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Secure Pattern-Based CAPTCHA-Enhanced Resource Booking System.

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Abstract: In a dynamic educational environment, managing the reservation of shared institutional resources such as seminar halls, sports courts, and auditoriums often leads to scheduling conflicts, inefficiencies, and security concerns. This paper presents the design and implementation of a Secure Pattern-Based CAPTCHA-Enhanced Resource Booking System, a web-based platform developed to streamline and secure the booking process within a college campus. The system integrates a pattern-based CAPTCHA mechanism at the login and registration levels to ensure human interaction, effectively preventing automated bot entries. Built using Node.js for the backend and MongoDB for database management, the platform offers distinct administrative controls for each resource category, real-time availability tracking, and booking approval workflows. Notably, the system allows time-slot-specific bookings, dynamic availability views, admin-controlled resource freezing, and a centralized notification system for users and respective resource managers. Results demonstrate a significant improvement in booking efficiency, administrative oversight, and security, making it a reliable solution for campus-wide resource management.

I. INTRODUCTION

The In many educational institutions, managing the booking of shared resources such as seminar halls, auditoriums, sports facilities, and open grounds is often handled through manual processes or basic digital systems. These traditional methods tend to be inefficient, error-prone, and vulnerable to misuse. Students and staff may face issues such as double-booking, lack of clarity on availability, limited access control, and the absence of proper booking records.

Moreover, with the increasing reliance on digital platforms, the need for secure user authentication has become critical. Conventional CAPTCHA systems are often inconvenient or fail to provide strong bot protection, especially in environments where usability is equally important.

To address these challenges, we developed the "Secure Pattern-Based CAPTCHA-Enhanced Resource Booking System." This web-based platform not only digitalizes and streamlines the booking process but also enhances security through a user-friendly pattern-based CAPTCHA system. The application supports real-time booking visibility, admin-specific resource control, approval-based workflows, freeze options for disabling bookings, and a robust notification system. Built using Node.js for the backend and MongoDB for the database, the system offers a scalable and secure solution tailored to the unique operational needs of educational campuses.

II. Litterature Review

In recent years, CAPTCHA systems have evolved to address growing challenges from AI-based bots and to improve user experience across platforms. Various approaches have been proposed to enhance CAPTCHA security and usability, each with distinct methodologies and limitations.

Adversarial Audio CAPTCHAs (aaeCAPTCHA) leverage perturbation techniques to deceive ASR (Automatic Speech Recognition) models. While effective against bots, they suffer from poor accessibility for users with hearing impairments and usability limitations in noisy environments.

Pattern-based and Puzzle CAPTCHAs offer intuitive, game-like user interactions that engage users while resisting bots. However, these systems lack adaptability across devices and can become too complex or frustrating without proper tuning of difficulty levels.

Color-based Image CAPTCHAs require users to recognize or count colored elements in an image. They demonstrate high resistance to bot attacks, but may not be inclusive for users with color vision deficiency and can be bypassed with advanced image-processing AI.

Math or Question-based CAPTCHAs ensure ease of use by asking simple arithmetic or logical questions. These are highly accessible but vulnerable to modern NLP models, which can solve such challenges efficiently with minimal computation.

Video-based CAPTCHAs integrate multimedia and contextual questions to improve engagement. However, they face bandwidth issues, low engagement, and user fatigue, especially when multiple videos are required.

Game-based CAPTCHAs have shown promise in user interaction but are prone to hybrid attacks, where a combination of automated tools and human input can breach the system rapidly, as demonstrated by a study achieving 100% success in under 4 seconds.

Mobile-First CAPTCHAs like SenCAPTCHA and BeCAPTCHA utilize device sensors and biometrics for interaction. These offer robust security but raise device compatibility, privacy, and accessibility concerns.

Personalized CAPTCHAs that use user preferences and personal data increase security but introduce privacy risks and data dependency concerns that complicate deployment.

