Multimodal Biometric Recognition Systems based on Physiological Traits: A Systematic Mapping Study

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Keywords: Multimodal, Physiological, Biometric, Recognition, Image Processing, Systematic Mapping Study, Systematic Literature Review, Deep CNN Methods.

Abstract: Context: Biometric systems are fundamental to protect against identity theft and illegitimate access. However most of them are unimodal and have several drawbacks such as: noisy data, intra-class variation, inter-class similarity, non-universality and spoofing attacks. Hence, multimodal biometric recognition systems (MBRS) are increasingly in demand to overcome these limitations.
Objective: This work aims to aggregate and synthesize available studies and provide a historical and geographical classification in order to guide researchers in their choices of biometric traits (BT) combinations and image processing (IP) techniques. Therefore, we conducted a Systematic Mapping Study (SMS). Method: We analysed 247 relevant articles to answer the research questions according to inclusion and exclusion criteria, namely: country, source and year of publication, BT combinations and IP techniques employed. Results: According to our results, India tops the list; iris, fingerprint and face are the most requested by researchers. Concerning IP techniques used, PCA Algorithm leads (24%), followed equally (14%) by LBP and Deep CNN.
Conclusion: This SMS was produced to guide stakeholders in choosing the most relevant configuration between of BT and IP methods when designing an MBRS. Findings are interesting as they provide a detailed overview of aspects that can impact the performance of a system.

1 INTRODUCTION

The pressing need to use computer security applications has increased considerably over time, making automatic personal authentication of great importance. Biometrics refers to the measurement and statistical analysis related to human characteristics. The main advantage of biometric authentication is that each person can be identified with a high degree of accuracy based on intrinsic physical or behavioral characteristics (Deriche, 1998). It has long been defined as a vigorous method of authenticating people. With new technological advances, biometric recognition systems have become an emerging solution to solve the problems related to revealing person's identity. Unimodal biometrics systems face various problems such as intra-class variations, non-universality, noisy data, restricted degrees of freedom, unacceptable error rates and spoof attacks (Ross & Jain, 2004). Therefore, the orientation towards a multimodal biometric system, which is based on multiple sources of information, is an alternative to solve these problems and improve the performance. Multimodal biometric systems are more reliable due to the presence of multiple proofs of identity and they can reduce vulnerability against spoofing attacks by using, at the same time, different modalities and varying biometric sources of information. In general, they provide better recognition performance than systems based on a single biometric modality (Jain, Nandakumar & Ross, 2005).

The studies defined in this work show that researchers are constantly proposing new models of biometric systems to achieve maximum authenticity, accuracy and reliability. (Nguyen, Fookes, Jillela, Sridharan, & Ross, 2017) review the state of the art

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design and implementation of iris-recognition-at-a-distance (IAAD) systems, present existing IAAD systems and also discusse current research challenges while providing recommendations for future research in IAAD. (Shaheed, Liu, Yang, Qureshi, Gou, & Yin, 2018) present a detailed review of finger vein recognition algorithms. The comparative studies indicate that the accuracy of finger vein identification methods is up to the mark. (Shaheed, Mao, Qureshi, Kumar, Abbas, Ullah, & Zhang, 2021) summarize and investigate various traditional and deep learning based biometric modalities. An in-depth examination of the biometric steps of several modalities using different levels such as pre-processing, feature extraction and classification is presented in detail. The result of the comparison indicates that there is still a need to develop a robust physiology-based method to advance and improve the performance. (Bharadwaj, Vatsa & Singh, 2014) introduce extensive reviews of biometric technology. (Unar, Seng & Abbasi, 2014) present the characteristics, strengths and limitations of existing techniques for assessing the quality of various biometric traits, including fingerprints, iris and face... ECG and Lip Print are two emerging biometric modalities. ECG can be combined with other robust biometrics such as fingerprints and iris to provide a reliable multimodal biometric system. The Lip Print can be combined with face and voice to develop a user-friendly biometric system (Chauhan, Arora & Kaul, 2010). (Rui & Yan, 2018) classify the existing biometric authentication systems by focusing on the security and privacy solutions. They figure and specify a number of important research directions that deserve special efforts in future research. Finally, (Abo-Zahhad, Ahmed, & Abbas, 2014) aim to review previous studies related to the use of ECG and PCG signals in human recognition and discusse the most important techniques and methodologies used by researchers in the preprocessing, feature extraction and classification of the ECG and PCG signals.

