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A Unique Identification System using Ear Acoustics Biometrics

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Abstract:
Identification systems play an important role in the field of security and control systems where the need to protect sensitive or privileged locations are a necessity. In recent times, the applications of biometrics are currently gaining grounds. The aim of this paper is to investigate the feasibility of an acoustics-based ear biometric system exploiting the reflective properties of the human ear canal as a Head Related Transfer Function (HRTF) suitable for real time recognition of individuals in dynamic environments. Using the dynamic simulations environment in MATLAB-SIMULINK real time data captures including enrolment and comparative similarity checks based on the cosine similarity metric method with threshold conditioning enrollment and authentication procedures were performed on a total of 4 subjects. Generated similarity values for the various comparison operations were further analyzed for possible trends with an autoregressive moving average (ARMA) filter method. Considering a dual subject analysis, experimental results revealed that 100% recognition accuracies are achievable. Also, trend analysis captured by moving average response plots revealed the tendency for subject1 and subject2 to move towards the low and high false acceptance rates respectively. Considering the need to approach the acoustics-based ear biometric authentication of individual persons at a systems level using very high level simulation language – MATLAB SIMULINK, and in addition to the need to gain insight into possible future recognition states of the system using the ARMA method, it has clearly demonstrated the potentials of the proposed approach in secured locations.

Keywords*: Acoustics-based Signal Processing; Auto Regressive Moving Average;Ear Biometric System; Head Related Transfer Function;Identification systems*

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I. Introduction.

Identification systems play an important role in the field of security and control systems as the need to determine the precise authenticity and granting of access to persons and/or systems is increasingly becoming an urgent requirement in many industries, organizations, institutions and diverse operational environments.In the not so recent times, identification systems (IS) have employed some sort of traditional image bio-metrics such as fingerprinting, facial e.g. eyes and nose etc., and non-image e.g. voice, that employed physiological and behavioral characteristics for identification purposes. These traditional (explicit) forms of biometrics were in the non-functional class of biometrics and mostly open [1]. But they lacked some essential security and technical features such as anti-spoofing and corrosion resistance. More recently, Functional Class Biometrics (FCBs) on the other hand have exploited some inherent features (geometry) of the human body to evolve a transfer function for identification. The acoustic inspired ear, skull-based and tooth-based biometric systems [1][2] fall under this category.

Biometrics has for long played a vital role in improving the resilience of person identification system and quite a wide body of research has been conducted in diverse areas till date. The field of ear biometrics however still represent an emerging area in the field of person identification systems as this particular area has until now been highly underrepresented – in particular, this has been the case for acoustics-based ear biometrics for which there seems to be a current reawakening. Indeed, active ear biometric research and experimental studies/designs span over two decades and has shown tremendous progress after the discovery of the potentials of ear for person identification several centuries ago [3].

Currently, there is the challenge of effectively and reliably identifying persons in the existing authentication systems without excessive data gathering and huge databases. Majority of existing systems used in the country, Nigeria currently still employ image-based biometrics as authentication but it is highly inefficient and does not scale well across different computing and human wearable and handheld devices. This problem is also related to the data-intensive crunching problem where very large databases have to be harnessed in order to effectively analyze security features of many individuals.A useful and re-emerging alternative is in the area of ear acoustics-based biometrics but it still suffers from the influence of noisy background and in addition the need to improve accuracy in person-dynamic mobile systems. Hence, it still presents an area for further research which this research is all about.In particular, this research also seeks to leverage on useful properties of temporal state processing to develop more adaptive, resilient and insight-gathering acoustics-based ear biometrics for identification systems.

While many biometrics have been proven to be very effective, they face the challenge of easy access and re-configuration. With the proposed solution, it is then possible to implement more effective biometric authentication systems that are well structured and less prone to hacking or reverse-engineering by intruders.In this research, an attempt at developing a more effective home-grown acoustics-based ear biometric system for person identifications is presented. In conducting this research, emphasis was placed on the temporal state dynamics inherent in real time systems as there seems to be a shortage of research ideas in this area. As the growth of biometrics-based solutions and its adoption increases, it is expected that this research will provide a useful reference to engineers for implementing local content solutions for novel biometric systems inspired by the ear acoustics.

