



# A Virtual Reality Based Simulation and Evaluation Framework for Industrial Welding Skill Training

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**ABSTRACT:** The increasing need for safe and effective vocational training has driven the development of immersive virtual reality (VR) applications capable of simulating real-world scenarios. This paper presents the design and implementation of a VR Welding Simulation system, developed as both a desktop and web-based application, aimed at enhancing practical welding skills, posture accuracy, and safety awareness. The system integrates interactive VR environments, gear selection, and real-time performance feedback into a unified, user-friendly interface. Developed using UNITY GAME ENGINE, the application supports scenario based learning, real-time welding angle assessment, and personalized skill progression tracking. The platform adopts a modular and scalable architecture, enabling easy updates and expansion of welding tasks. Experimental evaluation demonstrates the system's effectiveness in providing a risk-free, engaging, and context-aware learning experience. The VR Welding Simulation serves as a prototype for next-generation vocational training tools that combine immersive technology with practical skill development.

## I. INTRODUCTION

Industrial welding is a critical skill required in manufacturing, construction, automobile, and heavy engineering industries. Traditional welding training methods require physical equipment, workshop environments, and supervision, which can be expensive, risky, and not easily accessible to all learners. Beginners often face difficulties in understanding proper welding posture, maintaining correct torch angle, and controlling movement speed, which may lead to material wastage and safety hazards such as burns, sparks exposure, and harmful fumes. Due to these challenges, there is a need for a safe and effective training system that allows learners to practice welding techniques without real-world risks while still maintaining practical learning experience. With the advancement of Virtual Reality (VR), web technologies, and Machine Learning (ML), it is now possible to develop smart training applications that simulate real-world industrial environments. The **Virtual Reality Based Welding Simulation and Evaluation Framework** is designed to provide an interactive and immersive training platform where users can learn and practice welding skills in a safe virtual environment. The system uses modern technologies such as UNITY GAME ENGINE models to create a realistic first-person welding experience. The simulation allows users to interact with welding tools, perform welding operations, and receive real-time feedback on their posture, movement accuracy, and welding angle. The system consists of multiple modules that work together to create an effective learning environment. The user can select protective welding gear such as helmet, gloves, and jacket, ensuring awareness of industrial safety practices. The simulation provides realistic welding effects including sparks, object joining, and tool interaction to improve understanding of real welding processes. The machine learning feedback module evaluates user performance and provides guidance to improve welding accuracy and consistency. The system also stores performance data, allowing users to track their progress and identify areas for improvement. The VR Welding Simulation aims to create a reliable, user-friendly, and cost-effective training platform that enhances practical learning experience while reducing physical risks and training costs. By integrating immersive simulation technology with intelligent performance evaluation, the system helps learners develop confidence, improve technical skills, and prepare for real industrial welding tasks in a controlled and safe environment.

### A. Project Background

Vocational training, especially in technical trades like welding, requires significant hands-on practice to develop precision, accuracy, and safety awareness. Traditional training methods rely on physical workshops and equipment, which often involve high costs, material consumption, and potential risks of accidents or injuries. Additionally,

accessibility to such facilities can be limited for students, hobbyists, or remote learners. With the advancements in virtual reality (VR), web technologies, and AI-based analytics, immersive simulations have emerged as an effective solution for skill development. VR allows learners to experience realistic, interactive environments where they can practice tasks repeatedly without real-world consequences. The VR Welding Simulation project combines these technologies to provide both a desktop and web based platform where users can practice welding techniques safely, simulate gear usage, and receive real-time feedback on posture, angle, and performance accuracy. This approach aims to enhance vocational training efficiency while reducing risks and resource wastage.

### **B. Motivation**

The motivation behind this project arises from the need to improve welding training accessibility and effectiveness. Many learners face challenges due to limited availability of labs, high costs of welding equipment, or safety restrictions. Traditional training also lacks immediate feedback, making it difficult for students to correct errors effectively. By leveraging VR and web technologies, this project provides a safe, engaging, and interactive learning experience. Users can repeatedly practice welding skills, simulate different welding scenarios, and gain confidence without endangering themselves or consuming real materials. The project also aligns with the growing trend of using technology-enhanced learning tools to bridge the gap between theory and practice, providing learners with the freedom to train anytime, anywhere.

