills and expertise needed to assess all criminal incidents. For this reason, support staff specialized in various fields can produce results by using their skills in CSI. CSI officers and evidence technicians are specially trained police or civilian personnel for scene processing [11]. They are equipped to collect and store physical evidence at the scene. Experts can gather evidence at the crime scene by using a variety of tools and equipment, thanks to the training they receive [11].

Different disciplines work on fingerprints at the scene. They are classified as these who detect fingerprint data, who photograph the data, and who transfer the data for detailed examination. Identification officers (ID) working at the scene are responsible for detecting latent fingerprints [11]. Fingerprint analysts, often referred to as latent analysts, are those who are responsible for maintaining, inspecting and evaluating fingerprints, which are part of the CSI. For this reason, experts who record the scene with photos or videos are required to receive training to operate and maintain the required sophisticated equipment, and to produce high-quality records with appropriate scales by protecting data integrity [24]–[26]. Biometric evidence such as fingerprints, palm prints, footprints collected at the scene accelerates the detection of the offender and helps to conclude the case directly. For this reason, specialized personnel who work in CSI teams should show very high sensitivity when collecting such biometric or biological data. This sensitivity extends the CSI process and requires multiple experts to work simultaneously [11], [27].

### 3.3 Technological Infrastructures Used for Collection and Evaluation of Fingerprint

While technological advances affect every aspect of life, their impact on the CSI process is not surprising. One of the factors that directly affect the success of fingerprint experts is the equipment used in data collection and evaluation procedures. As the crime scene becomes more complex, the number of equipment used increases, and more specialized products are needed.

In this section, the procedures applied to fingerprints in the CSI steps which are making the fingerprint visible, transferring the fingerprint to the laboratory environment for detailed examination, analyzing the fingerprint in the laboratory environment, removing the characteristic feature from the fingerprints are evaluated, and the software/ hardware components and technological infrastructures used in comparing the fingerprints collected with the registered samples are examined.

#### 3.3.1 Fingerprint Collection Methods

There are established standards for devices used for imaging in CSI. These devices range from mid-level professional devices to high-level professional devices, depending on the budget of the investigation department and the specificity of the incident [4], [24].

In order to detect and make latent fingerprints visible, many procedures are applied. In these procedures, fingerprints are made visible by using components such as external powders, sprays, reflective light sources or chemical substances [23], [77]. Once the fingerprint becomes visible, it is stored for detailed examination by video recording or photographing.

#### 3.3.2 Fingerprint Processing

Fingerprints collected from the crime scene are not of the same quality as fingerprints collected with devices such as a sensor or scanner. Due to the ambient conditions, the fingerprint data may not have sufficient characteristics, only a part of fingerprint may be collected instead of the whole finger, the fingerprint may not have sufficient reference point due to the noise in the environment. In addition, clearing the noise in the received fingerprint data, separating the fingerprint from the scene, and the removal of incorrect reference points in the fingerprint make it easier to determine who the fingerprint belongs to because these processes increase the match score.

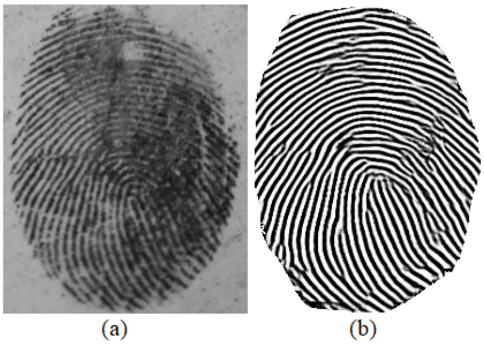


Fig. 5: Improving the fingerprint collected from the crime scene

The collected data is not used directly. Before removing the characteristics of the fingerprint collected from the scene, the determination of the singular point, calculation of the orientation and frequency of the ridges, segmentation, normalization, filtering, thinning processes are performed [28], [29]. A fingerprint in Figure 5(a) taken from the scene changes to Figure 5(b) after the enhancement steps applied. There are many academic studies on fingerprint improvement. The studies on fingerprint image enhancement in the literature have been subjected to a general evaluation, and the results are summarized in our previous study [30].

### *3.3.3 Fingerprint Matching and Storing*

As a result of the research conducted to determine which characteristics should be emphasized in the detection of the similarity of the fingerprint, features called minutiae were discovered for the fingerprint specialists to use in manual examinations. Using these features, which consist of different positioning of the fingerprint ridges, the topological equivalence of the data from the two fingerprints can be analyzed [31]. After the completion of the preprocessing step, the fingerprint collected from the crime scene becomes suitable with the minutiae extraction.

