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An improvised analysis of smart data for IoT-based railway system using RFID

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ABSTRACT
RFID (radio frequency identification) is a progressively adopted technology in today's automated world. Wireless technologies have enabled contactless payments, tracking, identifying, and many more features in a system that can be introduced to build a smart environment. This work overviews the usage of the IoT (Internet of Things) platform for tracking passengers and enabling online payments through wireless sensors and RFID technology in Chennai Suburban Railways. The tracking system consists of an RFID reader that can locate and track passive as well as mobile objects attached with passive RFID tags. The proposed system incorporates the installation of RFID readers at every entrance and exit of the railway station, and every passenger carries their own RFID tags. This not only enables online payments for passengers but also helps the government in tracking the crowd for demand monitoring. The new methodology creates a digital workspace and enforces lawful safety regulations both for the administration and the consumers. A prototype of the proposed system is implemented in real-time to understand the workings of the system. Data collection is done through RFID tags that act as transit cards and an analysis for consumer demand is done using the DBSCAN (Density-Based Spatial Clustering of Application with Noise) algorithm with a Randomized KD-tree for the analysis of spatial and temporal patterns. A new algorithm, the iDBSCAN (improved Density-Based Spatial Clustering of Application with Noise) algorithm is proposed for faster performance on the datasets.

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KEYWORDS
RFID; online payment; tracking; passengers; IoT; DBSCAN; transit cards

1. Introduction

Digitization and digitalization are the new trend in today's world that can be achieved by integrating wireless technologies to make things smart [1]. RFID is one such smart technology contributing to the advancement of automation wherever needed [2]. The low cost and convenience of deployment make RFID technology more favourable in using it for tracking and identifying objects [3,4]. The location of any object can be tracked by RFID either by "tag tracking" or by "reader tracking". This work discusses the tracking of mobile objects attached to RFID tags. These tags consist of a chip and antenna that are activated by the radio waves transmitted by the RFID reader [5]. These readers are installed at every entrance and exit of railway stations for localization, mapping, and activity analysis of the passengers [6]. When a passenger enters the railway station, his or her information is gathered by the reader and stored for further processing. As customer demand is the most essential factor in the decision-making of any business model, this passenger information can serve as the data required to analyse consumer demand. The DBSCAN algorithm is used to create clusters of high density and noise with low density, thereby categorizing the passengers based on their movement and also detecting the time dependency of the passengers with respect to the boarding time [7].

Moving on to the challenges faced in establishing the proposed structure, the localization of passengers by the reader is more difficult as it needs to be done within a stipulated time. Therefore, a reading space needs to be created especially for the detection of tags without passenger crowding. This avoids noisy data caused by the collision of signals [8]. Thus, the accuracy of passenger detection can be increased and tracking is made effortless.

Figure 1 shows the manual process ticketing system used in the existing system. The passenger either collects their ticket from the station ticket counter or through the UTS (Unreserved Ticketing System) ticket booking application. The wait time from the start to the end of the process is longer than the automated process proposed in the new system [9,10].

Although the existing system uses semi-manual data collection by gathering the passenger count based on the distribution of tickets inside the station premises or through the UTS ticket booking application, the behaviour of the passengers is tedious to analyse. Conversely, the proposed system can accumulate both the

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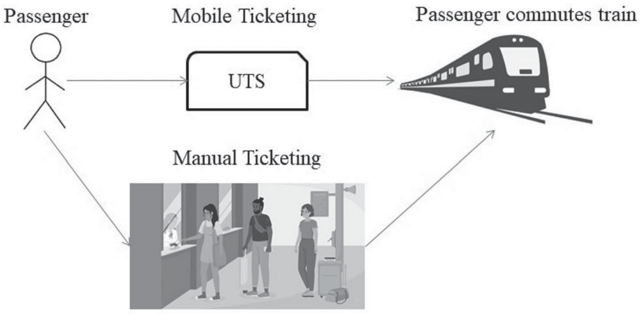

Figure 1. Ticketing process through the manual system in railway stations or through UTS mobile application.

count and the behaviour of a huge number of passengers within a few seconds.

2. Related works

There exists a variety of approaches to the advancement of a system. IoT paves new ways to fulfil these demanding upgrades for a better living. Since this new system uses RFID technology for ticketing, the same can be used for tracking purposes [10]. Though tracking always seems as a breach of one's privacy, controlled activity on the gathered data with proper security can yield expected benefits to both society and the government [11]. One of the major benefits that can be obtained from crowd management is the recognition of passenger behaviour [12]. These data can be clustered and classified to frame a timetable as it focuses only on customer demand. Thus, the last phase of SCM (Supply Chain Management) can be handled with IoT. Researchers have been deducing that all the phases of SCM can also be integrated with IoT to deliver automated SCM [13]. This can be very much helpful in the warehousing of raw materials and supplies [14].

3. Performance evaluation of the existing system

The performance evaluation of the mobile UTS application against the manual ticketing system was released by SWR (South Western Railway) press in December 2021. According to the data collected from the press release, it is known that there is a steady rise in the usage of mobile UTS by passengers [15]. It was stated by the General Manager of South Western Railway that "UTS on the mobile app would not only promote cashless transactions, but also ensure contactless, hassle-free ticketing".

From Table 1, one can find that there is a growth in the usage of mobile UTS among passengers. Although the app was rendered non-operational for around one year, from March 2020 to February 2021 due to the cancellation of passenger trains during the pandemic period, a steady rise in the usage of the app was once again registered immediately after it became fully functional.

Table 1. Mobile UTS application against the manual ticketing system was released by South Western Railway.

