Development of an IoT-enabled Smart Library System for a University Campus

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***Abstract*— With the accelerated advancement in technology infrastructure, the concept of libraries in the educational institution has evolved from a traditional system, which consists of several manual processes requiring human intervention to perform critical tasks, to that of a smart library system where the core activities are automated through the use of Internet of Things (IoT) devices. Integrating IoT devices in the different processes enables the streamlining of such processes rendering them more efficient through the capture of real-time data as they are being generated. This paper describes the implementation of a smart library system in a university campus using IoT devices. The system makes use of analytics and machine learning to analyze trends and make predictions. The system prototype is presented in the paper.**

***Index Terms*— Internet-of-Things, Machine Learning; Real-time Analytics; RFID; Smart Library.**

I. Introduction

The radical changes in the flow, transmission, and exchange of information and knowledge caused by advancements in information and communication technologies have led to the need for new changes in the contents, systems, and services of libraries and data centers [1]. Library systems around the world have had to adapt to these changes, transforming their processes to improve the type and means of delivering their services to users with the adoption of Internet of Things (IoT) devices, thus nurturing the concept of smart libraries. Transforming libraries' business processes towards that of smart libraries requires the usage of IoT devices at various stages of the processes. According to Gartner, the Internet of Things (IoT) can be described as a network of dedicated physical objects (things) that contains embedded technology to communicate and sense or interact with their internal states or the external environment [12]. The connecting of assets, processes, and personnel enables the capture of data and events from which a company can learn behavior and usage, react with preventive action, or augment or transform business processes [2]. Gartner also states that through the different implementation of IoT devices in different fields such as manufacturing, construction, and agriculture, several benefits have been generated by this initiative such as process improvement, workforce productivity enhancement, asset monitoring, and control of operation [12].

In the context of smart libraries, there are numerous applications of IoT devices, such as the use of RFID, Near Field Communication (NFC), infrared sensors, global positioning systems, and laser scanners to achieve intelligent identification, tracking, monitoring, and management [3]. Radio Frequency Identification Devices and NFC tags can be referred to as contactless technologies, which utilize radio waves for transferring data between the reader and the tags [4]. Other smart devices include biometric fingerprint scanners, which are implemented by smart gates at access and exit point in library premises for controlling access to the library. The benefit of this biometric scanner is that it takes less time for authenticating users, with minimal errors. Smart gates keep logs of a student entering and exiting as well as of errors which that may have happened.

The authors in [5] have proposed a system architecture of smart libraries. The system architecture consists of five layers, namely the perception layer, transport layer, processing layer, application layer, and business layer. The perception layer is the physical layer, which consists of the sensors used for gathering information about the environment [5]. The transfer layer conveys process information from the perception layer to the processing layer and vice versa using the internet and wireless networks. The processing layer, also known as the middleware layer, is the central nervous system of smart libraries, which can store and analyze the data from underlying layers. Databases, cloud computing, and big data processing modules are implemented at this layer. The application layer is responsible for delivering application-specific services to the user through different interfaces including management, maintenance, and operation. The business layer is the top layer that manages the whole IoT system, including applications, business profit models, and security issues [5].

This paper describes technologies used for the implementation of a smart library in the context of the University of Mauritius. The rest of the paper is structured as follows. In section II, related works are described. The system architecture of the proposed system and the technologies used are described in section III. Section IV presents the system prototype that implements the business processes of the smart library system. Evaluation of the smart library system along with discussion are presented in section V. Finally, section VI concludes the paper and presents future works.

II. Related Work

This section describes existing smart library systems. The system presented by [5] aims at providing an RFID Library Management System, which consists of smart gates equipped with sensors, smart kiosks for querying books, and RFID checkouts. The procedure for borrowing and returning materials include the user querying for the desired material using a smart kiosk. Then, the user must show the book to RFID readers for inserting and updating records. Furthermore, for the returning of the book, smart trays are set up to collect the books. The system makes use of RFID tags embedded in books and readers in smart gates and carts for lending and returning. The desktop application is built upon

C# and the .Net Framework with SQL Server as a database. The system also monitors and detects unissued item, which is being taken out of the library.

Another study [6] proposed an IoT based system to aid users in getting, issuing, and returning a book with the assistance of IoT based interconnected systems using a Wi-Fi-based Local Positioning System (LPS) along with Near Field Communication (NFC) tags embedded in the books. Users accessing the library premises must authenticate themselves using their fingerprints. The LPS enables the user to get the location of a book by using the NFC of their phone. Return carts equipped with NFC readers are placed at the entrance for returning books and the necessary updates are made in the database.

In view of all the above-mentioned existing systems, other technologies can be more appropriate in our context, such as the use of face recognition as compared to biometric identification. As the current library system usually suffers during high peaks, the process of authenticating users with the aid of face recognition is likely to be more fluid, hardly wasting any time for identification as compared to fingerprint sensors. Moreover, the latter requires occasional cleaning, else may lead to errors. Furthermore, the use of NFC tags in books might be less effective due to its reach requiring the NFC reader to be in immediate proximity or requiring users to have smartphone NFC reader features to be able to identify the book. For these reasons, RFID tags are a better choice, offering medium to higher reader range.

III. SYSTEM ARCHITECTURE

The actual library system at the University of Mauritius follows a traditional model, which makes use of a partially advanced system. The system consists of a web portal (OPAC) for users to view or reserve their desired book. After the users have searched for their desired book on the shelves, the issue process starts with the librarian having to manually input user and book details in the system, and then a time limit for returning the document will be initiated. The primary problems resulting from the actual system are unsecured access and exit to library premises, time-consuming along with a rate of errors occurring from the manual activities and inefficiencies faced during peak period. The AS-IS processes have been included in [3]. Through the application of IoT devices in the library processes, the desired result from this automatization is processed, which is more efficient, less time-consuming, and with fewer or no errors. The proposed TO-BE processes are illustrated in Figures 1 and 2. More details about the implementation of TO-BE are given in Section V. Figure 3 shows the system architecture of the proposed system.

The proposed smart library system makes use of the several technologies, as shown in Figure 4. The technologies are described in the following subsections.

