Application of Hertzberg stain in the identification and differentiation of polyvinyl acetate-based forged fingerprints

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Criminals generally try to mislead investigators by using forged fingerprints to conceal their identity. Forged fingerprints developed using artificial sweat make the task of establishing their true identity difficult. The present study was conducted to analyse the efficacy of the Hertzberg stain technique for detecting and differentiating polyvinyl acetate-based forged fingerprints. The utility of the Hertzberg stain was analysed for forged fingerprint detection in combination with conventional methods on porous and non-porous surfaces. The results indicate that the Hertzberg stain technique effectively differentiates real and forged fingerprints.

Keywords: Criminals, forensic science, real and forged fingerprints, polyvinyl acetate, software analysis.

FINGERPRINTS are one of the most significant pieces of physical evidence due to their prevalence and easy analysis for unique identification[1]. With the increased use of biometric authentication devices in access control systems[2], security of the stored information becomes extremely important as the associated risks posed by false fingerprints make fingerprint-based authentication highly critical. The history of fingerprint forgery is as old as that of producing and classifying fingerprints. However, the security evaluation of attacks using these artificial fingers has rarely been reported. The methods against forged fingerprints, such as 'live and well' detection, have been suggested in the patent literature only[3]. Technological advancement helps both sides: fingerprint experts and forgers of fingerprints, with equal effectiveness. Forged fingerprints are used by two categories of people: criminals to frame innocent people and forensic experts to understand the process of forging and the distinction between real and forged fingerprint[4,5].

In today's digital world, electronic gadgets like smartphones, tablets and laptops have become an integral part of our daily lives. Most of these come with fingerprint-based access control. Unauthorized access risk posed by forged fingerprints is massive as it exposes personal and valuable information to unscrupulous people and criminals. Forged fingerprints are also misused in vital documents pertaining to property, ID cards, legal papers and contracts. They can also be misused to implicate innocent individuals in crimes committed by master criminals. Many cases of fingerprint forgeries are reported in journals, books, magazines and newspapers, where forged fingerprints have been used[5–8]. Thus, there is a dire need to develop methods for an easy and effective distinction of forged fingerprints[9].

A large number of relatively quick and reliable methods have evolved over the years for the development of latent fingerprints. The automated fingerprint identification system (AFIS) has further expedited the time-consuming task of comparing latent fingerprints with suspects[10,11]. However, little progress has been made to differentiate between real and forged fingerprints. In September 1995, an appeal was made to over 180 countries via Interpol channels to obtain details of known fingerprint forgeries. However, this did not meet the desired objective, as only 13 countries provided the relevant data. These statistics indicated the lack of seriousness on the part of forensic communities of most countries. Moreover, forensic investigators did not seriously pursue the task of developing and distinguishing fingerprints to solve such crimes. Therefore, it is of utmost importance to evolve chemical-based methods to differentiate between forged and real fingerprints. The present study aims to evolve a new method by which forged and real latent fingerprints could be developed and differentiated to detect fingerprint forgeries. The study uses polyvinyl acetate (PVA)-based fingerprints, which are flexible and widely used.

Materials and methods

Developing forged fingerprints

PVA has been used for quite some time to prepare forged fingerprints, primarily due to its low cost and easy availability.

Preparation of the Hertzberg stain

For this, 25 ml of $ZnCl_2$ solution (50 g/25 ml) was mixed with 12.5 ml of iodine potassium iodide solution (0.25 g

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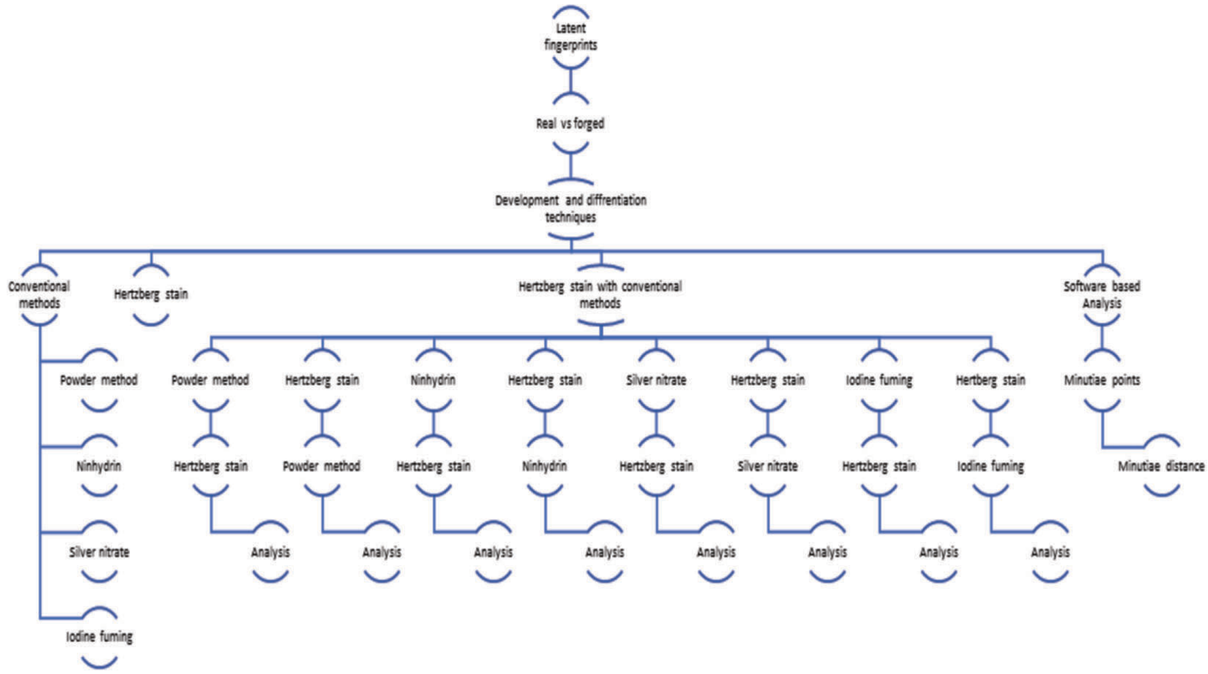

