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Original Paper

A RFID ENABLED INNOVATIVE FRAMEWORK FOR INSTITUTIONAL AUTOMATION IN IOT INFRASTRUCTURE

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ABSTRACT

In the current digital era, maintaining the comprehensive movement of individuals is imperative to ensure their security, especially within an organization. Traditional monitoring systems, such as offline attendance systems, offline tracking systems, etc. operate within specific time intervals and lack real-time tracking capabilities, requiring significant human intervention, leading to inaccuracies, delays, and administrative burdens. Consequently, the demand for real-time monitoring underscores the imperative for an advanced movement-tracking system to facilitate seamless surveillance and management of human activities. In response, this study presents an automated solution integrating the Internet of Things (IoT), Radio-Frequency ID notification (RFID) cards, NodeMCU, and Arduino Uno to monitor human movement, which could enhance organizational security and safety, and bolster decision-making capacities. The proposed model provides a user-friendly interface for real-time location tracking and attendance reporting, with offline functionality enabled through micro-SD card integration. Moreover, the comparative analysis with existing solutions demonstrates the efficiency of the proposed approach in real-time human tracking.

KEYWORDS

IoT, Cloud synchronization, Remote Monitoring, Data Transmission, Real-time tracking

1. Introduction

In today's organizational landscape, keeping accurate records of human movement is vital for many reasons. A tracking system for an organization is a technological solution used to monitor and manage various aspects of the organization's operations, assets, or personnel. It typically involves utilizing hardware devices, including sensing devices such as RFID modules, RTC modules, and microcontrollers like NodeMCU and Arduino Uno, combined with software applications to collect, Analyze, and visualizes data related to the organization's personnel. This system enables organizations to track the location, and status, efficient asset management, enhance security, optimize resources, ensure compliance, improve customer service, and facilitate emergency response in real-time [1]. Earlier, traditional monitoring systems, such as manual attendance tracking, were utilized, but they had numerous limitations. These systems operate at set times and need a lot of human effort and can lead to mistakes and delays, often aligned with scheduled check-in or check-out times. Consequently, they are unable to provide real-time insights into human movement patterns [1-2]. This deficiency results in a lack of immediate awareness regarding individuals' locations, rendering organizations vulnerable to potential security breaches or operational inefficiencies. Moreover, the reliance on manual processes inherent in traditional monitoring systems necessitates significant human involvement. This reliance not only increases the likelihood of errors and inaccuracies but also introduces delays in data collection and processing.

Real-time tracking systems are crucial for organizations as they enhance security, enable efficient resource management, improve operational visibility, ensure compliance, and facilitate crisis management. By providing up-to-date information on the location and status of assets and personnel, these systems allow for quick detection of anomalies, optimal resource allocation, and proactive decision-making [4]. Moreover, they also help organizations comply with regulations, promote accountability, and enable swift response to emergencies. As a result, real-time tracking systems are essential for organizations to streamline operations, mitigate risks, and adapt to dynamic business environments [3]. Therefore, in order to design an efficient real-time tracking system for an organization, this study proposed a robust solution by utilizing IoT technology, RFID cards, NodeMCU, Arduino Uno microcontrollers, and a user-friendly website interface. The proposed model is a big step forward from traditional methods, aiming for accuracy, efficiency, and proactive management. Moreover, the proposed model tackles concerns about data integrity and accessibility by seamlessly connecting with cloud platforms. This ensures that data is securely stored and can be easily synchronized, even during internet outages with Local Storage functionality. The proposed model successfully achieves several key objectives.

- Investigate and analyse weaknesses in existing attendance monitoring systems.
- Develops an innovative attendance monitoring system using IoT technology for enhanced precision and efficiency.
- Explores efficient microcontrollers and object detection mechanisms for effective data transmission and location identification.
- Provides continuous monitoring and data analysis by leveraging Firebase Cloud.
- Ensures data integrity and availability through the integration of cloud platforms and micro SD cards.
- Designs an intuitive, user-friendly interface for easy administration, insightful report generation, and real-time object tracking.

The remainder of the article is structured as follows: Section II reviews the literature. Section III details the proposed methodology and the materials used in the system architecture. Section IV presents the results. Section V provides the conclusion, and Section VI explores the future scope of this research.