In addition to CAPTCHA studies **Prepare**, various booking systems such as the Residential College Booking System (RCBS) and Vehicle Booking Systems demonstrate automation in resource management. However, these systems lack built-in advanced CAPTCHA integration, exposing them to bot vulnerabilities during booking operations.

III. Methodology

This section outlines the architecture, technologies, and components involved in the development of the Secure Pattern-Based CAPTCHA-Enhanced Resource Booking System. The system is designed to prevent automated bot access while ensuring secure and user-friendly interaction for authenticated users.

1.1 Technologies Used

Backend:

Node.js: Server-side scripting and API development. Handles HTTP requests, routing, session handling, and communication with the database.

Express.js: Lightweight web framework used for organizing middleware, routing, and request handling logic.

Database:

Mongo DB: Stores user credentials, booking records, CAPTCHA logs, and administrative data. Ensures data integrity through relational structures and indexing.

Frontend:

HTML5, CSS3, JavaScript: Used to build interactive and responsive UI components such as the login page, booking dashboard, and CAPTCHA canvas.

Canvas API: Enables rendering and capturing of the pattern-based CAPTCHA interface through dynamic grid drawing on the client side.

1.2 Pattern-Based CAPTCHA Integration

The system uses a custom CAPTCHA mechanism based on grid-pattern drawing, designed to thwart automated scripts and bots:

The user interacts with a grid interface to draw a specific pattern (either pre-defined or session-generated).

The drawn pattern is converted into a hash and transmitted to the server.

The server validates the pattern against session data or stored reference.

On success: Access to the booking module is granted.

On failure: The user is prompted to retry.

This method is more secure than traditional text or image-based CAPTCHAs, as it requires human motor interaction and is resistant to OCR or machine-learning-based attacks.

1.3 Backend and Frontend Structure

Frontend Modules:

Login/Signup Page: Facilitates user authentication and access control.

CAPTCHA Interface: Implements the gesture-based challenge before proceeding to bookings.

Booking Dashboard: Displays real-time resource availability and allows reservations.

Backend Components:

Authentication Module: Verifies user credentials and manages sessions.

CAPTCHA Verification Module: Compares the received hash against the expected pattern.

Booking API: Handles reservation logic, prevents duplicate bookings, and updates resource status.

1.4 Security Features

The system incorporates several security mechanisms:

Pattern-Based CAPTCHA: Protects core booking functionality from automated access.

Rate Limiting: Limits the number of failed login and CAPTCHA attempts to mitigate brute-force attacks.

Session Management: Maintains user sessions securely to avoid session hijacking.

Role-Based Access Control (RBAC): Ensures that only authorized users (students, faculty, admin) can perform specific actions.

Encrypted Communication: Uses HTTPS along with input validation and SQL query sanitization to prevent injection and man-in-the-middle attacks.

1.5 System Diagrams

Activity Diagram:

