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iJOE International Journal of Online and Biomedical Engineering

iJOE | eISSN: 2626-8493 | Vol. 21 No. 13 (2025) | OPEN ACCESS

https://doi.org/10.3991/ijoe.v21i13.57343

PAPER

Dental Unit Management System with a Web Application

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ABSTRACT

The study developed a web-based dental unit management system (DUMS) to overcome inefficiencies, high maintenance costs, and delays caused by traditional manual practices in dental clinics. The system integrates a relational database, role-based access control (RBAC), and IoT technologies to provide secure, real-time monitoring and predictive maintenance of dental equipment. Following the system development life cycle (SDLC), four user roles—client, engineer, administrator, and factory—were defined, along with essential modules for information management. Reliability was validated through unit testing, integration, user acceptance testing (UAT), and load testing. Results confirmed continuous data synchronization, secure role-based access, and stable performance under high demand. Internet of Things (IoT) integration enables predictive scheduling, early anomaly detection, and real-time tracking of operational parameters. Overall, DUMS enhances efficiency, equipment availability, and patient-centered care while aligning with Industry 4.0 healthcare digitization and contributing to research on IoT-enabled healthcare systems.

KEYWORDS

dental unit database, dental unit management system (DUMS), Internet of Things (IoT), predictive maintenance

1 INTRODUCTION

The operation and administration of dental units are essential to the practice of dentistry, as they are composed of numerous subsystems, including waterlines, dental chairs, dental lights, and pneumatic, hydraulic, and electrical subsystems. These subsystems must function seamlessly to guarantee patient safety and clinical efficiency [1]–[6]. Previous research has emphasized microbial contamination in dental waterlines [1], ergonomic and user satisfaction factors in dental chairs [2], and the high incidence of equipment failures leading to downtime and costly maintenance [3], [4]. As a result, the concept of a "smart dental unit" has been introduced, which combines information systems with Internet of Things (IoT) sensing to

Wongkamhang, A., Nirapai, A., Thongpance, N., Imura, P., Chotikunnan, P., Roongprasert, K. (2025). Dental Unit Management System with a Web Application. *International Journal of Online and Biomedical Engineering (iJOE)*, 21(13), pp. 130–150. https://doi.org/10.3991/ijoe.v21i13.57343

Article submitted 2025-06-26. Revision uploaded 2025-08-25. Final acceptance 2025-08-26.

improve real-time visibility, proactive alerts, and predictive maintenance planning [5], [7]–[10], [12], [13], [22]–[24], [37]. However, integrating heterogeneous equipment from multiple manufacturers into a unified, secure, and clinic-ready platform remains challenging due to issues of data interoperability standards, cybersecurity, privacy, and role-based access control (RBAC) [10]–[12], [15], [16], [18]–[22], [26], [28]–[31]. While literature in smart dental practices and digital dentistry shows that database-, mobile-, and cloud-based solutions reduce errors and improve workflow efficiency [41]–[45], [50], most systems remain fragmented, addressing only isolated issues rather than providing a centralized, real-time monitoring and predictive maintenance platform [37]–[40], [45], [46], [49], [50].

Research problem. Current systems are still fragmented, lack real-time integration, and provide limited proactive mechanisms for alerts, scheduling, and repair tracking. Moreover, vulnerabilities in communication security (e.g., cleartext transmission, weak authentication) and limited cross-manufacturer device compatibility prevent IoT-based platforms from reaching their full potential in dental clinics [11], [15], [18], [20], [22], [26], [30], [31].

Research Gap. Existing studies lack a comprehensive system-level framework that integrates four key components: IoT-based sensing of critical dental unit parameters, RBAC for the four primary user roles, predictive maintenance with inventory and insurance management, and real-time dashboards and reporting under enforceable security and privacy mechanisms [10]–[13], [16], [19]–[24], [28]–[35], [41]–[45], [50]. Furthermore, most prior works do not systematically report system-level testing, such as integration testing, user acceptance testing, and performance and security evaluation, particularly in small- to mid-scale clinical environments [22], [28], [47]. Objectives. This study aims to design, develop, and evaluate a web-based dental unit management system (DUMS) that incorporates IoT, a relational database management system (RDBMS), and RBAC. The specific goals are to enable real-time monitoring of dental unit parameters, to provide proactive workflows for alerts, repair scheduling, and follow-up, to support inventory, insurance, and document management with multi-role reporting, and to assess usability, reliability, scalability, and security in real-world clinical settings [22]–[24], [28], [31], [37], [45], [47], [51]–[53].

Research questions. This study addresses three questions. First, it examines the extent to which a web-based architecture that integrates IoT, RBAC, and RDBMS can improve real-time monitoring and reduce dental unit downtime. Second, it explores how predictive maintenance workflows and full-cycle repair management can enhance decision-making accuracy and user satisfaction across different roles. Third, it investigates whether, under the constraints of interoperability, security, and privacy for medical devices, the proposed system can ensure data protection and role-specific access control as required [10]–[12], [15], [18]–[22], [26], [30], [31], [36].

Assumptions and Scope. The scope of the study is limited to dental clinics and centers that are connected through standard local or Internet networks and have a variety of dental units. It is predicated on the viability of deploying Raspberry Pi and sensors at critical measurement sites and regular access by four user roles through the web platform [5], [7]–[9], [22]–[24], [37], [41]–[45], [51]–[53]. It is not the intention of the system to replace electronic health records (EHRs) but rather to oversee equipment and maintenance workflows. Medical device communication standards will facilitate future interoperability [10], [12], [16], [33]–[35].