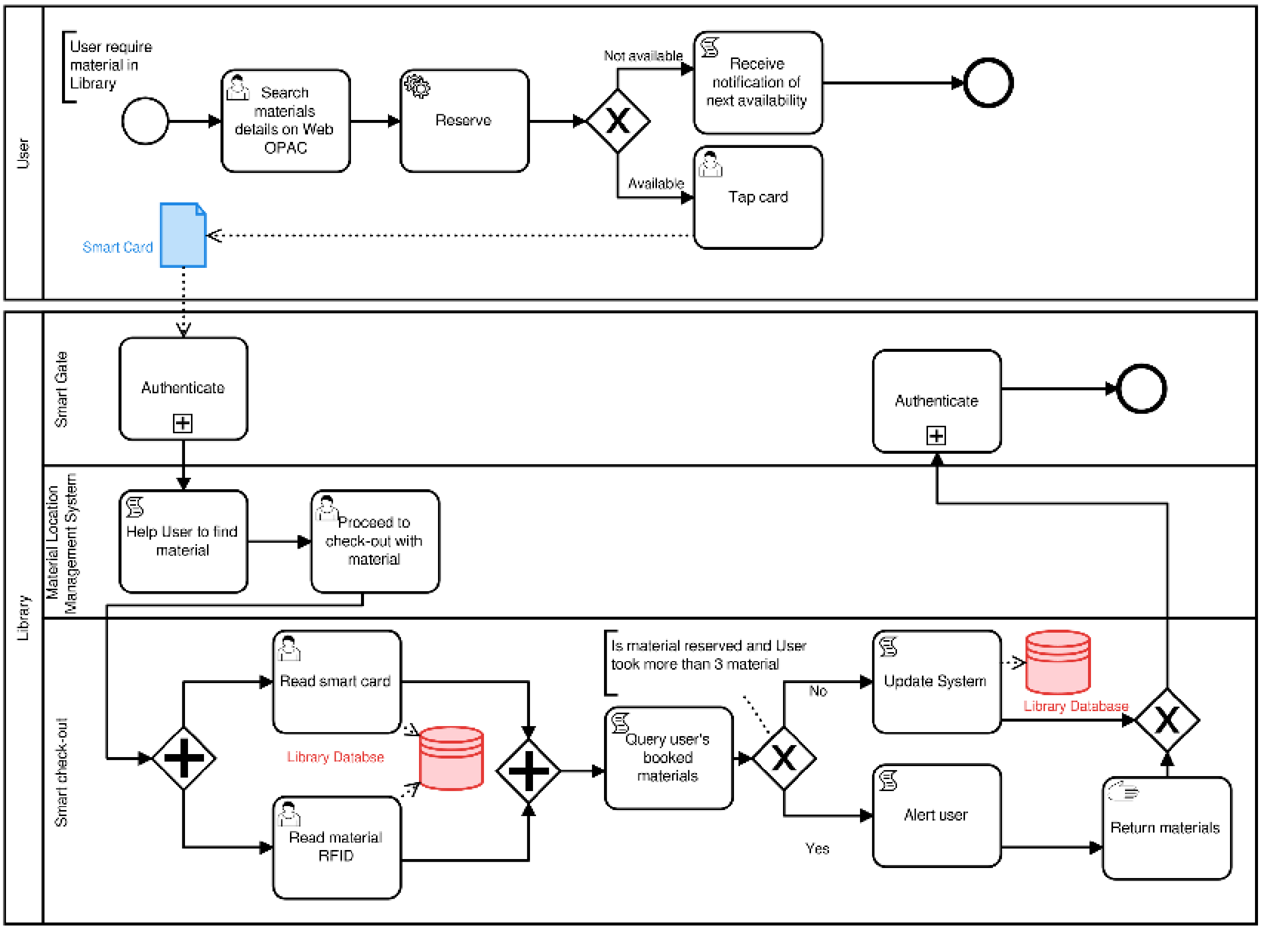

Figure 1: Booking material business process

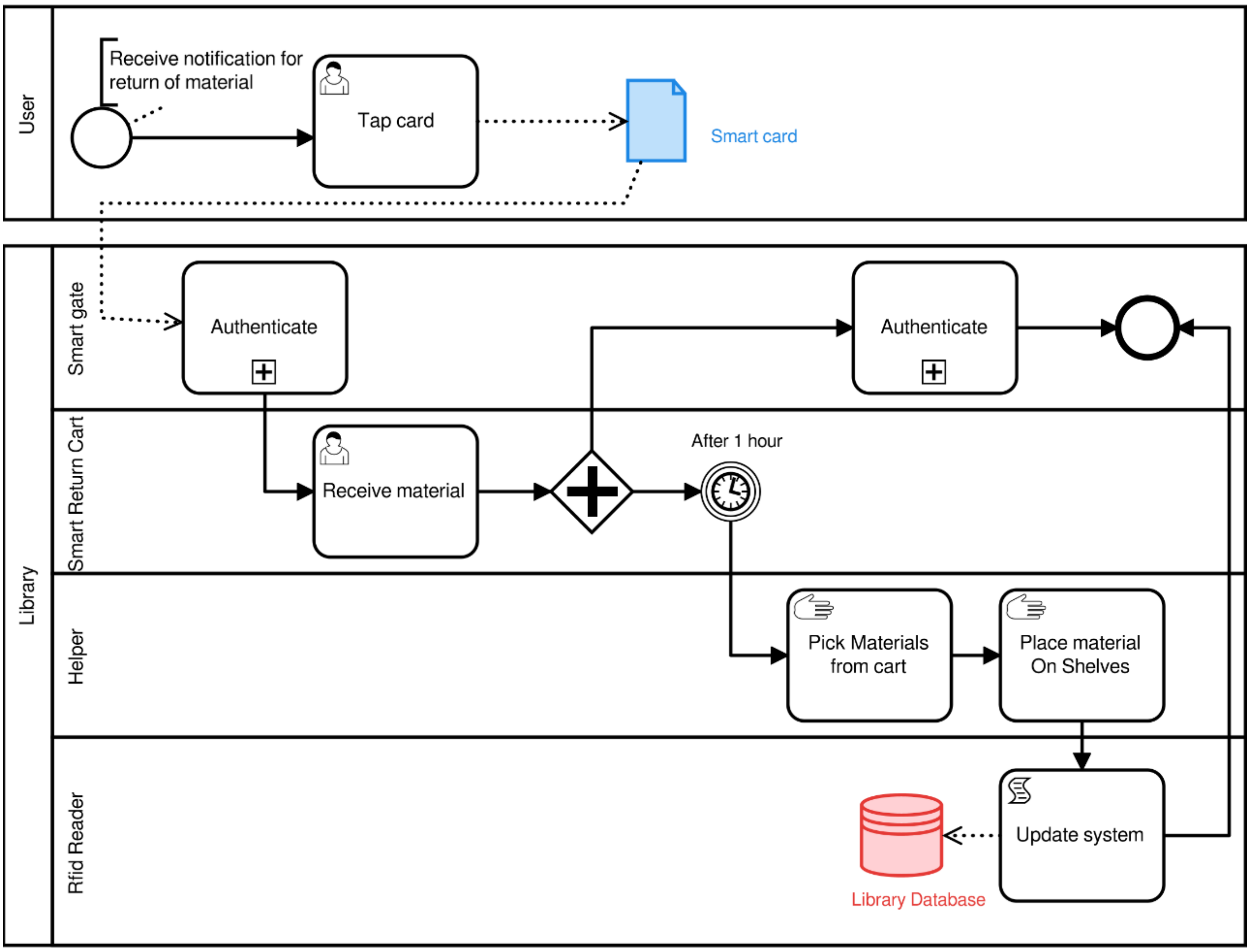

Figure 2: Return material business process with authentication extension

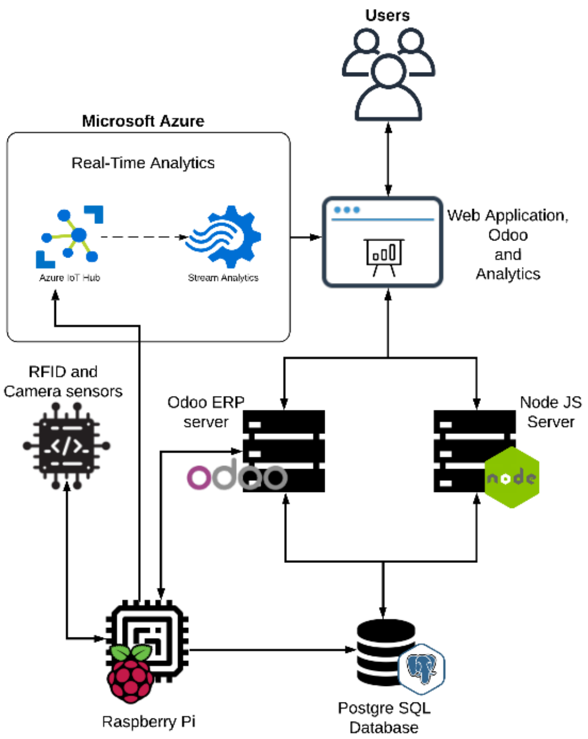

Figure 3: System architecture

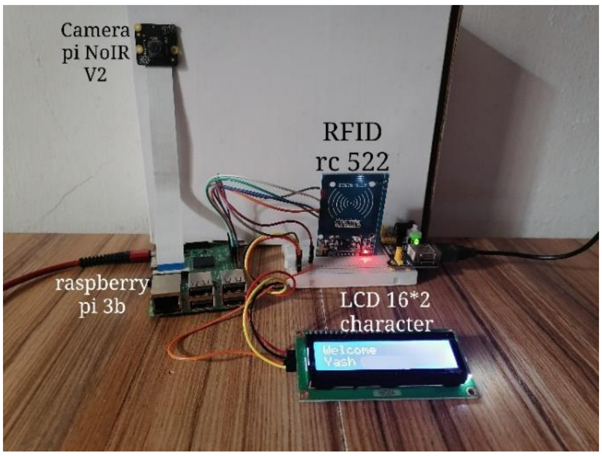

Figure 4: System prototype

A. Odoo ERP

Odoo ERP is a strong open source platform for enterprise applications with a collection of closely integrated modules designed to cover all areas of enterprise [13]. The ERP is used as it deals with the procurement of materials, human resources (HR), stock and finance management [3]. To meet the library's requirements additional modules such as "*School*" and "*Library Management*" were downloaded from the Odoo app store. As Odoo is open-source and its codes are written in python, this provides with more flexibility to add and customize functions.

B. Raspberry PI 3B

Raspberry Pi is a tiny machine, credit card size as shown in Figure 5 with a quad-core 1.2Ghz CPU and 1 GB RAM. This small device has great capabilities throughout the IoT environment. Raspberry Pi 3 also has Wi-Fi and Bluetooth and a storage space up to 128 GB. The Raspberry Pi has been used in several projects such as cloud monitoring [7] and the Car Safety System [8]. For the proposed smart library system, all the sensors used are connected to the Raspberry Pi through its 28 GPIO pins. Additionally, all pictures captured through the camera are sent to the raspberry. Processes such as face recognition, book identification, booking, returning, and access control are also processed on the Raspberry Pi.

Figure 5: Raspberry Pi 3B

C. RFID

RFID stands for radio frequency identification that transmits data using radiofrequency waves. The tags are attached to items, and the reader will then read the tags to identify the objects. Based on their frequency (low/high/ultra-high frequency), RFID varies, and each category has a reader that matches. It can also be categorized as an active and passive tag, where a battery is built into the active tag, and the passive tag uses radio waves to obtain power. RFID was used in the waste management system [9] and the control of inventories [10].

The proposed smart library system makes use of RFID RC522. It reads and writes data to tags being up to 5 cm away from it. The print (write) request made from Odoo ERP to Print data on the tag makes use of a web service located on the Raspberry Pi. The reader will read data from the tag that will be within the read range of the reader. Figure 6 is a picture of the RFID and its tag (which will be in materials). RFID technology detects material that is being booked (Smart booth), taken out (smart gate entry/ smart gate exit), and returned when place in the return cart.