Based on this and according to the knowledge of the author, no mapping study has been carried out to date with a focus on multimodal biometric recognition systems based on physiological traits. Therefore, we were interested by conducting this study to diagnose, analyze and summarize published articles in IEEE Xplore, Science Direct, Springer, Wiley, ACM, Scopus and Web of Science databases related to this type of systems. During the period between 2010 and 2022, we have selected 1289 papers. After an exhaustive selection study we have identified 247 relevant papers.

The remainder of this paper is organized as follows: Section 2 describes the research methodology used to achieve this work. Section 3 presents and discusses the mapping results. Section 4 discusses the results obtained and presents the implication for researchers. Finally, conclusion is presented in section 5.

2 MAPPING PROCESS

Mapping studies can be very useful to researchers in establishing a solid base for further research in a defined area. They are based on the same methodology applied in the development of SLRs, except that the difference lies in the objective of each one of them.

A systematic mapping study helps to structure the type of research reports and findings that have been published by organizing them and often provides a visual summary, the map, of its findings. It often requires less effort while providing a big overview (Petersen, Feldt, Mujtaba & Mattsson, 2008).

To perform this study, we follow the mapping process suggested by (Petersen, Feldt, Mujtaba & Mattsson, 2008), steps are outlined in figure 1, each step of the process is described in detail in the following subsections with the results they provide.

2.1 Definition of Mapping Questions

2.1.1 Mapping Questions (MQs)

According to (Petersen, Vakkalanka & Kuzniarz, 2015), the research questions in mapping studies are general as they aim to uncover research trends. Thus, we present this mapping study in order to provide a comprehensive overview of physiological-based biometric multimodal recognition systems and to identify the amount and the type of published researches between 2010 and 2022. The following mapping questions were identified:

- MQ1: How publications are distributed across countries?

Motivation: To identify the universities and research laboratories working on this subject around the world.

- MQ2: What is the quality of relevant articles according to conference and/or journal rank?

Motivation: To know the degree of scientific relevance of the different contributions.

- MQ3: According to MQ1 and MQ2, is there a correlation between the quality of the selected articles and the scientific production?

Motivation: To know if there is a proportional relationship between the quality and the quantity of

the published works according to conference and/or journal rank.

- MQ4: What is the annual trend of publications?

Motivation: To give researchers the opportunity to position themselves well in relation to this disciplinary field.

- MQ5: Where were the selected studies published?

Motivation: To know if there is a cumulative and progressive interest from the scientific community over time.

- MQ6: What are the most used biometric traits combinations studied in the selected papers?

Motivation: To find the most requested combinations of biometric traits in the studied systems.

- MQ7: What are the main image processing techniques identified in the selected papers?

Motivation: To know the different image processing techniques used when designing systems and be able to classify them according to the recorded performance.

2.2 Search Strategy

To perform this study, it was imperative to answer the predefined research questions. For this we have adopted the research approach detailed below.

2.2.1 Literature Resources

To carry out an exhaustive search and cover a wide range of information in the literature, we identified candidate primary articles to answer the research questions. The selection of these articles was performed by applying search strings in the following seven digital databases: Scopus, Springer Link, ACM Digital Library, Science Direct, Wiley, IEEE Xplorer and Web Of Science.

The search interval was limited between 2010 and 2022. Searches were conducted separately based on title, abstract, and keywords only for Scopus. For the other six databases, the search was extended to the entire article. Note that the searches must be adjusted according to the needs of each database.

2.2.2 Search Terms

a- Pico

According to the PICO (Population, Intervention, Comparison and Outcome) criteria suggested by (Kitchenham & Charters, 2007) and based on the main terms extracted from RQs and the semantically similar terms, the search string was defined as follows:

("Multimodal Biometric" OR "Multi-Modal Biometric" AND ("Recognition" OR "Authentication" OR "Identification" OR "Verification") AND ("System" OR "Scheme" OR "Approach" OR "Method" OR "Algorithm" OR "Technic" OR "Model") AND ("Physiological traits" OR "Finger Vein" OR "Palm Vein" OR "Finger Print" Or "Face" OR "Lips" OR "Iris" OR "Retina").

