UTM UNIVERSITI TEKNOLOGI MALAYSIA
INTERNATIONAL JOURNAL OF INNOVATIVE COMPUTING
ISSN 2180-4370
Journal Homepage : https://ijic.utm.my/

Design of a Biometric-based E-Ticketing and Access Control Framework for Public Transportation

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Submitted: 14/4/2023. Revised edition: 27/7/2023. Accepted: 17/9/2023. Published online: 24/11/2023
DOI: https://doi.org/10.11113/ijic.v13n2.406

***Abstract*—The use of public transportation has increased during the previous few decades. The management of the transportation systems and the sale of tickets have become increasingly difficult tasks as a result of the rise in usage. It is encouraging to see mobile devices being used for ticketing solutions. However, present approaches are frequently rigid and demand manual interactions that result in transient data. Other issues with the current systems include conflicts, environmental degradation, extortion, misapplication of funds, and unauthorized access to vehicles. Commuters may also become frustrated while waiting in lines to buy tickets or have their smart cards scanned. This paper presents the design of an e-ticketing and access control framework for the automated collection of transport fares and control of access to vehicles. The framework consists of e-ticketing and access control modules. The e-ticketing module enables passengers to register and make payments for transport fares based on their travel destinations. The access control module was designed to use a camera to capture the passenger's facial biometrics for processing and then make a decision on whether a passenger can board a vehicle or not. Full implementation of the framework will provide passenger convenience and improve the performance of the existing public transportation systems.**

Keywords—Public transportation, ticketing, biometric authentication, access control

INTRODUCTION

In today's world, everything is moving towards digitization. ICT-driven improvements have become widespread in a variety of spheres of life. Many of these advancements have also been accomplished in the field of transportation. Transportation is the movement of people, animals or goods from one place to another. Humans rely extensively and increasingly on motor vehicles or other forms of transportation every day for travelling to job places, schools, or our favourite destinations. According to (Oudah, 2016), by 2050, 68% of the world's population—more than half—will reside in urban regions. The number of people travelling in and around cities is anticipated to rise in the future due to the confluence of a growing global population and ongoing urban migration. As a result, there will continue to be traffic congestion, parking will be challenging, and air quality will deteriorate. However, these issues can be lessened by increasing the number of people using public transit. The number of people using public transportation to travel to workplaces or other destinations has significantly increased in recent years. However, due to several issues, including rising petrol prices, the expense of parking, and the inconvenience of travelling, people, even car owners, choose to use public transportation instead of driving their vehicles. Utilizing public transportation saves money and eases traffic in urban areas (Veerajay *et al.*, 2019).

It is noteworthy that the majority of public transportation sectors use outdated fare collection techniques, which is inconvenient for several reasons. Direct cash (onboard), paper tickets, and smart card systems are the most often used techniques. Using the direct cash method could result in conductors and passengers running out of transportation price balance while purchasing tickets, leading to conductor-passenger conflicts (Couto *et al.*, 2011). Paper tickets significantly increase the amount of paper used, and when discarded carelessly, they can lead to environmental pollution (Balu *et al.*, 2018). Even when the number of unsold tickets per day is fairly large, it is still feasible for a dishonest fare collector to demand more funds from a newbie traveller who is unaware of the actual fare beforehand (Fahim *et al.*, 2018).

Other problems include the tedious and stressful manual filling-up of the passengers' manifest, mismanagement of funds by vehicle conductors, misplacement of tickets by passengers, unauthorized or uncertified entry into vehicles, and the difficulty in determining who is eligible for bus passes (Rajkumar *et al.,* 2018). Different methods of fare payment, including Radio Frequency Identification (RFID), Global Payment Services (GPS), and ZigBee, have replaced the cash and paper tickets system in some public transportation sectors. The typical framework for these technologies is a smart card, which offers excellent portability and usability but also has drawbacks of its own. Hackers, pickpockets, and muggers frequently exploit smart cards for their nefarious activities. Given that the cash-onboard and paper ticket systems, which once provided convenient methods for simple payment, no longer meet the demands of the rapidly expanding population and the dynamic conditions that are present, as well as the fact that hackers are getting more powerful over time, there is a need for more advanced, secured systems to prevent the exploitation of valuable user information. One of the most effective methods for achieving this is the use of biometric technologies. Biometrics can be defined as human characteristics and trait-related metrics (Iwasokun *et al.,* 2015).