Figure 1. Summary of methodologies followed for the development and differentiation of real and forged fingerprints.

iodine + 5.25 g KI/12.5 ml). The mixture was allowed to rest for 12–24 h. The supernatant was decanted into amber-coloured, glass-stoppered bottles with a leaf of iodine.

Physical comparison of fingerprints using existing protocols

To begin with, we used well-established conventional methods to check their efficacy in the development and differentiation of fingerprints[12]. The real and forged fingerprints were developed and compared. Figure 1 summarizes the methodologies followed for the development and comparison of fingerprints.

Software-based comparison of real and forged fingerprints

CSIpix Matcher software was used to enhance, calibrate, compare and analyse real and forged fingerprints. Software analysis of forged fingerprints is important to examine their similarity with real fingerprints. The standard analysis compares two real fingerprints of the same origin, two forged fingerprints of the same origin and two real fingerprints of different origins. Then, the software is used to compare the questioned real fingerprint with the forged one from the same origin. The distance between the minutiae points is calculated for real versus real fingerprints, forged versus forged fingerprints and real versus forged fingerprints by the CSIpix matcher software[13].

Analysis of real and forged fingerprints using the Hertzberg stain

Application of the Hertzberg stain for fingerprint development and differentiation was tested on both real and forged fingerprints.

Development of real and forged fingerprints by protocol combinations

The Hertzberg stain was used along with conventional methods (black powder, ninhydrin ($C_9H_6O_4$), silver nitrate ($AgNO_3$) and iodine fuming)[12,14] in various combinations to analyse its applicability (Table 1). The results obtained were analysed to study the efficacy of these combinations for fingerprint development and differentiation on three non-porous (butter paper, chromogenic paper, floor tile) and three porous (simple paper, wood, cloth piece) surfaces.

Results

First, we present the results of conventional methods to develop real and forged fingerprints and distinguish between them. As anticipated, both real and forged fingerprints were developed successfully using the conventional methods, i.e. powder method (Figure 2 *a*), ninhydrin (Figure 2 *b*), silver nitrate (Figure 2 *c*) and iodine fuming (Figure 2 *d*). However, no differentiation was observed between the real and forged fingerprints.

Table 1. Performance of various methods used for development and differentiation between real and forged fingerprints

Method	Real fingerprint development	Forged fingerprint development	Colour difference between forged and real fingerprints
Powder method	✓	✓	×
Ninhydrin	✓	✓	×
Silver nitrate	✓	✓	×
Iodine fuming	✓	✓	×
Hertzberg stain	×	✓	✓
Powder method followed by Hertzberg stain	✓	✓	×
Hertzberg stain followed by powder method	✓	✓	×
Ninhydrin followed by Hertzberg stain	✓	✓	✓
Hertzberg stain followed by ninhydrin	✓	✓	✓
Silver nitrate followed by Hertzberg stain	×	✓	×
Hertzberg stain followed by silver nitrate	✓	✓	✓
Iodine fuming followed by Hertzberg stain	✓	✓	✓
Hertzberg stain followed by iodine fuming	✓	✓	✓

