Intelligent Bi-modal Timetable-aware Biometric Attendance System for Enhanced Classroom Attendance

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Abstract. Attendance management is integral to many organizations and academic institutions. The manner in which attendance is managed has evolved over the years encompassing various techniques and methodologies. Although significant improvements have been made, existing systems are mostly standalone systems without proper monitoring and control from a central point. This makes it difficult for several attendance devices to be linked by a common scheme like a timetable schedule. This is integral because the lives of students in every academic institution revolves around a schedule of events and classes. There is also a need to maximize the use of the data generated from attendance systems to make meaningful decisions and predictions about students' academic activities. The research led to the implementation of several modules which includes the key timetable-schedule module and an elaborate API structure deployed to a central server for a centralized communication network between attendance devices instead of standalone devices as traditional systems have employed. The research also investigates factors affecting the performance of students and which of these factors is the greater determinant. From the results and dataset investigated, it was found that attendance is in fact not the primary determinant of students' academic performance. Extra educational support, extra-curricular activities and family support are the top ranked factors affecting academic performance in accordance with the results obtained from this work.

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1 Introduction

Taking attendance is an important consideration in many colleges and organizations for a variety of reasons, and it is one of the most important requirements that students and workers must meet. The previous method of manually recording and maintaining attendance records was extremely inconvenient. With these issues in mind, over the years, an attendance system which automates the whole process of taking attendance and maintaining it has been developed. Iris recognition, speech recognition, facial recognition, fingerprint identification, DNA recognition, hand geometry recognition, signature recognition, and gait recognition are some of the most widely used biometric techniques for objective identification and verification [1]. The practical application of an attendance management system needs a consistent and predictable identity management system. Biometrics data are incorporated in attendance management systems to make the identity management system more secure and reliable for authentication. Biometric technology verifies identification by means of features like fingerprints, ears, irises, retinal patterns, palm imprints, speech, handwritten signatures, etc. These physical data-based techniques are gaining traction as a more convenient personal authentication tool than traditional methods [2].

Studies have highlighted that there is a clear relationship between a student's class attendance and performance level. The studies also mentioned that students with low attendance percentage generally have poor retention, and lesser commitment and interest towards a course. The studies claim that attendance is generally a better performance predictor [3]. This is why more recent studies focus on how to utilize the data generated by automated attendance systems to make attendance predictions and correlate it with student's performance, while some studies use attendance data for optimal timetable generation and venue allocation by allocating classes based on real student enrollment, this scheme seeks to achieve optimal room occupancy. This will address the issue because if the number of actual students who will attend the class is decided in advance, the timetable and distribution will be well prepared [4].

The conventional method of attendance management, which relies on attendance logs and excel sheets, is slow, inefficient, and error-prone, making the management, retrieval, and study of attendance records a time-consuming job. There are several automated attendance management systems available to address these issues, however, many of these created systems do not consider the usage of a timetable schedule, which plays an essential role in arranging and deciding student activities around schools. Although a few systems were developed to function with timetables provided by a central server, these systems lack a good network tolerant architecture due to their complete reliance on an active internet connection and the lack of a caching solution. These Attendance systems generate a lot of meaningful data but fail to utilize them in areas such as machine learning to make useful predictions. As a result, this project proposes the creation of an intelligent network tolerant system capable of evaluating attendance data, making predictions, correlating student performance to attendance, and operating autonomously according to a predetermined schedule. The aim of this system is to develop an intelligent bi-modal timbale aware attendance system [5-14].

The objectives of this project are to:

i. design a bi-modal timetable aware attendance management system using fingerprint scanner
ii. design and train a Random Forest Algorithm using data collected in (i)
iii. design an online portal for attendance management and report using Firestore and NodeJS
iv. integrate, simulate and deploy (i, ii) and (iii) and evaluate its performance using false positive rate, false negative rate, precision, recall and response time

2 Methodology

The methodology employed in the system uses a central server to house the attendance schedule and hold student biometric information. This allows for multiple attendance devices placed at different venues to sync with the central server and retrieve student information for each scheduled class at the required time. With attendance records and biometric information stored in a central server, this gives room for extra processing capabilities which allows the use of Data analytics tools and machine learning tools to perform important analysis and prediction on the generated data.

