ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

DIRECT PORE-BASED IDENTIFICATION FOR FINGERPRINT MATCHING PROCESS

Ph.D. THESIS

Vedat DELİCAN

Department of Applied Informatics

Information and Communication Engineering Programme

Thesis Advisor: Prof. Dr. Behçet Uğur TÖREYİN

SEPTEMBER 2023

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

PARMAK İZİ KİMLİKLENDİRME SÜRECİNDE POR TEMELLİ EŞLEŞTİRME SİSTEMİ

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Bilişim Uygulamaları Anabilim Dalı

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Date of Defense : 15 September 2023

To all martyrs, veterans and their families,

FOREWORD

First of all, I would like to express my deep gratitude to my supervisor Prof. Dr. Behçet Uğur TÖREYİN. His assistance and entire support in all the stages of the thesis and research help me to conclude this thesis.

I also acknowledge the members of my thesis jury for accepting this work for examination and thank them for their valuable comments and suggestions.

Finally, I would like to thank my family from my heart. The words cannot express my gratitude to them. I am very honored and happy that I am the son of Ayşe and Kemal DELİCAN Family.

September 2023

Vedat DELİCAN
(Officer-Major)

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ABBREVIATIONS

AFIS	**:** Automated Fingerprint Identification Systems
CVAT	**:** Computer Vision Annotation tool
FBI	**:** Federal Bureau of Investigation
FCN	: Fully Convolution Neural Network
ICP	: Iterative Closest Point
KCL	**:** Potassium Cloride
NaCL	**:** Sodium Chloride
PIA	**:** Projectina Image Acquisition
RUVIS	: The Reflected Ultra Violet Imaging System
SVD	: Singular Value Decomposition
US	: United States

SYMBOLS

dpi	: dots per inch
mm	**:** milimeter
nm	**:** nanometer
ppi	**:** pixels per inch

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DIRECT PORE-BASED IDENTIFICATION FOR FINGERPRINT MATCHING PROCESS

SUMMARY

Fingerprint, is considered one of the most crucial scientific tools in solving criminal cases. This biometric feature is composed of unique and distinctive patterns found on the fingertips of each individual. With advancing technology and progress in forensic sciences, fingerprint analysis plays a vital role in forensic investigations and the analysis of evidence at crime scenes. The fingerprint patterns of each individual start to develop in early stagesof life and never change thereafter. This fact makes fingerprints an exceptional means of identification. In criminal cases, fingerprint analysis is used to decipher traces, evidence, and clues at crime scenes. These analyses not only provide insights into how a crime was committed but also assist in identifying the culprits or individuals involved. Computer-based fingerprint identification systems yield faster and more accurate results compared to traditional methods, making fingerprint comparisons in large databases easier. These systems establish connections between fingerprints found at crime scenes and potential suspects' fingerprints, ensuring accurate results in forensic investigations.

Furthermore, fingerprint analysis is not limited to criminal identification. It also proves highly useful in situations like identifying missing persons or victims and locating individuals lost in disaster areas. Therefore, fingerprint analysis has become an indispensable tool for justice systems, security agencies, and related institutions.

Fingerprints are complex and unique characteristics that can uniquely identify individuals. This identification process typically consists of three levels, involving the features of ridge patterns, minutiae points, and pores. In the first level, the focus is on the ridge patterns present on the fingertips of each individual. Ridge patterns are raised areas on the fingertip surface and possess distinct shapes and flow directions for each person. These flow directions and shapes play a significant role in distinguishing one person's fingerprint from another's. In the second level, minutiae points are examined. Minutiae points are locations where ridge patterns intersect or bifurcate. These points can take various forms such as ridge endings, bifurcations, or ridge dots. Minutiae points are also utilized to determine the unique features of a fingerprint. The distinctiveness between two fingerprints often arises from differences in the types and positions of these points. The third level involves considering pores. Pores are tiny holes on the fingertip surface and have unique distributions in each fingerprint. The location and number of these holes are also used for fingerprint identification. These three levels constitute the fundamental components of fingerprint identification. This detailed examination and analysis demonstrate the high uniqueness of fingerprints and their effectiveness as a reliable biometric method for identity verification.

However, there are some limitations and challenges faced by fingerprint identification technology. One primary issue is the potential inability of imaging systems to capture fingerprints with sufficient clarity and detail. Such a process can complicate data collection for imaging systems and consequently hinder providing a complete and accurate representation of fingerprints. Secondly, the insufficient level of porosity details for the third-level identification limits the widespread use of this form of identification. These factors highlight the challenges faced by fingerprint recognition technology. It's essential to enhance the sensitivity of imaging systems to obtain clearer and more detailed images even under varying conditions.

Additionally, developing algorithms and data analysis methods to capture and process pore details more reliably is crucial. These solution-oriented approaches can unleash the potential of third-level identification, improving the reliability and widespread use of fingerprint recognition technology. Preserving pore-based fingerprint records in the unsolved cases database without subjecting them to any objective evaluation criteria underscores the importance of potential research in fingerprint analysis and identification. In this context, the presence of missing information in the said database emphasizes the inevitability of in-depth research in this field. Fingerprints captured in image records based on pores alone contain critical data reflecting individuals' unique biometric features.

However, storing this data without subjecting it to any assessment process is of great significance for developing new methods and optimizing current technologies in the field of fingerprint analysis and identification. This way, the existence of incomplete data in the database highlights the necessity for comprehensive research in this area. Such gaps pave the way for the emergence of novel approaches and techniques, thereby enhancing the accuracy, precision, and reliability of fingerprint analysis. In this context, systematic examination and analysis of image records based on pores in the database are crucial for the development and reinforcement of fingerprint-based identification systems. The scientific community can focus on creating new algorithms and methods using this missing data, taking steps toward improving the forensic investigation process and finding more effective solutions in the field of security. Preserving image records based on pores in the unsolved cases database without subjecting them to evaluation criteria is the cornerstone of progress in fingerprint analysis and identification. Careful examination of these records can contribute to the development of more reliable and effective security applications.

The research presented offers an innovative approach that goes beyond traditional fingerprint identification methods. In this study, an original dataset was created using a hyperspectral imaging system called "DocuCenter NIRVIS" and the "Projectina Image Acquisition-7000" software, where pores are more thoroughly examined compared to classical fingerprint identification methods. This dataset served as a foundation for a direct pore-based identification system developed for fingerprint matching. While traditional fingerprint identification methods generally rely on general skin surface characteristics, this research emphasizes the focus on pores using hyperspectral imaging. Hyperspectral imaging provides high-resolution images at different wavelengths, allowing for more detailed pore features to be captured. This enabled a more precise analysis of the unique pore patterns of each individual's fingerprint, leading to more reliable identification results. The DocuCenter NIRVIS device and the Projectina Image Acquisition-7000 software created a unique dataset

using this hyperspectral imaging approach. This dataset includes hyperspectral images of fingerprints from different individuals, capturing data that defines the unique features of each pore. This dataset forms the basis for the development and testing of a direct pore-based identification system for fingerprint matching.

The research presented offers a novel approach aiming to overcome the limitations of traditional fingerprint identification methods and provide a more accurate, precise, and reliable identification system. In this study, pores within the created dataset of 1050 fingerprint images were manually marked using the "Computer Vision Annotation Tool." This stage involves identifying and labeling each pore on each fingerprint. Manual marking was chosen to ensure the accurate and precise identification of pores. Following pore marking, an iterative nearest neighbor algorithm-based scoring system was applied. This algorithm identifies similar pore patterns by comparing different fingerprints within the dataset. This enables the matching of the pores contained in one fingerprint with similar pore patterns in other fingerprints. This step allows for the determination of the unique features of each pore and the comparison of various fingerprints. The scoring system evaluates the similar pore matches identified by the iterative nearest neighbor algorithm. A score is calculated for each match, indicating the degree of similarity between the pores. High-scoring matches are used to identify common pore patterns between different fingerprints. This stage is critical for making more precise matches between different fingerprints and identifying crime scene fingerprints.

The research ensures that manually marked pores are successfully analyzed using the iterative nearest neighbor algorithm-based scoring system. This approach not only results in more accurate fingerprint matching but also represents a crucial step in identifying crime scene fingerprints. According to the findings obtained, there is a direct correlation between the number of analyzed pores and the accuracy of marking. These results clearly demonstrate that more detailed and accurate marking of pores directly impacts the reliability and success of matches. The results indicate that increasing the number of analyzed pores and enhancing the accuracy of their marking led to a significant increase in match scores. In other words, more detailed and accurate identification of each pore on each fingerprint has improved the accuracy and reliability of fingerprint matching. These findings demonstrate that precise marking of pores improves the detection of similar patterns and enhances the accuracy of the matching algorithm, leading to more reliable results.Additionally, the query results indicate that the scores for subsequent ranked fingerprint images in the database are notably lower after matching fingerprints. This emphasizes the effectiveness and superiority of the proposed pore-based identification approach compared to other methods.

The results show that high scores are achieved for matching fingerprints, while the scores for subsequent fingerprint images in the database are notably lower. This observation highlights the effectiveness of the proposed pore-based approach in identifying and matching unique pore patterns more effectively than other methods. As the study highlights, the detailed analysis of pores and the accurate identification of similar pore patterns contribute to enhancing the accuracy and reliability of fingerprint identification. Therefore, the developed pore-based approach has the potential to yield more accurate, precise, and reliable results in fingerprint identification.

PARMAK İZİ KİMLİKLENDİRME SÜRECİNDE POR TEMELLİ EŞLEŞTİRME SİSTEMİ

ÖZET

Parmak izi, adli vakaların çözümünde en önemli bilimsel ispat araçlarından biri olarak kabul edilmektedir. Bu biyometrik özellik, her bireyin parmak uçlarında bulunan benzersiz ve tanımlayıcı desenlerden oluşmaktadır. Gelişen teknoloji ve adli bilimlerdeki ilerlemeler sayesinde, parmak izi analizi, adli soruşturmalarda ve suç mahallindeki delillerin analizinde hayati bir rol oynamaktadır.Her bireyin parmak izi desenleri yaşamın erken dönemlerinde gelişmeye başlar ve bir daha asla değişmemektedir. Bu durum, parmak izini olağanüstü bir kimliklendirme aracı haline getirmektedir.. Adli vakalarda parmak izi analizi, suç mahallindeki izleri, delilleri ve kanıtları çözümlemek için kullanılmaktadır. Bu analizler, suçun nasıl işlendiği konusunda ipuçları sağlamakla kalmaz, aynı zamanda suçlu veya suçluların kimliklerinin tespit edilmesine yardımcı olmaktadır. Bilgisayar tabanlı parmak izi kimliklendirme sistemleri, geleneksel yöntemlerden daha hızlı ve kesin sonuçlar elde etmekte ve büyük veri tabanlarında parmak izi karşılaştırmalarını kolaylaştırmaktadır. Bu sistemler, suç mahallinde bulunan parmak izi ile potansiyel şüphelilerin parmak izleri arasında bağlantılar kurar ve adli soruşturmalarda doğru sonuçlar elde etmeyi sağlamaktadır. Ayrıca, parmak izi analizi sadece suçlu tespitiyle sınırlı değildir. Kayıp kişilerin veya kurbanların kimlik tespiti, afet bölgelerinde kaybolanların bulunması gibi durumlarda da oldukça kullanışlı bir yöntem olarak karşımıza çıkmaktadır.. Bu nedenle, parmak izi analizi adalet sistemleri, güvenlik birimleri ve diğer ilgili kurumlar için vazgeçilmez bir araç haline gelmiştir.

Parmak izleri, bireylerin kimliklerini benzersiz bir şekilde tanımlayabilen karmaşık ve özgün özelliklerdir. Bu tanımlama süreci, genellikle üç aşamalı bir yapıya sahiptir ve bu aşamalar papil hatlarının özellikleri, minutiae noktaları ve porlar gibi detaylı özellikler üzerinden gerçekleşmektedir. Birinci seviyede, her bireyin parmak izinde bulunan papil hatlarına odaklanılmaktadır. Papil hatları, parmak yüzeyindeki kabartı ve çıkıntılardır ve her insanın parmak izinde farklı bir şekil ve akış yönüne sahiptir. Bu akış yönleri ve şekiller, bir kişinin parmak izini diğerlerinden ayırt etmede önemli bir rol oynamaktadır. İkinci seviyede, minutiae noktaları incelenir. Minutiae noktaları, papil hatlarının kesildiği veya birleştiği noktalardır. Bu noktalar, dönüş noktaları, bifurkasyonlar veya nokta sonları gibi farklı türlerde olabilir. Minutiae noktaları da, parmak izinin benzersiz özelliklerini belirlemek için kullanılmaktadır. İki parmak izi arasındaki benzersizlik genellikle bu noktaların türleri ve konumları arasındaki farklardan kaynaklanır. Üçüncü seviyede ise porlar dikkate alınmaktadır. Porlar, parmak yüzeyinde bulunan küçük deliklerdir ve her parmak izinde farklı bir dağılıma sahiptirler. Bu deliklerin konumu ve sayısı da parmak izini tanımlamak için kullanılır. Bu üç seviye, parmak izi tanımlamanın temel bileşenlerini oluşturur. Bu detaylı inceleme ve analiz, parmak izlerinin yüksek derecede benzersiz olduğunu ve bireylerin güvenilir kimlik tespitinde kullanılabilecek etkili bir biyometrik yöntem olduğunu göstermektedir.

Mevcut görüntüleme sistemlerinin parmak izi tespitinde yaşadığı bazı yetersizlikler ve por detaylarının istenilen seviyede olmaması, üçüncü seviye kimliklendirmenin yaygın kullanımını sınırlamaktadır. Bu faktörler, parmak izi tanıma teknolojisinin karşılaştığı zorluklara işaret etmektedir. Birincil sorunlardan biri, görüntüleme sistemlerinin parmak izlerini yeterince net ve detaylı bir şekilde yakalayamama ihtimalidir. Böyle bir süreç, görüntüleme sistemlerinin veri toplama sürecini zorlaştırabilir ve sonuç olarak parmak izinin tam ve doğru bir temsilini sağlamada zorluklar yaratabilmektedir. İkinci olarak, üçüncü seviye kimliklendirmenin temel dayanağı olan por detaylarının istenilen seviyede olmaması, kimliklendirme sisteminin güvenilirliğini etkileyebilmektedir.

Porlar, parmak izlerinde benzersiz özellikler sağlayan kritik noktalardır. Ancak, bazı durumlarda porların yeterince belirgin olmaması veya görüntüleme sistemlerinin bu noktaları doğru şekilde algılayamaması, tanıma doğruluğunu azaltabimektedir. Bu yetersizlikler, parmak izi tanıma teknolojisinin geliştirilmesi ve güvenilirliğinin artırılması gerekliliğini de vurgulamaktadır. Görüntüleme sistemlerinin daha hassas hale getirilmesi, farklı koşullarda bile daha net ve detaylı görüntülerin elde edilmesi için önemlidir. Aynı zamanda, por detaylarının daha güvenilir bir şekilde yakalanması ve işlenmesi için algoritmaların ve veri analiz yöntemlerinin geliştirilmesi öenm arz etmektedir. Bu çözüm odaklı yaklaşımlar sayesinde, üçüncü seviye kimliklendirme potansiyelini daha fazla gerçekleştirebilir ve parmak izi tanıma teknolojisinin güvenilirliği ve yaygın kullanılabilirliği artırılabilir. Faili meçhul veri tabanında yer alan porlara dayalı görüntülü parmak izi kayıtlarının herhangi bir objektif değerlendirme kriterine tabi tutulmadan sadece depolanması, parmak izi analizi ve kimliklendirme alanında yürütülecek potansiyel çalışmaların önemini açıkça ortaya koymaktadır. Bu bağlamda, söz konusu veri tabanındaki eksik bilgilerin varlığı, bu alandaki derinlemesine araştırmaların kaçınılmazlığını vurgulamaktadır.

Porlara dayalı görüntülü parmak izleri, bireylerin benzersiz biyometrik özelliklerini yansıtan kritik verileri içermektedir. Ancak bu verilerin sadece depolanarak herhangi bir değerlendirme sürecine tabi tutulmadan saklanması, bu alanda yeni yöntemlerin geliştirilmesi ve güncel teknolojilerin optimize edilmesi açısından oldukça önemlidir. Herhangi bir değerlendirmeye tabi tutulmayan por görüntüsü detayına sahip olay yeri parmak izi kayıtlarının veri tabanında yer alması, araştırmacıların parmak izi analizi konusundaki mevcut sınırlamaları ve zorlukları daha iyi anlamalarını sağlamaktadır. Bu eksiklikler, yeni yaklaşımların ve tekniklerin ortaya çıkmasına yol açarak parmak izi analizindeki doğruluk, kesinlik ve güvenilirliği artırma potansiyeli sunmaktadır.

Bu bağlamda, veri tabanındaki porlara dayalı görüntülü parmak izi kayıtlarının sistematik bir şekilde incelenmesi ve analiz edilmesi, parmak izi tabanlı kimliklendirme sistemlerinin geliştirilmesi ve güçlendirilmesi için kritik öneme sahiptir. Araştırmacılar, bu eksik verileri kullanarak yeni algoritmaların ve yöntemlerin oluşturulmasına odaklanarak, adli soruşturma süreçlerinin iyileştirilmesi ve güvenlik alanında daha etkin çözümlerin bulunması yolunda adımlar atabilir. Faili meçhul veri tabanındaki porlara dayalı görüntülü parmak izi kayıtlarının değerlendirme kriterlerine tabi tutulmadan korunması, parmak izi analizi ve kimliklendirme alanındaki ilerlemenin temel taşıdır. Bu kayıtların dikkatli bir şekilde incelenmesi, daha güvenilir ve etkili güvenlik uygulamalarının geliştirilmesine katkıda bulunabilir. Yapılan araştırma, geleneksel parmak izi kimliklendirme yöntemlerinin

ötesine geçerek, yenilikçi bir yaklaşım sunmaktadır. Bu çalışmada, klasik parmak izi kimliklendirme metotlarından farklı olarak porların daha ayrıntılı bir şekilde incelendiği hiperspektral bir görüntüleme sistemi olan "DocuCenter NIRVIS" cihazını ve "Projectina Image Acquisition-7000" yazılımını kullanarak özgün bir veri seti oluşturulmuştur. Bu veri seti, parmak izi eşleştirmesi için geliştirilen doğrudan por tabanlı bir kimliklendirme sistemi için temel oluşturmuştur.

Geleneksel parmak izi kimliklendirme yöntemleri genellikle deri yüzeyinin genel özelliklerini kullanarak çalışırken, bu araştırma hiperspektral görüntüleme ile porlara odaklanmaktadır. Hiperspektral görüntüleme, farklı dalga boylarında yüksek çözünürlüklü görüntüler elde ederek, porların daha ayrıntılı özelliklerini yakalayabilmektedir. Bu sayede, her bireyin parmak izindeki benzersiz por desenleri daha hassas bir şekilde analiz edilmiş ve kimliklendirme için daha güvenilir sonuçlar elde edilebilmiştir. DocuCenter NIRVIS cihazı ve Projectina Image Acquisition-7000 yazılımı, bu hiperspektral görüntüleme yaklaşımını kullanarak özel bir veri seti oluşturmuştur. Bu veri seti, farklı bireylerin parmak izlerinin hiperspektral görüntülerini içermekte ve her bir porun benzersiz özelliklerini yakalayan verileri içermektedir. Bu veri seti, por tabanlı kimliklendirme sisteminin geliştirilmesi ve test edilmesi için bir temel sağlamaktadır.

Yapılan araştırma geleneksel parmak izi tanıma yöntemlerinin sınırlamalarını aşmak ve daha güvenilir, doğru ve hassas bir kimliklendirme sistemini sağlamak amacıyla yeni bir yaklaşım sunmaktadır. Bu çalışma kapsamında, oluşturulan 1050 parmak izi veri setinde yer alan porlar, "Computer Vision Annotation Tool" adlı bir program aracılığıyla manuel olarak işaretlenmiştir. Bu aşama, her parmak izinin üzerinde bulunan porların belirlenmesini ve tanımlanmasını içermektedir. Manuel işaretlemenin kullanılması, porların hassas ve doğru bir şekilde belirlenmesini sağlamak amacıyla tercih edilmiştir. Porların işaretlenmesi aşamasının ardından, bir sonraki adımda iteratif en yakın nokta algoritması temelli bir puanlama sistemi uygulanmıştır. Bu algoritma, veri setindeki farklı parmak izlerini karşılaştırarak benzer por desenlerini tespit etmektedir. Bu sayede, bir parmak izinin içerdiği porların diğer parmak izlerindeki benzer por desenleriyle eşleştirilmesi sağlanmıştır. Bu adım, her bir porun benzersiz özelliklerinin belirlenmesini ve farklı parmak izleri arasında karşılaştırmalar yapılmasını sağlamaktadır.

Puanlama sistemi, iteratif en yakın nokta algoritması tarafından bulunan benzer por eşleştirmelerini değerlendirmiştir. Her bir eşleştirme için bir puan hesaplanmış olup bu puan porların ne kadar benzer olduğunu göstermektedir. Yüksek puan alan eşleştirmeler, farklı parmak izleri arasındaki ortak por desenlerini belirlemek için kullanılmıştır. Bu aşama, parmak izleri arasında daha kesin eşleştirmelerin yapıldığı ve olay yerindeki parmak izlerinin tespit edildiği kritik bir aşamadır. Çalışma manuel olarak işaretlenen porların, iteratif en yakın nokta algoritmasına dayalı puanlama sistemi kullanılarak başarılı bir şekilde analiz edilmesini sağlamaktadır. Bu yaklaşım, parmak izi eşleştirmesinde daha doğru sonuçların elde edilmesine olanak tanırken, olay yeri parmak izlerinin belirlenmesinde de önemli bir adımı temsil etmektedir.

Yapılan analizler sonucunda elde edilen bulgular, incelenen gözeneklerin miktarı ile işaretlemenin kesinliği arasında doğrudan bir korelasyon olduğunu açıkça ortaya koymuştur. Bu bulgular, parmak izi verilerinin daha etkili bir şekilde işaretlenmesinin, sonuçların güvenilirliği ve eşleşme başarısını doğrudan etkilediğini göstermektedir.

Elde edilen sonuçlara göre, incelenen por sayısının artması ve bu porların daha hassas bir şekilde işaretlenmesi, eşleşme puanlarında dikkate değer bir artışla sonuçlanmıştır. Yani, her bir parmak izindeki porların daha detaylı ve kesin bir şekilde belirlenmesi, parmak izi eşleştirmesinin doğruluğunu ve güvenilirliğini artırmıştır. Bu bulgular, porların belirgin bir şekilde işaretlenmesinin, iteratif en yakın nokta algoritmasına dayalı puanlama sistemi tarafından kullanıldığında, parmak izleri arasındaki benzerliklerin daha doğru bir şekilde tespit edilmesini sağladığını göstermektedir.

Porların daha iyi işaretlenmesi, bu eşleşme puanlarının yükselmesine neden olmuş ve algoritma daha güvenilir verilere dayalı olarak daha kesin eşleşmeleri belirleyebilmiştir. Bu bağlamda, çalışmanın temel sonuçları incelenen por sayısının artırılması ve por işaretlemelerinin hassasiyetinin artırılmasıyla parmak izi eşleştirme sisteminin başarısının arttığını göstermektedir. Aynı zamanda, yapılan sorgulama sonuçları, eşleşen parmak izlerinin ardından gelen veri tabanındaki diğer sıralı parmak izlerinin puanlarının belirgin bir şekilde daha düşük olduğunu açıkça göstermektedir. Bu durum, önerilen por tabanlı kimliklendirme yaklaşımının etkinliğini ve diğer yöntemlere kıyasla üstünlüğünü vurgulamaktadır.

Elde edilen sonuçlara göre, eşleşen parmak izleri için yüksek puanlar elde edilirken, sonrasında gelen diğer parmak izleri için puanların belirgin bir şekilde düşük olduğu görülmüştür. Bu durum, önerilen por tabanlı yaklaşımın, benzersiz por desenlerini daha etkili bir şekilde kimliklendirme ve eşleştirme yeteneğini yansıtmaktadır. Bu sonuçlar, çalışmanın geleneksel parmak izi kimliklendirme yöntemlerindeki eksiklikleri ele aldığını ve bu eksiklikleri gidermek için yeni bir yaklaşım sunduğunu göstermektedir. Özellikle gelişmiş hiperspektral görüntüleme teknolojisinin kullanılması, porların daha net ve ayrıntılı bir şekilde işaretlenmesini mümkün kılarak, parmak izi eşleştirmesinde daha yüksek bir doğruluk elde etmede önemli bir rol oynamaktadır. Çalışmanın vurguladığı gibi, porların ayrıntılı analizi ve benzer por desenlerinin doğru bir şekilde tespiti, parmak izi kimliklendirmesinin güvenilirliğini artırabilir. Bu nedenle, geliştirilen por tabanlı yaklaşımın, parmak izi kimliklendirme alanında daha doğru, hassas ve güvenilir sonuçlar elde etme potansiyelini ortaya koyduğunu söyleyebiliriz.

1. INTRODUCTION

Fingerprint, which is one of the instrument of scientific proof in solving forensic events, play a very important role in revealing criminals. The identity of the suspect person is determined through the analysis, comparison, evaluation, and verification processes related to the fingerprint [1]. With the increasing security issues, automatic fingerprint recognition systems are widely used in crime prevention and detecting criminals [2,3].

Fingerprint identification based on features such as minutiae, pores, and papilla unit thickness, which are the line characteristics extracted from fingerprints. These features are defined at three levels.

In the first level identification, a classification is made in which macro features related to line characteristics are evaluated. In this level, the central region, delta, flow direction, number of lines and pattern type of the fingerprint are examined [4,5]. In the second level identification, an evaluation is made according to the relative position and sequences of the line characteristics. Most of the automatic fingerprint recognition systems are based on second-level features since they are stable and distinctive [6,7]. In the third level identification, small, shaped details on the papilla line, papilla unit thickness, thinness, edge contours, small, shaped details such as wrinkles and scars and the positions of the pores formed by the sweat duct mouths are evaluated relative to each other [8,9].

When the pores are examined within the scope of the third level identification, it has been revealed that the pores have different shapes and can be single, double or groups in the form of chains. It has been evaluated that the pore sizes may vary from small to large and may be located in the center or around the papillary line [10]. The pores are located on the papillary line in two ways according to their location. Those with clear borders and located in the middle of the papilla line are called closed pores, while those with no borders located facing the gap between two papillae are called open pores [11].

From the past to the present, the analysis of second-level features has adequately met the need for identification in determining the identity of an individual. The satisfactory level of identification has enabled many academic studies on the automatic fingerprint identification system to focus on second-level features [12]. In fact, the concept of poroscopy has appeared in many publications in the forensic science literature that it may be involved in the identification process. However, these studies could not be put forward as a basis for the courts [13,14].

Currently, pores are still not being used effectively in the fingerprint identification process. Rather, fingerprint identification systems using second-level features are widely used [15]. As a result of the progress in biometric tools with technological developments, the use of third-level details in automatic fingerprint identification systems has revealed the importance of third-level details in cases where second-level features are not sufficient [16]. It has been emphasized that it is an important requirement to use third-level features to make more precise and strength identification in order to meet high-level security needs [17,18].

Ashbaugh defined the concept of Poroscopy as third-level features around the phenomenon of identification, where quality and quantity depend on several factors [19]. The main reason underlying the limited use of pores is that the images of the third level details cannot be obtained at a sufficient level due to the spatial resolution of live scan devices being much lower than 800 dpi [20]. Third-level identification has become more applicable after it has been developed as an optical resolution (≥1000 dpi) for live fingerprint devices [21]. In parallel with the technological development of optical resolution, with the development of pore-based imaging systems, pores contribute more to the effectiveness of fingerprint identification systems [22,23]. In addition to these developments, the number of pores and third-level details are considerably higher compared to the number of minutiae makes the analysis results more successful [24,25].

Fingerprint identification systems currently in use may not always be sufficient for identification [26-28]. This situation causes the number of latent fingerprints in the database to increase day by day. This situation leads to the need to include pore characteristics at different decision-making levels related to fingerprint in decision-making processes [28-30].

Although the presence of at least twelve characteristics in the second level identification does not seem to leave any room for doubt in the decision-making process, a third level identification will make the positive opinion tendencies of the experts stronger by using more details and using up to thousands of pore points [30,31].

Another important factor affecting the effective use of pores in decision-making processes and identification is the ability to detect qualified fingerprints from the crime scene. In the digital age we live in, it is an undeniable fact to examine and evaluate fingerprints with advanced technical analysis, by detecting more qualified fingerprints with more advanced imaging techniques.

