Pedals - Rental Bicycle System

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***Abstract*—**The need for creative mobility solutions has been brought to light in recent years by the rising demand for environmentally friendly and sustainable transportation within educational institutions. This study presents a smart campus bike rental system that uses a web-based application to let students rent and return bicycles. The system uses Firebase as a real-time database to manage user authentication, bicycle availability, and rental status updates, and it uses a React.js-based frontend interface for user interaction. The solution incorporates an RFID-based automated locking mechanism at the hardware level, which is managed by an ESP8266 Wi-Fi module and an Arduino microcontroller.by automating the rental process, guaranteeing safe bicycle access, and providing real-time status monitoring, the project seeks to reduce the amount of human intervention. Students can quickly log in, check out the bikes that are available at specific stands, and unlock loops through their gadgets. Returning the bicycle to any stand after the ride is over activates the RFID-based locking mechanism, which updates the database to mark the bike as available once more. The end-to-end system architecture, implementation process, hardware-software integration, and system performance evaluation using real-world testing scenarios are all described in this paper.The findings show that the system is scalable, dependable, and easy to use; it may find use in other corporate or closed-campus settings. In order to further improve functionality and user experience, future improvements like GPS-based tracking, the creation of mobile applications, and the integration of digital payments are also suggested. In line with the goal of sustainable and digital campuses, this research aids in the creation of intelligent transportation systems.

Keywords—component, formatting, style, styling, insert *(key words)*

1. INTRODUCTION

Numerous academic buildings, residence halls, libraries, cafeterias, and recreational areas are all found on large campuses, which usually cover large geographic areas. Frequent travel between these facilities can lead to inefficiencies, particularly when walking, shuttle buses, or personal bicycles are utilized as modes of transportation.

Personal bicycle ownership may result in parking shortages, theft, and unequal distribution, while shuttle services are constrained by set routes and schedules and have high operating costs. As a result, there is an increasing need for a user-centered, sustainable, scalable shared transportation

system. In order to address these issues, this study suggests a smart campus bicycle rental system that incorporates cutting-edge technologies like wireless microcontrollers, real-time cloud databases, and RFID-based access control to produce an automated, easily accessible, and environmentally friendly Inspiration

There has never been a more pressing need to switch to low-emission, sustainable transportation systems, especially for educational institutions that aim to set an example of ecologically conscious behavior. Bicycles are a great way to get around campus quickly because they are powered by people and don't emit any pollutants. However, poor use of shared bike facilities is frequently the result of a weak management and access mechanism. Manual rental systems are labor-intensive, prone to abuse, and ineffective at scaling across large campuses. Furthermore, there is a compelling argument for incorporating smart technologies into regular campus services given the growing digital transformation of the educational infrastructure. The chance to develop a contactless, technologically advanced bicycle sharing system that enhances convenience and security while also strengthening

This project's main goal is to use contemporary web and Internet of Things technologies to develop and deploy a fully functional smart bicycle rental system for campus use. The

system's goal is to offer a user-friendly, responsive web application that makes renting and returning bicycles simple. Bicycle locking and unlocking are managed by RFID authentication, which is interfaced with Arduino and ESP8266 modules to provide contactless and safe access. Firebase's cloud infrastructure manages real-time data, such as rental status, user authentication, and bicycle availability, allowing for smooth synchronization across all users and devices. By enabling users to pick up and drop off bicycles at several designated stations, the system also supports flexible usage patterns, improving accessibility and user convenience

II. LITERATURE REVIEW

A.Existing Systems

Globally, a number of city-scale bicycle-sharing programs have been put into place, making use of mobile applications, smart cards, and QR code scanning to manage rentals and grant access. The public bike-sharing schemes in Paris (Vélib'), London (Santander Cycles), and New York (Citi Bike) are notable examples. These systems have been successfully implemented on a large scale, but because of financial and maintenance limitations, they are not feasible for campus-level deployment because they frequently depend on expensive infrastructure such as GPS modules, cellular communication, and centralized docking stations. Additionally, a lot of these systems lack continuous real-time feedback on user status or bicycle availability, which results in inefficient resource allocation and poor user experience. This study aims to overcome these constraints by creating a scalable, lightweight system that is ideal for college campuses and incorporating reasonably priced confirm.

