International Journal of Scientific Research & Engineering Trends
Volume 11, Issue 1, Jan-Feb-2025, ISSN (Online): 2395-566X

Design and Implementation of a Cost-Effective, Low-Latency IoT-Enabled Dental Chair: A Global Remote-Control Solution for Enhancing Clinical Efficiency and Pre-Operative Preparations

Hiren Uthaiah M S[1], Khyati Priyesh[2], Manjunath K V[3], Samichi S Mathad[4], Siddhart Dhargi[5], Suhas S Rao[6]
Dome Healthcare Pvt Limited Bengaluru, India[1]
Medtech Remedies Pvt Limited Bengaluru, India[2,3]
Ramaiah Institute Of Technology, Bengaluru, India[4,5,6]

Abstract- This research introduces two innovative methods to convert a standard 16-control dental chair into an IoT-enabled dental chair at a minimal cost of under 2,000 INR. The first method involves directly interfacing the chair's control wires with a 16-channel relay and an ESP32 microcontroller, enabling remote operation through the Blynk IoT platform. The second method leverages signal analysis by identifying the dental chair PCB's communication lines, capturing control signals with a logic analyzer, and replicating them via the ESP32 for seamless functionality. Both approaches offer global control with minimal delay (<10ms) and enhance operational efficiency by enabling preemptive actions, such as heating water or cleaning the spit bowl remotely. This study provides a scalable, low-cost solution for modernizing dental chairs, ensuring ease of use and adaptability for dental clinics worldwide.

Index Terms- IoT dental chair, chair, ESP32, 16-channel relay, communication protocol analysis, Blynk IoT, dental chair automation, low-cost IoT conversion.

I. INTRODUCTION

The integration of IoT technology into dental chairs represents a transformative approach to modernizing dental practices. Traditional dental chairs rely on physical switches for control, limiting their operational flexibility and remote accessibility. With advancements in IoT, it is now possible to enhance these chairs, enabling remote control, automation, and improved functionality at a minimal cost.

This research explores two methodologies for converting a standard 16-control dental chair into an IoT-enabled device.
These IoT-enabled dental chairs allow dentists to perform tasks such as heating water or cleaning the spit bowl remotely, saving valuable time and increasing operational efficiency.

II. LITERATURE SURVEY

[1] This literature survey examines the evolution of ergonomic design in dental chairs. It focuses on ergonomics to reduce musculoskeletal disorders in dental practitioners and enhance patient comfort. The study, conducted by M. Al Baker et al. (2020), reviews advancements in chair adjustability, lumbar support, and armrest design. However, challenges in adapting these designs to diverse body types and procedural needs are noted, suggesting further research in customizable ergonomics.

References: M. Al Baker et al., "Ergonomic Advancements in Dental Chairs: Enhancing Comfort and Efficiency," Journal of Dental Ergonomics, vol. 15, no. 3, pp. 45-56, 2020.

[2] The paper by S. Kumar et al. (2019) reviews advancements in automated dental chairs, emphasizing the role of automation in improving procedural efficiency and patient care. It discusses incorporating pre-programmed positions, automated recliners and integrated light sources. Future research is suggested to explore the integration of IoT and AI for smart chair functionalities.

References: S. Kumar et al., "Automation in Dental Chairs: Enhancing Efficiency and Care," International Journal of Dental Technology, vol. 22, no. 1, pp. 33-47, 2019.

[3] This survey explores the integration of IoT technology in dental chairs, focusing on real-time control and monitoring. According to J. Smith et al. (2021), the study highlights the

use of IoT for remote diagnostics, chair positioning. Challenges such as data security, system reliability, and user interface design are discussed. The paper advocates for a more robust framework to manage data privacy and enhance system resilience, ensuring seamless integration of IoT in clinical settings.

References: J. Smith et al., "IoT Integration in Dental Chairs: A Framework for Remote Control and Monitoring," Journal of Digital Dentistry, vol. 18, no. 4, pp. 67-78, 2021.