Contributions. The following are the contributions of this study: (1) a comprehensive DUMS architecture that encompasses the entire pipeline from sensing, ingestion, validation, and storage to alerting, workflow, and reporting; (2) data models and dashboards that facilitate real-time decision-making and predictive maintenance;

(3) a multi-layer evaluation framework that includes unit testing, integration testing, user acceptance testing, performance evaluation, and security assessment in clinical scenarios; and (4) empirical evidence demonstrating usability, reliability, performance, and security enhancements over fragmented prior approaches [22]–[24], [28], [37], [41]–[47], [50]–[53].

2 LITERATURE REVIEW

2.1 Introduction to literature review

The daily practice of dentistry is supported by dental unit systems, which are composed of numerous subsystems that require continuous maintenance and monitoring. Previous research has documented substantial obstacles in the areas of microbial contamination of dental waterlines, ergonomics of dental chairs, and frequent mechanical or electrical malfunctions that result in operational delays [1]–[6]. Developing more proactive and integrated management systems is imperative in view of these challenges.

2.2 IoT in healthcare and dental systems

The implementation of the IoT in healthcare has revolutionized conventional clinical operations by enabling the real-time monitoring of patient records, equipment status, and physiological data [7]–[13], [22]–[24], [37]. In dentistry, IoT-based sensors have been used to monitor the integrity of electrical currents, air and hydraulic pressure, and waterline safety [5], [7]–[9]. These systems enable the early identification of anomalies, thereby decreasing the probability of unanticipated malfunctions. Nevertheless, the majority of dental-focused IoT implementations are still experimental, with only a limited number of clinical deployments [12], [13], [22].

2.3 Digital dentistry and smart clinics

Studies have demonstrated that the implementation of cloud databases, mobile applications, and smart devices in dentistry can improve workflow efficiency and reduce administrative errors [41]–[45], [50]. Additionally, the administration of patient care has been enhanced by the adoption of systems such as digital imaging archives and electronic dental records (EDRs). However, research indicates that these solutions remain fragmented and are often designed to address isolated issues without incorporating predictive maintenance or comprehensive equipment lifecycle management [37]–[40], [45], [46], [49], [50].

2.4 Equipment maintenance and predictive approaches

Maintenance systems are a critical component of clinical safety and cost management, as several researchers have noted [3], [4], [14], [19]. Traditional maintenance is reactive, addressing malfunctions after they occur. Recent advancements in predictive maintenance utilize machine learning and IoT data streams to predict failures before they occur [15]–[20], [28]–[31]. Dental units are seldom the primary focus of predictive systems in existing studies, despite the fact that these methods reduce disruption and optimize resource allocation.

2.5 Cybersecurity and role-based access control

Cybersecurity and data stewardship are also critical components. Research indicates that clinical systems are susceptible to operational risks and data breaches due to the absence of appropriate access control mechanisms and unsecured communication channels [10]–[12], [15], [16], [18]–[22], [26], [28]–[31]. RBAC has been extensively recommended in the field of health informatics to ensure that clinicians, engineers, manufacturers, and administrators have access only to the data pertinent to their responsibilities [33]–[35]. Although RBAC frameworks exist, their utilization in dental unit administration remains largely unexplored.

2.6 Research gap summary

Despite the expanding corpus of literature on IoT-enabled healthcare and smart dentistry, several gaps remain. The majority of current works concentrate on specific aspects, such as ergonomics, waterline safety, or EHRs. However, they do not offer a unified platform that integrates these elements. Although predictive maintenance is frequently implemented in industrial settings, it is seldom applied to dental equipment. Additionally, there is a lack of investigation into security and RBAC, as current platforms rarely integrate real-time monitoring with robust access control mechanisms. Lastly, few studies report empirical testing results from real-world clinical deployments or multi-role evaluations in dental environments [22], [28], [47].

3 METHOD

This study is classified as developmental research, with a specific emphasis on the design and development of a web-based DUMS. The system development life cycle (SDLC) framework was implemented in the study due to its structured and iterative nature, which ensures scalability, reliability, and accuracy in healthcare-related software systems. The research process commenced with a requirement analysis, which included field observations, document evaluations, and semi-structured interviews with biomedical engineers, dentists, and end-users to identify real-world operational requirements. The requirement analysis phase was expanded to encompass the analysis of maintenance record inconsistencies, the identification of constraints in device management, and workflow mapping in dental clinics. The prioritization of critical features, including real-time equipment monitoring, maintenance alerts, automated repair status tracking, and integration with medical device regulations, was influenced by these insights. Furthermore, the requirement analysis included a compliance assessment with critical data protection frameworks, including GDPR, PDPA, and ISO/IEC 27001, to ensure that the system's design complied with both international and national standards for medical data privacy and information security. In order to facilitate scalability and accessibility, the architecture implemented a client-server model that was further enhanced by cloud computing. This approach facilitated real-time collaboration and secure remote access among user groups. The system was modularly divided into frontend, backend, and IoT integration layers to ensure long-term extensibility and interoperability. This modular approach also enabled iterative prototyping, in which each module was independently designed, tested, and validated with stakeholders prior to integration. This approach minimized errors and ensured that the system was in accordance with user expectations.