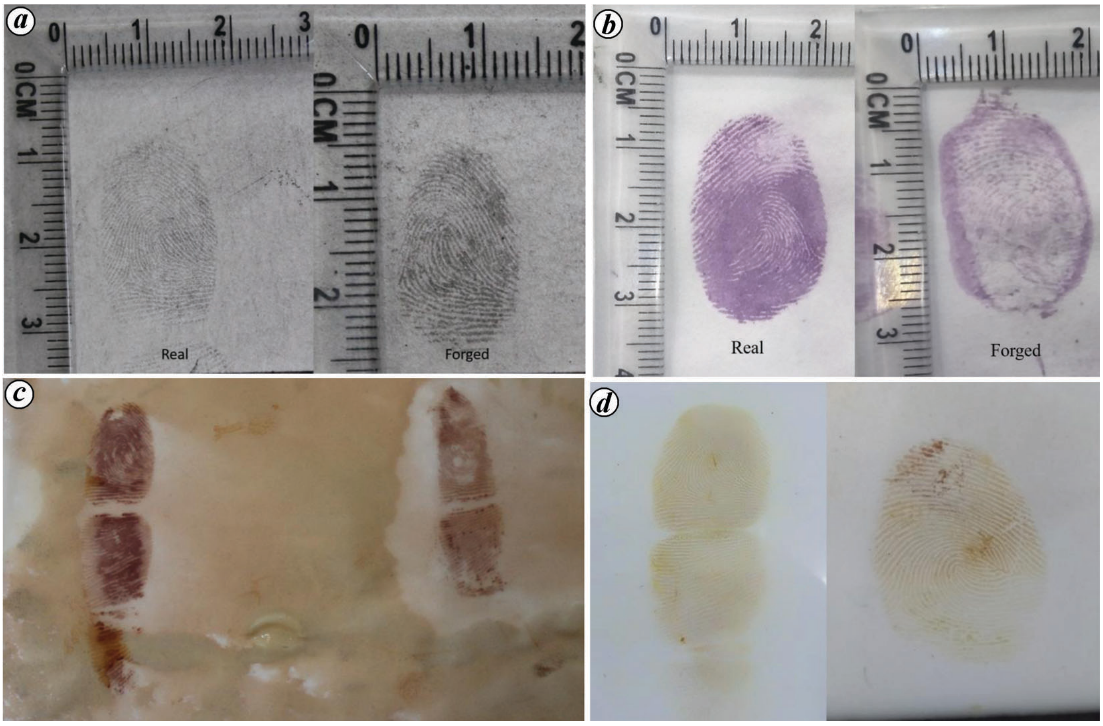

Figure 2. Development of real and forged fingerprints using (***a***) black powder method, (***b***) ninhydrin, (***c***) silver nitrate and (***d***) iodine fuming.

To compare real and forged fingerprints by using the CSIpix matcher software, matching and non-matching minutiae points were considered. Twenty-one matching minutiae points were observed between two real fingerprints of the same origin, and a few unmatched minutiae points were observed that could be due to natural variations (Figure 3 *a*).

A comparison of two real fingerprints of different origins revealed that only 13 minutiae points were clearly highlighted, whereas eight points were found at a distance less than 0.05 cm (Figure 3 *b*). On comparing real fingerprint with forged fingerprint, 18 matching minutiae points were observed (Figure 3 *c*). Whereas 15 matching minutiae points were observed in real and forged fingerprints previously developed with black powder (Figure 3 *d*).

A comparison of real and forged fingerprints previously developed with the ninhydrin method resulted in 33 matching minutiae points (Figure 3 *e*). Matching minutiae points were further analysed by calculating the inter-minutiae distance between two real fingerprints, two forged fingerprints, and real and forged fingerprints respectively. In the case of real versus forged fingerprints, out of 40 minutiae points, no difference was observed at eight points, less than 0.05 cm difference in distance at 29 points and ≥0.05 cm difference in distance at only two points (Figure 3 *f* and Table 2).