The goal of this research is to design a face-based system that automatically collects transportation fees from passengers and uses facial biometrics to control access to vehicles (boarding). The proposed system will allow passengers to sign up using facial biometrics, make payments, and have money automatically deducted from their accounts based on the destination or distance travelled. Facial biometrics will be linked to payments made through the system gateway, and only passengers whose biometrics indicate "paid status" will be allowed access to the vehicles. Entry will be denied for those whose biometrics indicate "unpaid status".

EXISTING SYSTEMS

Over the years, there exist different ticketing systems in use around the world. In general, almost every bus is controlled by a conductor and every passenger who wishes to travel must carry money along. In most regions, it is either ticket counters are placed at bus stations from where people buy tickets, or a bus conductor collects money from each passenger and issues tickets. A passenger has to manually fill out the passenger's manifest to provide information such as phone numbers, addresses, and next of kin among others. This process has to be repeated for all passengers, taking more time and wasting human resources as well as energy. Passengers need to carry tickets along with them throughout the journey to collect their remaining funds on reaching their destinations. Ticket loss might result in forfeiting the remaining funds while some passengers may forget to request these funds when they reach their destinations. Nowadays, transport fare collection could be done via portable handheld devices which are relatively slow, require operators to be trained, and demand printing of tickets (Arun and Lingeswaran, 2014*)*.

This scenario can be improved by developing clever mobile ticketing and digital payment capabilities. Existing Apps for smartphones offer commonplace electronic ticketing and payment possibilities but they still call for the same transaction processes as traditional paper tickets. RFID systems, as seen in Fig. 1, were developed to address the issues at hand with some of them automating payment collection by using fingerprint technology.

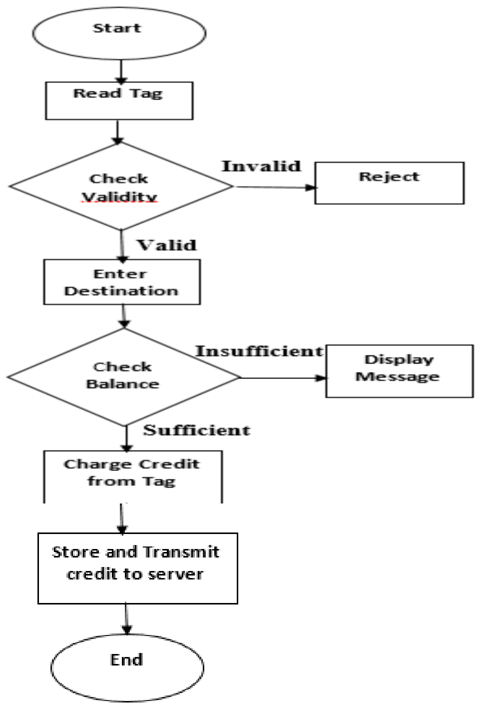

Fig. 1. RFID based Ticketing System

The drawback of RFID-based systems is that travellers must carry RFID cards and RFID detectors must be deployed (Sarkar and Chattrjee, 2014). The majority of the current technologies make it challenging to prevent impostors from gaining unauthorized access to vehicles. Utilizing fingerprint technology necessitates physical contact with equipment, putting users at risk for infections like COVID-19, chicken pox and so on. Additionally, most people dislike undergoing contact-based scans because they can be both inconvenient and uncomfortable (Achimba *et al.,* 2021).

