SignLang: An AI-Driven Interactive Tutoring System with Gesture Recognition for Pakistan Sign Language (PSL)

Project Team

Syed Saad kabeer 22P-9032

Sana Ullah 22P-9038

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Supervised by

Dr. Muhammad Amin

Department of Computer Science

National University of Computer and Emerging Sciences

Peshawar, Pakistan

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Supervisor
Dr. Muhammad Amin Signature: _____

FYP Coordinator Signature: _____

Head of Department (Computer Science) Signature: _____

National University of Computer and Emerging Sciences, Peshawar

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Syed Saad Kabeer
Sana Ullah

Abstract

SignLang is an AI-driven interactive tutoring system designed to facilitate the learning of Pakistan Sign Language (PSL) through gesture recognition and real-time feedback. The system integrates Computer Vision and Deep Learning models to detect and evaluate hand gestures using live camera input, ensuring accurate PSL posture recognition. Recognized signs are mapped to English and Urdu text, enhancing both comprehension and communication. The web-based platform enables students and tutors to engage through interactive lessons, quizzes, and AI-assisted evaluations. By promoting standardized PSL learning and inclusivity for the deaf and hard-of-hearing community, SignLang aligns with UN SDGs 4, 9, and 10, advancing equitable education and innovation in assistive technology.

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Chapter 1

Introduction

1.1 Overview

SignLang is an AI-powered interactive learning platform that enables users to learn Pakistan Sign Language (PSL) through real-time gesture recognition and feedback. The system employs Computer Vision and Deep Learning techniques to identify and evaluate PSL gestures captured via a camera, ensuring accuracy and adherence to standardized signs. It offers a web-based interface where students can take lessons, practice signs, and complete AI-assisted evaluations, while tutors can create customized lessons, track progress, and analyze performance trends. By combining AI-driven learning, interactive assessments, and bilingual support (English, Urdu), SignLang aims to make PSL education more accessible, inclusive, and standardized for the deaf and hard-of-hearing community in Pakistan.

1.2 Motivation

In Pakistan, the **deaf and hard-of-hearing community** faces significant barriers in accessing quality education due to the limited availability of trained sign language instructors and standardized learning resources. Existing teaching methods for **Pakistan Sign Language (PSL)** are largely manual, lacking interactivity, accessibility, and real-time feedback. This gap creates challenges in effective communication and social inclusion for hearing-impaired individuals.

The motivation behind **SignLang** is to harness the power of **Artificial Intelligence (AI)** and **Computer Vision (CV)** to make PSL learning **interactive, standardized, and accessible** for everyone. By enabling real-time gesture recognition, evaluation, and guided learning through a web-based platform, the project aims to **empower learners and educators**, promote **inclusive education**, and bridge the communication divide between hearing and non-hearing communities in Pakistan.

1.3 Problem Statement

In Pakistan, the lack of standardized and accessible platforms for learning **Pakistan Sign Language (PSL)** limits educational opportunities for the deaf and hard-of-hearing community. Traditional sign language teaching methods rely heavily on manual instruction, offering minimal interactivity and no real-time feedback. This creates inconsistencies in learning accuracy and slows the adoption of PSL across institutions. Furthermore, there is limited technological integration to assess and evaluate learners' gestures effectively. Therefore, there is a need for an **AI-driven interactive tutoring system** that can recognize, evaluate, and guide PSL gestures in real time, promoting **standardized, inclusive, and efficient learning**.

1.4 Project Scope

1. Data collection and preprocessing of Pakistan Sign Language (PSL) gesture datasets.
2. Training and fine-tuning of AI models for hand gesture recognition and pose estimation.
3. Mapping recognized PSL gestures to corresponding English and Urdu text.
4. Development of an interactive web-based learning platform for students and tutors.
5. Integration of real-time feedback and performance evaluation using AI-based accuracy analysis.
6. Implementation of tutor tools for lesson creation, quiz management, and progress tracking.
7. Deployment of the system for accessibility across desktop, mobile, and Smart TV platforms.

1.5 Objectives

- Develop an AI-driven tutoring system capable of recognizing and evaluating Pakistan Sign Language (PSL) gestures in real time.
- Convert recognized gestures into corresponding English and Urdu text for better understanding and accessibility.

