Pak. j. sci. ind. res. Ser. A: phys. sci. 2025 **68A**(2) 217-234

Review

Exploring the Fingerprints: A Review

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(received July 12, 2023; revised April 29, 2024; accepted April 30, 2024)

Abstract. The principal method for the identification of individuals, in the past, was a fingerprint. It is being applied persistently without ambiguity for profound acknowledgment and has achieved positive responses to date. The subjects like gender determination, identification of forced bribery, flourishing of effective norms of the justice system, analysis of DNA through remaining's sweat- amino acids and lipids, *etc*. which are the fundamentals that have augmented the importance of fingerprints. Furthermore, many chemical methods are utilized to improve and augment the scenario of fingerprints and various innovative techniques have been invented in the current period to make it effective. The recognition of fingerprint in various field is playing pivotal role to enhance development mechanism. It is reality that fingerprints are confronting with plenty of challenges but its bright future cannot be curtailed. The importance of fingerprints as well as ethical implication has fostered the ambient of modernization and putting the mechanism of justice at the apex of glory. As fingerprints facing variety of problems specially in the south Asian states for its recognition but it would flourish and will get its effective position.

Keywords: fingerprint, identification, chemical methods, justice system, DNA

Introduction

In 1892, Francis Galton and Edward Henry conducted the first study on fingerprinting and classification. They noted that there are three primary patterns that constitute up fingerprint categorization: Arch, Loop and Whorl. In Babylonian ceramic tablets, archaeologists found fingerprints dating from 1792-1750 BCE (Abbasi and Ayyoubzadeh, 2023). The visibility of digitally obtained fingerprints was impacted by the presence of cosmetic and daily use products (Liao and Urban, 2019). Depending on the features of each component, different outcomes were produced. By lowering the fingerprint quality, synthetic mehndi, alcohol based hand sanitizer, greasy lotion and viscous oil significantly alter the fingerprint impressions (Aseri *et al*., 2022).

Similar to this, the government of India's Unique Identification Authority of India (UIDAI) Aadhaar card carries a metric database that includes each citizen's fingerprints and may be used to identify the person (Kumari *et al*., 2021). In a different research looked at the dangers of forgeries and how well forensic experts could spot them. More than 53% of fake fingerprints were reported as genuine in the study, whereas 45% of real fingerprints were reported as counterfeit (Saharan *et al*., 2020). Forged fingerprints are typically utilised by someone who wants to commit a crime and then use them to either frame a victim or attract the attention of law enforcement (Saharan *et al*., 2020).

The world has used fingerprints for signing legal papers for three thousand years, making them the oldest kind of human identifying technology. For criminal investigations, fingerprints may generally be divided into three types: latent (invisible) prints, plastic preprints and patent (visible) prints (Militello *et al*., 2021). Additionally, it may be broadly classified into three varieties according to how well they can absorb water soluble deposits: porous surfaces, non-porous surfaces and semi-porous surfaces (Yadav, 2019). In criminal investigations, fingerprints are a crucial piece of evidence. They are crucial in criminal investigations since they are permanent, universal, distinctive and readily available (Smith and Miller, 2021). These are composed of eccrine components whose main constituent is an amino acid and sebaceous components whose main constituents are oil and fats (Barros and Stefani, 2019). In a sample of 60 volunteers (30 females and 30 males), seven different kinds of sweat pores (round, rhomboid, elliptical, square, rectangular, triangular and hexagonal) were examined for variability (Chovancová *et al*., 2023).

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Sweat from the finger pores makes patterns on surfaces as it comes into contact with them. On the surface of contact, this undetectable perspiration pattern leaves a fingerprint impression. Latent fingerprints are fingerprint imprints taken from the contact surface (Muhammed and Pais, 2023). About 30% of all recovered prints are latent palm prints, which are typically found at crime scenes. Latent palm prints also showed that females had higher ridge densities than males identifying sex based on latent palm prints found on papers (Ali and Ahmed, 2020).

One of the important areas of fingerprint identification science that has wide-ranging implications in several scientific disciplines is gender determination. In addition to forensic science, it has uses in anthropology and human biology to examine diverse characteristics among various people and civilizations (Yan *et al*., 2021). Traditional *vs* digital ink fingerprinting allows us to compare a huge number of fingerprint data at once and the digital technique yields quicker and more accurate findings. What are fingerprint scanners and why are they becoming more popular (Kumari *et al*., 2021). The Automated Fingerprint Identity Systems (AFIS) receive the fingerprint data *via* electronic transmission for the purposes of authentication, verification and creating a database of the offenders (Maltoni *et al*., 2017).