Consequently, an automated system that uses contactless facial biometrics is required in place of the conventional paper tickets and the other existing system trend. The proposed solution would be very helpful to the passengers because they won't have to stand in line to buy a ticket and won't need to carry cash or credit cards since the fare will be automatically withdrawn from their bank accounts. Access to the vehicles designated for transportation will be likewise controlled using the face biometrics.

RELATED WORKS

Krishna *et al.* (2019) presented a method for collecting fares for public transport corporations using a fingerprint recognition system with the help of Aadhaar. The work was motivated by the need to eliminate queues and the tedious process involved with the manual process of fare collection, which wastes a lot of time. The objective was to design a system that automates the transport fare collection procedure, which simplifies the tedious existing process. The research adopted histogram equalization and Fourier transforming methods for image enhancement. The distributed image pixel value was expanded in the histogram equalization method to improve its quality while the Fourier transform method was used to increase pixel density. The system has no provision for automated access control. In addition, the use of fingerprints for recognition involves making contact with devices which might result in candidates contracting diseases.

Rajkumar *et al.* (2018) and Desire and Papias (2019) presented systems that use GPS and RFID Technology for bus fare collection. The researchers were motivated by the need to improve the performance of existing public transportation systems and the objective was to develop system that calculates the distance travelled by passengers and automatically debit a corresponding amount from the passenger's account. The system uses RFID technology which consists of two components, an RFID Tag and an RFID Reader. The RFID Tag contains information such as name, address and mobile number. RFID reader reads the above information from the RFID Tag. An Infrared sensor is also used to count the number of persons entering the bus coupled with a GPS that calculates the distance travelled by the passenger and continuously monitors the position of the bus. The system has no provision for automated access control and lacks a biometric form of identification. The RFID technology is difficult, time-consuming and expensive to set up. It may malfunction during power outages and it is not reliable as it can be hacked or bypassed. Smart cards can also be lost or forgotten.

Chaudhari *et al.* (2017) proposed fingerprint recognition for a bus ticketing system. The system was motivated by the need to resolve issues surrounding the paper ticketing method. The objective of the research was to incorporate a biometric module into the existing electronic ticketing systems. The system has no provision for automated access control and the use of fingerprint for recognition involves making contact with devices which might result in candidates contracting diseases. Balu *et al.* (2018) presented a biometrics-based bus ticketing system. The research was motivated by the need to simplify the complexities such as corruption of ticketless travel and paper waste that accompany the ticket vending and management of the public transport system. The objective was to provide a secure system that uses fingerprints for booking bus tickets. The system stores the odometer reading of the bus against the value of a scanned fingerprint during the time of boarding and exiting the bus. The Infrared (IR) transmitter is used to stop the wrong use of entry points and smartcards are used in cases of fingerprint failure. With fingerprint recognition, users have to make contact with devices, exposing them to the risk of diseases such as COVID-19, chicken pox, among others. Some users experience inconvenience and discomfort in the process of always having to provide biometric traits for authentication.

Subramaniyan *et al.* (2021) presented the development of a smart ticketing system for public transport vehicles. The research was motivated by the need to address the tedious process involved in using the existing ticketing system and its objective was to develop a biometric-based system to automate ticketing services for public transport. The research explored an automated card-driven system using RFID for bus commuting. The RFID comprises of RFID Tagger and Reader. While the RFID tag contains data related to the user, the RFID reader deduces information from the passenger RFID tag. Face recognition is done by a camera that is implemented by Haar cascade techniques. IR sensor counts the persons entering the bus and a relay circuit opens the door for passengers while a proximity sensor analyses the distance travelled.

