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Digital Criminal Biometric Archives (DICA) and Public Facial Recognition System (FRS) for Nigerian criminal investigation using HAAR cascades classifier technique

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Abstract

In Nigeria, there are many different security concerns and thus crimes have increased despite the fact that there are stringent laws and punishments in place to deter them, making it appear as though the authorities are unable to stop it. In order to identify criminals and conduct investigations, it is imperative that a facial recognition system be connected to a constantly updated digital library. The focus of this paper is to develop an automatic criminal investigation system that can identify criminals based on their faces and produce real-time digital archives about them. However, as an object detection method and facial recognition model, the new system is built on the Haar Cascades Classifier technique in the OpenCV package. Additionally, appropriate programming languages that may provide the needed results were investigated. Python 3.6 was used with the Django 4.2 framework, OpenCV-Python, and Dlib for language execution. Due to Django's ORM, support for numerous databases, and usage of the SQLite3 database, a straightforward database was employed for lightweight applications. The 12 factor app idea was used to construct the DICA-FR system's essential skills. Face detection was applied to the image using the Haar method during processing, and during post-processing, the discovered face was compared with well-known criminal face encodings for matching purposes. Results demonstrated that DICA-FRS could effectively replace human systems since it can recover faces from the furthest distances, display the name of the offender, and sound an alert on the DICA web app's output screen. The DICA system is a working prototype of a system that might be used in the criminal investigative process in Nigeria.

Keywords: Crime; Facial Detection System; Criminal Biometrics; Criminal Investigation; Haar Cascades Classifier Technique

1. Introduction

Crime is a social canker-worm that has eaten deeply into the Nigerian society's social fabric, having a wide-ranging impact [1]. The functionality of crime in a society like ours must be taken seriously due to the social and psychological issues it has caused many victims to experience, even though [2] believes that crime is an inevitable and normal aspect of social life. Despite the fact that crime serves a purpose in society, committing a crime is nonetheless wrong and undesirable in a society that is functioning well [3].

Armed robbery, theft, assault, burglary, rape, and other popular crimes that were common in Nigeria in the 1970s have now given way to terrorism, bomb blasts, kidnapping, drug trafficking, money laundering, child trafficking, assassinations, and other criminal activities [4]. According to [5], Nigeria has a wide range of security issues, including abduction, terrorism, civil unrest, political violence, fraud, assassination, and armed robbery. Even though there are

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strict regulations and penalties in place to prevent these crimes, they have continued to rise, leaving the police seemingly unable to stop it. The primary challenge with this has been Nigeria's lack of effective digital crime detection and investigation [6].

The most crucial responsibility for the police is criminal identification since it requires them to look everywhere for it. However, it is also the most time-consuming and complex work [7]. Cities or public areas in Nigeria with a high population density will make it harder. A possibility to learn more about offenders is occasionally available when using manual identification techniques [8]. In order to identify criminals and conduct investigations, it is imperative that a facial recognition system be connected to a constantly updated digital library. Face recognition is a method for identifying someone or verifying their identity by looking at their face [9]. Identification comes next following the display of the faces. Using biometrics, a facial recognition system can map facial emotions from an image or video. The information is compared to a database in order to detect matches between known faces from the database [10]. Recognition of a person's identity by facial recognition may be possible.

To aid efficient digital criminal identification, investigation and archiving in Nigeria, this study proposes an automatic criminal identification/investigation system by detecting the face of criminals and creating real time digital archives for them. Face recognition technology, which is based on OpenCV, will be used to identify intruders entering any public space using CCTV video after the system has recognised the intruder's face. The person's collected photographs when they enter the area will be compared to the criminal records stored in the database or archives. If any other person's face from a public place match that of the criminal, the system will show that person's image on the screen and alert you with their name that the criminal has been discovered and is present in this public area. More than 80% of the collected photographs are expected to match database images using this approach. This will make it easier for the police to find and apprehend offenders in public areas.

2. Review of Related Literature

In order to replicate the excellent human recognition process, biometrics was developed as an automated way to identify individuals [11]. The human capacity to recognise a familiar face, voice, or walking style is a pure mental pattern-recognition process that first records and stores some features about the seen person and recalls them in a timely manner when necessary [12]. In order to identify people, biometrics has advanced; it not only makes the identification process faster, but it also adds some new modalities, such as the iris, veins, and EEG, on the basis of which the human recognition process is unable to identify the subject [13]. In comparison to human identification abilities, biometrics' main additional values are efficiency, speed, and diversity.

The term "biometrics," also known as "biometric recognition," is defined by the [14] as the automated identification of persons based on their biological and behavioural traits [15]. According to the definition, the term "automatic" refers to the creation of algorithms that a machine system will employ to recognise people [16]. A person might help the machine to improve results. The goal of "recognition" is to connect a person's identity to certain physical traits displayed inherently by his body parts and/or some behavioural qualities produced by the body [17]. The terms "identifiers" or "traits" are used to describe these qualities. A few examples of physical traits include fingerprints, the face, the iris, etc. On the other side, behavioural traits might be things like a signature, a voice, the dynamics of a keystroke, etc [18].

Unlike traditional identification systems that establish a person's identity based on what they know and/or what they have, biometric systems establish a person's identity based on what they are and/or what they do [19]. These unique identifiers are linked to the person directly and cannot be lost, duplicated, or transmitted. [19] claim that biometric systems make use of a range of biometric traits (or modalities), such as voice, signature, gait, odour, iris, retina, palmprint, and voice. In Figure 1, the most popular biometric modalities are given.