New fingerprint detection and imaging technologies are constantly being developed according to the needs of the field. Unlike traditional optical fingerprint detection systems, fingerprint detection surfaces are scanned by using light sources of different wavelengths (e.g., 460 nm (blue), 530 nm (green) and 650 nm (red)). Here, the surface area where the fingerprint is detected causes scattering and absorption movements depending on the wavelength of the light source. Ultimately, hyperspectral imaging technology is considered to provide better quality fingerprint detection compared to conventional optical sensors [32].

Today, where more precise evidence is needed to clarify the crime, this study detects fingerprints with hyperspectral imaging, which enables more qualified fingerprint detection. It is aimed to present a scoring system based on pore-based matching, using the Iterative Closest Point algorithm, which is based on third-level identification.

1.1 Subject and Importance

Fingerprints appear as one of the most common evidence at crime scenes in solving forensic incidents. Fingerprints are one of the most important means of scientific proof used by the investigating authorities on the way from the evidence to the accused. The elements that make fingerprints an indispensable identification method are that they are immutable - unchangeable, unique - incomparable and classifiable.

There are some linear lines between the first knuckle of the finger and the base of the nail. These lines differ from person to person. These lines are not constantly in the form of a set, but consist of restarts and terminations, including grooves. The lines formed by the sets are called papillary lines. Fingerprint is the trace formed on the surface of the object as a result of the contact of the papilla lines between the nail tip and the first node of the finger with any object.

Identification with fingerprints, which is one of the main examination areas of the field of forensic sciences, is performed at three levels. In the first level, the fingerprint group is classified as arces, loops and whorls, depending on the flow direction of the papillary lines, and there are not enough features for individual identification at this level.

Second-level identification is based on comparing the number and order of papillae on the fingerprint and some characteristic features (enclosure, bifurcation, point/dot, etc.). Papil characteristics such as bridge, bifurcation, short ridge, spur/hook, enclosure, ending ridge, trifurcation, break, overlap, crossbar and dock play a distinctive role depending on their different shapes and arrangements, enabling fingerprint detection. The third level includes the evaluation of small shaped details on the papillary line, papillary unit thickness, thinness, and the relative positions of the pores formed by the sweat duct mouths. Third-level details can be used with second-level features.

In many countries, the first level and the second level of these three levels are widely used in fingerprint identification. Third level identification is not yet widely used and can be used to strengthen positive and negative opinions in one-to-one matching identification. The inadequacy of the existing imaging systems in fingerprint detection and the lack of widespread use of the technologies being developed in this field and

the fact that the databases within the AFIS do not have fingerprints with a poroscopic image limit the widespread use of third-level identification.

With the work to be done, an integrated software that can work in a hybrid way with the existing AFIS systems by making use of the third level features will be developed, and it will contribute positively to the decision processes in the detection of the owner of many crime scene traces with poroscopic images, which are currently in the unsolved database. In addition, with the assumption that crime scene investigators can benefit from the third level features during a crime scene investigation, it will be a necessity to make more qualified crime scene fingerprint detection by taking into account that the fingerprints that can be detected at the crime scene, the locations of the pores will be used for identification.

The fact that the traces with poroscopic images in the AFIS databases with an unknown identity are not subjected to any evaluation criteria and continue to remain in the database with an unknown identity reveals the importance of the study. At the same time, it will not only affect the decision processes in the evaluation of fingerprints whose owner is unknown, but also help fingerprint experts in the decision processes of identification processes, which are second-level identification and used in many countries, in the positive inclusion and negative exclusion of a fingerprint at the point of detection.

1.2 Literature Review

Kaushik and Singh in their rsearch is evaluated that fingerprints contain very few second-level features and are not sufficient for proving identification due to partial or complete deterioration or contamination on them. It is stated that if the papillary line characteristics are insufficient, third level features with pore characteristics can be used for identification. It has been revealed that the shape of the pores, which are the sweat channels, their position relative to each other and their size are considered as one of the best identification methods for identifying individuals [33].

It has been revealed by Locard that the pores on the fingerprint have different properties such as their position relative to each other, shape, size, spacing and

frequency. It has been proven that the pores are unique and remain the same for life, and it has been discussed that identification can be made with the presence of an average of 40 or more pores, especially in cases where the fingerprint papillary characteristics are not sufficient for second level identification. Regarding the frequency of the pores in the fingerprint, it was evaluated that the unit set length and the average number of pores per unit area correspond to the pore frequency. It has been determined that the pores have different sizes and the sizes of the pores located on the same set and close to each other are different from each other. In addition to this view, it has been evaluated that the largest pore size on a fingerprint may be three to nine times the average pore size in the same fingerprint. It has been revealed that the pores can also be in different shapes such as rhombus, oval, elliptical [34].

Preethi et al. conducted a study on gender determination and personal identification, based on the frequency, size and pore structure of the pores in the fingerprint. In their studies, the pores on the flat-pressed thumb prints of a total of 200 people, 100 women and 100 men, in the 18-60 age range from the South Indian population, were used. As a result of the study, it was observed that the number of pores per unit area, that is, the frequency, is higher in women than in men, and that the frequency of pores can be used in determining gender, but the size and shape of the pores are insufficient and useless in determining gender [35].

Oklevski et al. made some assessments on the problems and difficulties associated with poroscopy in fingerprint identification. It is stated that the use of poroscopy, due to its microscopic structure and time-consuming work for scientists and experts, has decreased the interest in this field at the point of necessity to conduct detailed studies on pores. In the study, four different situations that are thought to affect the poroscopic examinations containing the third level features were examined and some findings were tried to be obtained. First of all, as a result of the application of ink, which is a physical fingerprint developer, with fingerprint scanners, the quality and quantity of the pores were evaluated. It has been observed that the quality and quantity of pores are at a better level in live scanned fingerprints. Secondly, the level of consistency regarding the presence of pores was evaluated when fingerprints were taken from the same finger at one-hour intervals for eight hours, and it was evaluated that the pores in the fingerprints taken with a live scanner were consistently present, except for the

fingerprints taken with ink. Thirdly, as a result of the applications made on different surfaces, the effect of surface difference on the presentation of the pores was investigated and no difference was detected. Finally, it has been revealed that there is a change in the presentation of the pores as a result of the studies on the extent to which the chemical methods used in the detection of fingerprints such as cyanoacrylate and ninhydrin affect the presentation of the pores. It has been evaluated that all these studies will make an important contribution to the role of poroscopy in the search and identification of a personal fingerprint [36].

The study by Alexandre Anthonioz and Christophe Champod proposes to include the strength of pore-related findings in assessments of identification when there is a hesitation between the offending fingerprint and the reference fingerprints in a fingerprint identification research. An algorithm was designed to automatically detect pore characteristics on papillary lines and a metric was defined to compare different fingerprints. The weight of the findings obtained in this metric is measured using a likelihood ratio. It has been evaluated that the obtained results and the second-level features of the pore characteristics and the statistical results in a holistic way contribute significantly to fingerprint research. At the same time, the study aimed to bring transparency to fingerprint research and evaluation processes. With the results obtained, it has been seen that the pore characteristics have a better discrimination ability than a papillary characteristic [37].

Anil Jain et al. state that the fingerprint resolution standard taken by the FBI (Federal Bureau of Investigation) is 500ppi and it is insufficient to display the third level pore characteristics. With the developments in fingerprint detection technology, it has been revealed that many fingerprint scanners are equipped with better sensor technology and high resolution scanning feature. However, it has been evaluated that increasing the scanning resolution alone will not perform well in fingerprint identification unless a third level extended feature set is used. For this reason, it is aimed to conduct a systematic study in AFIS, which will also evaluate the third level pore characteristics and provide a good performance gain. A hierarchical matching system is proposed using the third-level features obtained by scanning fingerprints at 1000 ppi quality. By providing automatic coding using the third level features Gabor filters and wavelet transform, it was desired to match location-based fingerprints with the ICP algorithm.

Studies have revealed that third-level features carry important discrimination information in identification [4].

A.Gupta et al. conducted a study on the reproducibility of third-level pore characteristics of fingerprints in personal identification. Cyanoacrylate and ninhydrin fingerprint development methods, which are chemical developers of latent fingerprints, were applied. The pore characteristic areas were measured by photomicrography using appropriate software tools. The obtained data were analyzed statistically and they revealed that the pore area in the developed invisible fingerprints is not reproducible. As a result, they have come to the conclusion that there is a lack of reliability of pores fields in individual identification [38].

Min-jae Kim et al. pointed out that although automatic fingerprint identification systems based on minutia features are used in second-level identification in their studies, there is very little research that uses pore characteristics to match fingerprints. Recently, they stated that the presence of high-resolution optical sensors has increased the interest in this field. In this context, the study offers a pore matching algorithm that eliminates papillary characteristic-line information and fingerprint-device dependency that limits identification applications. In this study, a new pore matching method using optimum geometric transformation and a two-part graph-based approach is presented. It has also been suggested that the proposed method can be used together with traditional minutiae-based methods to improve the performance of AFIS. They stated that they hope to design a robust pore extraction method based on machine learning algorithm in the future [39].

The study by Marcus de Assis Angeloni and Aparecido Nilceu Marana presents a fingerprint recognition system based on two types of third-level fingerprint papillary lines and pore pores. They wanted to extend a back-based fingerprint recognition method based on the Hough Transform, which was previously proposed in the literature and used as a starting point, to include sweat pore information in the matching step[40]. In the study by Feng Liua et al., they adopted the sweat pores on the fingerprint to create a high-resolution automatic fingerprint recognition system. It has been stated that pore matching is an important step in high-resolution fingerprint recognition. The article proposes a new pore matching method with high recognition

accuracy. In the study, two datasets containing high resolution (~1200 dpi) fingerprint images containing 4,480 fingerprints from 148 different fingers were used. Unlike other direct pore matching methods, a more effective method for matching each pore, called DeepPoreID, is proposed [41].

Nancy Singlaa et al. accepted latent fingerprints as key evidence in crime scene investigations. Since these fingerprints cannot be seen directly with the naked eye, they are developed and visualized using powder and chemical methods. However, these methods can damage fingerprints if not applied properly. For this reason, the actions taken are very important in terms of protecting the evidential value of fingerprints and identifying the suspect. In today's technologies, optical contactless tools are becoming widespread in the development and visualization of latent fingerprints. The Reflected Ultra Violet Imaging System (RUVIS) is one of the optical contactless devices mentioned. In the literature, it is mentioned that there is no database of latent fingerprints created by the use of optical contactless technologies. In this study, fingerprint database is created by using optical contactless fingerprint acquisition device. It has been observed that the extraction of third-level features of latent fingerprints plays an important role in matching crime scene print with plain print fingerprints. In addition, the invisible fingerprints detected by the use of optical devices, especially the pore characteristics and third level features were extracted with the Fully Convolution Neural Network (FCN) [42].

Qijun Zhao and Anil K. Jain studied ink rolled and plain fingerprints by utilizing pore characteristics. Although many previous studies are known to contribute to minutiae-based comparison solutions in terms of accuracy, it has been revealed that they have limitations on two issues; The first is the use of a high-resolution (>1000 ppi) live fingerprint scanner, and the other is considered to be not yet commercially used with minutiae-based comparison programs. In this study based on inked rolled and plain fingerprints, which is widely used in the field of forensic sciences. In the experiments, fingerprint images were used in three different quality and two different resolutions (500 ppi and 1000 ppi). It has been understood that the effect of fingerprint image quality on automatic pore coding and pore activity improves fingerprint recognition accuracy. In future studies, it is aimed to improve automatic pore coding performance and comparison processes based on pore and minutiae [43].

1.3 Purpose of Thesis

In identification by means of fingerprints, the second level papillary characteristics may not always be sufficient for identification after the limited morphological evaluation made by evaluating the flow direction of the trace at the first level, respectively. In this case, it creates the need to include the pore characteristics, which include the third-level features at different decision-making levels related to the fingerprint, into the decision processes.

Based on Locard's tripartite principle, we can list these decision-making levels as follows;

If the number of Minutiae is > 12;

Assuming that the line characteristics obtained in the second level identification are above 12 features, the third level identification studies made by using the pore characteristics will positively support the decision making process. Thus, positive results will be strengthened. Although at least 12 characteristic features in second-level identification based on the Locard principle seem to leave no room for doubt in the decision-making process, further details will be included with a third-level identification to be made in terms of pore characteristics. By using thousands of pore points, it will strengthen the positive opinion tendencies of the experts by supporting the decisions to be made regarding identification.

If the number of Minutiae is 8-12;

In accordance with the Locard principle (Locard tripartite rule), if there are 8-12 minutiae in the identification made on the fingerprints, if the fingerprint of the crime is the same as the fingerprint subject to comparison as a result of the evaluation of the fingerprints, or if it is evaluated that there may be a similar fingerprint among the candidates who are considered to be identical from the AFIS database. Even if there is a comparison with a fingerprint, it is obvious that the fingerprint, which is considered to be a match, is considered as weak evidence before the prosecutor's office or the court. However, in these cases, fingerprints, which are evaluated in detail together with the pore characteristics, may be strong evidence.

If the number of Minutiae is < 8;

In the presence of 8 or less papillary characteristics, contrary to the positive opinion in the first case, the negative opinion tendencies of the experts are strengthened by the identification made with pore characteristics. If we give an example of this situation; when we reveal that the fingerprint specialist is faced with a scenario where the seven characteristic features that come from the candidates from the database and are considered to be identical, have the same characteristics as the compared fingerprint, but one papilla characteristic is incompatible. In this case, the expert will be faced with the situation of not being able to make a clear decision between the fingerprint of the crime and the comparison fingerprint [44].

In such a case, the expert must give a negative opinion that there is no identical fingerprint in the identification made. Considering the seven papillary characteristics that are generally compatible, the presence of one or two incompatible papillae characteristics, when supported by the pore characteristics in the third level identification, will strengthen the negative opinion of the fingerprint specialist and remove all doubts in her mind.

As a result; While pore characteristics support the opinions positively in the presence of papillary characteristics above 12, they will contribute negatively in the presence of papillary characteristics below 8, and in the presence of 8-12 papillary characteristics, fingerprints will be a strong proof tool.

Basically, it is desired to introduce a pore characteristic-based scoring system that will be based on third-level identification applicable to fingerprint identification standards used in different countries, apart from the three cases where we have taken Locard's tripartite rule as basis. In the study to be carried out, a scoring system based on pore characteristics will be introduced, in addition to scoring based on second-level features, both one-to-one (in the identification made by comparing the fingerprint seized from the crime scene and the roled and plain ten fingerprints of the suspect or the victim) and among the candidates who are considered to be spouses from the AFIS database. It is aimed to increase the success rate in finding identical fingerprints.

2. TERMS AND CONCEPTS RELATED TO FINGERPRINTS

2.1 Definition and Structure of Fingerprints

There are linear lines in the area between the nail base and the first knuckle of the finger. These linear lines differ in each person. These lines are not always in the form of a set, but consist of beginnings and endings, in which there are grooves and certain characteristic shapes appear. Linear lines that form the set image are called papillary lines.

"Fingerprint Sourcebook" prepared by the US Department of Justice, National Institute of Justice; "Each individual has distinctive, distinctive marks on the fingers, palms and soles of the feet. And it defines such traces from the last knuckle of the fingers to the fingertips as fingerprints. To put it more clearly, "Fingerprint is the trace formed by the contact of an object with the surface area of the papillae between the nail tip and the first knuckle of the finger [45].

With the hyperspectral imaging system, the features on the papillary between the first knuckle of the finger and the nail can be seen in (Figure 2.1).

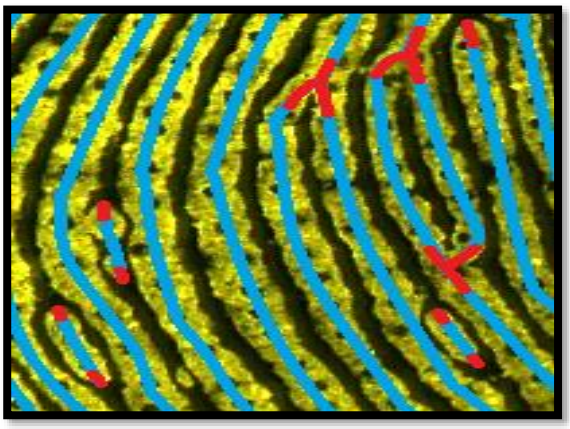


Figure 2.1: Features on the Papillaries

Fingerprint residue consists of 98.5% water, 0.5-1.5% of the remaining amount of urea, volatile fatty acids, butyric acid, urea, etc. organic substances, inorganic substances such as NacL and KCL, and a small amount of albumin [46].

Fingerprints are personal biometric data that begin to form in the mother's womb from the 10th week and become absolute and unchanged by the 24th week. Fingerprints have started to be used in the field of identification and detection of crimes, thanks to their immutability, dissimilarity and classifiable features [47].

The secretions in the fingerprint residue are secreted by three main glands.

Eccrine glands: They are glands in the fingers, palms and soles that produce organic and inorganic secretions.

Apocrine glands: These are the glands that are the source of body odor and located in various parts of the body such as the groin and armpits.

Sebaceous glands: These are glands located in the chest, head and back region and contain organic components such as oily substances [48].

Due to its greater secretion in the hand and foot region, more eccrine secretion is involved in the structure of the fingerprint residue. Also, depending on the fact that we are in constant contact with certain parts of our head during the performance of our daily activities, it is possible to have sebaceous secretion as well as eccrine secretion in the structure of the fingerprint residue. Although it is not possible to encounter the apocrine secretion in the structure of the fingerprint residue, it is possible to contaminate other secretions during the execution of some types of crimes such as sexual crimes.

Eccrine, apocrine and sebaceous glands vary from person to person in terms of quality and quantity. Depending on the components in the fingerprint residue structure, the trace development technique to be used in the development of the fingerprint is directly related to the type of surface and the reaction of the chemicals with the materials in the residue structure. After the fingerprint residue is left on the surface, some structural changes may occur in the content of the original outbreak, depending on exposure to external environmental factors such as temperature and humidity. In addition, the surface on which the fingerprint is left plays a major role in the changes that may occur in the structure of the secretion. The temperature, structure of the surface and whether there is an electrostatic attraction or not are the factors that directly cause this change [49].

2.2 Features of Fingerprints

Fingerprints appear as one of the most common evidence at crime scenes in solving forensic incidents. Fingerprints on the way from evidence to the accused are one of the most valid means of scientific proof used by the investigative authorities. The fact that fingerprints are unique to the person, their ability to be classified and the fact that they give a near-conclusive result in detecting the criminal are the most important elements in making them a scientific proof tool [50].

It has three important features that make fingerprints an indispensable identification method. These properties are immutable – unchangeable, dissimilar – inimitable and classifiable. When evaluated in terms of the number, shape and location of the minutiae formed by the fingerprint papillary characteristics, the probability of two fingerprints being the same in the world has been put forward as 1/64,000,000,000 (one in sixty-four billion) [51].

2.2.1 Immutable and unchangeable property

Fingerprints begin to form in the fetal maternal blood at the age of three months, and in the following periods, apart from the changes in the inter-papillary distance and papillary thickness, they preserve their original structure due to their characteristic features for life. The deterioration of fingerprints is not possible only with a level of destruction that will affect the dermal papilla on the skin. However, if there is a level of destruction on the skin that will affect the dermal papilla and it is 1-2 mm deep, it may cause a permanent or temporary scar tissue on the fingerprint.

Fingerprints taken from the German Anthropologist Welker by Giessen in 1856, are the oldest known traces of fingertip lines. He identified his fingerprints at the age of 34 and determined that there was a one-to-one similarity with the prints he took when he was 75 years old, and he put forward the idea that the fingerprints would not change over time. Galton, one of the pioneers of dactyloscopy, determined that these traces remained unchanged even 5000 years after death, in the examinations he made on the parchmented skin of mummies. Herschel, the founder of modern dactyloscopy, also took his own fingerprints, and as a result of the thinning and comparison he made after 28 years, he did not find any different points different from his old traces [52].

2.2.2 Unique and incomparable property

Considering that a fingerprint of a person has 80 to 120 papillae characteristics on average in the pattern region, and the same number of features can be found in the same sequence in another person's fingerprint, and it is assumed that these people are suspects at the same crime scene, how important is the fingerprint in the identification and diagnosis of a person and appears to play a distinctive role [53]. Based on this example, it is understood that fingerprints are an important means of proof and an important piece of legal evidence in clarifying a crime or catching a criminal based on the assumption that any two fingerprints are different from each other.

Some images of the minutiae, called the feature on the fingerprint, are as follows;

Bifurcation: It is the papilla characteristic that occurs when the papilla line continues to divide into two branches and continue parallel to each other (Figure 2.2).

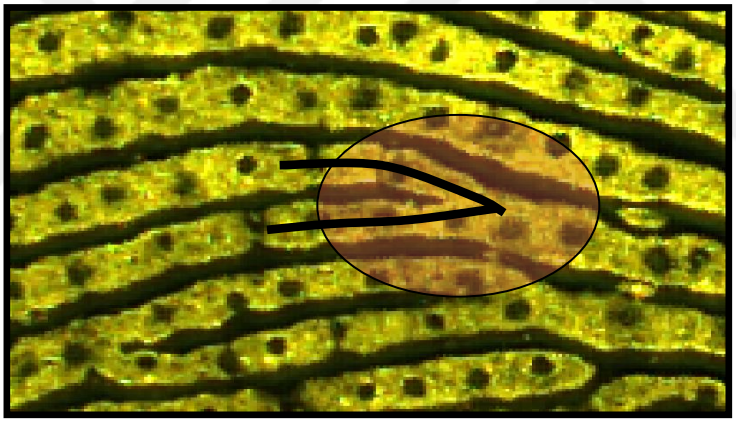


Figure 2.2: Bifurcation

Point/Dot : It is the characteristic feature that consists of one or two pores coming together (Figure 2.3)

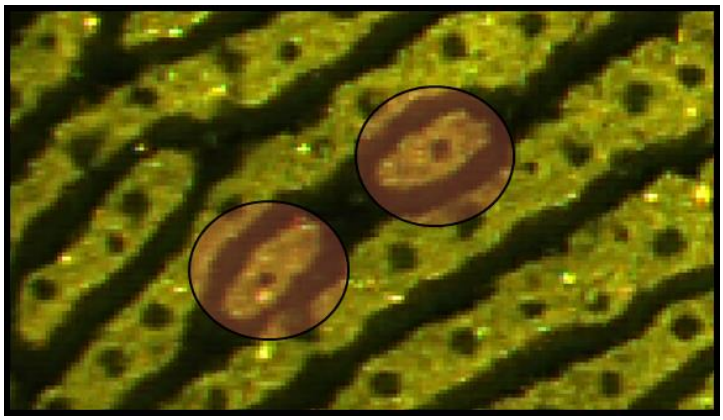


Figure 2.3: Point/Dot.

Enclosure: The shape formed when a papilla splits into two while continuing and rejoins after a while (Figure 2.4).

Figure 2.4: Enclosure.

Bridge: The shape formed as a result of the joining of two parallel papillae by means of a short papilla line is called a bridge (Figure 2.5).

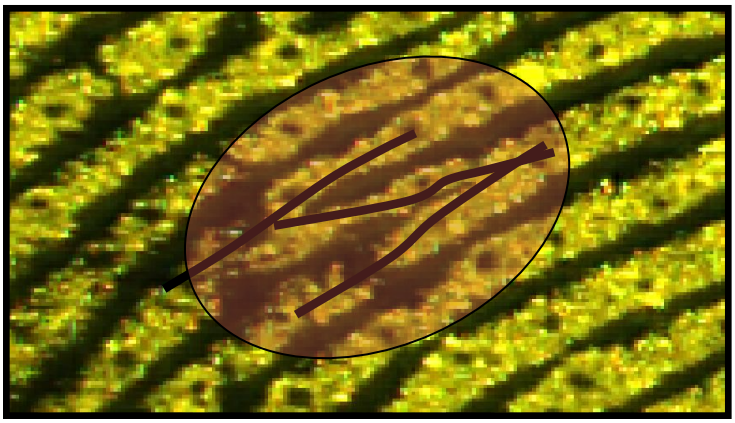


Figure 2.5: Bridge,

Spur/Hook: The shape formed by a small papillary projection that gives the appearance of a hook from the side of a papilla is called hook (Figure 2.6).

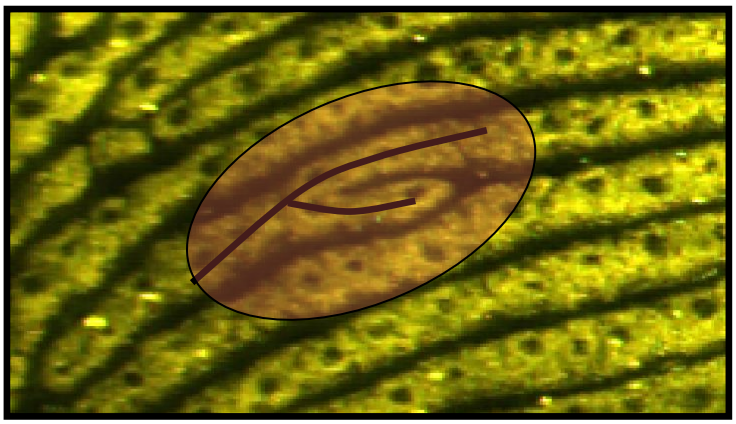


Figure 2.6: Spur/Hook.

Delta: It is the delta region, where the base line and the perimeter line converge or converge (Figure 2.7).

Figure 2.7: Delta.

Ending Ridge : A single friction ridge that terminates within the friction ridge structure (Figure 2.8).

Figure 2.8: Ending Ridge.

Short Ridge : A single friction ridge begininig , travelling a short distance, and then ending (Figure 2.9) [54,55].

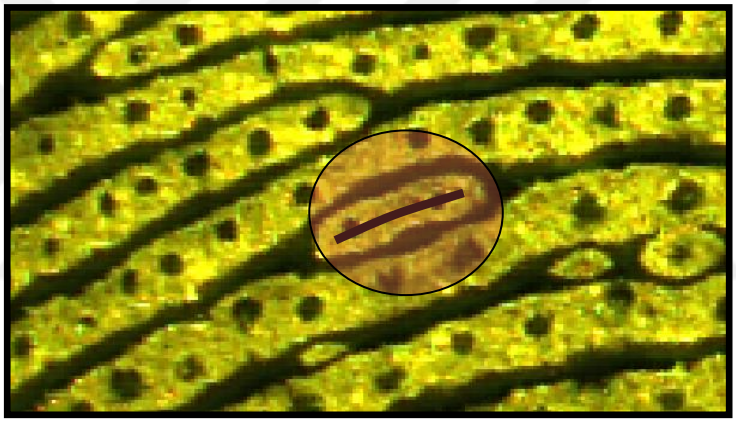


Figure 2.9: Short Ridge.

2.2.3 Classifiability property

Papillae characteristics on fingerprints can be formulated in various ways depending on their shape and arrangement. With the development of technology, manual sorting has been replaced by automatic systems. With the execution of archive activities in the computer environment, the fingerprints or palm prints requested by the fingerprint specialist were found in a shorter time and the transactions started to be carried out quickly. Although the manual classification process of fingerprints has been replaced by automatic systems, it does not eliminate the necessity of making a comparison

between the comparison fingerprint and the fingerprint that is the subject of the crime, compared to the manual system, by a fingerprint expert [56].

2.3 Types of Evidence in Fingerprints

2.3.1 Embossed fingerprints

They are three-dimensional traces formed as a result of finger contact with soft objects (wet paint, wax, etc.). Embossing does not require an additional technique to make fingerprints visible. However, in such fingerprints, it is necessary to use various lighting techniques to view from the surface where the trace is found and to record it with a photograph. The use of silicone mold release agent for tool marks can give good results.

2.3.2 Visible fingerprints

Visible fingerprints are negative fingerprints formed as a result of interaction with a substance such as soot and dust on the surface, or positive fingerprints formed as a result of contamination with substances such as paint, blood, ink. As long as the contrast between the fingerprint and the surface is sufficient, sufficient images can be obtained. In some cases, if the fingerprint does not develop or the contrast of the surface is not sufficient, the fingerprint can be made more visible with coloring and lighting techniques.

2.3.3 Latent fingerprints

Fingerprints that cannot be seen with the naked eye or that need to be improved by making them visible because they are partially seen are called latent fingerprints. In order to develop invisible fingerprints, a number of fingerprint development methods are used [57]. The fact that latent fingerprints are evidence is related to the fact that they can be used for detection and diagnosis after they are developed with certain trace development techniques from the surface on which they are left [58].

The expression latent, which is used in the sense of 'hidden and not visible', can be used in the sense of crime scene trace as well as being used in the sense of invisible fingerprint. Crime scene prints are also examined in three groups as visible, invisible and embossed fingerprints [57].