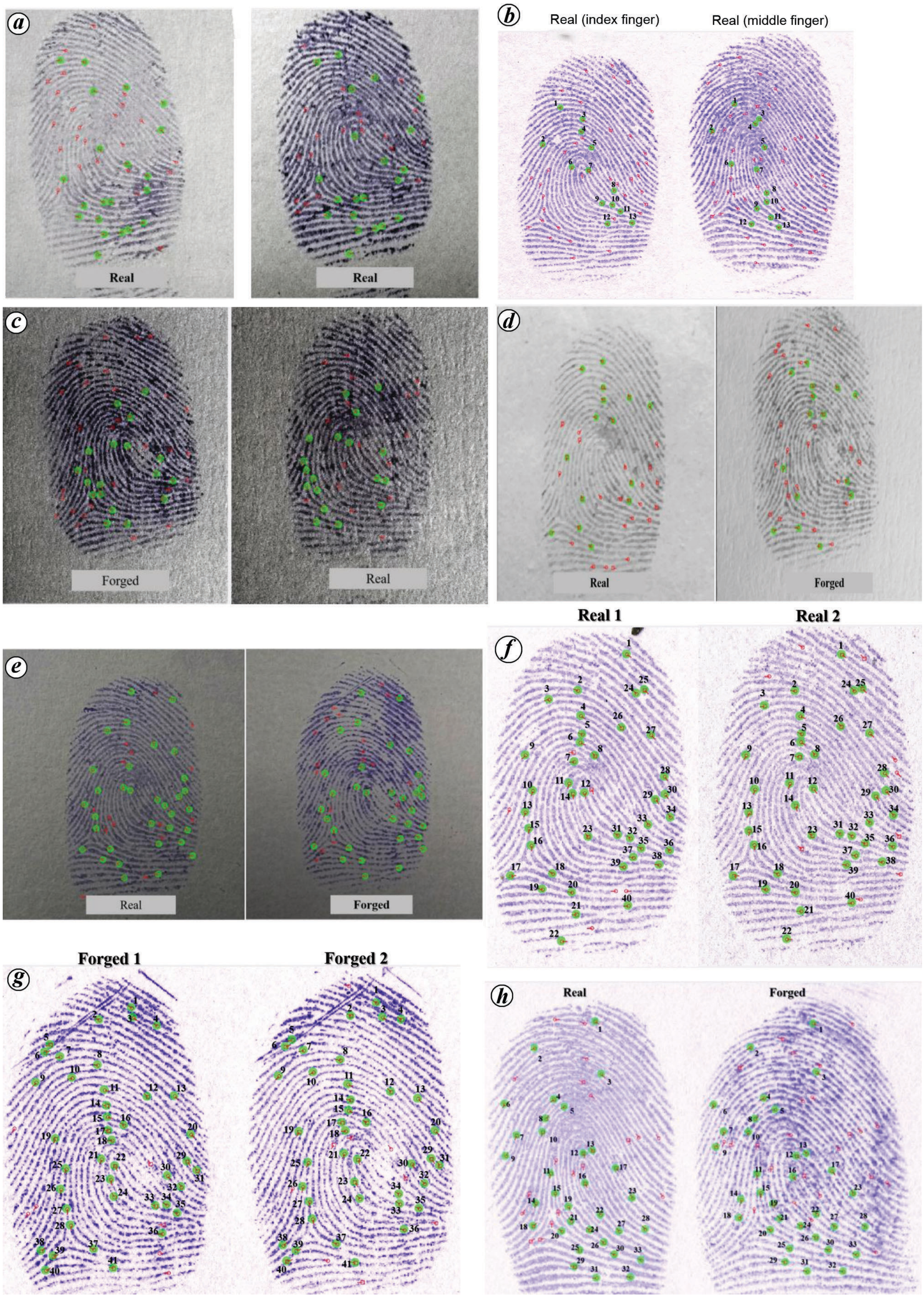

Figure 3. Comparison of minutiae points between (***a***) two real fingerprints of the same origin, (***b***) two real fingerprints of different origin, (***c***) real and forged fingerprints of the same origin, (***d***) real and forged fingerprints of the same origin developed using the powder method, (***e***) real and forged fingerprints of the same origin developed using the ninhydrin method, (***f***) two real fingerprints of the same origin, (***g***) two forged fingerprints of the same origin and (***h***) real and forged fingerprints.

For real fingerprints of different origins, 13 matching points were observed, of which five minutiae points had a distance ≥0.05 cm (Figure 3 *a* and Table 3).

While comparing two forged fingerprints (Figure 3 *g*), out of 41 matching points, 15 minutiae points were found to be placed exactly at the same distance from minutia one, whereas distance variation ≥0.05 cm was observed at five points (Table 4).

While comparing real and forged fingerprints, out of 33 matching minutiae points, a distance difference ≥0.05 cm was observed at 10 points (Figure 3 *h* and Table 5).

Since conventional methods failed to differentiate between forged and real fingerprints, the Hertzberg stain was used thereafter in the above-mentioned combinations to study its efficacy in establishing the differentiation. It was observed that the Hertzberg stain, when applied as a standalone method, developed only forged fingerprints

Table 2. Distance (cm) between minutiae points of two real fingerprints

Minutiae points	Real fingerprint 1	Real fingerprint 2
1–2	0.42	0.41
1–3	**0.63**	**0.63**
1–4	0.53	0.51
1–5	0.63	0.61
1–6	0.68	0.66
1–7	*0.82*	*0.76*
1–8	0.73	0.71
1–9	0.98	0.95
1–10	1.14	1.10
1–11	0.97	0.96
1–12	1.00	0.94
1–13	1.29	1.26
1–14	*1.02*	*1.08*
1–15	**1.37**	**1.37**
1–16	1.46	1.45
1–17	1.71	1.69
1–18	1.59	1.57
1–19	1.72	1.69
1–20	1.68	1.66
1–21	1.81	1.79
1–22	2.02	2.00
1–23	1.27	1.26
1–24	0.28	0.27
1–25	**0.27**	**0.27**
1–26	0.51	0.49
1–27	**0.58**	**0.58**
1–28	0.88	0.86
1–29	1.01	1.00
1–30	**1.00**	**1.00**
1–31	1.24	1.23
1–32	1.26	1.24
1–33	1.18	1.17
1–34	**1.16**	**1.16**
1–35	1.33	1.31
1–36	1.38	1.37
1–37	1.38	1.39
1–38	**1.45**	**1.45**
1–39	1.46	1.44
1–40	**1.71**	**1.71**

Bold indicates no difference in distance.
Italics indicates distance difference ≥ 0.05 cm.