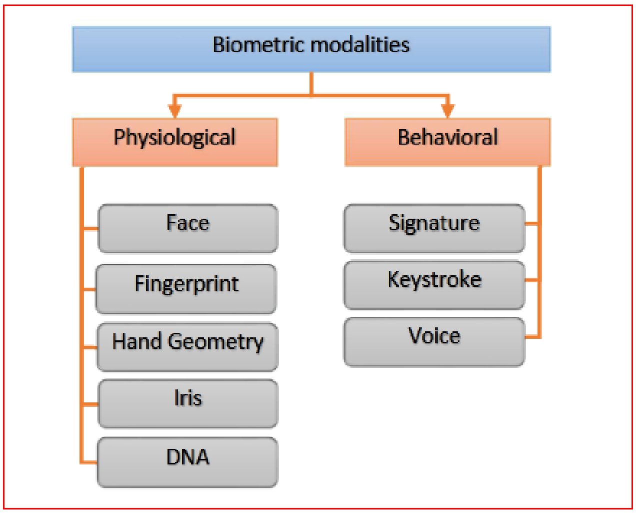

Figure 1 Principal biometric modalities (Palma & Montessoro, 2022)

When someone intentionally violates the law by an action, omission, or neglect that is punishable, it is considered a crime. A criminal offence is defined as the violation of a legal provision or a regulation [20]. Crime investigation is an applied science that uses fact-based analysis to find, track down, and establish an accused person's guilt. A thorough investigation into a crime may entail searching, speaking with witnesses, questioning suspects, gathering and preserving evidence, and using different investigative techniques. Modern scientific methods, generally known as forensic science, are often used in criminal investigations nowadays [21].

In Nigeria, conducting a criminal investigation takes a long time (conventional technique), which drives up the cost since it causes so much inefficiency and delay [22]. Criminal record administration and investigation take less time when computers are employed [23]. The investigative procedure is also more accurate and efficient when computers are used. The field of biometrics covers identity verification methods based on physical characteristics and behavioural patterns, such as handwriting and fingerprint recognition. The use of biometrics as a technique for preventing crime and as a security measure for confirming identification and identifying criminal activity is common [24].

Once a crime has been reported to the Nigeria Police Force, an officer will conduct an initial investigation [25]. The phases of a police investigation are; Initial Investigation, Investigative Assessment and Closure of Investigation [26].

One of the most crucial aspects of a forensic investigation is fingerprinting. The fact that each person's fingerprint is distinct makes it possible for law enforcement to identify suspects with great accuracy and perhaps even establish their guilt or innocence [25]. Due to its widespread application in all facets of law enforcement, students in criminal justice degree programmes must become familiar with the method. Due to the evolving nature of criminal activity and the investigator's function, the goals of crime investigators may be more complicated than people realize [25].

In Nigeria, fingerprints are utilised to accomplish the following in criminal investigations, including [25]:

- discover, identify, and record suspects in crimes;
- prepare strong criminal cases for prosecution; detect crime;
- discover, document, and preserve evidence in crimes.
- Capture criminal suspects;
- Recover stolen goods

A straightforward rectangular Haar-like feature may be described as the difference between the sum of pixels of regions inside the rectangle, which can be at any position and size inside the original picture [27]. The name of this updated feature set is 2-rectangle feature. The terms 3-rectangle features and 4-rectangle features were also established by Viola and Jones. Faces are scanned, looking for the stage-appropriate Haar traits. AdaBoost's machine learning technique is used to create both the features' weights and sizes as well as the features themselves [28], [29]. The learning method produces constants called weights.

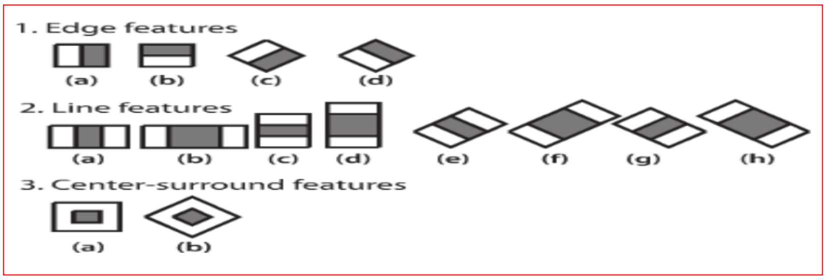

Figure 2 Variety of forms of features [29]

The area of each rectangle is taken into account while calculating each Haar feature's value, which is then multiplied by the corresponding weights and added together [30]. The integral picture makes it simple to calculate each rectangle's area. Using the integral picture, one may find the total number of pixels above and to the left of any corner of a rectangle by knowing its coordinate. The area may be easily calculated by utilising each corner of a rectangle, as shown in "Figure 3". A must be put back on since it has been deducted twice in order to get the right area of the rectangle [29].

Using the positions of the integral picture, the area of the rectangle R, also known as the rectangle integral, may be calculated as follows: C + A - B – D

Figure 3 Examples of Haar features. Areas of white and black regions are multiplied by their respective weights and values added [29]

Each level of the cascade classifier's list of stages includes a list of weak learners. The system moves a window over the image to identify the necessary object. Each level of the classifier assigns a positive or negative label to the region defined by the window's current location, where positive denotes the discovery of an item in the picture and negative denotes its absence [27]. If the labelling produces a negative result, the window is moved to the next place and the categorization of that specific area is finished. The area advances to the next level of categorization if the labelling yields a favourable result. When all phases, including the final one, produce positive results, the classifier declares the final result to be positive, indicating that the needed item was located in the picture [27]..