Population: It refers to specific software engineering role, category of software engineer, an application area or an industry group (Kitchenham & Charters, 2007). In our context, the population are Multimodal Biometric Systems based on physiological traits;

Intervention: It refers to a software methodology, tool, technology, or procedure (Kitchenham & Charters, 2007). In this study, we focus on recognition of morphological biometric images;

Comparison: It refers to the software engineering methodology /tool/ technology/ procedure with which the intervention is being compared (Kitchenham & Charters, 2007). In this study, it intends all terms related to the biometric recognition process;

Outcomes: No measurable results are taken into account, since we do not evaluate the results obtained in the different articles studied.

b- Adapted Search String:

In order to refine the search in certain electronic databases, it was necessary to adapt the search string and some of the associated filters. It should be noted that the search in these databases was carried out on 09/02/2022.

2.2.3 Search Process

In order to ensure that no candidate article was eliminated, a research process was followed as outlined below:

1st step: The first author conducts search in the seven predefined databases to find an initial batch of candidate papers, then carefully reviews the title, abstract, and keywords using the inclusion and exclusion criteria. In case or information contained in the metadata is not sufficient to accept or reject the paper, the full-text must be explored.

2nd step: On a shared spreadsheet, the same author stores extracted data from selected studies and for each article he indicates his decision to accept or reject the paper. In case of doubt, he must imperatively

mention that he is uncertain in order to open the discussion with the other authors until they agree.
3rd step: To reduce threats, the other two authors evaluate independently the validated selection that has been stored in the previous shared spreadsheet and review the rejected articles to ensure that no potential article is excluded. In case of disagreement, a meeting between the three authors is scheduled to make a final decision.

2.3 Study Selection Procedure

In this section, we determine the filtering process applied to the potentially relevant articles. For this, we describe the following list which specify inclusion and exclusion criteria used in this study combined by the OR boolean operator. The number of included and excluded articles is shown in figure 2 at each stage.

- Inclusion criteria

IC1: The publication format is a peer-reviewed academic journal or conference paper.
IC2: The study was published online during the period 2010 until 2022.
IC3: The paper develops new and/or use existing image processing techniques for Multimodal Biometric Recognition Systems.

- Exclusion criteria

EC1: The paper is a duplicate found in another source of publication.
EC2: The paper is not in English language.
EC3: The paper cites Multimodal Biometric Recognition Systems just as an example.
EC4: The paper is available as abstract and/or PowerPoint presentation.
EC5: The study focuses on Continuous Multimodal Biometric Authentication Systems.
EC6: The paper is a survey, systematic mapping study, systematic literature review, a web page or a poster.

2.4 Data Extraction and Synthesis

In order to extract information from the primary selected studies, the model described in Table 1 was developed. The extraction was performed by the first author and reviewed independently by the second and third authors. The latter read the full text of all selected articles and collected the data necessary to answer the research questions addressed in this article.

2.5 Threats to Validity

The threats to the validity of this work mainly relate to the exclusion of relevant articles, publication bias and data extraction bias. One of the main problems we faced was to find all articles that addressed the research questions in order to minimize the threat of exclusion of relevant articles. To achieve this objective, we searched the seven electronic databases listed in section 2.2.1, using a search string adapted to their search engines while respecting the main search terms and their semantic similarities. However, it is probable that some relevant studies were not returned by the search terms we used. To reduce this threat, we used "Backward Snowball Sampling"; this means that a manual check of the reference list of each of the relevant studies to identify those that were missed during the automated search. To further reduce the risk of incorrectly excluding relevant articles, two researchers conducted the process of selecting relevant studies separately, using inclusion and exclusion criteria based on title, abstract and keywords. If in doubt, the full article has been read. In case of disagreement, a meeting between the three authors is scheduled to make a final decision. Besides searching and selecting all relevant studies, data extraction was the most crucial task of this study. To properly extract data from these studies, two researchers read each article independently. The data extracted for each article was compared and any disagreements were discussed by the researchers.

3 MAPPING RESULTS

This section presents and discusses the results related to the systematic mapping questions presented previously. Note that Figures 3, 4 and 5 were extracted using Biblioshiny (Aria & Cuccurullo, 2017).

3.1 Overview of the Selected Studies

Figure 2 illustrates the number of articles returned at each stage of the selection process. We notice that the search of the seven electronic databases has generated 1289 candidate articles. The application of inclusion and exclusion criteria served to identify those that were relevant, because many of the articles would not be valuable in answering the research questions. This procedure generated 247 articles. Examination of the reference lists of the selected articles did not reveal any other relevant article.
Table 2 indicates the number of studies published by channel for the period from 2010 to February 2022.