II. Review of Related works

Earlier studies have exploited the ear canal property considering the Head Related Transfer Functions (HRTFs) and cryptographic signatures with especially created cryptographic hashing function and helper data for improved biometric systems authentication. [4]Investigated a fast person authentication system simulator considering an artificial commercially available earbud for microphone signal probing and three feature vector representations – the Ear Canal Impulse Response (ECIR), Ear Canal Transfer Function (ECTF) and Mel-Frequency Cepstral Coefficient (MFCC). Reference [1]Proposed Ear Dynamic, a dynamic in-ear acoustic based authentication system that exploits the deformational (signal-reflective) properties of the ear canal with respect to the stationary and mobile patterns of the human head and phoneme-pronunciation while the human speaks. Acoustic based ear biometric exploiting the feature of the pinna in the ear for person identification have been firstly proposed in [5] [6]. Experiments performed on 31 subjects using 8 ear transfer functions for earphones and headphones platforms and 17 subjects for mobile phone platforms.The concept of an Acoustics-based Signal Processing (ASP) for ear-based biometrics is as shown in Fig. 1.

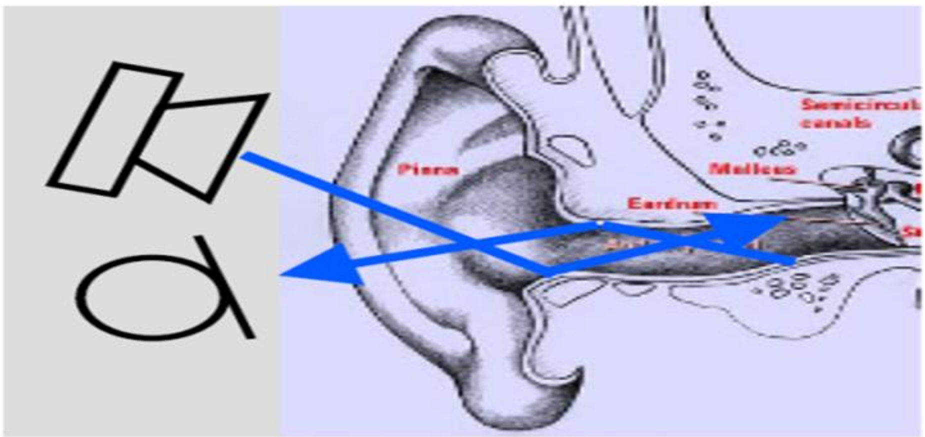

Fig. 1: Concept of ASP Ear Biometrics System [6]

As shown in Fig.1, a speaker provides a directed sound wave signal into the ear canal which due to the obstacles along the way, most parts of these waves gets reflected backwards and then gets captured by microphonic sensor while others are lost constituting an error signal.

Reference [7] proposed an in-ear acoustics biometric system that exploits the presence of in-audible probe signals for acoustic feature representation and capture. Their proposed system used primarily a three-tier feature extraction (signal recording/data capture) process including the Fast Fourier Transform (FFT) to obtain the two components of the Discrete Fourier Transform (DFT), the Cross Spectral Density (CSD) to obtain the ear canal transfer function and the Mel-frequency Ceptral Coefficient (MFCC) to obtain the intra-class invariant feature representations while considering fixed and variable earphone positioning.

In the reviewed works, the existing researches do not account for analyzing possible trends in estimated similarity measures based on temporal state representations which to the best of our knowledge play an important part in real time enrollment and authentication analysis. In particular, using such a temporal trend analysis approach can assist the operating research expert to identify the key parameter settings and establish relevant controls for adequate authentication considering continual streaming novel data. In addition, the use of a dynamic systems simulation model environment for real time ear biometric authentication is largely absent in most researches. Thus, this research emphasizes a dynamic systems model in addition to a temporal trend analysis for real time ear biometric data captures, enrollment and authentication.