Before automated fingerprinting technologies are used, fingerprints are classified according to their physiological characteristics to enable one to many searches. Catalogs of fingerprints are grouped with a classification method based on Henry's system, and matching of each fingerprint was performed under expert control. Because of the increase in population, the process of pairing the fingerprint with the traces in the database led to an increase in the number of comparisons. This increase leads to another increase in workload and time spent, and human resources used [31]. In the criminal justice system, fingerprint recognition systems have been used for more than a century to detect suspect in crime and terrorism in order to support public security. During the criminal investigation, the latent fingerprints, which are found, developed and improved at a crime scene, are compared with the previously registered fingerprints of the persons. The fingerprints left behind at the scene, whether full or partial fingerprints, can be identified with today's technology. A list of potential candidates similar to the fingerprint to be identified can be found using image recognition algorithms. The systems that do this automatically are called AFIS. For this reason, AFIS has been seen as a tremendous improvement for local, state and federal law enforcement agencies to manage fingerprints and to identify people [31].

## 4. Problems in Forensic Fingerprint Analysis

The basic principle of CSI is to obtain material findings, to separate legal evidence from the other collected findings, and to use legal evidence for arresting the perpetrator. In the CSI, the outputs obtained from the evidence collected are evaluated and criminal action is taken against the perpetrator. For this reason, even the slightest omission made during the detection, classification, collection, laboratory examination of findings may result in significant

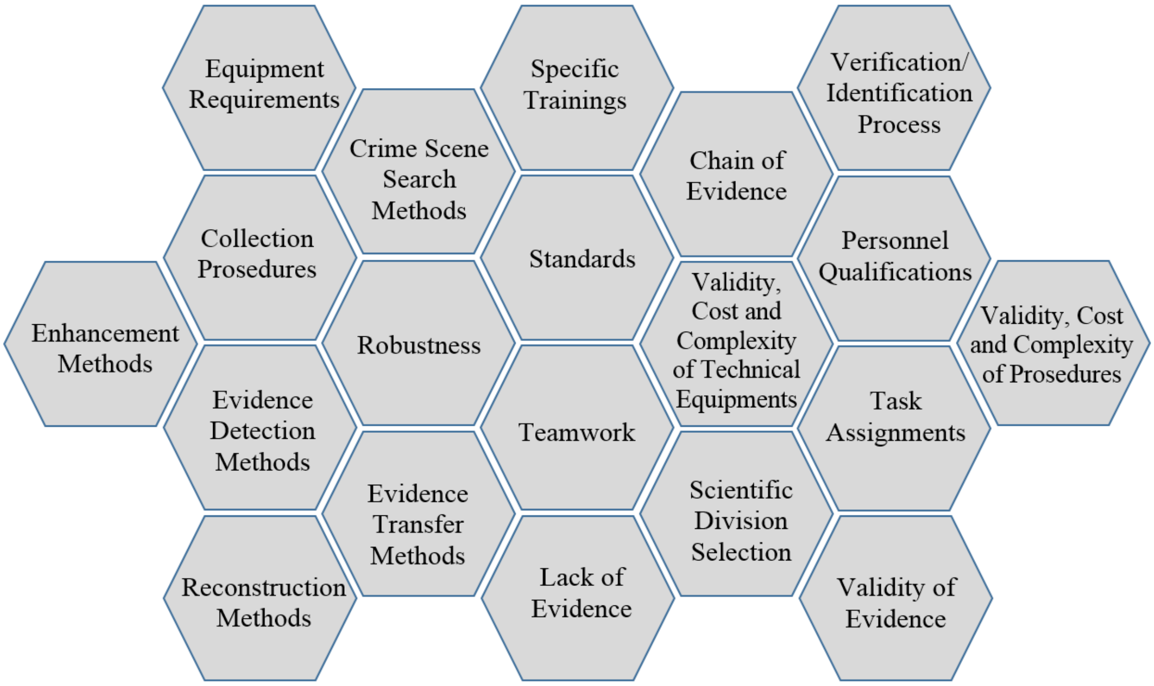


Fig. 6: Problems Encountered in Fingerprint Collection and Analysis

errors in the judicial process [74].

Subjectivity is one of the main problems that concern many areas of forensic sciences and fingerprint analysis. The CSI process is shaped by tested scientific methods and the analyst's subjective inferences. The hypothesis of how the incident took place depends on the examination of the analyst and interpretation of the evidence. Another key problem is the inability to undo any action taken during the review process. If the procedure to be followed is incorrect, a non-reversible path has been taken. These two problems form the basis of every problem that can be encountered during the CSI process.

In this part of the study, the problems encountered in CSI (Figure 6) are discussed. These problems have been explained under a number of questions.

### 4.1 What are the types of crime scene?

The environment in which the crime was committed is considered a key point in terms of how the incident should be examined and in which aspect the crime scene components should be evaluated. The environment in which the incident takes place determines which specialist, equipment, method, methodology, and technique should be used. For this reason, possible scenarios in which potential problems may occur were developed in this study in order to illustrate how the components of the investigation were affected by the crime scene.

If the necessary precautions are not taken to protect the environment after the first arrival to the scene, the whole analysis process is in danger. Fingerprint specialists are forced to perform more complex processing steps in crime scenes that are not properly protected. Experts may have to use more specific methods and equipment during the data collection process in these scenes. In addition, when the collected data becomes contaminated, external processing steps should be used in the detailed analysis of the collected data. In this case, the collection of fingerprint data can become time-consuming and costly. In addition, integrity and validity may be violated due to the corruption of fingerprint data [2].