They were published in different sources, mostly journals or conferences. 50.79% (123 papers) were presented in conferences, 45.63% of the studies (115 papers) in journals, 1.98% (5 papers) in symposiums and 1.19% (3 papers) in workshops; the last paper was a book chapter.
According to figure 3, Expert Systems with Applications, Pattern Recognition and the International Journal of Biometrics top the list of publication sources for the journal category with a rate that reaches 5.21%, 4.35% and 3.48% respectively . As for the conferences, just International Conference On Trends in Electronics and Informatics (ICEI 2017) which has a rate of 2.43% (3 conference papers out of 123) and for the others each of them has published two papers (IET Biometrics, Neurocomputing, Procedia Computer Science….).

3.2 MQ1: How Publications Are Distributed across Countries?

The main objective of this question is to identify universities and research laboratories that are interested in the subject, for this, we considered the country of the first author's university. Indeed, as confirmed in figure 4, India tops the ranking with 32% of publications and about 246% more than its successor: China (13% of publications). Next comes Malaysia with a rate of 2%. The remaining 53% of publications are distributed among other countries (Canada, Algeria, USA, Cyprus, Italy, etc.) with a rate not exceeding 1.5%.

3.3 MQ2: What Is the Quality of Relevant Articles According to Conference and/or Journal Rank?

We chose to assess the relevance of each selected paper according to Scimago Journal & Country Rank for the scientific journals providing SJR and H Index scores, and CORE Conference Ranking for the conferences. In order to standardize the ranking between journals and conferences, we have calculated a new score according to the following nomenclature:

- For journals: (+5) if the journal ranking is Q1, (+4) if the journal ranking is Q2, (+3) if the journal ranking is Q3, (+2) if the journal ranking is Q4, and (+1) for others.
- For conferences: (+5) if the conference is CORE A, (+4) if the conference is CORE B, (+3) if the conference is CORE C, (+2) if the conference is CORE D, (+1) if the conference is not ERA ranked but according to Qualis, and (+0) for others.

We found that 49% of the articles are published in ranked journals and conferences and the remaining 51% in unranked sources.

3.4 MQ3: According to MQ1 and MQ2, Is There a Correlation between the Quality of the Selected Articles and the Scientific Production?

From the results obtained in section 3-2, we could see that the scientific production rate in the Asian continent was very high (47% of all selected articles) compared to other parts of the world. This led us to seek more information about the quality of these works. For this, we calculated an average score for each country based on the scores obtained for the research question MQ2, the results are presented in Table 3. It seems that the number of articles published per country is not the only criterion to determine the interest of a laboratory or a university for a given subject. If we take the example of India and Turkey, we can deduce that during the period (2010 - February 2022), Turkey published only 4 papers that met the selection criteria for this work, with an average score of 4.25; while India has been able to publish an interesting number of articles in this field, but the average score is only 1.5.

This observation led us to further examine the reasons for the interesting increase in the number of articles published in India. The following was observed; As we all know; India is the second most populated country in the world (with 1.41 billion inhabitants in 2022). In 2010, The Indian government established the largest biometric database in the world, called "Aadhaar", managed by the Unique Identification Authority of India. The system includes a 12-digit national identification number associated with each person in addition to biometric data, including iris image, facial image and fingerprints. The project also incorporates more standard data, such as name, gender, date and place of birth (Chander & Kush, 2010).

Therefore, to succeed in this huge project, unique in the world, the commitment of the scientific community was indispensable. This could explicitly explain the peak of scientific production in India in this field; the results deduced above place India at the top of the list for this specific period.

3.5 MQ4: What Is the Annual Trend of Publications?

Answering this question will give researchers the opportunity to properly position themselves with

respect to this disciplinary field and to have an overall idea of the evolution of annual scientific production. We see in figure 5 that the number of publications peaked in 2016 and 2019. On the contrary, in 2017, a decrease was observed.

3.6 MQ5: Where and When Were the Selected Studies Published?

As noted in section 3-1, 247 studies were selected out of 1289 candidate papers, of which 131 were conference papers, 115 were journal articles, and only one book chapter. The distribution of publications across libraries and their types are provided in figure 6. IEEEXPLORE and Scopus dominate the ranking with 38% and 30% respectively; representing 68% of the total selected articles. The remaining 32% are distributed as follows: 13% for SpringerLink, 4% for WOS and ACM; the last 1% is attributed to Wiley.