S. No.	Year	Total no. of Mobile UTS passengers	Total no. of tickets sold	Growth of usage
1.	2018–19	3.5 million	5.67 lakhs	0.72%
2.	2019–20	7.6 million	13.43 lakhs	1.81%
3.	2020–21	4.98 lakhs	2.79 lakhs	5.61%

Figure 2 provides an insight into the usage of the UTS mobile app. As stated by the officials, the passengers also prefer contactless payments. When this system is enhanced with RFID technology, various other services can also be furnished and also prediction samples can be used for analysis to build better infrastructure using algorithms such as the iDBSCAN algorithm.

4. Process of the proposed system

The process of the proposed system starts with user registration when the passenger registers their unique RFID in the UTS mobile application. The user details are verified and validated in the next stage. Subsequently, all the details are stored in the database, usually in the cloud. These data are retrieved based on the services provided to the passenger. Here, the passenger uses the RFID tag as a transit card for a railway journey. Therefore, only the required details are retrieved and processed for ticketing.

Figure 3 shows the workflow of the proposed system. The flow begins with user registration followed by user data processing based on the services requested by the customer. The customer is either the passenger or the government determined by the data retrieved for the required service. Further, data analytics can be performed for various purposes to predict and find a solution to enhance the system in different aspects.

The detail of every single passenger is taken into consideration to build the cluster of high demand. Based on the results of the analysis, the passengers can be categorized into regular passengers with regular time and route, irregular passengers with irregular time and regular route, and habitual passengers who do not follow any pattern. This helps the government authorities to

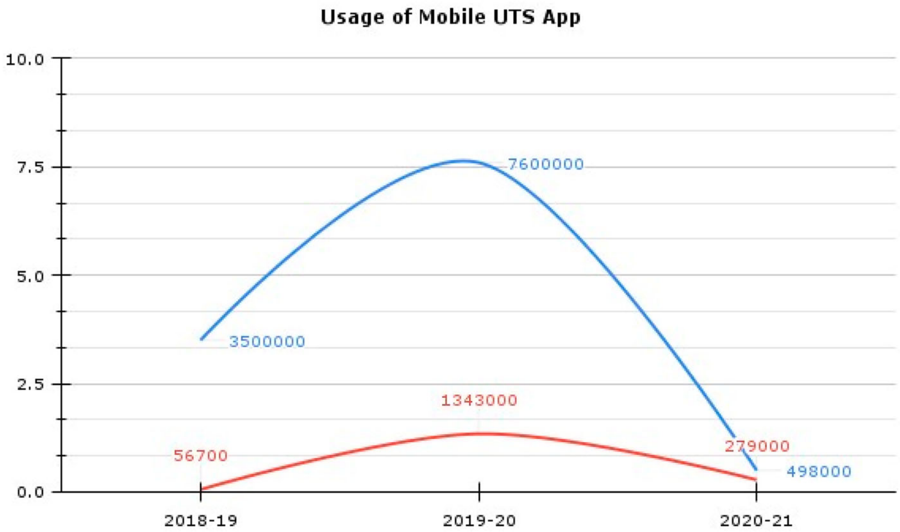

Figure 2. Performance evaluation UTS mobile application as per the data of South Western Railway.

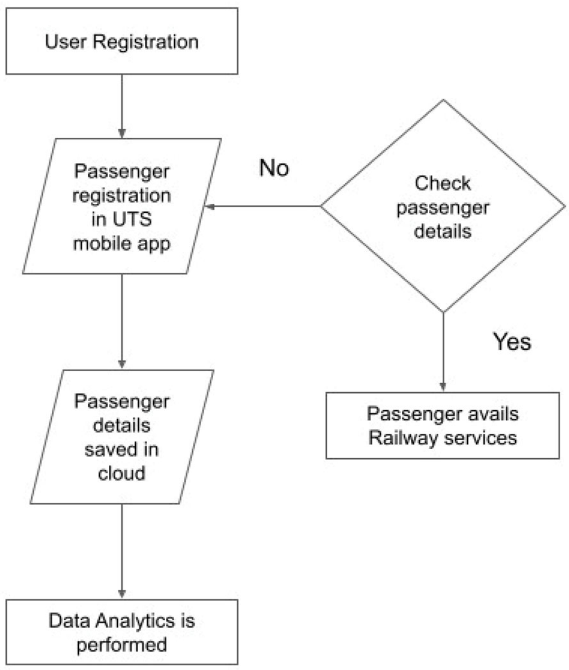

Figure 3. Flowchart of user validation.

facilitate the consumers with high demand, i.e. during peak hours.

5. Working model

Firstly, the passenger receives their unique RFID tag which is used as a lifetime ticket for railway transportation. This tag is registered in the existing UTS mobile application with its unique ID that already has the general passenger details such as the passenger name, date of birth, age, gender, and address, which are retrieved from any one of the government issued ID submitted: KYC (Know Your Customer). Once this process is completed the passenger needs to recharge their transit cards to avail tickets. Whenever passengers need to use railways to commute they can enter the source and destination of their travel in the application. The specified amount of price for the selected journey will be deducted from the application wallet. After all this online process is done, the passenger can proceed with the journey. Above all, this process can be performed from anywhere within a 5 km radius of the source station and anytime within one hour before the commencement of the journey.

Figure 4 presents the working model of online railway ticketing through IoT. RFID tags are used by the passengers to register their journey which is later read by the RFID readers in the railway stations. The pools of data from the readers are later used for analysis purposes as required by the user. In between data connectivity and data analytics, various processes take place. Encryption of data is performed to secure the shared resources as both user data and client activities on the data are classified. After data retrieval from the cloud, the preferred platform for analytics should be used to simulate the desired results. The sample results can be used by government officials for the enhancement of the system and also as a part of the samples shared with the user for the betterment of user services.