When latent fingerprints are successfully developed, they can aid in solving crimes but when they are muddled, deformed or overlapped, the question of whether it is still feasible to identify a person without using dermatoglyphics emerges (Ryan, 2020). Sweat residue present in the latent prints is supposed to have quite a good quantity of cellular material which if analyzed properly can be used to generate forensic DNA profile of the individual (Kumar *et al*., 2015). The eight key fingerprints that the FBI (Federal Board of Investigation) has been using upto this point were separated apart based on owning development methods and patterns. There are two variations of the arch pattern; Tented Arch and Plain Arch (TAPA). Additionally, there are three subgroups of the loop pattern: Plain Whorl, Central Pocket Loop, Double Loop (DL) and Accidental Whorl (AW). There are also two subcategories of the loop pattern; Radial Loops and Ulnar Loops (RLUL) (Chakravathy *et al*., 2018).

Additionally, ninhydrin and its analogues can be used to create the surfaces of fingerprints (Wang *et al*., 2015), diazaflurenone (DFO) reported by (Yadav, 2019), physical developers (PD) (de la Hunty *et al*., 2015) and multimodal deposition (MMD) (Jouzel *et al*., 2007). Fingerprints on non-porous surfaces can be developed using fingerprint powders (Barros and Stefani, 2019) small particle reagents (Moghadam *et al*., 2015) cyanoacrylate fuming and vacuum metal deposition (VMD) (Davis *et al*., 2016). The surface that chooses to make fingerprint development harder is frequently seen at crime scenes.

According to certain research, dermatoglyphics analysis may be used to identify a patient's genetic propensity for a specific class of hereditary disorders early on (Kouri *et al*., 2022). In order to improve curved structures in noisy fingerprint photos, Gottschlich developed curved Gabor filters (CGFs). For the improvement of poor-quality fingerprint photos, these CGFs are created based on curved areas and then applied to previously determined orientations and ridge frequencies (Le *et al*., 2020).

Furthermore, poroscopy is a specialized examination of the pores on the skin's papillary ridges. Additionally, the science behind horoscopes is not being fully utilized. The purpose of the current study was to evaluate the impact of submerging hands in water of various temperatures (Kaur and Dhall, 2022). Caldermatoglyphicyphia, often known as "immigration delay disease," is an extremely uncommon syndrome that has been linked to the absence or disappearance of fingerprints (Hijosa-Valsero *et al*., 2011). A frequent side effect of numerous chemotherapy treatments and foot syndrome (palmar-plantar erythrodysesthesia or palmoplantar erythrodysesthesia or chemotherapy-induced acral erythema) is linked to the loss of fingerprints (Kanchan and Krishan, 2018). The documented dermatoglyphics drug associate in two breast cancer patients reported by Cohen (2017), who received Capecitabine, an oral 5-fluorouracil prodrug. A similar incident involving a breast cancer patient receiving Capecitabine treatment who was refused permission to conduct a financial transaction owing to the loss of fingerprints has been reported (Saharan *et al*., 2020).

In result, we increasingly rely on touch to engage with gadgets like smartphones, tablet, computers and control panels regardless of the technology. Touchscreen technology thus regularly come into contact with bodily lubricant (Busch and McCarthy, 2021). Therefore, surface deposition results from localized in homogeneous pollutants from fingers sticking to a surface and degrading the user's visual/optical experience (Stoehr *et al*., 2016). Although it is generally known how reliable fingerprint evidence is for identifying criminals, no research has yet been done on atypical prints (Baryah *et al*., 2023). Therefore, in the present study, we attempted to define rarely encountered fingerprints in a human population. Unusual fingerprint patterns in humans, implications for forensic casework and fingerprint research (Baryah *et al*., 2023). The data suggest that changes could mask the known sex differences in ridge density, so a better comprehension of the topological changes in epidermal ridge width throughout the life cycle and the contributing factors would help interpret the differences between the sexes (male, female) and different age groups with the development of surfaces by using a variety of chemical methods (Sánchez-Andrés *et al*., 2018).

Chemical methods for fingerprint detection. To make the ridge patterns on a fingerprint more visible, chemical fingerprint analysis techniques are used. The chemical methods used in these procedures make it easier to see the furrows and ridges of a fingerprint, which can be used to recognize a person (Kumari *et al*., 2021).

The following are the chemical methods that are used in the detection method and availability of tests with their ranks has been shown in the Fig. 4.

Ninhydrin method, silver nitrate method, cyanoacrylate fuming method, physical developer method, DFO (1,8-diazaflurene-9-methoxy ethanol (2-methoxy ethanol) method, polydimethylsiloxane (PDMS) dissolved in xylene (PDQ) method, small particle reagents (SPR) method, oil red O method, amido black method, acid yellow and method, methyl 3,5 dinitro benzoate (MBD) method and vacuum metal deposition method (Table 1).

Ninhydrin method. The chemical reagent ninhydrin is frequently used to identify fingerprints (Fig. 4). The technique is based on the fact that when ninhydrin interacts with the amino acids in sweat, a visible residue is left behind on the skin's surface (Bleay *et al*., 2021). Latent fingerprints may be created chemically on porous materials like paper, cardboard and textiles using the ninhydrin process (Table 1). This technique is based on the creation of a purple blue hue as a result of the interaction between ninhydrin and the amino acids found in perspiration (Kanodarwala *et al*., 2019). The quality and amount of the latent fingerprint and the substrate on which it is deposited are some of the variables that might affect how well the ninhydrin technique of fingerprint detection works (Khare and Singla, 2022). The ninhydrin technique is often regarded as a very sensitive and trustworthy way to create latent fingerprints (Wang *et al*., 2017). It is the only test that is mostly used for the examination of latent fingerprints.