The temperature and humidity of the environment we live in, the type of surface, the working conditions of the person, the gender of the person, the time elapsed after the fingerprint is left, the age of the person, the person's occupation, the person's health status, the factors affecting perspiration, the food eaten, any substance contaminated before the fingerprint is left. are the factors that affect the trace structurally. In addition, the structure of the liquid formed by the fingerprint is directly related to the hormonal structure of the person, to the situations such as sadness, happiness and excitement. Depending on these situations, the fluid secreted by the body varies in terms of quality and quantity, but even fingerprints belonging to the same person show different characteristics at different times when structurally examined [59].

2.4 Factors Affecting the Development of Fingerprints

There are factors that affect the residence time of fingerprints on surfaces. We can list them as follows:

- Occupation: Physically heavy-duty construction workers, auto mechanics, etc. deformation of the papillary lines of the employees in the occupational group.
- Gender : The papillary lines of women are also smaller than men and their body fluids are less.
- Age : Decrease in the amount of fluid in the human body due to age and deformation of the papillary.
- Diseases : Diseases that adversely affect the secretory glands cause an increase or decrease in the amount of secretion.
- Feature of Surface : Whether the surface is porous or non-porous.
- Contamination : Contamination and loss of purity of the substance by the effect of foreign matter, contamination.
- Expert Error : Incorrect physical, chemical or physico-chemical techniques are used, causing distortion of the trace and making mistakes in the photographing process.
- Form of Contact with the Surface: Leaving the fingerprint on the surface at different angles.

- Climate and Environment: Whether the weather conditions are rainy, hot, cold or humid, depending on whether it is an indoor environment or an open environment [60].

2.5 Comparison of Fingerprints and Comparability

The method applied in fingerprint comparisons in our country and in the world in general; It is a diagnosis with at least 16 points where the expert's opinion is also at the forefront. However, 16 points are not standard, and comparisons can be made with a smaller number of similar points according to the evaluations of the fingerprint specialist.

Evaluations; As a result of the applications, whether fingerprints can be made visible or not, and whether the made visible traces are suitable for comparison. Whether it is suitable for comparison or not was decided in the light of the following criteria.

It is stated that in order for a crime scene fingerprint to be considered sufficient for identification, at least 16 characteristic features must be detected in the fingerprint. However;

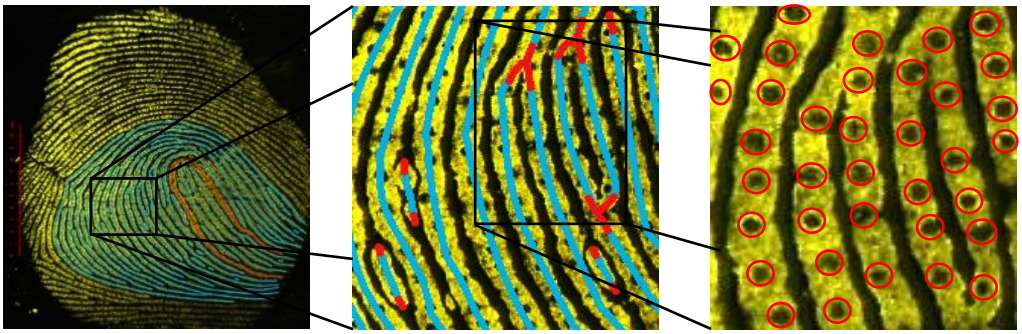
- Fingerprints contain rare characteristics (enclosure, point, bridge, hook, short ridge, triple, trifurcation, opposed bifurcation),
- Having disorders like cuts, holes, burns etc. on the fingerprint,
- The center or deltas of the fingerprint are obvious,
- In case of insufficient number of features such as papilla counting or papilla guidance in the fingerprint,

based on experience and opinion, it can be concluded by the expert that the traces are sufficient for identification.

2.6 Levels of Identification in Fingerprints

Structurally, fingerprints are identified at three levels (Figure 2.10). At the first level; fingerprint groups and subgroups, second level details; fingerprint line characteristics,

and the third level details include details such as pores, papilla structure, width, mold area and fractures [61].



Level 1 **Level 2** **Level 3**

Figure 2.10 : Fingerprint features at Level 1 (general pattern), Level 2 (minutiae), and Level 3 (sweat pores).

2.6.1 First level

In the first level identification, a pattern analysis is performed depending on the flow direction of the fingerprint. In the identification made at this level, a kind of classification is made, there is no individualization, there is a class evaluation. When querying the database, the target fingerprint cannot be reached directly, but it can be used for exclusion by classifying among fingerprints in a specific fingerprint search file. The features based on the first level can be expressed as the center and delta of the fingerprint. Based on these features, fingerprints are divided into 3 main groups as arches, loops and whorlsAnd these categories can be further subdivided. These subgroups are shown as follows.

First, in the Plain Arch category, the lines enter from one side of the mold area and emerge from the other side after taking their shape in the center of the track (Figure 2.11). Then, starting from one side of the finger parallel to each other, papilla lines; The shape that is formed by curling over a straight line with a height of at least 2.5 mm in the center and ending on the other side is called the Tented Arch (Figure 2.12).

Figure 2.11: Plain arch.

Figure 2.12: Tented Arch.

If the arms of the intact lasso in both hands go to the thumb side, that fingerprint is called Left Loop (Figure 2.13). If the arms of the intact lasso in both hands go to the little finger side, that fingerprint is called the Right Loop (Figure 2.14).

Figure 2.13: Left Loop.

Figure 2.14: Right Loop.

The Plain Whorl is formed by arranging the lines forming a single detached circle or several concentric circles in the center (Figure 2.15). Double Loop Whorl is a side-depressed, oval-shaped type of central circle tracks(Figure 2.16).

Figure 2.15: Plain Whorl.

Figure 2.16: Double Loop Whorl.

Pocket-shaped fold in the center; If they are detached or consist of up to four papillae, such fingerprints are called Central Pocket Whorl (Figure 2.17). Fingerprint groups called Accidental Whorl are formed by the combination of two or more fingerprint groups (Figure 2.18) [55].

Figure 2.17: Central Pocket Whorl

Figure 2.18: Accidental Whorl

2.6.2 Second level

In the second level identification, it refers to the details formed by the features called minutiae formed by the papilla lines. While papilla lines flow on one side, they can be divided into different papillary lines on the other. At the same time, a papillary line can terminate suddenly or start again at any point. All these details are also called Galton points or features or individualizing features called minutiae [62].

2.6.3. Third level

Third level identification is a state of detail that is directly related to the shape of the papillary line characteristics. This situation is handled in two ways. The first case is examined on the basis of the dimensions of the papillary lines under the concept of edgeoscopy. And the width and width variations of the papillary lines are based on. In addition to the concept of edgeoscopy, the concept of poroscopy refers to two main situations in which the pores on the papillary lines are examined and discussed. And the shape and width of these pores, which are included in the concept of poroscopy, and the way and order of their location on the papillary lines are discussed within the concept. (Figure 2.19)

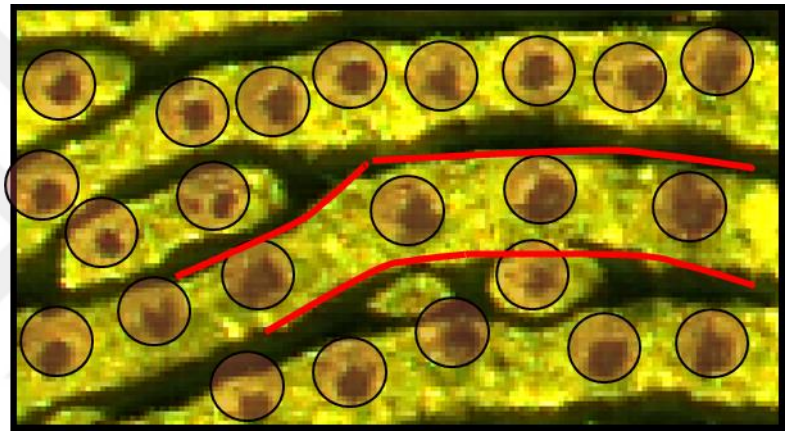


Figure 2.19: Examples of level 3 detail.

2.7 Poroscopy

2.7.1 Definition of poroscopy

With the development of the fetus in the mother's womb, the sweat channels expand towards the upper part of the skin and appear in different series on the papillary lines. The pores formed by these sweat channels after reaching the epidermis layer are called pores. The pores may be completely closed along the papillary ridges, partially open along the ridge, or open on both sides of the ridge [63].

With the invention of the microscope, Marcello Malpighi was the first to examine the pores on the fingerprint [64]. More than 200 years later, Edmund Locard has studied pores in detail. And Locard has been successful in individual identification using pore details as a basis for court. Locard supported the identification processes he made in 1912 with academic studies [63].

These studies revealed that pore pores vary in shape, location, size and frequency. He observed that the pores are square, triangular, oval, elliptical and rhombic. Locard also determined the frequency by calculating the average number of pores on a papillary ridge of a certain length and the average number of pores located in a particular area. Afterwards, by making statistical analyzes on the findings on the fingerprint on Locard, he made a definition that 20-40 pores compatible with each other between two fingerprints are sufficient for a positive identification. In the beginning, the poroscopy concept, which was believed to be of little value in the field of fingerprinting due to the lack of reproducibility and detail of the studies, has been provided to detect the pore pores and to use them in the identification area with the technological developments after the studies published by Locard and Ashbaugh [67].

2.7.2 History of poroscopy

The science of poroscopy was founded in France in 1912 by Dr. Edmund Locart. Edmund started to work on poroscopy after the house of M.Chardonnet was broken into and theftThe thieves stole a few pieces of jewelry and 400 francs. There are no witnesses present. However, there are fingerprints on the wooden jewelery box in which the stolen jewels were found.
The fingerprints were scanned at a local fingerprint archive and identified as belonging to a thief named Boudet. When it became clear that Boudet was not working alone but was acting with an accomplice named Simonin, both men were arrested and fingerprinted. Both persons did not confess their crimes and the case went to court.

At that time, identification from fingerprints was still in its infancy. Locard wanted to present as much conclusive evidence to the court as possible. Locard decided to compare them, as both fingerprints showed very distinct relative pores. After comparing the positions of the pores, it was found that 901 pores were in the correct position in Boudet's fingerprint. On the palm print of Simonin, 2000 pores were in harmony. This number of pores is of great value in the identification phase. Both persons were found guilty and sentenced to severe punishment [66].

However, from that period until now; Poroscopy is theoretical due to reasons such as insufficient technological developments, fingerprints taken from the crime scene and fingerprints taken with ink on Fingerprint and Photo Registration Forms, the pores do

not always show the same features, the pores are not clearly visible in the fingerprint, and there is not enough systematic data about the pores. although it has not been used in practice. In recent years, important technological developments in fingerprint identification and crime scene investigation methods have made some concepts, especially poroscopy, able to be included in the examinations.

2.8 Automated Fingerprint Identification Systems (AFIS)

The term AFIS consists of combining the initials of the words "Automatic Fingerprint Identification System". They are computer-based systems created for the purpose of encoding the features on the fingerprints, recording them in the database and querying them. Fingerprints are first grouped using certain algorithms and then turned into a numerical data according to the features on them, and the result of the query is based on the logic of bringing candidates close to the same fingerprint [67]. Automatic software systems, originally based only on grouping and scoring of features on fingerprints, have evolved over time into more comprehensive systems that also take into account papillary flows, uniqueness of fingerprint characteristics, direction and angle of fingerprint, and combinations of placement between features. In systems where more parameters are taken into account, query processes used to take days and weeks in the past, but with the developing technology, it has been reduced to a few minutes [68].

On the one hand, query speed performance from optes technologies has increased, on the other hand, large databases of countries have begun to form. With the development of technology, the number of elements providing data entry to databases has also increasedThe formation of large-volume databases has brought with it the necessity of query software that can meet more comprehensive query needs. While the development of query software focuses on the fact of making queries faster, on the other hand, it has focused on software performances that bring higher accuracy candidate lists while reaching the target fingerprint as a result of the queries made [69].

When the world AFIS systems are examined; Fingerprint query and detection systems are generally based on second level details [70]. .First-level identification is not sufficient for interrogating and identifying fingerprints. Studies on fingerprint detection, which is the basis for third-level identification, are continuing. Here, the inadequacy of existing fingerprint imaging systems is the biggest obstacle to

developments. However, third-level details are used to increase the success rate in fingerprint detection and studies are gaining weight in this direction [71].

3. MATERIALS AND METHODS

In this research, fingerprints were taken in an accredited laboratory environment and a total of 1050 fingerprint samples were used from 105 donors who signed a consent form. 20×10 cm. images of fingerprints left on mirror plates specially prepared for the study in size of 13.2× magnification and 530 nm lumi light source were taken by using Projectina Image Acquisition (PIA)-7000 software with Projectina Docucenter Nirvis Hyperspectral Imaging System (Spectral range 350 nm - 1100 nm).

From 1050 fingerprints, a database was created from 800 plain fingerprints which was evaluated to have a sufficient level of pore quality and detail. Fingerprints with low number of features and low quality were considered insufficient and excluded from the research. The system was implemented by using MATLAB R2021a [72]. The flow chart of the entire process in the experiment is shown in (Figure 3.1).

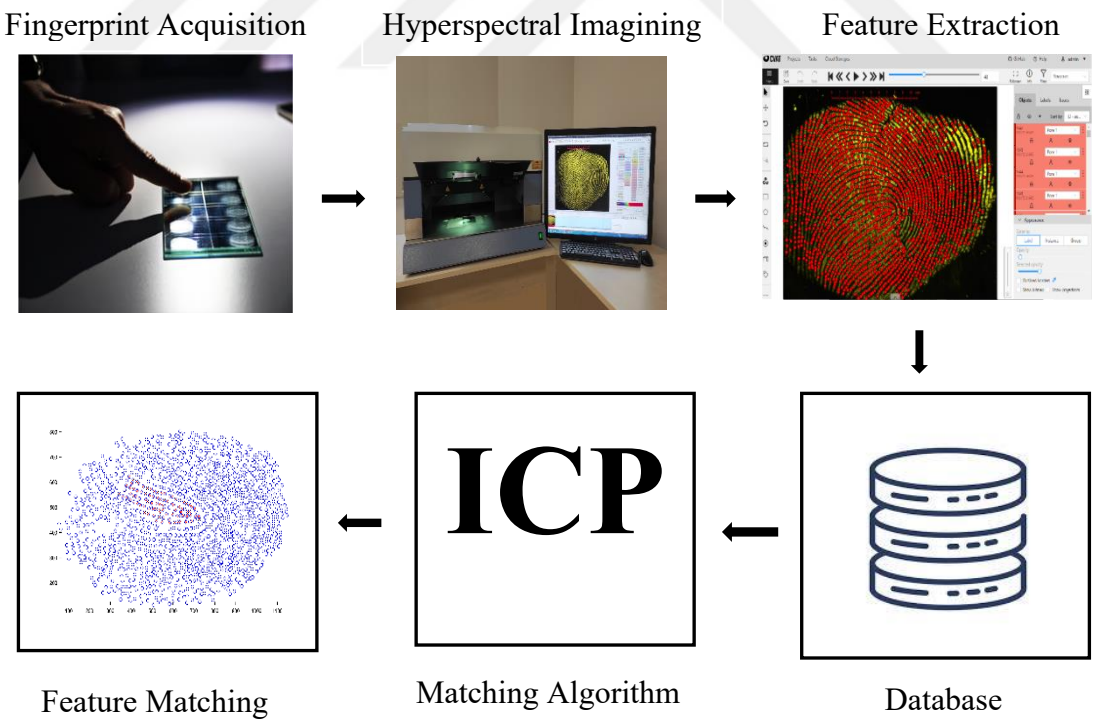


Figure 3.1: The process followed in the experiment

3.1 Validation of the Database

For the validation of the fingerprints that we used in the database, we randomly selected a fingerprint from the database. Then, we compared the four pore-based fingerprint cross-section images of a fingerprint, taken one day apart, in terms of time and distortion in (Figure 3.2). We have observed that the positions of the pores have not changed, and they are all actively existing.

However, we cannot say this validation process in the same way for latent fingerprints, especially when evaluating the contribution of third-level features in the identification process, we should pay attention to the changes that may exist on latent fingerprints.

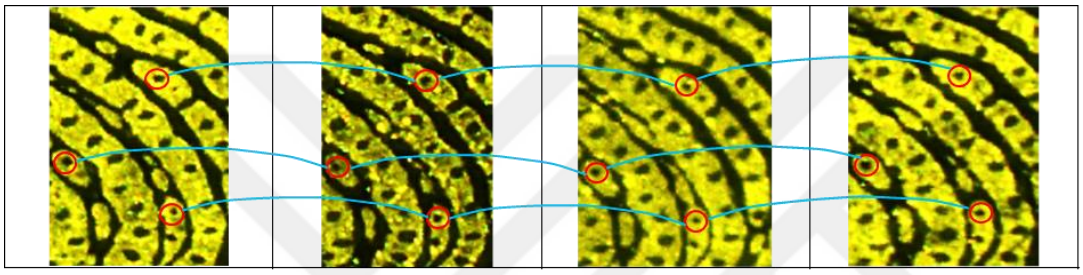


Figure 3.2: Pores on different impressions of the same friction ridge skin area

3.2 Creation of the Database and Marking of Pores

The fingerprints taken, sequentially, were automatically scanned in the entire spectrum first on the projectina docucenter nirvis hyperspectral imaging device. The imaging of the pores was provided at the most appropriate light source and wavelength, and then fingerprints with images of the pore characteristics were scaled one-on-one. Within the scope of the protection of personal data, all fingerprints in the database were anonymized by giving a sequence number for each doner and visualized as shown in (Figure 3.3).

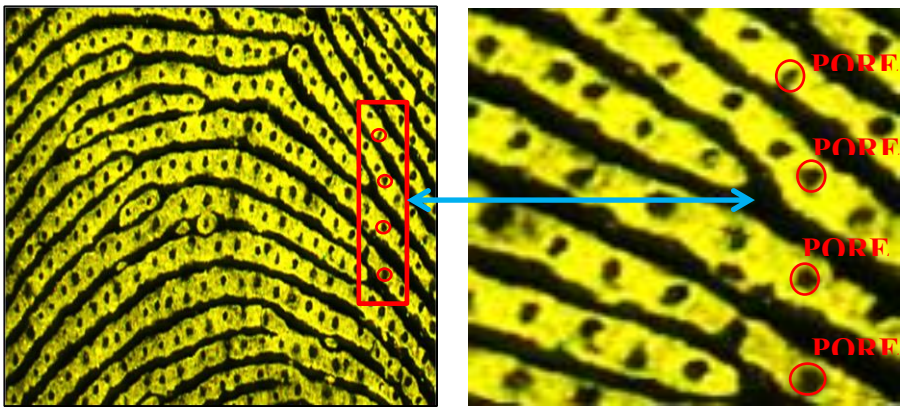


Figure 3.3: Image of Pores

The coding process was carried out by marking the pores on all fingerprint images with the computer vision annotation tool (CVAT) program in the database we obtained (Figure 3.4). As a result of this coding process, two-dimensional coordinate information of the pores of each fingerprint was obtained.

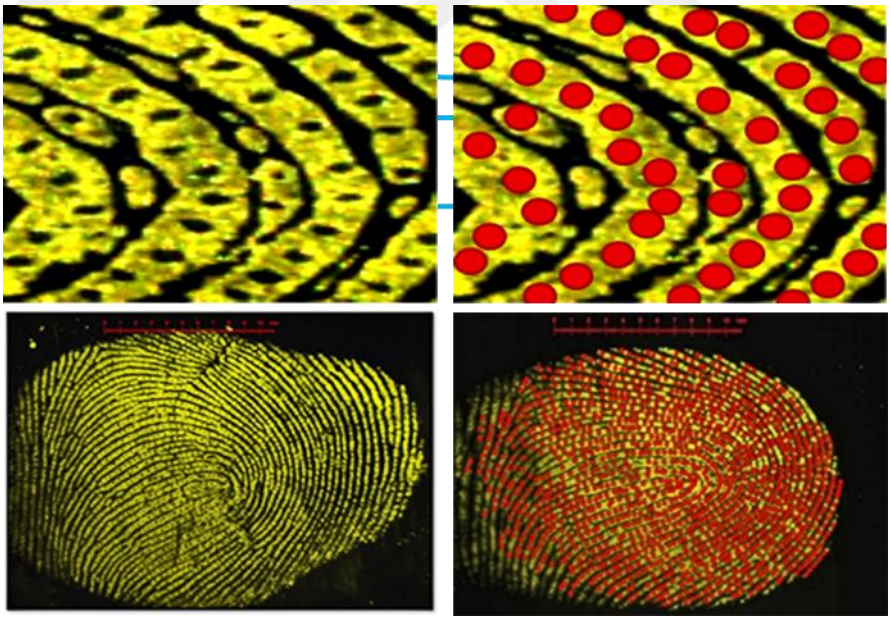


Figure 3.4: Encoding the pores of the fingerprints in the Database

3.3 Matching Algorithm

3.3.1 Iterative closest point (ICP) algorithm

Each marked pore was accepted as a point in the two-dimensional plane and the ICP algorithm was used to compare the two fingerprints [73]. Iterative closest point basically tries to find the correspondence of each point by minimizing the error between two different point cloud clusters. In scoring the match rate, the distances between the aligned points obtained as a result of the use of the ICP algorithm and the pore points of the fingerprint corresponding to the latent fingerprint in the database were used as the error score. These error scores were distributed linearly between 0-10000 points and the matching rate of each fingerprint was scored.

Iterative closest point basically determines the rotation and translation matrix between two different point sets. It minimizes the Euclidean distance between the sets using the singular value decomposition (Figure 3.5). For two different point sets the Singular Value Decomposition (SVD),

$$P_1 . P_2 = USV \tag{3.1}$$

where P_1 and P_2 are the points which represented in the first and second points sets, respectively. In the SVD, U is an $m\ x\ m$ complex unitary matrix, S is an $m\ x\ n$ rectangular diagonal matrix with non-negative real numbers on the diagonal and V is $n\ x\ n$ complex unitary matrix. The rotation at iterative closest point defined as

$$R = UV' \tag{3.2}$$

where matrix R defines the rotation between points sets P_1 and P_2. And the translation defined as,

$$T = \mu_{P_1} - R\mu_{P_2} \tag{3.3}$$

where μ_{P_1} and μ_{P_2} are the mean of the coordinates of the points in the point sets P_1 and P_2, respectively.

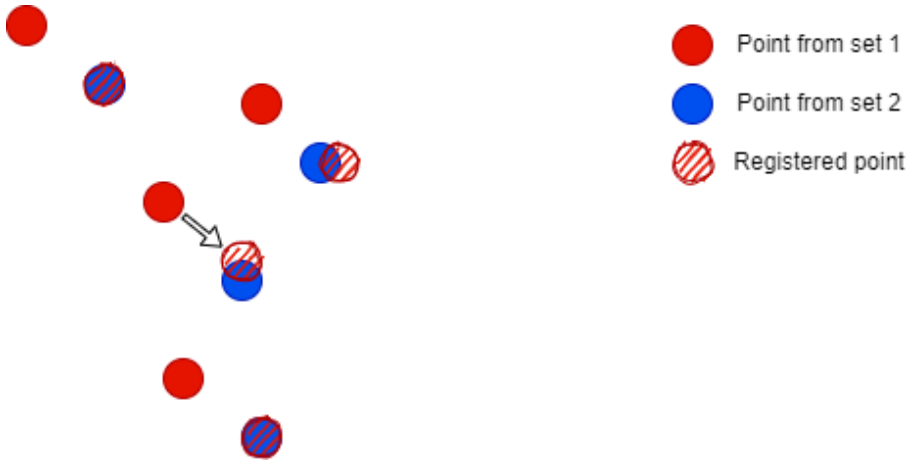


Figure 3.5: Illustration of the ICP algorithm. The sketch version of the red dots is estimated positions of registered points.

With the help of (1), (2) and (3), rotation and translation are calculated. After implementation of ICP algorithm, expected locations of points from set 1 represented as registered points in the (Figure 3.5). Registered points almost match to points from set 2 [73].

3.3.2 A blob detection-based algorithm for auto coding

A blob detection-based algorithm has been developed in the MATLAB environment to provide automatic encoding of pores. Since blob detection algorithms work on monochromatic images, all fingerprints are scaled as gray images. After this cycle, the optimal threshold value for each pixel is determined with the help of adaptive thresholding. Then this threshold value is compared with the average pixel value of the entire image and marked as 0 if the average pixel value is greater than the optimal threshold and 1 if not.

With the help of the resulting binary image and MATLAB's "regionProps" algorithm, regions are detected, and the area of each region is calculated. As a result of the field calculation, all regions except with the field values of 10 and 80 are deleted. Then the centers of gravity of all remaining regions are recorded and the accepted as pore points. The process begins with converting the initial image into grayscale, stripping away color to focus on the underlying intensities. This grayscale image then undergoes adaptive thresholding, a technique that tailors threshold values individually to each pixel based on its surrounding context. This forms a threshold map, guiding subsequent steps. The next step involves computing the average pixel value across the entire grayscale image. This average value serves as a reference point for further decisions.

Depending on whether this average value surpasses an optimal threshold, pixels are assigned binary values. If the average value is higher, the pixel is marked as 0; otherwise, it's marked as 1. To ensure clean results, a majority operator is introduced. This operator scans neighboring pixels and removes small isolated areas where at least 5 neighboring pixels have a value of 1. This helps in reducing noise and maintaining coherent shapes. Once the image is preprocessed, regions within it are pinpointed using the regionProps function. This step segments the image into distinct regions, each representing a connected area of interest. The subsequent step focuses on refining the identified regions based on their sizes. The area of each region is calculated, and those falling outside a specific range, typically between 10 and 80 pixels, are removed. This stage streamlines the selection, excluding regions that are too small or too large to be of significance. Finally, the centers of gravity are calculated for the remaining regions. These centers serve as spatial indicators, revealing the pore locations around which the regions are distributed. This comprehensive process systematically transforms the original image into a refined representation, highlighting significant areas while minimizing noise and irrelevant elements.

3.4 Creation of Latent Fingerprints and Finding the Threshold Value

In this research, the fingerprint no. 127 randomly selected from the database was determined as the latent fingerprint. In order to determine the threshold value of the pore amount to be used in the database query, latent fingerprints with 20, 40, 60, 80, 100 and 120 pores were produced in six different point clusters cumulatively marked from the central region. (Figure 3.6).

Threshold value determination was specified based on the hit scores of the sequential matching fingerprints that came after first hit, rather than the hit scores obtained as a result of the database query of the first matching fingerprints.

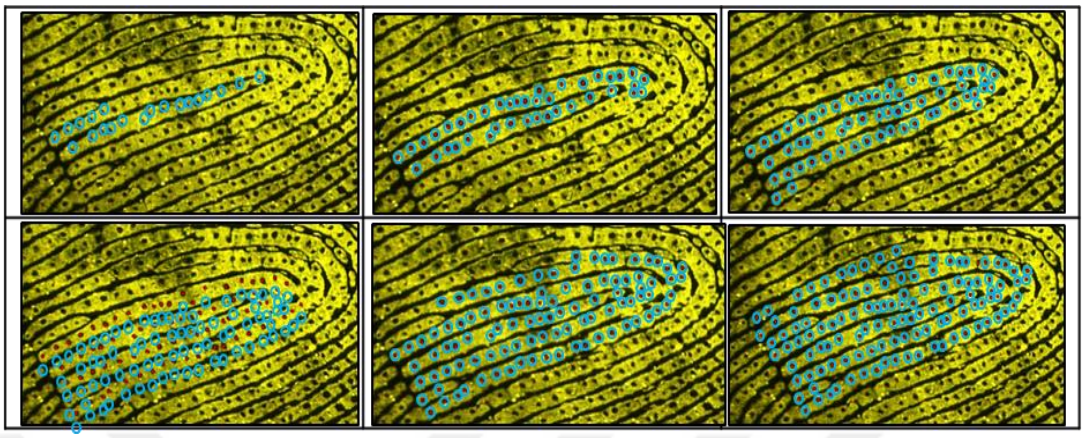


Figure 3.6: Latent Fingerprints Marked 20, 40, 60, 80, 100 and 120 Pores

3.5 Query from the Database

3.5.1 Finding the mean and standard deviations

In the light of the data obtained on the threshold value until this stage of the study, all of the 800 fingerprints in the database were automatically marked as 20, 40, 60, 80, 100 and 120 pore groups by the computer to be queried by one to n.