The analysis of transit passenger behaviour leads to the enhancement of results obtained from the automated ticketing system. This involves breaking down each type of passenger into subcategories based on various transfer behaviours, modes and routes utilized, card types, and frequency of usage, using an improvised DBSCAN algorithm adopted from the existing model [16]. Essentially, the objective is to leverage the broad information about passenger types to achieve a more detailed comprehension of clusters, their specific requirements, and the necessary capabilities for effective service provision. It is noticeable that in the existing model, passenger categorization is done through travel

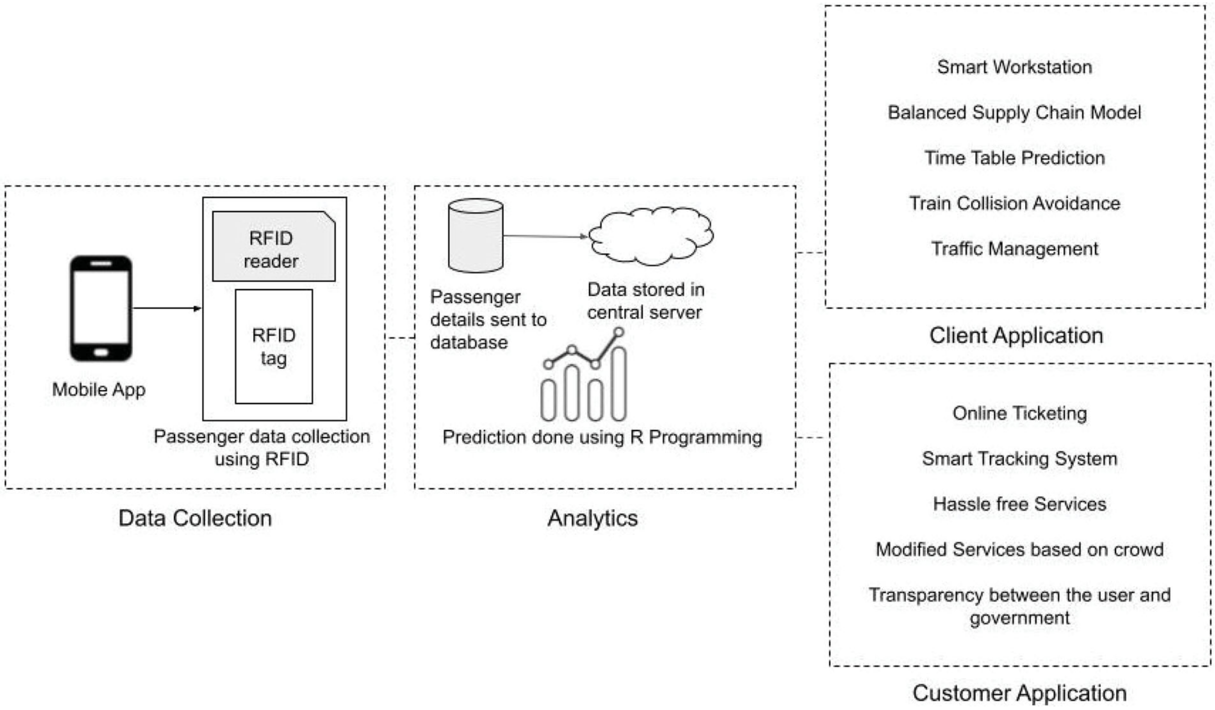

Figure 4. The three phases of workflow in the proposed system.

pattern analysis by reconstructing the travel itineraries [17]. Thereby, the mining of spatial and temporal data is done from the history of the journey with timestamps performed by the passengers.

The proposed model incorporates a Random KD-Tree with a DBSCAN algorithm to build a better way to organize data points in space. In dealing with public data, the algorithm must work in high-dimensional spaces addressing the limitations of mapping the queries with the right points to achieve the desired outcome with the shortest decision time. The iDBSCAN algorithm works well in this case. The working of the algorithm is represented in Figure 5.

6. Design and implementation of the system

The requirement specification states the technical essentials of the proposed system. It comprises the RFID reader and tag, a host computer to control the operations performed in the environment, a database to store the passenger data, and a data analytics tool for further processing of demanding enhancements study.

Figure 6 presents the physical design of the proposed system. The RFID reader is embedded with Arduino UNO that processes the passenger data once read by the RFID reader. These data are stored in the cloud and only the required data are retrieved based on the factors demanded by the passengers.

The main RFID system can be categorized into two modules: the base module and the consumer module. The base module comprises the RFID reader, host computer, and database and the consumer module comprises the RFID tag and a mobile application. The major components used in the hardware design of the system are as follows.

6.1. RFID system

The following are the various types of RFID systems according to the frequency they operate at [18].

Based on the survey in Tables 2 and 3, High-Frequency Passive RFID tags are used in the proposed system as it has higher data throughput and faster communication. The reader can read 50 tags per second and can aid in ticketing payment and data transfer applications.

6.1.1. RFID reader

The RFID reader forms the base of the RFID technology. It has its antenna through which radio signals are transmitted in the environment it is being installed [19]. These radio waves need to be detected by the tags registered with the particular readers and a response is sent from the tags to register their presence in the premises [20]. Thus, a reader collects all the data from its surroundings and these data are gathered for further processing. RC522 is used as the reader to collect data [21]. It is an 8-pin board and requires a 3.3 V power supply to operate.

6.1.2. RFID tag

The core of the RFID system is the RFID tags that are battery-free [22]. These tags contain a chip that is identified by its unique identification number [23]. Each tag is peculiar and unique and thus solves the case for single object identification.