3.7 MQ6: What Are the Most Used Biometric Traits Combinations Studied in the Selected Papers?

After analyzing the results obtained, we decided to retain only the first six findings for which the number was significant compared to the others. In fact, it was observed, as shown in Figure 7, that the Face-Iris and the Fingerprint-Iris combination are the most frequent. Followed by the Face-Fingerprint combination, then an equal ratio for the Face-Palmprint and the Fingerprint-Fingervein combination; in the last comes the Ear-Face combination. We can therefore see that the iris is in great demand; which can be explained by the fact that the iris is one of the most accurate biometric features, with very low false match rates and high processing speeds in large-scale datasets (Bowyer, Hollingsworth, & Flynn, 2008); it is an organ of the eye, situated directly in front of the cornea and in behind the lens (Ross, 2010). These observations are reinforced by the complex texture of its stroma that differs from an individual to another, the perceived permanence of its discriminant characteristics, its high universality and its restricted genetic penetration (Nguyen, Fookes, Jillela, Sridharan, & Ross, 2017).

3.8 MQ7: What Are the Main Image Processing Techniques Identified in the Selected Papers?

The image processing techniques used in the data extraction phase and mentioned in the selected papers are very varied as mentioned in Figure 8; note that more than half (52%) opted for the three main methods, namely the PCA Algorithm (24%), the LBP (14%) and the Deep CNN (14%); followed by the Gabor filter (11%). The other methods were less used: PSO and DCT Algorithm (8%), Minutiae Algorithm (7%), DWT (6%) and LDA (4%).

3.9 Tables

Table 1: Data extraction form.

Data Item	Value	RQ
DOI		
Article Title		
Extractor//Checker		
Source	Book/conference/journal	MQ3
Publication Year		MQ3
Country		MQ1
Publication Type		
MQ2	Conf and/or journal rank	
MQ4		
MQ5		
MQ6		
MQ7		

Table 2: Selected Paper's Venue.

Publication source	Publication Type	Number of Papers	% of Selected Papers
Conference	Conf. paper	123	50.79%
Journal	Journal paper	115	45.63%
Symposium	Conf. paper	5	1.98%
Workshop	Conf. paper	3	1.19%

Table 3: Average Rating of Publications by Country.

Country	Study	Conf	Journal	Average Score
India	132	76	56	1,5
China	33	11	22	2,67
Algeria	10	7	3	1,3
Malaysia	8	3	5	2,75
Canada	7	7	-	0,71
USA	6	4	2	1
Morocco	5	3	2	1,8
Korea	5	2	3	1,2
Turkey	4	0	4	4,25
UK	4	2	2	2,75
Italy	4	1	3	2
Egypt	4	3	1	0
Iran	3	1	2	3,33
Tunisia	3	1	2	2,75
KSA	3	0	3	2
Pakistan	2	0	2	4
Portugal	2	2	0	2,5

Table 3: Average Rating of Publications by Country.(cont.)

Country	Study	Conf	Journal	Average Score
Australia	1	0	1	3
Cyprus	1	0	1	3
Sth Africa	1	1	0	1
Hong Kong	1	1	0	0
Irak	1	1	0	0

3.10 Figures

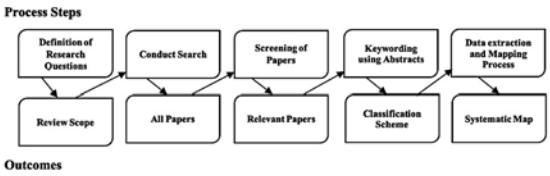

Figure 1: Mapping process.

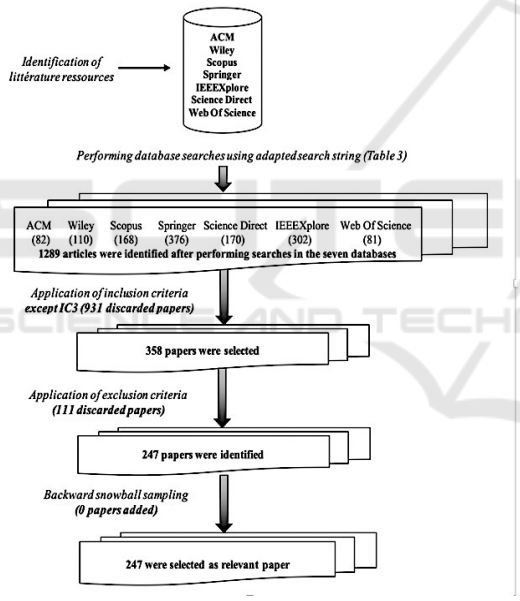

Figure 2: Study selection process.