Figure 6: RFID RC522 reader/writer and tag

D. Pi NoIR Camera V2

The camera v2 Pi NoIR has an 8-megapixel Sony IMX219 sensor, compared to the original camera's 5-megapixel OmniVision OV5647 sensor. The camera ensures more than 97% accuracy [11] and it can work along with OpenCV. The camera captures images in real time and if a face is detected, it sends the latter to the server using a web service. The image is then compared with all the faces on Odoo's database.

E. LCD

The LCD as shown in Figure 4 is an HD44780 and it is a communication means for the microcontroller to communicate to the external world. The HD44780 is used to display information such as the username and the book's title.

F. Breadboard and Power Supply

The power supply provides 3.3v to the RFID device and simultaneously provide 5v to the 16*2 display via the breadboard. The breadboard is used to connect all the different sensors to the Raspberry Pi as shown in Figure 7.

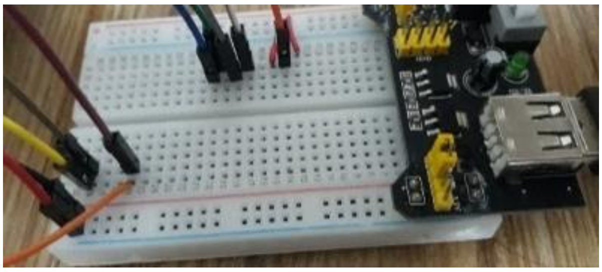

Figure 7: Breadboard and power supply

G. Smart Gate, Booking Booth, and Return Cart

When the Raspberry Pi 3, RFID Rc522, LCD, breadboard, and power supply are connected, they form the *Smart Gate*, *Smart Booth*, and *Return Cart*. Smart gates are placed in entrance and exit to control access to the library. The *Smart Booth* is placed in the library to allow users to book their material using the RFID tags inserted into the books and *Return Carts* are placed in the library for users to drop their borrowed items, these *Return Carts* can also be placed outside the library for ease of access.

H. Microsoft Azure

Microsoft Azure is considered to be both a Platform as a Service and Infrastructure as a Service that offers a diverse range of services that often form the foundational elements of cloud computing [14]. Examples of services being offered are Azure SQL Database, Azure websites, Azure virtual machines, and virtual networks. Through its evolution, Azure has progressed to offering analytics services through its Machine Learning Studio where data scientists and developers can quickly build, test, and develop predictive models using cutting-edge machine learning algorithms [15].

I. Node JS Server

Node JS is a server-side Javascript environment that is built on top of the V8 JavaScript runtime developed by Google [16]. Node adopts a single-threaded approach for processing event has driven inputs and outputs and is implemented in C and C++. Node architecture favors more functional language as opposed to object-oriented and with the use of the fast and powerful V8 engine, the node can achieve excellent performance [17].

J. Postgre SQL Database

Postgre SQL is a powerful and robust framework that can be used for many kinds of data processing and also for non-data server tasks [18]. Postgre SQL is nonetheless used more like a storage system, where SQL statements have to be executed for communicating with it [18]. Postgre SQL can run on all major systems including Linux, Unix, and Windows, and is fully ACID compliant.

Following the proposed system, the flow of data in the system debuts with the RFID scanner and camera sending book's an image's data to Raspberry Pi for booking and face recognition process respectively. Throughout this process, the Raspberry Pi communicates with the Postgre database. The Raspberry pi also receives a request from Odoo for printing on RFID tags. The data in the Postgres database is used by both the Odoo server and Node Js server for manipulation and viewing by the web application and Odoo interface. In parallel, data from the IoT sensors are sent to Microsoft azure's IoT Hub for analytics with Azure Stream Analytics, which are broadcasted to admin for viewing through a dashboard.

IV. SYSTEM PROTOTYPE

This section describes how the different processes have been implemented using the technologies described in section III. The processes are described as follows:

A. The Query of Material and Services

The smart library system integrates a web application as a means for users to perform library transactions. In contrast to the current system which makes use of a website, the web application follows responsive web application design principles, which allow users to view the application on their mobile and desktop shortcoming in the design and layout which could affect the user experience. Apart from integrating the existing digital collection of materials and reservation of library items, the application provides additional functionality, which enables users to set a notification for items that are not available.

Moreover, users have the option to view the location of the item on a top-view map upon reservation. Other features include users having a personal account displaying their history of material borrowed, bookmarks, comments and the possibility of swapping of materials between students. Additionally, the student can query materials using the web application. First, the user log-ins and based on his title, he is redirected either to ERP/Analytics or the web OPAC. The web application covers many services such as view student's details as in Figure 8, view materials as shown in Figure 9, search for specific materials and swapping and reservation of materials. Figures 10 and 11 show the swapping process of materials from user1 to user2.