- Provide interactive lessons, quizzes, and AI-based feedback to enhance learning accuracy and engagement.
- Enable tutors to create, manage, and track lessons and student performance using intelligent analytics.
- Deploy the system as a responsive web-based platform accessible via desktop, mobile, and Smart TV.

1.6 Expected Outcomes

- A trained AI model for accurate PSL gesture recognition using computer vision and deep learning.
- A fully functional web-based learning platform supporting interactive PSL lessons and real-time evaluations.
- Tools for tutors to create content, manage quizzes, and monitor student progress through AI-generated insights.
- Bilingual support (English and Urdu) for improved communication and inclusivity.
- An accessible and standardized platform promoting PSL education nationwide.

1.7 SDG Alignment

- **Goal 4:** Quality Education – Ensure inclusive and equitable education for the deaf and hard-of-hearing community.
- **Goal 9:** Industry, Innovation, and Infrastructure – Promote innovation in assistive and educational technologies using AI.
- **Goal 10:** Reduced Inequalities – Empower persons with disabilities by providing equal access to digital learning tools.

Chapter 2

Review of Literature

2.1 Introduction

Sign Language Recognition (SLR) has gained significant attention in recent years as a crucial step toward bridging communication gaps between the hearing and speech-impaired communities and the rest of society. With the advancements in computer vision and deep learning, researchers have focused on recognizing hand gestures and postures to automate the interpretation of sign languages, including Pakistan Sign Language (PSL). However, challenges remain due to limited datasets, variations in lighting and background, and the complexity of continuous sign gestures.

2.2 Pakistan Sign Language Recognition

Several studies have explored PSL recognition using machine learning and deep learning techniques. Imran et al. (2021) developed a dataset for PSL and focused on recognizing hand configurations of Urdu alphabets using traditional machine learning methods. Their work laid the foundation for PSL dataset availability. Mirza et al. (2022) further enhanced recognition accuracy using a Bag-of-Words model and Support Vector Machines (SVM), proving that vision-based models can handle PSL with reasonable success.

2.3 Deep Learning Approaches in PSL

Recent work has shifted toward deep learning due to its superior performance in image and gesture recognition tasks. Hamza and Wali (2023) demonstrated the use of deep learning models for PSL recognition even with limited data, emphasizing transfer learning as a viable approach. Similarly, Arooj et al. (2024) combined Convolutional Neural Networks (CNN) with Scale-Invariant Feature Transform (SIFT) to improve feature extraction and classification accuracy in PSL datasets.

2.4 Challenges and Research Gaps

While significant progress has been made, several challenges persist. Zahid et al. (2022) conducted a systematic review highlighting issues such as inconsistent datasets, lack of standardization, and the need for real-time recognition systems. Moreover, Khan et al. (2021) discussed the broader challenges in developing PSL through information technology, including limited community engagement, insufficient linguistic resources, and lack of government-backed standardization.

2.5 Literature Review Summary

No.	Literature	Year	Methodology	Limitations
1	Imran et al.	2021	Created PSL dataset; used ML for Urdu alphabet recognition	Limited to static hand shapes
2	Mirza et al.	2022	Vision-based PSL recognition using BoW + SVM	Dependent on image quality
3	Zahid et al.	2022	Systematic review of ML classifiers for Urdu SL	Lacks implementation and real-time testing
4	Hamza & Wali	2023	Deep learning with limited PSL data using transfer learning	Dataset too small for robust models
5	Arooj et al.	2024	CNN + SIFT hybrid approach for PSL gesture recognition	Focused on static gestures only
6	Khan et al.	2021	Discussion on developing PSL using IT	Conceptual; lacks technical implementation

Chapter 3

Project Vision

3.1 Problem Statement (Revisited)

In Pakistan, the hearing-impaired community faces significant barriers to education and communication due to the limited availability of standardized and accessible learning tools for Pakistan Sign Language (PSL). Existing methods rely on manual instruction or non-interactive video tutorials, which fail to provide personalized feedback or real-time gesture evaluation. Moreover, PSL lacks a unified digital learning platform that aligns with officially recognized standards and is easily deployable across classrooms, Smart TVs, and personal devices.