III. Materials and Method

3.1 Materials

The following materials are used for the research: A pair of ear-phones attached to human ear
A loudspeaker, sound cardpersonal computer and power amplifier.

3.2 Method

The functional methods utilized in the design and development of an acoustics based ear biometric system is presented. The required tools and techniques for a data capture including the computations of the audio signals, the Head Related Transfer Functions (HRTF), similarity metrics and moving average predictors are presented.A systems level architecture of Ear Biometric System (EBS) employed in this research is as shown in Fig.2.

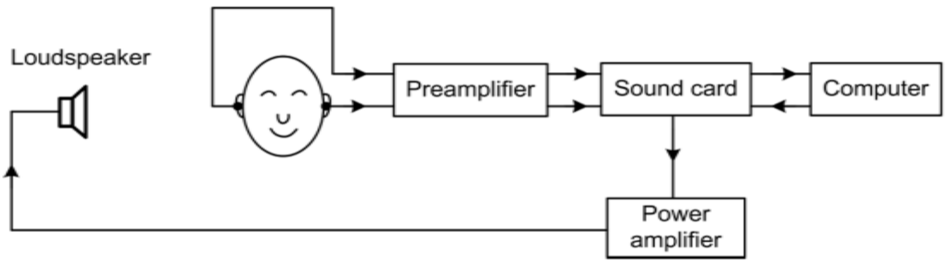

Fig.2: Ear Biometric System Architecture for Data Capture and Training [8]

As can be seen, signals emanating from a Loudspeaker device close to ear are captured by the ear and pre-amplified using a Preamplifier; the pre-amplified signals are parsed by a Sound Card device to a PC for signal processing. Also, the Sound Card furnishes a probing sound signal that is amplified by a Power amplifier and sent to the Loudspeaker.A Blocked Ear Canal (BEC) scheme for microphonic data capture is as shown in Fig.3 while the flowchart describing the processes involved in the actual data capture, enrollment and comparison operations is as shown in Fig. 3**.**

Fig.3. A Blocked Ear Canal Scheme for Microphonic Signal Data Capture [8]

The flowchart for data capture is shown in Fig.4.