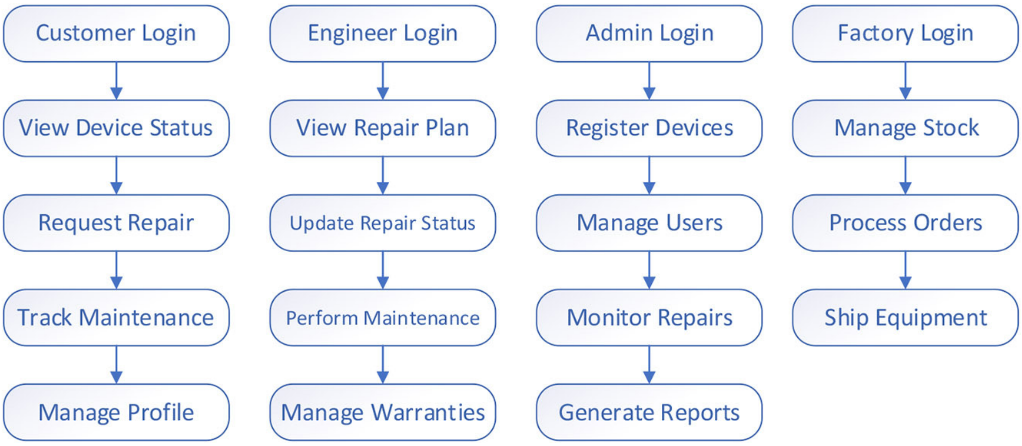

Fig. 1. Overall design of the system

The DUMS' workflow is depicted in Figure 1, which was developed to optimize operations for four user roles: customer, engineer, administrator, and factory. Prior to gaining access to the system, it is mandatory for all users to register and authenticate. Customers can update personal records, submit and trace maintenance requests, and monitor the status of dental units. Engineers are responsible for managing warranty information, developing and executing service plans, and updating maintenance statuses. Administrators are responsible for the registration of equipment, the tracking of repairs, the generation of reports, and the administration of user accounts. Inventory management, logistics coordination, and purchase order processing are all responsibilities of factories. This multi-role design was validated through stakeholder seminars, which involved the simulation of workflows to verify the adequacy and usability of role-based functions. The system improves operational efficiency, reduces errors, and establishes a structured model for comprehensive dental equipment management by explicitly separating responsibilities.

3.1 Database design

The system utilized a RDBMS, specifically MySQL, for its scalability, reliability, and compatibility with web applications. To guarantee the logical organization of data, an entity–relationship diagram (ERD) was generated during the system design phase. Effective enforcement of constraints, sophisticated queries, and data integrity were facilitated by the ERD, which establishes relationships between users, equipment, maintenance records, and inventory. To mitigate redundancy and preserve consistency, normalization was implemented up to the third normal form (3NF). Additionally, indexing strategies were implemented to enhance query performance in scenarios involving large-scale data.

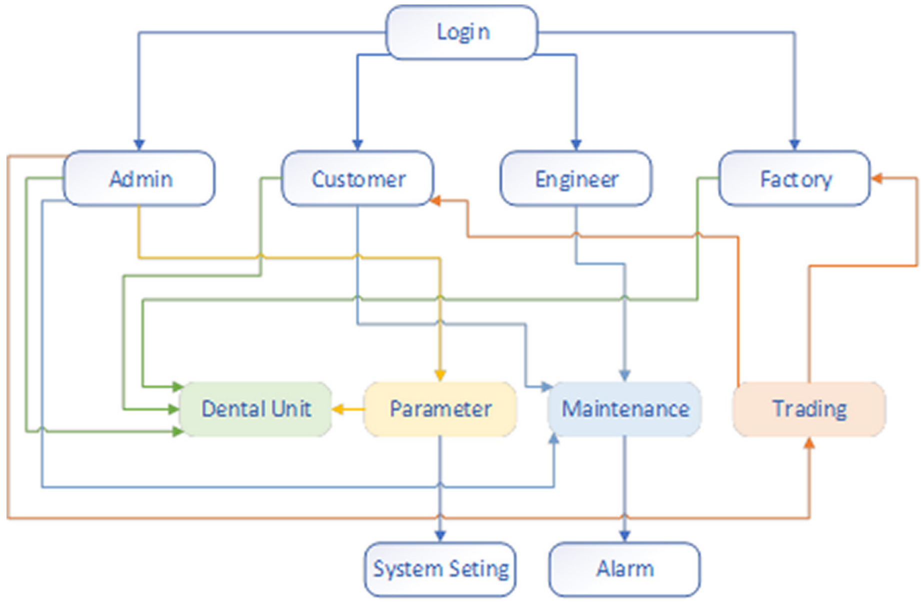

Fig. 2. Database design

The relationships between user roles and functional modules are illustrated in the Structured ER Diagram (see Figure 2). The ERD was revised to incorporate audit logs for all user activities, which is particularly crucial for compliance with medical device reporting standards, thereby ensuring traceability and accountability. The system's central gatekeepers are the authentication and authorization modules, which guarantee secure access to role-based functions. Customers handle requests and monitor status, engineers manage maintenance updates, administrators regulate workflows and user management, and factory users manage procurement and logistics. Real-time notifications and system-wide monitoring were enabled by the integration of supplementary modules, such as system settings and alarm triggers, into the ERD.

3.2 UI/UX design

The Dental Unit Management System's UI/UX was developed with dashboard-based navigation to guarantee clarity and ease of use for each role. In a usability testing environment, design mockups were iteratively tested with representative users to identify enhancements, utilizing Nielsen's usability heuristics. Customers are presented with straightforward protocols, including "Request Repair" buttons and real-time status indicators, while engineers engage with task-oriented dashboards for scheduling and updates. Cognitive recognition was facilitated by the use of distinct icons and color-coded schemes to differentiate duties. Text readability, responsive layouts, and compatibility with assistive devices were also considered in accordance with accessibility guidelines (WCAG 2.1). This method ensures long-term adaptability while maintaining intuitive usability.