2. LITERATURE REVIEW

RFID technology has emerged as a promising solution for various applications, including attendance management systems. In this context, Ahsan et al. [5] provided an introductory and exploratory study on RFID applications in 2010, shedding light on its potential across diverse domains. Later, after three years, Nainan et al. [6] delved deeper into RFID technology, focusing specifically on the same attendance management systems that highlighted the technical components and implementation challenges associated with RFID-based attendance systems. Moreover, Chiagozie et al. [7] proposed an RFID-based attendance system with an automatic door unit, enhancing access control alongside attendance management, while Taha et al. [8] further expanded on RFID applications, presenting a company attendance and access control system based on RFID technology. They emphasized the operational benefits and challenges of implementing RFID for corporate attendance management. Qureshi et al. [9] proposed the implementation of an RFID-based attendance system, focusing on workflow optimization and student engagement in Organizations. This proposal aligns with the growing demand for efficient attendance-tracking solutions in academic settings. Hopjan et al. [10] explored mesh network applications, which can optimize communication within RFID-based systems, enhancing scalability and reliability. Shah et al. [11] presented an IoT-based SAS using RFID technology, offering real-time tracking and analysis capabilities. Their study highlighted the potential of integrating IoT with RFID for advanced attendance management solutions. In another article, Rjeib et al. [12] made a contribution to the literature by merging web-based apps with RFID to facilitate attendance and information management in the academic area. Their system was designed to simplify attendance tracking and enhance the retrievability of organizational data. Nevertheless, Maier et al. [13] present a detailed evaluation of ESP32 microcontroller module-based IoT implementations that share their practical experiences. The study also provides important guidelines on the strategies to be followed in hardware selection and how system performance can be improved to achieve an effective realization of such RFID-based applications. In a related development, Anusuya et al. [14] 2023 put forward a smart entrance system for colleges based on IoT and RFID that aimed at improving access control and attendance management in line with the changing needs of digital age Organizations.

In addition, Lim et al. [15] brought forward an RFID attendance system at the IEEE Symposium on Industrial Electronics and Applications in 2019 to add more to this knowledge base. They demonstrated a robust solution that aims to automate attendance management, hence reducing administrative burdens and manual errors. In a similar way, Qaiser et al. [16] presented RFID systems for time and attendance automation. They emphasized how the technology can provide precise attendance records and real-time tracking, which enhances productivity and, in turn, employee control in businesses. Additionally, Koppikar et al. [17] suggested a smart attendance system based on the IoT that uses RFIDs to track attendance in learning management systems. This research explained that the incorporation of IoT with RFID is not only helpful in enhancing the identification of attendances but can also provide further utilities including distant tracking ability and data exploration, explaining the potential of an exhibited intelligent environment.

Altogether, these articles emphasize the value of adopting RFID and IoT to establish qualitative, effective, easy-to-use, and emerging attendance registry systems. They focus on the constant introduction and improvements of these technologies relevant to different sectors such as scholars and business organizations to improve how operations run with maximum precision and achieve greater system reliability.

3. PROPOSED METHODOLOGY

We have suggested this methodology in order to intelligently monitor individuals and store their data both locally and in the cloud, creating a decentralized network, as previously stated due to the flaws in the prior system. There are four major phases to this proposed model:

- **Data Sensing**
- **Local Storage**
- **Cloud Storage**
- **Application**

3.1 Data Sensing

In the Data Sensing phase, the system employs RFID technology and Real-Time Clock (RTC) modules to capture information. When an RFID tag in a card interacts with an RFID reader, it transmits unique identifying data. Concurrently, RTC modules autonomously uphold precise date and time records, guaranteeing temporal accuracy in data collection.

3.2 Local Storage

Different kinds of nodes are introduced into the system structure as part of the system architecture during this phase; these are nodes that are involved in the process of data acquisition, data storage, data manipulation, and data transfer.

Sensing Nodes: Sensing Nodes serve as primary data collecting points; integrated with RFID readers, RTC modules, and Node MCUs for transmitting the data wirelessly. They extract identification information, time-stamp it using RTC, and use wireless modules to transmit the information to the other nodes in the network.

Buffer-Sensing Nodes: As a development of the Sensing Node's roles, the Buffer-Sensing Node includes more elements comprising Arduino boards for data handling and memory units for caching data locally within the scope of the network. It allows them to store, process, and buffer RFID information before they are sent off for central analysis. There is bi-directional communication between Arduino and NodeMCU whereby NodeMCU stores or fetches information from the RFID, RTC, or other connected nodes, and sends these collected signals to Arduino. If the internet connection is available, it directly sends it to the cloud else it will store the data locally in the memory unit which is attached to Arduino.