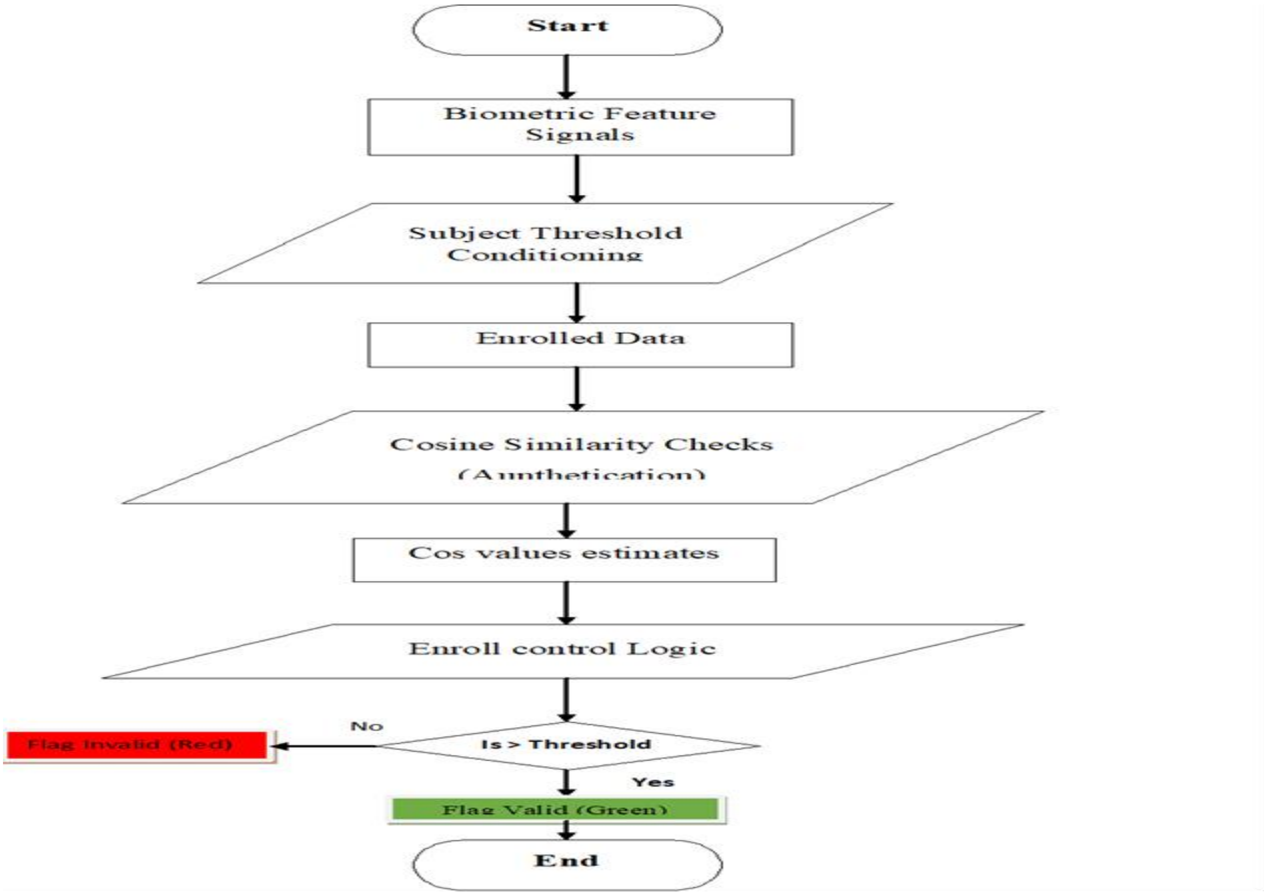

Fig. 4: Flowchart for Data Capture

3.2.1 Head Related Transfer Function and Feature Representation Computation

In order to determine the uniqueness of a given (test) human subject during EBS analysis and considering the modifying effect of environment on sound pressure waves impacting on the human ear, it is common practice to compute a so-called Head Related Transfer Function (HRTF) of the considered subjects. This enables effective evaluation of the response of human ear to variations in stimulus excitation probes as [8]:

$$H_L(r,\theta,\phi,f,a)=\frac{P_L(r,\theta,\phi,f,a)}{P_0(r,f)}, \quad (1)$$

$$H_R(r,\theta,\phi,f,a)=\frac{P_R(r,\theta,\phi,f,a)}{P_0(r,f)} \quad (2)$$

where,

P_L = sound pressure at left ear
P_R = sound pressure at right ear
P_0 = sound pressure at free field
r = source distance related to head center
θ = azimuth
ϕ = elevation of head relative to center
f = source distance related to head center
a = human subject

Considering a Maximal Length Sequence (MLS) signal characterized by state, x, its circle cross-correlated relation with a recorded signal say, y, may be expressed as:

$$R_{xy}(n)\approx h(n)-\frac{1}{N}\sum_{n=0}^{N-1}h(n) \quad (3)$$

where,

N = number of sampled sequences

h = transfer function

One key advantage of using MLS signal computation approach is that it allows a high signal-to-noise ratio measurement via averaging and hence is less prone to noise.

Furthermore, if we consider the ear-system as a one end open and one-end closed laminar tube - also called quarter-wave resonator. The key parameter to exploit hence is the ear canal natural resonant frequencies, $_{fear}$ and the incoming air frequencies, $f_{air(n)}$ which must match that of the ear canal. These matched or matching frequencies will be characterized by higher amplitudes. Thus, the matching f_{air} will be the one with the highest amplitude.