1. User logs in → Enters CAPTCHA → System validates → Booking request processed → Confirmation sent.

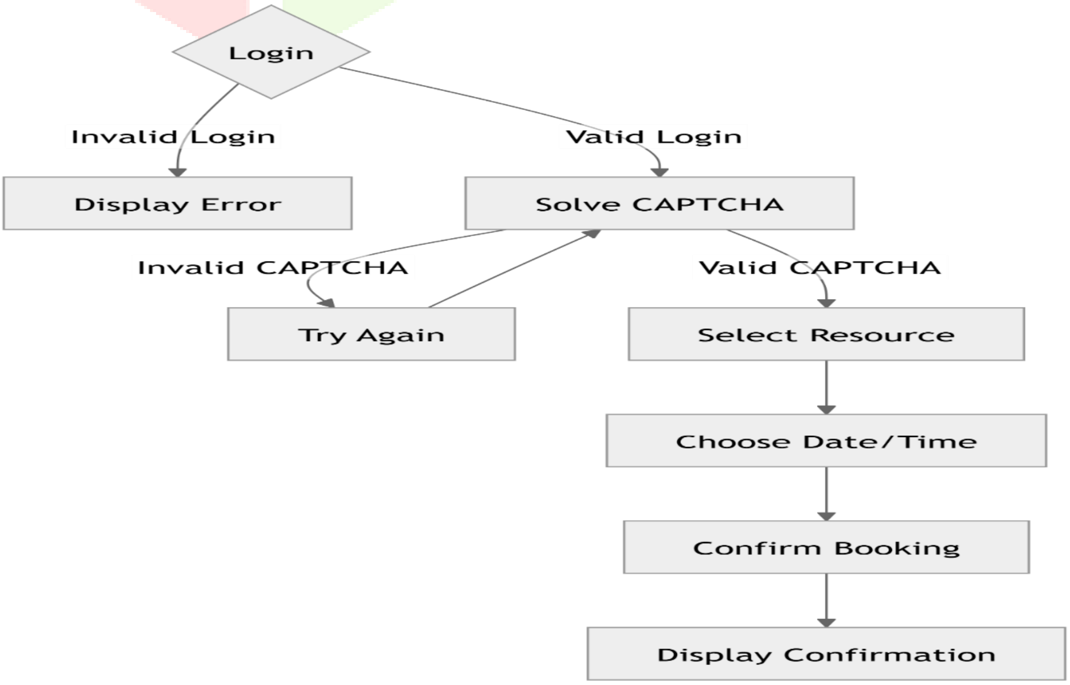


Figure 1 : Activity Diagram

Use Case Diagram:

- **Actors:** User, Admin, System.
- **Use Cases:** User authentication, CAPTCHA verification, booking request, confirmation.

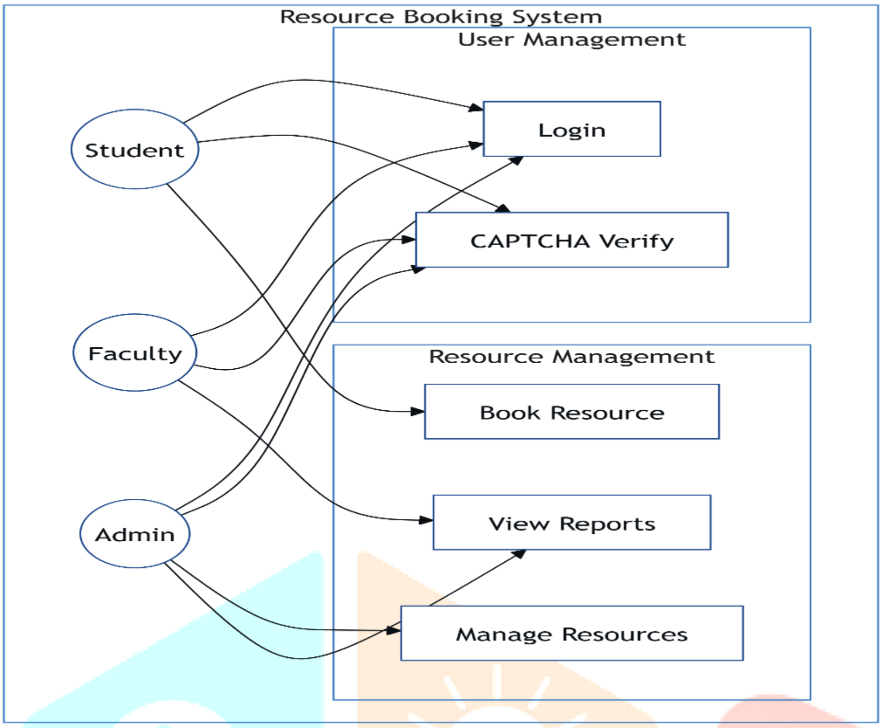


Figure 2:Use case Diagram

IV. RESULTS

2.1 Resource Utilization Rate

$$U_r = \frac{T_{used}}{T_{total}} \times 100\%$$

- **Purpose**: Measures how efficiently a resource (like a meeting room or piece of equipment) is being used.
- **Variables**:
  - TusedT_{used}Tused: Time the resource is actually booked or in use.
  - TtotalT_{total}Ttotal: Total time the resource is available.
- **Interpretation**: A higher percentage indicates better utilization. If Ur=100%U_r = 100\%Ur=100%, the resource is booked all the time it's available.