To eliminate any oils or impurities, the surface to be tested is first cleansed using a solvent such as alcohol (Abubakar and Haque, 2020). The next step is to brush or spray a little amount of ninhydrin solution over the surface (Dawkins *et al*., 2020). To activate the ninhydrin and quicken the reaction, the surface is then heated, often using a hot plate or hairdryer (Pregent,2021).

The surface of the sweat takes on a purple or blue hue as a result of the ninhydrin's reaction with the sweat's amino acids (Prabakaran and Pillay, 2021). The complex that forms when the amino acids and ninhydrin interact produces this colour (Kumar and Rub, 2020). To facilitate further examination, the generated fingerprint can be seen and photographed (Li *et al*., 2019).

Silver nitrate ($AgNO_3$). In forensic science, silver nitrate is a frequently used reagent for the identification of fingerprints. A visible silver chloride precipitate is created as a result of a chemical interaction between the silver nitrate and the salts and oils found in fingerprints (Kanodarwala *et al*., 2019).

Here is how to use silver nitrate to identify fingerprints step-by-step. Prepare a silver nitrate solution by combining it with distilled water. Depending on the surface being examined and the age of the fingerprints, the solution's concentration will vary but a common value is 5% (Davis and Fisher, 2015). Apply a little amount of the silver nitrate solution to the area of the surface where you think there could be fingerprints. Use a dropper, brush or spray bottle for this (Laurin *et al*., 2015). Wait 2 to 5 min, on average, for the solution to rest on the surface. Any salts and oils inside the fingerprints will react with the silver nitrate during this period (O'Hagan and Calder, 2020). To get rid of any extra silver nitrate solution, rinse the surface with distilled water (Banne *et al*., 2017). To see the silver chloride precipitate, expose the surface to UV light, such as a black lamp. A white or light coloured back-ground will make the silver chloride stand out as a dark or black color (Bécue *et al*., 2020).

Iodine fuming method. Latent fingerprints can be created on non-porous surfaces like glass, metal or plastic using the chemical procedure known as the "iodine fuming method" in forensic science (Chang *et al*., 2019). The process includes spraying iodine vapour on the surface, which interacts with the fatty acids and oils in the fingerprint remnant to generate a noticeable brownish-yellow colour (Patel *et al*., 2009).

The steps below are typical for the iodine fuming technique procedure. Place the item containing the invisible fingerprint inside a fuming area (Wei *et al*., 2022). At the bottom of the chamber, put a small number of iodine crystals in a heat resistant dish or foil boat (Strathmann, 2014). Use a heat source, such as a hot plate, to gradually heat the iodine crystals until they start to evaporate (Fu *et al*., 2019). Let the iodine vapour encircle the item in the chamber for a few minutes (Wang *et al*., 2020). Take the item out of the chamber and check to see whether you can observe the fingerprint (Tehranipoor *et al*., 2017).

Cyanoacrylate fuming method. Forensic science frequently uses the cyanoacrylate fuming process to create latent fingerprints. It requires exposing a surface or item to cyanoacrylate vapors, a form of adhesive also known as super glue, that may contain latent fingerprints (Bumbrah, 2017). The method begins by putting the item in a container or enclosed chamber with some cyanoacrylate. After that, heat is applied to the cyanoacrylate, which causes it to evaporate and distribute throughout the container (Li *et al*., 2023). The fumes cause the latent fingerprints to polymerize and become visible as white ridges by interacting with the amino acids and other compounds found there (O'Neill and Lee, 2019). The item is then taken out of the chamber, and the detectable fingerprint can be captured on a camera or wiped using fingerprint powder or adhesive tape (Askarin *et al*., 2020). The cyanoacrylate fuming technique is used in forensic investigations (Table 1) because it produces latent fingerprints quickly, accurately and without any harm to the object being studied (Ansari *et al*., 2022). It may be applied to many different surfaces, including non-porous ones like metal, glass and plastic (Bumbrah, 2017).

Physical developer method. In forensic science, the physical developer method is a method for identifying invisible fingerprints on a substrate. The surface on which the fingerprint is thought to be present is treated with a solution of silver nitrate and a reducing agent, such as hydroquinone or pyrogallol (Machelska and Celik, 2018). A silver chloride precipitate that outlines the ridge patterns is produced when the silver ions in the solution are combined with the chloride ions in the latent fingerprint residue (Yang *et al*., 2022). Then, the reducing agent converts the silver ions to metallic silver, darkening and illuminating the ridges (Fouda-Mbanga *et al*., 2021). Latent fingerprints on porous or challenging-to-process media, such as paper, cardboard, or leather, can be seen using the physical developer approach (Bumbrah, 2017). To be effective, this technique takes time and requires specific tools and knowledge. The technique is also susceptible to contamination and may be impacted by the presence of other materials on the surface, such as oil or dirt (Riser-Roberts, 2020).