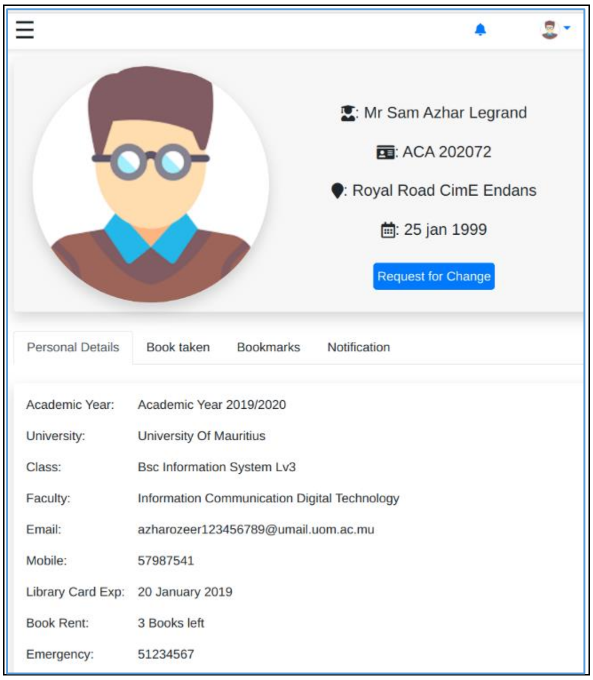

Figure 8: Student's details

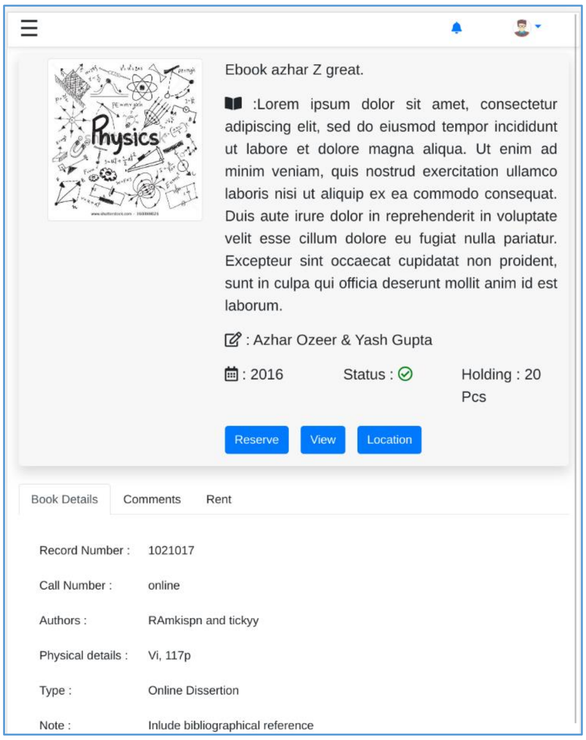

Figure 9: Material's details

B. Automated Access Control

Access and exit to the library premises are completely automated with the implementation of smart gates where users are required to authenticate themselves through facial recognition. Upon registration of a user on Odoo ERP, a picture of the latter is requested and is captured using OpenCV's Cascade Classifier and is saved to the library's database for the authentication process. Generally, when a user steps near the camera, the latter will be detected using OpenCV's Cascade Classifier. The face is then sent via the "POST" method to the server for face recognition using the python face_recognition package. After the recognition process has been successful the id of the user is obtained else the server returns ‘0’ and the system denied the user’s access. If successful, the RFID device looks for potential materials in the user’s possession and if found, the system checks if the user is the owner. If the user does not own the item, the system will alert the guard and record the user as theft in the database else the user is allowed to leave. Figure 12 shows the message displayed to the users when an unauthorized material is detected and Figure 13 shows a flowchart that demonstrates the Smart Gate Exit process.

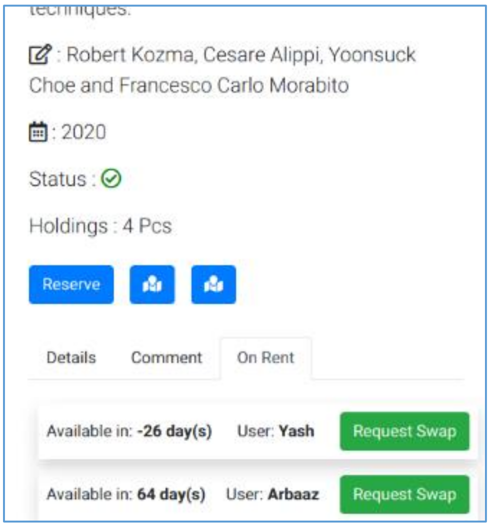

Figure 10: Swapping in book detail

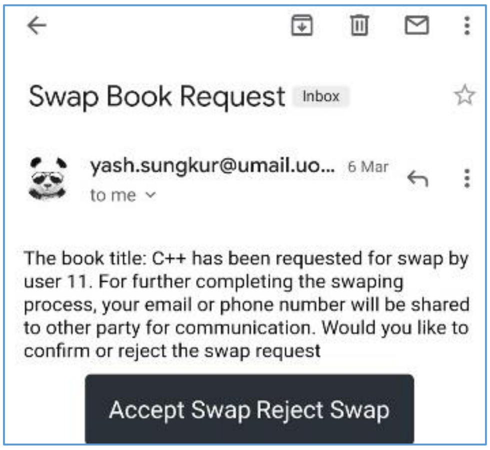

Figure 11: Request for swap

Figure 12: RFID reading a book's tag

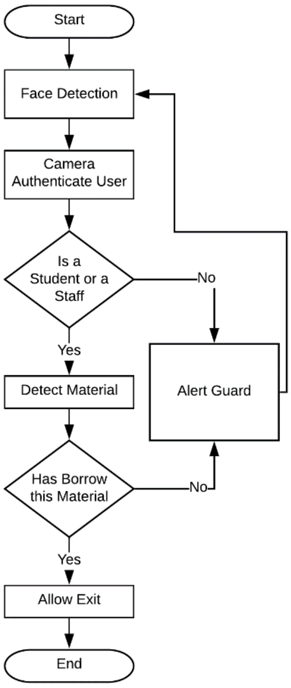

Figure 13: Smart gate exit process

C. Automated Lending and Returning Process

The system implements smart check-out booths that are equipped with RFID readers to facilitate the lending process. After retrieving the desired items from the shelves, the user will tap the material, which is embedded with an RFID tag and validate his face through facial recognition to record the booking in the library’s database. Furthermore, there will be controls in the check-out booth to allow transactions, only when the item has been reserved by the user and he has borrowed not more than two items. This will reduce considerably human errors in the process. The reservation process starts within the web application after the user logins and decides to reserve a material. The user searches for the book and afterward, the system checks for its availability and checks for the user’s booking limit. In case the user is eligible but the item is not available, the user can ask to be notified the availability of the book. Otherwise, the book is reserved for the specific user. The user can then pick the book at the library.

The user’s face is detected and validated at the entry of the library. At the booking booth, the RFID detects the user’s material for booking. If no item is detected within the first 5 seconds, the transaction is canceled. Otherwise, the user’s virtual library card is validated. During the card validation process, the system checks with the server whether his card has expired or if he has already borrowed three books. Finally, if he is eligible and has reserved the item, the booking takes place and he is notified afterward whether the booking was successful or failed. The returning process also integrates smart devices in the form of a smart return cart where the user will only need to place the material in the cart, which will read the material’s RFID, and records the successful return of the material in the database. The helper will retrieve the location of the material with the help of a handheld reader and place it on the shelf after updating the system.