The resonant frequency may be computed as:

$$f = \frac{c}{4l} \tag{4}$$

where,

f = resonant frequency

c = velocity of sound in air, 343m/s

l = ear canal length

To design an effective moving average filter for acoustics based ear recognition and validation analysis, it is usual to describe a Q-order auto-regressive moving average (Q-P-order ARMA) as a system of equations in the complex-Z domain [8]:

$$H\left(z^{-1}\right) = \frac{b_0 + b_1 z^{-1} + \cdots + b_Q z^{-Q}}{1 + a_1 z^{-1} + \cdots a_P z^{-P}} \tag{5}$$

where,

$a_{1,\dots,}\, a_P$ = denominator filter coefficients

$b_{1,\dots,}\, b_P$ = numerator filter coefficients

The expression described in (5) gives the equivalent HRTF for acoustics based ear analysis. Thus, the solution of the trend analyzer is described by how well it matches the original pattern which is in-turn a function of the correct choice of coefficients described in (5).

3.2.2 Requirements and Experimental Procedures

Before live implementation, testing of the developed technique is required. Most of the time, testing and evaluating the protocols or theories proposed is not practically feasible through real experiments as it would be more complex, time consuming and even costly. So, to overcome this problem, "SIMULATORS and TESTBEDS are effective tools to test and analyze the performance of protocols and algorithms proposed [9].

Initial live test measurements were conducted on a total of 4 subjects conducted in a closed room of the Department of Electrical Engineering laboratory, Rivers State University and University of Port-Harcourt, all in Rivers State, Nigeria. The test subjects comprised of two males and two females and several consecutive measurements were taken with each participant reciting the word "Hello" for a total of 3 different simulation trials.In order to facilitate and assure correct test data capture, the following key requirements have been adopted.

3.2.2.1 Dynamic Test Requirements:

1. Limit ear canal volume changes by adopting some simple rules – not chewing gums, minimal mouth movement e.g. yawning, smiling or laughing etc.
2. Limit head-phones movement by avoiding sudden head movements.

3.2.2.2 Static Test Requirements:

3. Subjects are to remain in still position while sitting for at most 10 seconds.
4. Remove any hair obstructing ear measurements.

Though it was not unexpected to have some disturbances in the signal capture process, the experimental test requirements will suffice.

IV. Results and Discussions

The details of the simulations capturing the biometric template recognitions in a dynamic context are presented.The data capture process model for in-earphone signal acoustics within the MATLAB-SIMULINK environment is as shown in Fig.5.

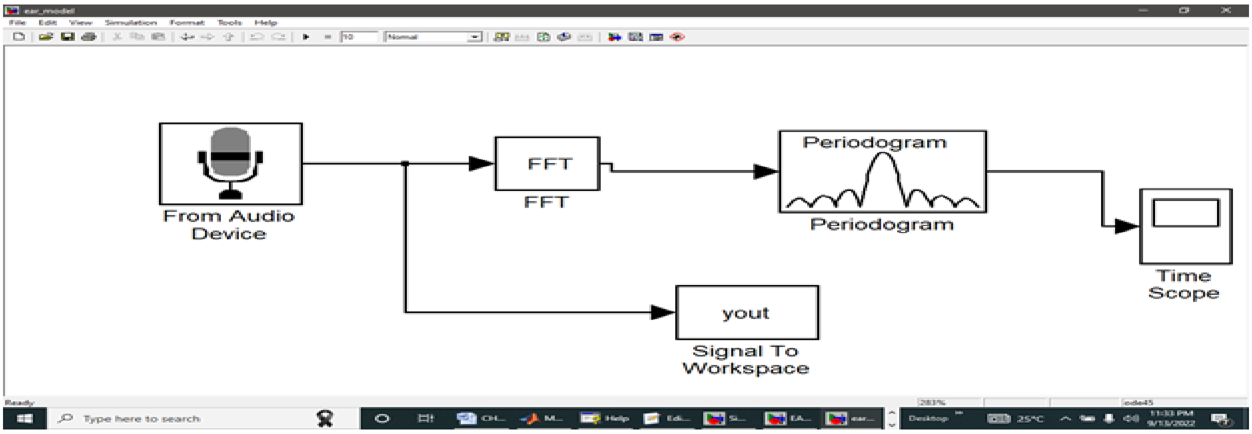

Fig. 5: Snapshot of Simulation model for Real-time Capture of Acoustics In-Earphone Signals