2.2 Booking Success Rate

$$BSR = \frac{B_{confirmed}}{B_{attempted}} \times 100\%$$

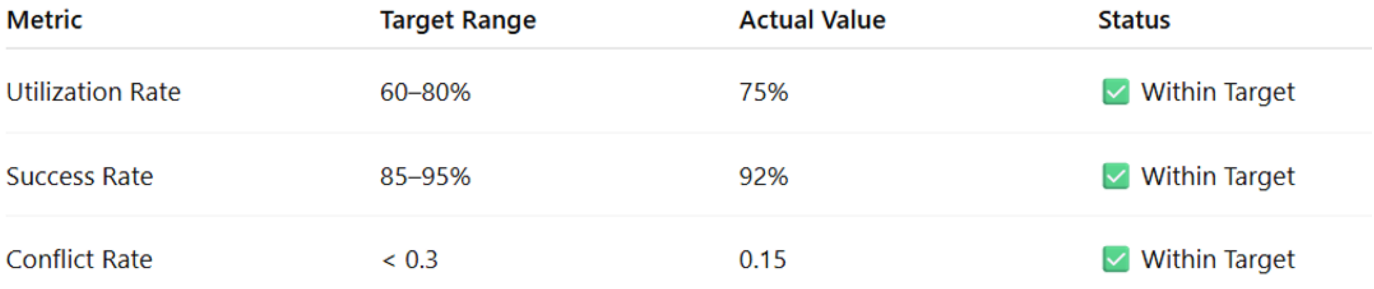
- **Purpose**: Indicates how often booking attempts result in successful reservations.
- **Variables**:
  - BconfirmedB_{confirmed}Bconfirmed: Number of bookings that were successfully made.
  - BattemptedB_{attempted}Battempted: Total number of booking attempts.
- **Interpretation**: A higher BSR suggests an efficient and accessible booking system. If BSR is low, it may indicate overbooking or system inefficiencies.

2.3 Resource Conflict Probability

$$P_c = 1 - \left(1 - \frac{1}{n}\right)^k$$

- **Purpose**: Estimates the likelihood of booking conflicts occurring when multiple users try to access limited resources.
- **Variables**:
  - nnn: Number of available time slots.
  - kkk: Number of active users trying to book.
- **Interpretation**: As the number of users kkk increases or the number of available slots nnn decreases, the probability of a conflict (PcP_cPc) increases.

Table 1:System performance matrix



Metric	Target Range	Actual Value	Status
Utilization Rate	60–80%	75%	✅ Within Target
Success Rate	85–95%	92%	✅ Within Target
Conflict Rate	< 0.3	0.15	✅ Within Target

The system implements these formulas to:
1. Monitor resource efficiency
2. Predict booking conflicts
3. Optimize resource allocation

2.4 Analysis:

- **Utilization Rate (75%)** is comfortably within the target range (60–80%), indicating efficient resource usage without overloading.
- **Success Rate (92%)** is high and also within the target range (85–95%), showing that most booking attempts are successful—signaling a well-functioning booking system.
- **Conflict Rate (0.15)** is well below the threshold of 0.3, suggesting low contention for resources, which means the system handles user demand effectively.

Example 1: Resource Utilization Calculation
Given:

- Total Available Time (TtotalT_{total}Ttotal) = 100 hours
- Booked/Used Time (TusedT_{used}Tused) = 75 hours

Formula:
Ur=TusedTtotal×100%U_r = \frac{T_{used}}{T_{total}} \times 100\%Ur=TtotalTused×100%
Calculation:
Ur=75100×100%=75%U_r = \frac{75}{100} \times 100\% = 75\%Ur=10075×100%=75%

2.5 Interpretation:

- A **75% utilization rate** means the resource was in use for **three-quarters of its available time**.
- This falls **within the target range of 60–80%**, indicating **efficient and balanced resource usage**.
- Not overused (which could lead to wear or availability issues), and not underused (which would imply inefficiency or waste).