D. Library Management Using Odoo ERP

The librarian, through the proposed system has access to Odoo ERP (Enterprise Resource Application) which is linked to the web application. The Odoo ERP provides the librarian with functionalities such as registering students, adding library materials, handling user book request and issue. The ERP also permits the librarian to read, edit and write to RFID tags directly through appropriate user interfaces. Odoo ERP is used only by admin to perform the creation of contacts such as supplier, admission of a student (as shown in Figure 14) and the creation of faculties. The ERP also handles the purchase, scrapping and selling of library items. Figure 15 shows the RFID print button and the book creation's page.

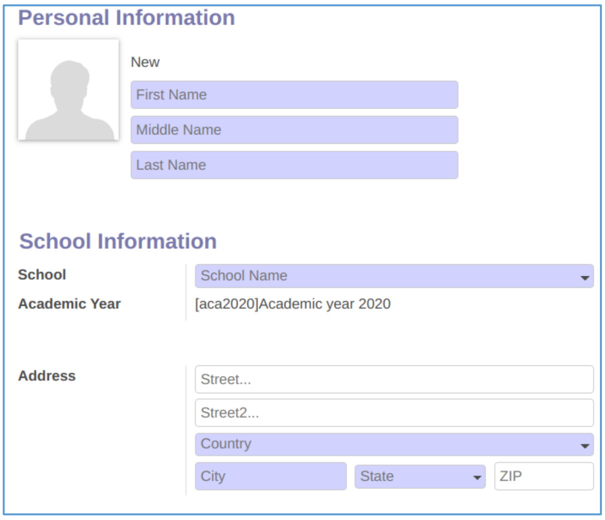

Figure 14: Admission of student

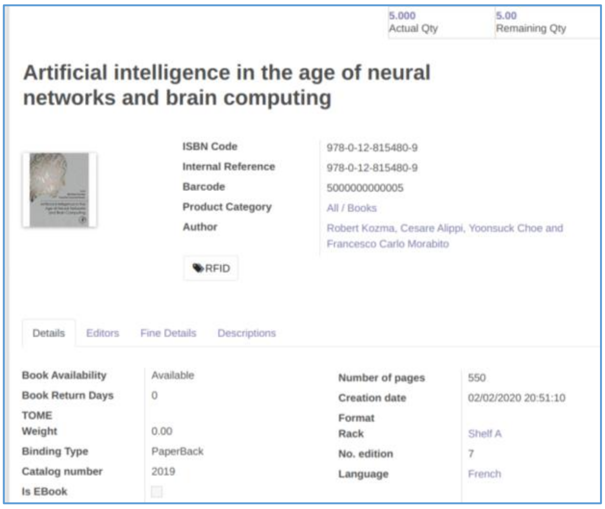

Figure 15: Material creation page

E. Decision Making Using Real-Time Analytics

Administration features of the web application include the ability to view and perform real-time analytics from data collected through the IoT sensors. The collected raw data are pushed to Azure IoT Hub, where the data can be analyzed and processed through Azure Stream Analytics or stored in its Blob storage. For the library use cases, after the data have been processed through Stream Analytics, the data are sent to Microsoft Power BI, which provides appropriate visual tools, and an API for viewing and integrating the web application.

Analytics is a service that uses real-time data obtained from the sensors, and then displays it into meaningful information so that manager can take a better and real-time decision. Figures 16, 17, and 18 show graphs generated from the system. Figure 16 shows the total number of library materials being borrowed each day and Figure 17 shows the preferred books of users. These data can be very helpful for the management as they can enhance decision making such as the availability of a particular material. Management can thus take necessary action to ensure adequate quantity is available to fulfill users'demand.