B.RFID in Access Control

Numerous fields, including inventory management, library systems, employee attendance, and secured entry systems, have seen substantial research and implementation of Radio Frequency Identification (RFID) technology. RFID is a great option for applications that need smooth user interaction because of its contactless nature and quick authentication capabilities. RFID makes it possible for automated, user-specific access control in bicycle-sharing systems without requiring complicated authentication processes or human intervention. Previous studies have demonstrated how well RFID works to increase user convenience, decrease operational delays, and improve system security. A strong and secure access mechanism that is especially appropriate for busy campus settings can be created by integrating RFID readers into bike stations and connecting them with distinct user credentials.

C.Firebase and IoT

Google created Firebase, a cloud-based backend-as-a-service platform that offers device synchronization, authentication services, and real-time database capabilities—all crucial components for contemporary Internet of Things applications. Firebase has been effectively incorporated into real-time communication platforms, asset tracking, smart home systems, and agricultural monitoring in earlier research. It is very useful for IoT systems that need instant data consistency because of its real-time database, which enables instantaneous reflection of data changes across all connected clients. Furthermore, Firebase makes it easier to integrate with microcontrollers and front-end interfaces by supporting REST APIs and mobile/web SDKs. Firebase is essential to this project because it manages user information, rental history, bicycle availability, and synchronization between the web interface and hardware (ESP8266 + Arduino), allowing for a responsive and seamless user experience.

III SYSTEM WORK FLOW

Using their institutional email address, students register through the web application to start the rental process. System security and identity verification are guaranteed by this step. The signup and login processes are handled by Firebase Authentication, guaranteeing safe and easy user management. Users can view available cycles and rental history on the dashboard after successfully registering.

The user chooses their preferred cycle stand from a dropdown list or map on the interface after logging in. Bicycle availability at the chosen stand is checked in real time by querying Firebase.

The application issues a command to Firebase after the user confirms the request. This command is retrieved from the Firebase real-time database by the ESP8266 module that is connected to the cycle stand. After that, it instructs the Arduino to use a motor to activate the unlocking mechanism. At this point, the RFID reader determines whether the chosen bicycle has a valid RFID tag attached to it. The lock is released and the cycle is made usable if the tag and the database record match. The Firebase bicycle status is updated by the system to "In Use."

The student can now ride their bike anywhere on campus. The rental is still in effect during this period, and the bike's Firebase database status is still "In Use." Ongoing rental time or other trip-related information may be optionally displayed on the web interface.

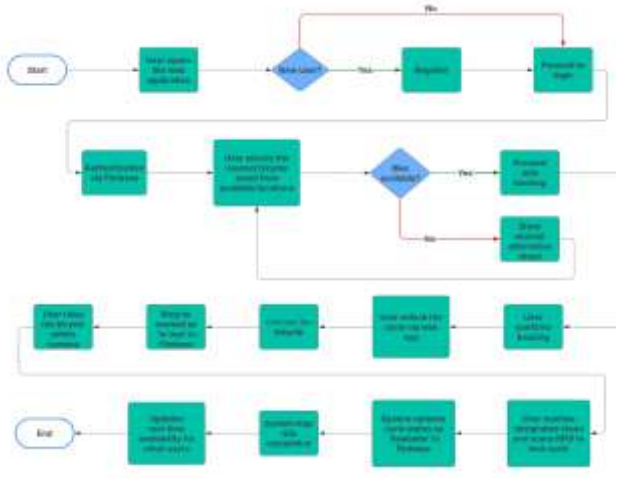

fig 1 : System Flow Diagram

The student is required to park the bicycle at any designated return stand after finishing the ride. The system recognizes the bike's tag as it approaches the stand's RFID reader. The Arduino initiates the locking mechanism to secure the bicycle after the ESP8266 notifies Firebase that the item has been returned. The rental cycle is completed when the database is updated to reflect the bicycle as "Available" once more.

IV. HARDWARE DESIGN

A.RFID System

An essential part of automating the locking and unlocking of bicycles is the RFID system. Every bicycle has a unique RFID tag that the EM18 RFID reader at the stand scans. Operating at 125 kHz, the EM18 can identify RFID tags up to 5 to 10 cm away. This short-range capability reduces unwanted access and guarantees accurate identification. The contactless and smooth tag-reader interaction offers a quick and safe way to validate a bicycle.

B. ESP8266

An essential component of wireless communication between the Firebase database and the hardware layer is the ESP8266 Wi-Fi module. It makes use of REST APIs to retrieve and transmit data while connecting to the campus Wi-Fi network. When the ESP8266 receives a rental request, it asks Firebase for the most recent command and handles it appropriately. When a bicycle is returned, it also adds new status values to the database, guaranteeing that user actions and system records are synchronized in real time.