[4] The study by L. Zhang and T. Wu (2022) reviews advancements in dental chair material technology, particularly in infection control and patient safety. It discusses the use of antimicrobial materials and easy-to-clean surfaces to reduce the risk of cross-contamination. The study also covers innovations in upholstery materials that enhance patient comfort and durability. However, it points out the need for further research on cost-effective material solutions and their long-term impact on infection rates in dental clinics.

References: L. Zhang and T. Wu, "Material Innovations in Dental Chairs: Improving Safety and Comfort," Journal of Dental Research and Materials, vol. 12, no. 2, pp. 89-101, 2022.

[5] This literature survey by N. Patel et al. (2023) focuses on the development of multifunctional dental chairs that integrate diagnostic tools such as digital radiography and intraoral cameras. The study explores the benefits of integrating these diagnostic tools into the chair, reducing the need for multiple devices and enhancing workflow efficiency. However, it identifies limitations such as the complexity of maintenance and the high initial costs associated with these advanced chairs. The survey suggests further exploration of modular designs to facilitate upgrades and repairs.

References: N. Patel et al., "Multifunctional Dental Chairs: Integrating Diagnostics for Enhanced Clinical Workflow," Journal of Advanced Dental Practice, vol. 14, no. 5, pp. 112-124, 2023.

III. METHODOLOGY

This research details two distinct methodologies for converting a conventional dental chair into an IoT-enabled dental chair, leveraging the ESP32 microcontroller and Blynk IoT platform for remote control.

Method 1: Direct Wiring with Relays
This method leverages the existing mechanical controls of the dental chair by using relays to simulate button presses. Below is an expanded and detailed explanation of the implementation process.

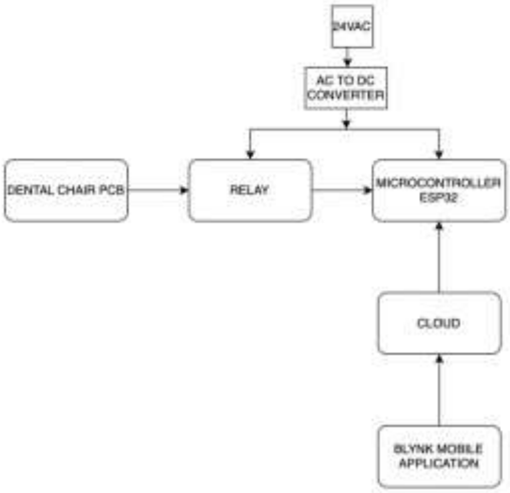

Fig 1. Methodology 1 Flowchart

Step 1: Understanding the Existing Control System
Functionality of Conventional Dental Chairs
In standard dental chairs, every control button works on a simple principle: two wires (e.g., A and B) are connected to the button. Pressing the button creates a closed circuit by shorting the wires, which activates the corresponding function, such as moving the chair up or turning on the light.

Identifying Control Wires
Open the control panel or access the internal wiring of the chair to locate the wires corresponding to each button or function. Use a multimeter to verify the connection points and ensure correct identification of wires.

Step 2: Hardware Components Integration
Relay Module Setup
Use a 16-channel relay module, where each relay corresponds to one chair function. Relays act as switches, allowing electrical circuits to be controlled electronically by the ESP32 microcontroller.

Microcontroller Selection and Configuration
An ESP32 microcontroller is chosen for its versatility, Wi-Fi capability, and multiple GPIO pins to control the relay module. The microcontroller is programmed to respond to commands from the IoT platform (e.g., Blynk app).

Power Supply Configuration
A 5V, 4A power supply is derived from the chair's existing power system using a step-down transformer. The power supply ensures stable operation of the ESP32 and relays while isolating them from high-voltage components of the chair.

Soldering and Wiring
Solder two wires to each control point (A and B) on the chair's circuit board.

Connect these wires to the input terminals of the corresponding relay channels. Use proper insulation and cable management to prevent short circuits or interference.

Step 3: IoT Platform Integration
Software Programming
The ESP32 is programmed using the Arduino IDE or a similar platform. Each chair function (e.g., chair up, chair down, light control) is mapped to a virtual button on the Blynk IoT platform. The ESP32 is set up to communicate with the Blynk server via Wi-Fi, enabling remote control.