If the crime scene has a chaotic structure due to the way the crime is committed, critical decisions should be made on both the working specialist and the equipment used. If the number of fingerprints that need to be examined increases, more specialists should work at the scene. However, due to the inadequacy of staff with the appropriate criteria to work in the field, the investigation is usually carried out with a small number of specialists. In this case, the collection of fingerprint data can become time-consuming and costly [33], [34].

The mistake in terms of experts worked and equipment used in the fingerprint collection process creates irreversible effects. Data collection may fail if the expert does not have sufficient field knowledge or does not have the experience and ability to overcome factors arising from the nature of the environment [35].

All techniques and technological infrastructures used in the visibility, storage, improvement, and matching of the fingerprint must be legally valid. Interventions at these stages should not affect the uniqueness of the collected fingerprint data. If these steps are not designed appropriately, it is inevitable that there will be problems in terms of cost, validity, and integrity [36].

### *4.2 What are the equipment requirements and collection procedures for fingerprint recording?*

The selection of equipment used to collect fingerprints from the crime scene and procedures to be followed at the scene is a critical process. Considering the environment in which the incident took place, the suitability, performance, usability and validity of the equipment, as well as the performance of the specialist in the use of the equipment can guide the scene investigation process. For this reason, to illustrate how the selection of equipment to be used and procedures to be applied to fingerprint collection affect the components of CSI, problems were given in the following possible scenarios.

Crime scene investigators can use many different methods to photograph an incident. Nowadays, video recording and digital photographing methods are widely preferred due to their ease of use compared to film rolls and videotape technologies. It should be noted that the devices used should have special features required for CSI and should comply with standards accepted by forensic sciences. Parameters such as memory cards, lenses, filters, external light sources, reflective chemicals, and the age of the devices constitute a reliability problem for the collected evidence. Keeping technical equipment in extremely hot and humid environments, lack of maintenance, failure of bringing extra storage units and external batteries make the investigation of the scene difficult [37]–[39]. That's why data integrity and validity are at risk if the procedures and equipment used in the fingerprint collection process do not comply with standards accepted by forensic science.

The fact that the devices used for CSI have the appropriate criteria does not eliminate the whole problem. In addition, the technical knowledge of the expert using this device directly affects the process. In particular, evidence may not be considered legally valid if the analyst monitors it without taking into account certain criteria such as fingerprints, correct angle, light, and resolution detected during forensic photographing [37]–[39].

In order to complete the collection of fingerprint data in the most trouble-free way, innovative approaches are needed in terms of experts and equipment used in the examination of the incident.

As technology advances rapidly, the functionality of all types of equipment has increased and can offer higher performance. However, features added to improve performance can increase the complexity of the equipment. Because of this complexity, specialists may need additional training to use this equipment, and it can be seen as a cost disadvantage. Although the increase in functionality provides an advantage in terms of validity and time in the data collection process, it can be disadvantageous in terms of complexity and cost.

### *4.3 Where to look for fingerprints?*

In a theft investigation, the perpetrator's entry point should be where the fingerprint model begins to be searched. The door handles can be the first points to look at, or if the burglar has entered through the window, it is possible to have fingerprints on the window handle or glass. In the case of an injury or death, the murder weapon at the scene, the surfaces likely to come into contact during the fight, or the fingerprints left by the killer on the victim should be handled. If there is access to the scene after a long period of time, the environment may be polluted by living things such as animals, people, or for natural reasons such as rain and wind. In such cases, it is a very technical detail to decide which region the fingerprint should be searched and by which techniques. If it is necessary to investigate a crime scene in such specific cases, it is essential to collect prints that are directly relevant to the incident by the appropriate technical infrastructure and experienced investigation personnel. The faster solution is generated, the easier it is to catch the perpetrator.

However, if the process of analysis and producing the results is prolonged, those who commit the crime or participate in the crime may escape or disappear. Also, searching for the evidence in the wrong place and analyzing the incorrect data increases the cost as well as causing the loss of time, adversely affecting the performance of the expert, and leading to misuse of resources [11], [18].

### *4.4 What are the collection methods of the fingerprint from different surfaces?*

The methods of collecting the fingerprint vary according to the surface on which it is located. On the solid surface, fingerprints are made visible by dusting and are collected by taping or photographing, while on soft surfaces fingerprints are collected by photographing. The fingerprints of the suspect may be detected on clean, dry, hairless parts of the victim's body, and these marks are likely to be recovered. To collect this kind of fingerprints, a variety of chemical, electronic and photographic techniques should be applied, as well as dusting. As can be seen from these examples, a different procedure is required for each surface and each procedure requires different expertise and forensic technology. Experts can try to collect fingerprints by using incorrect methods and components if they do not have sufficient field knowledge. It is a serious problem that it is not possible to correct the deterioration in the fingerprint that is attempted to be collected with these wrong choices. Such situations pose a great risk to the validity of fingerprint data collected from the scene [37], [40].