DFO(1,8-diazaflurene-9-one) method. The DFO (1,8-diazafluorene-9-one) technique is a typical method used for identifying latent fingerprints on porous materials such as paper, cardboard and unpainted wood (Flanders, 2017). The DFO technique is based on the DFO's interaction with the amino acids in perspiration and oils in fingerprints, which results in the formation of a fluorescent molecule that can be seen under UV light (Wang *et al*., 2017). It is a moderate method that is used for the identification of latent fingerprints.

The following steps are part of the DFO method. To make the latent fingerprints stand out more against the porous surface, the porous surface is first coated with a black fingerprint powder (Vadivel *et al*., 2021). A solution of DFO dissolved in a solvent like methanol or ethanol is then sprayed over the surface (Table 1).

On the surface, the solution is allowed to dry (Rassu *et al*., 2015). After that, UV light is shone on the surface, which causes the DFO to react with the amino acids in the fingerprints and create a fluorescent compound that can be seen when illuminated by UV light (Wang *et al*., 2017). The glowing fingerprints that appear can be captured on camera or removed with tape (Li *et al*., 2019).

MMD (2 methoxy ethanol) method. A typical solvent for creating latent fingerprints on non-porous surfaces is MMD (2-methoxy ethanol) (Banne *et al*., 2017). The steps of the MMD approach are as follows: To eliminate any potential dirt or debris, the surface to be examined is cleansed (Lusher *et al*., 2014). A little MMD is rubbed onto a fresh cloth or cotton swab (Gao *et al*., 2021). The object's surface (Table 1) is then gently rubbed with the cloth or swab, using just enough pressure to let the solvent penetrate any potential latent prints (Héritier, 2022). After fully rubbing the surface, an ultraviolet (UV) inspection is performed on the cloth or swab. Any developed latent prints will manifest as an observable pattern (Morgan, 2023). The print is subsequently lifted using tape or other specialist lifting methods, or it can be photographed (Ewing and Kazarian, 2017).

Polydimethylsiloxane (PDMS) dissolved in xylene (PDQ) method. Forensic science uses the Polydimethylsiloxane (PDMS) dissolved in xylene (PDQ) method to create fingerprints on non-porous substances including metal, plastic and glass (Krishna *et al*., 2020). This method is less commonly used for the fingerprint identification as shown in Fig. 4. This approach is also referred to as the "sticky tape method" or the "PDMS in xylene" method (Lee and Kim, 2022).

The method operates as follows. To make a solution, a little quantity of PDMS is dissolved in xylene. The surface with the fingerprint is then treated with this solution (Liu *et al*., 2021). It only needs a few minutes

Table 1. Various method is enlisted for effective understanding

Chemical method	Result	Suitable surface	Limitations	Reference
Ninhydrin	Purple-blue print	A porous surface such as paper, card, board and fabric	Can cause skin irritation and staining	(Wang *et al*., 2020)
Cyanoacrylate fuming	White print	Non-porous surfaces such as glass, metal and plastic	Can damage or destroy fragile evidence	(Casey *et al*., 2019)
DFO (1,8-diazafluoren-9-one)	Yellow-green print	A porous surface such as paper, cardboard and fabric	Limited sensitivity and specificity	(Zhang *et al*., 2019)
Physical developer	Brown print	Non-porous surfaces such as glass, metal and plastic	Requires specialized equipment and training	(Vos de Wael *et al*., 2018)
Silver nitrate	Black print	A porous surface such as paper	Limited sensitivity specificity cardboard and fabric	(Swofford and Champod, 2021)
Small particle reagent	Gray-black print	Both porous and non-porous surfaces	May interfere with subsequent DNA analysis	(Steiner and Bécue, 2018)
Amido black	Blue-black print	Porous surfaces (paper, cardboard etc.)	Limited effectiveness on non-porous surfaces. Interference with DNA analysis	(Datta *et al*., 2001)
MMD (multi-metal-deposition)	Greyish deposition of metal on ridges	Non-porous surface (glass, metal and plastic	Sensitive to environmental conditions, Not suitable for porous surfaces (paper)	(Wang *et al*., 2020)
Oil Red O	Reddish-orange to red	Best use on non-porous surfaces (glass, metal and plastic)	Not effective on all surfaces, and may not be sensitive enough to detect faint or partial fingerprints	(Jasuja *et al*., 2016)
Polydimethyl-siloxane (PDMS) dissolved in xylene (PDQ) method	No visible stain but a 3D impression of a fingerprint is produced on the PDMS surface	Non-porous surface (plastic, glass, metal)	Requires careful handling due to the flammability and toxicity of the solvents involved. May not be effective on highly porous and textured surfaces	(Yang *et al*., 2019)
Acid yellow method	Yellow to orange-colored print on the green or blue background	Porous surface (paper, cardboard and fabric)	Only work on a porous surface It may not work on a surface that has been treated or cleaned with chemical	(Jiang *et al*., 2018)
Methyl 3,5 dinitro benzoate (MBD) method	Yellow colored print on the dark background	Non-porous surface	Only work on the non-porous surface It may not work on the treated surface or in higher humidity	(Shahbazi *et al*., 2020)
Vacuum metal deposition method	Metallic	Non-porous surface	Expensive, time-consuming, Sensitivity	(Subramanian *et al*., 2019)