3.2 Business Opportunity

- **Educational Institutions** — Schools and special education centers can integrate the system into their curriculum to promote inclusive learning.
- **Tutors and Trainers** — Instructors can create customized PSL lessons, track student progress, and receive AI-driven insights on gesture performance.
- **Students and Learners** — Individuals can practice and learn PSL interactively through real-time gesture recognition and accuracy feedback.
- **Organizations and NGOs** — Assistive technology programs can adopt this solution to train staff or provide accessible communication tools.

3.3 Goals and Objectives

The primary goal of this project is to design and develop an AI-driven, web-based tutoring system that enables real-time learning and evaluation of Pakistan Sign Language. The

objectives include:

- Implement computer vision models for gesture recognition and accuracy evaluation.
- Convert recognized signs into English and Urdu text for accessibility.
- Develop interactive modules with quizzes and assignments for student assessment.
- Enable tutors to create, manage, and evaluate lessons via a centralized portal.
- Deploy the platform on web and Smart TV interfaces to enhance accessibility.

3.4 Constraints

- **Dataset Limitations** — Lack of large-scale, standardized PSL datasets for model training.
- **Model Complexity** — Real-time gesture detection requires efficient yet accurate deep learning models.
- **Hardware Dependence** — Performance varies based on camera quality and system processing power.
- **Standardization** — PSL still lacks complete official standardization, making linguistic alignment challenging.
- **Deployment and Maintenance** — Ensuring consistent performance across multiple devices and platforms.

3.5 Expected Impact

The proposed system will have a transformative effect on the accessibility and quality of PSL education in Pakistan. It will:

- Standardize PSL learning and teaching through AI-assisted evaluation.
- Enhance inclusivity by providing equal learning opportunities to deaf and hard-of-hearing individuals.
- Empower teachers through data-driven insights on student progress.
- Encourage adoption of assistive AI technologies in the education sector.
- Contribute to the Sustainable Development Goals (SDG 4, SDG 9, and SDG 10) by promoting quality education, innovation, and reduced inequalities.

Chapter 4

Software Requirements Specifications

4.1 Overview

This chapter outlines the functional and non-functional requirements of the SignLang tutoring system. It defines the system features, use cases, user interaction flow, and activity diagrams that form the foundation for development and evaluation.

4.2 List of Features

- Real-time PSL gesture recognition using AI model.
- Interactive lesson modules and quizzes.
- Student portal for lessons, evaluation, and progress tracking.
- User authentication.
- Web-based deployment.

4.3 Functional Requirements

1. The system shall authenticate all users.
2. The system shall detect and classify PSL gestures using a camera.
3. The system shall evaluate gesture accuracy and provide real-time feedback.
4. The system shall track user progress for lessons and tests.
5. The system shall store lesson content, evaluation data, and profiles.

4.4 Non-Functional Requirements

- **Performance:** Gesture recognition must produce results within 0.5–1.5 seconds.
- **Usability:** The user interface must be responsive and accessible.
- **Scalability:** Capable of supporting multiple simultaneous users.
- **Security:** Passwords encrypted; role-based access enforced.
- **Reliability:** System uptime must exceed 95%.
- **Compatibility:** Works on desktop, mobile, and Smart TV browsers.

4.5 Use Cases

- **Use Case 1: User Login** – User logs in with email/password.
- **Use Case 2: Lessons with PSL Signs** – Student practices correct signs of PSL language, related to their course content.
- **Use Case 3: Attempt Quiz** – Student attempts PSL accuracy-based quiz, to verify their knowledge for the course material as well as correct PSL gestures.
- **Use Case 4: Track Progress** – System displays performance analytics.

4.6 User Interaction Flow

4.6.1 User Login and Authentication

1. User enters credentials.
2. System verifies user identity.
3. User is redirected to student/tutor dashboard based on role.

4.6.2 Query Submission and Analysis

1. User starts sign test.
2. Camera captures hand gesture in accordance to the word.
3. AI model processes gesture and predicts PSL sign.

4. UI displays recognized sign and accuracy.

5. If the predicted Sign is correct, user moves onto another word or question.

4.7 Response Generation

- AI model returns predicted label.
- System calculates accuracy percentage.
- Feedback is displayed visually and textually.

4.8 Activity Sequence

- User logs in.
- Selects lessons from the dashboard.
- Starts course lessons with PSL gesture recognition.
- AI model detects hand pose in accordance to words.
- Accuracy and feedback shown on screen for the selected word.