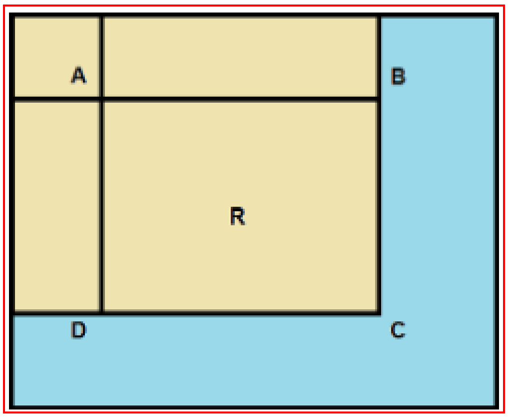

Figure 4 Calculating the area of a rectangle R is done using the corner of the rectangle: C + A – B – D [31]

Using a series of phases, the Viola and Jones face identification algorithm swiftly eliminates face contenders. By enforcing stronger criteria at each level and making it considerably harder for applicants to pass later stages, the cascade eliminates candidates. If they pass every level or fail any stage, candidates are eliminated from the cascade. If a candidate makes it through every level, a face is discovered. "Figure 5" depicts this procedure.

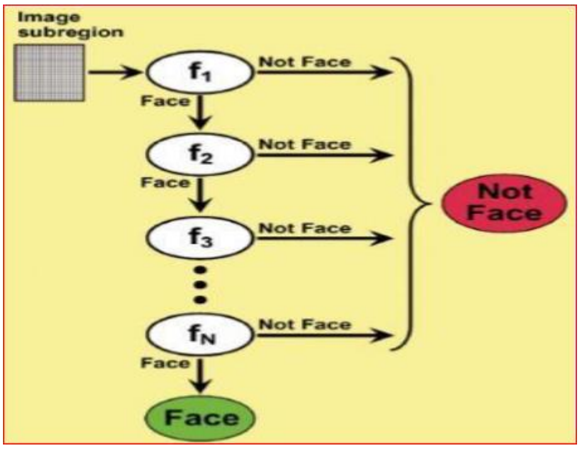

Figure 5 Cascade of stages [31]

To reach the final stage, the face must pass each step in the cascade. There are several variables that affect the system's accuracy when image quality is taken into account. It is essential to employ a range of picture pre-processing techniques in order to uniformize the images you provide to a face recognition system. According to [27], most face recognition algorithms are extremely sensitive to illumination, therefore if it was trained to recognise a person in a dark setting, it probably won't do so in a bright one.

There are many other issues as well, such as the face's consistency in size, rotation angle, hair and cosmetics, mood (smiling, furious, etc.), and the location of lights (to the left or above, etc.). This issue is referred to as "illumination dependent," and there are many other issues as well, such as the hair and makeup. Because of this, it's essential to use high-quality image preprocessing filters before doing face recognition.

3. Methodology

This section examines the techniques used to create a public facial recognition system and digital criminal biometric archives for Nigerian criminal investigation. It investigates ways to create a system that replaces the manual criminal archive system that is already in place. The technique is a process for developing an item step by step. We go into great depth on the particular system needs for the DICA-FRS and look at the appropriate programming language and version, system features, usability, testing, and deployment readiness for production, among other things.

The requirements analysis determines whether a system or software project succeeds or fails. The needs must be spelt out, measurable, testable, executable, and traceable [32]. They must also be linked to recognised business opportunities or needs, and they must be sufficiently specific to allow for system design. The system should be set up so that it is unaffected by the implementation environment, according to the system requirements analysis [32]. The system's behaviours and limitations may now be identified. The system requirements analysis activity is the second major development stage in the entire process [33]. For the DICA-FRS, there are specific system requirements for a standard performance. The DICA-FRS app is an AI enabled powered archive that requires basic underlying infrastructure of the host system to operate in full capacity.

Below are the system requirements for optimal function

- Windows 10 OS
- Linux Ubuntu 20.04 OS
- Python 3.6
- The Project Library requirements are;
- OpenCV- Python
- Haar Cascades Algorithm library
- DLib
- Face Recognition Lib

- Django 4.2

Other list of libraries hat enhance the system's functionality in various ways include; asgiref, backports.zoneinfo,django-resized, numpy, sqlparse, tzdata.

Django's ORM makes it simple to support many databases. In this system, we use the straightforward SQLite3 database, which is perfect for simple demo applications. It is quick and lightweight for easy to medium applications.

In this work, we utilize Haar Cascades Classifier algorithm in OpenCV library as object detection algorithm and facial recognition process. The process include:

- Loading of input image from the camera or digital archive.
- The input image is converted into gray scale images
- Haar cascade classifier algorithm is applied to detect human faces
- Known images are compared with provided sample image using stored face encodings
- Recognition is done and image is detected with output of name of person with bounded boxes

The Haar cascade classifier is a machine learning approach that build a cascade structure for human frontal face identification utilising sub-window operation. They were first proposed by Viola and Jones in their study [34]. In order to identify objects using Haar features and recognise faces using facial landmarks and face encodings, Haar Cascading makes heavy use of both positive and negative pictures, as seen in figure 6.