Table 3. Distance (cm) between minutiae points of two real fingerprints of different origin

Minutiae points	Real fingerprint (Index finger)	Real fingerprint (Middle finger)
1–2	*0.39*	*0.34*
1–3	0.25	0.27
1–4	0.31	0.28
1–5	0.49	0.50
1–6	*0.59*	*0.55*
1–7	**0.66**	**0.66**
1–8	0.94	0.90
1–9	1.00	1.01
1–10	*1.05*	*0.98*
1–11	1.14	1.13
1–12	*1.20*	*1.15*
1–13	*1.29*	*1.24*

Bold indicates no difference in distance.
Italics indicates distance difference ≥ 0.05 cm.

Table 4. Distance (cm) between minutiae points of two forged fingerprints

Minutiae points	Forged fingerprint 1	Forged fingerprint 2
1–2	0.23	0.19
1–3	*0.06*	*0.11*
1–4	**0.21**	**0.21**
1–5	0.60	0.62
1–6	0.66	0.69
1–7	**0.59**	**0.59**
1–8	0.45	0.46
1–9	0.82	0.83
1–10	0.62	0.64
1–11	**0.58**	**0.58**
1–12	**0.61**	**0.61**
1–13	0.66	0.70
1–14	**0.68**	**0.68**
1–15	**0.75**	**0.75**
1–16	0.80	0.81
1–17	0.85	0.84
1–18	0.91	0.89
1–19	**1.02**	**1.02**
1–20	0.94	0.95
1–21	1.05	1.04
1–22	1.08	1.08
1–23	*1.17*	*1.22*
1–24	*1.28*	*1.33*
1–25	**1.17**	**1.17**
1–26	1.31	1.33
1–27	1.43	1.42
1–28	**1.53**	**1.53**
1–29	1.10	1.12
1–30	*1.16*	*1.11*
1–31	1.19	1.18
1–32	1.26	1.26
1–33	1.35	1.37
1–34	*1.36*	*1.30*
1–35	**1.41**	**1.41**
1–36	**1.54**	**1.54**
1–37	**1.65**	**1.65**
1–38	**1.75**	**1.75**
1–39	**1.76**	**1.76**
1–40	1.87	1.85
1–41	**1.76**	**1.76**

Bold indicates no difference of distance.
Italics indicates distance difference ≥ 0.05 cm.

due to the traces of PVA used in preparing forged fingerprints.

Table 1 summarizes the outcome of applying the Hertzberg stain as a standalone method and its use in combination with the conventional methods. The sequential impact of various components of each of these combinations in terms of colour difference is described below.

Powder method followed by Hertzberg stain

First, with the powder method, both real and forged fingerprints were developed. Next, the Hertzberg stain was applied, and no colour change was observed in either the real or forged fingerprints (Figure 4 *a*).

Hertzberg stain followed by powder method

When the Hertzberg stain was applied, only forged fingerprints were developed. Next, the powder method was applied to real and forged fingerprints; both were developed, but no colour difference was observed in either of them (Figure 4 *b*).

Ninhydrin followed by Hertzberg stain

When ninhydrin solution was applied, both real and forged fingerprints were developed. On subsequent application of the Hertzberg stain, forged fingerprints appeared distinctly darker than the real fingerprints (Figure 4 *c*).

Hertzberg stain followed by ninhydrin

When the Hertzberg stain was applied to latent fingerprints, only forged fingerprints were developed. Next, ninhydrin was applied to both real and forged fingerprints, and a significant colour difference was observed (Figure 4 *d*).

Silver nitrate followed by Hertzberg stain

Silver nitrate solution developed both real and forged fingerprints successfully. Subsequently, when the Hertzberg stain was applied, the colour change was observed in forged fingerprints, whereas the real fingerprints were completely destroyed (Figure 4 *e*).

Hertzberg stain followed by silver nitrate

When the Hertzberg stain was applied as a standalone method, only forged fingerprints were developed. Thereafter, when silver nitrate solution was sprayed on these fingerprints, the real fingerprints were also developed, and colour difference was observed between real and forged fingerprints (Figure 4 *f*).

Iodine fuming followed by Hertzberg stain

When iodine fuming was applied on real and forged fingerprints, both were developed. Subsequently, the Hertzberg stain was used on both the fingerprints and a colour difference was observed on the forged fingerprints (Figure 4 *g*).

Hertzberg stain followed by iodine fuming

As mentioned earlier, the Hertzberg stain developed only forged fingerprints. However, on subsequent application of iodine fuming, both real and forged fingerprints were developed with a colour difference (Figure 4 *h*).