Chapter 5

Iteration Plan

5.1 Overview of Iterations

The development of SignLang follows an incremental and iterative model. Each iteration delivers functional components, allowing evaluation, testing, and refinement.

- **Iteration 1:** System design, architecture, diagrams, basic UI layout.
- **Iteration 2:** Prototype of, Gesture recognition model and Web UI.
- **Iteration 3:** Finalization of Web Interface and full lesson and quiz module, along with complete AI model.
- **Iteration 4:** Analytics, optimization, deployment.

5.2 System Architecture Overview

The system adopts a modular architecture consisting of:

- Frontend (Next.js web interface)
- Backend (Node.js / Express APIs)
- AI Model Server (Python/MediaPipe/TensorFlow/PyTorch)
- Database (Supabase)

5.3 Query Flow Representation

1. User performs a PSL gesture.
2. Camera feed is streamed to AI Recognition API.

3. AI model returns predicted sign.

4. User interface displays result and confidence score.

5.4 Data Flow in the System

1. User data stored in database .

2. Lesson and quiz data delivered to frontend on demand.

3. Tutor dashboards retrieve all lessons made for students.

Chapter 6

Iteration 1

6.1 Objectives Achieved

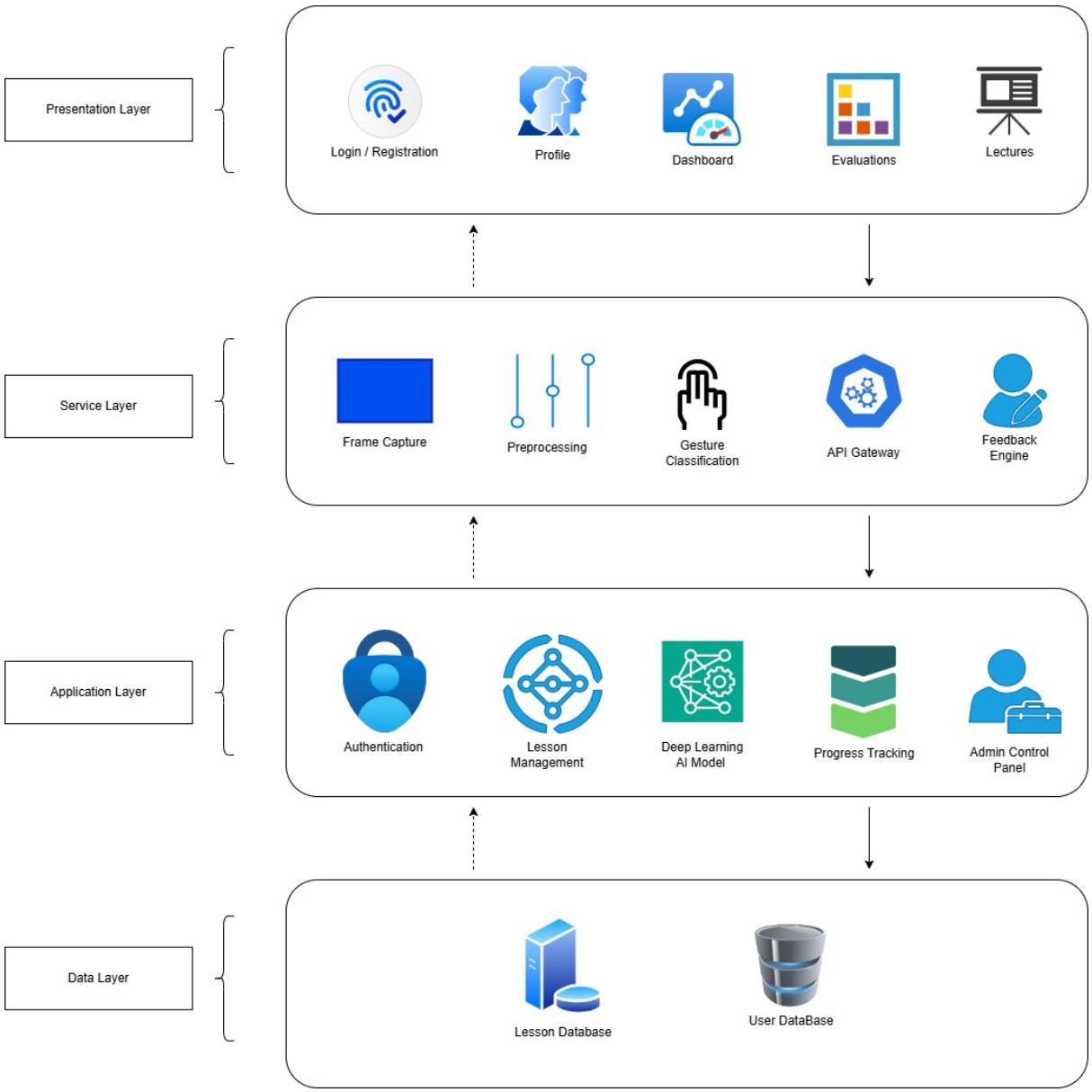
- Defined system architecture.
- Created prototype Web UI.
- Created user login / registration.
- Made a prototype user dashboard with Test, Lessons and Profile options.
- Built prototype AI model for PSL character recognition.
- Developed initial architectural diagrams.