3 Design Analysis

The attendance system consists of several modules. Each of these modules contribute to achieving all the desired functionalities. The system is divided into modules which includes:

i. The central server
ii. Timetable Schedule module
iii. API module
iv. Admin, student and staff portal
v. Data Synchronization module
vi. Attendance device

vii. Authentication module
viii. Data Analytics module

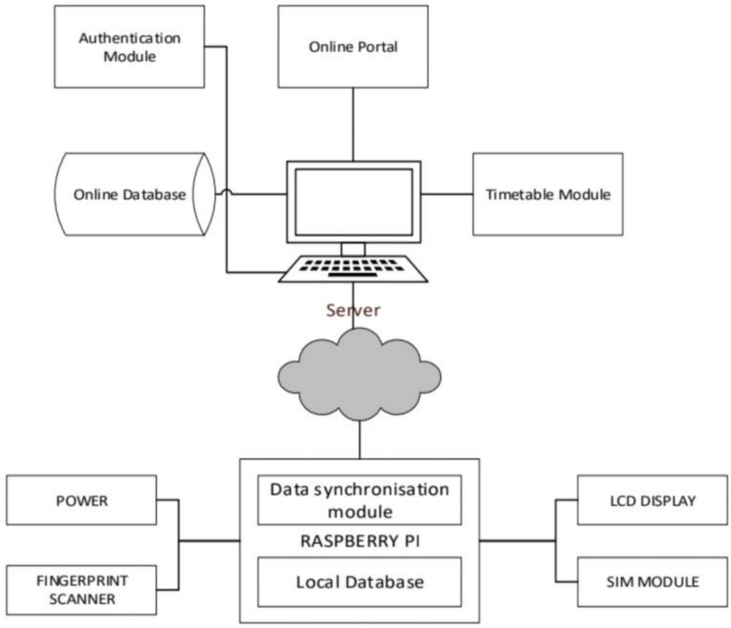

Fig. 1 Overall System architecture

3.1 Attendance Device

Several hardware and software requirements are put into consideration in building the attendance system's hardware. These specifications include an RTC, LCD, battery pack, Raspberry Pi controller, and fingerprint sensor. The operation of the attendance device is largely controlled by the timetable module and the Data synchronization module. The flow diagram below shows how these modules interacts to form a working system [15-20].