The efficacy of the Hertzberg stain was analysed on non-porous (butter paper, chromogenic paper and floor tile) as well as porous (ordinary paper, wood and cloth piece) surfaces. On non-porous surfaces, a combination of ninhydrin and the Hertzberg stain showed efficacy compared to other combinations. A colour difference between real and forged fingerprints was observed in all the three non-porous surfaces considered in the present study (Figure 5). The forged fingerprints appeared darker and

Table 5. Distance (cm) between minutiae points of real and forged fingerprints

Minutiae points	Real fingerprint	Forged fingerprint
1–2	0.51	0.50
1–3	0.40	0.38
1–4	0.69	0.68
1–5	0.70	0.71
1–6	0.95	0.99
1–7	1.06	1.08
1–8	0.83	0.84
1–9	1.24	1.20
1–10	0.95	0.98
1–11	1.21	1.23
1–12	1.00	1.01
1–13	0.98	0.99
1–14	1.44	1.46
1–15	1.36	1.35
1–16	*1.23*	*1.17*
1–17	1.13	1.14
1–18	1.63	1.59
1–19	1.42	1.41
1–20	1.63	1.61
1–21	1.52	1.51
1–22	1.48	1.45
1–23	*1.37*	*1.32*
1–24	*1.60*	*1.55*
1–25	1.76	1.72
1–26	*1.68*	*1.63*
1–27	*1.62*	*1.57*
1–28	1.63	1.60
1–29	*1.88*	*1.83*
1–30	*1.78*	*1.73*
1–31	*1.95*	*1.87*
1–32	*1.97*	*1.90*
1–33	*1.85*	*1.80*

Italics indicates distance difference ≥ 0.05 cm.