A noise was created both to determine the resistance point of the applied algorithm and to express the losses in the latent fingerprint due to corruptions. A noise was generated by performing a random shift of a maximum of five pixels in the x-y plane at all pores for each point groups. And for each group of points, latent fingerprints were queried by one to n. In other words, a model was established in which the number of pores and the amount of noise are constant, and the latent fingerprint is variable.

As a result of the query, after the noise applied to each group of latent fingerprints (20, 40, 60, 80, 100 and 120 pore groups); data on the ‘score-based average’ and ‘standard deviations’ of all other latent fingerprints that came after the matching fingerprint were obtained.

Furthermore, as a result of the query, after the noise applied to each group of latent fingerprints (20, 40, 60, 80, 100 and 120 pore groups); data on the "score-based

positional average" and "positional standard deviations" the rank of the matching fingerprint, were obtained.

Thus, the effect limits of random noise applied to all fingerprints in the database on the match rate scores of the other fingerprints coming after the first matching fingerprint and the ranking of the matched fingerprint were determined.

3.5.2 Verification of the model

In order to verify the data obtained on score-based mean and standard deviations and score-based positional average and positional standard deviations; In the same way, fingerprints with 20 to 100 pore marks and a random shift of maximum five pixels in the x-y plane were created in the pores. These latent fingerprints were queried in the database of 800 fingerprints.

As a result of the query, it was observed whether the previously determined latent fingerprint number 127 existed within the limits of the mean and standard deviation values obtained from the noisy fingerprints with 20 to 100 pore marks and a maximum of five pixels random shift in the x-y plane in the pores.

Afterwards, 20 hit list scores and pore matching images of latent fingerprints corresponding to 3 different fingerprints (Fingerprint ID Number 416,431 and 362) randomly selected from the dataset and created by marking 20 and 100 pore with noise and without noise are shown in (Figure 19-Figure 42).

In order to base the study on precise values, all fingerprints in the database were manually coded and queried at a pre-emptive stage. It is more practical to automatically encode ten fingerprints in practice. Starting from this point, in order to evaluate and observe the automatic coding data, the latent fingerprints of 20 and 100 pores, which were randomly selected from the database and manually coded in the previous stage, and which were marked with noise and without noise, were automatically coded by the computer at this stage. And then a query was made in the database. Subsequently, 20 hit list scores and pore matching images corresponding to 4 different automatically encoded latent fingerprints (Fingerprint ID Numbers 127, 416, 431 and 362) are shown in (Figure 43-Figure 69).

4. RESULTS

To find the threshold value of the number of points to be used, six different point sets were evaluated. In order to observe this situation, the results of the second hits with the highest scores after the matching latent fingerprints which marked with 20, 40, 60, 80, 100 and 120 pores are shown in (Figure 4.1).

The main reason for observing the scores of the second and later hits was to evaluate the effect of the number of marked pores on the difference in the score between the identical fingerprints and the dissimilar hits.

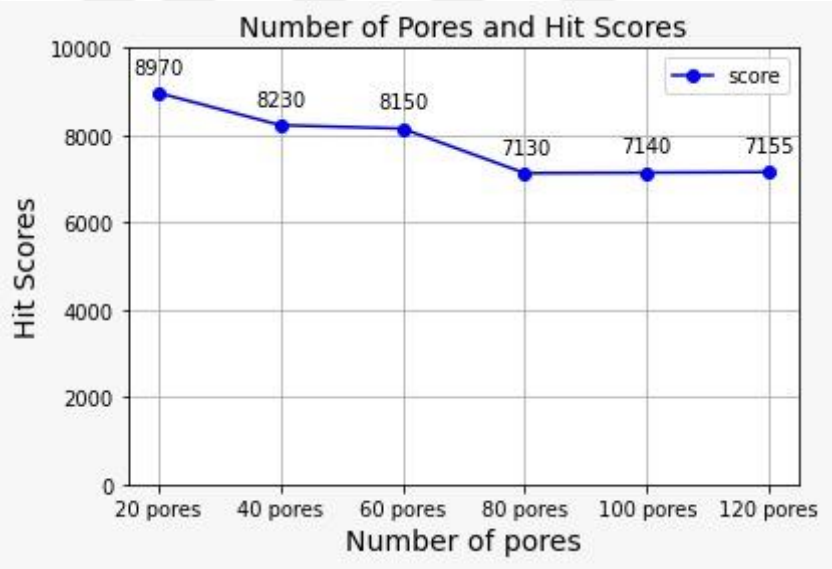


Figure 4.1: The Second Hits Scores

As a result of the query, after the noise applied to each group of latent fingerprints (20, 40, 60, 80, 100 and 120 pore groups); data on the 'score-based average' and 'standard deviations' of all other latent fingerprints that came after the matching fingerprint is as seen in Table 4.1. Since coincidental match rate is inverse proportional with the number of features, as expected, mean value decreases while the number of pores increasing. At the same time the results are distributed in a narrower range with decreasing standard deviation by showing consistency.

Table 4.1 Table of Data with Score-based Mean and Standard Deviation

Number of Pores	Mean	Standard Deviation
20	5943.65	1221.55
40	5702.19	904.46
60	5605.53	747.18
80	5547.64	650.85
100	5508.12	586.81
120	5478.51	545.00

The graphical display of the data given in Table 4.1 is as in (Figure 4.2)

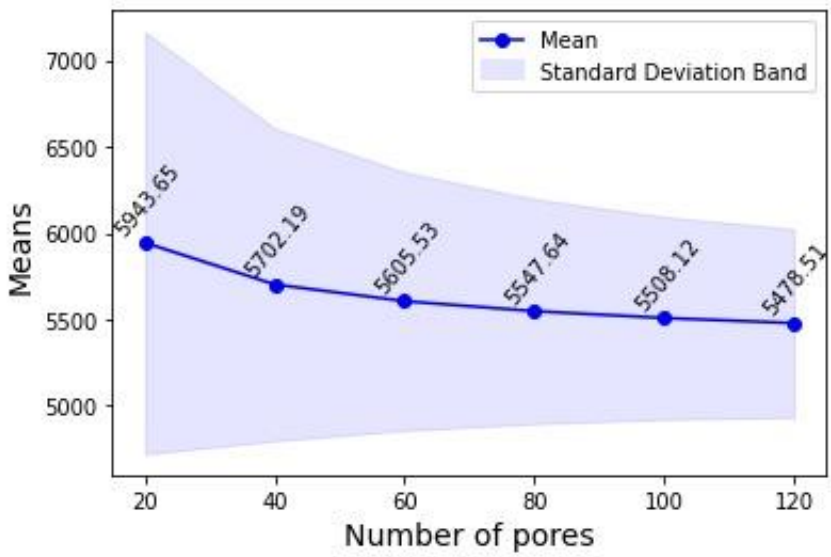


Figure 4.2: Graph of Score-based Mean and Standard Deviations Data

As a result of the query, the data obtained regarding the score-based positional average and positional standard deviations of the different latent fingerprints in each fingerprint group after the noise applied are as seen in Table 4.2. As expected, for fewer number of pores the positional mean and the standard deviation of the hits increasing, due to the decrease in features of fingerprint while standard deviation decreases.

Table 4.2 Table of Data with Score-based Positional Mean and Positional Standard Deviation

Number of Pores	Positional Mean	Positional Standard Deviation
20	27.1863	32.19600
40	5.0763	6.18000
60	2.1576	1.99710
80	1.4212	0.85488
100	1.2304	0.63796
120	1.1876	0.49459

The graphical display of the data given in Table 4.2 is as in (Figure 4.3)

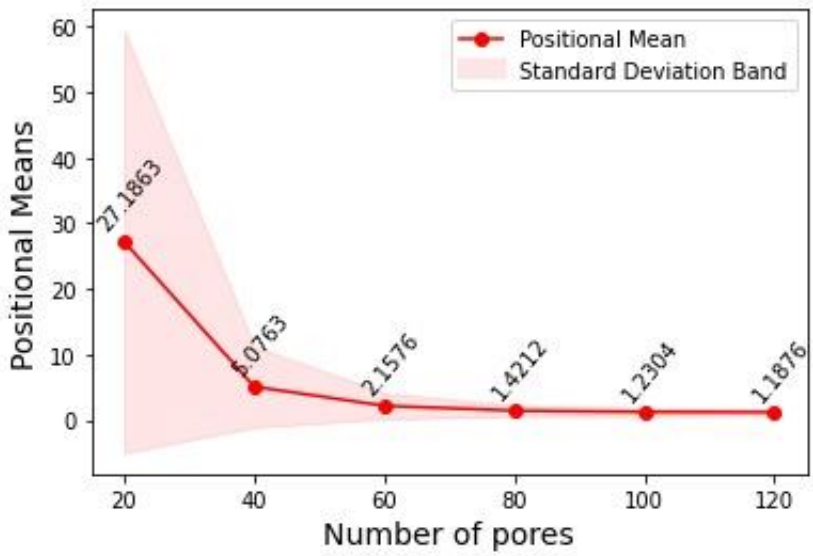


Figure 4.3: Graph of Score-based Positional Mean and Positional Standard Deviation

Table 4.3 Automatic Coding Table of Data with Score-based Mean and Standard Deviation

Number of Pores	Mean	Positional Standard Deviation
20	5759.57	3920.46
40	5230.38	1638.72
60	5203.74	1405.16
80	5195.51	1230.18
100	5193.46	1093.81
120	5192.29	994.71

The graphical display of the data given in Table 4.3 is as in (Figure 4.4)

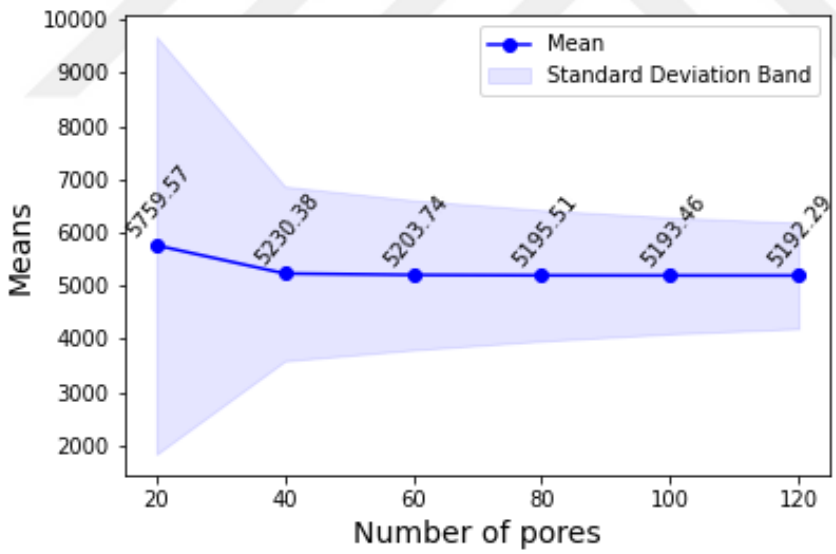


Figure 4.4: Automatic Coding Graph of Score-based Mean and Standard Deviations Data

Table 4.4 Automatic Coding Table of Data with Score-based Positional Mean and Positional Standard Deviation

Number of Pores	Positional Mean	Positional Standard Deviation
20	55.01	24.0784
40	33.79	15.2584
60	21.92	9.6979
80	15.39	7.4786
100	10.56	4.8145
120	7.69	3.8186

The graphical display of the data given in Table 4.4 is as in (Figure 4.5).

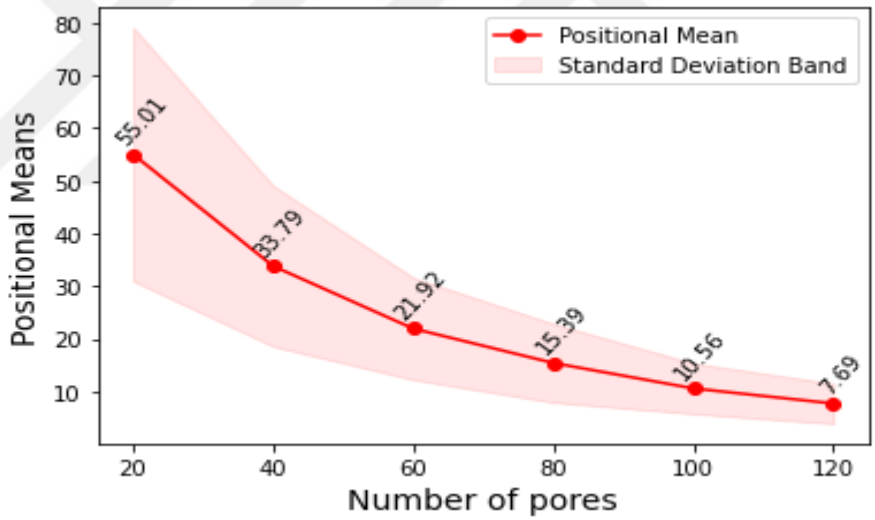


Figure 4.5: Automatic Coding Graph of Score-based Positional Mean and Positional Standard Deviation

The matched fingerprint scoring values of 20 and 100 pore marked latent fingerprints which matched with Fingerprint ID Number 127 from the database without noise and the pore matching image of the matched fingerprint are given in (Figure 4.6-Figure 4.9).

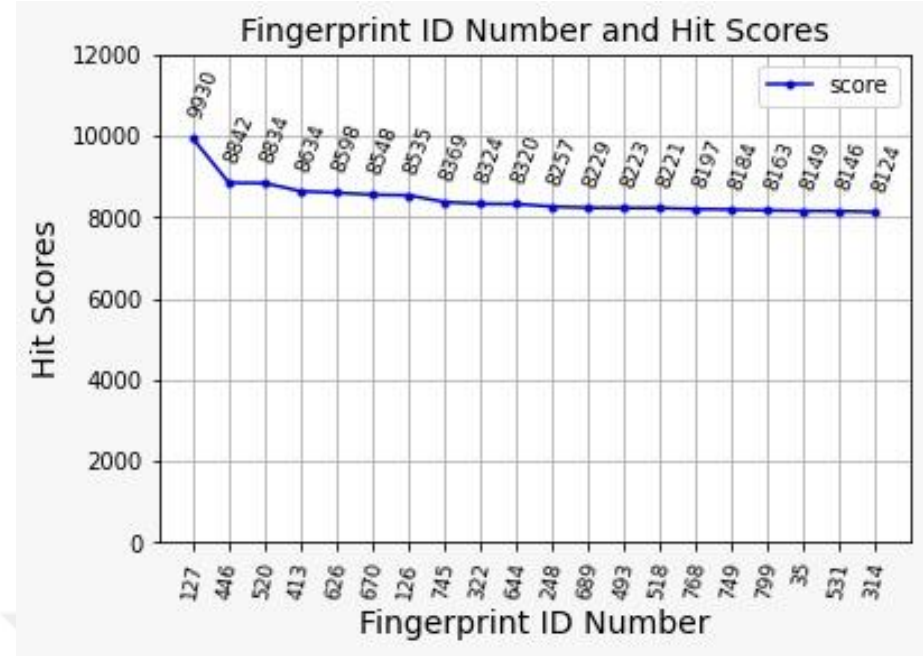


Figure 4.6: 20 Pore-marked First 20 Hit List Scores without Noise (Fingerprint ID No.127)

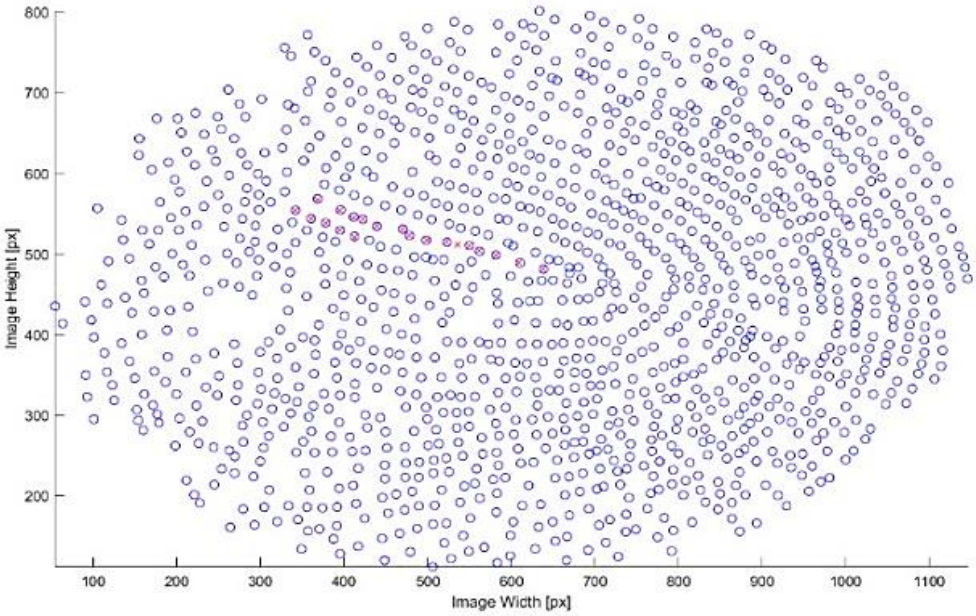


Figure 4.7: 20 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.127)

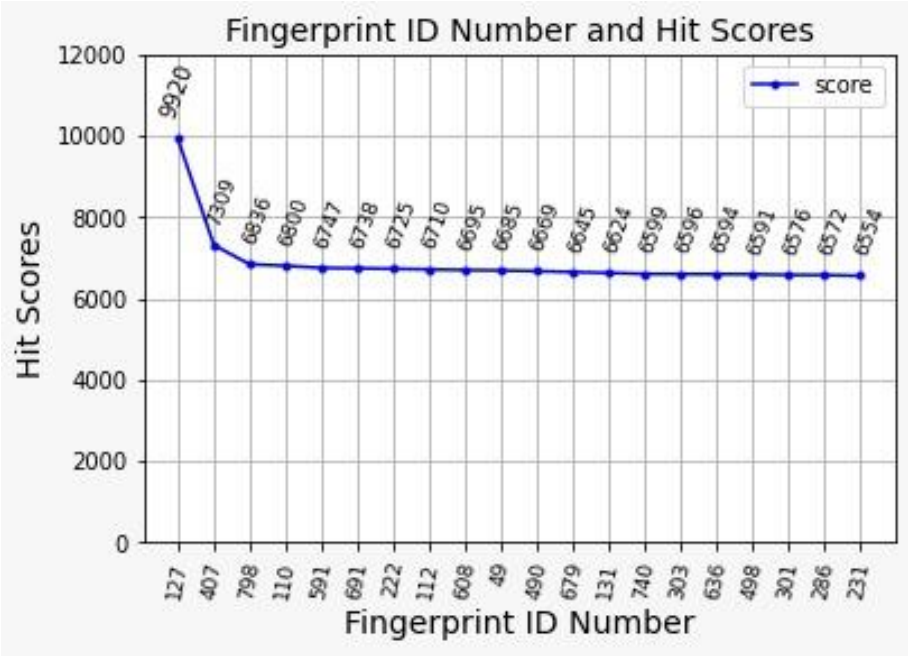


Figure 4.8: 100 Pore-Marked First 20 Hit List Scores without Noise (Fingerprint ID No.127)

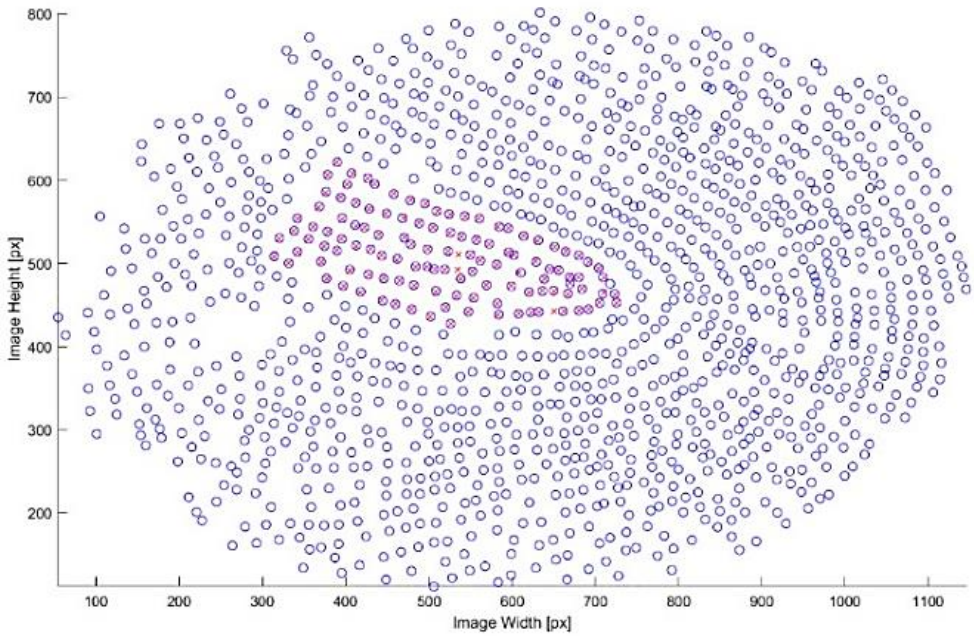


Figure 4.9: 100 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.127)

The matched fingerprint scoring values of 20 and 100 pore-marked latent fingerprints which matched with Fingerprint ID Number 127 from the database with a maximum random shift of five pixels in the x-y plane and the pore matching image of the matched fingerprint are given in (Figure 4.10-Figure 4.13).

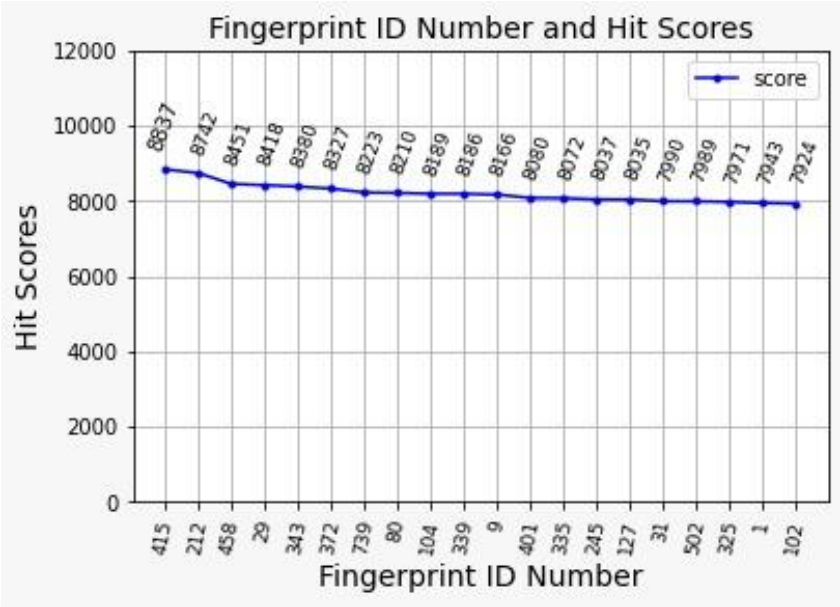


Figure 4.10: 20 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.127)

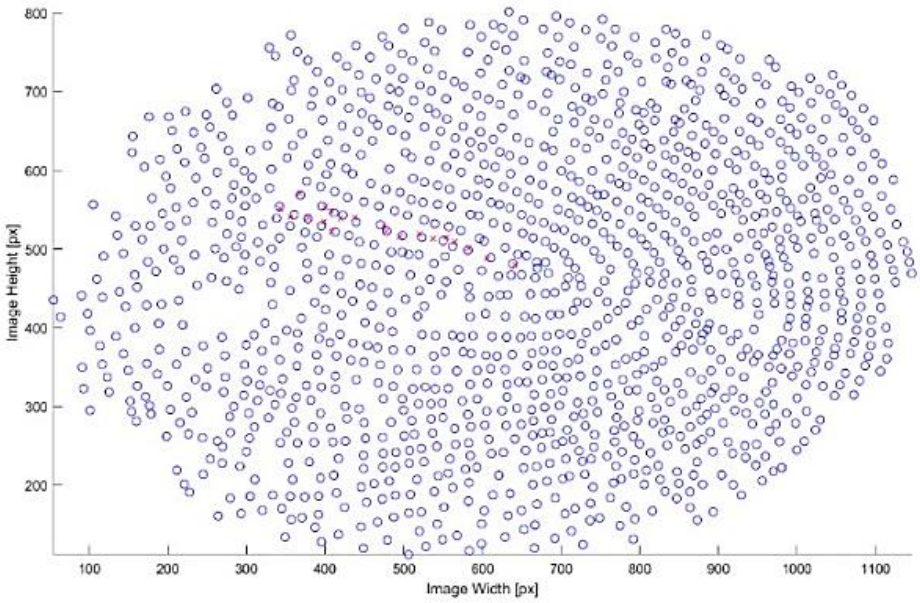


Figure 4.11: 20 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.127)

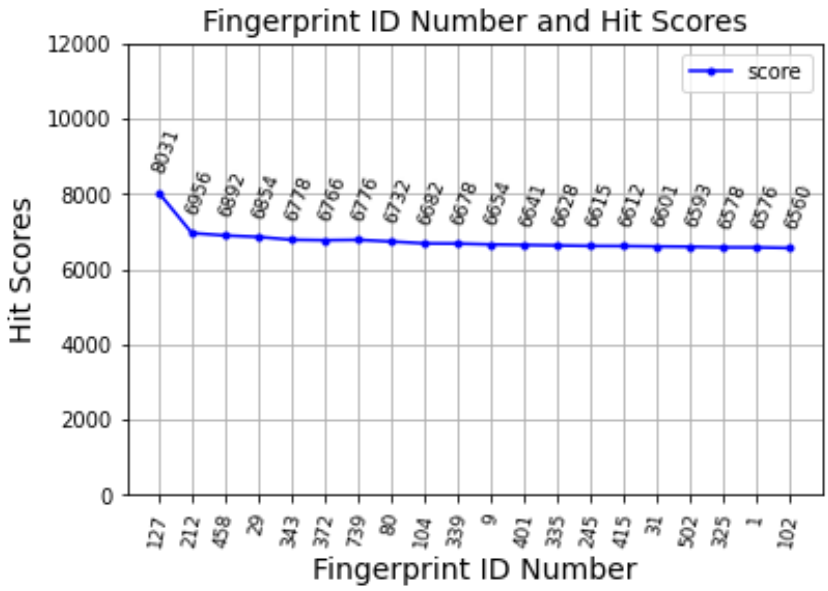


Figure 4.12: 100 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.127)

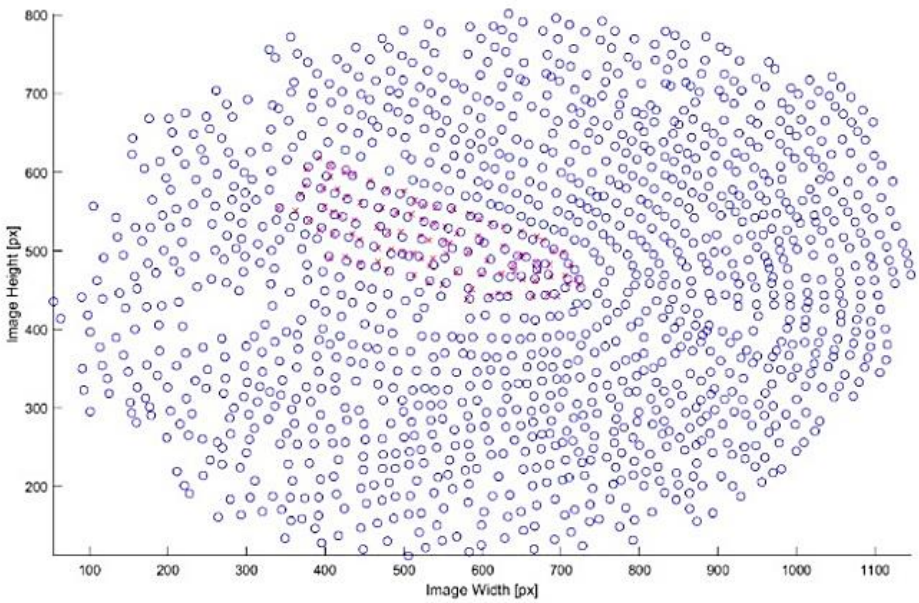


Figure 4.13: 100 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.127)

The matched fingerprint scoring values of 20 and 100 pore marked latent fingerprints which matched with Fingerprint ID Number 416 from the database without noise and the pore matching image of the matched fingerprint are given in (Figure 4.14-Figure 4.17).