When internet connectivity is available, the NodeMCU requests the data from the Arduino, which then shares the data. The NodeMCU attempts to send this data to gateway nodes. If the data is successfully transmitted, the NodeMCU sends an acknowledgment back to the Arduino, prompting it to delete the data from its storage. If the data transmission to Firebase is unsuccessful, the NodeMCU repeats the request for the data. Fig. 1 shows the communication between them.

Gateway Nodes: These are responsible for data storage and transmission to the cloud. Gateway Nodes require memory units and NodeMCU to transmit data to the cloud when internet connectivity is available.

Interconnected via wireless connections, these nodes form a decentralized network infrastructure capable of efficiently handling data storage and exchange. Thus, to form a connected graph of all the nodes, this model uses the concept of mesh networking. Mesh networking within devices is achieved through an open-source library namely Painless Mesh, which is a networking protocol designed for creating mesh networks, where each node in the network acts both as a sender and receiver of data, facilitating decentralized decision-making and distributed data processing.

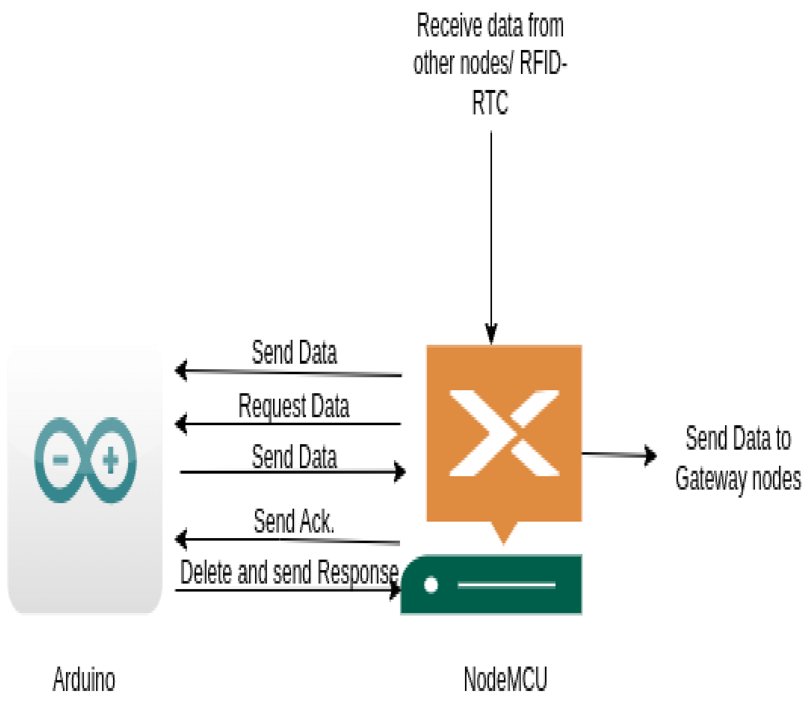

Fig. 1. Communication in buffer-sensing node

A circular queue-like structure is implemented in the local data storage system to manage data storage and retrieval efficiently. Each file in the circular queue can accommodate a fixed number of entries, allowing seamless rotation of data without the need for resizing. Metadata files maintain essential information about the current state of the data storage system, facilitating operations such as data insertion, deletion, and access.

Fig. 2 illustrates the data flow between these 3 nodes. Sensing and Buffer-Sensing nodes will sense the data and send it to the cloud if the internet is available, else it will store data locally.

3.3 Cloud Storage

The Cloud Storage phase involves the transmission of filtered data to cloud-based storage platforms for systematic management. Leveraging the Firebase platform, the system utilizes Firestore collections to organize data hierarchically, ensuring scalability and accessibility. Firestore's NoSQL cloud database enables seamless synchronization and persistence of data across multiple clients in real time, enhancing overall efficiency. There are four collections we build for the system, namely users, live data, tracked data, and attendance. User collection is used for storing data of each individual belonging to the institute. Live data stores live tracked data coming from the RFID reader, tracked data contains only current data for marking current day attendance, and we are storing these calculated attendances in attendance collection.