6.2 Structural Design

6.2.1 System Architecture

The system layered architecture illustrates interactions between:

- Presentation Layer: Web Interface (Front-end)
- Service Layer: Backend Server / API Layer
- Application Layer: AI Model Module
- Data Layer: Database Management System

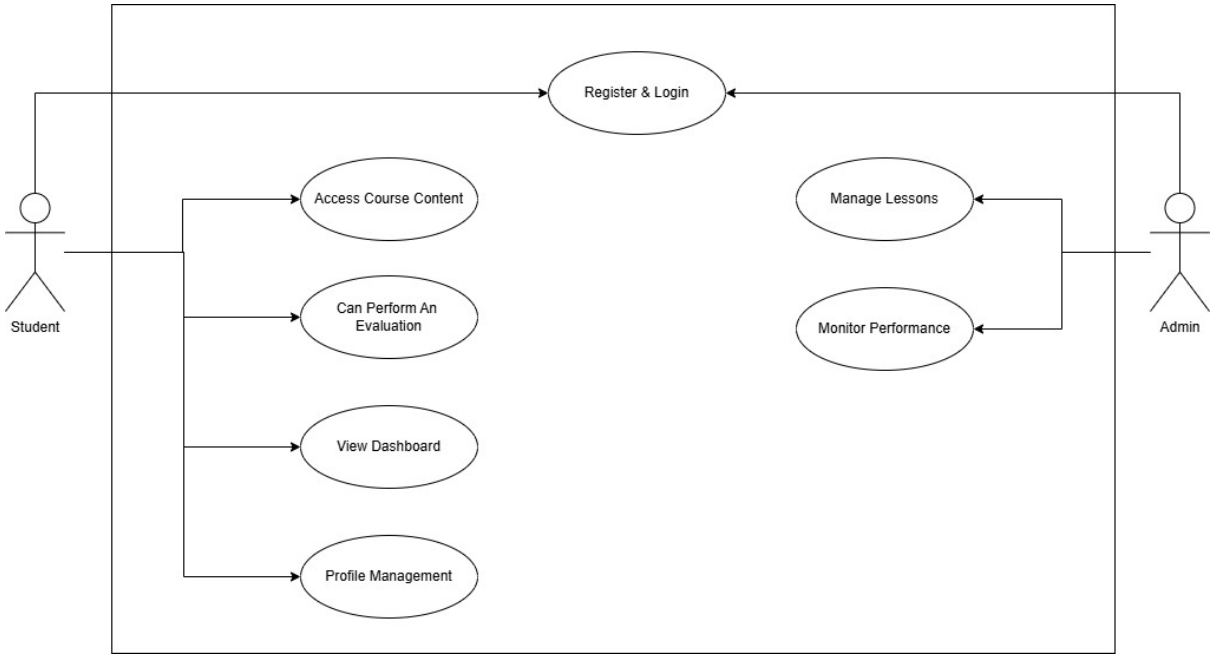


6.2.2 Use Case Diagram

The primary actors are:

- User (Student + Tutor)
- Admin

Use cases include login, gesture recognition, quiz interaction, lesson creation, and progress monitoring.