### **C. Statement of Problem**

Welding is a skill that requires precision, practice, and guidance. Conventional training methods often face several limitations:

1. **Safety Risks:** Physical welding exposes learners to heat, sparks, and toxic fumes, making it unsafe for beginners.
2. **Material Wastage:** Practice sessions consume welding rods, metals, and other materials, increasing costs.
3. **Accessibility Issues:** Limited availability of workshops and equipment restricts learning opportunities for students and professionals.
4. **Lack of Real-Time Feedback:** Learners often do not receive instant corrections on angles, posture, or technique, slowing skill development. This project addresses these challenges by creating a virtual, interactive, and safe welding environment where users can practice welding techniques with guidance and receive real time performance feedback. It provides a scalable solution that can be easily updated with new tasks, scenarios, and learning modules.

### **D. Aims and Objectives**

To develop a VR Welding Simulation platform that enables learners to practice welding safely, accurately, and effectively, improving their technical skills while reducing risks and costs.

Objectives:

1. **Design a Realistic Welding Environment:** Create immersive VR welding scenarios for both desktop and web applications.
2. **Integrate Gear and Tool Simulation:** Allow users to select helmets, gloves, and jackets, replicating real welding conditions.
3. **Provide Real-Time Feedback:** Assess posture, angles, and technique accuracy to help learners improve continuously.
4. **Enable Skill Tracking:** Record user performance data to monitor progress and identify areas for improvement.
5. **Ensure Modularity and Scalability:** Develop the system with a modular design to support future enhancements, new welding tasks, and additional VR scenarios.
6. **Facilitate Safe Learning:** Reduce physical risks, material wastage, and cost associated with traditional welding training

### **E. Organization of the Report**

The report is structured as follows:

- Chapter 1 – Introduction: Provides an overview of the project, including background, motivation, problem statement, and project objectives.
- Chapter 2 – Literature Review: Reviews existing welding training methods, VR simulations, and related educational technologies.
- Chapter 3 – System Design and Architecture: Explains the technical implementation, including application architecture, tools, technologies (UNITY GAME ENGINE), and VR integration in future.
- Chapter 4 – Implementation: Describes the development process of the VR Welding Simulation application,

including features, gear system, interaction design, and web integration.

- Chapter 5 – Testing and Evaluation: Presents testing methodologies, user experience evaluation, performance analysis, and feedback from learners.
- Chapter 6 – Conclusion and Future Work: Summarizes the outcomes, highlights the contributions of the project, and discusses potential future enhancements, including AI-based adaptive learning and expanded welding scenarios.

## II. REVIEW OF LITERATURE

### A. Related Work

Over the past decade, VR and simulation technologies have increasingly been used in vocational and technical training, especially in high-risk trades like welding. Key developments include:

1. **VR-Based Welding Training Systems:** Researchers and companies have developed VR simulators specifically for welding, such as VR Weld Trainer and Lincoln Electric's VR Welding Simulator. These systems provide immersive, 3D environments where learners can practice welding without the risks associated with physical welding. Users interact with virtual welding torches and surfaces, receiving performance feedback based on weld length, consistency, and angle accuracy. Such systems have been shown to improve learning outcomes, reduce training time, and decrease material wastage.

However, they are largely hardware-intensive, requiring VR headsets, sensors, and high-performance computing systems, limiting accessibility for many learners.

2. **Web-Based Vocational Simulators:** Several web-based applications have attempted to bring technical training online using 3D simulations. These platforms leverage UNITY GAME ENGINE and WebGL to create interactive environments that can be accessed via a browser, eliminating the need for specialized hardware. While they provide easier accessibility, most lack the immersion of VR and detailed real-time performance feedback. Users can perform basic welding tasks, but the simulation does not replicate physical resistance, protective gear interaction, or posture correction effectively.

3. **AI-Assisted Skill Assessment:** Recent research has explored integrating machine learning and AI into vocational training to provide intelligent feedback. Systems track user movements and analyze angles, posture, and tool usage to detect errors and suggest improvements. Studies indicate that AI-assisted VR simulators can accelerate skill acquisition by giving learners detailed, contextual guidance, which is not possible in traditional workshops or older VR systems. For example, simple ML models have been used to detect improper welding angles and recommend corrective actions in real time.