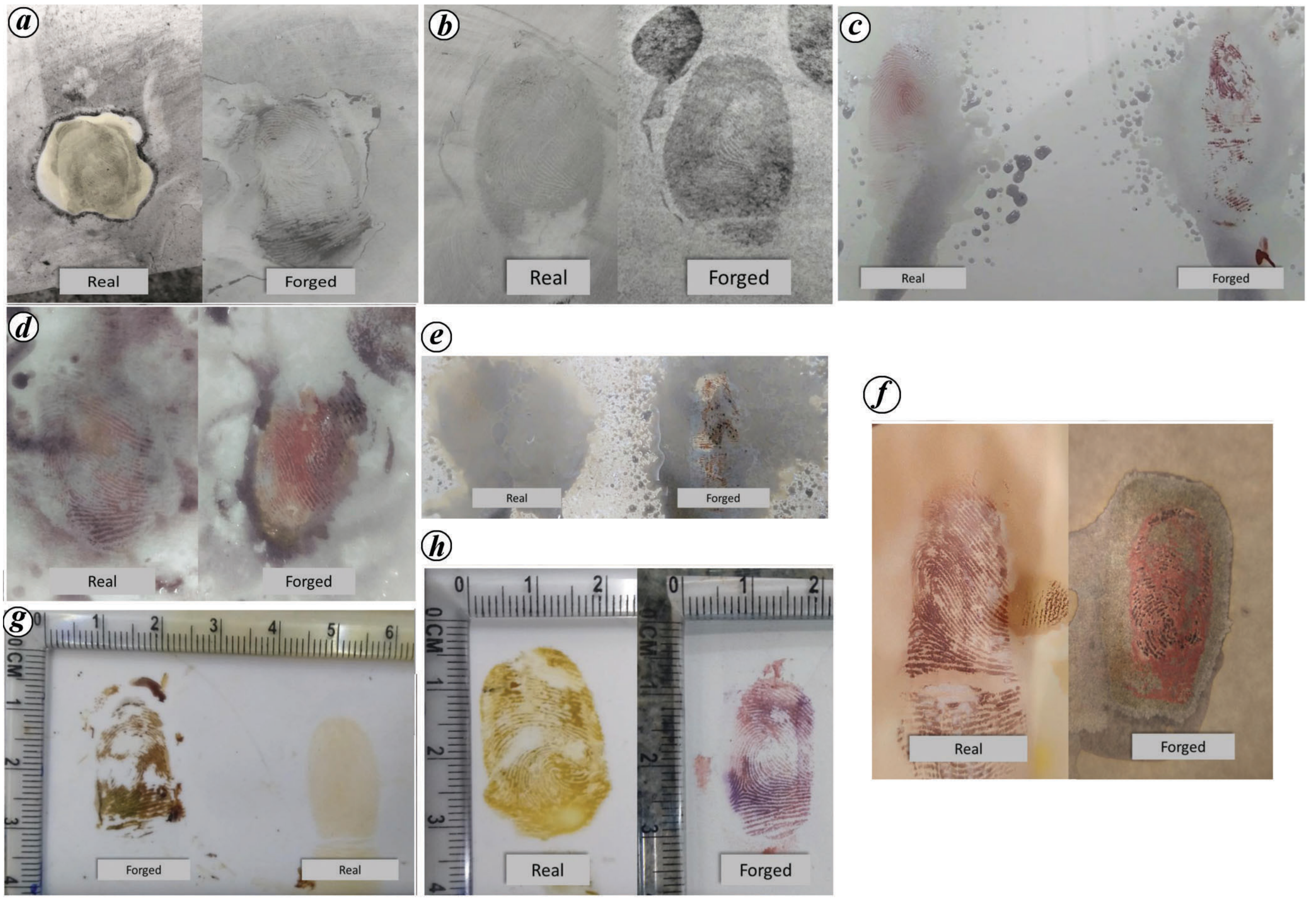

Figure 4. Fingerprint differentiation analysis: (***a***) powder method followed by Hertzberg stain, (***b***) Hertzberg stain followed by powder method, (***c***) ninhydrin followed by Hertzberg stain, (***d***) Hertzberg stain followed by ninhydrin, (***e***) silver nitrate followed by Hertzberg stain, (***f***) Hertzberg stain followed by silver nitrate, (***g***) iodine fuming followed by Hertzberg stain and (***h***) Hertzberg stain followed by iodine fuming.

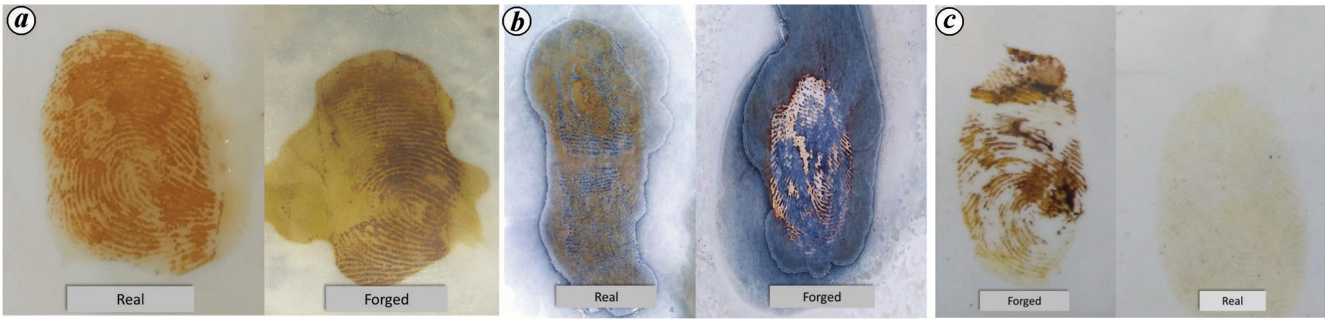

Figure 5. Analysis of real and forged fingerprints on (***a***) non-porous surface (butter paper) with ninhydrin followed by Hertzberg stain, (***b***) non-porous surface (chromogenic paper) with ninhydrin followed by Hertzberg stain and (***c***) non-porous surface (floor tile) with iodine fuming followed by Hertzberg stain.

brownish compared to the real fingerprints, facilitating colour-based differentiation.

The effectiveness of this technique was tested on porous surfaces. The results showed remarkable distinction in the case of ordinary paper (Figure 6 *a*), whereas only forged fingerprints were developed on wood (Figure 6 *b*). On cloth, both real and forged fingerprints were developed, but without any differentiation between them (Figure 6 *c*).

Discussion

Fingerprint forgeries are generally associated with document fudging, ID card duplication, legal contract forgery and crime scene manipulation. Forensic practitioners have detected many forgeries in the past based on intrinsic characteristics of latent fingerprints. However, some recent cases have brought out serious limitations of this approach,