Also, shown is the line plot and histogram plots of captured patterns for Subject 1 in Fig. 6 and Fig.7

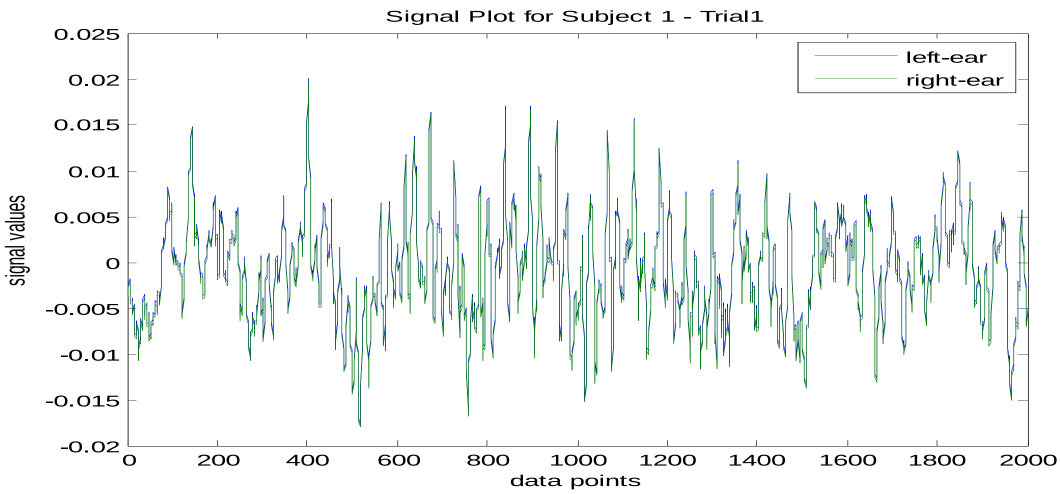

Fig. 6: Line Plot of Subject 1 in-earphone Signal Response – Trial 1

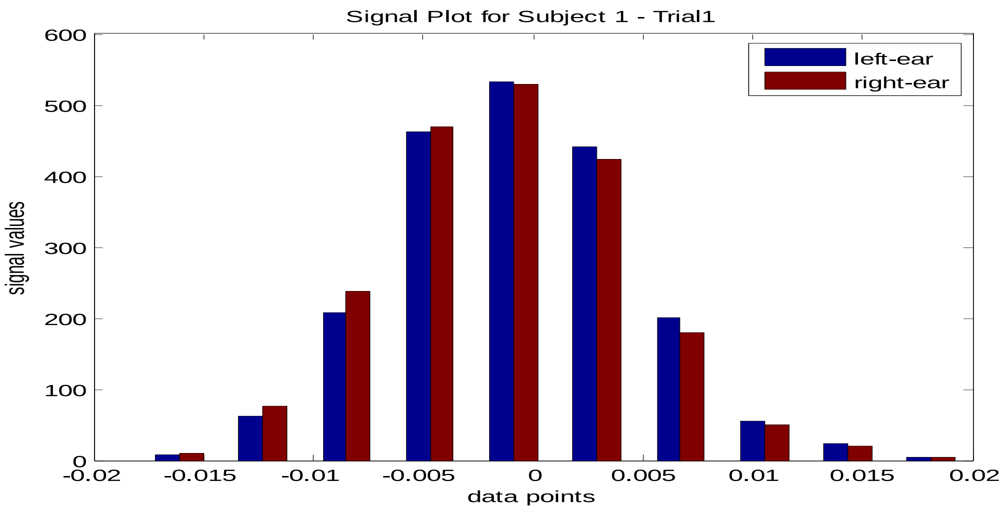

Fig. 7: Histogram Plot of Subject 1 in-earphone Signal Response – Trial 1

To evaluate the reflected Head Related Transfer Function (HRTF) signals on real time data capture, the data for a given subject are verified using enrolment procedures. This required several trial sample captures and is achieved practically using the system model in Fig.8.