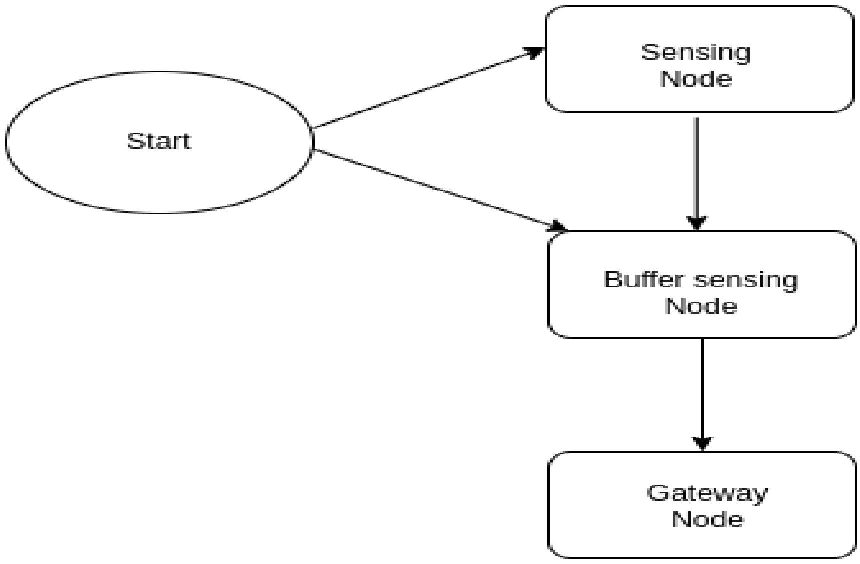

Fig 2. Data flow between node

3.4 Application

The Application phase utilizes collected data for tracking and attendance management purposes. The system facilitates seamless communication and data processing through user-friendly interfaces developed using ReactJS for frontend and Node.js and Python for backend.

3.4.1 Tracking report

This section fetches data from the live data collection and displays it through the interface.

3.4.2 Attendance report

Data is stored in a collection named Track Data, containing information for a particular day. After retrieving the data, operations are performed to determine student attendance based on time spent in class. The equation used for this determination is as follows: Let $H = \{h_1, h_2, h_3, \ldots, h_n\}$ represent the set of time slots and, for each time slot h_i in H, let $D_i = \{d_{i1}, d_{i2}, \ldots, d_{im}\}$ be the set containing in-time and out-time pairs for the person. If D_i is odd, then d_{im} = upper bound of time slot h_i

$$T_c = \sum_{k=1}^{k=m/2} (d_{i,2k} - d_{i,2k-1})$$

Where, T_c gives the total time spent by the person at the place during the time sloth_i. If$T_c \geq \alpha$, the student is marked present in that time sloth_i; otherwise, the student is marked absent. After that, the attendance data is kept in the attendance collection. This all-inclusive strategy makes it possible to analyse and manage attendance data effectively; giving users the actionable insights they need to make wise decisions.

Fig. 3 indicates the flow between these layers. This flowchart shows the operating cycle of the IoT-feature smart monitoring and attendance. The first phase is the Sensing Entity which can be the IoT periphery namely the things or the sensors that collect data from the users. After capturing the data, the system checks if there is an internet connection available. Should an internet connection be possible; then, the data is transferred to the so-called “Cloud” as the next step in storage and analysis. On the other hand, when the Internet is not accessible, the information is saved in “Local storage” so that the user does not lose any data in case of losing connection briefly. When the internet connection is back, the locally stored data is then uploaded to the server by synchronizing with the cloud. The last stage is ‘Read users attendance and tracked data’, in which only the people with the authorization level have the right to attend with attendance records and the data that it has recorded on the cloud giving a way of monitoring the attendance in real-time and also having a full way of gathering all the recorded data. This flowchart demonstrates how the system is reliable and strong, enough to adapt to online form and offline forms to ensure that the attendance capture is continuous and accurate.

4. Experiment and Result

The three sections that make up the Experiment and Results section are Setup, Experiment, and Result. This structure provides a clear and comprehensive overview of the process and findings of this study.

4.1 Setup

An overview of the hardware and software components used in the creation of the suggested Smart Monitoring and Attendance System (SMAS) is given in the setup section. The specifications and other characteristics of these components are listed in Table 1.