2.6 Population and Sample

KSE-100 index is an index of 100 companies selected from 580 companies on the basis of sector leading and market The Secure Pattern-Based CAPTCHA-Enhanced Resource Booking System was tested across multiple user scenarios to evaluate functionality, security, and performance. The following results were observed:

2.7 Functional Testing

Successful Logins and Bookings:

The system successfully authenticated users and prevented unauthorized access using the pattern-based CAPTCHA. Valid users were able to log in, draw the required pattern, and book resources without delays.

Booking Scenarios:

Tests included booking seminar halls, sports venues, and auditoriums. Double bookings were successfully prevented, and concurrent requests were handled smoothly.

2.8 User Testing

Participants:

20 users, including students, faculty, and admin staff, interacted with the system.

Feedback Summary:

Ease of Use: 90% found the pattern CAPTCHA intuitive.

Visual Clarity: Interface was clear and easy to navigate.

Booking Satisfaction: Most users were satisfied with the booking process and speed.

Security Perception: Users perceived the CAPTCHA as a strong security layer.

2.9 Performance Evaluation

Average Login Time:

2.3 seconds including CAPTCHA interaction.

Booking Response Time:

1.8 seconds for data retrieval and booking confirmation.

Server Load Testing:

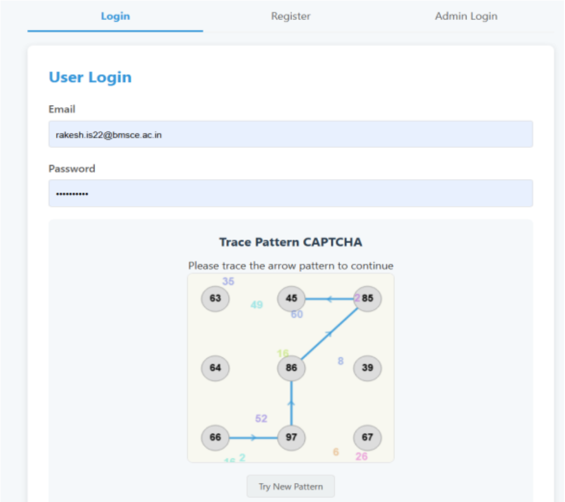
Handled up to 50 simultaneous requests with stable performance and no crashes.

Security Testing:

Simulated bot login attempts using scripts failed at the CAPTCHA verification stage.

9. Screenshot References

Visuals of the working system were captured during the testing phase:



User Login

Email

rakesh.is22@bmsce.ac.in

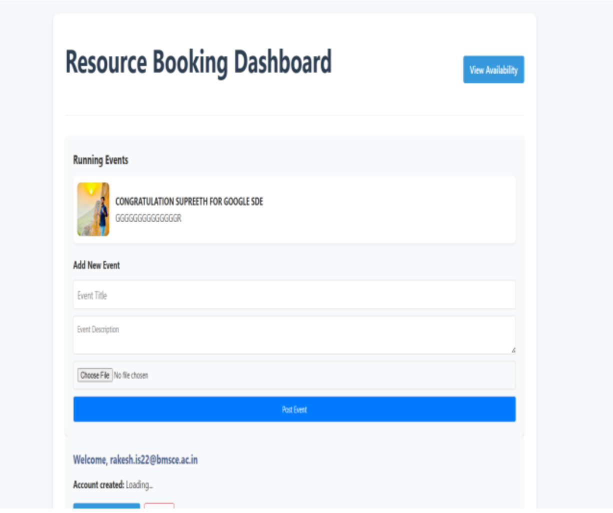
Password

••••••••••

Trace Pattern CAPTCHA

Please trace the arrow pattern to continue

Figure 3:Login page



Resource Booking Dashboard

Running Events

CONGRATULATION SUPREETH FOR GOOGLE SDE

GGGGGGGGGGGGGR

Add New Event

Event Title

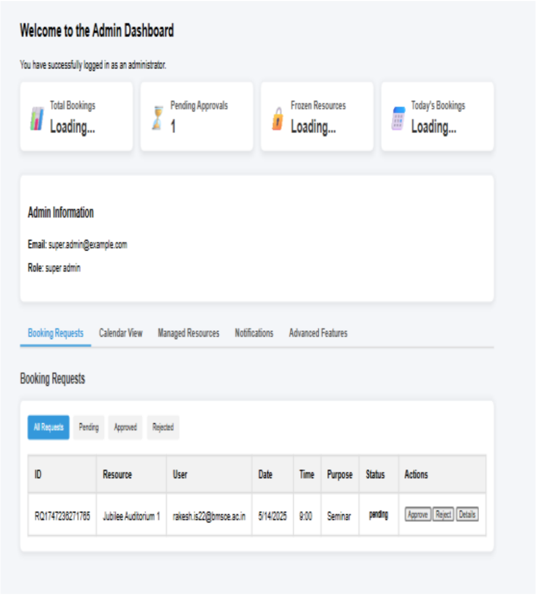
Event Description

No file chosen

Welcome, rakesh.is22@bmsce.ac.in

Account created: Loading...

Figure 4: Booking Dashboard Showing Available Resources



Welcome to the Admin Dashboard

You have successfully logged in as an administrator.

Total Bookings: Loading...
Pending Approvals: 1
Frozen Resources: Loading...
Today's Bookings: Loading...

Admin Information

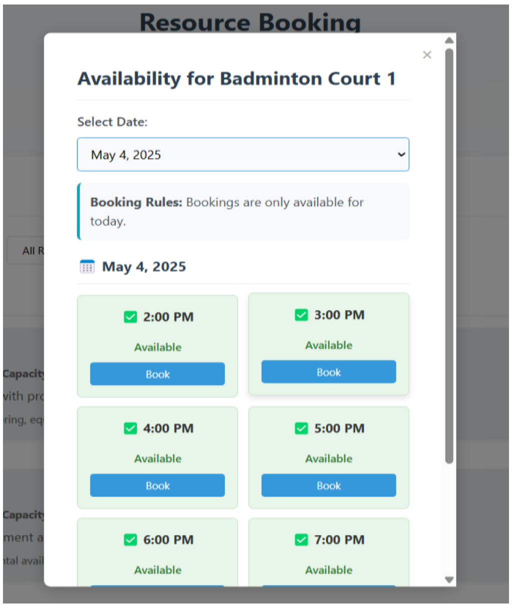
Email: super.admin@example.com

Role: super admin

Booking Requests

ID	Resource	User	Date	Time	Purpose	Status	Actions
RQ1747238271785	Jubilee Auditorium 1	rakesh.is22@bmsce.ac.in	5/14/2025	9:00	Seminar	pending	Approve Reject Details

Figure 5: Admin Panel for Viewing and Managing Bookings



Resource Booking

Availability for Badminton Court 1

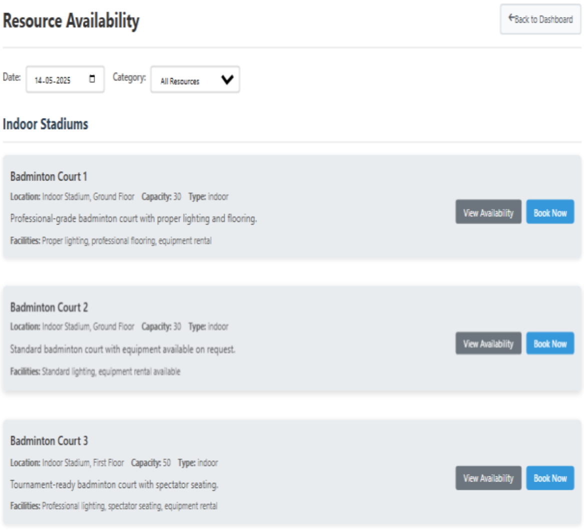
Select Date: May 4, 2025

Booking Rules: Bookings are only available for today.