Priyanka *et al.* (2020) developed a smart ticket system for metro trains. The research was motivated by the need to address the inflexibility and inefficiency of the current traditional ticket systems and its main objective was to use image recognition and artificial intelligence models to provide a ticketing system that eradicates the paper-based system. The research uses the Haar cascade classifier which is based on the Haar wavelet technique to analyze pixels in the image into squares by function. This uses integral image concepts to compute the features detected. Haar cascades uses the Ada-boost learning algorithm which selects a small number of important features from a large set to give an efficient result of classifiers and then uses cascading techniques to detect the face in an image. The system needs an improved user-friendly GUI as the application varies according to real-time application. Furthermore, there is a need to train the model with images belonging to a particular location to improve the accuracy of the prediction

A face detection concept for car theft detection applications using skin colour information is presented in (Mahendra *et al.*, 2018). The research was motivated by the need to protect cars from unauthorized access which often results in theft. The main objective is to provide a face detection concept for real-time car theft detection. Skin colour detection was performed on the input colour image to reduce the computational complexity while an Adaboost algorithm was used for face detection and a principal component analysis (PCA) algorithm was used for face recognition. The research only introduced car theft detection but failed to implement the car lock security system. Kumar *et al.* (2017) and Hanumanth *et al.* (2022) presented face recognition systems for locking and unlocking doors. The researchers sought to address the inefficiencies of the present lock opening system which include a remote keyless entry system, RFID door unlocking system among others. The objective of the research was to develop a face recognition system for unlocking doors. The approaches involve capturing real-time images with a Webcam, conversion of the images into digital format for access by the PC and the use of Open CV software for image processing and comparison. They also involve utilization of 'Blynk' cloud server programs for various functions like remote electronic door locking, multitasking, and receiving notifications. The limitations of the system include difficulty to operate, lack of an alternative in a case where the biometric trait fails and no provision for e-ticketing.

Roy *et al.* (2018) and *Vamsi* et al. (2019) presented face-based recognition door lock and unlocking systems using Raspberry Pi. The researchers were motivated by the need to eliminate the drawbacks of the existing conventional door lock system which include information theft, lack of security and violation of privacy. The objective was to create a smart door, which secures the gateway using face recognition. The approaches involve the analysis of a real-time face recognition system with a Local Binary Pattern Histogram (LBPH) algorithm, the use of the Haar Cascades classifier as a face detection algorithm and the Adaboost machine learning algorithm, which is inbuilt into the OpenCV library that is a cascade classifier, to eliminate the redundancy of the classifiers. The limitations of the systems include remote control of access to the door by an individual which could impede the automation process as well as lack of provision for e-ticketing.

Yedulapuram *et al.* (2020) used face recognition to design a door lock system. The research was motivated by the need to address the security challenges encountered with the traditional door lock system. The objective was to develop a door lock system that uses face recognition to secure access. Face detection is done with the help of a Pi camera on the Raspberry platform. Python and Open CV libraries were used for coding. Haar classifier method for face detection was used to get an accurate and clear picture of individuals. The system does not have any other alternative in case the face recognition fails. Automated electronic payment systems for the collection of transport fares in public transportation are presented by Boiko *et al.* (2018) and Dhule (2018). The researchers were motivated by the need to address the difficulties and travel expenses involved with the existing systems. The systems provide an easy-to-use payment platform with the use of mobile phones or smart cards and control the amount of travel expenses for a certain period. They involved the concept of the Internet of Things which makes use of Near Field Communication (NFC) to make payments. There is also a description of the main characteristic of an automated electronic payment control system (AEPCS) and a proposal on the stages of its implementation at the transport enterprise to ensure full control over the transportation process and cost estimates. The systems are susceptible to theft, transfer, loss or forgetfulness. There is also no provision for access control to the vehicles.

The limitations of the existing and related works include lack of provision for automated access control while the operations are complex in nature, susceptible to the transfer of contagious diseases, time-consuming and expensive to set up. Other limitations are the impediment of remote control of access and the lack of provision for e-ticketing missing alternatives in cases of recognition failure. The quest to fill the research gap created by these limitations served as the motivation for the research being reported. A framework that adopts biometric technology as a means of addressing these limitations is proposed for e-ticketing and access control in public transportation.