4. **Interactive Gear and Tool Simulations:** Some systems have incorporated virtual representations of welding helmets, gloves, and jackets to improve training realism. Simulating protective gear encourages proper safety habits and enhances immersion. However, these features are often limited to high-end VR setups and are rarely integrated with web-accessible platforms. The absence of realistic gear simulation in most accessible simulators reduces the effectiveness of training, especially in reinforcing safety and ergonomics.

5. **Hybrid Desktop-Web Training Approaches:** A few recent studies have attempted hybrid approaches, combining desktop VR simulations with web-based modules. These allow learners to access practice sessions from multiple platforms, track their progress online, and integrate AI-assisted feedback. Nonetheless, these systems remain experimental and often focus on a limited number of welding techniques.

## III. SYSTEM ANALYSIS AND DESIGN

This chapter presents the detailed architectural framework for the **Virtual Reality (VR) Based Welding Simulation and Evaluation System**. It begins by translating the project's aim and objectives into a structured design plan, identifying the complete set of functional and non-functional requirements required to build an interactive and immersive welding training environment. The chapter also outlines the required software, hardware, and machine learning components, including UNITY GAME ENGINE models for real-time welding posture and angle evaluation. The system supports first-person interaction, gear selection, real-time feedback generation, and performance tracking to enhance skill development in a safe and controlled virtual environment.

Further, a feasibility study validates the implementation of a cost-effective and scalable web-based VR approach that eliminates the need for expensive physical welding equipment while still maintaining realistic training conditions. The system design is illustrated using Data Flow Diagrams (DFDs) to represent the flow of user inputs, simulation processing, and feedback generation. A UML class diagram defines the structural relationship between modules such as user interface, simulation engine, machine learning feedback module, and data storage. In addition, the system architecture diagram demonstrates the integration of user interaction controls, 3D simulation environment, performance evaluation module, and database components, ensuring efficient communication between system modules and enabling accurate real-time welding skill assessment.

## A. Requirements

### A.1 Functional Requirements

**User Registration and Authentication:** The system allows users (trainees or learners) to register and log in securely before accessing the welding simulation environment. Authentication ensures that user progress, performance scores, and selected training modules are stored individually. The login system maintains personalized training records and helps track improvement over multiple sessions.

**Virtual Welding Environment Simulation:** The system provides an interactive 3D virtual welding environment where users can practice welding tasks safely without physical risk. The simulation replicates real welding conditions such as welding sparks, torch movement, and object joining. Users can interact with objects in the virtual workspace using keyboard and mouse controls.

**Gear Selection and Safety Equipment Simulation:** The application allows users to select welding safety equipment such as helmet, gloves, and protective jacket before starting the welding process. This feature improves realism and helps users understand the importance of safety measures required in real industrial welding environments.

**Real-Time Welding Feedback using Machine Learning:** The system uses a Machine Learning (Simple ML) model to monitor welding posture, angle, and speed in real time. The ML module evaluates the accuracy of welding movements and provides immediate feedback to help users improve technique and avoid incorrect welding posture.

**Performance Evaluation and Progress Tracking:** The system records performance metrics such as welding accuracy, angle consistency, and task completion time. The user's progress is stored and can be reviewed to analyze improvement over time. This helps learners identify mistakes and enhance their welding skills effectively.

**Interactive Controls and User Navigation:** The system allows users to move in the virtual environment using WASD keyboard controls and interact with objects using mouse input. Users can pick welding tools, perform welding actions, and navigate the training workspace in first-person view for immersive experience.

**Data Storage and Session Management:** The system stores user profile details, selected gear, and performance data using JSON format. This ensures that each session's progress is saved and can be retrieved later for evaluation and comparison of performance improvements.

### A.2 Non-Functional Requirements

**Performance:** The system should provide smooth and responsive interaction in the virtual environment. The welding simulation should operate without lag, ensuring real-time response between user input and system output. The ML feedback module should generate performance analysis quickly to maintain training continuity.