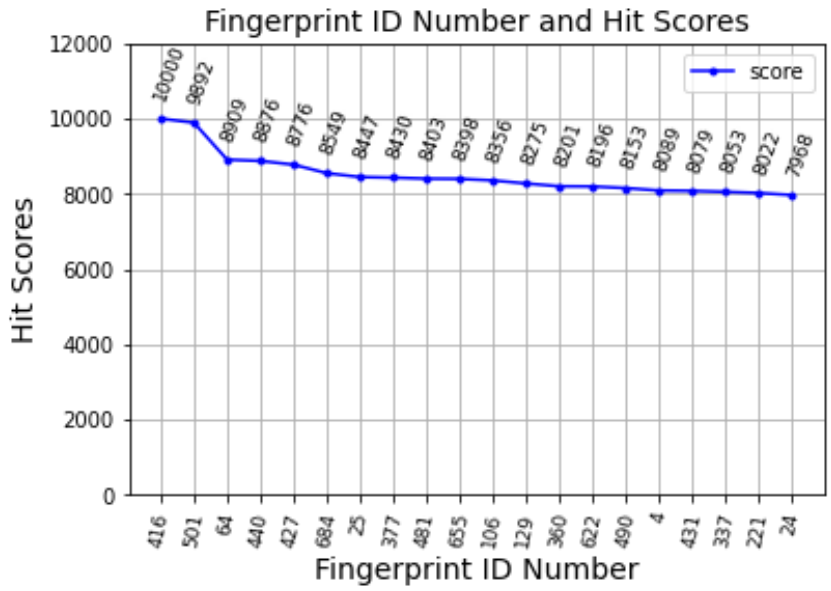


Figure 4.14: 20 Pore-marked First 20 Hit List Scores without Noise (Fingerprint ID No.416)

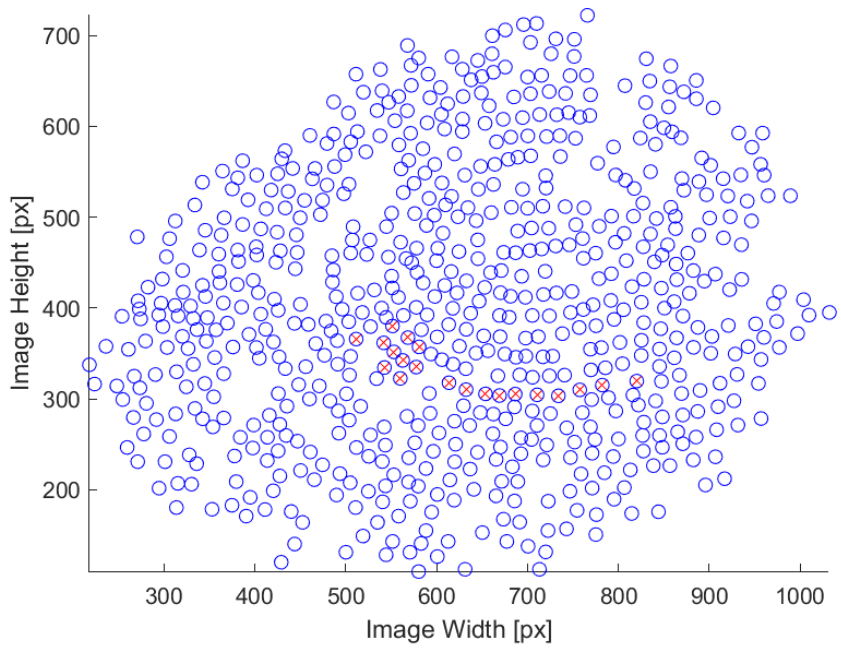


Figure 4.15: 20 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.416)

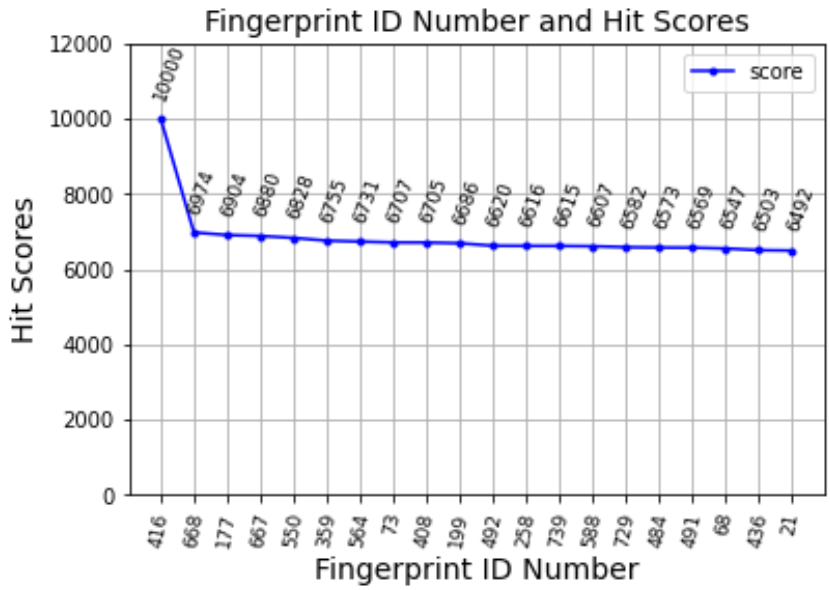


Figure 4.16: 100 Pore-Marked First 20 Hit List Scores without Noise (Fingerprint ID No.416)

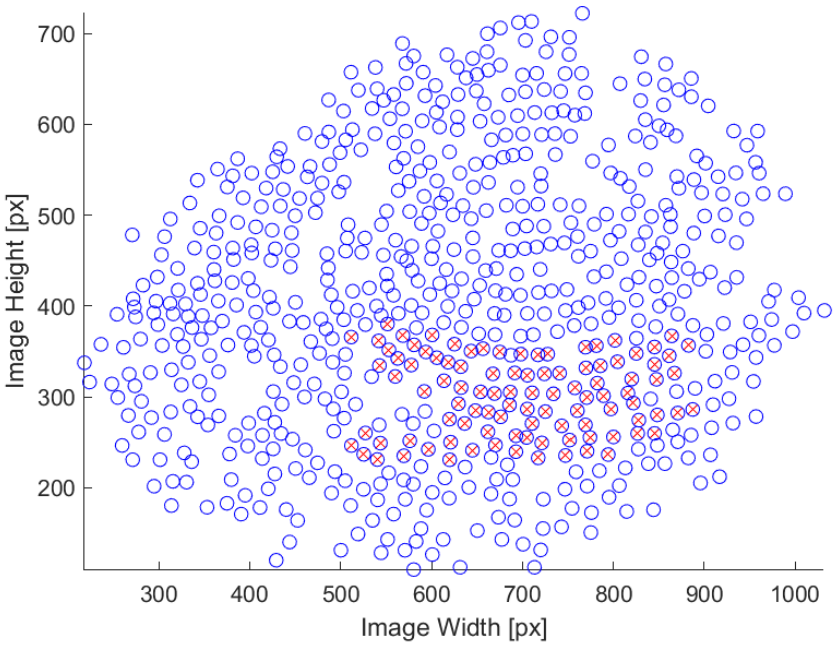


Figure 4.17: 100 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.416)

The matched fingerprint scoring values of 20 and 100 pore-marked latent fingerprints which matched with Fingerprint ID Number 416 from the database with a maximum random shift of five pixels in the x-y plane and the pore matching image of the matched fingerprint are given in (Figure 4.18-Figure 4.21).

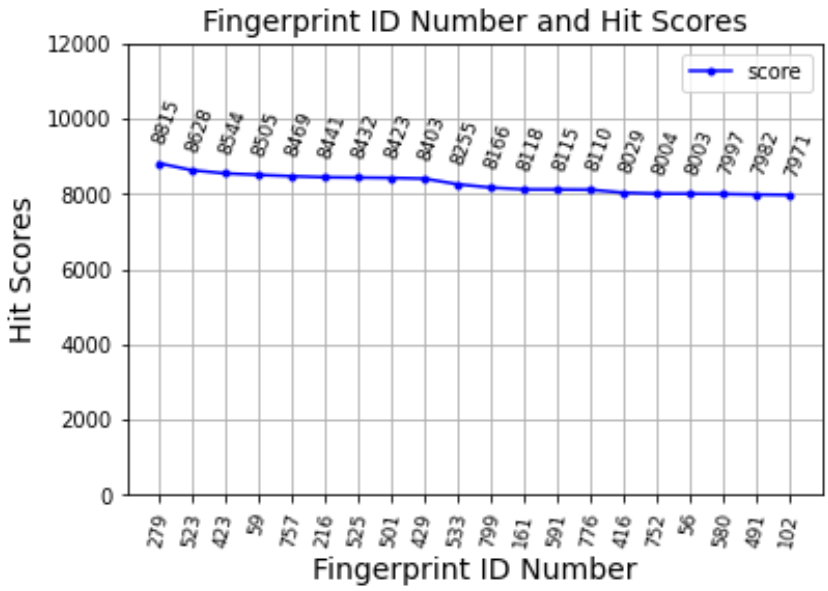


Figure 4.18: 20 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.416)

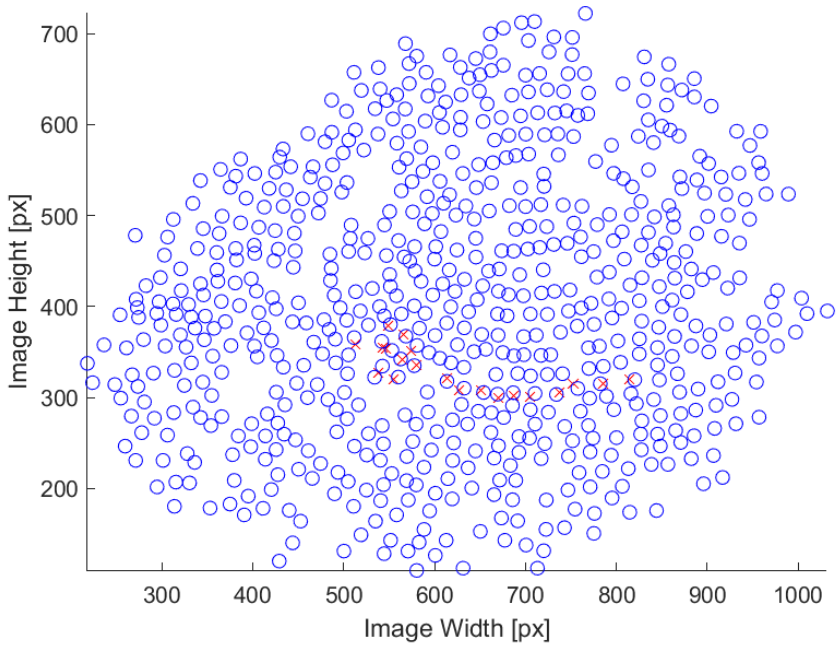


Figure 4.19: 20 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.416)

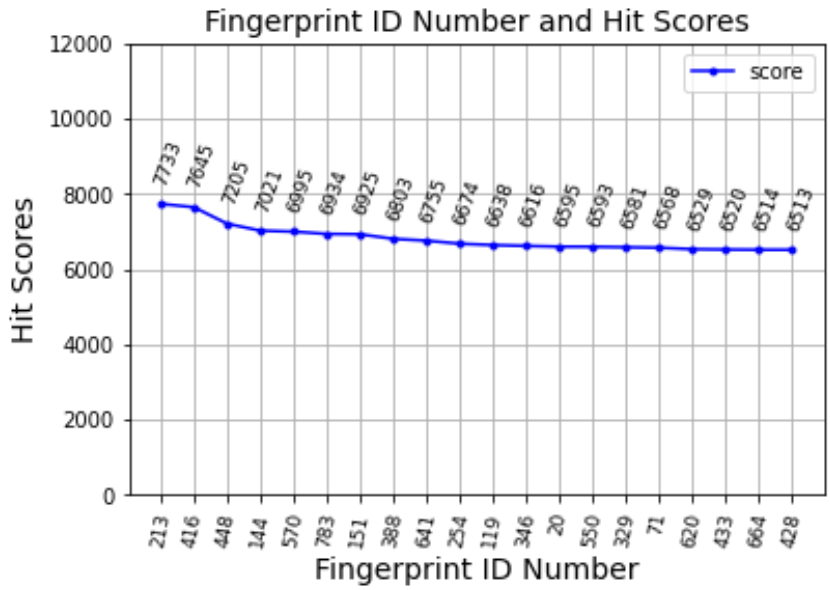


Figure 4.20: 100 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.416)

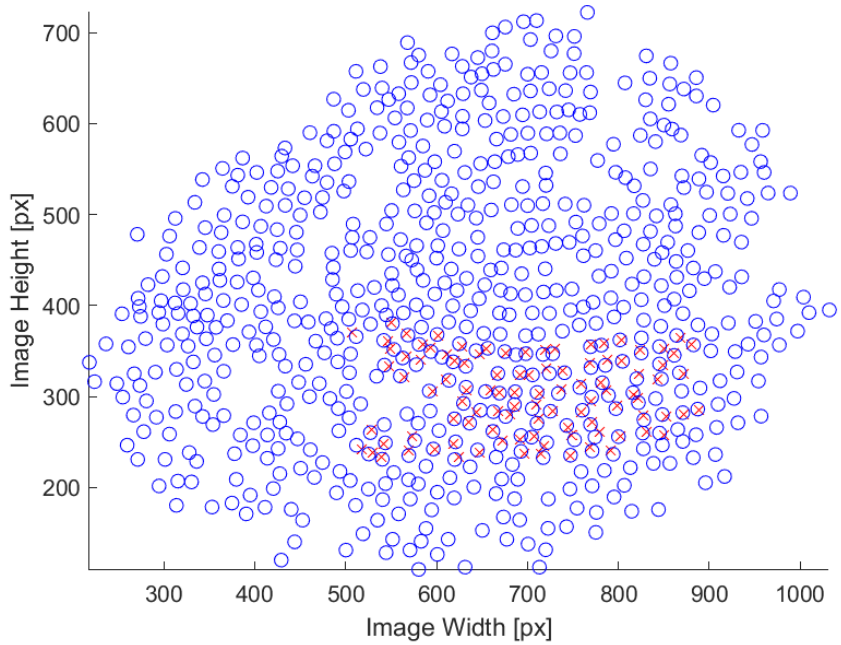


Figure 4.21: 100 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.416)

The matched fingerprint scoring values of 20 and 100 pore marked latent fingerprints which matched with Fingerprint ID Number 431 from the database without noise and the pore matching image of the matched fingerprint are given in (Figure 4.22-Figure 4.25).

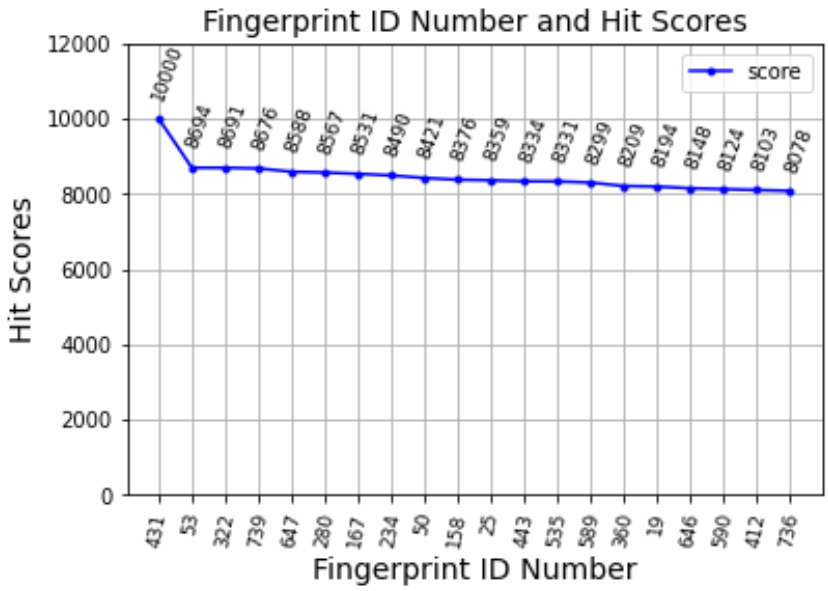


Figure 4.22: 20 Pore-marked First 20 Hit List Scores without Noise (Fingerprint ID No.431)

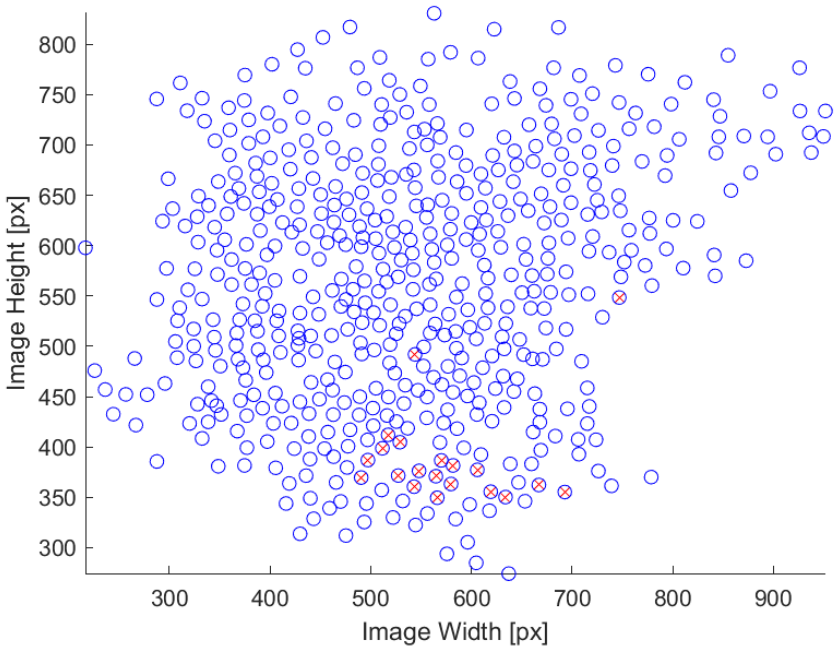


Figure 4.23: 20 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.431)

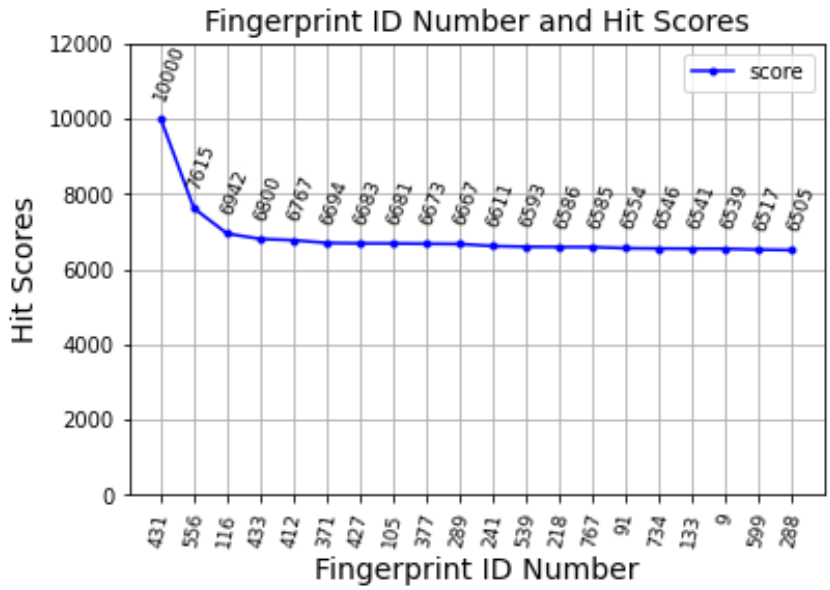


Figure 4.24: 100 Pore-Marked First 20 Hit List Scores without Noise (Fingerprint ID No.431)

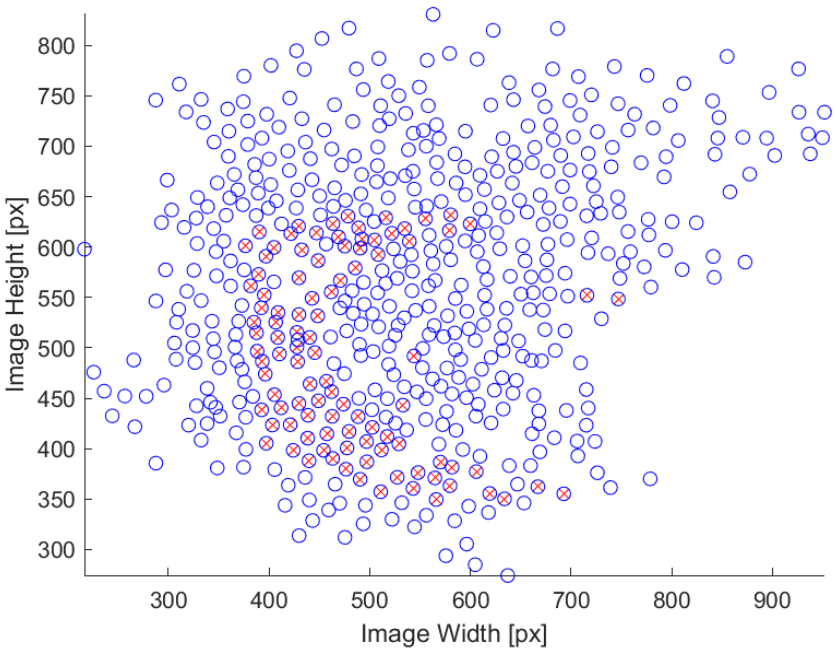


Figure 4.25: 100 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.431)

The matched fingerprint scoring values of 20 and 100 pore-marked latent fingerprints which matched with Fingerprint ID Number 431 from the database with a maximum random shift of five pixels in the x-y plane and the pore matching image of the matched fingerprint are given in (Figure 4.26-Figure 4.29).

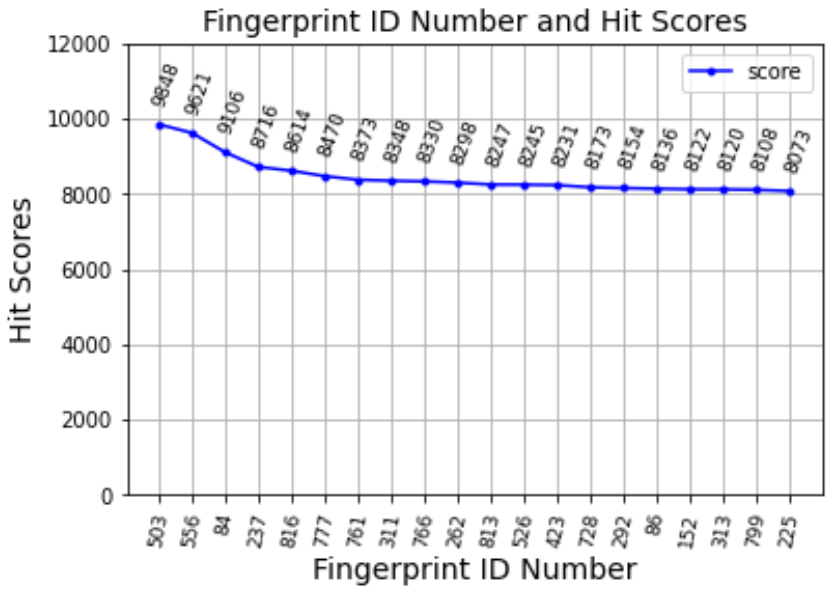


Figure 4.26: 20 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.431)

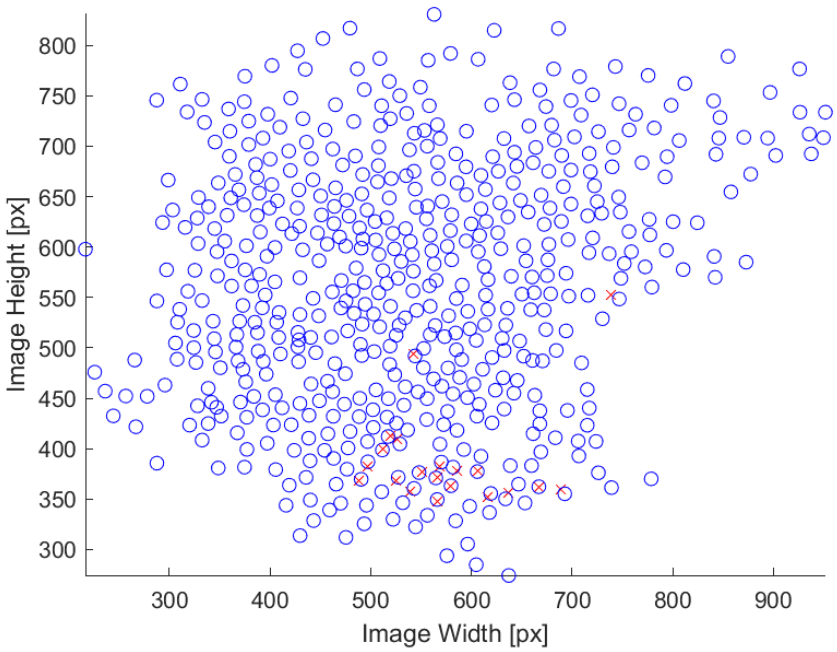


Figure 4.27: 20 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.431)

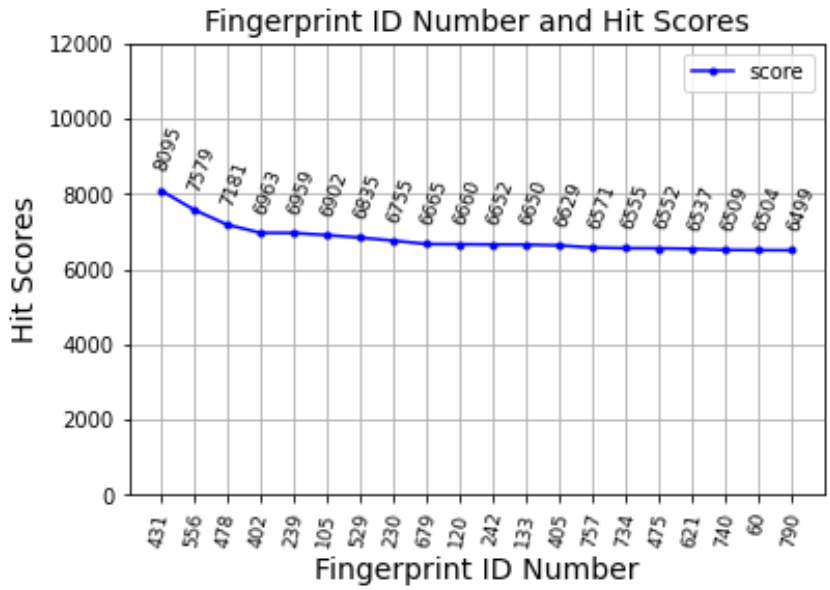


Figure 4.28: 100 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.431)

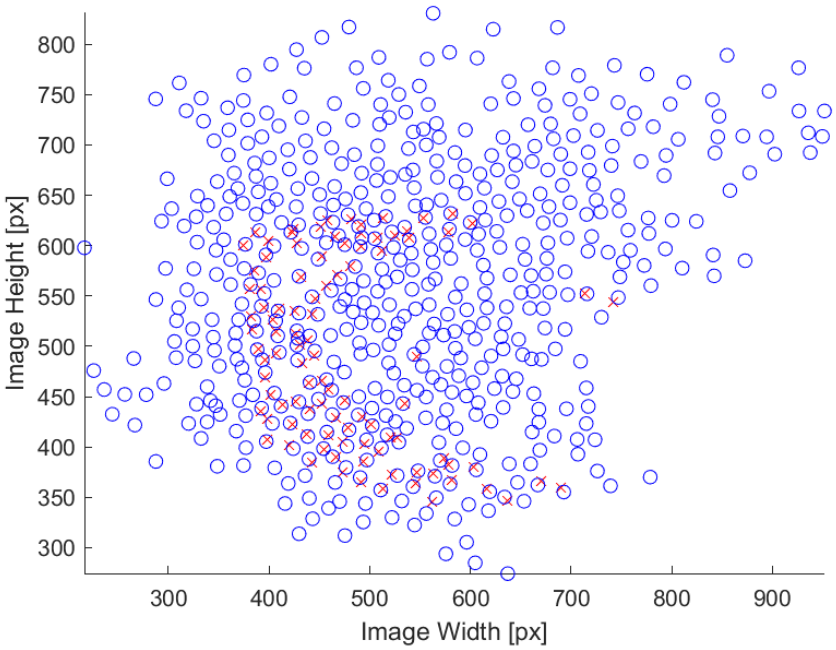


Figure 4.29: 100 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.431)

The matched fingerprint scoring values of 20 and 100 pore marked latent fingerprints which matched with Fingerprint ID Number 362 from the database without noise and the pore matching image of the matched fingerprint are given in (Figure 4.30-Figure 4.33).