PROPOSED FRAMEWORK

The proposed framework focuses on allowing passengers to pay for transport fare electronically and associating the payments with their facial biometrics. The facial biometrics are subsequently used for passengers' authorization and access to the vehicles. The framework is conceptualized in Fig. 2 with modules for e-ticketing and access control.

E-Ticketing Module

The e-ticketing module has a signup page where passengers are allowed to input their details including facial biometrics for pre-registration to the web application. The passengers can select their destinations and make payments through this module. Pentium 4 with specifications not below 3.6 GHz Processor and 4TB HDD for the server and 3 GHz Processor with 500 GB HDD and 8 GB RAM for the client are required for very reasonable computational speed at the experimentation level (Iwasokun *et al.*, 2019), with a webcam (such as Microsoft LifeCam Cinema camera or Logitech C920 HD Pro Webcam).

Access Control Module

As soon as a passenger gets to the point of entry the vehicle, the camera captures the image for face recognition. If the captured image is found to match with any of the pre-registered database image, the door is unlocked for the passenger to board the vehicle, otherwise, boarding is denied. The operational structure of the access control module is shown in Fig. 3. The main components of the operational structure are discussed below:

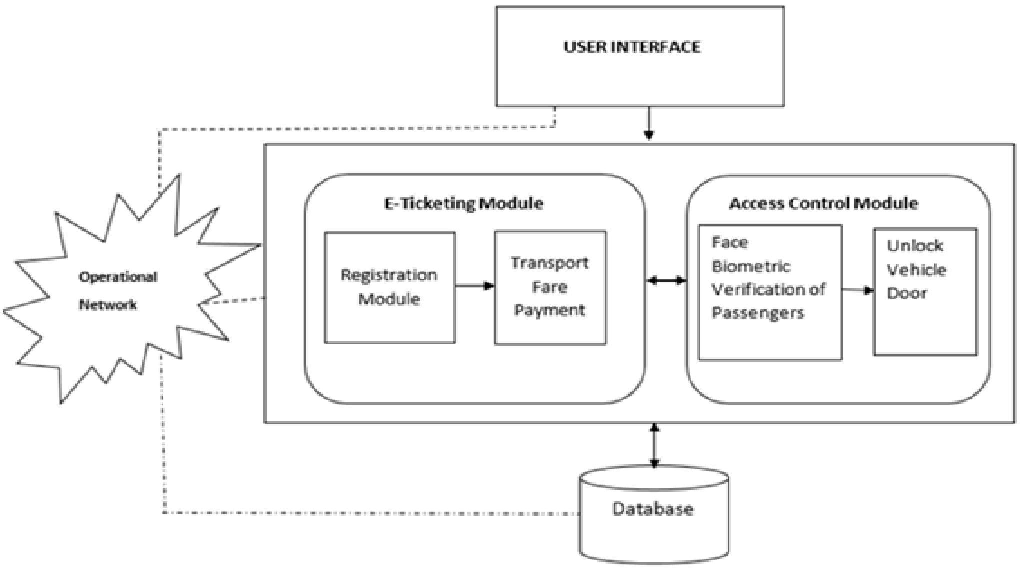

Fig. 2. The operational framework of the proposed E-Ticketing and Access Control System

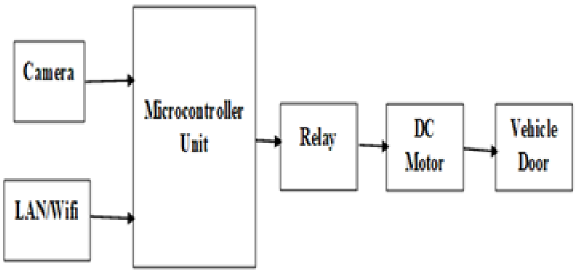

Fig. 3. Operational Structure for Access Control

Pi Camera

The Raspberry Pi Camera Module 2 is recommended. It has a Sony IMX219 8-megapixel sensor and can be used to take high-definition video as well as still photographs.