4.2 Experiment

The proposed concept was put to the test in an actual educational environment as part of the experiment. The Proposed concept was contrasted with the conventional approach to student attendance, which usually involves paperwork and human entry. The subsequent actions were carried out:

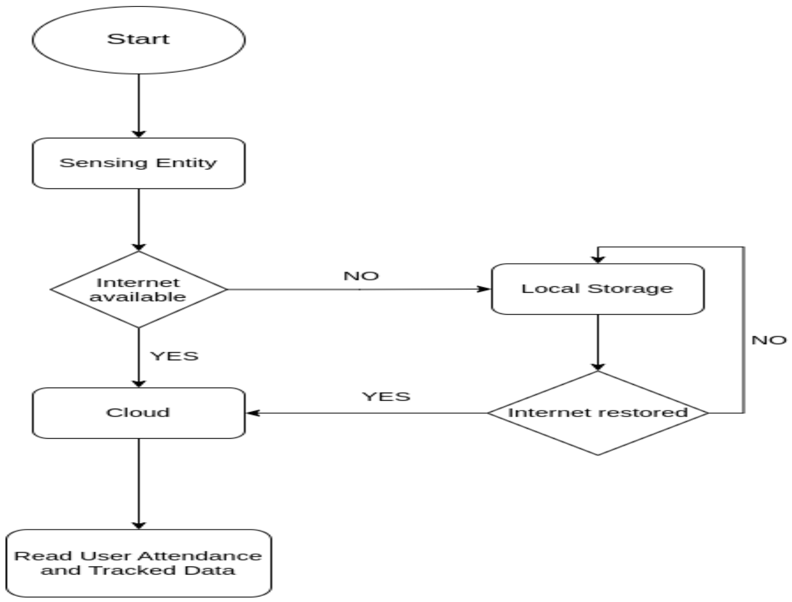

Fig 3. Data Flow diagram of the proposed model

4.3 Deployment

RFID readers were placed in key areas of the organization. RFID tags were given to the students so they could be identified.

4.4 Data Collection

Both the conventional approach and the suggested RFID-based solution were used to gather attendance data.

4.5 Local and Cloud Storage

The system was designed to assess the effectiveness of local data storage and later cloud synchronization in a variety of network circumstances.

4.6 Parameter Comparison

Important factors like user interface, accuracy, system security, work put in, human intervention, and resource usage were assessed for both approaches.

4.7 Performance Analysis

With an emphasis on situations involving a large number of people, the amount of time needed for attendance tracking using both approaches was examined and compared.

Table 1. Components used and specification

Component	Specification
RFID Readers	model-RC522, range - 5 to 10cm, operating frequency- 13.56 MHz
NodeMCU	model-ESP8266, range - 10 to 15 m, operating voltage - 5v
Arduino Uno	microcontroller -ATmega328P, operating voltage - 5v
RTC Module	model - DS1307, access via I2C protocol
Node.js	version - 20.13.1
Firebase	version - 10.11.1
ReactJS	version - 18.3.1
Arduino IDE	version - 1.8.19

5. Result

In the proposed model we have developed an intelligent human tracking and attendance system through RFID technique. It is important to note that though born with the aim of operating in any broader organizational environment, its practical embodiment has been primarily suitable for application in the educational setting. Perhaps, the most important aspect of this system concerns its scope is decentralized architecture, which is essential when working in areas with unstable or no access to the internet. This intrinsic capability permits local data storage during offline phases, thereby ensuring uninterrupted functionality and preserving data integrity. Through adept orchestration of transitions between local storage and cloud synchronization modalities, our system exhibits robustness and accessibility across fluctuating network conditions. The traditional method for taking a student absence report is usually done by using paperwork and handwriting on the advertisement wall. Hence, the paperwork method consumes workforce requirements, duplicates effort, and is time-consuming and inefficient. Table 2 shows a comparison of the developed model with the traditional attendance system (paper-work) on different parameters, i.e. human interference, efforts spent, system security, resources, accuracy, and user interface. The comparison shows that the proposed model works more efficiently in comparison to the traditional system. Furthermore, Fig 4 demonstrates that the developed system requires less time compared to the traditional system, especially when there are more individuals, as it can simultaneously track multiple humans. Fig 5 illustrates the prototype of the discussed system, offering a physical depiction of its components. It showcases sensing nodes, buffer sensing nodes, and a gateway node interconnected and powered by a dedicated power supply.