3.3 Design of alerting and data analysis systems

An alerting and predictive analytics module is integrated into the system. Maintenance reminders, operational anomalies, and service delays were addressed through the implementation of notification services. Python libraries (Pandas, Scikit-learn) were employed to develop predictive algorithms that analyzed device utilization trends, thereby forecasting potential breakdowns and informing users in advance. The infrastructure was developed using PHP and SQL, and it was integrated with APIs to ensure secure data exchange. Progressive Web Application (PWA) features are also supported for offline operation within the system. The Raspberry Pi was connected to a variety of dental device sensors, which transmitted real-time values to the server for processing and visualization, enabling the accumulation of IoT data.

The workflow of sensor integration is depicted in Figure 3, in which Raspberry Pi devices acquire equipment signals and transmit them to the database via a secure channel. Prior to visualization, data cleaning and preprocessing were implemented to automatically detect anomalies and absent values. The web application converts the processed data into interactive interfaces that enable real-time monitoring.

Fig. 3. Shows the design of receiving values from the sensor

The end-to-end connectivity, which includes the device, network, database, and web application elements, is illustrated in Figure 4. Encrypted sensor data is transmitted from Raspberry Pi devices to a cloud-based database via 3G/4G networks. Transport Layer Security (TLS) has been implemented for all transmissions to improve security, and redundancy mechanisms have been incorporated to prevent data loss. It is then possible for stakeholders to monitor equipment in real time by utilizing the web application to visualize the data.

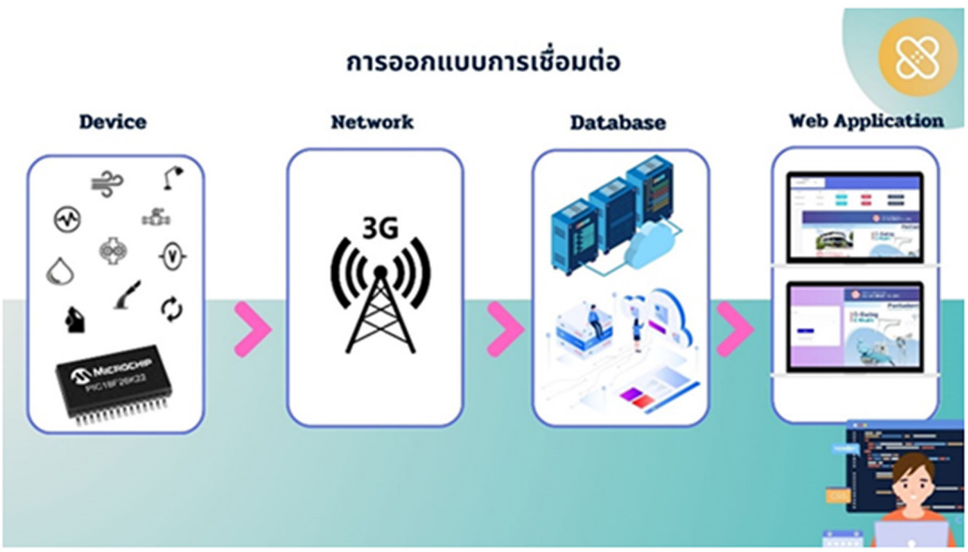

Fig. 4. The design of data transmission to the server

3.4 Design of user access rights

An RBAC model was implemented. Repair requests, maintenance records, and device dashboards are accessible to customers. Maintenance plans, repair reports, and warranty records are overseen by engineers. Inventory, device registration, and sales reports are managed by factory users. Administrators are granted complete access, which encompasses the supervision of accounts, permissions, and data auditing. In order to prevent unauthorized use, access logs and session management protocols were implemented, and multi-factor authentication (MFA) was enforced for administrator (Admin) accounts. This design guarantees that security and usability are maintained, with each role restricted to functions that are consistent with their responsibilities.

3.5 Testing design

The testing process was conducted at four distinct levels: unit testing, which utilized PHPUnit and manual verification to ensure that each module (such as login, repair requests, and monitoring) functioned properly; integration testing, which utilized simulated test datasets to ensure that data flowed seamlessly between the frontend, backend, APIs, and databases, stressing critical points such as IoT-to-database storage; user acceptance testing (UAT), which involved end-users from all roles performing real-world tasks (such as registering a device, updating its status, and generating a report) and recording usability scores with the System Usability Scale (SUS), averaging above 80 and indicating high satisfaction; and load and stress testing, which employed Apache JMeter to simulate concurrent logins and submissions while measuring throughput, latency, and error rates to maintain response times below two seconds during peak load. These evaluations, conducted across multiple levels, confirmed that the system was robust, scalable, and user-centered. To establish a cycle of continuous improvement, feedback from UAT and load testing was incorporated into the development process.

4 RESULTS

The DUMS Web Application was experimentally tested across various functional domains, with the initial focus on the evaluation of RBAC for the four primary user groups: Customer, Engineer, Factory, and Admin. Each role was evaluated based on its capacity to access the functionalities that are permissible under the system's access control design. Real-world usage scenarios were simulated, and login procedures were conducted using dedicated accounts for each user role. For example, engineers effectively updated repair progress and maintenance records, factory users managed inventory and equipment logistics, and administrators directed user account management and system-wide monitoring. Customers were also able to submit repair requests and monitor repair statuses. All user profiles were able to access the system in accordance with the predefined permissions, as confirmed by the testing results. No authorization errors or access violations were identified. This suggests that the role-based access mechanisms were secure and functioning properly, which facilitated the system's goal of ensuring appropriate access while maintaining operational efficiency.