### *4.5 How to make task assignments in CSI?*

Crime scene investigators are responsible for evaluating evidence at crime scenes, photographing/ packaging/ transporting evidence and creating reports and testifying in court. Investigators should have a clearly defined role in the tasks in which they are adequately trained to perform. In some crime scenes, staff may need to play more than one role because of the size and type of the scene, or because the incident has to be evaluated with fewer experts than it needs. Improper staff appointments cause the evidence to be collected incorrectly. This situation causes major mistakes in the investigation process [37], [41]. In addition, the sudden increase in the number of incidents per day or the specific circumstances in which a series of crimes are considered as serial murders may directly affect the number of officers and specialists working within a day. Unsuitable assignments for personnel cause an excessive workload. The fact that non-specialist staff is employed at the scene or the expert staff is exposed to working hours exceeding their capacity invites mistakes in the CSI process [41]. Especially when the fingerprint collection from the scene is a complicated process, non-specialist personnel may disrupt the integrity of the crime scene and the chain of custody. In cases when a small number of specialist personnel is overloaded, the cost of the CSI may increase due to the overtime of the specialist, and there may be a risk of evidence invalidity due to the possibility of a loss of quality in the collected data.

### 4.6 What is the specific training for CSI?

There are three different crime scene examination certificates. These are Certified Crime Scene Investigator (CCSI), Certified Crime Scene Analyst (CCSA) and Certified Senior Crime Scene Analyst CSCSA) [42]. They are internationally recognized, and in order to receive them, a high level of experience and training is required. With these training contents, crime scene investigators can become qualified personnel. The most crucial problem is the difficulty of law enforcement agencies to provide the budget for these certificate programs and whether the person who wants to follow these programs can find the external time to attend the courses. Certification programs are not particularly preferred by law enforcement officers in terms of cost and time, especially when considered in terms of the participation of staff working in small areas [41].

### 4.7 What are the key attributes of personnel?

By using international standards and procedures, existing problems in the data acquisition and technical evaluation components can be overcome, and improvements in the results obtained from these components can be made. However, the field expertise component, the subject of which is human, should be evaluated from different perspectives. The physical and mental characteristics of the staff affect the success of the CSI process. The expert who will work at the scene should be hired considering the parameters such as cognitive ability, experience, physical trait, mental endurance. However, as experts having these criteria can be costly for law enforcement agencies, the units firstly recruit civilian personnel for short-term employment for economic reasons. With this method, it is aimed to solve the need of experts for less cost temporarily. This situation is a major chaotic problem as experts cannot gain experience at different crime scenes [35].

In all law enforcement agencies, the staff working in the crime scene unit are uniquely stressed compared to other officers. Because they are closest to the crime scene and spend quite a long time at the crime scene. Also, CSI is stressful because critical judicial decisions are made based on the results of this process, and these decisions vary according to the success of the investigation. Failure to provide a sufficient number of experts due to criteria such as cost, time and experience during the CSI process causes the team to be subjected to heavy working tempo. Studies have shown that even experienced personnel still have the same level of stress in CSI.

In addition, personal characteristics directly affect stress levels. As with any profession, extreme stress leads to errors, and this inference applies to CSI teams. Excessive stress brings risk. For this reason, it is necessary to adopt new approaches to alleviate the workload per employee [43].

### *4.8 What are the standards of forensic science technologies?*

Under normal circumstances, there is only one opportunity to conduct an investigation at the scene and to collect the relevant material from there. For this reason, each step must be carried out meticulously. Complete registration of all areas where fingerprints are made visible should be done using appropriate methodologies and equipment which are accepted as valid by judicial authorities. The material used to display all evidence at the scene is determined by international ISO/IEC 17020 and ISO/IEC 17025 standards [44], [45]. In addition to the standards mentioned above, all technologically assisted data collection devices may adversely affect the validity of the collected data [46], [47].

### *4.9 What is the relationship between image processing and validity?*

Despite advances in image processing, the examination of the latent fingerprint is complicated process. It is a complex task that is mainly dependent on the visual judgment of highly educated human supervisors. Fingerprints collected from crime scenes contain less information than fingerprints collected under controlled conditions. They are often noisy and distorted and may contain a partial of the total fingerprint pattern. It is known that the less the intervention to the fingerprint collected from the scene, the higher the validity of the data. For this reason, approaches that lead to loss of characteristic features in the data improvement process or proposed methods on data repair/ restructuring are considered legally invalid in law enforcement. In particular, there is a lack of alternative approaches that can be used when performing partial fingerprints analysis, if there is not enough reference point [33], [34], [48], [49].