Table 2. Comparison between Traditional and Developed Model

Parameters	Traditional System	Proposed Model
Human Interference	Yes	No
Efforts Spent	Yes	No
System Security	More vulnerable	Authenticated persons only
Resources (Documents)	Physical record	e-record
Data Accuracy	Low	High Accuracy
Interface	Pen and Paper	User Friendly website

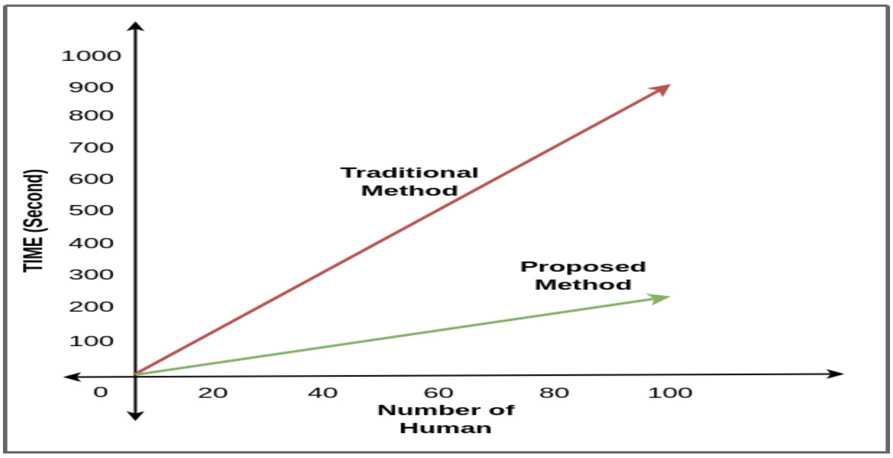

Fig 4. Graph representing the difference between tracking time in the Traditional and Proposed Model

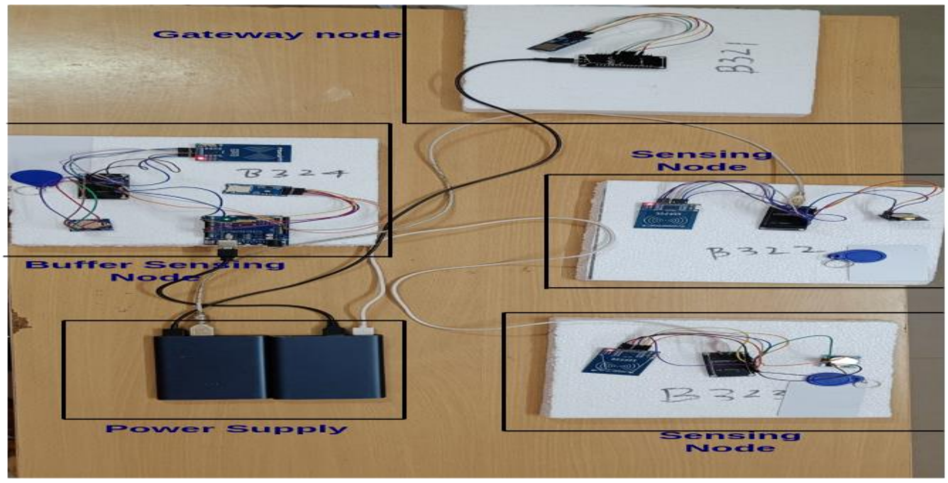

Fig 5. Prototype of Proposed system

6. Conclusion

This article has presented a detailed development and implementation of an IoT-based smart monitoring and attendance system aimed at enhancing accuracy and efficiency in human tracking. By integrating RFID technology and IoT devices, the system provides real-time tracking and automated data processing, addressing the shortcomings of traditional manual methods. The proposed model demonstrated high accuracy in human monitoring and significantly reduced administrative workload through automated data collection and processing. The dual storage strategy, involving local storage on SD cards and cloud synchronization via Firebase, ensures data integrity and reliability even during network outages. The user-friendly web-based interface developed using ReactJS facilitates easy monitoring and management of attendance data by administrators. The deployment and testing of the system in a real-world educational environment confirmed its effectiveness and robustness. The positive feedback from users highlighted the system's reliability, ease of use, and operational efficiency.

7. Future Scope

The developed model initially focused on human tracking and attendance management systems and further, it can be extended to incorporate advanced features leveraging Machine Learning (ML) algorithms, psychoanalysis techniques, and enhanced access control mechanisms. The proposed framework can be implemented at full scale for an organization, with or without incorporating the factors mentioned below:

- Apply ML algorithms for student clustering, analysing attendance, location, performance, and behaviour for psychoanalysis.
- Integrate real-time monitoring and intervention for deviations in behavior and attendance, with predictive analytics for tailored strategies.
- Provide access control to digital resources, implementing multi-factor authentication and blockchain for secure identity management.

This scope outlines a comprehensive vision for the research, emphasizing its potential to influence advanced technologies for the benefit of students, researchers, and other stakeholders in academia and industry.

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