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Multi-Biometrics: Survey and Projection of a New Biometric System

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***Abstract**: Multi-biometric systems using feature-level fusion allow more accuracy and reliability in recognition performance than uni-biometric systems. But in practice, this type of fusion is difficult to implement especially when we are facing heterogeneous biometric modalities or incompatible features. The major challenge of feature fusion is to produce a representation of each modality with an excellent level of discrimination. Beyond pure biometric modalities, the use of metadata has proven to improve the performance of biometric systems. In view of these findings, our work focuses on multi-origin biometrics which allows the use of pure biometric modalities and metadata in a feature fusion strategy. The main objective of this paper is to present an overview of biometrics as bordered in the literature with a particular focus on multibiometrics and to propose a model of a multi-origin biometric system using pure biometric and soft biometric modalities in a feature-level fusion strategy. The curvelet transformation and the order statistics are proposed respectively for the extraction the feature of the pure biometric modalities, and for the selection of the relevant feature of each modality in order to ensure a good level of discrimination of the individuals. In this paper, we have presented the overview of biometrics through its concepts, modalities, advantages, disadvantages and implementation architectures. A focus has been put on multi-biometrics with the presentation of a harmonized process for feature fusion. For the experiments, we proposed a global model for feature fusion in a multi-origin system using face and iris modalities as pure biometrics, and facial skin color as metadata. This system and the results will be presented in future work.*

***Keywords**: Features, Fusion, Hierarchical-Sequential, Multi-Origin.*

I. INTRODUCTION

Individual authentication has become essential to ensure the security of systems and organizations in a world where digitalization is gaining ground in all sectors of activity. Faced with this growing need for security, various means of traditional identity verification have proven themselves. These include means based on knowledge (login, password, etc.) [1] or possession (key, badge, etc.) [2] [3], [4], [5]. But unfortunately, these means have many flaws. It is easy to see that knowledge and possessions can be stolen, lost, forgotten or falsified [6]. Faced with this problem, biometrics has taken over from traditional authentication methods [4], [5], [7]. It has the advantage of being unique because it can be measured on each individual and therefore difficult to duplicate. Biometrics is part of the technological domain that allows the identification and/or verification of the identity of people using their individual characteristics, which can be physiological or behavioral [8], [4]. To a lesser extent, these authentication methods based on biometric modalities also present shortcomings over time. In particular in terms of implementation costs, but especially in terms of performance and vulnerability to attacks [6]. Biometric systems rely on a recognition rate that is never 100%, unlike traditional authentication methods. Nowadays, technology allows biometric identity theft. In order to overcome these weaknesses of unimodal biometric systems, experiments with multibiometrics have gained ground in research 2 because it improves the performance of unimodal biometric systems [6] and it is difficult for an impostor to steal two modalities of the same person at the same time [7]. In this sense, multimodality seems to be a promising way to improve the performance of a unimodal biometric system [8], [7]. The objective of this work is to present biometrics in general, multibiometrics in particular, and especially to propose a multimodal biometric model that is resistant to identity theft and has better performance. The first section of this document presents the panorama of biometric modalities with a focus on a few modalities of each type. In the same section, we present the different modes of operation of biometric systems before discussing the types of biometrics that exist in the next section. Thereafter, we describe multibiometrics in all its aspects before presenting our feature fusion model in a multi-origin system. The synthesis of our research and the prospects for future work are presented in the last section of this document.

II. LITERATURE SURVEY

A. The Different Modalities in Biometrics

Biometrics is the science that deals with the analysis of physical or behavioral characteristics specific to each individual and allowing its identification or the authentication of its identity [9].

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In a literal sense and in a more simplified way, biometrics means the "measurement of the human body" [10]. There are two categories of biometric technologies: physiological measurements, and behavioral measurements [2], [11], [7], [12], [13], [6], [4]. [10] Physiological modalities can be divided into three types, namely morphological (face, facial thermogram, fingerprint, retina, iris, hand vein network, hand geometry, ear shape, etc.), biochemical (e.g., DNA, odor), and bioelectrical (electrocardiogram, electromyogram, MRI, X-ray).