### *4.10 How much information is required for identification/verification?*

Even if the fingerprint data was collected through the most appropriate procedure and improved by the best preprocessing methods, the acquired properties may not be sufficient to identify the person. The features extracted from the fingerprint may not be specific enough to identify the person or sufficient features may not be extracted when the fingerprint is partial. When the feature group extracted from the fingerprint is not distinctive enough to identify the person, many matching examples can be encountered in the AFIS query. If there is not enough feature for evaluating the fingerprint, it is necessary to examine the fingerprints which are filtered by using AFIS in detail by fingerprint experts and determine which pattern matches precisely. In the absence of sufficient characteristic points in partial fingerprints, the collected fingerprint data is not considered valid. These situations reveal the need for new approaches in fingerprint matching. Alternative perspectives should be developed in cases where the fingerprint is partial or the characteristics are insufficient [34], [50]–[52].

### *4.11 How reliable are fingerprints in solving crimes?*

In the 2010 report issued by the US National Institute of Justice, it was noted that automated systems made less accurate conclusions than well-trained Fingerprint examiners while comparing latent fingerprint collected from the incident with fingerprints registered from the database. On the other hand, the US National Research Council's 2009 report on forensic science is a milestone for fingerprint biometry. This report states that the only forensic method that has been rigorously verified is nuclear DNA analysis and that all other forensic sciences, including fingerprints, are questionable. Due to high mismatch rates and expert requirements, the current fingerprint matching methods have been questioned in this study and a need for external approaches for fingerprint identification was detected. Today's AFIS is known to make more errors, especially in partial fingerprints, because it uses the minutiae-based matching method. It has been observed that new approaches should be developed apart from the similarity of minutiae points. However, if all software and hardware supported mechanisms used in fingerprint recognition need to be rearranged for a new approach to be proposed, a major transformation process in terms of applicability, cost and time may need to take place [36], [75].

### *4.12 Technical Equipment Cost*

Technical equipment used to make the fingerprint visible (chemicals/ powders/ light sources), technical equipment used to collect fingerprint (video recorders, cameras, high-resolution lenses, scanners), software/ hardware-assisted equipment to process the fingerprint (Image enhancement/ reconstruction software, 2D-3D image converter software), the infrastructure used for matching and storing (AFIS, IAFIS, ALFIS, MAFIS) constitute the technical evaluation component of the CSI [53], [54]. Depending on the capacity of the country, the requirements such as the supply/ installation/ maintenance/ repair of the infrastructures needed to store, protect and analyze millions or even billions of fingerprints are cost-increasing factors [47], [52], [54], [55]. However, due to the lack of sufficient technical infrastructure, especially in local areas, old technology-supported approaches continue to be used.

### *4.13 How complex is the technical equipment?*

The most desirable approach in the CSI process is that the fingerprint, which is easily visible to the field expert, can be collected effectively and processed in the simplest methods to produce a result. The increasing complexity of the techniques and methods used to manage crime scene components consequently leads to an increase in time spent and cost. The more complex the equipment used, the lower the number of experts who use the equipment effectively, and this reduces the performance of the CSI [49].

### *4.14 Why is teamwork important?*

The most critical element in CSI is teamwork. The investigation of criminal proceedings is usually carried out by the joint evaluation of persons working in different institutions. This system is designed in such a way that no person or institution can work independently. For this reason, the multidisciplinary working process involves problems such as defining to whom the responsibility belongs and who should perform which task. If appropriate authorization is not made, CSI can become a chaotic process. Crime-management approaches designed far from a result-oriented approach may have poor results in terms of time, cost, integrity, and validity [2], [11], [18].

## 5. Challenges in Forensic Fingerprint Analysis

In order to accept the fingerprint as evidence by the forensic sciences, three essential claims need to be confirmed: (a) each individual has a unique and permanent fingerprint, (b) fingerprint collected from the scene can be used to identify the individual, (c) the fingerprint recognition system has to have zero or near-zero error [76]. However, the results obtained from software and hardware supported infrastructures to verify these claims are not sufficient enough. Because:

- the fingerprints of individuals can be very similar,
- the collected fingerprint may not have many characteristics,
- as a result of a query in AFIS, there may be multiple samples that are similar to the fingerprint collected.

Thus, software and hardware supported mechanisms only minimize the number of suspects. Then, fingerprint experts determine which pattern exactly matches with each other. Forensic fingerprint analysis has been used for over a century as a way of identifying criminals. In order for the fingerprint to be considered as evidence, analysts have to claim absolute certainty that the fingerprint has been left by a suspect. In summary, the decision made about fingerprint identification is based on an expert's opinion instead of scientific data.

When all of the problems encountered in crime scene analysis were evaluated on the basis of environment, people, methods, and the headings in fourth section were determined. Thus, the main goals in CSI are:

- To optimize the scene for the investigation,
- To have the opportunity to maximize data quality by having every evidence gathered by the most experienced experts,
- To ensure that the methods used to collect and analyze evidence are legally valid,
- To ensure that the evidence collected is sufficient by itself without consulting an external expert in court.

For this reason, in order to achieve the aforementioned objectives and to eliminate the problems mentioned in fourth section or to minimize the effects of these in the forensic fingerprint examination process, the difficulties to be overcome are examined in detail in this section.