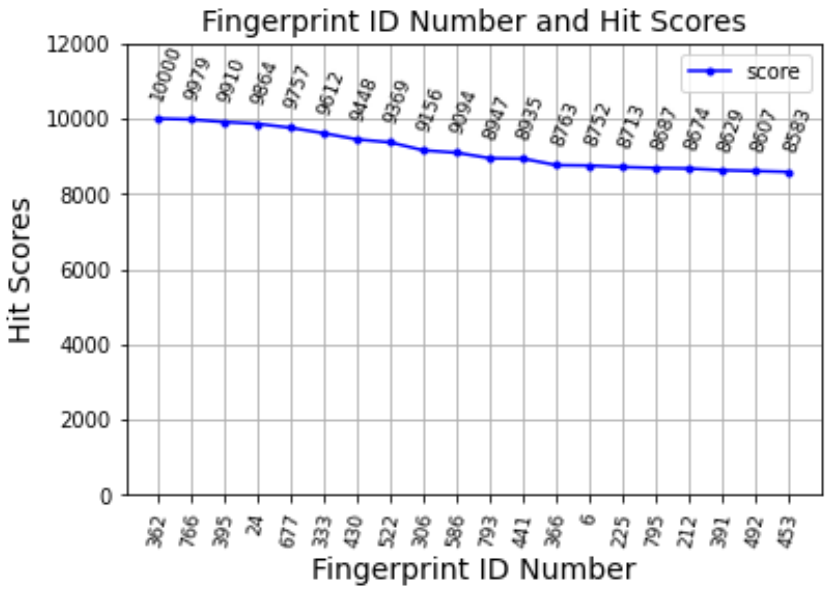


Figure 4.30: 20 Pore-marked First 20 Hit List Scores without Noise (Fingerprint ID No.362)

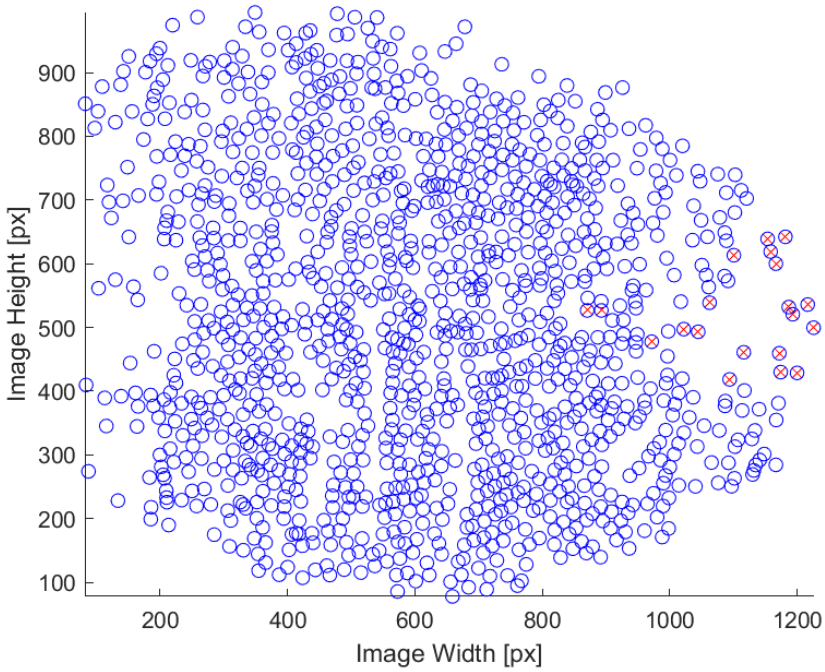


Figure 4.31: 20 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.362)

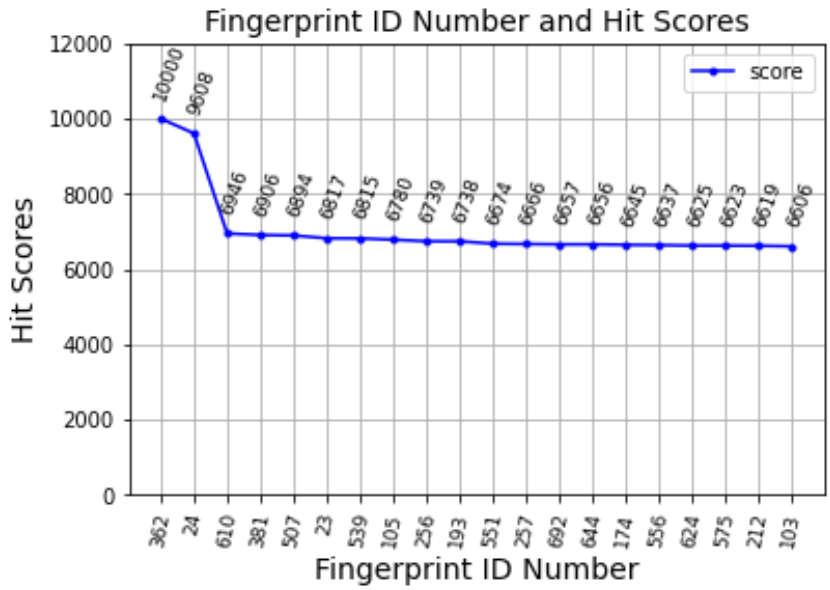


Figure 4.32: 100 Pore-Marked First 20 Hit List Scores without Noise (Fingerprint ID No.362)

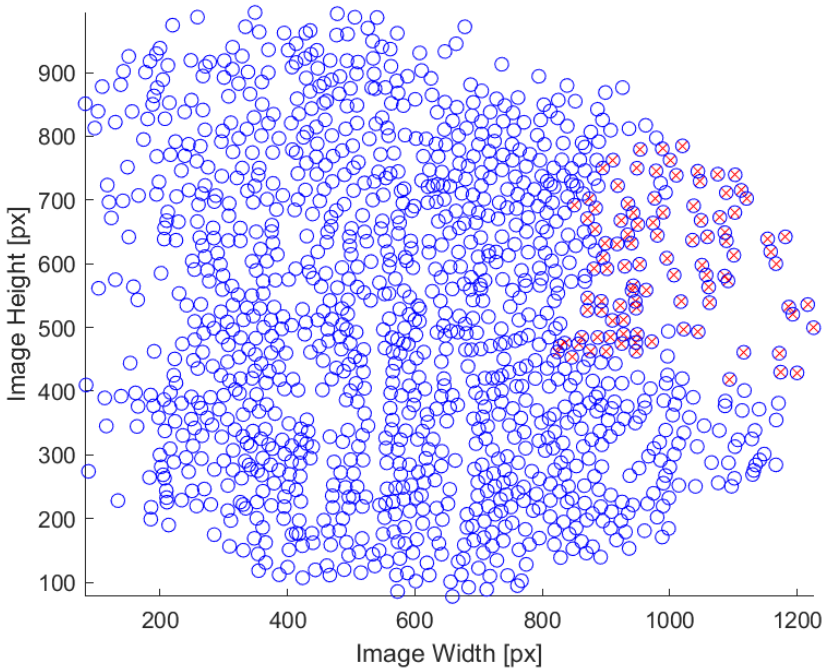


Figure 4.33: 100 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.362)

The matched fingerprint scoring values of 20 and 100 pore-marked latent fingerprints which matched with Fingerprint ID Number 362 from the database with a maximum random shift of five pixels in the x-y plane and the pore matching image of the matched fingerprint are given in (Figure 4.34-Figure 4.37).

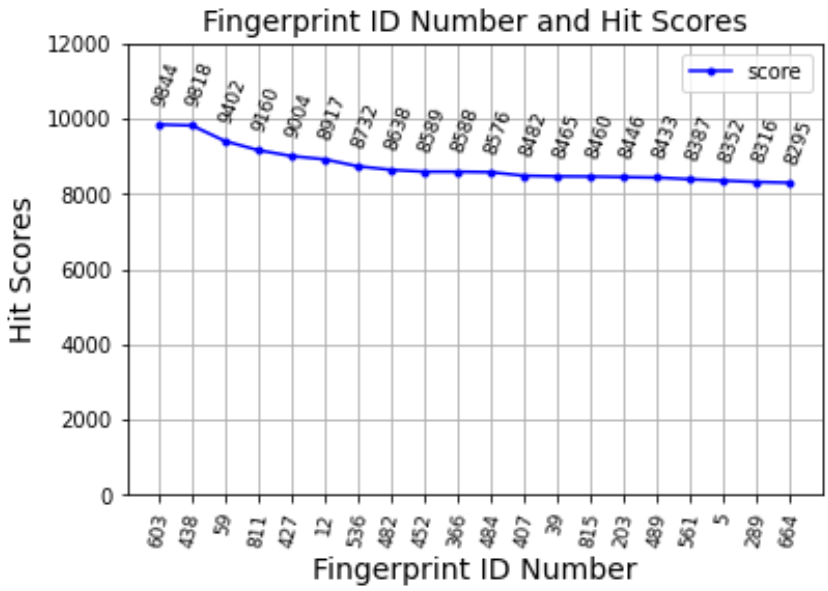


Figure 4.34: 20 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.362)

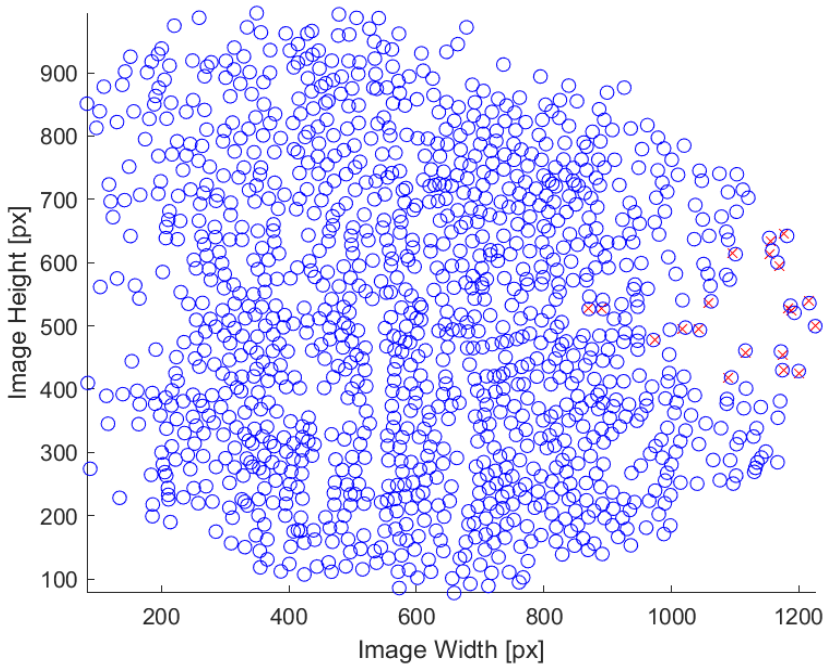


Figure 4.35: 20 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.431)

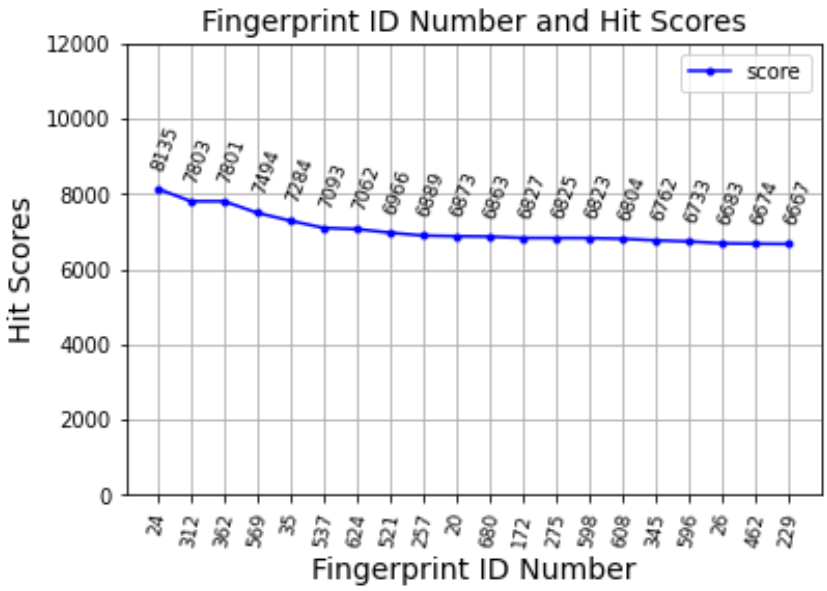


Figure 4.36: 100 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.362)

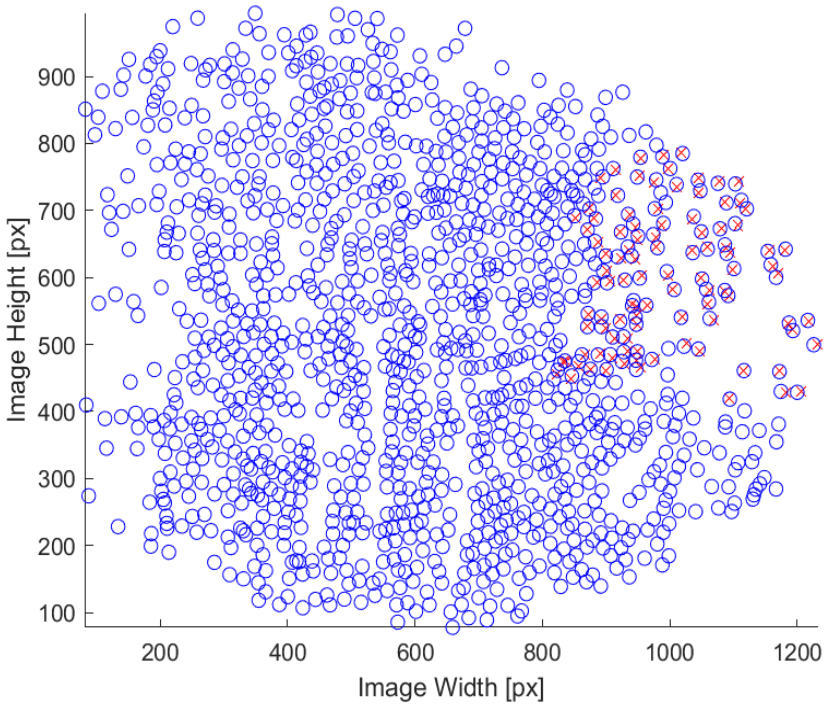


Figure 4.37: 100 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.362)

The data of the latent fingerprints ID number 127, 416, 431 and 362, which are automatically encoded at this stage, are shown below.

The matched fingerprint scoring values of 20 and 100 pore marked latent fingerprints which matched with Fingerprint ID Number 127 from the database without noise and the pore matching image of the matched fingerprint are given in (Figure 4.38-Figure 4.41).

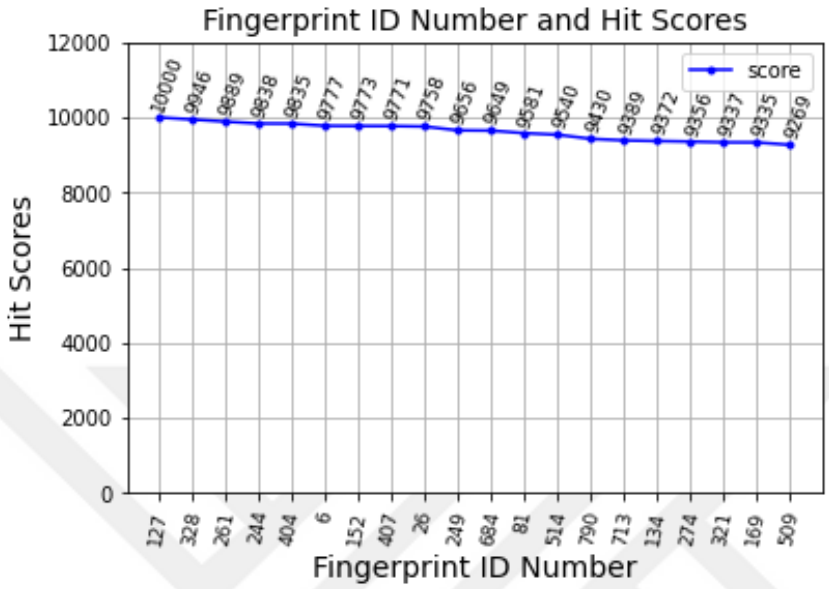


Figure 4.38: Automatic Coding 20 Pore-marked First 20 Hit List Scores without Noise (Fingerprint ID No.127)

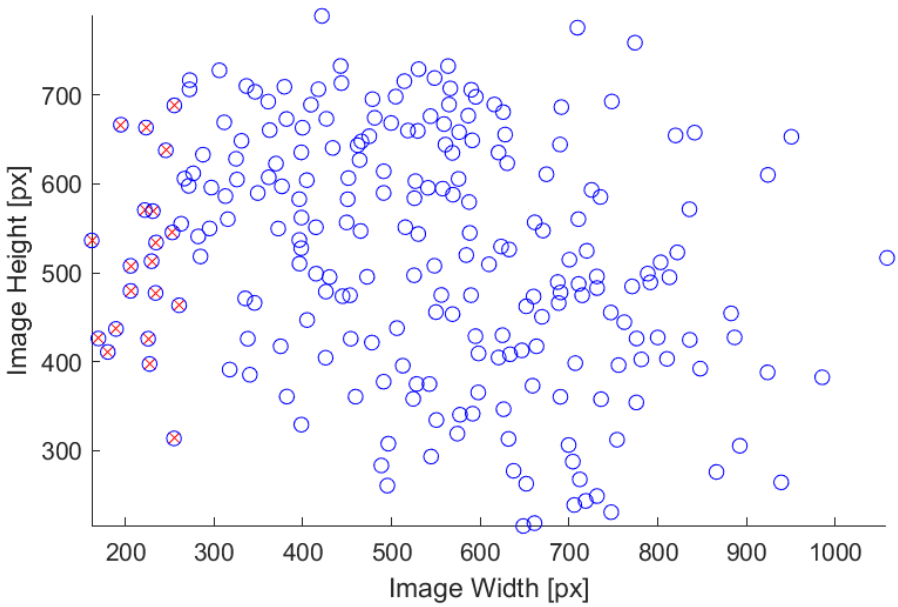


Figure 4.39: Automatic Coding 20 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.127)

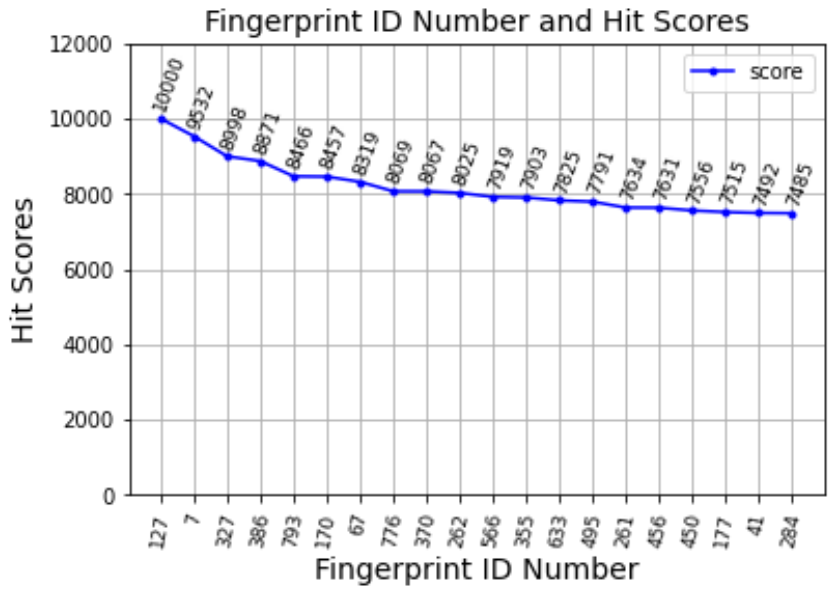


Figure 4.40: Automatic Coding 100 Pore-Marked First 20 Hit List Scores without Noise (Fingerprint ID No.127)

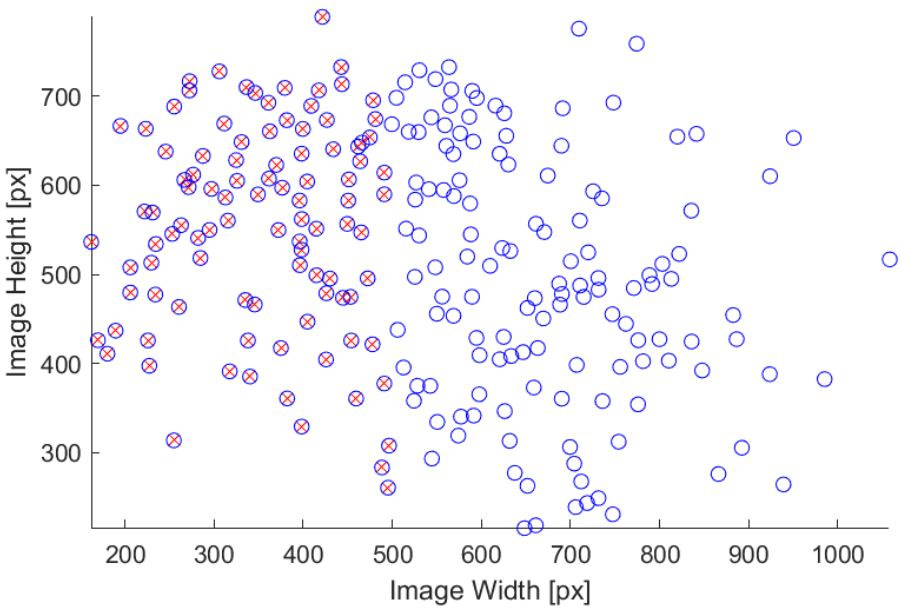


Figure 4.41: Automatic Coding 100 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.127)

The matched fingerprint scoring values of 20 and 100 pore-marked latent fingerprints which matched with Fingerprint ID Number 127 from the database with a maximum random shift of five pixels in the x-y plane and the pore matching image of the matched fingerprint are given in (Figure 4.42-Figure 4.45).

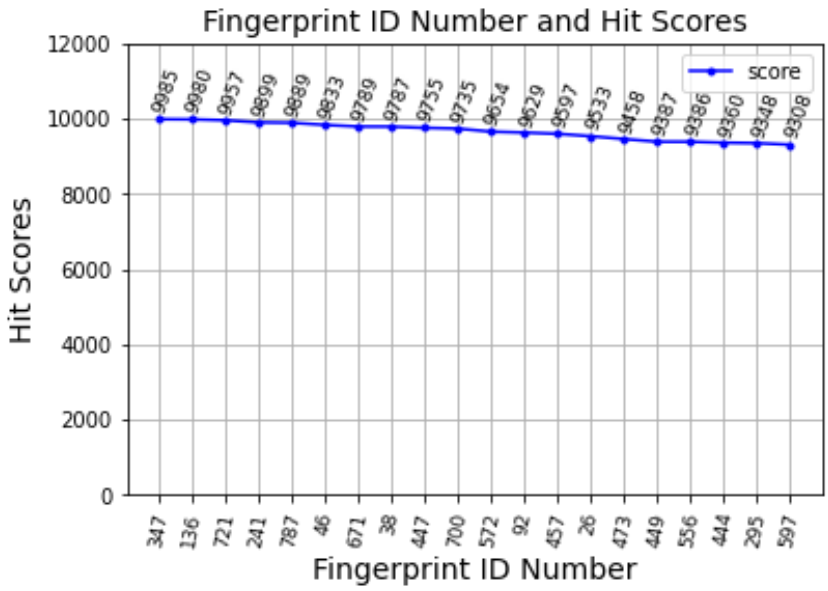


Figure 4.42: Automatic Coding 20 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.127)

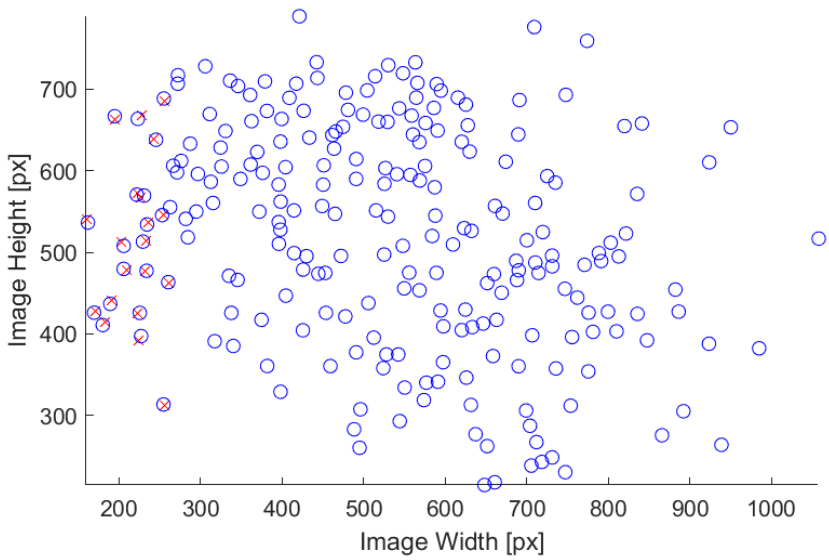


Figure 4.43: Automatic Coding 20 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.127)

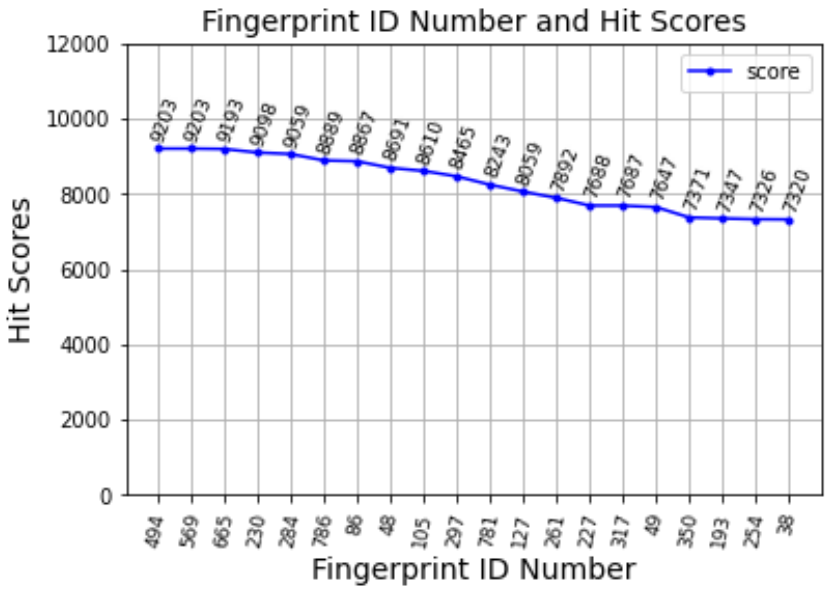


Figure 4.44: Automatic Coding 100 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.127)

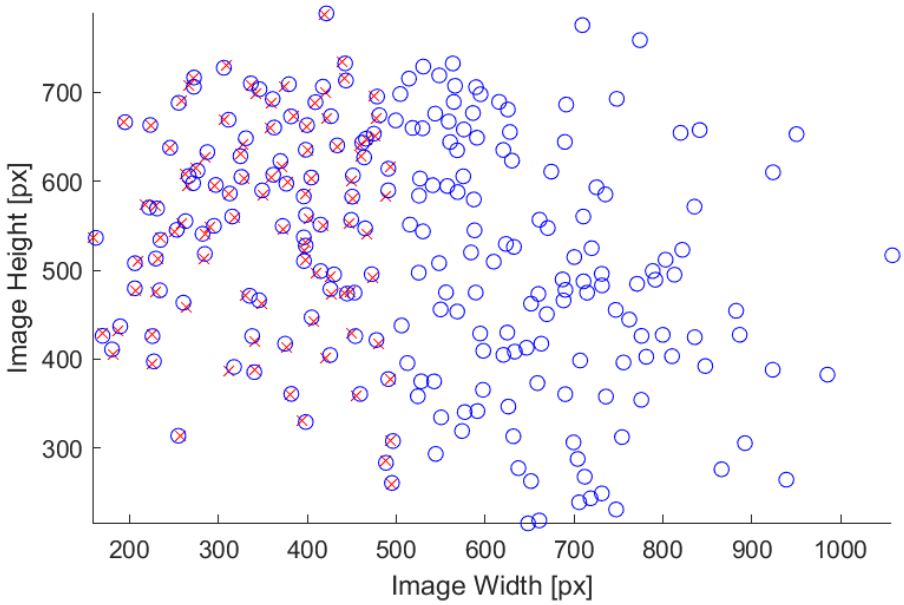


Figure 4.45: Automatic Coding 100 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.127)

The matched fingerprint scoring values of 20 and 100 pore marked latent fingerprints which matched with Fingerprint ID Number 416 from the database without noise and

the pore matching image of the matched fingerprint are given in (Figure 4.46-Figure 4.49).