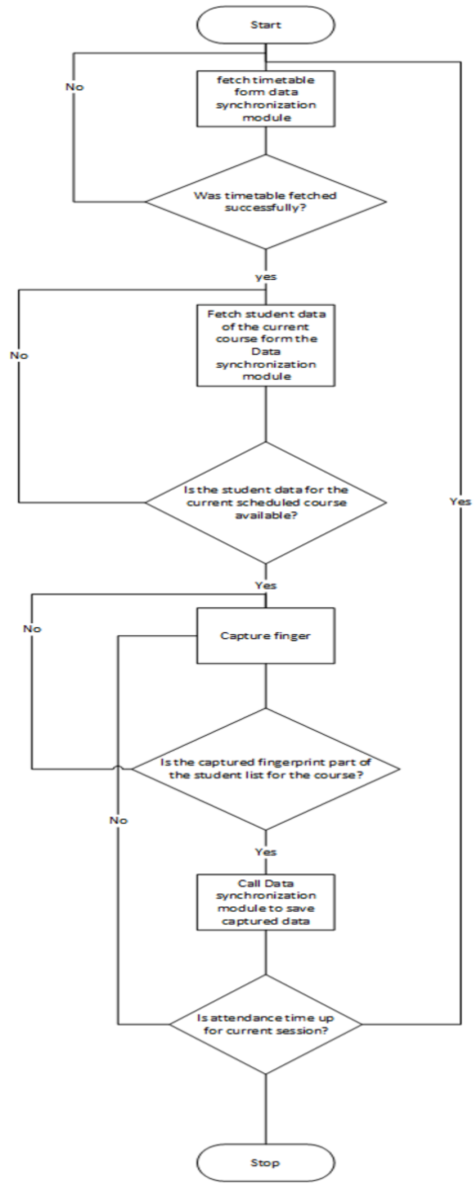

Fig. 2 Flow diagram of the system's operation

3.2 Data synchronization module

This module resides in both the central server and the attendance taking device. The Data synchronization module is responsible for ensuring data integrity and keeping information across all attendance devices synchronized and up to date. This module is what makes this attendance management system bi-modal by making it possible to work perfectly with or without internet connections. When there is no internet connection, the local data saved into the memory of the attendance device is used. When the internet becomes available, normal operations are resumed and data is synchronized with the central server. The flowchart below describes the general operation of the Data synchronization module [21-24].

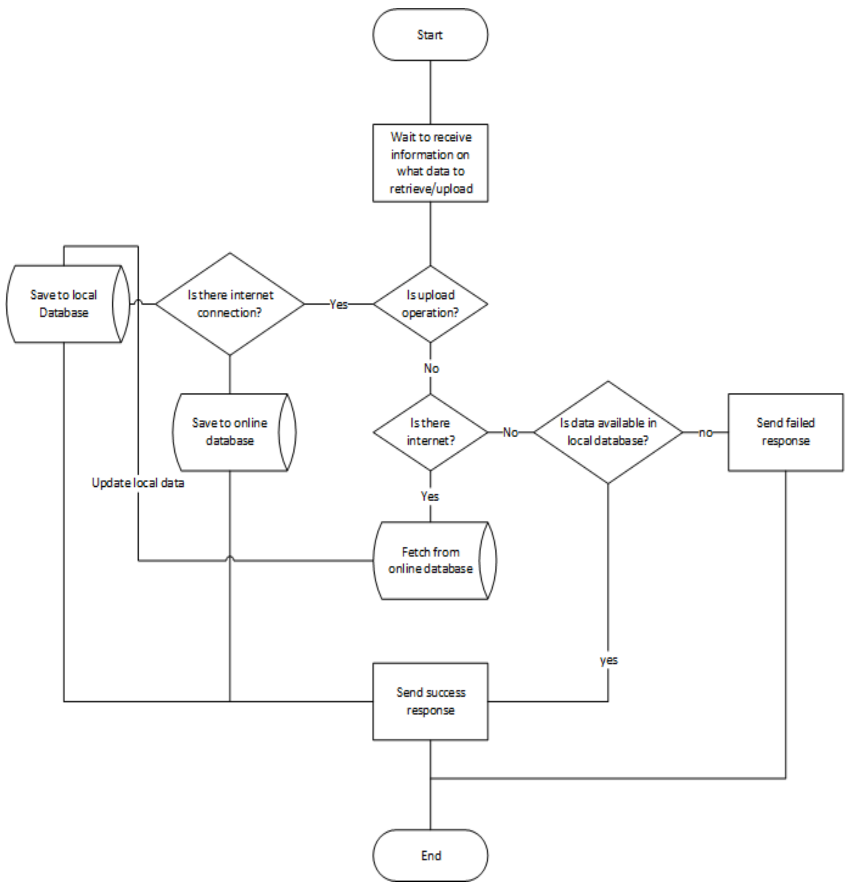

Fig. 3 Flow diagram of the data synchronization module

3.3 Timetable Schedule Module

This is responsible for keeping track of lecture time and venues associated with each lecture. The Timetable module is the main control unit for the attendance system as attendance flow is fully dependent on it. The Attendance system is designed to work with multiple attendance devices all linked to the central server. The Timetable module is hosted in this central server and controls the operation of all linked attendance devices [25, 26]. The time table module is built on top of the Schedule Schema and Routes. Admin, staff and student portal:

The online portal allows students and staff to register to the attendance management system. The portal consumes the API endpoints provided by the API module to handle authentication and creation of new users. The portal provides an admin interface that allows the system admin to alter the timetable, update course information and other relevant information. The portal also allows students and staff to view and visualize attendance records.

3.4 Data Analytics module

This module is responsible for data visualization and analysis. It makes use of a machine learning prediction system to analyze and make predictions based on the attendance records and other factors collected over time. The data set used for training and analysis is data collected from two schools. The data attributes include student performance, social and school related features which was collected from school reports and questionnaires [27-31].