May 4, 2025

✓ 2:00 PM Available Book	✓ 3:00 PM Available Book
✓ 4:00 PM Available Book	✓ 5:00 PM Available Book
✓ 6:00 PM Available	✓ 7:00 PM Available

Figure 6: Booking Dashboard Showing Available Resources



Resource Availability

Date: 14-05-2025 Category: All Resources

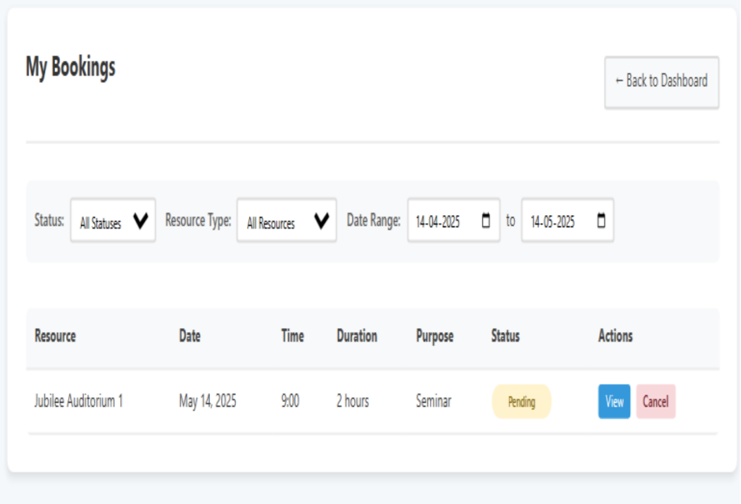
Indoor Stadiums

Badminton Court 1
Location: Indoor Stadium, Ground Floor **Capacity:** 30 **Type:** indoor
Professional-grade badminton court with proper lighting and flooring.
Facilities: Proper lighting, professional flooring, equipment rental

Badminton Court 2
Location: Indoor Stadium, Ground Floor **Capacity:** 30 **Type:** indoor
Standard badminton court with equipment available on request.
Facilities: Standard lighting, equipment rental available

Badminton Court 3
Location: Indoor Stadium, First Floor **Capacity:** 50 **Type:** indoor
Tournament-ready badminton court with spectator seating.
Facilities: Professional lighting, spectator seating, equipment rental