- **Morphological Modalities**

➢ **Face**

Facial recognition is the most acceptable of the biometric modalities since it corresponds to what humans use in visual interaction [3]. The features considered significant for face recognition are: the eyes, the mouth, and the circumference of the face [14]. According to the work of M. Lemmouchi [8], biometric face recognition is based on two approaches to choose from. One popular approach to face recognition is based on the location, dimensions, and proportions of facial attributes such as eyes, eyebrows, nose, lips, and chin and their 3 spatial relationships. Another widely used approach is based on the global analysis of the face image which represents the face as a weighted combination of a number of canonical faces [15].

➢ **The iris**

According to A. Boucetta [3], the iris is the colored area between the white of the eye and the pupil (see Figure 2), it is the only internal human organ visible from the outside, it is stable during the life of a person. The texture of the iris is unique for each eye of a person [7], it is a combination of several elements that make it one of the richest distinctive textures of the human body. The iris therefore has a unique characteristic of being both an organ protected from the external environment while at the same time being relatively easy to acquire compared to other internal organs of the human body such as the retina [16]. The image of the eye is an image that is often obscured by eyelashes, eyelids, lenses, light reflections or uncontrolled movements of the person [17]. The texture of the iris is unique and rich in information so it must be well analyzed by an extractor giving a reliable representation of the iris. We then propose in our model an extractor based on the curvelet transform for the extraction of iris texture features.

- **Biochemical modalities**

➢ **Deoxyribonucleic Acid (DNA)**

Present in the cells of the body, it is specific from one individual to another and can be identified with certainty from a simple fragment of skin, a trace of blood or a drop of saliva. Currently, the time required for an analysis and the cost associated with it restrict its use for forensic purposes [18]. The genetic information of an individual is unique, as no two members of the species have the same combination of genes encoded in deoxyribonucleic acid (DNA) [14], [19]. This test has been successful with its use in the recognition of paternity in men.

➢ **Body odor**

Each person has a unique odor. Biometric systems that exploit this technology analyze the chemical components contained in the odor and then transform them into comparative data. [18].

- **Bioelectrical modalities**

➢ **The heart rhythm**

The ECG is a signal representing the activity of the heart. It is mainly used in clinical applications to diagnose cardiovascular diseases. The ECG signal is characterized by the shape of its beats composed of five typical waves, namely P, Q, R, S, and T or sometimes the U wave [20], [21].

It has been discovered that the heart rhythm, and more precisely the shape of the peaks in an electrocardiogram, are unique to each individual and will allow them to be identified [22]. Various research laboratories in Europe and North America working on this subject confirm that this cardiac profile does not vary with age or even if the heart rate increases following an effort or an emotion [23]. Moreover, recent technical advances in electrocardiograms have made it possible to develop miniaturized and inexpensive sensors that operate from the fingertips. Thus, the idea of using heart rate as a biometric tool has quickly gained traction [18].

➢ **X-ray of the hand**

Radiography is an X-ray transmission imaging technique. It allows to obtain an image whose contrast depends on both the thickness and the attenuation coefficient of the structures crossed. Radiography is used in medical radiology, industrial radiology and radiotherapy. Medical radiography allows the development of 2D images of human bones. With this type of image, bone structures are clearly accentuated. The application of this type of technology in biometrics can be envisaged by exploiting radiographic images of the hand, for example, where the aim is to characterize the phalanges using some image processing tools [21], [24].

- **Behavioral modalities**

➢ **Keyboard typing dynamics**

According to S. Ayeswarya and J. Norman [6], keystroke dynamics measuring keyboard typing characteristics is accepted as unique to an individual user and supposed to be difficult to duplicate. Keystroke dynamics is measured by a software device that calculates the time a finger presses a key and the time a finger is in the air (between keystrokes). This measurement is captured approximately 1000 times per second. The keystroke sequence is predetermined in the form of a password. Initially, the user must type the password a few times in order to build up a reference template [18], [25].