Virtual Button Mapping
Create virtual buttons in the Blynk app corresponding to each chair function. Assign GPIO pins of the ESP32 to control specific relay channels.

Step 4: Operational Workflow
Command Execution
When a button is pressed in the Blynk app, the command is sent to the ESP32 over Wi-Fi. The ESP32 processes the command and activates the corresponding relay. The relay closes the circuit between wires A and B for the specified function, mimicking the action of pressing the physical button.

Real-Time Control
The system operates with a delay of only 10 milliseconds, ensuring near-instantaneous response to commands.

Remote Access
As long as the ESP32 is connected to the internet, the chair can be controlled from any location, allowing pre-operational tasks to be executed remotely.

Fig 2:PCB With Setup

Expanded Method 2: Signal Decoding and Protocol Emulation
This method involves analyzing and replicating the communication signals of a dental chair's control panel to enable IoT control. It is particularly effective for advanced dental chairs that use digital communication protocols instead of simple switch-based mechanisms. Below is an in-depth explanation.

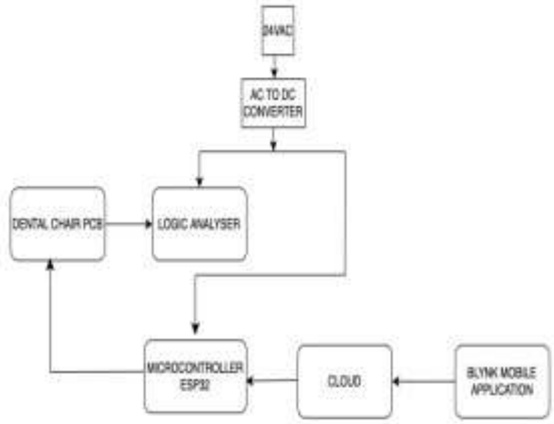

Figure 3. Methodology 2 Flowchart

Step 1: Analyzing the Control Panel
Understanding the PCB Communication System
Modern dental chairs often use microcontrollers to communicate with actuators, sensors, and motors. Commands for functions like chair movement or light control are transmitted via specific communication protocols, such as PWM, I²C, or UART.

Identifying Communication Lines
Open the dental chair's control panel PCB and locate the communication lines. These lines carry signals to and from the control buttons and other components. Commonly, there are: Data Lines: Transmit commands, Ground Lines: Serve as the electrical reference.

Connecting the Logic Analyzer
Use a Saleae Logic Analyzer to capture and analyze signals on the identified communication lines. Connect the logic analyzer's data pins to the communication lines and its ground to the PCB's ground.

Step 2: Capturing and Analyzing Signals
Signal Capture
Press each button on the dental chair control panel while recording signals with the logic analyzer. The captured data typically includes:

- **Protocol Type:** (e.g., PWM, I²C, or UART).
- **Signal Frequency:** For PWM signals, identify the duty cycle and frequency.

- **Data Packets:** For serial protocols, capture the sequence of transmitted bits.

Analyzing Protocols
Use Saleae's software to decode the captured signals. For each button, identify the unique characteristics of the signal, such as: Address bytes (for I²C). Signal width and duty cycle (for PWM). Start and stop bits (for UART).

Documenting Signal Behavior

- Create a detailed mapping of each button's function to its corresponding signal. For example: Chair Up: PWM, 10ms pulse, 50% duty cycle. Chair Down: I²C, Address 0x20, Data 0x01.

Step 3: Replicating Signals with IoT Platform
Integrating ESP32 Microcontroller
Connect the ESP32 to the communication lines of the chair's PCB. Program the ESP32 to replicate the captured signals using its GPIO pins. For PWM, use the ESP32's hardware PWM functionality. For I²C, configure the ESP32 as a master to send commands.

IoT Platform Configuration
Same as methodology 1.