### 5.1 Improvement of Fingerprint Identification Methods

Most of the fingerprint recognition/ verification mechanisms are based on the matching of minutiae points. Minutiae point-based techniques analyze fingerprints according to local characteristics such as termination and bifurcation. If the matching scores of the Minutia points are above the threshold level set by the system, the two fingerprints are matched. This approach has been extensively studied and is the backbone of most of the current AFISs [73].

Fingerprints collected by devices that are used to digitize fingerprints (sensors, scanners) or by techniques such as the inking method used in forensic anthropology have many minutiae points. When an AFIS scan is performed using these patterns, it is effortless to determine who the fingerprint belongs to. Since fingerprints in AFIS databases are collected for use in biometric recognition/ verification mechanisms, the collection of fingerprint data is performed in environments where there is no data loss. However, to express the same situation for invisible fingerprints is quite out of the question. Fingerprints collected from the scene contain many problems. First, the fingerprint may have been exposed to noise. In addition, the fingerprint may be partial and the collected part may not have sufficient characteristics to identify the person. As a result of a comparison between the latent fingerprint collected from the scene and those in the AFIS database, it is possible to obtain many matching fingerprints. For this reason, different approaches should be considered in order to examine especially low quality or partial fingerprints. The first option is to find another distinctive criterion that can be used instead of minutiae for fingerprint recognition. One of them is the use of Level-3 characteristics which fingerprint analysts use to separate similar fingerprints.

There is no general definition of Level 3 characteristics; they can be everything such as scars, deformations, pores, and ridge shapes. Since even a small portion of the fingerprint contains many of these features, it is considered to be suitable for evaluating fingerprint data collected from the scene. However, the biggest problem in identifying the fingerprint using Level-3 features is that the fingerprint data used must have a high resolution. The fingerprint data collected by using low-resolution sensors are not suitable for this method. When the fingerprints registered in the AFIS databases are evaluated within this scope, no matter how many characteristics are removed from the partial fingerprint data, it is not possible to use the Level-3 characteristic features because fingerprint data in AFIS has not been collected by considering Level-3 characteristics and it is not possible to use level-3 characteristics in a scenario where the same data cannot be re-collected [59].

In order to work with fingerprints in the existing databases and to improve the low matching rate due to insufficient minutiae points, deep learning-based approaches are seen as a solution [60].

### 5.2 Development of Automatic Evidence Collection System

Making the latent fingerprint visible is a time-consuming process, and a crime scene examiner conducts all stages of the techniques and methods of data collection. However, a crime scene can sometimes have hundreds of invisible fingerprints. This results in an increase in the time of the CSI and a delay in the conclusion. That's why a more practical method for data collection from the crime scene needs to be modeled and it is thought that such a model will accelerate the process. To achieve this, approaches to fingerprint collection with equipment that does not require professionalism are needed to accelerate data collection procedures. Scenarios capable of expressing, defining and making sense of the data acquisition stage should be developed in order to indicate in which environment and by which method the fingerprint data will be collected independently from the expert. Exemplary prototypes such as Forenscope, Wampire, Papilon Fosko have been developed to be used in this context [56]–[58]. In order for these prototypes to develop evidence collection capabilities, different disciplines should conduct joint studies in order to collect valid fingerprint data.

### 5.3 Improvement of Data Storage Infrastructures

Detection of a person through a biometric feature is important for many different applications in criminology and forensic identification. The fingerprint is seen as an effective tool for identifying the individual because of universality, uniqueness, and permanence. Many different approaches have been proposed in the literature to accurately determine whether two fingerprints belong to the same person. Among these, matching mechanisms based on minutiae points stand out as the most accurate techniques due to their distinctive capabilities. However, fingerprint recognition systems running with a massive database have some difficulties such as lack of scalability, low performance and high cost of complex matching algorithms, and loss of accuracy due to the comparison of millions of data.

Large-scale automated biometric recognition systems have many specific requirements:

- The system should provide reliable identification services with large databases.
- The system should be able to support existing and evolving standards.
- System-generated templates or databases must be suitable for use on different platforms.
- If clients are remote from the server hosting the central database, the system must be able to run on a network.
- Latent fingerprints must be processed before being sent to the system.
- The cost to design a system with these requirements must be acceptable.

There is a need for infrastructures, techniques and technologies that can produce fast and error-free results with fingerprints and have no problems in analyzing and processing ever-increasing data. Biometric systems based on big data technologies should be considered as an alternative approach to meet similar requirements and to contribute to the solution of different problems in CSI. In a recent report published by Forbes, it was stated that Big Data Technologies are being used to establish, manage, and maintain the register of citizens by UIDAI [61]. The biometric research group defines big data as "a term used to describe big and complex data sets that can give a clearer result when analyzed meaningfully" [62].

Big Data technology is expected to be used by law enforcement officers for evidence association and identification, as it incorporates a variety of data that provides the opportunity to relate different biometric characteristics of individuals as well as fingerprinting. Renewing or completely replacing existing technological infrastructures creates high cost for institutions and adversely affects the adoption of big data technologies. However, the increased data size requires the use of such technologies.