➢ **Gait**

The way a person walks can distinguish them from others. In a recognition system using this modality, we seek to identify an individual by the way he or she walks and moves while analyzing video images of the candidate's walk [1]. So, it is a remote identification modality [3]. People show different features while walking such as body posture, distance between the two feet, position of joints such as knees and ankles, and sway angles which significantly helps to identify them [21]. This modality is particularly suitable for video surveillance applications [3].

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- **Metadata**

Beyond these modalities described above that we can call pure biometric modality, there is another group of biometrics modalities called metadata. According to Jain et al [26], metadata are a set of features that provide some information about an individual, but not enough to uniquely identify him or her. They are data that are used to characterize the acquired pure biometric data. They can be personal information about the user (eye color, age, height, etc.), contextual information related to the acquisition conditions at a specific time (temperature, luminosity, noise, etc.) or accessories (glasses, hat, veil, etc.) associated with an individual. These data are therefore of a different nature from those of the acquired image or signal, and must either be entered by the user or the controller, or be acquired automatically by an acquisition device complementary to the biometric data acquisition system [27]. When acquired automatically, they are referred to as some soft biometrics modalities [26]. The use of these metadata in addition to pure biometric modalities, allows to improve the performance of biometric systems [11], [27], [28].

B. How Biometric Systems Work

According to S. Dargan, M. Kumar [7] and M. El-Abed [29] depending on the context of the application, a biometric system can be either a verification system or an identification system:

- **Identification**

In identification mode, the biometric system determines the identity of an unknown individual from an identity database, this is referred to as test $1:N$ [13], [7]. In this case, the system can then either assign the unknown individual the identity corresponding to the closest profile found in the database (or a list of close profiles), or reject the individual. The identification process can be formalized as follows: Let the input vector C_U define the biometric features extracted by the system when a user U comes in front of it, identification amounts to determining the identity of $I_t, t \in \{0,1,\dots,N\}$, where $I_1,\dots,I_N$ are the identities of the users previously enrolled in the system, and I0 denotes unknown identity. The identification function f can thus be defined by:

$$f(C_U) = \begin{cases} I_k \ if \ max_{1\leq k\leq N} \ S(C_U, M_k) \geq \theta \\ I_0 \ else \end{cases} \quad (1)$$

where M_k is the biometric template corresponding to identity I_k , S is the similarity function, and θ is the decision threshold.

- **Verification**

Identity verification consists of checking whether the individual using the system is the person he or she claims to be [13], [7]. The system compares the acquired biometric information with the corresponding biometric template stored in the database, we refer to this as a $1:1$ test. In this case, the system returns only a binary decision (yes or no) that can be weighted. The verification process can be formalized as follows:

Let the input vector C_U defining the user's biometric characteristics U extracted by the system, and M_U its biometric model stored in the database, the system returns a Boolean value following the computation of the function f defined by:

$$f(C_U, M_U) = \begin{cases} 1 \ if \ S(C_U, M_U) \geq \theta \\ 0 \ else \end{cases} \quad (2)$$

where S is the similarity function defining the correspondence between the two biometric vectors, and θ is the decision threshold at which the two vectors are considered identical.

C. Types of Biometrics

There are two types of biometric systems: **unibiometric** and **multibiometric**. It is important not to confuse these systems with unimodal and multimodal systems, which refer to the numbers of modalities in a biometric system [7]. Confusion between these topics is common in the literature.

- A unibiometric system is a system that relies on a single modality and recognition method. A unibiometric system is a unimodal system that relies on a single recognition method.
- A multibiometric system is a system that relies on several modalities or recognition methods. Any multimodal system is first of all a multibiometric system. While any multibiometric system is not necessarily multimodal.

D. Multibiometrics

According to Sobabe et al, [30] there are six types of multibiometric systems based on the systems they combine.

- Multi-sensors when they combine several sensors to acquire the same modality, for example an optical sensor and a capacitive sensor to acquire the fingerprint.
- Multi-instances when they associate several instances of the same biometry, for example the acquisition of several images of a face with modifications of the pose, expression or lighting.
- Multi-algorithms when several algorithms process the same acquired image, this multiplicity of algorithms can intervene in the extraction module by considering several sets of features and/or in the comparison module using several comparison algorithms.
- Multi-samples when they combine several different samples of the same modality, for example two different fingerprints or two irises.
- Multi-modal when several modalities are taken into account, for example face and fingerprints.
- Multi-origin when the modalities in presence come from different origins. This is the case, for example, of the combination of pure biometric modalities (hand geometry, voice, iris, retina, etc.) and soft biometric modalities (skin color, gender, height, weight, eye color, etc.) or metadata in general [20].