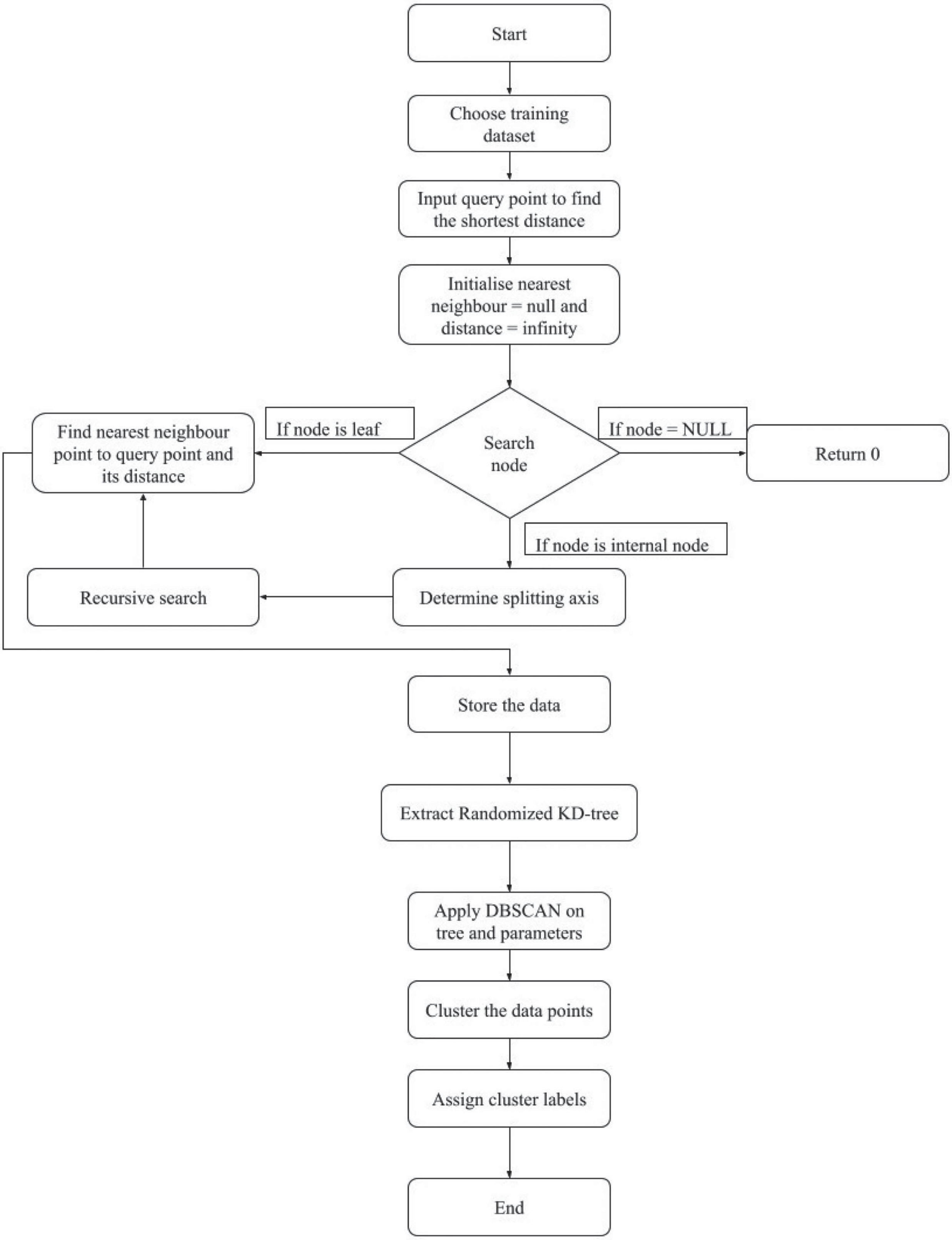

Figure 5. Flowchart of the proposed iDBSCAN algorithm.

6.2. Arduino UNO

There exist various types of Arduino according to its usage. Based on the requirement of the proposed system, the Arduino UNO is chosen as the microprocessor wired with the RFID reader to process the collected data into the cloud [24,25]. The Arduino UNO is a 40-pin board and uses the SPI protocol to establish communication with RFID.

6.3. Host computer

The host computer is the system that is installed with the application software where the data are stored,