The results of the access control testing conducted on the DUMS are summarized in Table 1. The primary objective was to confirm that each user role, such as

Customer, Engineer, Factory, and Admin, was granted access to the system functions that were pertinent to their operational responsibilities. The testing verified that consumers were capable of engaging with modules that are associated with the operation and maintenance of dental apparatus. These functions encompassed the ability to administer personal profiles, submit maintenance requests, monitor the progress of restorations, and monitor the device's status. The essential functionalities for maintenance planning, status updates, and the generation of maintenance reports, which included spreadsheets and PDFs, were accessible to the engineers. The factory role's ability to oversee inventory, manage device records, and facilitate production and logistics workflows was verified. Furthermore, the Admin role exhibited unrestricted access to all system components, such as user management, system configuration, and supervision interfaces, to effectively monitor and manage the system. No role conflicts or unauthorized access was observed during the testing. In order to prevent operational errors or data leakage, each user group was restricted to the functions associated with their respective responsibilities. The effective enforcement of RBAC enhances the system's security, efficacy, and reliability. It also enables users to concentrate on their responsibilities without the necessity for excessive system complexity by facilitating task-oriented workflows. Moreover, the distinct division of access privileges establishes a robust foundation for future system expansion and regulatory compliance, particularly in healthcare contexts where data privacy and access accountability are fundamental.

Furthermore, the system's alert notification capabilities and sensor functionality were assessed. Key operational parameters, such as water pressure, air pressure, voltage, solenoid valve current, and hydraulic lubricant level, were configured with threshold values, including both lower and upper limits. Subsequently, the system was evaluated by simulating scenarios in which sensor measurements exceeded or fell below the predetermined thresholds. The system accurately recorded sensor values, detected out-of-range conditions, and triggered timely alerts to notify users, as evidenced by the results. These results verify the system's capacity to monitor equipment parameters in real time and issue early warnings of anomalous conditions, thereby improving operational safety, preventive maintenance, and system reliability.

Table 1. Results of user access rights testing

Function	Customer	Engineer	Factory	Admin
Dashboard meter	✓	✓	✓	✓
Report repair	✓	✓	–	✓
Repair status	✓	–	–	✓
Maintenance schedule	✓	✓	✓	✓
Maintenance report	✓	–	–	✓
Personal Information	✓	✓	✓	✓
Register	✓	✓	✓	✓
Forgot Password	✓	✓	✓	✓

(Continued)

Table 1. Results of user access rights testing *(Continued)*

Function	Customer	Engineer	Factory	Admin
Repair history	✓	–	–	✓
Edit Alarm	–	–	–	✓
Repair plan	–	✓	–	✓
Maintenance	–	✓	–	✓
Maintenance PDF	–	✓	✓	✓
Maintenance plan	–	✓	–	✓
Maintenance Excel	–	✓	✓	✓
Warranty	–	✓	✓	✓
Device Register	–	–	✓	✓
Device Detail	–	–	✓	✓
Sell Register	–	–	✓	✓
Sell Detail	–	–	✓	✓
Sell Report	–	–	✓	✓
Member	–	–	–	✓
New Member	–	–	–	✓

The system's ability to accurately acquire, process, and display real-time sensor data from various components of the dental unit is demonstrated by the results of sensor performance testing, which are presented in Table 2. The system was subjected to testing using critical operational parameters, such as water pressure, air pressure, electrical voltage, and current flow in solenoid valves and other components. Sensors connected to Raspberry Pi devices continuously detect these values, transmit them to the centralized database, and display them through the web-based interface of the system. The system enables Admins or engineers to establish permissible value ranges (thresholds) for each parameter. The system immediately generates a visual alert when the measured data exceeds the maximum or falls below the minimum, indicating that the data has departed from these parameters. In particular, the interface utilizes a prominent alert notification to display an "ABNORMAL" status, which is intended to captivate the user's attention and encourage prompt action. The real-time dashboard incorporates these alerts, offering a centralized perspective on all critical system states. The testing verified that the system accurately differentiates between normal and aberrant values without delay or error. Furthermore, the alert mechanism's dependability was confirmed through numerous simulations that were conducted under a variety of anomalous conditions. Each of these conditions was accurately identified and communicated to the user. This level of performance emphasizes the system's capabilities as an IoT-enabled monitoring solution, as it offers intelligent alerting capabilities that support prompt decision-making by technical staff, reduce operational risk, and enhance preventive maintenance. Additionally, it provides accurate real-time data acquisition. Consequently, the system is well-suited for deployment in clinical environments that necessitate uninterrupted equipment functionality and high safety standards.

Table 2. Notification function upon receiving parameters from the sensor

No.	Data List	Values	Min	Max	Test Results
1	Water Pressure	2	1 Bar	3 Bar	Passed
2	Main Air Pressure	5	4 Bar	6 Bar	Passed
3	Handpiece Air Pressure	3	2 Bar	4 Bar	Passed
4	Power Supply	220	210 Volt	240 Volt	Passed
5	Hydraulic Solenoid Valve Current	200	150 mA	450 mA	Passed
6	Water Solenoid Valve Current	200	150 mA	450 mA	Passed
7	Dental Light Current	500	400 mA	3000 mA	Passed
8	Hydraulic Oil Level	0.6	0	0.5	Passed