The following Fig. 1, illustrates these types of multibiometrics perfectly.

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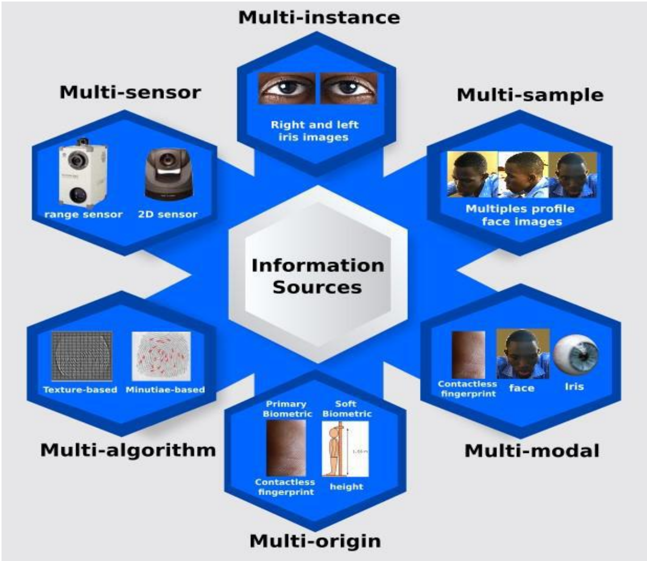

Fig. 1: Taxonomy of Multibiometrics [11]

- **Fusion levels**

Based on several modalities, or recognition methods, multibiometrics inevitably involves the concept of fusion. As shown in Fig. 2, fusion can be performed at four different levels: sensor-level fusion, feature-level fusion, score-level fusion, decision-level fusion. These four levels can be classified into two subcategories, namely fusion before the classification stage and fusion after the classification stage [3], [8].