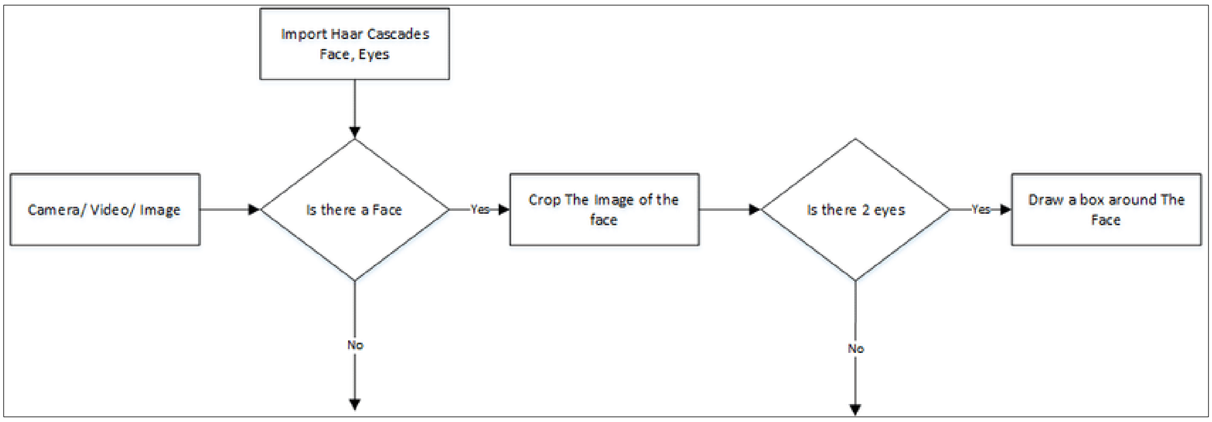

Figure 6 Haar Cascades Flowchart, [35]

Haar algorithm works in three simple steps,

The input image is taken from a video camera using either the function cv2.VideoCapture (for real-time web cams) or cv2.imread(img_path), supplying the image path as an argument.

Changing the image's mode to grayscale.

Application of the Haar cascade classification method.

The algorithm's accuracy may be lowered by false positives in Haar cascades, which is why pre-processing is necessary. Traditional filter-based and image-based approaches to pre-processing are the two primary categories. Traditional filter-based approaches commonly use the Gaussian filters He (Helium) and median to reduce false positives and remove noise components. These methods, however, require a significant amount of processing time. Given the DICA system's peculiarities and how quickly the system must operate, the contraction-image based approach will be used. The image contraction-based pre-processing algorithms analyse data faster since the amount of false positives and picture size are reduced.

The image is reduced in size and converted to grayscale during pre-processing before the Haar cascade classifier is used. In figure 7, Haar method is used during the processing stage to apply face detection to the picture, and during the post-processing stage, the detected face is compared with well-known criminal face encodings for recognition matching.

Haar calculation

Equation 1:

$$Pv = \frac{\sum Dp}{NDp} - \frac{\sum Lp}{NLp}$$

Where:

Pv = Pixel Value

Dp = Dark Pixels

Lp = Light Pixels

NDp = Number of Dark pixels

NLp = Number of Light pixels

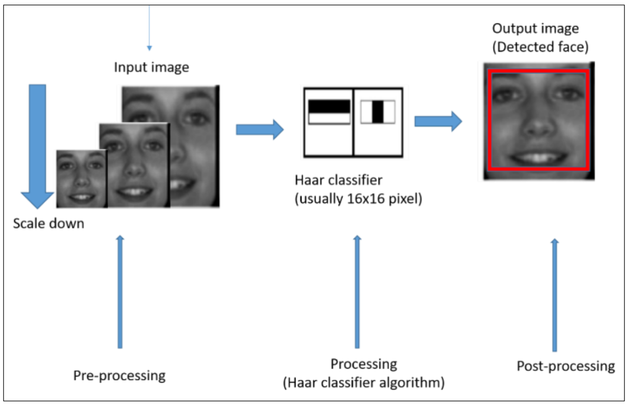

Figure 7 Haar cascades

Steps in proposed system:

- The camera turns the image to grayscale after it has captured it.
- When a face is discovered, the cascade classifier checks to see if both eyes are there.
- If both eyes are present, the classifier normalizes the size and orientation of the face image.
- The image is then subjected to face recognition processing, where it is compared to a library of face samples in the criminal archive system.
- When image is recognized, details of location of detection is saved in the system for intelligence and alarm is raised.

3.1. The 12 Factor APP Principle

This process will adhere to the 12 Factor Principle. A technique or set of rules known as the "12-factor app" is used to create scalable, efficient, independent, and resilient commercial applications. It outlines the key guidelines and requirements for producing reliable business apps [36]. The 12-factor app concepts are quite popular since they follow the microservice guidelines. According to [37], "microservices architecture" is a method of architectural design for developing apps. A huge system may be broken down into smaller, autonomous components with separate sets of responsibilities using microservices. The Python framework Django, which was used to create the DICA system, is built to accommodate microservice architecture. But for this project, we chose a monolith architectural design owing to the expense of maintaining microservices. The twelve-factor is rendered useless when several apps use the same code. This methodology is used in the core design of the DICA system.

Since information about known criminals is inputted and saved in the database, the DICA system is essentially an input/process/output (IPO) system. Human faces are first recognised in suspect images using Intel's

Haarcascades_frontalface_default.xml algorithm, which is based on the Haar-like features suggested by [28] in the OpenCV library. The eyes, nose, and mouth are calculated as distinct face characteristics known as feature extraction, which are then recorded in the database as facial encodings. The system accepts a live camera feed as input and processes it using the OpenCV library and the Image Utils library (Imutils) to transform the images into formats that may be processed further. The input picture is scaled and translated from OpenCV's preferred BGR colour space to RGB for further processing using the face-encoding Python package library. The pre-processed live camera image's face features are computed, and they are compared to known facial features in the database. The known faces with the shortest distance to the input faces are determined using the Numpy module. An alert sound is activated and rectangular bounded boxes containing the name of the identified face are drawn on the image, enlarged, and shown as output to the user interface.