for the solution to dry. The PDMS develops a thin coating from over-fingerprint throughout this period (Bécue *et al*., 2020). Once the remedy has dried, the area is covered with transparent adhesive tape and firmly pushed down (Latthe *et al*., 2019). The PDMS layer is then carefully removed from the surface together with the tape. The PDMS layer pulls the fingerprint off the surface and onto the adhesive tape as it is raised (Han *et al*., 2020). To preserve and analyze the tape, it is then placed on a fingerprint card or other appropriate surface (Subhani *et al*., 2019).

Small particle reagents (SPR). To make latent fingerprints on surfaces more visible, the Small Particle Reagents (SPR) method is a fingerprint analysis methodology. With this technique, a finely split powder, such as titanium dioxide or zinc oxide, is placed on an object's surface to enhance the visibility of the latent fingerprints (Dawkins, 2019). For dealing with non-porous surfaces like glass or metal, where conventional dusting procedures may not be as successful, the SPR approach is extremely effective (Yuan *et al*., 2021). The tiny particle size of the powder employed in the SPR process enables it to stick to the oils and perspiration in the latent fingerprints. Also, due to the powder's high refractive index, under certain lighting circumstances, the latent fingerprints stand out more (Woods, 2013). Several methods, including brushing, spraying, and immersion, can be used to apply the SPR approach. The technique is extremely sensitive and occasionally reveals fingerprints that would otherwise be challenging to find using other techniques (Sharma *et al*., 2021).

Oil red O method. To identify and measure the number of lipids contained in cells and tissues, the staining technique Oil red O is often employed in biology (Andrés-Manzano *et al*., 2015). Oil red O can be used to make latent fingerprints more evident in the setting of fingerprints (invisible prints left on a surface by natural oils and sweat from the skin (Table 1) (Moreno *et al*., 2021).

There are multiple phases in the Oil Red O technique. Gathering the fingerprint: A fingerprint brush or tape must be used to gather the fingerprint initially (Chávez *et al*., 2021). Make the staining solution by diluting the dye in a solvent, such as isopropanol or ethanol, to create the Oil red O staining solution. Following that, the staining solution is filtered to get rid of unwanted contaminants. The collected fingerprint is submerged in the staining solution for several minutes to stain it. During this period, the dye will ingest the fingerprint's lipid components and turn them red (Darshan *et al*., 2023). Following staining, the fingerprint is washed with a solvent, such as isopropanol, to remove any extra colour. It is then dried, the fingerprint is next left to dry naturally or with a soft heat source (Kanodarwala *et al*., 2021). When placed against a white or light-colored backdrop, a fingerprint stained with Oil red O will appear red (Mumbo, 2019). The technique helps make latent fingerprints more visible on surfaces that are difficult to identify with conventional techniques, including porous or uneven surfaces (Wang *et al*., 2020).

Amido black method. It is standard practice to use amido black to see fingerprints on porous materials like paper, cardboard, or fabric (Coffey and John, 2018). The process includes employing an amido black dye solution (Table 1), which when in contact with the proteins and amino acids found in the perspiration and fingerprint oils, creates a blue-black stain (Praska and Langenburg, 2013).

The amido black method for seeing fingerprints involves the following steps. The dye should be dissolved in water or a solution of water and methanol to create the amido black solution (Fox *et al*., 2014). Put the fingerprint-covered porous surface on a flat surface (Celma *et al*., 2019). For a few seconds, submerge the surface in the Amido Black solution (Duan *et al*., 2020). To remove any excess color, remove the surface from the solution and rinse it with water (Bai *et al*., 2022). Let the surface dry out. It should now be possible to see the fingerprint as a blue-black mark on the surface (Friesen, 2015). Forensic investigators and law enforcement organizations may identify and compare fingerprints from crime scenes using the amido black procedure (Harush-Brosh *et al*., 2021).

Acid yellow method. Fluorescein, often known as acid yellow 7, is a fluorescent dye that is frequently employed in fingerprint recognition technology. When acid yellow 7 is sprayed onto a surface, it sticks to the proteins and amino acids found in perspiration as well as other oils found in fingerprint residue (Bumbrah, 2016). This makes the fingerprints more noticeable by having them glow under a certain kind of light (Table 1). A sort of dye called acid yellow is used in the field of forensic science to make latent fingerprints on non-porous materials like glass, plastic or metal more visible (Prabakaran and Pillay, 2021). The perspiration and oils included in the fingerprint residue allow the acid yellow dye, a fluorescent stain, to stick to them. The dye glows when exposed to UV light, making the fingerprint visible and permitting identification (Pattarith *et al*., 2021).