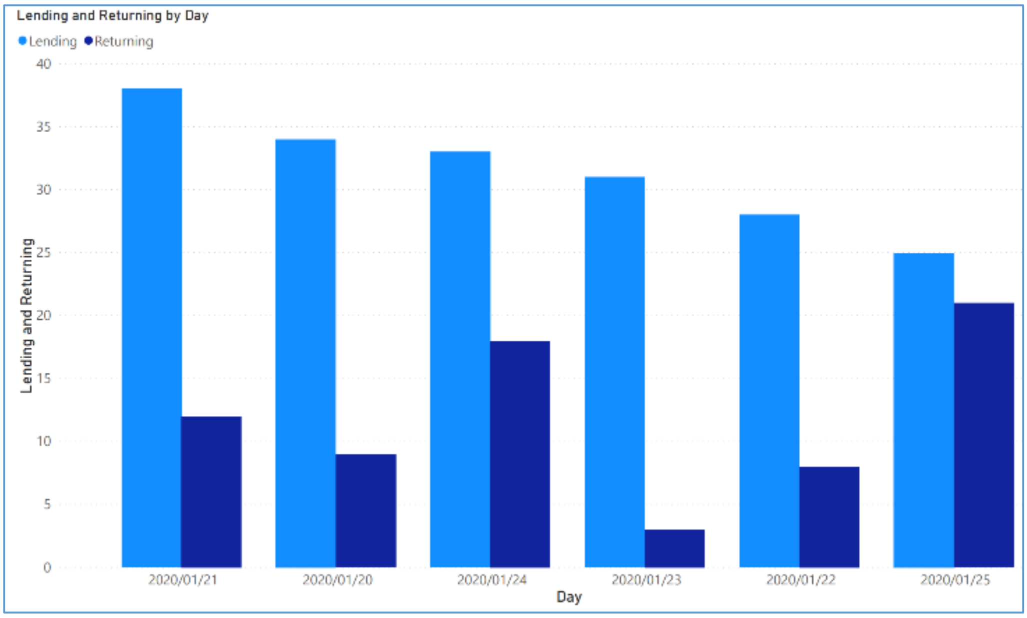

Figure 16: The total amount of leading and book return by day

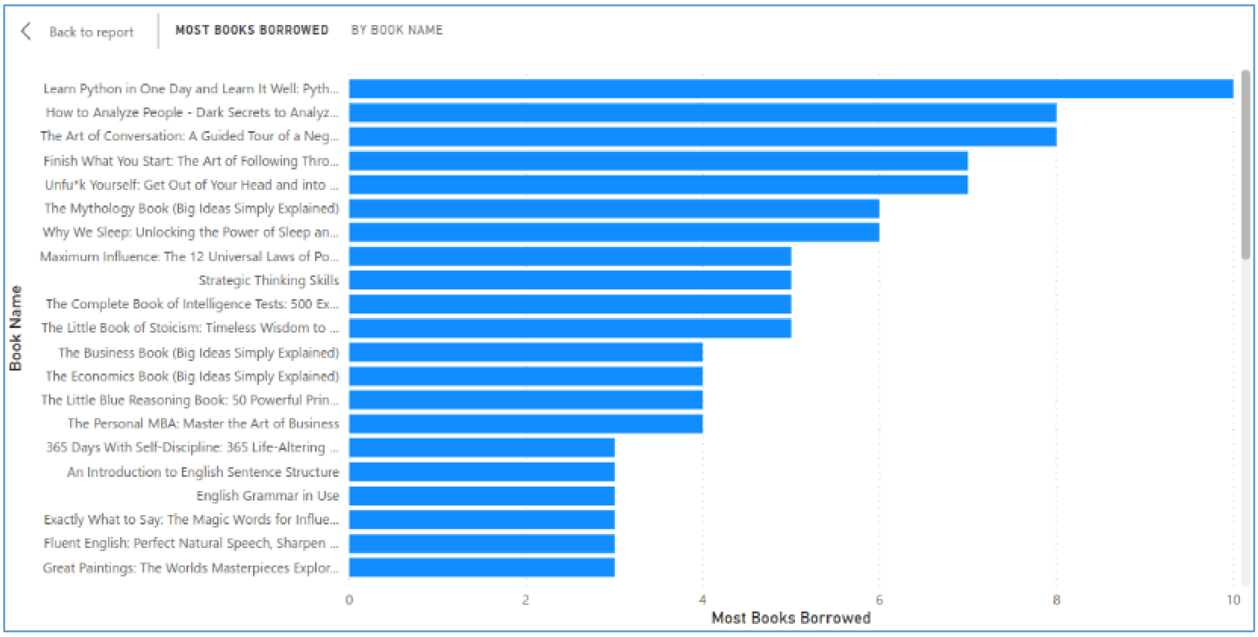

Figure 17: Most borrowed book

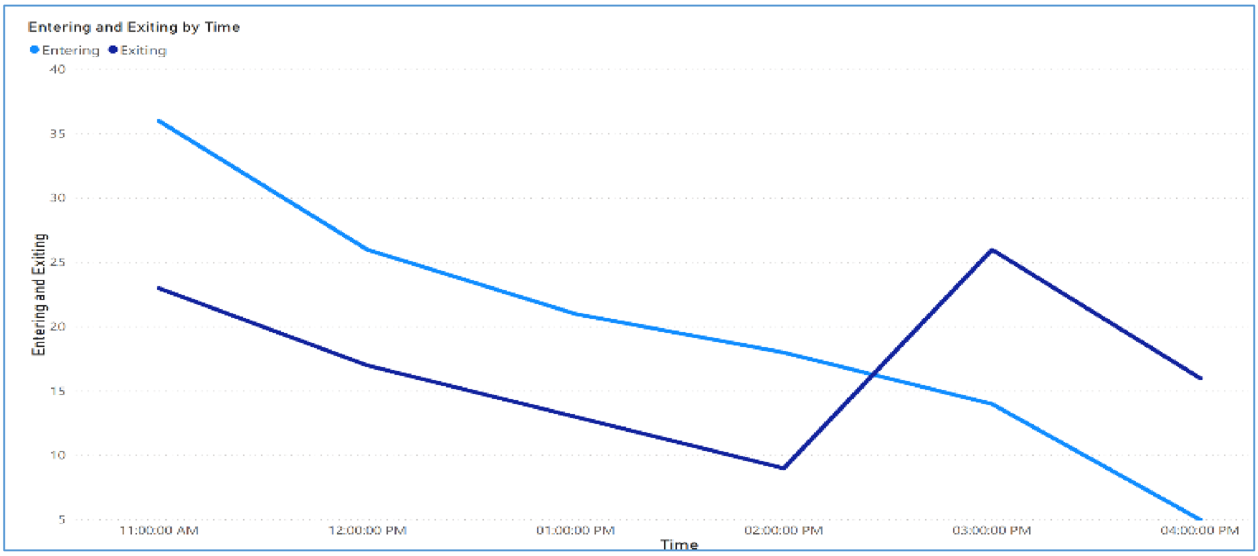

Figure 18: Real time data of user entering and exiting the library

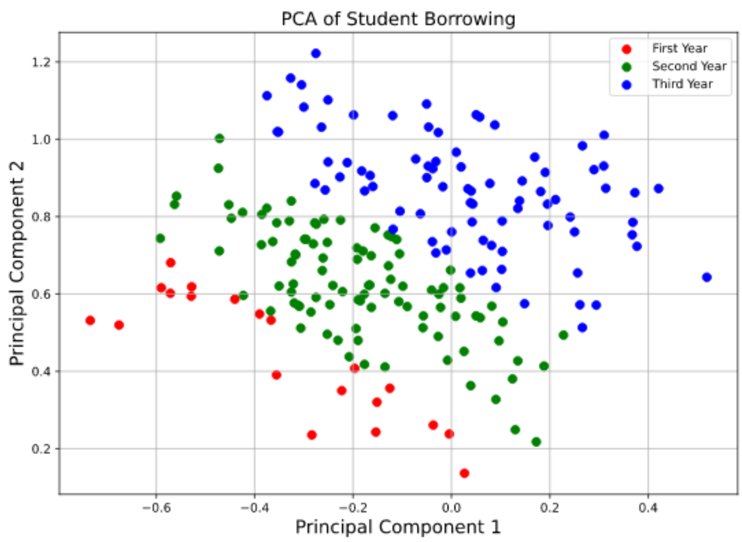

Figure 19: Student borrowing using PCA

Additionally, through the use of real-time analytics, like monitoring the number of users who are entering and exiting the library premises (as shown in Figure 18), management can better plan personnel for controlling crowd during high peak periods or add additional smart booth for lending and returning library materials.