Table 1. Dataset attributes information

Attribute	Description
Sex	Student's sex (Male or Female)
Age	Student's Age (15-22)
Family size	LE3-less than or equal to 3 or GE3-greater than or equal to 3
Divorced Parent	TRUE (if parents live part) or FALSE (if parents live together)
Primary guardian	Student's guardian (Father, Mother or other)
Study time	Weekly study time 1(less than 2 hours), 2 (between 2 and 5 hours), 3 (5 to 10 hours), 4 (more than 10 hours)
Extra Educational Support	TRUE or FALSE
Family Support	If student's academics is supported by the family (TRUE or FALSE)
Extra-curricular activities	If student engages in outside classroom activities (TRUE or FALSE)
Internet access	Internet access at home (TRUE or FALSE)
Free time	If the student has free time after school (TRUE or FALSE)
Attendance percentage	Percentage attendance of student
Performance	Student's final performance rating (Failure, Poor, Good, Satisfactory, Excellent)

4 Testing, Result and analysis

The outcomes of the development of intelligent bi-modal time table aware biometric attendance systems for enhanced classroom attendance are presented in this chapter. The system's performance, functionality, and efficiency are assessed using computational evaluations and analysis such as false positive rate, false negative rate, accuracy and recall.

4.1 Performance Evaluation of the Biometrics System

The developed system was evaluated using some metrics which includes: FPR, FNR, accuracy, precision, sensitivity, recall and response time which was discussed in the previous chapter.

Table 2. Biometric capture result for first 20 templates

Students S/N	True Positive	True Negative	False positive	False Negative	Response Time(sec)
1	V				1.62
2	V				2.00
3		V			1.38
4	V				1.26
5	V				1.58
6		V			1.43
7	V				1.11
8	V				1.71
9	V				1.45
10	V				1.51
11				V	1.57
12		V			1.65
13	V				3.27
14				V	2.23
15		V			1.38
16	V				2.43
17	V				1.76
18		V			2.04
19	V				1.98
20				V	3.53

The True Positive was 29, the True Negative was 20, the False Positive was zero, and the False Negative was seven. The response time was in the range of 1-4, and the average response time was 2.122, implying that the time it takes for the system to respond after a fingerprint is placed on it is minimal. Figure 4 depicts the response time variation for the student's tested

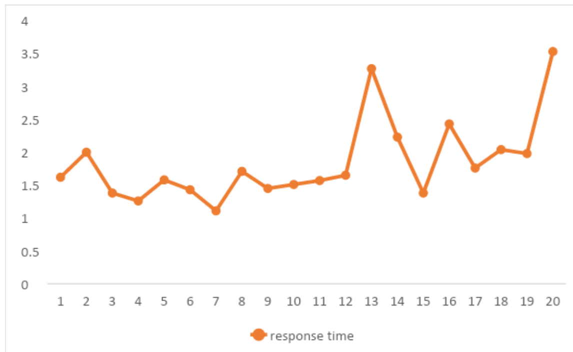

Fig. 4 Graph showing Response Time vs. Student

4.2 Performance Evaluation of the Data analytics module's Result of the Classifiers

This section compares the outcomes of three distinct classifiers that were used to train the system. Random forest, Naive Bayes, and the K Star method were employed as classifiers. The dataset contained several attributes for each student. Each of the classifiers were tested against all attributes of the dataset and then tested against some selected attributes based on the information gain ranking.

4.2.1 Random Forest

Table 3. Random Forest Algorithm with all Features Selected Based on information gain

Performance Metrics	values	Percentage accuracy
Correctly classified instances	173	43.7975%
Incorrectly classified instances	222	56.2025%
Kappa statistics	0.064	
Mean absolute error	0.2511	
Root mean squared error	0.3759	
Relative absolute error	97.3452%	
Root relative squared error	104.8366%	
Total Number of instances	395	

The test result of Random Forest classifier against all features yielded an accuracy of 43.8% with 173 instances correctly classified out of 395 with an inaccuracy score of 56.2025%. The mean absolute error and root mean squared error are 0.2511 and 0.3759 respectively with a root relative squared error of 104.8366% as seen in Table 3

4.2.2 Naive Bayes

The Naive Bayes classifier has a 40.25 percent accuracy against all features, with 159 samples correctly classified out of 395 and a 59.7468 percent inaccuracy score. The mean absolute error and root mean squared error are 0.2646 and 0.3698, respectively, with a root relative squared error of 102.43 percent, as given in Table 4.