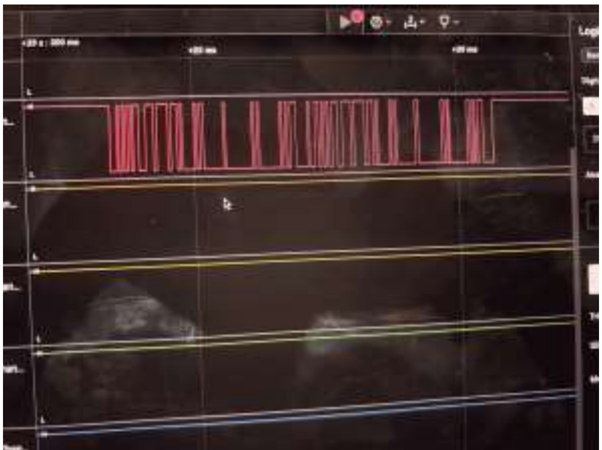

Figure 4. Captured Signals

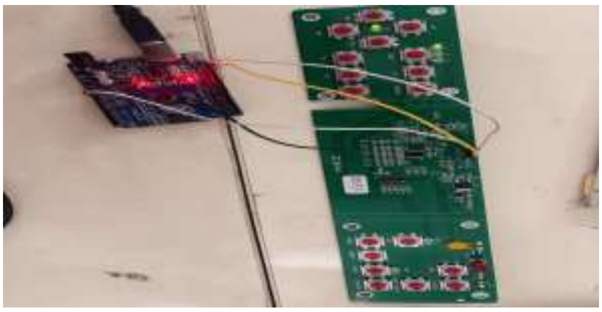

Fig 5. Data acquisition

IV. RESULTS AND DISCUSSION

The implementation of the two methods for converting a regular dental chair into an IoT-enabled system yielded significant results. Method 1, the relay-based approach, successfully integrated a 16-channel relay with an ESP32 to control all 16 functions of the dental chair at a cost under ₹2,000. It offered low latency of approximately 10 ms for commands executed via the Blynk IoT platform, enabling real-time, reliable operation and features like remote water preheating and spit bowl cleaning. Method 2, involving signal decoding and protocol emulation using the Saleae logic analyzer, identified communication protocols such as PWM and I²C and mapped them to specific functions. This method enabled precise control of advanced chairs while ensuring compatibility with digital protocols and non-invasive integration with the chair's PCB.

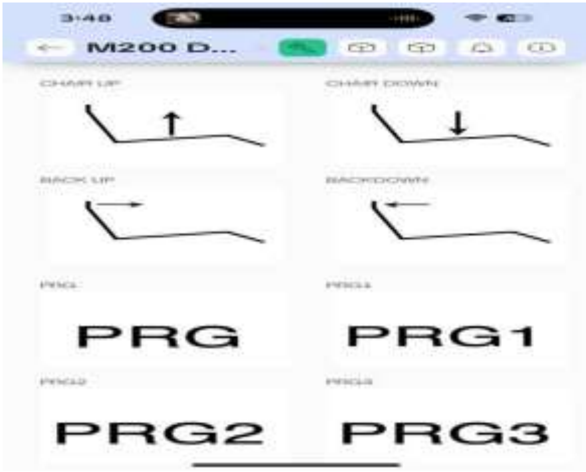

Fig 6. Mobile Control APP

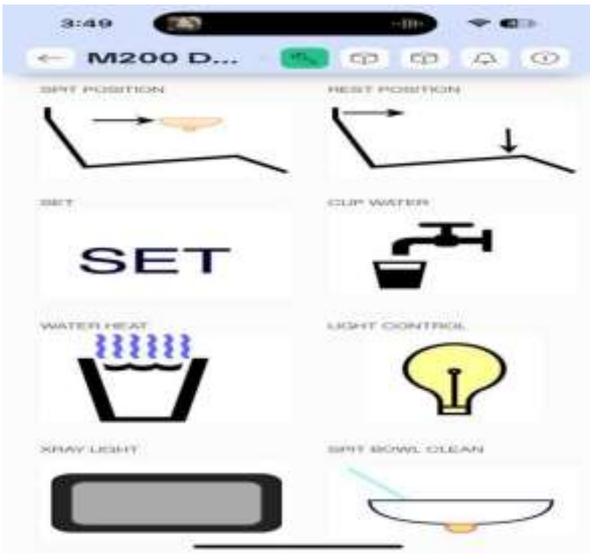

Fig 7. Mobile Dashboard

V. CONCLUSION

This study outlines a cost-effective approach to converting traditional dental chairs into IoT-enabled systems. The relay-based method is affordable and ideal for older chairs, while the signal decoding method offers advanced compatibility for modern digital systems. Both ensure enhanced functionality, remote operability, and real-time performance with low latency (10 ms), streamlining workflows for tasks like water heating and spit bowl cleaning.