Raspberry Pi

The Raspberry Pi model B3 is the recommended Microcontroller unit for the proposed system. The ability to adapt to various programming modes, low cost, and high processing capacity are the primary factors in this decision. The system runs on Linux, which provides access to a huge selection of libraries and programs that are compatible with it (Shrutika *et al.,* 2017).

Relay

A relay is a switch that is activated and deactivated by another electrical circuit and typically has a single-pole-double-through-the-switch or a double-pole-double-through-double-switch.

They are also capable of having more sets of switch contacts, such as four sets of changeover contacts in some relays. A magnetic field that is perpendicular to the direction of electron movement is created when an electric current flow through a conductor. The magnetic field generated by that conductor will be orientated down its length if it is wound into a coil shape. All other things being equal, the magnetic field intensity increases with increasing current (Sowjanya *et al.,* 2018).

Direct Current (DC) Motor

A DC motor is a device that converts electrical energy into rotational mechanical energy. It moves as a result of electromagnetism's physical characteristics. Inside DC motors are inductors that create the magnetic field needed to drive motion. A current-carrying conductor experiences a mechanical force anytime it is put in a magnetic field, according to the operating principle of a DC motor. The linked DC motor's speed changes to changes in terminal voltage (Sowajanya *et al.,* 2018).

Verification

The process of facial-based verification is conceptualized in Fig. 4. Face-based verification involves the enrolment and processing of each passenger's facial biometric trait to decide whether or not a passenger should be granted entry to a particular vehicle. Decision-making involves feature extraction, normalization of biometric features and matching of the extracted features. The facial trait of a passenger is verified using some sequence of activities while PCA technique is used to determine eigenfaces. For a given D dimensional data set X:

First, the mean vector μ[d] of dimensions Dx1 is computed, where N is the number of samples in the data set (Stankova-Frenkel, 2022):

$$\mu[d] = \frac{1}{N}\sum_{n=1}^{N} x[d.n], \quad (1)$$

Compute the D x D covariance matrix C as follows:

Subtract the mean vector μ[d] from each column of the data matrix X resulting in matrix B of D x N dimension.

$$B = X - \mu.1, \quad (2)$$

Compute the covariance matrix C of D x D dimension:

$$c = \frac{1}{N}B.B^{*}, \quad (3)$$

The extraction of the Eigenvectors (e_d) is through the computation of matrix V, formed by D columns vectors of D length each, which diagonalizes the covariance matrix C as follows:

$$V^{-1}CV = \wedge \ , \quad (4)$$

$$V = [\, e1 \ \dots \ eD \,]. \quad (5)$$

The eigenvalues (λ_d) are the diagonal values of D x D matrix L. It is presented as follows:

$$\lambda d = \begin{bmatrix} \lambda_1 & 0 & \dots & 0 & 0 \\ 0 & \lambda_2 & & 0 & 0 \\ \vdots & & \ddots & \vdots & \\ 0 & 0 & \dots & \lambda_{D-1} & 0 \\ 0 & 0 & & 0 & \lambda_D \end{bmatrix}, \quad (6)$$