### *5.4 Development of Evidence Association Models*

Fingerprints are fully formed in the womb during the nine-month development of the baby, and ridge-valley configurations in the fingerprint do not change during an individual's life unless an external condition such as an accident or injury happens [61]. Although biometric features such as gender and age do not have distinctive features to distinguish the individual, they are used as additional evidence to complement primary biometric identifiers such as fingerprints, face, and iris [62]. During criminal analysis, biometric data such as fingerprints and blood collected from the crime scene, records of the security camera at the time of the crime, statements of eyewitnesses are analyzed and correlated with each other. In light of this information, the reconstruction model of the crime is formed. Approaches such as the assessment of whether the blood and fingerprint taken from the scene belong to the same person, and the association of gender and age information collected from security cameras/ eyewitnesses with fingerprint patterns directly affect the criminal investigation process. Such approaches can be used for selection (or elimination) between matching samples, especially where the invisible fingerprint matches a number of samples in the database records.

Table 1 presents the studies in which fingerprint is associated with biometric and biological characteristics. If the correlation between fingerprint characteristics, facial features, blood type, gender and age information are to be evaluated:

- the relationship between the fingerprint and biological/ biometric data of the individual is

TABLE 1: Studies on the association of fingerprint and other biometric properties

| Ref. | Associated Feature | Main Purpose | Methods | Dataset | Success Rate |
|---|---|---|---|---|---|
| [65] | Fingerprint/ Gender | To identify the dominant fingerprint patterns of the South Indian population and the probability of gender distribution between fingerprints | the t-test in SPSS and $p<0.05$ | The trace of ten fingers of 250 men and 250 men | In women, 55.28% of the ulnar structure 26.84% whorl/ in males, 49.32% ulnar 30.64% whorl structure was observed |
| [66] | Fingerprint/ Gender | To predict gender based on the density of fingerprint ridges | Bayes theorem | 275 men and 275 women between the ages of 18-65 | Men' ridge density is less than 13 ridge / 25 $mm^2$ and women' ridge density is larger than 14 ridge/ 25 $mm^2$ |
| [67] | Fingerprint/ Gender | Estimation of sex using ridge count, ridge thickness to valley thickness ratio (RTVTR), white lines count, ridge count asymmetry, and pattern type concordance | Fuzzy CMeans (FCM)/Linear Discriminant Analysis (LDA)/ Neural Network (NN) | 10-fingerprint images for 2200 persons of different ages and gender (1100 males and 1100 females) | Obtained results of 80.39%, 86.5%, and 88.5% using FCM, LDA, and NN, respectively |
| [68] | Fingerprint/ Face | To generate the face border of a person using only fingerprint biometric feature of the same person without any information about his/her face | Artificial Neural Networks | 120 people | Fingerprints and face borders have relations among each other closely |
| [69] | Fingerprint/ Face | To analyze the existence of any relationship among fingerprints and face parts | Artificial Neural Networks | 120 people | Developed system generates the stationary face parts of a person including eyebrows, eyes and nose from only one fingerprint image of the same person without knowing any information about his or her face with the errors among 1.4% and 4.8% |
| [70] | Fingerprint/ Blood Group | A quick and efficient technique of blood group detection using a set of features of the fingerprints | Neural Network Classifier for feature extraction | The approach is tested over a dataset of 4 images in each blood group | After testing the fingerprint images with the training set of fingerprint images and the approximate result of 80% of matching is achieved |
| [71] | Fingerprint/ Age | To develop an algorithm for estimating the age through fingerprint | 2D- Discrete Wavelet Transform (DWT)/ Principal Component Analysis (PCA)/ The Support Vector Machine (SVM) | 300 Fingerprints belonging to the various ages in between 1 – 80 | The age information of the sample fingerprints tested is shown. No external success rate has been given |
| [72] | Fingerprint/ Age | To develop a procedure to extract discriminating features using Curvelet Transform to classify fingerprints into three age groups | Extracted features into the principal component (PCA) subspace/ Age group estimation using K-nearest neighbor (KNN) | 250 images for training and 100 images for testing | The results are shown in tables and graphs |

evaluated with two approaches. In the studies examined, it is stated that fingerprint is related to blood group, age, gender, and face shape. The relationship between the fingerprint and the other features mentioned is evaluated statistically and the distributions of which feature or feature combinations of the fingerprint are related to blood group/ gender/ age information and facial features is calculated. The other approach is about deriving the relationship model between fingerprint characteristics and blood group/ gender/ age information and facial features and estimating other biometric and biological characteristics of an individual by using a fingerprint.

- statistical or learning-based approaches are used to estimate other biometric properties from fingerprints.
- the relationship between different biometric properties can be used to understand the relationships between evidence collected from the scene. In this way, the data that should be investigated in the chain of custody can be determined.
- priority analysis of data directly associated with the fingerprint at the scene can be carried out. If there are fingerprints that are not related to the incident but are somehow detected in the environment, priority may be given to the examination of the directly associated data. In addition, disregarding non-relevant data will result in significant time and cost savings.