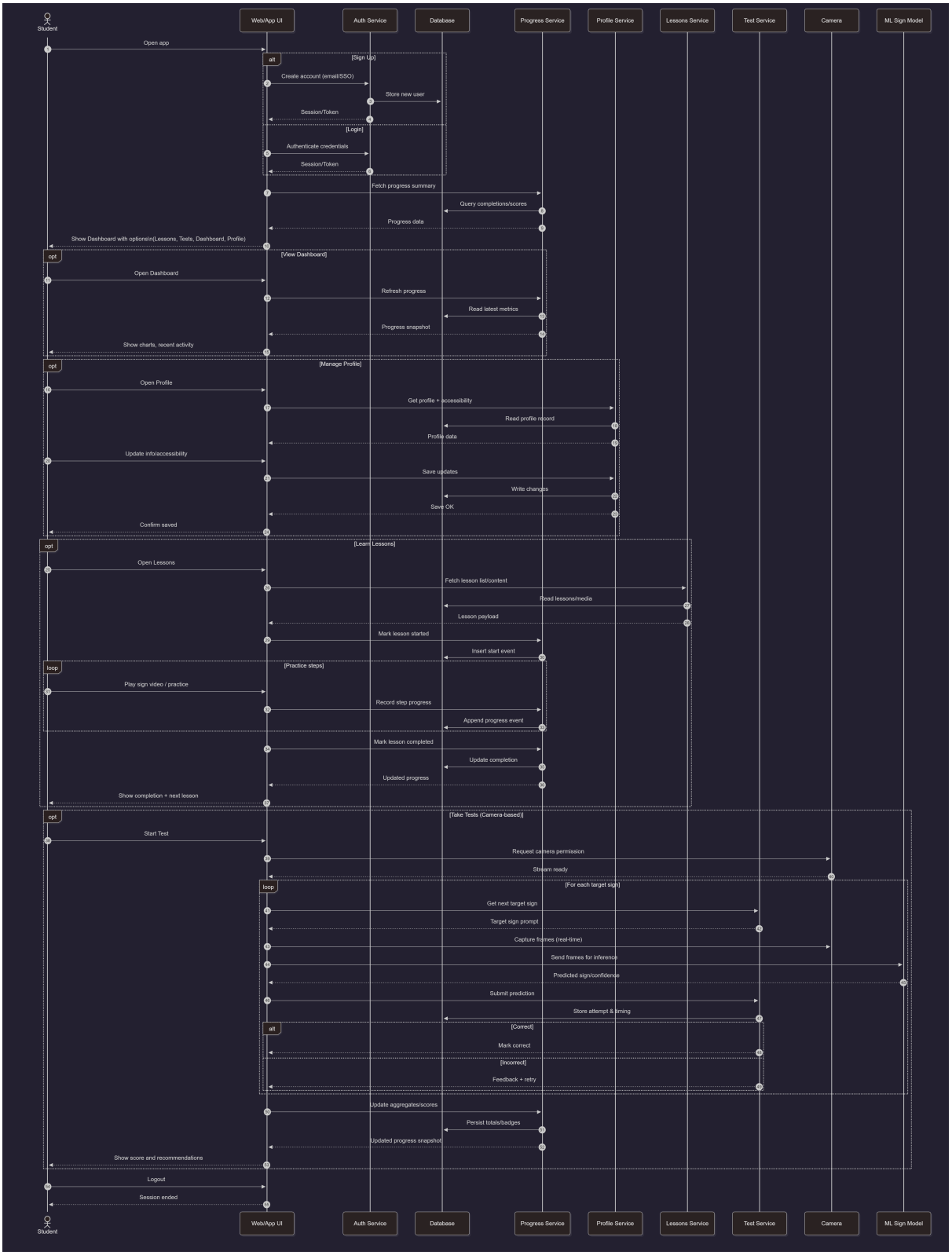


6.3 Behavioral Design

6.3.1 Sequence Diagram

The sequence consists of:

1. User requests gesture evaluation.
2. Camera captures input.
3. AI model predicts gesture.
4. System sends back recognized sign + accuracy.