F. Use of Machine Learning and Deep Learning for Prediction

Principal Component Analysis is an unsupervised machine learning technique, which aims at reducing the dimensionality of the datasets, magnifying interpretability and at the same time minimizing information loss [19]. The process of PCA entails creating new uncorrelated variables that subsequently maximize variance. Findings, such new variables, the principal components (PCs), reduce to solving an eigenvalue/eigenvector problem [19]. PCA has been implemented to have a deeper insight into which level of students (level 1, 2, or 3) have access to the library and as a result, are apt to borrow more books. Figure 19 illustrates the clustering of students by their year of study.

Long short-term memory (LSTM) network is a type of recurrent neural network, which implements a gated cell to store information. This attempts to improve traditional artificial neural networks when analyzing sequential data where memory is needed to store the outputs of the previous steps [20]. Besides, LSTM also solves the problems of vanishing or exploding gradients of typical recurrent neural networks (RNN), where the gradient can get relatively complex due to RNN involving time dimension data [20]. The LSTM model for forecasting book lending as shown in Figure 20 produces satisfactory results when being applied for the period of 2019 to 2020. Based on modeling using the train and test dataset, the model can be extended for the prediction of future lending of books for the period of 2020 to 2021. Figure 21 shows the forecasted book lending for the period 2020 to 2021.

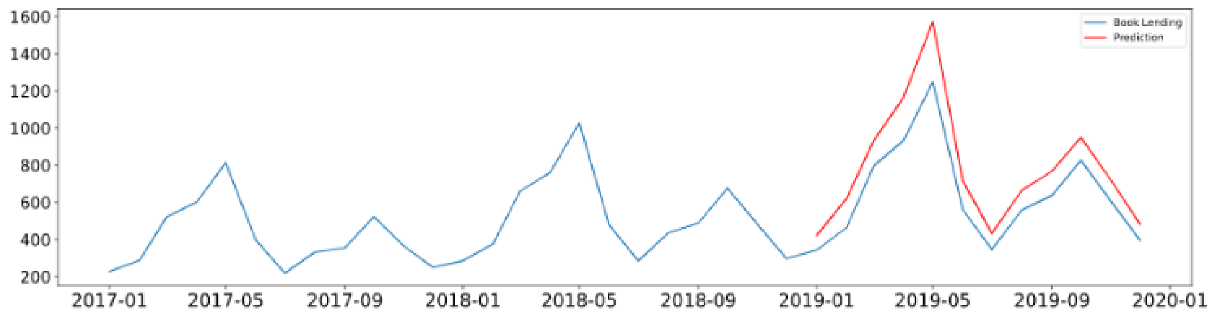

Figure 20: Forecasting book lending

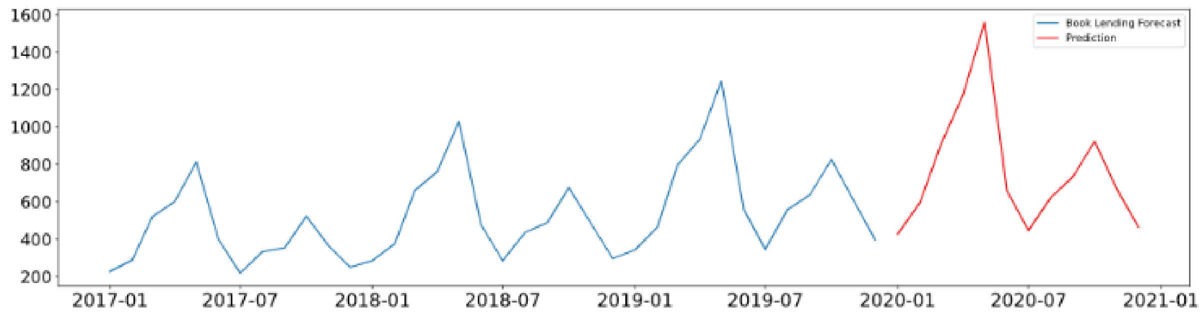

Figure 21: Forecasted book lending

V. Evaluation and Discussion

The smart library as compared to traditional library brings many benefits to the system. This new smart library automates the main business process of the smart library such as "*Booking of Material*", which decreases the amount of invalid data being inserted into the system. Although the capital invested in the system can be huge, varying from organization to organization, the return on investment is expected to be three years. Moreover, as the IoT devices handle some business processes, the cost, in the long run, will be reduced. The real-time analytics of data provides decision-makers with live reports and this enhances resource utilization. The web application presents a new method of booking known as "Swapping", which allows the users to exchange items between themselves without having to move. However, the smart system may fail to work with unfamiliar cases such as a user booking a magazine without an RFID tag. The system does not detect users removing RFID tags from the library's material, but these can be solved by using theft detection in camera surveillance (computer vision). In case of power failure, the system requires an uninterruptible power supply (UPS) to continue supplying the devices with electricity.

VI. Conclusion and Future Works

The emphasis for this paper is on the implementation of a smart library using IoT, which captures data, analyzes them in real-time, and generates reports using real-time analytics. The implementation upgrades the traditional library to a smart library while automating some of its processes. The algorithms mentioned allow the recording and validation of most of the system's transactions such as *'a user borrowing* *book from the library'* or *'a theft stealing books from the library*' independent from admins' intervention. In cases such as theft, the system (smart gate) requires a security guard to stop the thief. Nevertheless, the implementation of these algorithms on devices such as Raspberry Pi 3B may slow down the transaction due to its processing power. Moreover, using passive RFID tags may fail to detect the material if it is not in the reading range. Compared to the prototype shown in this paper, all the devices need to be upgraded for a real-world smart library system to run at optimal performance. Upgrading the system, such as making use of active RFID readers, will extend the read range of the smart gate and reduce the risk of theft. The Raspberry Pi 3B can also be upgraded to Raspberry Pi 4B with quadruple amount of ram and a better processor, thus decreasing the processing time considerably.

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