Fig 2 : Locking Mechanism

C.Arduino Uno

The Arduino Uno serves as the mechanical operations' local control unit. It receives commands directly from the ESP8266 and uses the stepper motor to carry out the appropriate actions. The Arduino works with the RFID module to verify the bicycle ID when a user instructs it to unlock or lock the bike. The Arduino then powers the motor to carry out the physical action. Additionally, it makes sure that, in accordance with RFID confirmation, the locking mechanism is correctly engaged or disengaged.

D.Stepper Motor

The mechanical lock that holds the bicycle in place at the stand is operated by the stepper motor. It is incorporated into the stand structure and rotates in predetermined steps under precise Arduino control. The motor releases the bicycle by disengaging the lock in response to an unlock command. After the RFID tag is verified, it re-engages the lock during the return phase. For dependable operation in a variety of environmental conditions, the stepper motor guarantees precise, repeatable movements.

V. SOFTWAR IMPLEMENTATION

A. Web Application

React.js, a well-liked JavaScript library for creating dynamic and responsive user interfaces, is used to create the front-end interface of the smart campus bicycle rental system. Even people with little technical expertise can easily navigate the system thanks to the web application's smooth and user-friendly interface.

Key Features:

User Authentication: Users can safely register and log in with their institutional email addresses thanks to integration with Firebase Authentication. To protect data privacy and guarantee that only authorized users can access the system, session handling and access control are put into place.

Dashboard Interface: After logging in, users are taken to a customized dashboard that shows their ride status, rental history, and options for renting or returning a bicycle.

Selecting a Stand and Bicycle: The interface displays a list or map of every bike stand on campus, along with real-time availability indicators for each stand. With just one click, users *can select a location and an available bicycle.*

Rental Status Tracking: The user interface shows the bicycle's status, such as "In Use," "Available," or "Pending Return," while the rental is in effect. Future improvements might include optional features like a live timer or an estimated of cost.

Fig 3 : Working Cycle Stand Lock

Mobile Compatibility: The React web application is compatible with desktops, tablets, and smartphones thanks to its responsive layouts.

B. Backend Server

Node.js and the Express.js framework power the backend system, acting as a lightweight and effective server to manage HTTP requests and facilitate communication between the Firebase database and the front-end.

fig 4 : Cycle Stand with locking System

Firebase is the main cloud platform in charge of authentication, real-time communication, and data storage. It keeps important data like session history, bicycle availability, RFID mappings, user credentials, and rental statuses. The ESP8266 module on the hardware side and the frontend interface can react quickly thanks to Firebase's Realtime Database, which makes sure that updates are immediately reflected across all connected clients and devices. Additionally, Firebase Authentication uses email and password authentication techniques to manage user logins in a secure and scalable manner. Low-latency performance and reliable cloud connectivity are guaranteed by this Firebase integration, which is crucial for an IoT-based system to function in real-time.

VI. IMPORTANT FEATURES

The suggested smart campus bike rental system has a number of cutting-edge features that improve system scalability, operational effectiveness, and user convenience. Contactless rentals, made possible by the incorporation of RFID technology, are one of the main features. By eliminating the need for manual intervention or physical contact, users can authenticate themselves and access bicycles, promoting hygiene, lowering surface transmission, and conforming to contemporary smart infrastructure standards.

Real-time status synchronization, made possible by Firebase's Realtime Database, is another noteworthy feature. When a bicycle is rented, returned, or undergoes a status change, this guarantees that all connected clients—whether they be web application users or embedded devices like ESP8266 modules—are updated at the same time. This feature guarantees accurate, consistent system behavior, reduces confusion, and avoids double bookings.

Bicycles can be picked up from one place and returned to any other registered stand on campus thanks to the system's support for a multi-stand configuration. Because users are not limited to returning the bicycle to the original location of rental, this flexibility enhances overall usability and promotes frequent usage. In a more portable and campus-friendly format, such a system more closely resembles urban bike-sharing networks.

Finally, the system is designed to be modular. An RFID reader, ESP8266, Arduino, and motor mechanism are among the hardware components that operate separately and are not dependent on a single physical controller. Scalability is guaranteed by this decentralization, which makes it simple to add or remove stations as needed without requiring significant system changes. Campuses of different sizes can use this plug-and-play hardware model.

VII. TESTING AND EVALUATION

Extensive testing was done in both functional and real-world scenarios to guarantee the smart bicycle rental system's dependability, usability, and performance. Validating the entire rental process—from user login to unlocking and returning a bicycle—under various network conditions was the main goal of functional testing. To test the system's resilience, various Wi-Fi signal intensities and server response times were applied. The system successfully maintained operational stability in every tested scenario, handling hardware responses and user requests with accuracy and without experiencing any major malfunctions.