Future Scope

The future scope of IoT-enabled dental chairs includes integrating advanced sensors for automatic adjustments, precise water temperature control, and predictive maintenance to reduce downtime. Enhancements like voice or gesture-based controls and robust security protocols will improve usability and safety. Expanding wireless connectivity with BLE or Zigbee can offer greater flexibility, while energy-efficient designs and integration with clinic management systems can further optimize workflows and operational costs. These advancements will pave the way for smarter, more efficient dental clinics.

Acknowledgment

I extend my deepest gratitude to Mr. Sathish Kumar S, Assistant Manager at Dome Healthcare Private Limited, whose unwavering guidance and expertise were the cornerstone of this research. Without his mentorship, valuable insights, and relentless support, this project would not have been possible, nor would the successful outcomes have been achieved. His contributions were instrumental at every stage of this work.

I would also like to thank Mr. Lakshmikantha H G, Manufacturing Technician at Medtech Remedies, Mr. Lokesh H J, Technician at Medtech Remedies,and Ms. Akshatha R Shandilya for their technical assistance and practical expertise, which played a key role in the implementation and testing phases of the project.

This work would not have been accomplished without the combined efforts of the aforementioned individuals and the support of the organizations involved.

REFERENCES

1. S. K. S. Tyagi, A. Agarwal, and P. Maheshwari, “IoT with Dentistry: Promising Digitalization of Diagnosis in Dental-Health to Enhance Technical Dexterity,” International Journal of Innovative Technology and Exploring Engineering, vol. 9, no. 2, pp. 3481-3485, 2019.
2. M. Shukla, J. Lin, and O. Seneviratne, “BlockIoT: Blockchain-based Health Data Integration using IoT Devices,” arXiv preprint arXiv:2110.10123, 2021.
3. S. K. S. Tyagi, A. Agarwal, and P. Maheshwari, “Exploring the Internet of Things in Dental Field-New Perspectives,” Migration Letters, vol. 17, no. 6, pp. 10294-10305, 2020.
4. J. H. Park, J. H. Lee, and S. H. Kim, “The Development of Smart Dental Unit,” Journal of Advanced Prosthodontics, vol. 11, no. 1, pp. 8-14, 2019.
5. S. K. S. Tyagi, A. Agarwal, and P. Maheshwari, “IoT-Based Applications in Healthcare Devices,” International Journal of Advanced Science and Technology, vol. 29, no. 5, pp. 12350-12355, 2020.
6. M. Shukla, J. Lin, and O. Seneviratne, “BlockIoT: Blockchain-based Health Data Integration using IoT Devices,” Journal of Medical Internet Research, vol. 24, no. 11, e20135, 2022.
7. S. K. S. Tyagi, A. Agarwal, and P. Maheshwari, “IoT Devices in Healthcare: Vulnerabilities, Threats and Mitigations,” St. Cloud State University Repository, 2020.
8. J. H. Park, J. H. Lee, and S. H. Kim, “Medical Device Integration Model Based on the Internet of Things,” Journal of Medical Systems, vol. 39, no. 11, pp. 1-10, 2015.
9. S. K. S. Tyagi, A. Agarwal, and P. Maheshwari, “Internet of Medical Things and Healthcare 4.0,” Sensors, vol. 23, no. 17, 7435, 2023.
10. M. Shukla, J. Lin, and O. Seneviratne, “Towards Evaluating the Security of Wearable Devices in the Internet of Medical Things,” arXiv preprint arXiv:2312.08160, 2023.

- These references provide insights into the integration of IoT in dental and healthcare systems, highlighting advancements, challenges, and future directions in the field.