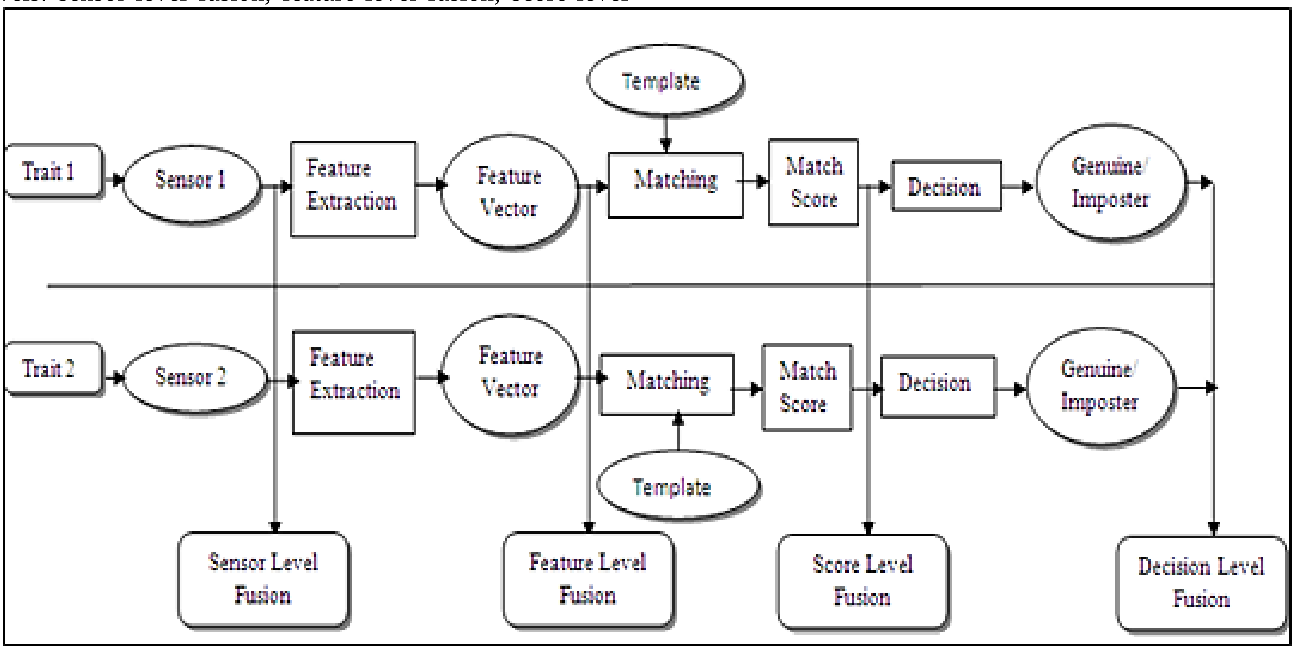

Fig. 2: The Different Levels of Fusion in a Multimodal Biometric System (Adapted From [14])

- **Fusion Architectures in a Multibiometric System**

Fusion modes or architectures describe the set of sources, how they are assembled, and the mathematical or statistical techniques for processing [21]. In a multibiometric system, data fusion can operate in one of three (03) architectures: serial mode, parallel mode and hierarchical mode [31].

- **Serial mode**

In the serial architecture (Fig. 3), individual systems are invoked in sequence. Some of them may be used only when a possible condition occurs at the output of the previously invoked systems, which allows a decision to be reached without necessarily involving all of these systems [31]. For example, a multimodal system that combines several features (face and iris) does not need to process all of them, if the system accepts with a good recognition rate the user after processing the first modality required by the system, the system will no longer request the other modalities. This system increases efficiency by using the inexpensive and less accurate systems first and the expensive but more accurate systems second.

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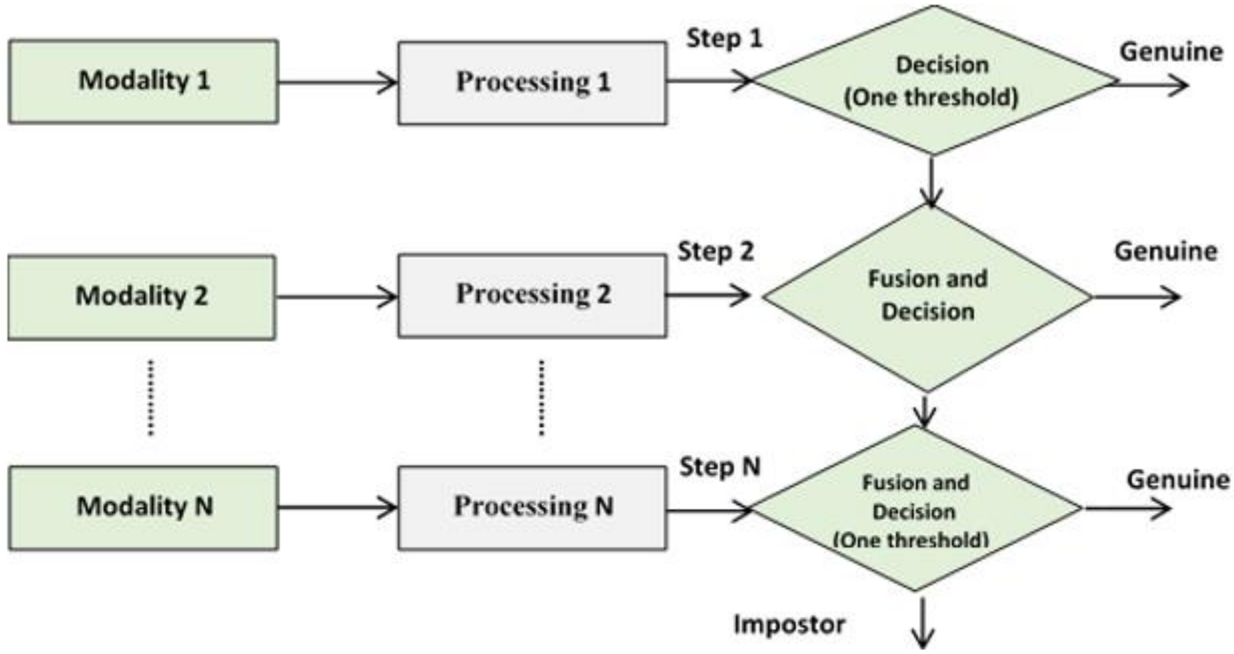