**Reliability:** The system must function consistently across multiple sessions without crashes or errors. The simulation should perform reliably on standard desktop systems and browsers, ensuring uninterrupted learning experience.

**Security:** User profile data and performance results must be securely stored to prevent data loss or unauthorized access. The system should ensure safe storage of training progress and prevent corruption of stored data.

**Usability:** The system interface should be simple, intuitive, and easy to understand for beginners. Navigation controls should be user-friendly so that users can easily interact with the virtual environment without requiring technical expertise.

**Scalability:** The system should support future enhancements such as additional welding tasks, advanced ML models, and extended VR features. The modular design allows developers to add new simulation environments without affecting existing functionality.

**Availability:** The system should be accessible anytime using modern web browsers. Users should be able to practice welding skills without requiring special VR hardware, ensuring wide accessibility.

**Portability:** The application should run on different operating systems such as Windows, macOS, and Linux using standard web browsers. The simulation should not depend on specific hardware configurations.

### A.3 Hardware and Software Requirements Hardware

**Processor:** Intel i3 or higher processor required for running the simulation environment smoothly. Recommended processor is Intel i5 or above for better rendering performance.

**RAM:** Minimum 4 GB RAM required for running the simulation. 8 GB RAM is recommended for smooth execution of 3D simulation and machine learning feedback module.

**Storage:** Minimum 10 GB free storage required for application files, 3D models, and user performance data. SSD storage is recommended for faster performance.

**Input Devices:** Keyboard and mouse are required for interacting with the simulation environment. Users can control movement, camera view, and welding actions using these devices.

**Display:** Minimum display resolution of 1280×720 required. Full HD display (1920×1080) recommended for better visualization of 3D welding environment.

**Internet Connection:** Internet connection is required for downloading application resources, updates, and storing user performance data when required.

#### Software

**Operating System:** Windows, macOS, or Linux operating system compatible with modern web browsers. Programming language: UNITY GAME ENGINE are used for designing the simulation interface and implementing interactive functionality.

**3D Simulation Engine:** Antigravity engine is used to create immersive first-person welding simulation environment and realistic object interaction.

**Machine Learning Module:** Simple ML model is used to analyze welding posture, angle, and movement accuracy to provide real-time feedback.

**Database:** JSON is used for storing user profiles, gear selections, and welding performance results.

**API Integration / Browser Support:** Modern web browsers such as Google Chrome, Mozilla Firefox, or Microsoft Edge with WebGL support are required for running 3D simulation.

**IDE:** Visual Studio Code or any modern code editor is used for writing and testing program code.

## B. Feasible Study

A feasibility study is the process of evaluating whether a proposed system or project is practical, achievable, and worth implementing. It examines technical capability, economic cost, operational factors, and possible risks to determine whether the project can be successfully developed and maintained. For the Virtual Reality Based Welding Simulation system, the feasibility study confirms that the application can be developed using available web technologies and machine learning tools within reasonable cost and resource limits. The proposed system provides a safe and cost-effective alternative to traditional welding training methods by reducing dependency on physical equipment while maintaining realistic training experience.

### B.1 Technical Feasibility

The VR Welding Simulation system is technically feasible using modern web technologies, lightweight machine learning models, and browser-based 3D rendering frameworks. The project achieves real-time welding interaction, performance feedback, and immersive simulation without requiring expensive VR hardware, making it suitable for academic and training purposes.

- **Architecture fit:** Standard desktop or laptop systems with modern web browsers can efficiently run the 3D welding simulation environment. Technologies such as UNITY GAME ENGINE support real-time rendering of welding objects, sparks, and user interaction, ensuring responsive and smooth performance.

- **Performance feasibility:** The simulation processes user inputs such as movement, welding angle, and tool interaction instantly. The Simple ML model evaluates posture and welding accuracy in real time, providing immediate feedback without noticeable delay.

- **Power and system efficiency:** The application uses lightweight web technologies and optimized scripts, ensuring that the system runs efficiently without excessive CPU or GPU usage. This prevents system overheating and allows the simulation to run smoothly on standard devices.

- **Data and ML pipeline:** The system collects user interaction data such as welding angle, movement accuracy, and task completion time. This data is processed using Simple ML algorithms to generate performance feedback. JSON-based storage ensures fast data access and efficient handling of user progress records.