Figure 5 illustrates the parameter monitoring interface for the dental unit with device ID DEN0005BEST, as it is implemented in the Dental Unit Management System. By utilizing data from embedded IoT sensors, this interface is a component of the real-time monitoring module of the system, which is designed to aid engineers, technicians, and administrators in the evaluation of the operational quality of dental equipment. The interface displays a variety of critical parameters that are measured within the unit, including the status of the hydraulic actuator, water pressure, air pressure, high-voltage supply, and other diagnostic indicators that are essential for performance evaluation. A status label is present to accompany the current reading, indicating whether it falls within the predetermined acceptable range. The unit of measurement for each parameter is clearly indicated, including bar, volt, and milliampere (mA). In the scenario that is currently being presented, all sensor readings are labeled as "ABNORMAL" and highlighted in red. This functions as an immediate visual cue for the user to conduct further investigation. This status signifies that the sensor values have either exceeded or fallen below the configured threshold limits, which may suggest malfunctions, anomalous system conditions, or defective sensor behavior. The "OFFLINE" overall system status indicates that the device is currently not connected to the central server or has not transmitted recent data. The timestamp 01/01/1971 is likely a failsafe system default date that is employed in the event of a valid data update, which frequently occurs when there is no active communication between the device and the system. The interface's efficacy is attributed to its user-centered design, which seamlessly incorporates real-time diagnostics and numerical sensor data into a single, user-friendly screen. This allows users to promptly identify and prioritize technical issues without the necessity of manually inspecting the tangible device, thereby facilitating rapid troubleshooting. In addition, the interface is particularly advantageous in the context of multiple dental units, as it enables administrators to monitor the status of each unit from a centralized location. This enables the effective administration of system availability, maintenance scheduling, and resource planning. By presenting real-time diagnostic information in a clear, structured format, this system component significantly contributes to the objectives of proactive defect detection and predictive maintenance. These objectives are indispensable elements of modern, data-driven healthcare equipment management strategies.

The web application interface was used to display data that was retrieved from the PhpMyAdmin-managed database as part of the database and application testing. The results confirmed that the data was presented in a comprehensive and precise manner, with all relevant documents accurately represented on the user interface. Furthermore, the system's real-time functionality, which encompassed status updates, was verified to guarantee that the database and application layer interact in a synchronized and timely manner. In the final phase, a performance assessment procedure was implemented to evaluate the system's ability to handle high-demand scenarios. The system's responsiveness and stability under load were assessed by simulating concurrent access by numerous user accounts and concurrently submitting a large number of requests within a brief time frame. The system maintained a consistent level of performance under the duress conditions, and no critical errors or significant delays were observed. These findings demonstrate the system's resilience and its capacity to operate efficiently in environments that require high availability and scalability.

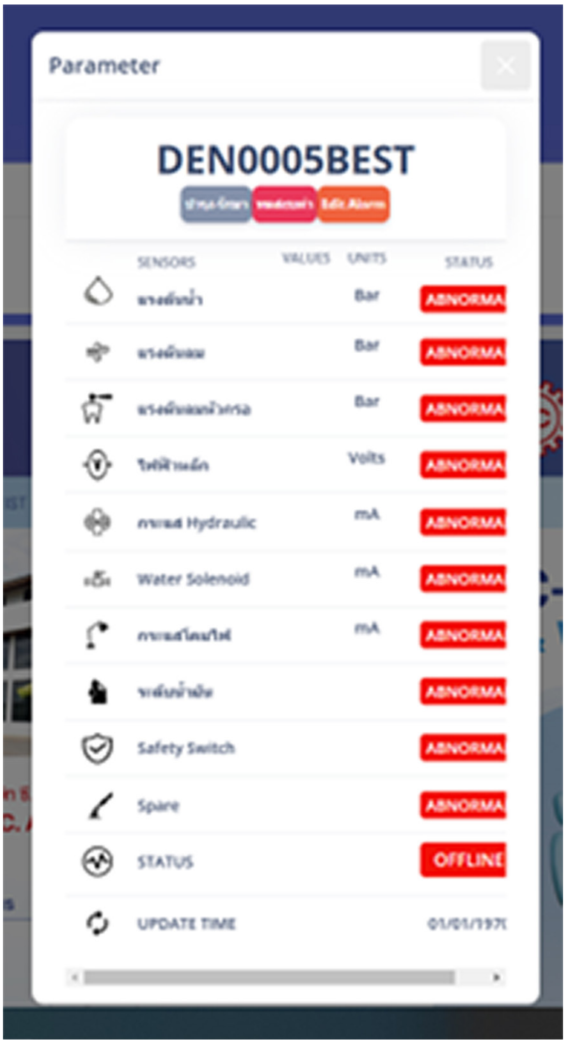

Fig. 5. The warning screen in case of machine malfunction

The DUUMS' registration interface, depicted in Figure 6, has been engineered to be both contemporary and user-friendly. The layout is divided into two primary sections. On the left-hand side, a login form is displayed, which includes input fields for the user's email and password, as well as a prominent blue "Login" icon. An additional feature is the "Remember me" option, which enables the system to save the user's logon credentials. Additionally, the system provides links for "Sign up" (for new user registration) and "Forget Password?" to facilitate password recovery. This combination of components facilitates seamless user account management and improves accessibility. A promotional banner for the Pentadent Innovation Dental Treatment Center, a facility that is committed to the advancement of dental unit systems, is displayed on the right side of the screen. The banner incorporates the product names "C-Swing" and "Wealth," which underscore the importance of high-performance dental solutions, as well as an image of a contemporary dental chair and associated equipment. The logo of C.C. AUTOPART CO., LTD., the manufacturer and distributor of dental equipment, is prominently displayed at the banner's top. The interface is designed with a blue and purple color scheme that evokes a sense of technological sophistication, purity, and compliance with medical aesthetics. Furthermore, the system's potential incorporated feature is represented by a wireless network icon, which denotes IoT connectivity. The usability and brand engagement are both improved by the overall layout and visual composition, which enable users to concentrate on the registration process while simultaneously being introduced to pertinent products and services.