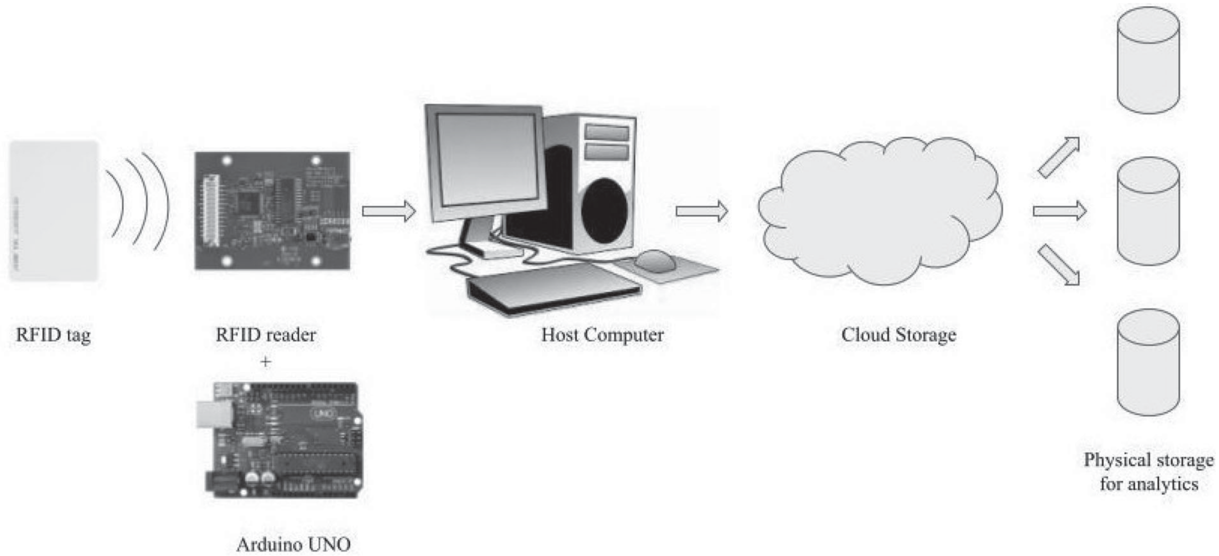

Figure 6. Components of Online Railway Ticketing System using RFID.

Table 2. Overview of different types of RFID.

Features	LF	HF	UHF
Frequency range	30–300 kHz	3–30 MHz	300 MHz–3 GHz
Operates at	125 –134 kHz	13.56 Mhz	860–960 MHz
read range	$\leq$ 10 cm	$\leq$ 30 cm	$\leq$ 100 m
interference	Not sensitive	Moderately sensitive	Very sensitive
Data transmission	Very low	Moderate	Very fast
applications	Access control Animal control	Contactless payment Used in smart cards	Store inventories Identification of medication

retrieved, and processed [16]. The data flow happens between the host computers to the RFID reader. This is directly managed by the administrator either physically or virtually present in the particular environment. It indirectly supplies all the data that are stored in the cloud storage.

6.4. Power supply unit

Though the DC power supply unit is not considered one of the physical components, it is vital for modern electronic equipment to perform a wide range of operations [26]. The RFID readers and other components need the right range of voltage supply to operate without interruptions.

6.5. Data analytics

This section exploits the usage pattern of each passenger type to understand the daily usage of the transit network. To deduce the spatial and temporal pattern of passengers the iDBSCAN algorithm is used as it has the capability to detect clusters of varying shapes and sizes. Similarly, a travel pattern, influenced by the diverse nature of human behaviour, may exhibit a wide range of shapes and sizes. It uses the boarding and destination points of every single passenger to create clusters. The analytics of the consumer data is done with R studio. The working of the iDBSCAN algorithm is shown in Figure 5. Randomized KD-tree is integrated into the iDBSCAN algorithm to find the number of clusters in the given dataset. This resultant of this event is stored and further clustering of the data points is performed using the proposed iDBSAN algorithm.

Table 3. Study of difference between passive and active RFID tags.

Features	Passive RFID tags	Active RFID tags
Power source	External (reader provided)	Internal
Tag readability	Only within the area covered by the reader (3m)	Extended range (100 m)
Energization	Energized only when the reader is present	Always energized
Magnetic Field strength	High	Low
Shelf life	Very High	5 years
Data storage	Limited (128 bytes)	Larger amounts of data
Cost	Cheaper	Expensive
Size	Smaller	Bulky

7. Experimentation

The hardware setup is done between RC522 and Arduino UNO. Table 4 represents the wiring between Arduino UNO and RFID reader which is used to read the data of the passengers from the environment it is installed in.

Figure 7 shows the real-time implementation of the proposed system done is a closed setup. The Arduino

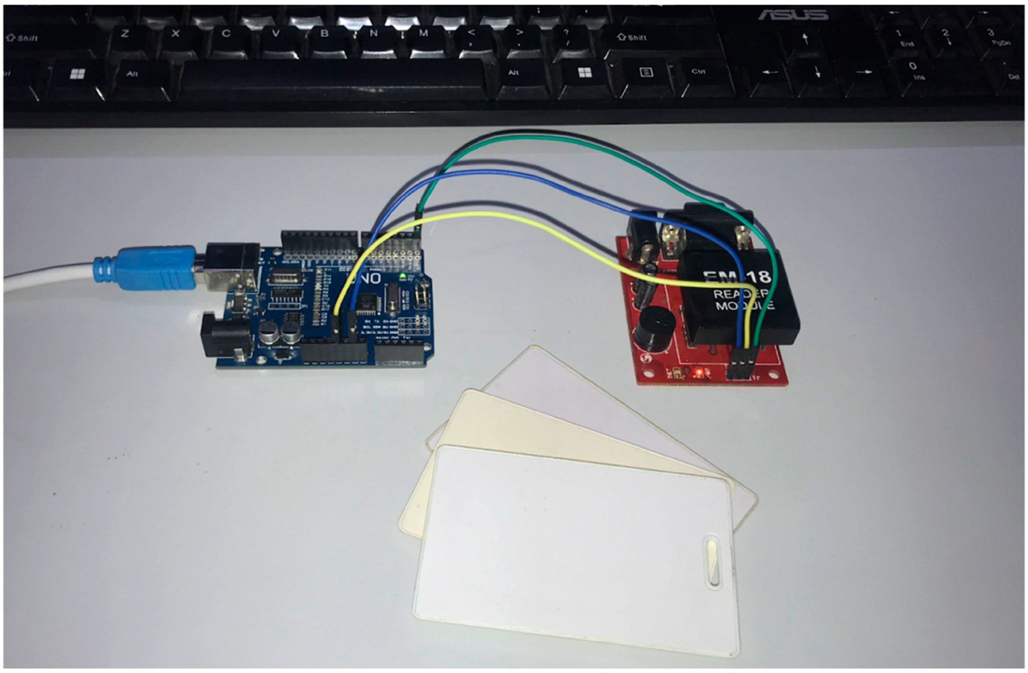

Figure 7. Interfacing of RFID module with Arduino for automatic data collection from the users.