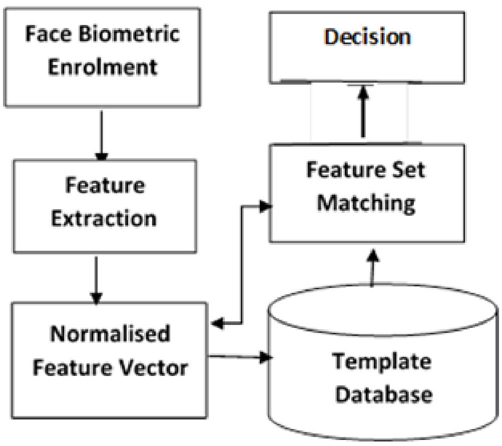

Fig. 4. Face biometric authentication process

The directions of maximum variance correspond to the eigenvectors with the largest eigenvalues. Following that, it is necessary to select the L largest eigenvalues and related eigenvectors, presuming that the remaining D-L dimension space contains no useful information. There will be some information loss, but the smaller the eigenvalues, the less amount to be lost. It is necessary to create an L x L matrix A with the L eigenvectors as columns once the components (eigenvectors) have been formed. The original dataset must then be multiplied by the transposed matrix A, having already calculated its mean value (Kutller, 2022).

$$x' = A^{t}.(x - \mu), \quad (7)$$

Applying the following back projection will result in the inverse transform, which will return the original data.

$$x'' = A\,.x' + \mu, \quad (8)$$

A facial image is projected onto N' dimensions based on the formula (Kyungnam, 1996):

$$\Omega = [v_1, v_2, \dots, v_{N'}]^{T}. \quad (9)$$

Where $v_d = e_d^{T}B.\ v_d$ is the facial image's d[th] coordinate in the new space, which represents the principal component.

The vectors e_d are also images, sometimes known as eigenimages or eigenfaces which can be seen as images and indeed resemble faces. So, Ω defines the role played by each eigenface in representing the facial image by using the eigenfaces as a basis set for facial images. For the decision on which face class best describes the input face image, the Euclidean distance is minimized based on the formula:

$$C_k = ||(\Omega - \Omega_k)|| \quad (10)$$

Where Ω_k is a vector that describes the kth face class and a face is classified as belonging to the class k if C_k is less than some predefined threshold θ_C.

A public transportation system that runs on the proposed platform will perform customer verification based on the steps enumerated above as a follow-up to the payment of ticket fees. Successful verification established true payment and qualification for eventual boarding.

The payment system is a gateway that registers and allows a passenger to make ubiquitous and online payments for transport fares on a PC or mobile phone via a pre-linked bank account. The transport fare will be calculated based on the expected distance while the payment status will be associated with the fa cial biometrics of the passenger. At the vehicle station, as the passenger approaches the vehicle, the passenger’s face is captured by a camera for processing on payment status. Only passengers with the correct payment status and successfully verified will be granted boarding permit. The implementation proceeds and is expected to produce a system that guarantees increased convenience and efficiency, fraud prevention, less waste, reduced costs among others.

CONCLUSION

The paper presents the design of a framework for e-ticketing and access control for public transportation. The framework will adopt face-based authentication of passengers for payment and boarding certifications. The authentication process will require facial image capturing followed by feature extraction. Useful information from the extracted features will form a feature set whose attributes will be compared with those from pre-stored feature sets towards deciding whether a passenger can board a vehicle or not. The implementation of the framework is ongoing in the Windows 11 Home Edition version 22H2 operating system. Python and Open CV libraries provide the programming terrains while MySQL provides the database platform.

The implementation is expected to produce a system that addresses key ethical issues of facial recognition. The resulting system will require the consent or notification of the individual being recognized as well as ensure the privacy and preservation of all financial, business, social and bio data generated by the system. Strict measures will be taken to enforce transparency and guide against data abuse and right violation. Its mode of operation will adhere to all legal and constitutional terms and conditions defined by the host country for biometrics applications.

The post-implementation solution is expected to provide a ubiquitous ticket processing mechanism for passengers and hence eliminates the queue and other physical means of ticketing. It will also eliminate corporeal disbursement of cash using a credit card or any other manual method because payment will be through an automated system that is an integral part of the biometric authentication process.

ACKNOWLEDGEMENT

We would like to thank The Federal University of Technology, Akure, Nigeria for providing the enabling environment and relevant tools for the conduct of the research.

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