## 6. Recommendations

Within the scope of the information and findings obtained, the study was evaluated under different titles. The summary of this evaluation is given under the following sub-headings:

- **Crime Scene Realities:** There are great differences between those proposed in theory for scene investigation and those applied in practice. CSI process models, proposed procedures for data collection, techniques and technologies, and data processing methods have been designed taking into account the case examples that have been experienced so far. However, in the case of an incident scene that has not been observed so far, the experience and knowledge of the law enforcement forces that manage and illuminate the process, the expert's innovative approach, experience, and analytical thinking ability, the used equipment's modification capability, diversity, capacity, and functionality criteria play a critical role. For this reason, the most important and risky part of the CSI is the approaches to identify the crime scene and data collection, the disciplines to be studied, and the stages of determining the technical infrastructure. Also, to minimize the problems encountered at these stages, data collection/ improvement/ analysis mechanisms and procedures to be applied by the expert should be determined and automated from a systematic point of view.
- **Cognitive and Human Factors:** No matter how automated the CSI process is, it is impossible to produce a definite result without the human factor with today's theoretical and practical knowledge. In the CSI, where the intervention of a field expert is considered to be mandatory, the most appropriate action to improve the process and produce the perfect result is the development of technological software/ hardware, tools and mechanisms to reduce the workload of the human factor. In addition, training facilities should be provided to improve the expert's field knowledge. Finally, the criteria that will ensure professional competence should be determined in the most appropriate manner and personnel

should be recruited according to these criteria. Forensic science often involves interpretation and subjectivity. Therefore, cognitive and human factors are important for making the most accurate judicial decisions in critical processes. To maximize objectivity and decision quality, forensic researchers should receive cognitive bias training and evaluate only contextual information.

- **Identification:** The software and hardware-based mechanisms currently used in fingerprint matching should be updated periodically due to the impact of new approaches and inventions. Forensic experts, law enforcement and judicial decision-makers are therefore inevitably strengthened by a strategic working alliance with their industry counterparts.
- **Standards, Validation and Accreditation:** Standards have been developed to help practitioners use technology and methods in a clear and robust way. The use of equipment and procedures in accordance with the standards will also protect the validity of the collected data. In cases where the process is evaluated in accordance with standards and there is no violation of the rules arising from the expert, the CSI process is accredited and the validity of the hypotheses presented legally increases. For this reason, all the steps of the crime scene investigation should be designed in accordance with the standards.
- **Reliability of Forensic Sciences:** Forensic science plays an important role in the effectiveness of the Criminal Justice System. To retain confidence in that forensic approach, it is important to consider how they are implemented; not only in terms of its scientific accuracy, but also to show that evidence is handled appropriately to avoid contamination, and to demonstrate the impartiality and integrity of the staff undertaking the work.
- **Future Approaches in Analytical Crime Sciences:** From the perspective of 2025, forensic sciences will take a new direction with breakthroughs in the fields of large-scale data analysis, self-learning mechanisms, new analytical techniques, and digital forensics. Undoubtedly, technology will play an important role in the future of forensic science and how it is used in both legal and criminal practices. One of the cornerstones of social life is the proper realization of justice. The slightest mistake can cause an individual's life to be shaken fundamentally, and the consequences may cause reactions while deeply harming society. The correct decision of the judiciary depends on the existence of a large number of correctly collected and evaluated evidence. In addition to the known and applied classical methods, information from other disciplines is needed today. Also, it is possible to intervene in the new crimes and criminals that have emerged with the development of technology by the information provided by new disciplines. Society, science, and technology are dynamic structures. It is necessary to develop new solutions to new situations that arise. For this reason, all forensic sciences used in the CSI have to keep up with this development.

## 7. Conclusions

The latest advances in biometric technology, equipped with computational intelligence techniques, replace manual identification approaches in modern forensic science and fill the gaps in the systems. In this study, the contributions and limitations of biometrics in the field of forensic identification are explained. The scope of the study can be expressed as:

- The examination of the fingerprints at the scene was focused on and the elements necessary for the successful realization of this process were identified.
- The scene investigation process was divided into three components: information acquisition, field expert activity, and technical evaluation.
- The relationship between each component and the fingerprint was evaluated.
- In order to objectively evaluate the process steps performed by the each crime scene component and their interaction with each other, a number of criteria were determined.
- The problems encountered during the forensic fingerprint analysis process were identified and technology-supported solution suggestions were presented to solve these problems.
- To overcome the difficulties, feasible approaches were identified and the applicability of these approaches were discussed.
- In order to overcome these difficulties, feasible approaches were identified and the applicability of these approaches were discussed.
- The disciplines supported by the forensic sciences, and the components that compose the scene were approached from a different point of view and the difficulties encountered in evaluating the process were identified and,
- 14 problems and four challenges were summarized.

Finally, the deficiencies in the current approaches used in the CSI processes and the risks that may arise as a result of these deficiencies were emphasized. This study is expected to have a guiding effect in order to eliminate these risks and to prove the validity of innovative approaches to institutions and to evaluate the crime scene with an analytical point of view and proposed future directions to researchers and academics for better and faster processing.

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