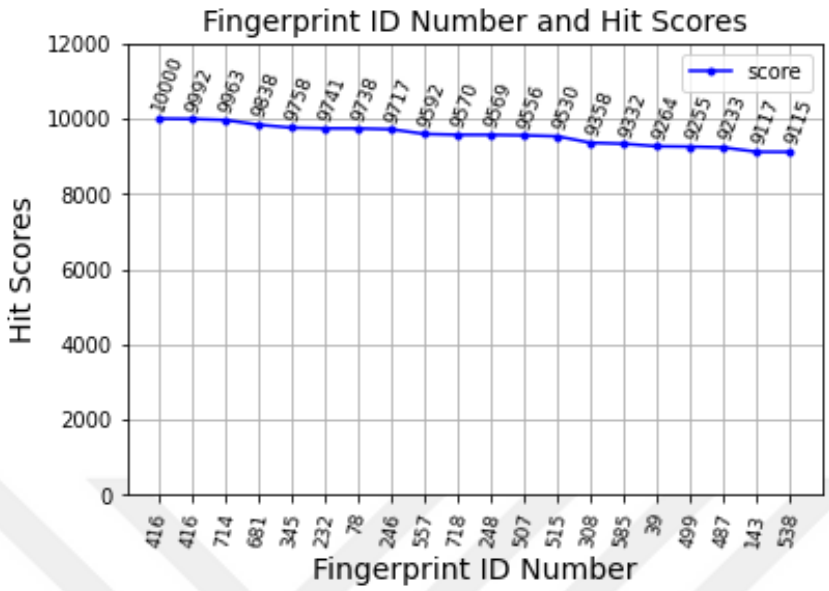


Figure 4.46: Automatic Coding 20 Pore-marked First 20 Hit List Scores without Noise (Fingerprint ID No.416)

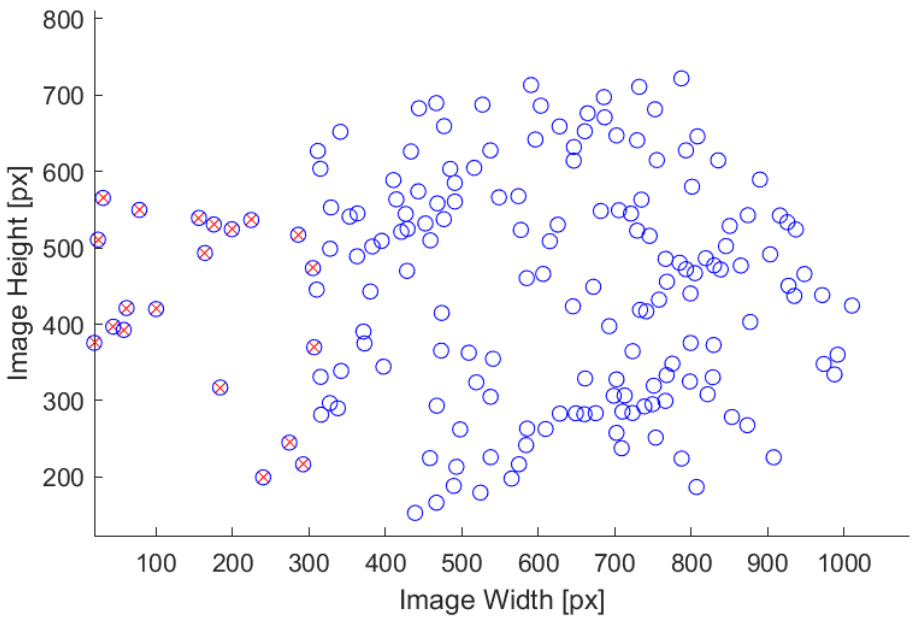


Figure 4.47: Automatic Coding 20 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.416)

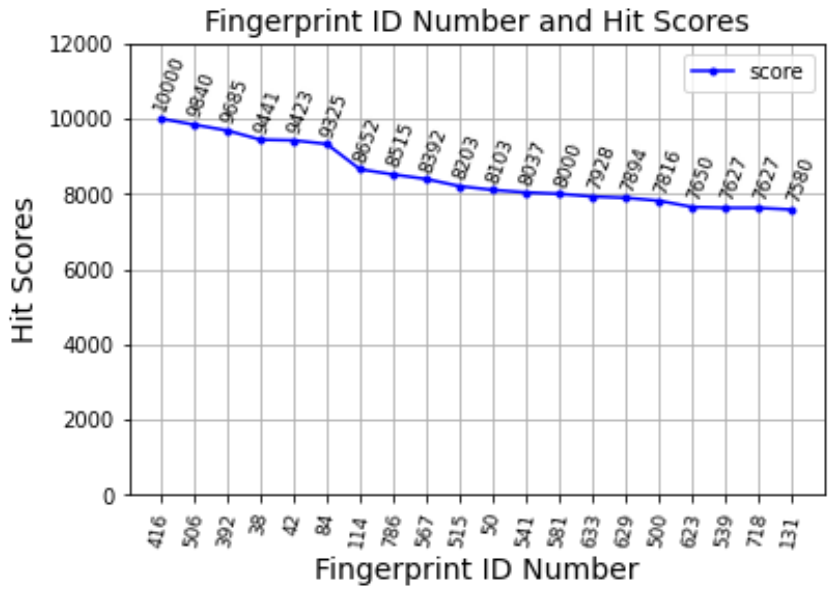


Figure 4.48: Automatic Code 100 Pore-Marked First 20 Hit List Scores without Noise (Fingerprint ID No.416)

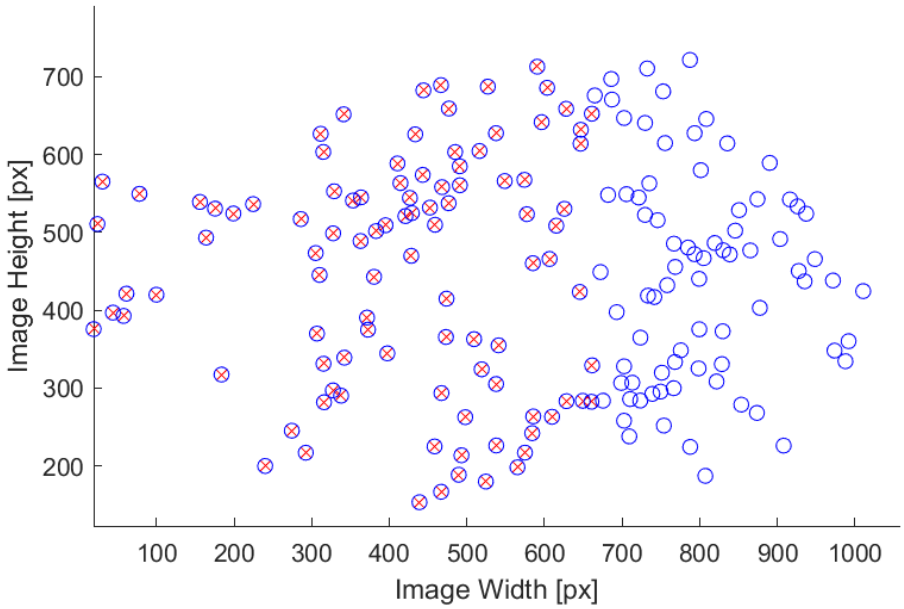


Figure 4.49: Automatic Code 100 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.416)

The matched fingerprint scoring values of 20 and 100 pore-marked latent fingerprints which matched with Fingerprint ID Number 416 from the database with a maximum random shift of five pixels in the x-y plane and the pore matching image of the matched fingerprint are given in (Figure 4.50-Figure 4.53).

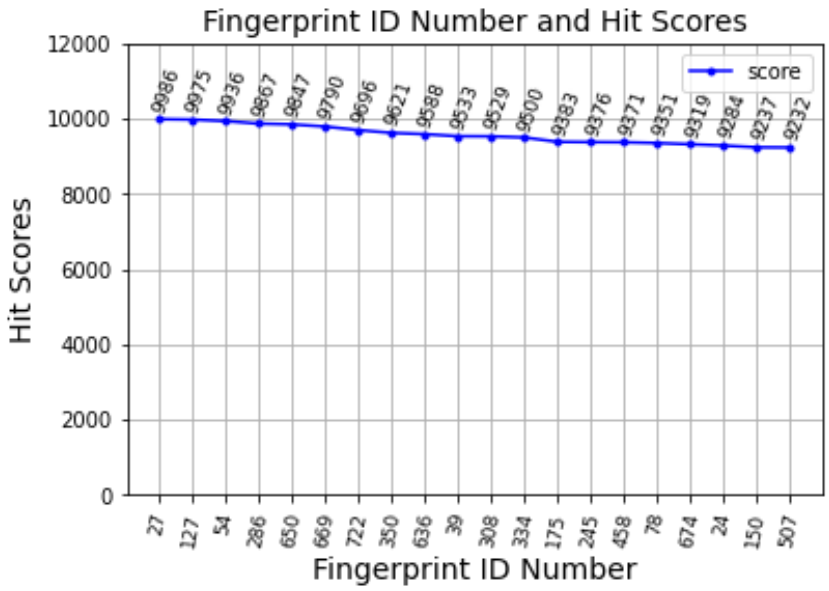


Figure 4.50: Automatic Coding 20 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.416)

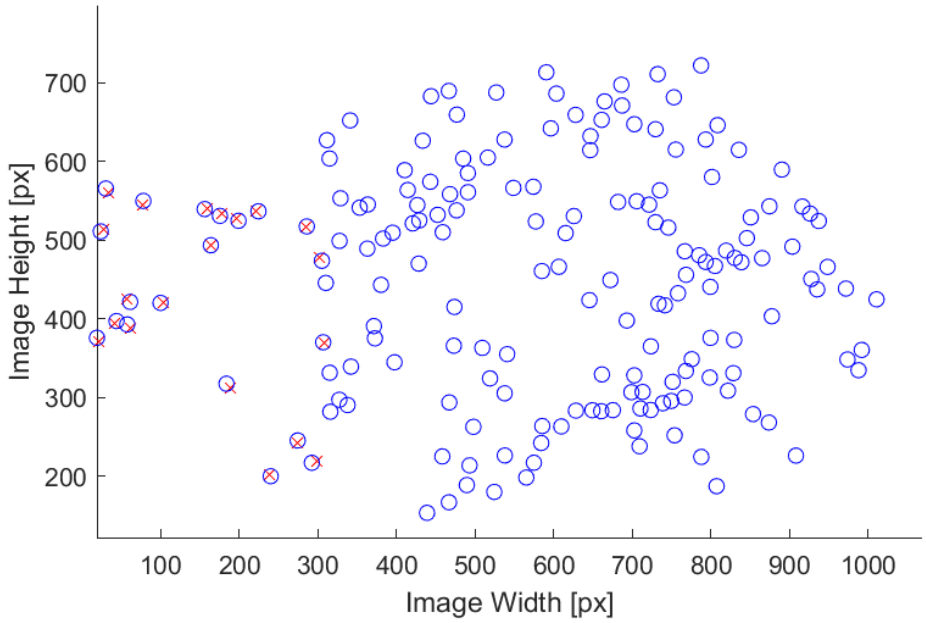


Figure 4.51: Automatic Coding 20 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.416)

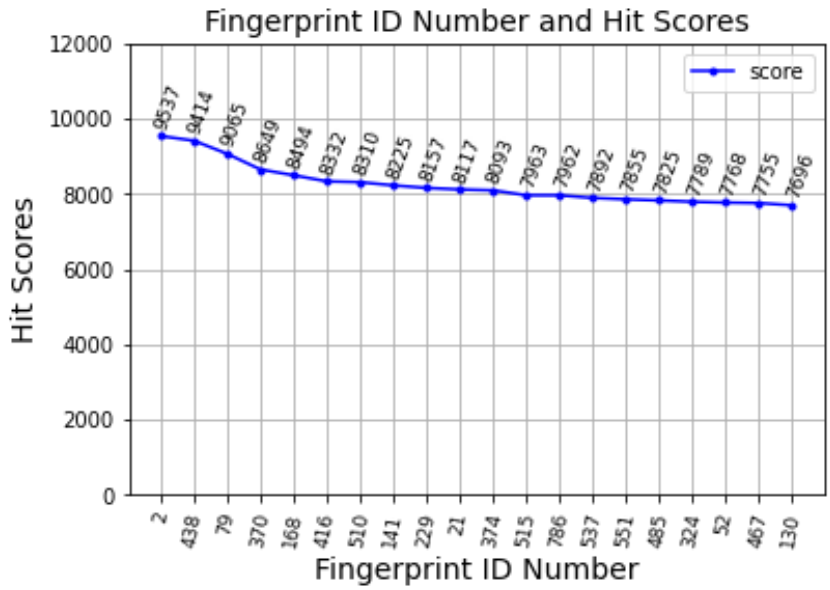


Figure 4.52: Automatic Coding 100 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.416)

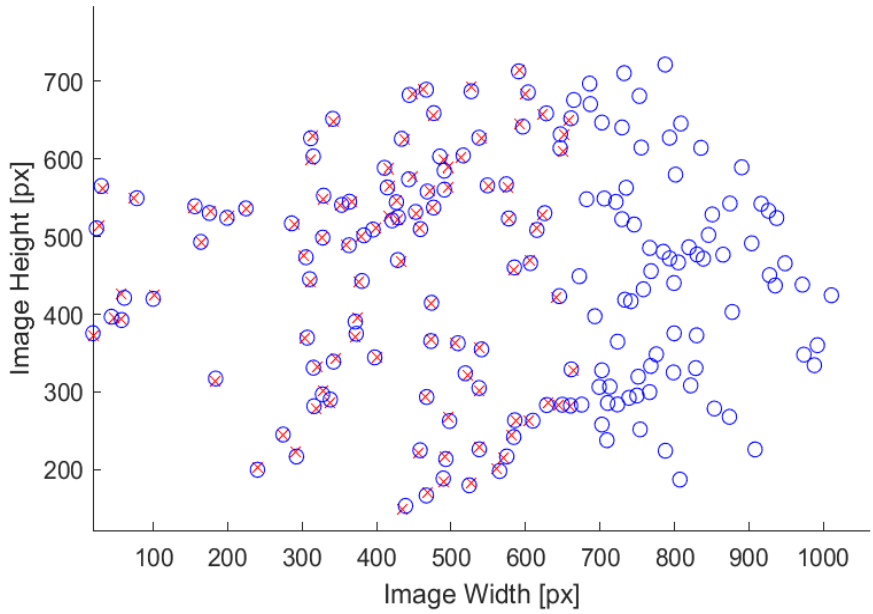


Figure 4.53: Automatic Coding 100 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.416)

The matched fingerprint scoring values of 20 and 100 pore marked latent fingerprints which matched with Fingerprint ID Number 431 from the database without noise and the pore matching image of the matched fingerprint are given in (Figure 4.54-Figure 4.57).

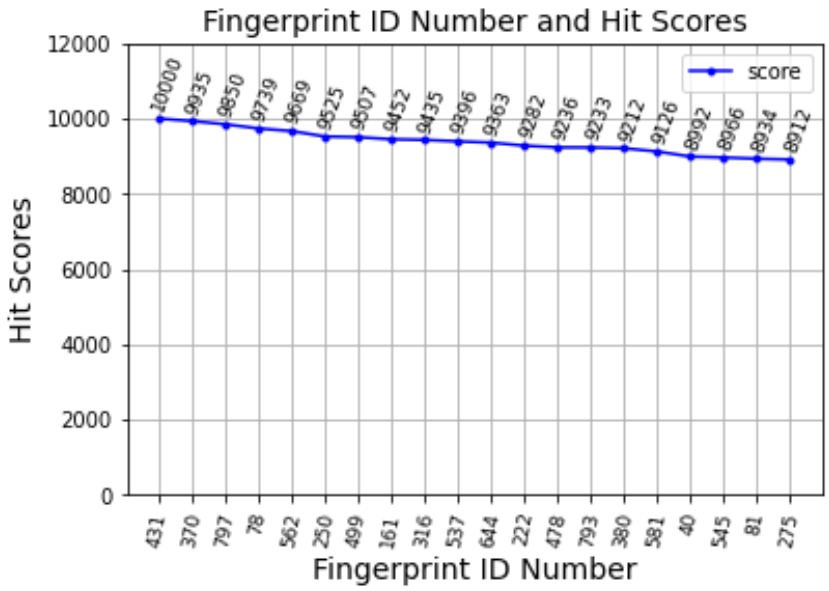


Figure 4.54: Automatic Coding 20 Pore-marked First 20 Hit List Scores without Noise (Fingerprint ID No.431)

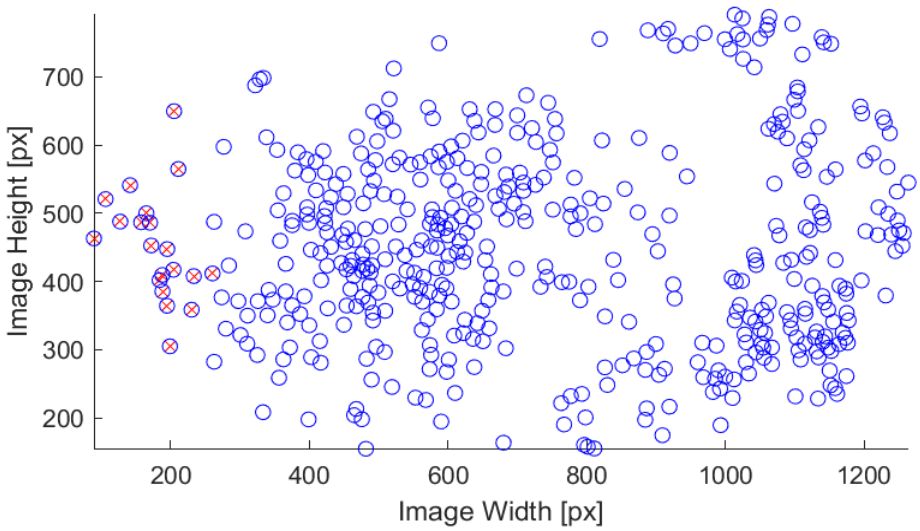


Figure 4.55: Automatic Coding 20 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.431)

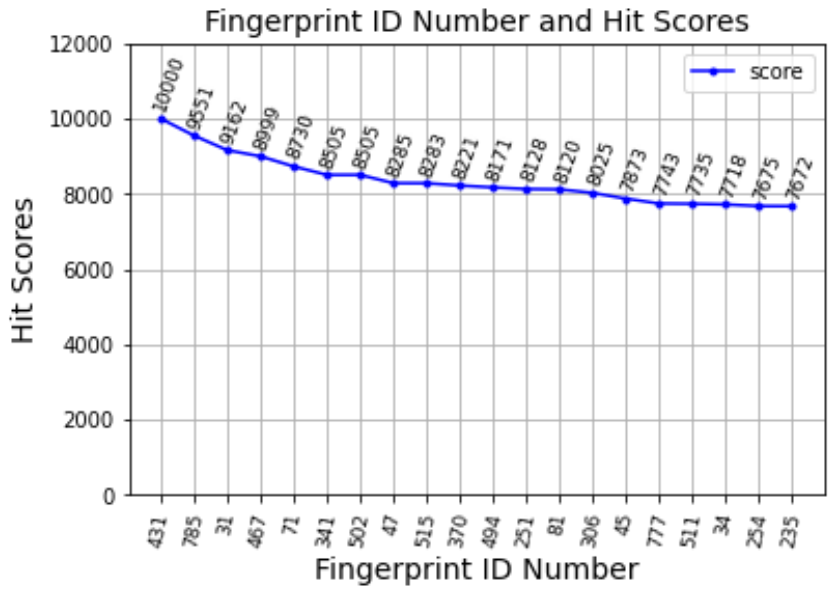


Figure 4.56: Automatic Coding 100 Pore-Marked First 20 Hit List Scores without Noise (Fingerprint ID No.431)

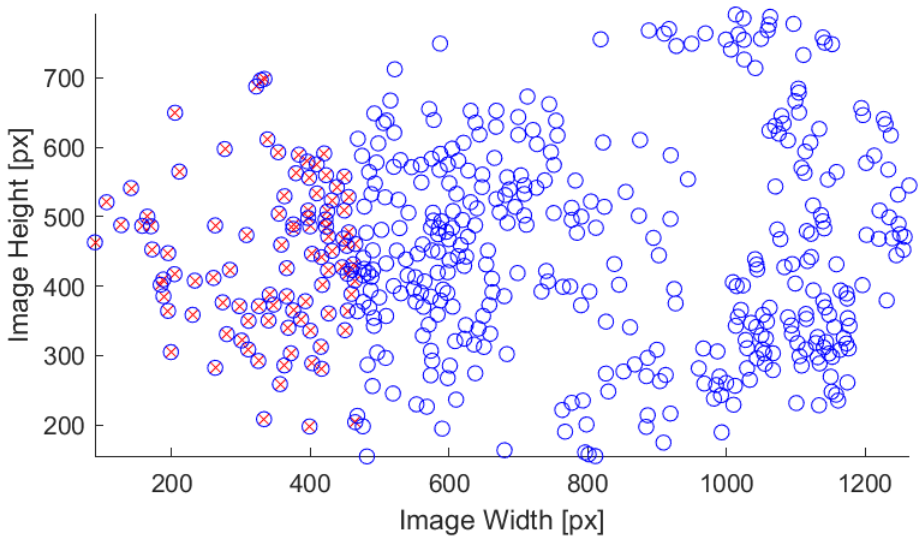


Figure 4.57: Automatic Coding 100 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.431)

The matched fingerprint scoring values of 20 and 100 pore-marked latent fingerprints which matched with Fingerprint ID Number 431 from the database with a maximum random shift of five pixels in the x-y plane and the pore matching image of the matched fingerprint are given in (Figure 4.58-Figure 4.61).

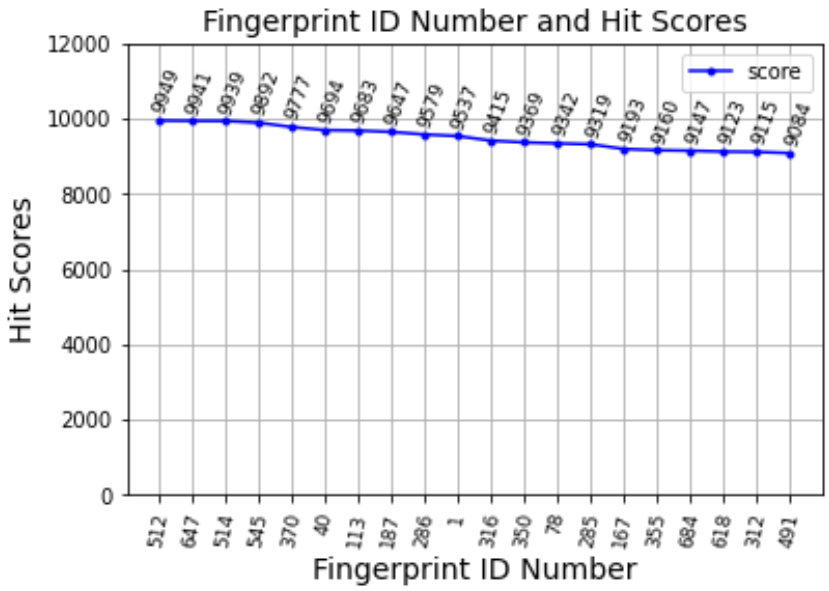


Figure 4.58: Automatic Coding 20 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.431)

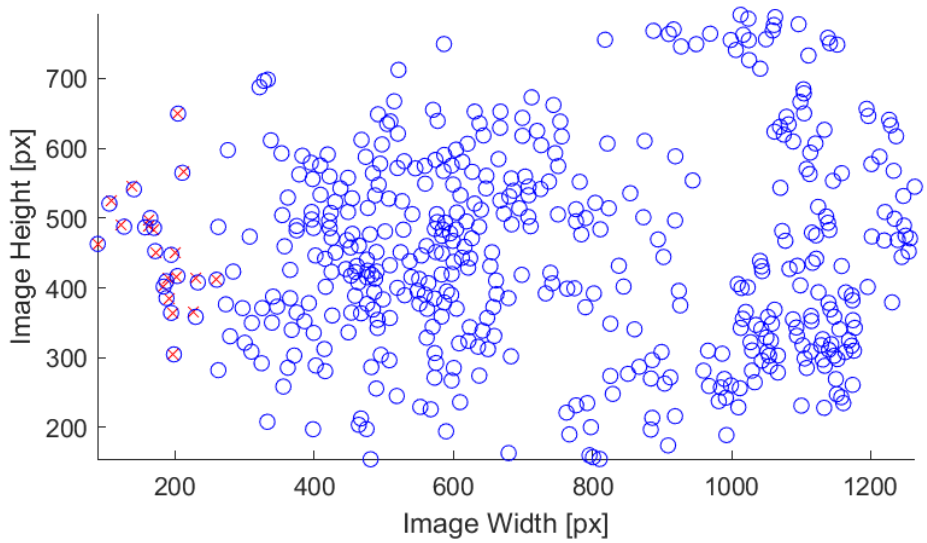


Figure 4.59: Automatic Coding 20 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.431)

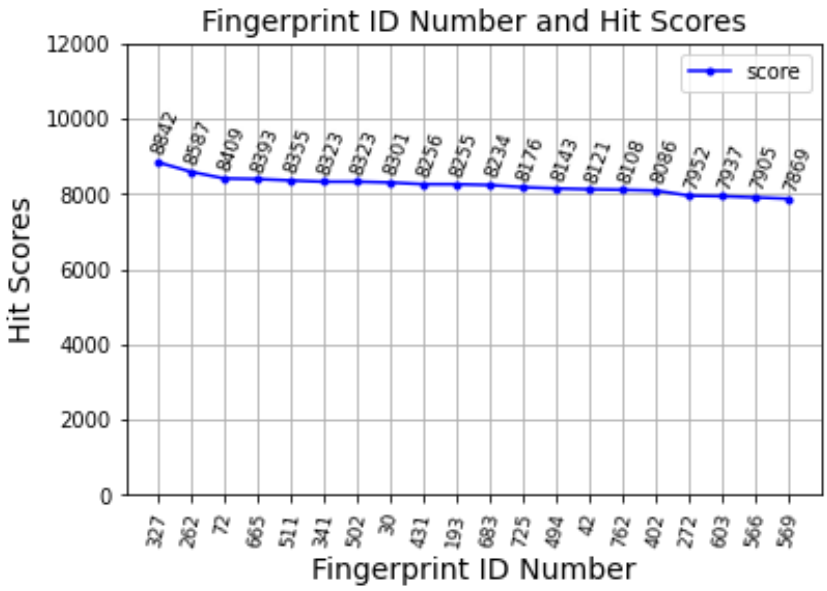


Figure 4.60: Automatic Coding 100 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.431)

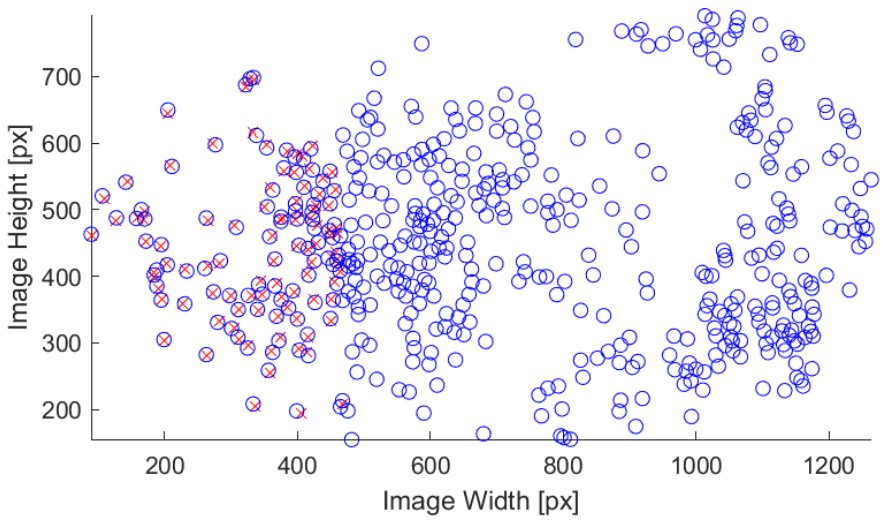


Figure 4.61: Automatic Coding 100 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.431)

The matched fingerprint scoring values of 20 and 100 pore marked latent fingerprints which matched with Fingerprint ID Number 362 from the database without noise and the pore matching image of the matched fingerprint are given in (Figure 4.62-Figure 4.65).