In order to replicate actual usage conditions, user testing was carried out by recruiting campus student volunteers in addition to technical validation. Using the web interface and RFID-enabled stands, participants were asked to register, rent, and return bicycles short surveys were used to get their input, with a focus on overall satisfaction, responsiveness of the interface, and ease of use. Most users said that the rental process went smoothly, with little waiting time and clear instructions all along the way, and that the application was easy to use.

Both test phase observations were encouraging. Even with moderate network fluctuations, the lock/unlock mechanism's average latency was consistently measured at less than two seconds. Any update, like a change in the status of a bicycle, was reflected almost instantly across the hardware modules and user interface thanks to Firebase's real-time synchronization capabilities. These results verify that the system's accuracy, responsiveness, and user experience all meet its design objectives.

VIII. CHALLENGES ENCOUNTERED

Performance, usability, and reliability were all impacted by a number of real-world issues that were discovered during the creation and implementation of the smart bicycle rental system. Wi-Fi dependability was one of the main problems. A steady and reliable internet connection is necessary for the ESP8266 module, which acts as the main communication interface with Firebase, to operate as intended. Rental operations were either delayed or unsuccessful as a result of the module's inability to receive commands or push updates during brief network outages or in areas with weak signal strength. This made it clear that in order to increase system resilience in practical situations, backup options like offline operation modes or local data caching must be included.

RFID sensitivity presented another major obstacle. The EM-18 RFID reader has a narrow operating range of about 5 to 10 cm, and environmental variables like humidity, temperature, and electromagnetic interference can affect how well it works. Occasionally, these circumstances resulted in missed scans or delayed tag recognition, particularly when tags were exposed to metallic surfaces or improperly aligned. System reliability may be increased by integrating visual or

audio feedback for successful scans and improving the tag-reader interaction zone.

Durability of the hardware was another issue, particularly because the bicycle stands and related electronics are supposed to be used outdoors. The RFID reader, stepper motor, and exposed circuitry were at risk from exposure to rain, dust, and temperature changes. Over time, the components displayed wear and instability due to inadequate weatherproofing. To guarantee long-term durability and reduce maintenance in campus conditions, future iterations of the system will need sturdy enclosures, protective sealing, and perhaps industrial-grade components.

IX Result and Discussion

The campus bicycle rental system was tested on university grounds in real-time. To validate the fundamental features including user registration, bicycle availability check, unlocking and locking mechanisms, real-time database synchronising, and multi-stand returns, several test cases were carried out. With a 98% success rate in tag detection inside the designated range of 5–10 cm, the RFID-based authentication system proved to be rather dependable.

Students who used the web application claimed a good experience with regard to the simplicity of navigation and clarity of instructions. The dashboard could show correct information on the availability of bicycles among stands. The system was shown to be responsive by completing rental initiation and return procedures in under ten seconds on average. The minor 1–2 second delays in database update propagation fell within reasonable limits and had no effect on usability.

Under repeated cycles of operation, hardware components including the EM18 RFID reader, Arduino Uno, ESP8266, and stepper motor operated in concert. Over 500 lock/unlock cycles without mechanical failure, stress testing found the mechanical locking system with the stepper motor to be dependable. Validating its fit for constant IoT communication, the ESP8266 regularly maintained its link to the Firebase database and campus Wi-Fi network.

Scalability and Future Scope

The system can be expanded to more stands or integrated with other campus smart infrastructure thanks to the hardware and cloud backend's modular design. Potential improvements in the future could include:

a) Integration of mobile apps for rentals

b) GPS-based bicycle tracking to keep an eye on activity and stop abuse

c) Support for Digital Payments for Profitable Rentals

d) Admin Dashboard for scheduling maintenance and system-wide analytics

ACKNOWLEDGMENT

The suggested Smart Campus Bicycle Rental System successfully illustrates how web technologies and embedded systems can work together to offer a practical, safe, and automated means of transportation on college campuses. Through the integration of an RFID-enabled hardware layer managed by Arduino and ESP8266, and a React.js-based web application with real-time Firebase database support, the system provides a comprehensive end-to-end rental experience that is frictionless and easy to use.

With real-time tracking and RFID-based authentication, this system not only makes renting and returning bicycles easier, but it also improves safety and accountability. It is appropriate for a range of campus sizes and user volumes due to its modular design, which guarantees simplicity of maintenance, scalability, and adaptability. In keeping with contemporary demands for mobility solutions, the versatility of enabling users to retrieve a bicycle from one stand and return it to another enhances overall convenience.

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