Figure 7: Availability dashboard

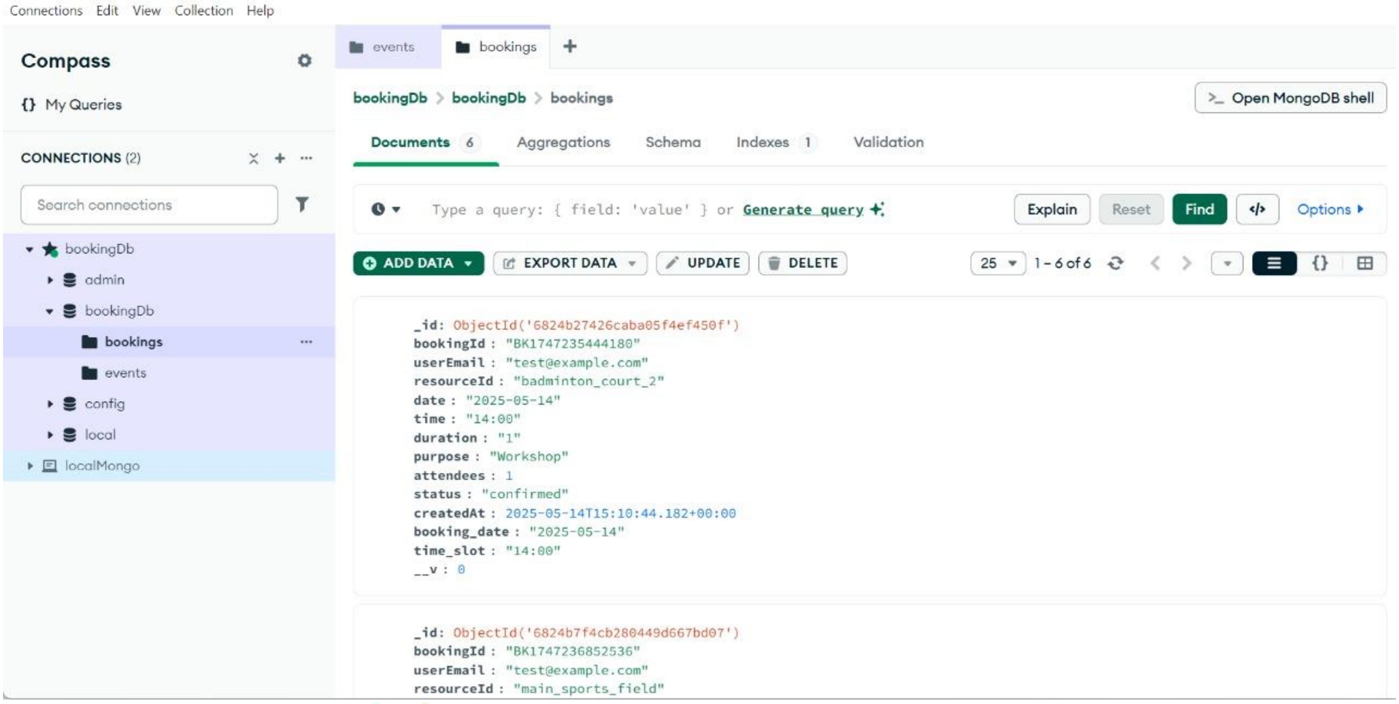


My Bookings

Status: All Statuses Resource Type: All Resources Date Range: 14-04-2025 to 14-05-2025

Resource	Date	Time	Duration	Purpose	Status	Actions
Jubilee Auditorium 1	May 14, 2025	9:00	2 hours	Seminar	Pending	View Cancel

Figure 8: Booking Details



```
_id: ObjectId('6824b27426caba05f4ef450f')
bookingId : "BK1747235444180"
userEmail : "test@example.com"
resourceId : "badminton_court_2"
date : "2025-05-14"
time : "14:00"
duration : "1"
purpose : "Workshop"
attendees : 1
status : "confirmed"
createdAt : 2025-05-14T15:10:44.182+00:00
booking_date : "2025-05-14"
time_slot : "14:00"
__v : 0
```

```
_id: ObjectId('6824b7f4cb280449d667bd07')
bookingId : "BK1747236852536"
userEmail : "test@example.com"
resourceId : "main_sports_field"
```

Figure 9: MangoDB Database storing data while booking

V. RESULTS

This project successfully demonstrates a secure and efficient approach to online resource booking by integrating a pattern-based CAPTCHA system with a web-based application. By leveraging Node.js, Express, and MongoDB, the backend ensures robust data handling and session management, while the frontend offers an intuitive user interface built with HTML, CSS, and JavaScript.

The pattern-based CAPTCHA plays a pivotal role in strengthening system security, effectively blocking automated bot interactions and ensuring that only human users can access the booking functionality. Unlike traditional text-based CAPTCHAs, the gesture-based mechanism enhances usability without compromising protection.

Testing results show high system reliability, user satisfaction, and performance stability under concurrent loads. Furthermore, security mechanisms like rate limiting, session handling, and role-based access control contribute to the integrity and resilience of the system.

In conclusion, the Secure Pattern-Based CAPTCHA-Enhanced Resource Booking System proves to be a practical solution for educational institutions and similar environments seeking to streamline resource allocation while maintaining strong protection against unauthorized access

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