- **System integration:** Integration of Antigravity for 3D simulation, JavaScript for interaction logic, and JSON for data storage ensures smooth communication between system components. These technologies allow seamless interaction

between simulation environment, ML feedback module, and user interface.

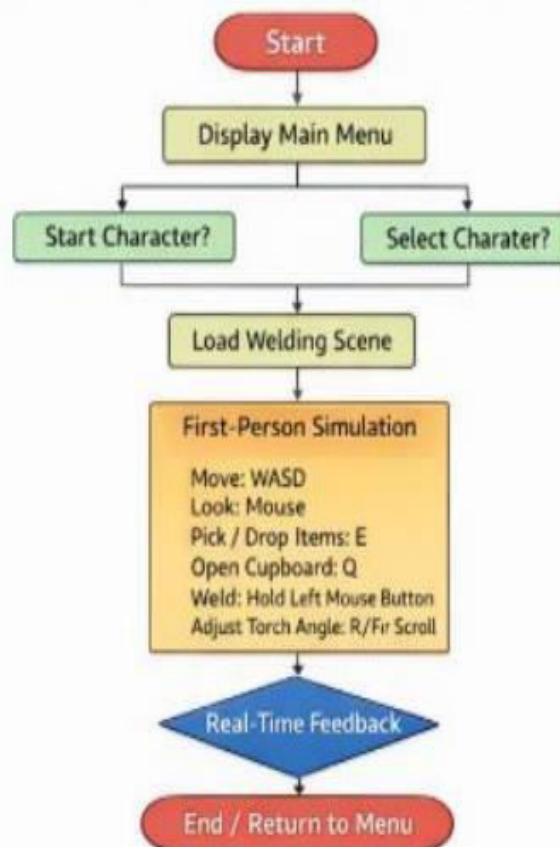
- **Maintainability and upgradation:** The system follows modular architecture, allowing developers to easily modify simulation scenarios, add new welding tasks, or improve ML feedback models. Future upgrades may include additional VR features, improved AI accuracy, and expanded training modules.
- **Familiarity:** The technologies used in the project are widely known and commonly used in web development and machine learning. Developer familiarity with UNITY GAME ENGINE ensures easy implementation, debugging, and future enhancements.

### B.2 Economic Feasibility

- **Low Development Cost:** The project uses open-source technologies such as UNITY GAME ENGINE, reducing the need for expensive licensed software. Development can be performed using standard computers without additional cost.
- **Affordable Infrastructure:** Since the application runs in a web browser, it does not require high-end VR hardware or expensive simulation equipment. This significantly reduces infrastructure cost compared to traditional welding training labs.
- **Maintenance Cost:** The modular design allows easy modification and updates in simulation logic, ML models, or interface design without requiring major redevelopment. Maintenance cost remains low because the system uses lightweight and easily manageable technologies.
- **Scalability without High Investment:** The system can be expanded by adding new welding tasks, improved ML algorithms, or enhanced simulation features without requiring significant financial investment. Additional training modules can be integrated easily using existing architecture, ensuring long-term usability and cost efficiency.