Table 4. PIN wiring of Arduino UNO to RFID reader.

RC522	Arduino UNO
1	Gnd
2	5
3	3.3V
4	-
5	12
6	11
7	13
8	10

UNO is interfaced with an RFID reader to read the data from the RFID tags.

Algorithm 1 is used to initiate a serial communication between Arduino and host computer and interface the RFID reader with Arduino. Algorithm 2 is used to check for new cards, so as to notify for the new registration of unregistered RFID user cards. Once the Arduino RFID set-up is done, the unique code of the RFID card is obtained by reading and displaying it on the host computer serial monitor with Algorithm 3.

Algorithm 1: RFID reader Setup

```
void setup()
{
    Serial.begin(9600);
    SPI.begin();
    mfrc522.PCD_Init();
    Serial.println("Approximate your card to the reader … ");
    Serial.println();
}
```

Algorithm 2: RFID tag check

```
loop()
{
    if(!mfrc522.
    PICC_IsNewCardPresent())
    {
      return;
    }
    if(! mfrc522.PICC_ReadCardSerisl())
    {
       return;
    }
}
```

Algorithm 3: Display UID on Serial Monitor

```
Serial.print("UID tag :");
String content = "";
byte letter;
for(byte i = 0;i < mfrc522.uid.size;i++)
{
    Serial.print(mfrc522.uid.uidByte[i] < 0x10?"0":" ");
    Serial.print(mfrc522.uid.uidByte[i],HEX);
    content.concat(String(mfrc522.uid.uidByte[i] < 0x10?"0":" "));
    content.concat(String(mfrc522.uid.uidByte[i],HEX));
}
Serial.println();
Serial.print("Message: ");
content.toUpperCase();
if (content.substring(1) = = BD 22 C2 32)
{
    Serial.println("Authorized access");
    Serial.println();
    delay(3000);
}
else {
    Serial.println("Access denied");
    delay(3000);
}
```

The iDBSCAN algorithm characterizes clusters as areas of high point density, separated by regions with lower point density. It involves two key global parameters: the maximum density for destination points and the minimum number of boarding points. A point is considered a central point if it has a density of at least a specified threshold within a given radius. The algorithm is applied independently for mining spatial and temporal patterns. In the context of regular passengers, a two-level iDBSCAN application is utilized –

Figure 8. RFID tag access checking with the reader module.

Table 5. Test cases on flow of a single event in the process of user validation.

Test case no.	Description	Pre-conditions	Pass/Fail	Expected results
TC_001	Validate user login	Registered user only allowed	Pass	Login successfully
TC_001a	Validate user login	Registered user only allowed	Fail	Login Unsuccessfully
TC_002	Put Smartcard	Valid user only allowed	Pass	Value Get Successfully
TC_003	Get Input Values	Registered user only allowed	Pass	Get Values successfully
TC_004	Value Pass Arduino	Registered user only allowed	Pass	Pass Values successfully
TC_005	File Upload with Encryption	Registered user only allowed	Pass	Upload successfully
TC_006	Stored Database	Registered user only allowed	Pass	Stored successfully
TC_007	Validate Admin login	Admin only allowed	Pass	Login successfully
TC_008	Download the excel sheet	Admin only allowed	Pass	Download Successfully
TC_009	R Programming Process	Valid user only allowed	Pass	Process Successfully
TC_010	Show the Prediction	Valid user only allowed	Pass	Result Successfully

first on destination points and second on boarding points. Importantly, the order of these two levels can be swapped without altering the results. Employing iDBSCAN separately in each level enhances the overall clustering algorithm's robustness, and the results from each level prove valuable for subsequent passenger categorization.

Meanwhile, the users are provided with an upgraded version of UTS that also saves the unique ID number of the passenger's RFID tag and the trip details. This set-up not only creates an automated system, but brings in the concept of transparency between the governing body and the public.

8. Results and discussion

The proposed system uses IoT devices and mobile application for online ticketing. Further, the gathered data from the environment are used for prediction. RFID, Arduino, and a host computer are the physical devices used in the environment. The aggregate of the data collected is used to draw a graph to analyse the difference in time taken between manual ticketing and online ticketing.

Figure 8 shows that a registered RFID tag is authorized for further services, here the passenger does online ticketing, whereas a tag that is not registered is denied services.

The modules are run through test cases to analyse if the system satisfies the conditions and yields the expected output or not. Based on the outcomes in Table 5, future modifications are done to frame the perfect model according to the requirements.

Table 5 shows the various test cases run on the proposed system in the flow of a single event. This test starts with user validation until the result analysis. Also, based on the result, the cases are tested if prediction for enhancement is possible or not with the obtained results.

Figures 9–11 show the graph drawn from the analysis of the results obtained through the RFID module. It is evident that the number of tickets purchased by the passengers is more through the online ticketing process when compared with the traditional manual process. Though there may be a drop due to network issues, the performance of the proposed system is more efficient than the existing system. Analysis was made for different time periods during peak hours, afternoon hours, and late nights.

Thus, the IoT based Indian Railways System brings in the concept of Online Ticketing System for the passengers with the following advantages:

- Decrease in wait time
- Crowd management
- Hassle -free ticketing
- Reduced labour and paperwork for the government

The data collected can be used for various analyses based on the user's requirement. Hence, RFID with Arduino makes data collection simple and easier.

This paper categorizes passenger travel characteristics into spatial and temporal travel patterns, defining distinct passenger types. Three clusters of passengers emerge as follows:

1. Regular Passengers: Defined as individuals with consistent travel times and routes. Their travel schedules and journeys remain constant.