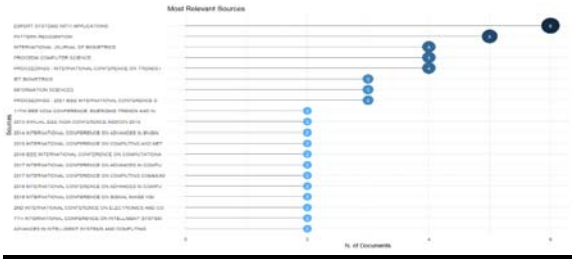

Figure 3: Most relevant sources.

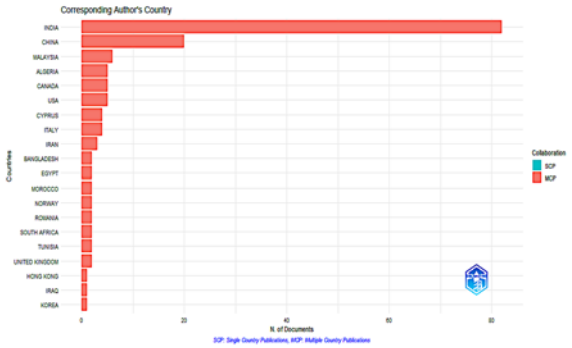

Figure 4: Corresponding Author's Country.

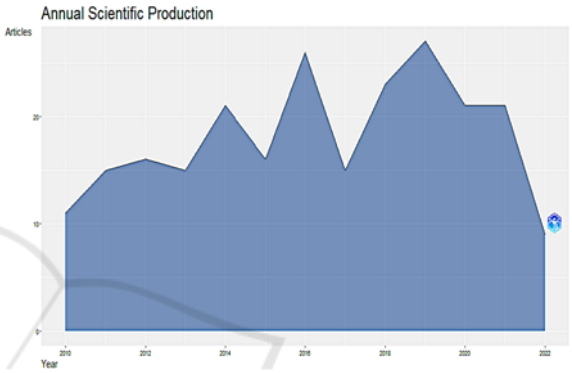

Figure 5: Annual Scientific Production.

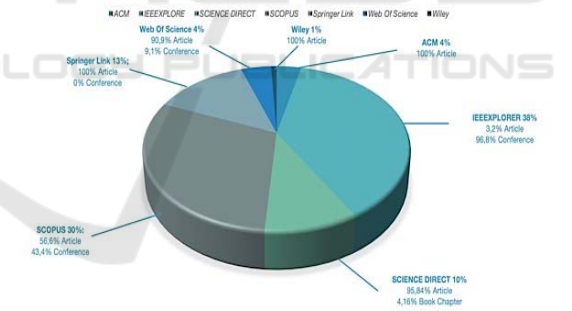

Figure 6: Libraries in which selected papers were published.

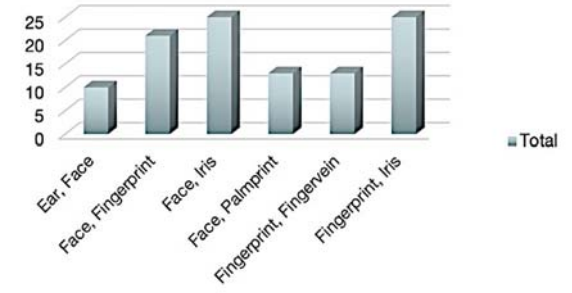

Figure 7: The most common biometric trait combinations.

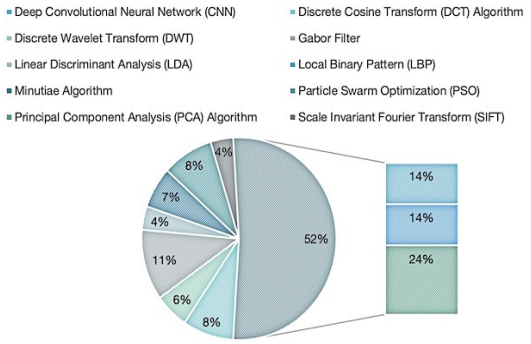

Figure 8: Distribution of the most used Image Processing techniques.

4 CONCLUSION AND FUTURE WORK

The purpose of this SMS was to analyze and synthesize articles dealing with the design of multimodal biometric recognition systems based on physiological traits. 247 relevant articles published between 2010 and February 2022 were selected and analyzed by year, source and country of publication, combinations of biometric traits and image processing techniques employed.

The current work aims to conduct a literature review in order to compare the performances recorded by the different image processing techniques and to discuss in depth the results obtained from these works while considering the choice of the used biometrics.

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