## C. Project Design

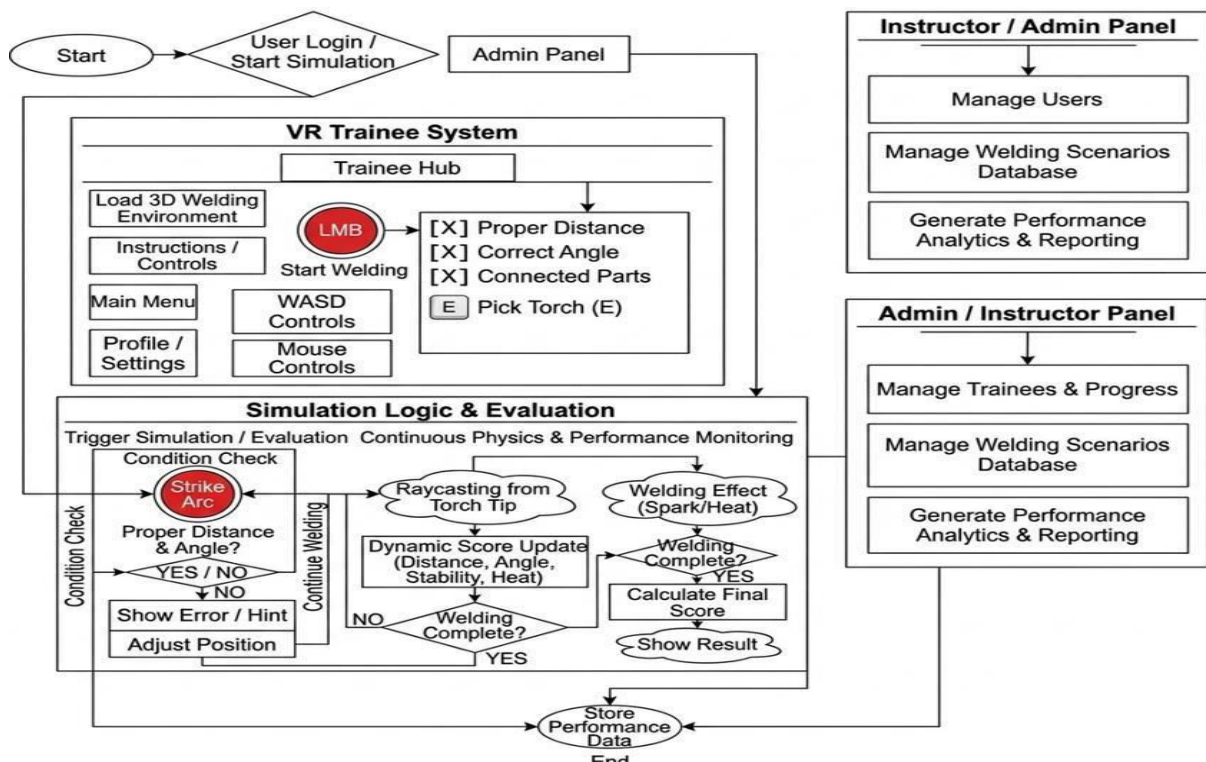
### C.1 Flow chart



1. **Start:** The process begins when the user launches the CampusShield mobile application.
2. **User Login/Register :** The user either registers a new account by entering her details (name, phone number, emergency contacts) or logs in using existing credentials.
3. **Verify Details :** The system verifies the login information by matching it with the user database.
  - If valid, the user gains access to the main menu.
  - If invalid, an error message is displayed, and the user is asked to retry.
4. **Home Page Menu (SOS, Chatbot, etc):** After successful login, the main dashboard appears with different safety options such as:
  - Emergency Call/Alert
  - AI Chatbot (Defence Tips)
  - Admin Message
5. **Emergency Call / Alert :** When the user triggers an SOS or emergency call, the system immediately sends an alert and location details to the admin and emergency services.
6. **AI Chatbot (Defence Tips):** If the user selects the chatbot option, she can ask safety-related questions. The chatbot responds with self-defence tips or short training videos stored in the database.
7. **Admin Message:** If the user feels unsafe, she can send a text message to the admin containing her current location or address. The admin receives this as a notification with an alarm sound.
  - Notify Admin / Show Tips / Send Alert + Alarm:
  - For emergency calls, the admin gets a real-time SOS notification.
  - For chatbot requests, the user receives guidance or videos instantly.
  - For unsafe messages, an alarm notifies the admin of the danger.
8. **Log Incident:** The system records every SOS alert or emergency interaction with date, time, and user details in the database for future reference.
9. **Admin Responds:** The admin can reply to SOS messages, confirm the user’s safety, or dispatch help if needed.
10. **End / Exit:** The process ends when the user closes the app or the admin marks the incident as resolved.

**IV. METHODOLOGY & IMPLEMENTATION**

**A. Block diagram of the project**



**B. Tool and Technology****1. Front-End Development**

- Technology: UNITY GAME ENGINE and WebGL
- Framework: React Native / Flutter
- Purpose : To design a user-friendly mobile interface for registration, SOS alert, and chatbot features.

**2. Back-End Development**

- Technology: Python / Node.js
- Framework: Flask or [Express.js](#)
- Purpose: To handle server-side logic, database connectivity, and API integration for location tracking and admin communication.