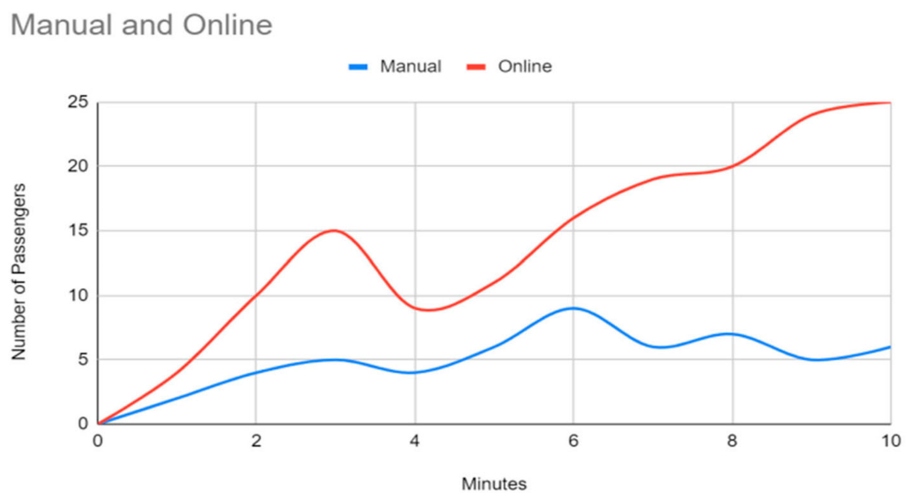

Figure 9. Analysis of traditional ticketing system vs automated ticketing system during peak hours.

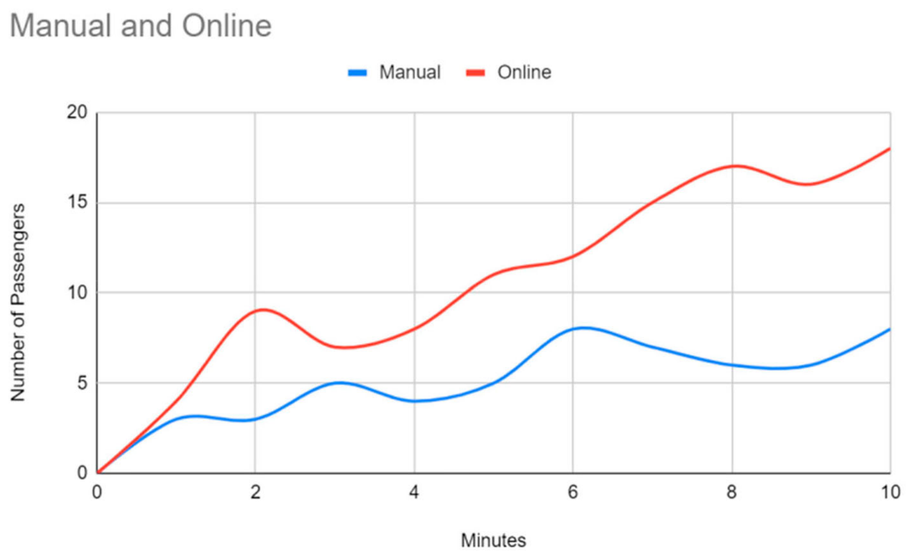

Figure 10. Analysis of traditional ticketing system vs automated ticketing system during afternoon hours.

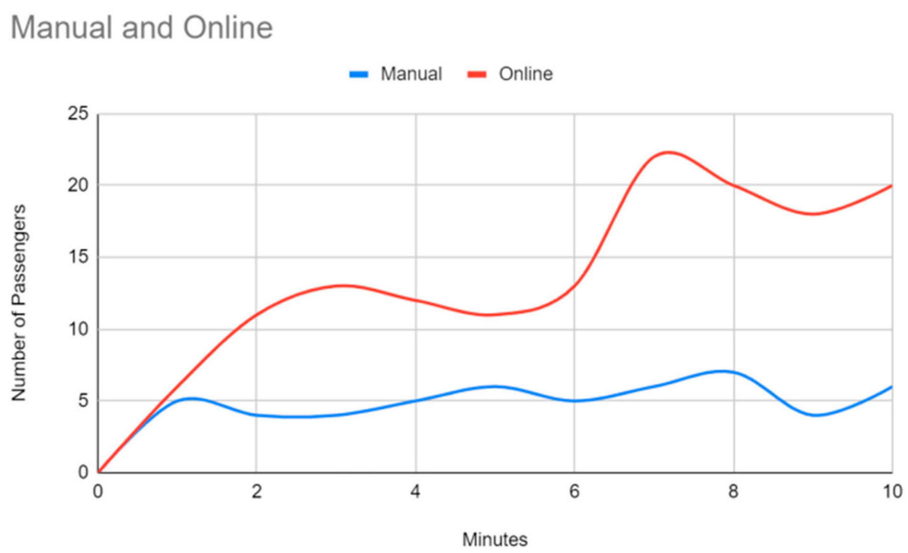

Figure 11. Analysis of traditional ticketing system vs automated ticketing system during night hours.

2. Irregular Passengers: Characterized by irregular travel times but consistent routes. These passengers do not adhere to specific time ranges but follow regular routes.
3. Habitual Passengers: This category includes passengers who exhibit neither temporal nor spatial patterns in their travel. They lack regular travel times and routes.

The categorization is based on two straightforward rules:

1. Rule 1: If no temporal or spatial travel pattern is identified, the passenger is classified as an irregular passenger.
2. Rule 2: If more than 50% of journeys occur within regular times and routes, the passenger is identified as a regular passenger.
3. Rule 3: The remaining passengers fall into the category of habitual passengers.