The following steps are commonly included in the procedure for employing acid yellow in the fingerprint detection process:

Gathering the sample. After inspecting the object that may have fingerprints on it, the surface is swabbed or dusted to gather the fingerprint dust (Kamanna *et al*., 2017).

Application of acid yellow. After making a solution of the acid yellow dye, the obtained sample is processed. The sample is typically sprayed with the solution or submerged in it (Fai *et al*., 2016).

Rinse. Any excess color that did not stick to the fingerprint residue is then washed off the sample using water (Chen *et al*., 2017).

Examination. Under UV light, the sample is inspected, causing the acid- yellow dye to glow and display the latent fingerprint (Bhardwaj *et al*., 2022).

Documentation. The fingerprint is then captured on film or by other means to be studied later and put up for comparison with other prints in a database (Alsmirat *et al*., 2019). Overall, forensic investigators can benefit from using acid yellow to improve the visibility of fingerprints on non-porous surfaces, enabling more precise identification of those involved in criminal activity (Truccolo *et al*., 2020).

Methyl 3,5 dinitro benzoate (MBD) method. Because it can identify specific carbonyl-containing molecules in the fingerprint residue, the MBD method is a potent tool for fingerprint analysis and it is also least commonly used method as shown pattern in the Fig. 4 (Ma *et al*., 2009). The oils, perspiration and other fluids from a person's skin are left behind when they contact with anything (Table 1). Several diverse substances including fatty acids, amino acids and other chemical molecules, can be found in this residue (Pereira, 2018). Sebum an oily material produced by the skin's sebaceous glands is one of the most typical types of chemicals discovered in fingerprint residue (Lee and Joullié, 2015). Many substances including fatty acids, triglycerides and other lipids with carbonyl groups are found in sebum. MBD selectively interacts with these carbonyl containing substances when it is applied to a fingerprint, creating a recognizable derivative (Chen *et al*., 2021).

Spraying the MBD reagent onto a surface and then exposing it to UV light are two ways to visualize fingerprints using the MBD technique (Dagar *et al*., 2022). The MBD derivative absorbs UV light, enabling it to glow and provide a vivid picture of the fingerprint in yellow or green. This makes it possible to see and recognize the fingerprint including on surfaces that are dark or have several colors (Drahansky *et al*., 2012). The MBD technique may also be used to examine the makeup of the fingerprint residue. It is feasible to determine the precise carbonyl-containing chemicals that are present in the sample by examining the gas chromatography fingerprint of the MBD-treated fingerprint (Aliakbarzadeh *et al*., 2016). This can also provide important details about the person who left the fingerprint, such as their food, way of life, age and gender (Singh and Jackson, 2021). The MBD technique is an effective tool for fingerprint analysis in general because it enables the detection and identification of certain carbonyl-containing chemicals in the fingerprint residue (Ma *et al*., 2009). This may be utilized for forensic investigation and other purposes and can offer important insights into the make-up and origin of the fingerprint (Morgan, 2017).

Vacuum metal deposition method. Forensic science uses vacuum metal deposition as a technique for identifying and enhancing fingerprints on non-porous surfaces like metal, glass and plastic (Bumbrah, 2016). A small layer of metal is applied to the object's surface throughout the procedure, which might reveal latent or invisible fingerprints that were previously undetected (Zhu *et al*., 2018). A metal, such as zinc or gold is heated at a high temperature until it vaporizes in the procedure, which entails putting the item within a vacuum chamber (Dan *et al*., 2022). The metal vapor then cools and condenses, producing a thin coating on the surface of the item. This coating of metal can stick to perspiration and fatty residues left behind by fingerprints, boosting their contrast and making them more noticeable (Singh *et al*., 2022). The residue is then combined with a chemical solution and applied to the metal-coated surface, where it reacts to create a distinct fingerprint (Fan *et al*., 2020). For additional study, the resultant fingerprint can be photographed or lifted with adhesive tape (Shi *et al*., 2020). Vacuum metal deposition is a sensitive and reliable way to find latent fingerprints, especially when other approaches to fingerprinting have failed (Zampa *et al*., 2022). Yet, it may be time-consu-ming and expensive and it calls for specific tools and knowledge (Majone *et al*., 2015).

Legal and ethical implications of fingerprint. The ridges and furrows on the fingertips of many animals, including humans, create distinctive patterns known as fingerprints. As they have been used for identification for more than a century, fingerprints have significant ethical and legal implications (Militello *et al*., 2021).

Legal implication. Criminal investigation. In criminal investigations, fingerprint evidence is frequently used to identify suspects or connect them to a crime scene, a representation in Fig. 1. To solve crimes and bring offenders to justice, fingerprint analysis may be a very effective technique (Gehl and Plecas, 2017).

Civil cases. In civil proceedings, such as those involving will or contract disputes, fingerprint evidence may also be utilized (Page *et al*., 2019).

Employment screening. Fingerprints may also be used by employers to assess potential hires as part of background investigations (Denver *et al*., 2017).