**3. Database**

- Technology: Firebase Realtime Database
- Purpose: To store user details, emergency contacts, SOS logs, chatbot responses, and incident records.

**4. AI and Chatbot Integration**

- Technology: UNITY GAME ENGINE
- Purpose: To implement the AI chatbot that provides defence tips and self-safety responses.

**5. GPS and Location Tracking**

- Technology: Google Maps API
- Purpose: To detect and share the user's live location with admins during emergencies.

**6. IDE and Development Tools**

- Tools: Visual Studio Code
- Purpose: For coding, testing, and deploying the mobile application.

**7. Notification and Communication**

- Technology: Firebase Cloud Messaging (FCM)
- Purpose: To send instant SMS or push notifications to registered emergency contacts or admin

**C. Key Features Implemented**

The applications core functionality is divided between the immediate, life-saving features on the User Panel and the centralized oversight provided by the Admin Panel.

**1. User Panel Core Features**

1. One tap SoS button with Location Sharing to the admin panel and emergency contacts
2. AI Self-defence chatbot that contains fighting skills, women training videos, and contact no of ambulance, police, and fire Briget
3. Emergency contact button, which can contact people
4. Siren /Loud Alarm, which should work and make noise
5. Video recording that will be sent directly to the admin and will be downloaded in the user panel, also
6. Heat maps showing the areas that are dangerous and the safe ones for the user based on their location, and also show the user in that location
7. Settings contain a black or white background and name, email ID , and phone no. Edit option also adding contact no.

**2. Admin Panel Core Features**

1. Total number of users using the app in a box, people who are offline in the second box, and the notification box
2. The notification box will go to the notification page, where the notification will come from the user. If the Sos button is tapped by the user, the video is sent by the user.
3. The User Emergency button will go to the page that will show the list of users in the critical area, the less safe area, normal area with their phone numbers.
3. CCTV access with YOLO8 technologies that detects threats and notify the admin. Add the technology to show a threat for this camera of laptop, which can be used through the admin panel

4. The community chat button allows you to join in the chat panel with other users who have logged in through the user panel.
5. The Google map location button shows another page where he can see the map with the user active, and below it, a button that can take the phone no. Also find the person with that no. On the map. The map should contain the names of places that can be zoomed in and out. Make it work using GPS.

## V. CONCLUSION

The **Virtual Reality Based Welding Simulation and Evaluation Framework for Industrial Welding Skill Training** is designed to provide a safe, interactive, and cost-effective environment for developing practical welding skills. The system goes beyond traditional theoretical learning by offering an immersive first-person simulation that allows users to practice welding techniques without exposure to real-world risks such as heat, sparks, toxic fumes, or material wastage. The strength of the system lies in its integration of real-time user interaction with intelligent performance evaluation. It effectively combines 3D simulation technology with machine learning-based feedback to analyse welding posture, torch angle, and movement accuracy, enabling learners to understand their mistakes and improve their skills continuously. The simulation environment creates a realistic workflow where users can select protective gear such as helmet, gloves, and jacket, interact with welding tools, and perform welding operations in a virtual workspace. The system processes user actions instantly and provides real-time feedback using Simple ML models, ensuring that learners receive immediate guidance on their welding performance. This continuous feedback loop helps users develop precision, consistency, and confidence in welding techniques. The JSON-based data storage mechanism maintains user performance records, allowing tracking of progress and improvement across multiple sessions. On the technical side, the modular architecture of the system ensures smooth communication between different components such as the user interface, simulation engine, machine learning feedback module, and data storage system. The use of lightweight web technologies including UNITY GAME ENGINE that the system can run efficiently on standard desktop systems without requiring expensive VR hardware. This makes the solution accessible to students, training institutes, and individuals who may not have access to physical welding laboratories. Overall, the proposed system demonstrates how virtual reality and machine learning can be effectively combined to create a modern vocational training platform. By reducing physical risks, minimizing training costs, and providing real-time skill evaluation, the system improves learning efficiency and enhances practical understanding of welding techniques. The project represents a significant step towards technology-driven skill development, where immersive simulation tools can support industrial training and bridge the gap between theoretical knowledge and practical experience.

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