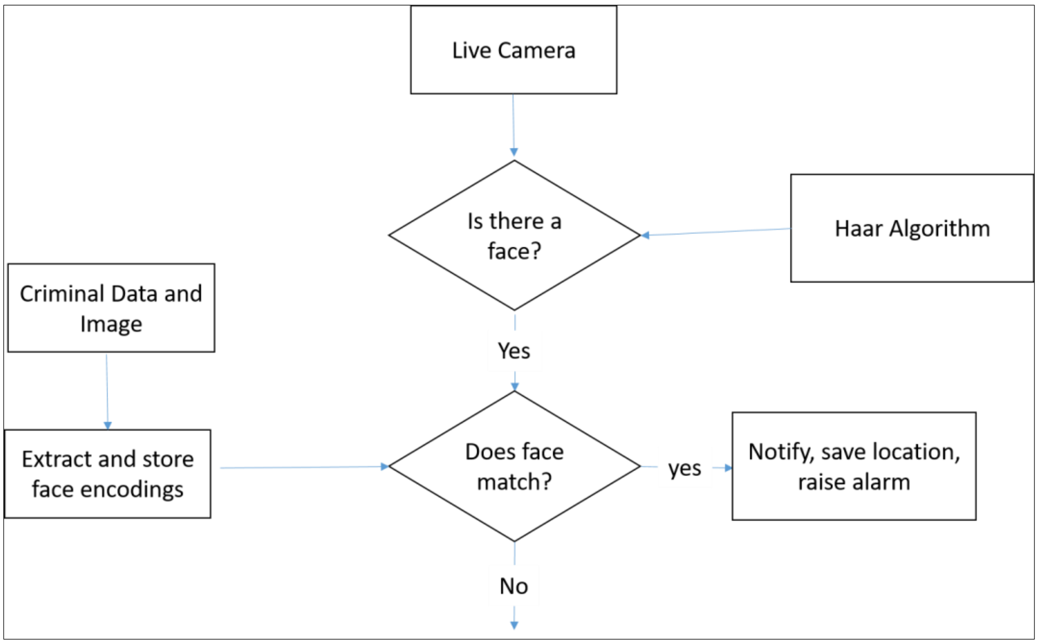

Figure 8 Simple Face Recognition Flowchart of DICA

3.2. The Website Input Form

Data of the criminal is entered and stored in the database via the input form. On saving of the data, the image of the criminal is pre-processed, facial features extracted and saved in array format.

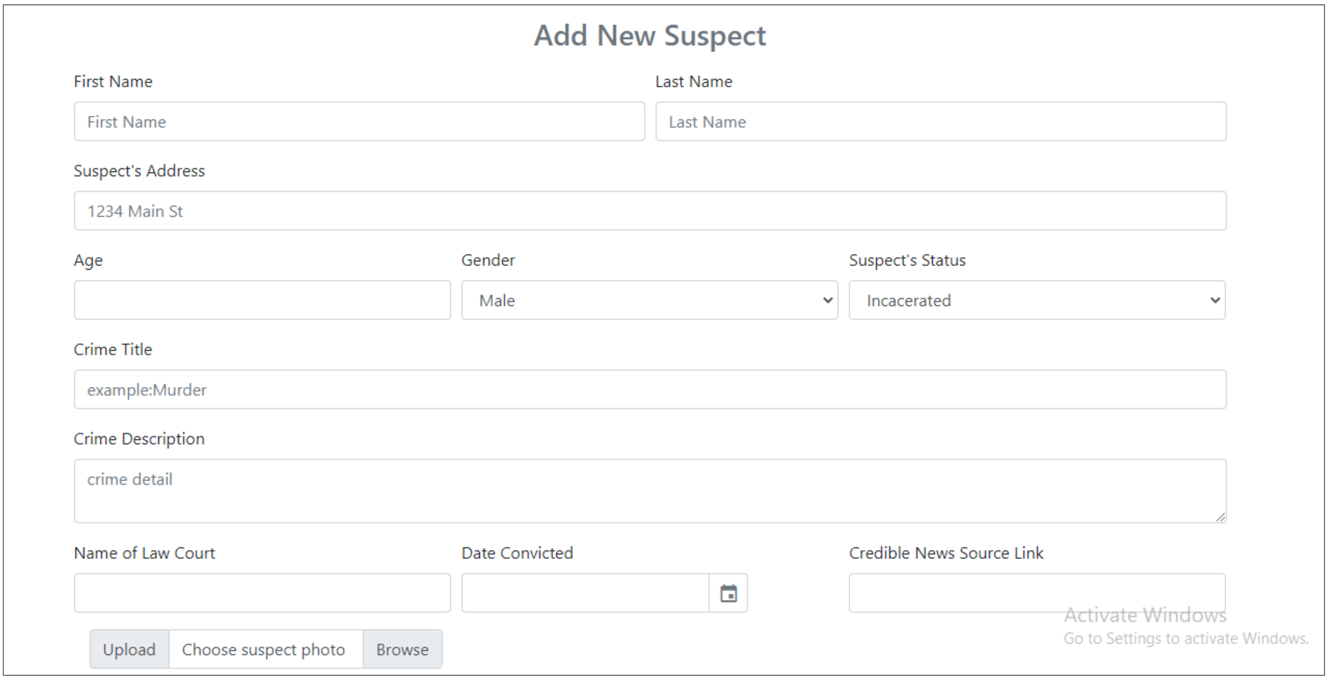

Figure 9 Criminal Data Input Form

3.3. Extraction of Facial Features from Criminal Image for Storage

When form is filled and image is added to the database, pre-processing and feature extractions are carried out and stored as face encodings for recognition process. A pre-trained algorithm *haarcascades_frontalface_default.xml* in OpenCV library does the face detection and feature extraction. Below is a breakdown of how this algorithm works.