Immigration. As part of the screening procedure for visa applications or other immigration proceedings, immigration officials may also acquire fingerprints (Villegas, 2015).

Legal Implications of fingerprint. Because fingerprints are individualized, their distinct ridge patterns make them a reliable biometric identification. Fingerprint evidence is essential to criminal investigations in forensic contexts because it can be used to identify suspects, correlate people to crime sites and provide vital proof in court cases. Experts may securely match and analyze fingerprints using cutting-edge methods like automated fingerprint identification systems (AFIS), guaranteeing their admission in court. Even though fingerprint analysis has a high degree of accuracy, there are still issues with methodological rigor, expert testimony and privacy within the legal system. However, fingerprint evidence continues to be a fundamental component of forensic science, aiding in the prosecution and defense of criminal cases as well as the administration of justice.

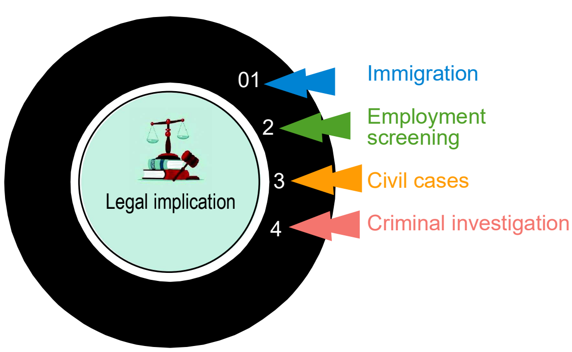

Fig. 1. Graphical representation of legal implication of latent fingerprint.

Ethical implication of fingerprint. Privacy. Privacy issues arise with the acquisition and storage of fingerprint data. Some could feel uneasy with the thought of having their fingerprints taken and kept in a database, especially if they are not involved in any illegal activity (Neo and Teo, 2020).

Misuse of data. Also, there is a chance that fingerprint data may be abused. Identity theft might result from unauthorized access to the database, and the information could be utilized for monitoring (Habibu *et al*., 2019).

Discrimination. There is a chance that using fingerprint data will result in prejudice toward some populations (Royakkers *et al*., 2018). For instance, biased results in criminal investigations or job screenings may result if some populations are more likely to have fingerprints that are hard to read or regularly misidentify their owners (Fountain, 2022).

Accuracy. In rare instances, the accuracy of fingerprint analysis has been questioned, and mistakes in fingerprint identification may result in erroneous judgments or other unfair consequences (Dror and Scurich, 2020).

Thus, even if using fingerprints to identify criminals and provide security in some situations has significant advantages, diagrammatically depiction is shown in Fig. 2, it is crucial to carefully assess any potential ethical and legal ramifications (Fromberger *et al*., 2018). To preserve privacy, stop data abuse, and guarantee that technology is applied fairly and properly, safeguards must be put in place (Hoofnagle *et al*., 2019).

Importance of latent fingerprints in the society. In society, latent fingerprints are crucial, especially in the area of law enforcement. A latent fingerprint has been left behind on a surface but is not immediately noticeable (Sankaran *et al*., 2015). These fingerprints may be seen on a variety of surfaces, including glass, metal, paper and plastic. Latent fingerprints are used by law enforcement to identify suspects in criminal investigations (Bruno *et al*., 2017). Latent prints discovered at crime scenes are collected, examined and compared to known fingerprints in a database as part of the procedure. Law enforcement officers may be able to identify a suspect or rule out certain people if a match is made (Kellman

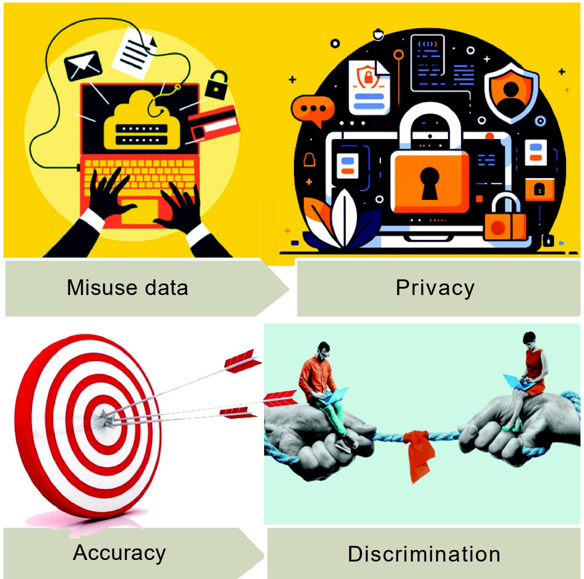

Fig. 2. Graphical representation of ethical implication on the latent fingerprint.

et al., 2014). Latent fingerprints are also utilized in background checks for job applications and security clearances in addition to criminal investigations (Braga and Dusseault, 2018). When other methods of identification are unavailable, they can also be used to identify accident or catastrophe victims. Latent fingerprint technology has been quite helpful for recognizing criminals, prosecuting them and protecting the public (Johnson and Riemen, 2018).