6.3.2 Activity Diagram

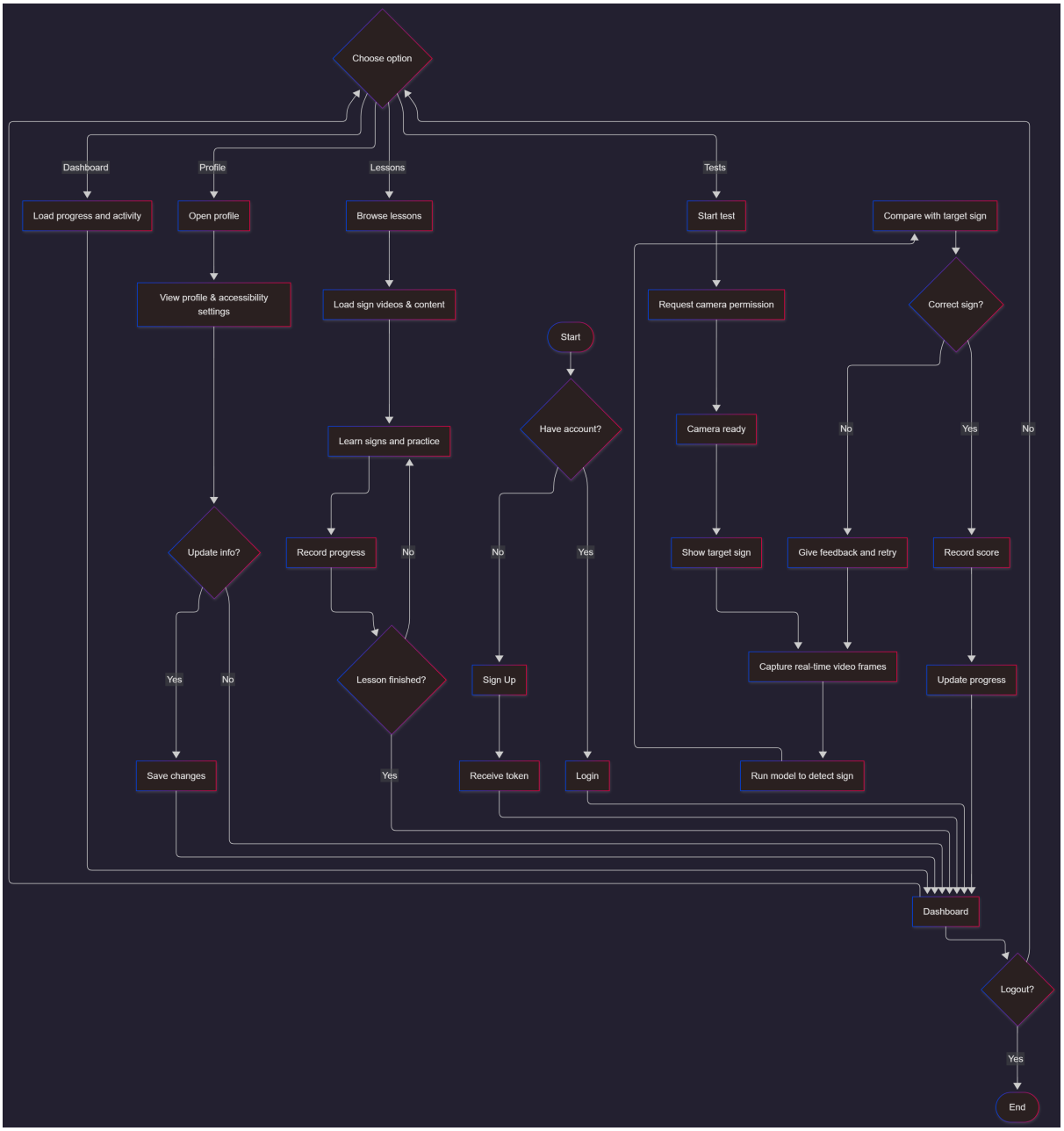
The activity flow includes:

1. Start recognition.

2. Capture frames.

3. Process gesture.

4. Evaluate and display results.



6.4 Data Flow Representation

Iteration 1 includes preliminary data flow diagrams showing the movement of gesture data, system requests, and analytics.

6.5 Iteration Summary

Iteration 1 established the core foundation for system development, including architecture, requirement gathering, structural design, and workflow modeling. These components provide a stable groundwork for implementing gesture recognition and interactive learning modules in future iterations.

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