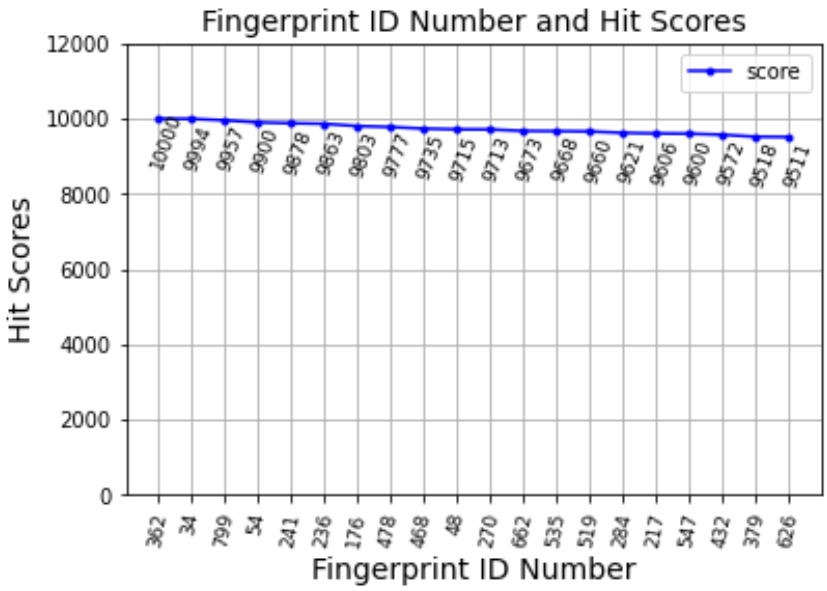


Figure 4.62: Automatic Coding 20 Pore-marked First 20 Hit List Scores without Noise (Fingerprint ID No.362)

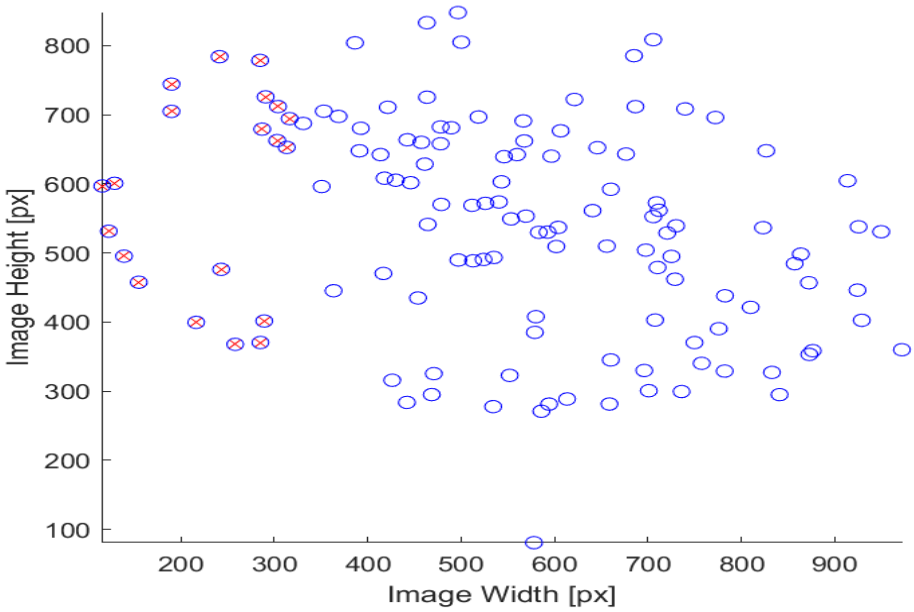


Figure 4.63: Automatic Coding 20 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.362)

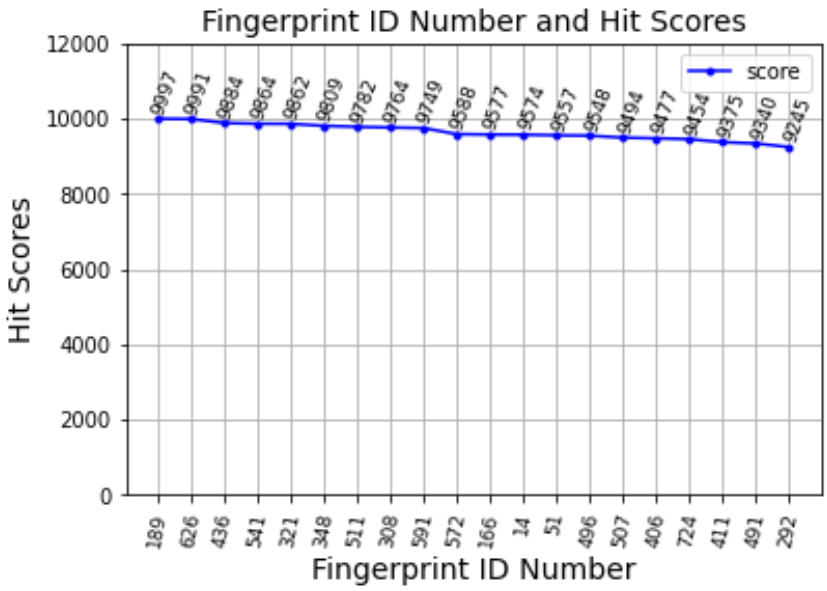


Figure 4.64: Automatic Coding 100 Pore-Marked First 20 Hit List Scores without Noise (Fingerprint ID No.362)

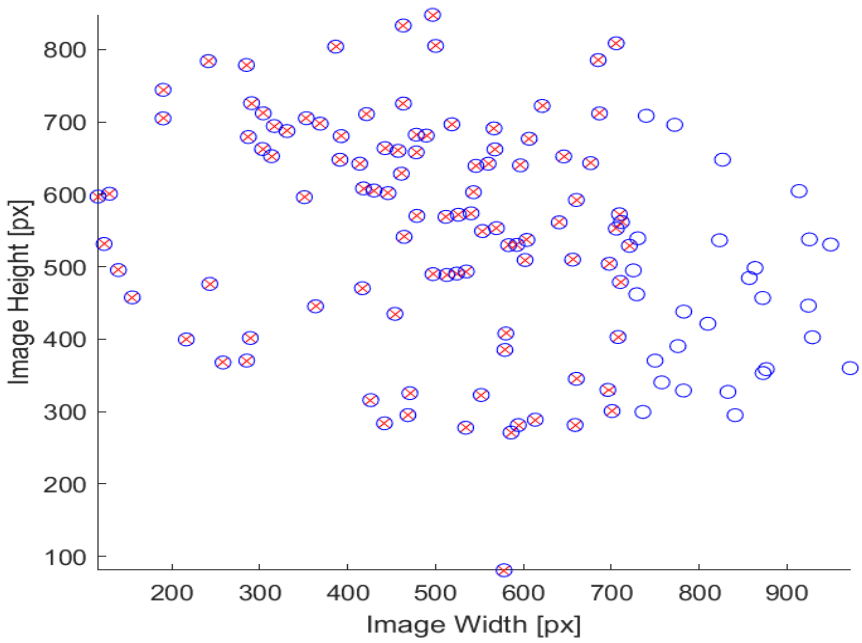


Figure 4.65: Automatic Coding 100 Pore-marked Matched Fingerprint Pore-matched Image without Noise (Fingerprint ID No.362)

The matched fingerprint scoring values of 20 and 100 pore-marked latent fingerprints which matched with Fingerprint ID Number 362 from the database with a maximum random shift of five pixels in the x-y plane and the pore matching image of the matched fingerprint are given in (Figure 4.66-Figure 4.69).

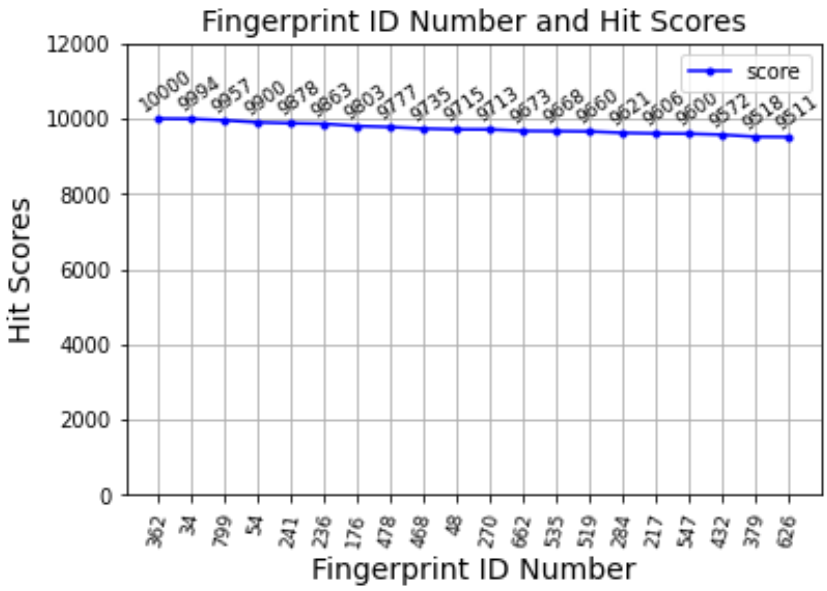


Figure 4.66: Automatic Coding 20 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.362)

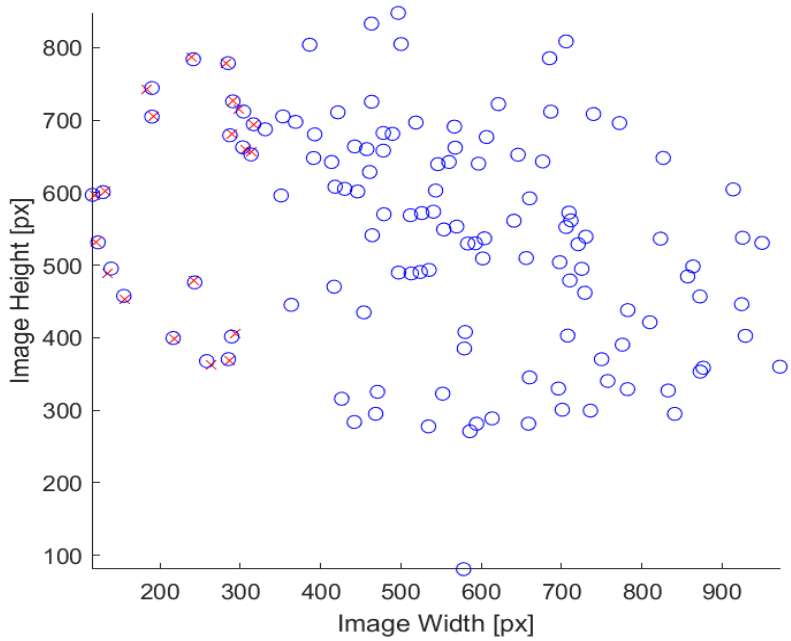


Figure 4.67: Automatic Coding 20 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.431)

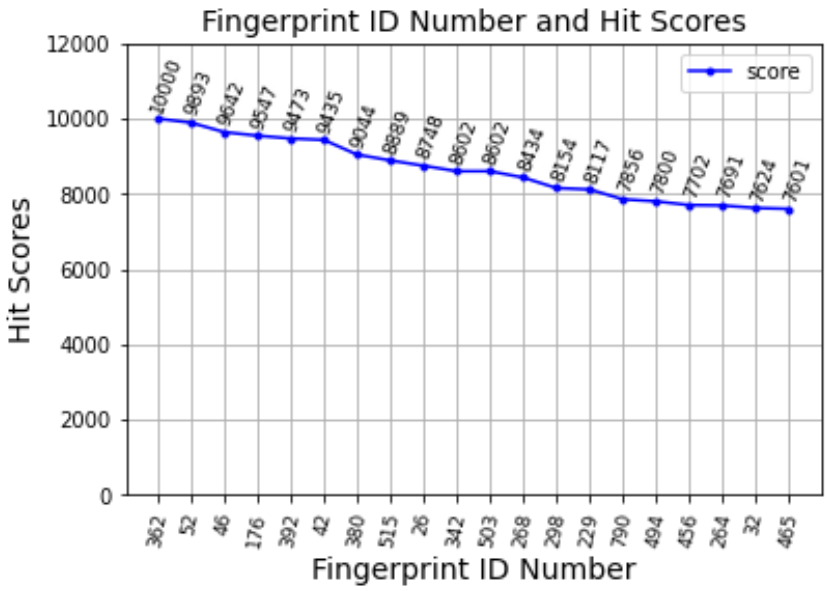


Figure 4.68: Automatic Coding 100 Pore-Marked First 20 Hit List Scores with Noise (Fingerprint ID No.362)

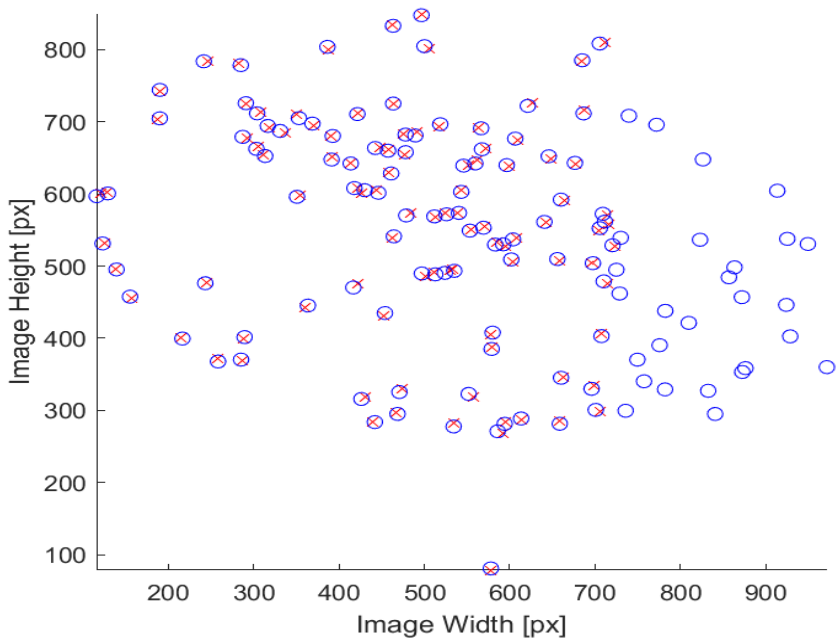


Figure 4.69: Automatic Coding 100 Pore-marked Matched Fingerprint Pore-matched Image with Noise (Fingerprint ID No.362)

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, while creating the database in which latent fingerprints will be queried, unlike classical fingerprinting methods, hyperspectral imaging was preferred in order to get more details in the detection of pores.

In the light of the findings, a threshold value was specified for determining the amount of pore to be marked first in detecting the latent fingerprint in a third-level identification. By applying a fixed amount of noise, the response level of the algorithm against the noise was observed at different pore amounts. After the effect of noise was observed, the amount of pore and the amount of noise were kept constant and all the fingerprints in the database were queried within themselves. After the query, new hits rankings were determined depending on the response of the algorithm to the noise.

In our study, it was observed that the increase and decrease in the scoring of latent fingerprints and fingerprints in the database were directly related to the number of marked pores and the amount of noise. As expected, the hit scores of the second and later fingerprint decreased as the number of marked pores increased. As the number of marked pores decreased, the hit scores of the second and later fingerprint increased. This shows us how important the amount of marked pore is in detecting latent fingerprints.

Considering the high number of pores, different opinions have been put forward about how many pores are required for identification. Ashbaugh has assessed those 20 to 40 pores are sufficient for identification [74]. In our study, it was observed that latent fingerprints could be detected when 20 pores were marked, but the hit scores of the subsequent fingerprints were also very close to it (Figure 5.1).

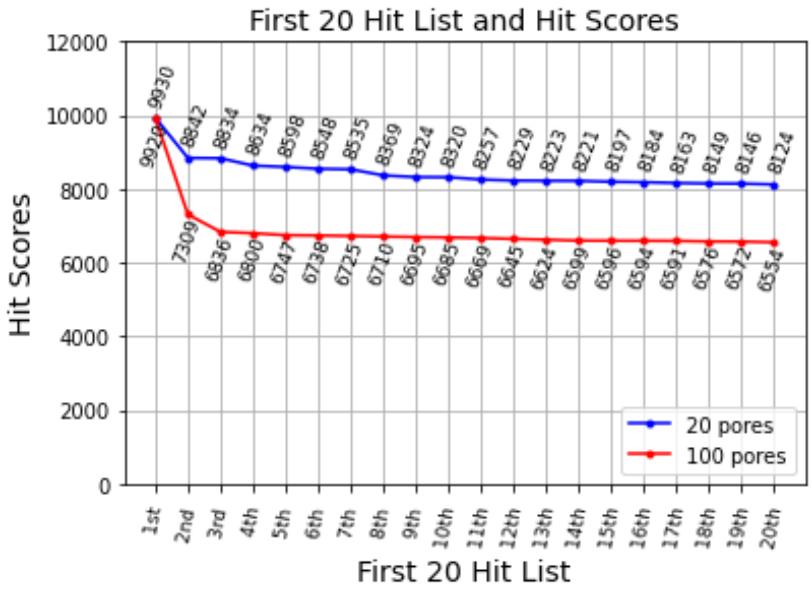


Figure 5.1: 20 and 100 Pore-Marked First 20 Hit List Scores without Noise

It is evaluated that the presence of hits with a high matching rate after the latent fingerprint, and the small number of marked pores may adversely affect the identification.

Besides the number of marked pores, another important factor is the amount of noise related to fingerprints. The amount of noise also directly affects the detection of latent fingerprints. (Figure 5.2).

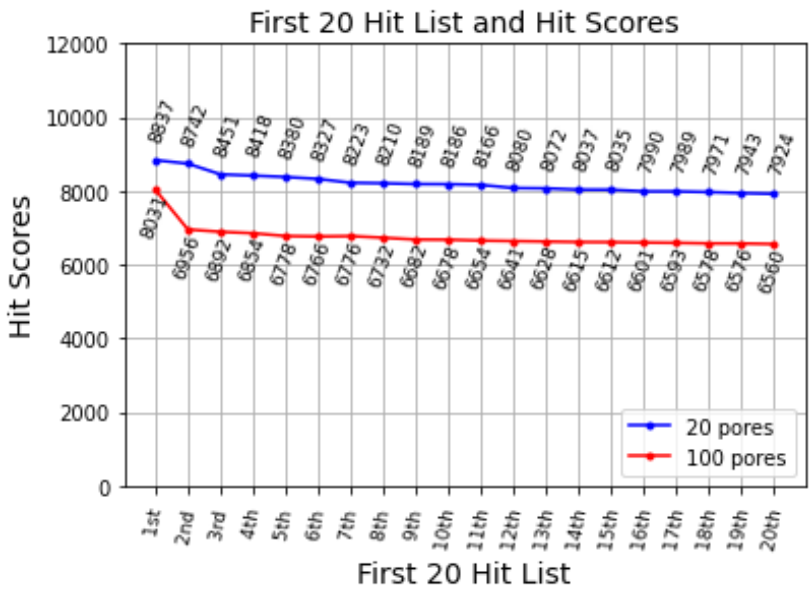


Figure 5.2: 20 and 100 Pore-Marked First 20 Hit List Scores with Noise

Therefore, the amount of marked pore and the amount of noise are the most important components in detecting latent fingerprints. While evaluating fingerprints in identification processes, we cannot consider the amount of marked pore and the amount of noise independently each other.

Ashbaugh, in a study on Poroscopy, stated that the physical detection methods used in the detection of fingerprints on the evidence at the crime scene during the identification process adversely affect the visible surface area of the pores, and sometimes it is one of the factors that make the detection of pores even difficult [75]. Therefore, the amount of noise that makes it difficult to detect the pores in the fingerprints negatively affects the resistance coefficient of our Iterative Closest Point (ICP) algorithm-based system.

In our study, the latent fingerprint of the 127th person, whose 20 pores were marked with a maximum random shift of five pixels in the x-y plane, fell to the 15th rank (Figure 4.10). As a result of the query, the same latent fingerprints marked with 100 pores proceed to the first rank again (Figure 4.12). From this result, we can see how the amount of noise negatively affects the identification process.

Considering the results obtained in the graph given below, we see the score performance of the candidate fingerprints coming after the fingerprint matching the target fingerprint, in the matching order of the comparative standard deviation and mean values.

At the same time, besides the results obtained after the noise applied to the latent fingerprint, the results regarding the manual and automatic marking of the pore features, which is one of the important stages of identification from fingerprints, are also shared below comparatively (Figure 5.3).

At the same time, besides the results obtained after the noise applied to the crime scene fingerprint, the results regarding the manual and automatic marking of the pore features, which is one of the important stages of identification from fingerprints, are also shared below comparatively (Figure 5.3). From these results, it reveals the importance of algorithms to be used automatically for marking pore features together with the algorithms used for matching.

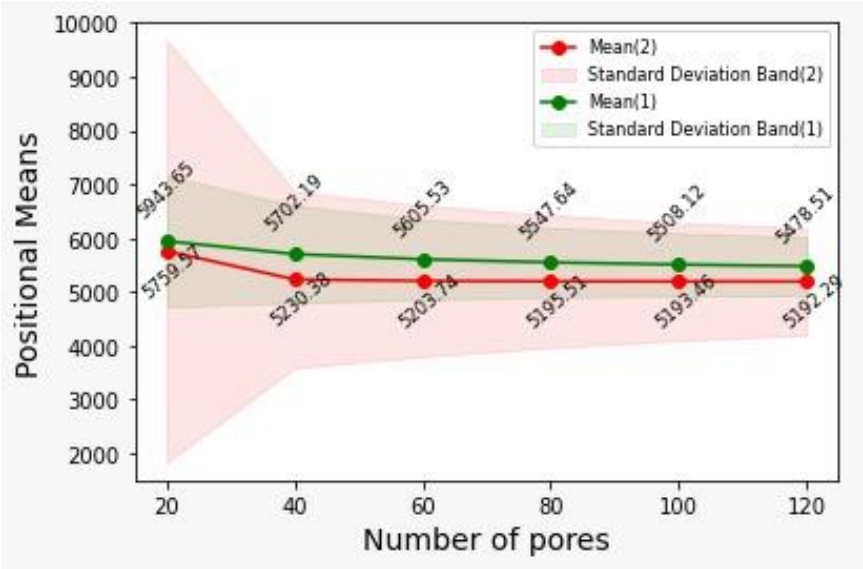


Figure 5.3: Comparison of Auto (1) vs. Manuel (2) Coding Graph of Mean and Standard Deviation

According to the results obtained in this study, it is seen that the results of manually marked pore features are more precise than the results of automatically marked pore marks. Although significant results have been obtained with the Blob Detection algorithm used for automatic marking, it is considered that different algorithms can be used to achieve precise results in further studies.

When the Positional Standard Deviation and Positional Average results are evaluated, it is seen that the ranking results of manually marked fingerprints are more precise and the matching order is higher.

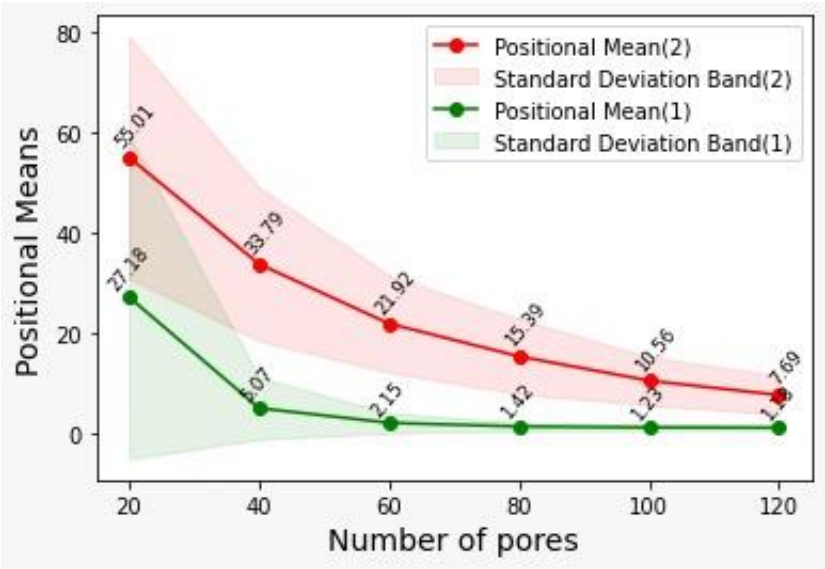


Figure 5.4: Comparison of Manuel (1) vs. Auto (2) Coding Graph of Score-based Positional Mean and Positional Standard Deviation

It was observed that the matching order went backwards after the noise applied to some of the randomly selected and manually marked fingerprints from the Data Set. It was observed that the same fingerprints that regressed to the lower ranks became delisted after automatic marking. This situation is clearly observed in the comparison chart.

Although the study was conducted hierarchically within the scope of third-level identification, the evaluation we made proceeds independently of first-level classification and second-level minutiae-based identification.

In this case, on the axis of second-level identification, fingerprint experts will be able to independently support opinion trends at different decision levels that they may encounter, depending on the hit score.

If the number of features is 8-12 in the minutiae-based identification process; It is obvious that the fingerprint, which is considered to be matching, is evaluated as weak evidence by the judicial bodies. However, in the cases mentioned, fingerprints evaluated in detail with pore characteristics will be able to be strenght evidence.

If the number of Minutiae is <8; Contrary to the positive opinion in the first case, in the presence of eight or less papillary characteristics, the negative opinion tendencies of the experts can be strengthened by identification with pore characteristics [76].

As a result, pore characteristics will support opinions in a positive direction in the presence of papil characteristics above 12, while it will contribute negatively to the presence of papil characteristics below 8, and in the presence of papil characteristics below 8-12, it will ensure that fingerprints are a strenght means of proof.

5.2 Recommendation

The study presents an approach based on direct pore matching, independent of the minutiae-based fingerprint matching system, which is the classical method. Although the proposed method works independently of second-level identification, it plays a supporting role in decision scales in second-level identification processes. In addition to this, it provides the opportunity to detect fingerprints whose owner is unknown in databases. Working separately from the minutiae-based approach, our method complements second-level identification processes. Its ability to provide extra support adds nuance to the decision-making process, improving the overall effectiveness of the identification process. Moreover, our method introduces a new aspect by enabling the

detection of fingerprints whose owners are unknown in extensive databases. This amplifies its potential impact on criminal investigations and security operations.

One of the most compelling aspects of our method is how it transforms latent fingerprints. Traditionally considered less important due to their perceived limitations, latent prints now gain significance. Instead of being fragile pieces of evidence that could be ignored or deemed unsuitable for comparison, our method offers a powerful way to increase their value. By using enough pore details, latent prints can overcome their initial weaknesses and become compelling evidence that courts can accept. In legal proceedings, our approach brings about a significant change. Latent prints, which often struggled to make an impact in court, now have the potential to influence judicial decisions. This not only marks a major advancement in forensic sciences but also reshapes legal arguments. The potential for latent prints to be seen as strong evidence adds a new dimension to legal discussions, ushering in an era where analyzing pore-based features can have significant implications for determining guilt or innocence. Furthermore, the practical implications of our study extend to expert testimony and the daily work of fingerprint professionals. Our method empowers fingerprint experts to navigate the complex process of identification with greater precision. The accuracy of our method in distinguishing the details of latent fingerprints strengthens the decision-making process and enhances the reliability of forensic analyses, reinforcing the integrity of the entire criminal justice system.

A latent fingerprint that can be used as weak evidence or ignored by saying that it is not suitable for comparison can be used as strength evidence by supporting the fingerprint with enough pore numbers and can be accepted in the courts. It will also assist fingerprint experts in the decision processes of identification operations with positive inclusion and negative exclusion in the evaluation of latent fingerprint. Our focus will shift to exploring various algorithms that can remain accurate despite the noise commonly found in real-world situations. The need for strong methodologies that maintain their accuracy even under challenging conditions highlights our commitment to advancing the field. The potential of models that can autonomously and accurately mark pores holds great promise in streamlining the identification process. This not only speeds up forensic analysis but also places the field at the forefront of technology-driven advancements, facilitating the convergence of technology and human expertise.

In future studies, we will conduct research on methods that will use different algorithms that can perform matching that are more resistant to noise and provide high success with fewer pore numbers. At the same time, we will focus on models that will accurately mark pores automatically in order to speed up fingerprint identification processes. In conclusion, our study emerges as a key development that reshapes the landscape of fingerprint identification. The approach we've developed, combining direct pore matching with advanced forensic techniques, has far-reaching implications for science, law, and justice. By breaking down conventional barriers, our method opens up new perspectives, and higher levels of confidence in the outcomes of identification procedures.

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