Fig. 3: Serial Fusion Architecture (Adapted From [27])

To improve fusion performance, L. Allano [27] proposed the sequential (Fig. 4) or incremental fusion mode, which is really only a specification of the serial architecture in the sense that the mode is determined by the data fusion strategy. The particularity of this type of serial architecture is to have two decision thresholds instead of one threshold in the classical serial mode. The two thresholds here allow the system to save processing time because with the low threshold in addition to the high threshold, the system now has two certainty zones (client, impostor) at each iteration. Thus, the system can no longer go through all the steps to recognize an impostor or a client.

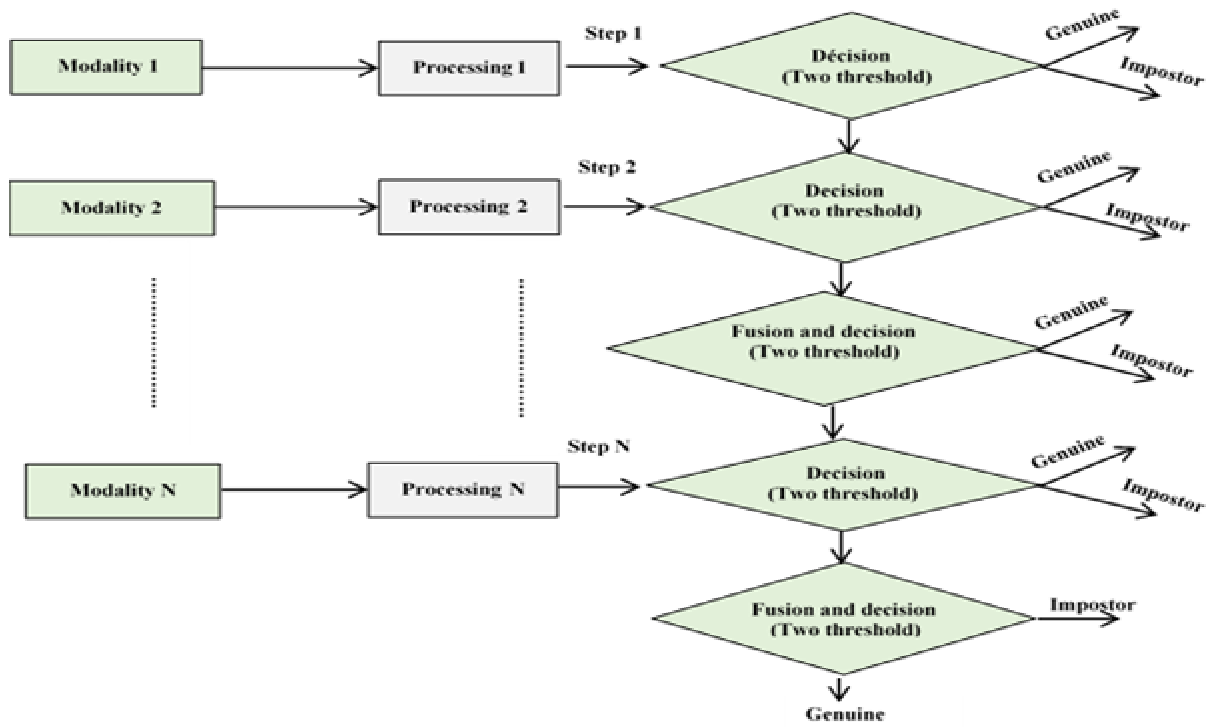

Fig. 4: Sequential Fusion Architecture (Adapted From [27])

- **The parallel mode**

In the parallel architecture (Fig. 5), information from different systems is used simultaneously to perform the recognition task [31]. It improves the performance of the system but is costly in time and hardware [27].