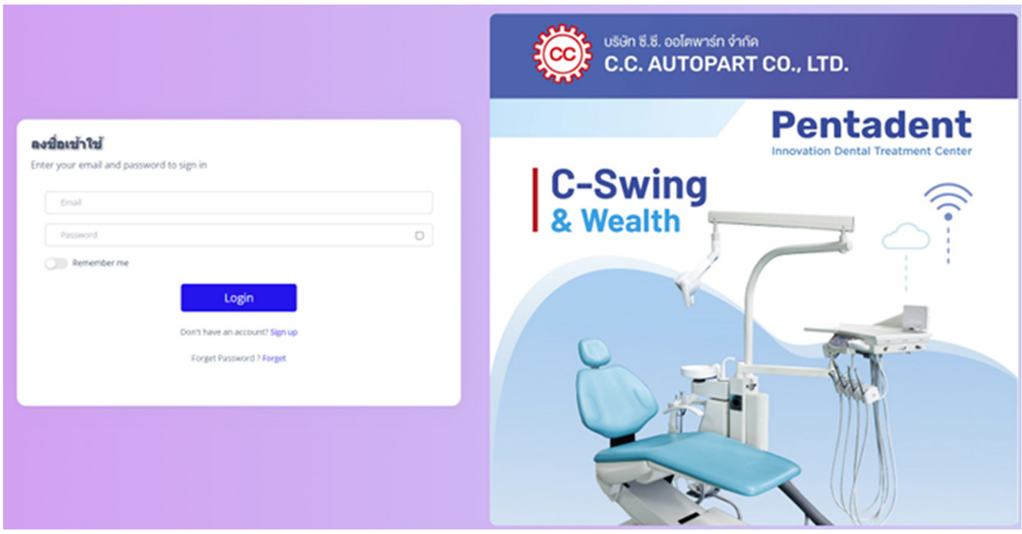

Fig. 6. The system homepage

The DUMS' primary interface, as depicted in Figure. 7, is intended to offer users easy access to the system's fundamental capabilities. A navigation menu is situated on the left side of the interface, providing access to modules including user settings, system configuration, maintenance request submission, status monitoring, and usage records. The top of the screen displays a collection of action icons and categorized controls. These enable users to submit repair requests, review utilization history, receive abnormal status alerts, and view equipment parameters. To facilitate the rapid interpretation of system states by users, visual status indicators are implemented through the use of color coding. The interface is designed with a blue-and-white color scheme, which promotes a user-friendly, professional, and spotless experience. The lower section of the dashboard presents data about the Pentadent C-Swing & Wealth dental device products, manufactured by C.C. AUTOPART CO., LTD. Technical specifications, descriptive content, and illustrative images are included in this section to support informed decision-making by users and enhance the credibility of the product. This interface functions as a centralized control panel, facilitating real-time monitoring and intuitive navigation, thereby enhancing the overall user experience and operational efficiency.

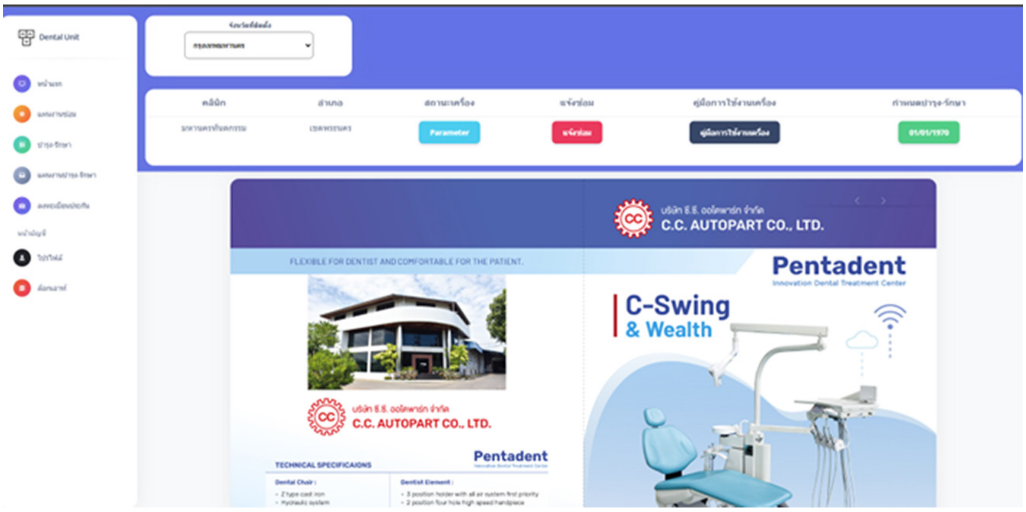

Fig. 7. The first page of the system after login

5 DISCUSSION

5.1 Interpretation of results in the context of existing literature

The results of this study indicate that the web-based platform for dental unit management effectively supports core operational tasks, including searching, displaying, adding, editing, and deleting, while also providing RBAC tailored to different user categories. This is consistent with the health informatics literature, which emphasizes the efficacy of centralized platforms with RBAC in reducing redundancy, mitigating retrieval errors, and ensuring transparency. Additionally, our findings substantiate prior research on the significance of traceable maintenance workflows and real-time equipment monitoring, particularly in enhancing service continuity and reducing patient safety risks. This implies that the system not only meets administrative requirements but also ensures the availability of equipment for patient care, thereby addressing clinical quality dimensions.