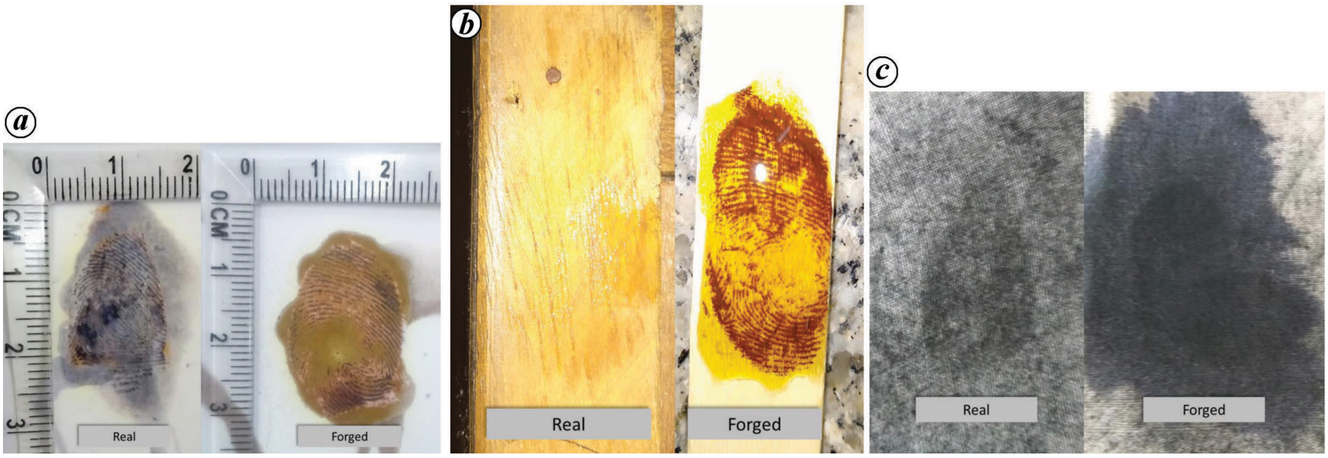

Figure 6. Analysis of real and forged fingerprints on (***a***) porous surface (ordinary paper) with ninhydrin followed by Hertzberg stain, (***b***) porous surface (wood) with ninhydrin followed by Hertzberg stain and (***c***) porous surface (cloth piece) with black powder followed by Hertzberg stain.

as the forgers have started using flexible material capable of incorporating intrinsic characteristics. If forged fingerprints are made using carefully chosen techniques, they cannot be differentiated from real fingerprints. In the present study, we have detected forged fingerprints and differentiated them from real fingerprints on porous and non-porous surfaces.

The conventional methods known to produce good results for developing fingerprints are generally ineffective in detecting fingerprint forgeries. In many cases conventional methods have failed to differentiate between forged and real fingerprints[4,15]. With the advanced modes used by forgers nowadays, traditional methods for differentiation based on features like background noise, presence of air bubbles, unexpected appearance of ridges, the overall shape of a fingerprint and absence of significant sweat pores have become almost irrelevant[4].

Using the software approach, two fingerprints are considered to match if they have 12 or more matching minutiae points[16,17]. This approach failed to differentiate between real and forged fingerprints as they had more than 15 matching minutiae points when developed with black powder and 33 matching minutiae points when developed with ninhydrin. These values are much higher than the critical limit set for differentiation. Inter-minutiae distance between two real and two forged fingerprints was calculated and compared using the software, thus providing its differentiation efficacy. A distance ≥0.05 cm was observed at two minutiae points of real fingerprints of the same origin, possibly due to natural variation, whereas it was observed at five minutiae points of two forged fingerprints of the same origin. While comparing real and forged fingerprints, a distance ≥0.05 cm was observed at ten points, whereas a distance <0.05 cm at 23 points was sufficient to give the matching report.

In this study, the Hertzberg stain technique was tested to detect and differentiate forged fingerprints based on fortified PVA. When used as a standalone technique, the Hertzberg stain and conventional methods have been successful in developing forged fingerprints. On the other hand, the Hertzberg stain failed to develop real fingerprints, unlike the conventional methods, which developed both real and forged fingerprints without differentiation.

The Hertzberg stain, when combined with the conventional methods like iodine fuming and ninhydrin, gave a clear distinction between real and forged fingerprints. The forged fingerprints appeared dark pink when developed in combination with ninhydrin. Forged fingerprints appeared dark brown when developed with a combination of the Hertzberg stain and iodine fuming. However, the Hertzberg stain did not differentiate between real and forged fingerprints when pre-treated with black powder, as the colour produced by the Hertzberg stain was dominated by the black colour of activated charcoal. When the fingerprints were treated with silver nitrate followed by the Hertzberg stain, they were completely destroyed. However, when the Hertzberg stain was applied prior to silver nitrate treatment, forged fingerprints appeared darker than the real ones.

In the case of porous surfaces, a combination of the Hertzberg stain and ninhydrin produced a marked colour difference only on ordinary paper. In the case of wood, only forged fingerprints were developed successfully, whereas for cloth, both real and forged fingerprints were developed but without differentiation, possibly due to the high porosity of cloth.

Conclusion

The present study aimed to develop a method to differentiate between real and forged fingerprints. The software approach tested in the present study did not provide satisfactory results for the differentiation of real and forged fingerprints, as the minutiae points analysis gave the number of matched points much higher than the critical limit set for differentiation. The chemical-based approach was tested by applying the Hertzberg stain on both real and forged fingerprints for their development and differentiation. It can be concluded that the Hertzberg stain is an effective approach for differentiating between real and forged fingerprints when combined with conventional methods. Among all the combinations considered in this study, ninhydrin and the Hertzberg stain produced the best results for differentiating forged from real fingerprints on non-porous surfaces.

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ACKNOWLEDGEMENT. We acknowledge financial support under DST-FIST Grant No. SR/FST/PS-I/2019/68 from the Government of India.

Received 31 August 2021; revised accepted 27 April 2022

doi: 10.18520/cs/v123/i2/160-168