3.4. Face Detection and Feature Extraction Using Haar Cascades

The system's initial action is to take imageuploaded from the form input. After that, the RGB image is changed into a grayscale image. Gathering the Haar features is the initial stage.

3.4.1. Haar Features

A Haar feature in a detection zone is really the outcome of computations on neighbouring rectangular parts. The pixel intensities in each location must first be summed up in order to determine the distinction between the amounts.

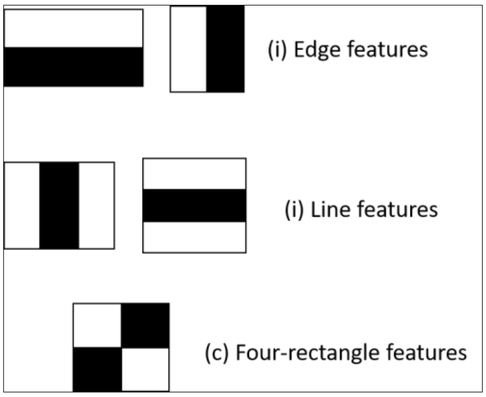

Figure 10 Haar-like features (Author's construct)

The output is generated by subtracting the sum of features in the dark area from the sum of features in the white area given by equation 2:

Ho = $\sum PD - \sum PL$

Where:

Ho = Haar Output; PD = Sum of pixels in dark area; PL = sum of pixels in white area.

The output is enormous that computing that will become problematic. This is solved by integral image approach.

3.4.2. Integral Image

In essence, integral pictures speed up the computation of these Haar characteristics. Instead of computing at each individual pixel, it creates sub-rectangles and array references for each of them. Then, utilising these, the Haar characteristics are calculated.

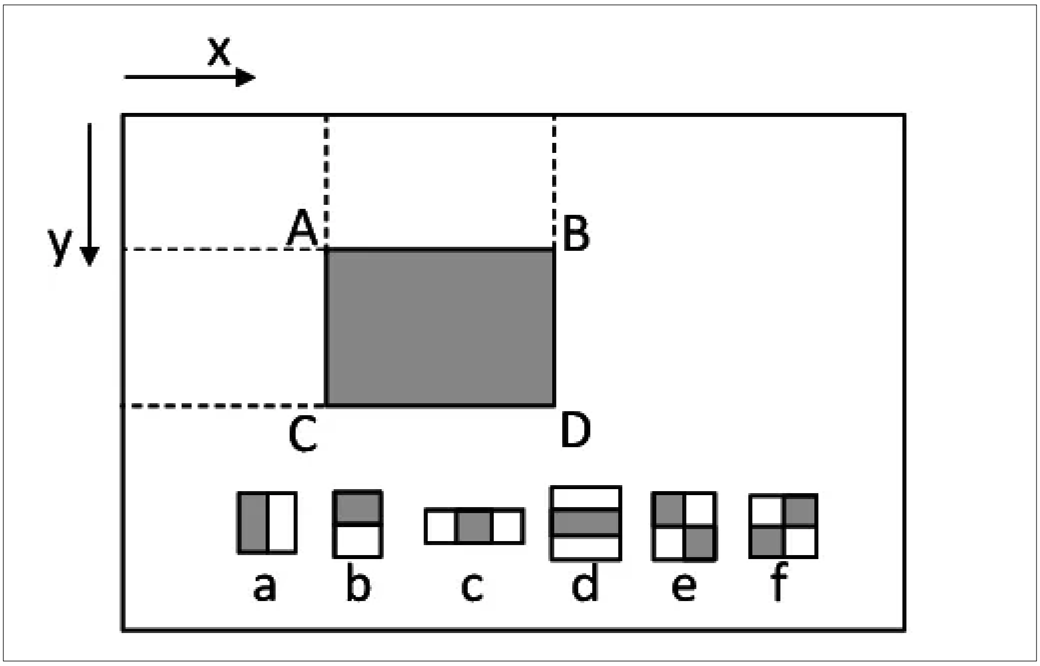

Figure 11 Integral Image Calculation Illustration [38]

In integral image, prior to applying the Haar features, the objective is to multiply each pixel's intensity by the total of all the pixels to its left and above. This speeds up and makes the computation smaller for additional feature extraction by reducing it to only 4 integers for each square. This is represented by equation 3:

Equation 3:

Hi = $\sum D + \sum A - \sum B + \sum C$

This makes it difficult to choose from among the tens of thousands of Haar features that best reflect an item. This challenge is solved by Adaptive Boosting, refered to as Adaptive Boosting (Adaboost).

3.4.3. Adaboost

In essence, Adaboost selects the strongest features and trains the classifiers to utilize them. It combines "weak classifiers" to produce a "strong classifier" that the algorithm can utilize to identify objects. This is illustrated in equation 4:

F(c) = β 1f 1(c) + β 2f 2(c) + β 3f 3(c) . . . + βnf n(c)

Where:

F(c) = Strong classifier:fn(c) = Weak classifier;β = weight

The more significant the weightβ, the more significant the feature.

3.4.4. Cascade Classifiers

The cascade classifier is made up of several stages, each of which has a collection of poor students. Weak learners are trained via boosting, which produces an extremely accurate classifier from the average prediction of all weak learners. A decision is made by the classifier to either go on to the next region (negative) or to signal that an object has been identified (positive). Negative samples are rejected as quickly as feasible by stages. This makes the processing and detection speed faster.