In Figure 12, it is evident that regular passengers predominantly undertook their travels during peak periods. In contrast, irregular passengers exhibited a more flexible pattern, initiating their journeys later in the morning (from 8:00 AM) and concluding earlier (by 6:00 PM) than other passenger classes. A tentative assumption about trip purposes can be made: regular passengers are likely engaged in school- and work-related trips, whereas irregular passengers may be associated with less rigidly scheduled activities, such as leisure or shopping. Conversely, habitual passengers, characterized by an absence of any discernible temporal travel pattern, tended to travel during peak periods, akin to transit commuters.

Table 6 presents the descriptive statistics for each passenger type, contributing valuable insights to the characterization of passengers. The analysis of passenger categorization provides a comprehensive understanding of each passenger type and yields key insights into their characteristics.

Table 6. Descriptive statistics of the transit passenger types.

	Usage of transit card	Average journey made
Regular passenger	68%	82%
Irregular passenger	15%	65%
Habitual passenger	6%	1%

1. Most irregular passengers exhibit a lack of discernible travel patterns. This group infrequently utilizes public transport, with 99% of them being sporadic users of the automated ticketing system. Additionally, their contribution to the total ticket revenue is relatively low, accounting for only 15%. This suggests that promoting the sale of more transit cards may not yield significant profits for both the governing authority and society. Instead, there is a need to encourage these passengers to increase their travel frequency.
2. Regular passengers encompass individuals with constrained time and travel patterns, exemplified by college-going students. This passenger category tends to undertake more travel during peak periods compared to other types.
3. Habitual time passengers refer to individuals who frequently travel but lack a consistent time schedule and travel to various destinations. Given their necessity to visit multiple locations, this passenger category demands greater transit mobility. Consequently, they engage in more transfers and bus journeys than any other type, with school students being a notable example.

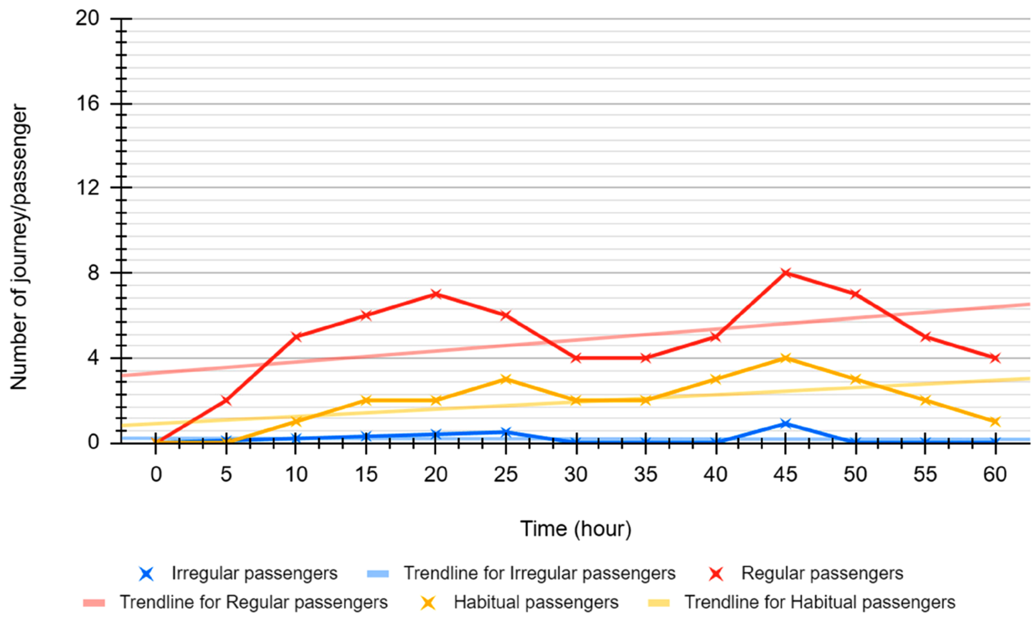

Figure 12. Journey made by the passenger with respect to time.

Characterizing passenger demand based on the proportion of each type provides insight into the overall service requirements for each region. An area dominated by regular passengers necessitates timely services, while an abundance of irregular passengers may indicate issues with the provided transit service. Governing authorities have the opportunity to enhance revenue and promote transit-oriented developments by increasing the number of high-value customers, such as transit commuters. However, it is also important to address the needs of other passenger types to maintain customer equity and the overall attractiveness of the system. This section proposes practical service improvements leveraging the knowledge of passenger categorization. Understanding each passenger type aids transit authorities in strategic planning, allowing for the development of transit-on-demand services that cater to individuals requiring regular travel where standard routes are not available.

9. Conclusion

This research depicts the features of a system when a part of it is automated with IoT enabling technologies. Though the world has been following the manual method of gathering and processing data for decades, embedding IoT with everyday things has introduced humans to smart things. The process performed and measured in this research triggers the integration of IoT technologies in the near future. Integrating sensors and actuators with the existing system creates a whole new environment of automatic processing in the payment system. Fully contactless online payments are introduced in Chennai Suburban Railways for efficient crowd handling. The raw data collected can be used for numerous analyses based on the user's requirements. Various other ensuing works discussed open new approaches and ways to build a smart city.

Ongoing efforts are underway to extend this paper, utilizing transit card data from additional time periods to assess the impacts of various policies on passengers. Further examinations into behaviours like "coming-back-home" and the categorization of trip distances will contribute to a more comprehensive understanding of passenger types. Simultaneously, the insights obtained from this paper have proven valuable in enhancing passenger characterization and improving services for individual regular passengers.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Availability of Data and Materials

All data generated or analysed during this study are included in this published article.

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