Future of latent fingerprint. The study of latent fingerprints is a discipline that is continually developing, and several emerging methods and technology may one day completely alter how latent prints are gathered and studied (González *et al*., 2020). One such technique is 3D imaging, which can record a fingerprint's intricate details in far more detail than conventional 2D imaging. This could result in more precise and trustworthy identifications, particularly when the print is damaged or imperfect (Liu *et al*., 2017).

Using nanotechnology to improve the visibility of latent prints is another promising technique. Fingerprints that are normally undetectable to the human eye may be revealed by utilizing nanoparticles that bind to the chemical elements present in fingerprints (Aggarwal and Chitkara, 2022). The latent print analysis is also probably going to rely more and more on artificial intelligence (AI) and machine learning (ML). With the use of these technologies, the identification process may be automated and analysis can be done more quickly and accurately (Sarkar *et al*., 2023). Finally improvements in DNA analysis could potentially have an impact on latent fingerprint analysis (Monson *et al*., 2018). Latent print analysis and DNA analysis may be combined to link suspects to crime scenes ore. Overall, the future of latent fingerprint analysis seems optimistic, with a range of developing technologies and methodologies which can enhance speed, reliability, and accuracy (Lee *et al*., 2019). Before becoming extensively used in forensic science, it is crucial to maintain funding for research and development to make sure that these technologies have been thoroughly examined and verified (Gill *et al*., 2015).

Challenges to fingerprint identification evidence. Why courts need a new approach to finality. Biometric systems are frequently used for safety purposes and offer a wide range of options for authenticating and identifying users, relieving a lot of the user's load in the process (Yang *et al*., 2021). Because of their individuality, fingerprint recognition technologies are frequently utilized in biometric systems for system access authentication. The term "uniqueness of fingerprint" refers to the fact that no two individuals have the same fingerprint pattern, meaning that their patterns do not alter through time and are unique to each individual (Rathore *et al*., 2022). Even identical twins' fingerprints do not match exactly. A few areas, such as sensors, feature extraction, and matching algorithms, among others, are making it difficult to construct a fingerprint identification system (Singh *et al*., 2019).

The following list of FRS significant issues and difficulties. The mismatch is brought on by physical deformation, such as finger cuts and injuries (Sano and Ogawa, 2014). The mismatch is brought on by rotation or displacement while the finger is being scanned over the sensor (Han *et al*., 2020). Unauthorized access is brought on by clay printing or finger plasticity (Kumar and Singh, 2020). Variability in finger impressions may be caused by noise in the sensor or a skin disease. There is a lot of room for study in this area to enhance FRS performance (Bibay Thakkar and Talwekar, 2022). Make the input image as nice as possible using image processing techniques so that features can be retrieved more precisely without losing information (Laina *et al*., 2016). Develop a better algorithm to lessen mismatching caused by physical displacement and distortion, among other things (Acikgoz *et al*., 2017). A new method for FRS with a higher identification rate and matching procedures may be developed by combining various fingerprint recognition algorithms (Raja *et al*., 2022).

Applications of fingerprint recognition systems in many fields. Physical access control at border crossings and airports, etc. (Fig. 3) (Caldwell, 2015). The Ministry of Defense and other National Security Organizations have physical access controls (Lima *et al*., 2021). All card security, including that of ATM, credit and other types of cards (Imran *et al*., 2019). Security measures in banking, such as account transactions (Tsai and Su, 2021). Use fewer cards, criminal recognition (Abdullah *et al*., 2017).

Fig. 3. Various applications of fingerprints in daily life.

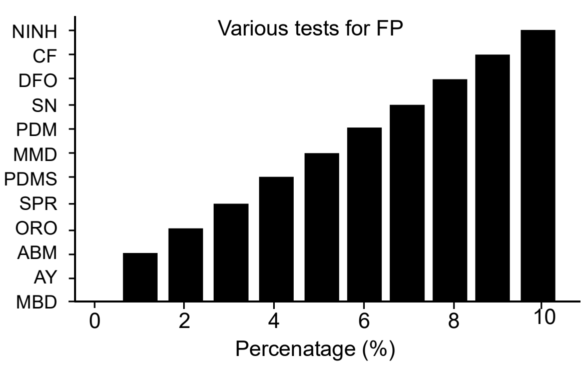

Fig. 4. Methods for FRS by combining different FP recognition algorithms.

Conclusion

The importance of fingerprints in crime scene investigation *vis-a-vis* analysis of organic substituents by adopting chemical methods has magnified the role of fingerprints in contemporary times. The best chemical methods that have plausible results for the development of fingerprints are ninhydrin, cyanoacrylate fuming (CF) and DFO. Various chemical methods have played a vital role in the development mechanism but these are principal methods. Furthermore, the analysis of types of fingerprints like whorls, arches and loops with their further classification has been made cognizable by adopting these chemical methods. Along with this, poroscopy and edgeoscopy for dermatoglyphics are being utilized for smooth analysis to restrict ambiguity. Finally, it summarizes the chemical methods for the development of fingerprints and their types with implications in the future and challenges that are being faced at this time.

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