3.5. Face Encoding using Euclidean Distance For Recognition

The first stage which is face detection as explained above is a step in face recognition system of DICA. The second stage is the face encodings, using the Euclidean distance ***Eu*** calculation. In addition to measuring the absolute distance between points in N-dimensional space, the Euclidean distance can be used to determine the distance across any two points in two-dimensional space. Smaller numbers represent more comparable faces in facial recognition.

The image to be identified undergoes processing by a function to create a 128-dimensional facial features vector, which forms the basis for face matching computation under Euclidean distance. The feature points representing facial features are estimated according to the Haar feature values described in part A.

Assuming the extracted facial feature of the input image to be detected is:

I = (i_1, i_2, i_3...i_{128}) and the training sample featured stored in the database about the criminal is T = (j_1, j_2, j_3...j_{128}). Equation 5 illustrates how to calculate the Euclidean distance Eu between 2 points in the 128 dimensional space.

Equation 5:

$$IT_{\text{Eu}} = \sqrt{(i1 - j1)^2 + (i2 - j2)^2 + \cdots + (i128 - j128)^2}$$

This distances are stored in the database as face encodings.

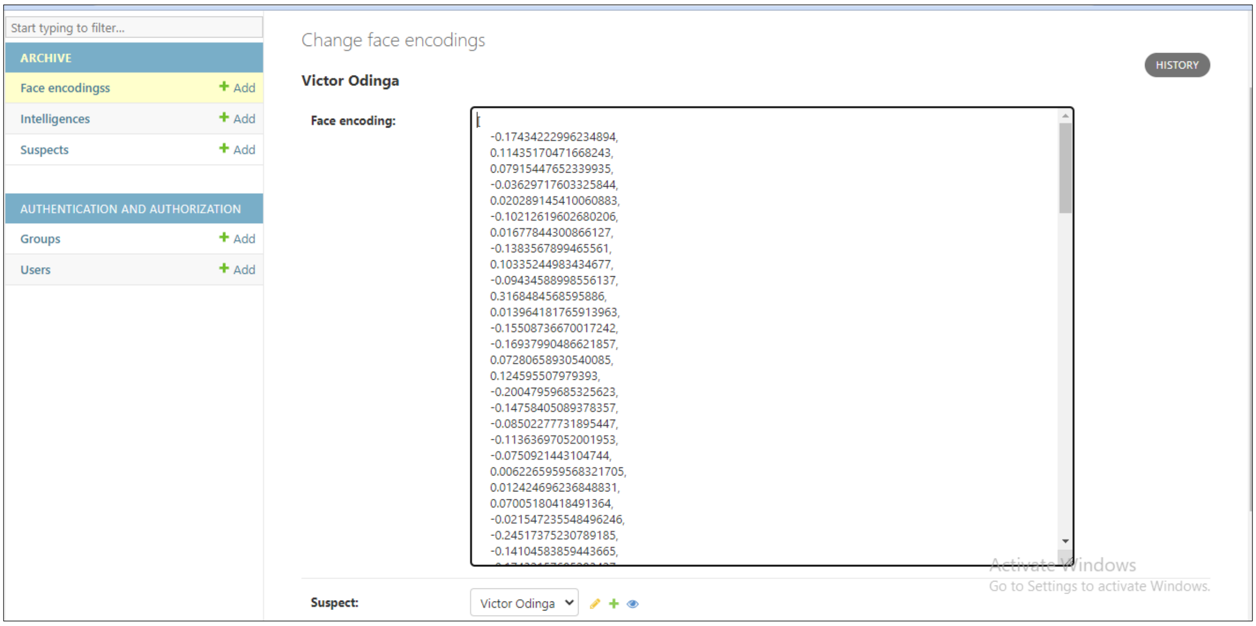

Figure 12 Face encodings extracted from a demo criminal image and stored in database

3.6. Output System of DICA

The face with smallest distance is retrieved and rectangular box is drawn over the face, the name of the criminal displayed and alarm is raised in the output screen of the DICA web app.

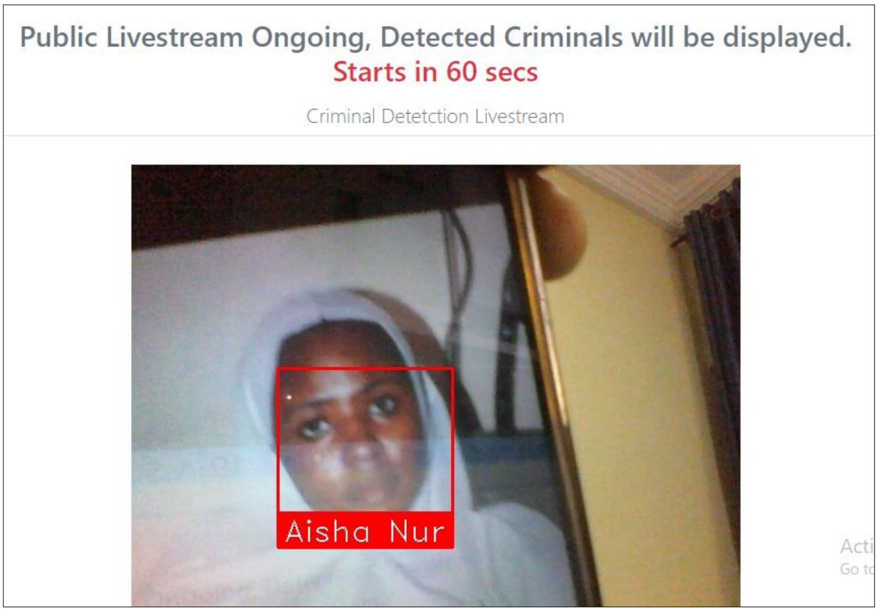

Figure 13 Recognition of Aisha Nur, a wanted criminal in Nigeria from DICA system