5.2 Comparison with previous studies

Many current medical equipment management systems are restricted to specific functions, such as rudimentary maintenance reporting or inventory management. Conversely, the proposed platform is designed to encompass the entire process of dental unit management by incorporating four distinct user roles: engineer, warehouse manager, client/clinical user, and system administrator. This design minimizes cross-role workload and ensures explicit task separation. This work is distinctive because it is specifically designed for dental units, where the continuity of dental treatment is directly influenced by preventive maintenance and immediate troubleshooting, in contrast to previous studies that focused on general hospital devices. The platform's integration of warehouse management further distinguishes it from previous systems, as the majority of previous works did not consider spare parts tracking as a critical component of service efficacy.

5.3 Study limitations and implications

Although the results are promising, it is important to recognize the limitations of this study. Initially, the testing was conducted in a simulated deployment, which may not accurately reflect the operations of a real-world clinic. Secondly, the interoperability and broader data transfer were restricted by the lack of integration with hospital information systems (HIS) and EHRs. Third, while fundamental security mechanisms (authentication and access control) were implemented, more sophisticated measures such as session termination management, strong password policies, data encryption standards, and penetration testing are necessary to comply with clinical-grade cybersecurity standards. Lastly, there is currently a lack of long-term evaluation data regarding operational cost savings, staff burden reduction, and patient satisfaction. These constraints suggest that, despite the platform's immediate utility and feasibility, it is necessary to exercise caution when scaling deployment to resource-intensive and diverse environments.

5.4 Recommendations for future research

The objective of future research should be to expand system validation and improve clinical integration by conducting multi-site testing across institutions of varying sizes to assess scalability, adaptability, and robustness. Interoperability should be enhanced by integrating with HIS and EHRs using standards such as HL7 FHIR to enable seamless data exchange. Predictive analytics based on accumulated sensor and maintenance data could be implemented to facilitate AI-driven predictive maintenance and reduce unplanned downtime. In addition, it is imperative to implement sophisticated data security measures, including encryption, enhanced authentication protocols, and adherence to regulations such as GDPR and HIPAA, to safeguard sensitive information. It is advised that usability studies and A/B testing of role-specific dashboards be conducted to increase staff acceptability and improve the user experience, thereby reducing the necessity for training. In conclusion, future research should broaden the platform framework to include other medical devices in addition to dental units, facilitating the assessment of cross-specialty applicability and hospital-wide equipment management.

6 CONCLUSION

A DUMS with a web application that integrates IoT technologies, role-based access control, and predictive analytics was successfully developed and evaluated in this study to support the operational and maintenance requirements of modern dental clinics. Under simulated conditions, the platform exhibited robust fault detection, responsiveness, and high accuracy. Additionally, it provided functionalities that were tailored to the specific roles of clients, engineers, factories, and administrators. The system improves upon previous methods of medical equipment management that frequently prioritized isolated functions, such as asset tracking or basic maintenance scheduling, in the context of the existing literature. This work empirically supports the increasing consensus in health informatics that centralized, interoperable systems enhance service continuity, reduce downtime, and improve transparency by consolidating maintenance workflows, spare parts logistics, and predictive fault detection into a single web-based platform. The system facilitates the connection between theoretical recommendations for IoT-driven healthcare management and their practical applications in dental contexts. In contrast to previous research, which was primarily focused on the management of generic or hospital-wide medical devices, the current system is specifically designed to address the operational complexity of dental treatment units. This concentration pertains to distinctive necessities, including the incorporation of spare parts inventories, the monitoring of water and air pressure, and the reduction of service interruptions in high-volume outpatient workflows. The system's pioneering contribution to dental healthcare technology is distinguished by these features, which surpass prior work that lacked this level of specialization and predictive capability. It is also necessary to recognize the limitations. The evaluation was conducted in controlled and simulated environments, which limits its generalizability to a variety of clinical settings. Data interoperability is still restricted by the limited integration with HIS and EHR. Multi-factor authentication, sophisticated encryption, and penetration testing are necessary to enhance the security mechanisms, which are at least adequate during the prototype phase. Additionally, longitudinal evidence regarding patient satisfaction, maintenance efficiency, and cost savings is not yet accessible. In order to verify scalability across a variety of clinical environments, including large university hospitals and small private dental practices, future research should focus on multi-site deployments. International standards such as HL7 FHIR will be necessary to guarantee seamless data exchange and interoperability through deeper integration with HIS/EHR. The integration of sophisticated machine learning models into predictive maintenance functions can further improve the intelligence of the system. In addition, longitudinal performance assessments and user-centered interface refinements should be implemented to assess long-term cost-effectiveness, equipment availability, and user satisfaction. In conclusion, this study introduces a cutting-edge, web-based dental unit management platform enabled by the IoT. This platform facilitates the advancement of both academic knowledge and practical healthcare innovation. The system establishes a standard for smart dental equipment administration that is consistent with the principles of Industry 4.0 by addressing the deficiencies of traditional manual processes and previous partial solutions. Ultimately, it enhances service quality, operational transparency, and patient care outcomes in resource-constrained healthcare settings by establishing a foundation for future advancements toward predictive, interoperable, and data-driven clinical environments.

7 ACKNOWLEDGEMENT

This research has been approved by the Research Ethics Office of Rangsit University (RSUERB) under the certification number RSUERB2024-025 as a study that does not fall under the category of human research. Moreover, AI-driven methods (QuillBot Premium) were utilized for grammatical verification, paraphrasing, and linguistic augmentation to ensure the accuracy and clarity of the text.

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