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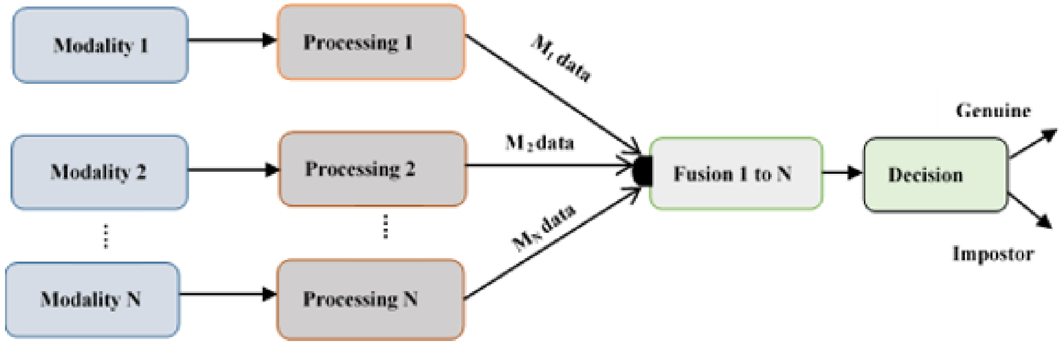

Fig. 5: Parallel Fusion Architecture (Adapted From [31])

- **The hierarchical mode**

This mode (Fig. 6) combines the first two modes in a tree structure. This architecture is considered to be the most flexible and allows to face the problems of missing or poor-quality data often encountered in biometric systems [33]. In such a scheme, an initial subset can be formed by a few modalities combined in parallel, while the remaining modalities can be combined in series [2].

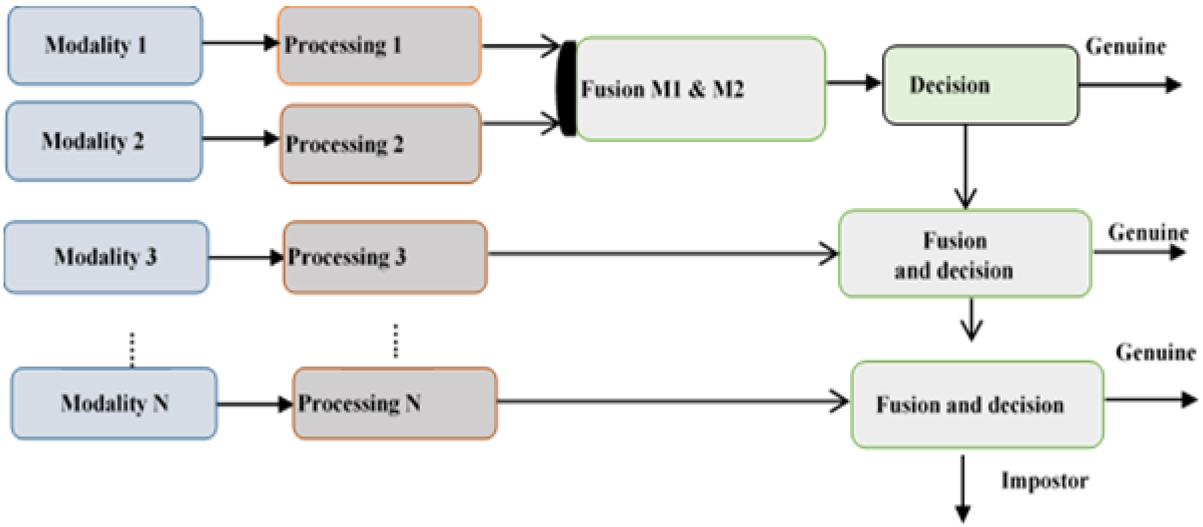

Fig. 6: Hierarchical Fusion Architecture (Adapted From [32])

The introduction of the two thresholds proposed by L. Allano [27] would allow to reduce considerably the processing time of the system. Such an architecture could be called hierarchical-sequential architecture. To improve the performance of multimodal biometric systems, Djara et al [30] suggested the inclusion of metadata in multimodal biometric systems. In this framework, they proposed a new architecture (adaptive sequential fusion architecture) to adapt the multibiometric system to each user through the consideration of metadata in the recognition system. When we analyze in depth this architecture, we notice that it is a hierarchical architecture in general and hierarchical-sequential in a specific way where some pure biometric modalities can be replaced by metadata.