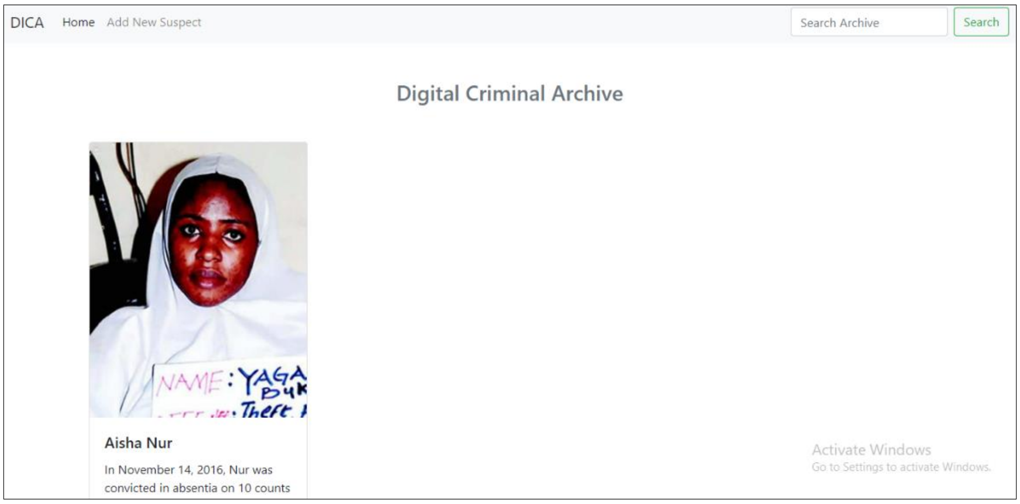

Figure 14 List of wanted criminals stored in the DICA system.

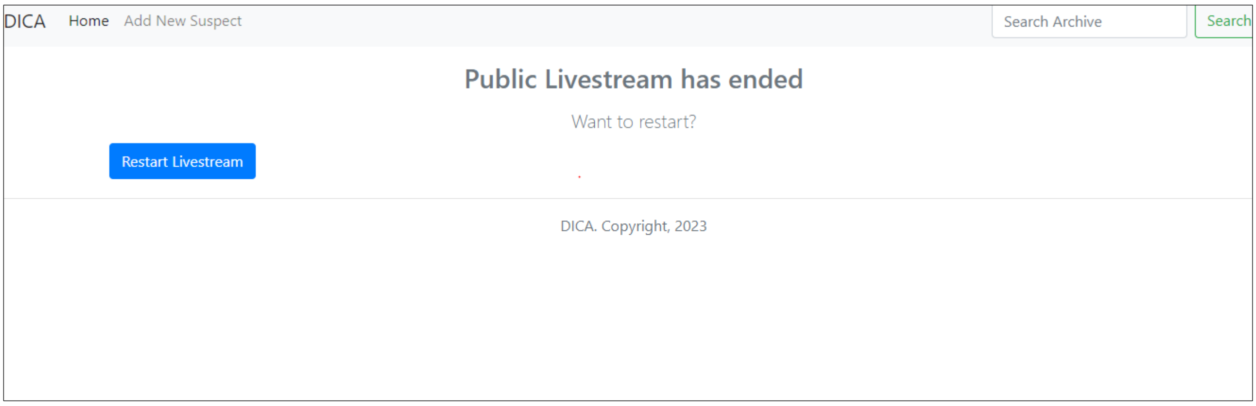

Figure 15 Livestream Restart Screen of DICA system

4. Conclusion

Digital Crime Archives of Facial Recognition System (DICA-FRS) is an automatic criminal identification/investigation cloud based system that can efficiently bridge the gap of real time crime records, detection and investigation currently observed in the Nigeria Security Agencies. This is practical digital solution to the proposed Nigeria Crime and Criminal Tracking System (CCTS) [39] which is poised to create streamlined process for conducting crime investigation [40]. As a response to the CCTS Bill, DICA-FRS will bring the criminal database and operations of the Nigerian Police Force into the modern era by serving as a model for the design, development, installation, and management of a crime and criminal tracking database — a criminal record registry and establishment of Central Criminal Registry (CCR) under the Force Criminal and Intelligence Department of the NPF.

DICA-FRS is built as an automatic criminal identification/investigation system by detecting the face of criminals and creating real time digital archives for them. Face recognition, which is based on OpenCV, is a technique that uses CCTV video to identify criminals who enter public spaces by detecting their faces and identifying them. The person's recorded photos when they enter the area will be compared to criminal records in the database or archives. The system will display that person's image on the screen and notify you with their name that the criminal has been located and is present in this public area if any other person's face from a public location matches. More than 80% of the collected photos and database photographs could be matched by the system, according to testing. This will help Police to identify and catch the criminals in public places.

Recommendation

While the constructed prototype system may show how a gap might be closed, it also reveals potential prospects for innovation in this area of interest. DICA-FRS was created as a prototype with a focus on the elements that real-time criminal investigation lacked in comparison to manual archives and systems already in place. However, effective large scale system from the prototype should be developed by the Nigeria Police Force in collaboration with National Information Technology Development Agency (NITDA).

Furthermore, collaborative system architecture with other Africa regional security agencies (West Africa etc) for effective regional crime recording and investigation is yet to be captured in the developed prototype. Therefore, in future studies, a more reliable system design and model may be developed. This can be regional and international policing standalone crime archival and investigation management system to combat trans-border crimes. This can also be integrated in existing systems as an improvement.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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