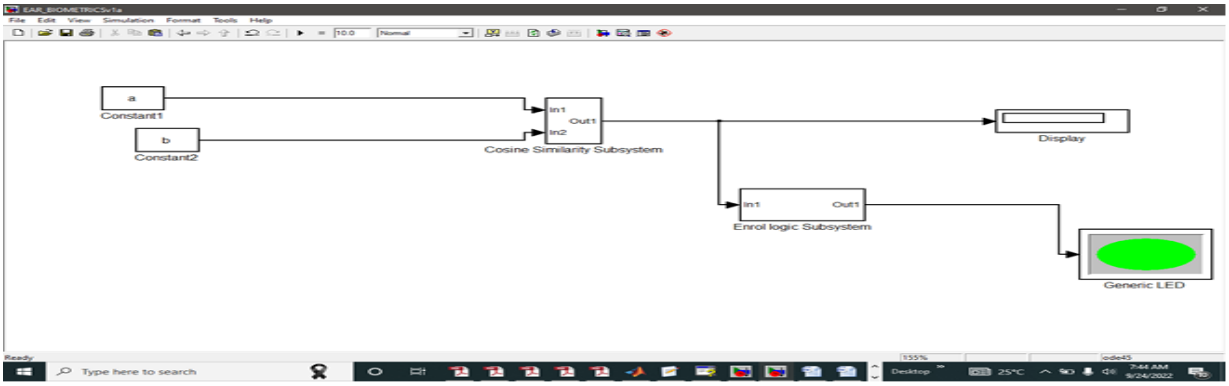

Fig.8: System for Enrollment and Acoustics-based Ear Biometric Capture

As shown in the Fig.8, there are two inputs to the system – the top input (input-a) is a constant block representing the enrolled reflected HRTF signal input while the bottom input (input-b) represents the incoming or new input reflected HRTF signal to be validated by the systems model. These signals are fed to a cosine similarity sub-systems model to perform a similarity check of correlation with existing (enrolled) reflected HRTF signal patterns and then fed to an enroll logic subsystem block to generate the desired control signal state display output – green or red where a green indication indicates that new incoming signal is enrolled and a red indicates not-enrolled.

Considering the first subject, the results for conducting ear biometrics are as shown in Table.1. The results show the cosine similarity values of the subject first pattern against the second and third and then against that of the second subject (first pattern only). This gives a total of three recognition comparison operations.

Table 1: Acoustics-based Ear Recognition Test – Subject 1

Comparison Count	Cos(a,b)
1	0.3782
2	0.4820
3	0.0573

From the Table 1, the comparison counts 1 and 2 represent the acoustics-based intra-subject ear biometric recognition cases (subject 1) while the comparison count 3, the inter-subject case (subject 1 and 2 compared).As can be seen from Table 1, the cosine similarity values of comparison counts 1 and 2 are much higher than that of comparison count 3. The reason for this is that the comparison count 3 is an inter-subject ear recognition test i.e. it is a test between a given subject and another different subject. Thus, as expected, it should give very low *cos* values. This formed the basis of our threshold which is set at 0.35.

V. Conclusion

An acoustics-based ear biometric system for identifying individuals was developed. Considering the dynamics of real time data capture and using real persons for user authentication applications. The system has been developed in the MATLAB-SIMULINK language which supports dynamic real time data captures.Extensive experiments considering the Head Related Transfer Functions (HTRF) of several human subjects in the Rivers State University and the University of Port-Harcourt campus environs were conducted.

The results of simulation experiments showed that with proper experimentation and threshold calibration, it is possible to develop acoustics-based authentication systems that can identify individuals correctly and with 100% recognition accuracy. Depending on human subjects under study, threshold cosine similarity setting may vary between 0.2 and 0.4. However, this variation is offset with the enrollment procedure deployed in practice.

Thus, it becomes necessary to conduct extensive simulation experiments to further reveal likely failures in proposed solutions model and minimize the problem of over-fitting on datasets.

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