- **Summary of the Operating Modes of Multibiometric Systems**

The choice of system architecture depends on the needs of the application. In user-friendly, low-risk applications, serial architecture is preferred for its cost advantages in time and hardware over parallel architecture requiring the acquisition and processing of a large number of biometric data. However, in applications where security is of paramount importance (e.g., in military applications), the use of a parallel architecture is more appropriate. The tree architecture is preferred in applications with a higher risk of acquiring poor quality biometric data (e.g., a multi-sample fingerprint-based attendance control system in a hospital environment). It is also used in applications where one or the other modality is likely to be missing (e.g. a multi-sample fingerprint attendance system in a wood factory). Seen from another angle, the serial architecture may be preferred in some applications; for example, if multimodality is used to give an alternative for people who cannot use one of the modalities.

III. OUR CONTRIBUTIONS

To make a contribution to the improvement of biometric systems, we propose a multi-origin system with a feature-level fusion strategy. The face and iris modalities are chosen as pure biometric modalities and the skin color as metadata.

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The face modality is well accepted by all and it is also the first means of recognition between individuals. Its acquisition can be done with the available and cheap webcams. All these aspects favored our choice of the face modality in addition to the possibility of collecting directly the metadata (color of the skin of the face) on a face image. The choice of the iris modality is motivated by its better performances among all the other pure biometric modalities and the difficult fraud with this modality. The literature on skin color shows that it is a metadata that has a good discrimination rate between individuals and it rarely changes with age even if it can be slightly influenced by makeup. For our system, the hierarchical architecture and more specifically the adapted sequential fusion architecture proposed by A.A. Sobabe [11] will be used to call our modalities in a tree structure.

IV. RESULTS AND DISCUSSIONS

We started from the objective of improving the performance of biometric systems which, unlike traditional authentification systems, do not recognize an individual 100%. In this perspective, several works have gone towards multimodality with encouraging results using several levels of fusion. It appears from this work that the fusion at the level of the characteristics would offer better results. Some works have shown that the use of metadata in addition to pure biometric modalities improves the performance of biometric systems in the order of 4 to 5%. It is in view of the promising prospects of these various works that we are moving towards multi-origin biometrics in a strategy of features fusion which remains a field not yet explored in the literature to contribute to the improvement of the performance of biometric systems. After designing the framework, the next step will focus on its implementation in order to evaluate its performance. The implementation will consist of features fusion of these three biometric modalities to be implemented. These are face, facial skin color and iris. The features obtained with an extractor to be defined will be merged by concatenation with the adapted sequential fusion algorithm. The implementation will be under the Python environment. The results obtained will be compared with the results available in the literature in order to position our model.

V. CONCLUSION AND PERSPECTIVES

In this paper, we have studied deeply biometrics in general and multibiometrics in particular to lead to the proposal of a mutltibiometric system. The different levels of fusion that can be applied and their architectures have also been presented. Our proposal is a multi-origin biometric system with a feature fusion strategy overcoming the limitations of single mode biometric systems and whose performance could be better than existing systems. For the experiments we intend to use pure biometric modalities (face and iris) and a metadata (facial skin color). We also bring clarifications on many concepts of biometrics that are sometimes misused in the literature. In perspective, we intend to develop this model and then evaluate its performance compared to existing systems.

DECLARATION

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	Abdoul Kamal Assouma, Thesis Student, declare to be the Correspondence Author. Tahirou Djara, Thesis Director, declare that l contributed to the proofreading of this article. Abdou-Aziz Sobabe, Thesis Supervisor, declare that l contributed to the proofreading of this article.

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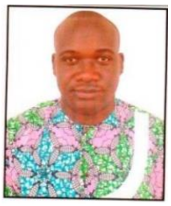

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