Table 4. Naive Bayes classifier with all features selected based on information gain

Performance Metrics	values	Percentage accuracy
Correctly Classified Instances	159	40.2532%
Incorrectly Classified Instances	236	59.7468%
Kappa statistic	0.0126	
Mean absolute error	0.2624	
Root mean squared error	0.3698	
Relative absolute error	101.6949%	
Root relative squared error	103.1217%	
Total Number of Instances	395	

4.2.3 K Star

The K Star method was used to train the identical data set as in table 5, with a 37.7215 percent accuracy. Table 5 shows the accuracy in detail by class for the K Star algorithm trained with all features. The K Star classifier has a 37.7215 percent accuracy against all characteristics, with 149 samples correctly categorized out of 395 and an inaccuracy score of 62.2785 percent. Table 5 shows that the mean absolute error and root mean squared error are 0.251 and 0.3965, respectively, with a root relative squared error of 110.5635 percent.

Table 5. K Star classifier with all features selected based on information gain

Performance Metrics	values	Percentage accuracy
Correctly Classified Instances	149	37.7215 %
Incorrectly Classified Instances	246	62.2785 %
Kappa statistic	0.0035	
Mean absolute error	0.251	

Root mean squared error	0.3965
Relative absolute error	97.2848 %
Root relative squared error	110.5635 %
Total Number of Instances	395

5 System Integration

This section shows the breadboard implementation and final integration of the project. The implemented project was tested on breadboard as shown in Figure 5 which was coupled and packaged with other parts to make the finished project as shown.

Fig. 5 Final integration of hardware

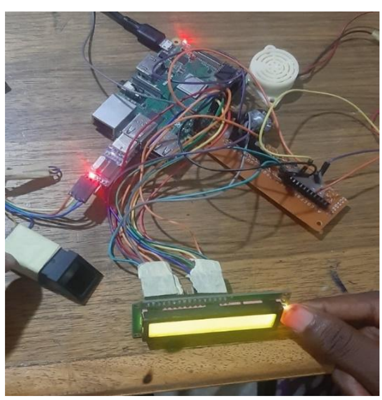

Fig. 6 Breadboard Implementation

6 Conclusion

As part of the project's goal, the design and development of a bimodal schedule aware attendance management device was completed. With the schedule module playing an important part in automated device control, the system gains an advantage because there is no need for an administrator to be always present. According to the results of the performance tests, the accuracy of the device's biometric system was high, with a value of 87 percent. With these factors in mind, the system may be relied on to fulfill its intended functionality effectively, while there is still space for development. This project's staff, student, and admin portals provide flexibility and ease of data updating, retrieval, and report production. This portal enables administrator to change the timetable that controls the attendance device, monitor attendance data, and manage student biometrics. The portal, on the other hand, allows students to see their attendance record and follow their academic success.

The development and testing of the prediction system made it evident that attendance alone cannot accurately predict how a student will perform thus important for other factors to be considered which is why several prediction algorithms were tested to determine which combination of attributes and prediction model performs better based on the provided dataset. From the results of this project, the Kstar classifier algorithm has the highest accuracy of 47.77%. Followed closely by the Random forest algorithm with an accuracy of 43%. Comparing IGR-RF and the RF algorithms, the IGR-RF has a lower accuracy with less feature selection which is not the case for IGR-NB and NB with ICR-NB having a higher accuracy than the Naïve Bayes algorithm.

The integration of all the subsystems was achieved through the central server which acts as the central control for the entire system. Looking at the entire architecture, it is evident that a seamless integration of an effective data analytics module coupled with decentralized attendance taking devices can go a long way in improving the classroom experience of both students and staff in an academic institution.

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