Digital Twin

Software Requirement Specifications part 1
presented to the academic faculty
by

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1 Introduction

1.1 Purpose

The purpose of this document is to outline the Software Requirements Specification (SRS) for the Digital Twin project for Habib University's Projects Lab and Digital Instrumentation Lab. This document provides a comprehensive overview of the functional requirements, non-functional requirements, use cases, system architecture, and technical specifications for our project.

This SRS serves as the foundational blueprint for developing a digital twin that integrates real-time crowd monitoring, energy management insights, and emergency alerts into a unified platform. The digital twin will provide campus management with live 3D visualization, enabling data-driven decision making for space utilization, energy efficiency, and safety preparedness.

1.2 Scope

The scope of this project is to develop a proof-of-concept digital twin system for two adjacent university laboratory spaces: the Projects Lab and the Digital Instrumentation Lab on the lower-ground floor. The system addresses three critical challenges in campus management that are traditionally handled separately: occupancy monitoring, emergency preparedness, and energy efficiency.

The digital twin will perform real-time, anonymous crowd counting using vision-based analysis of video segments. Occupancy data will be visualized in a 3D virtual environment using avatars and crowd-density heatmaps, providing an intuitive interface for monitoring space usage. The system will automatically generate alert notifications for security personnel during emergency or evacuation scenarios, identifying spaces that remain occupied to support faster, coordinated responses. Additionally, the system will integrate simulated IoT data - such as temperature and lighting - with real-time occupancy levels to identify inefficiencies like lighting or cooling systems operating unnecessarily in empty rooms.

2 Functional Requirements

This section describes each function/feature provided by our system. These functions are logically grouped into modules based on their purpose as well as intended users.

- **User Authentication & Role Management:**
  - The system will enforce Role-Based Access Control (RBAC). Roles include:
    - **Security Admin (Super Admin)** – Includes personnel from:
      - Office of Security, Safety and External Affairs

· Safety and Control Room

These users are granted full administrator access to all system modules.

* **Facilities Manager** – Responsible for managing air-conditioning and other infrastructure-related issues. They are granted access to the Energy Management dashboard.
* **Security Officer (CSO)** – Secondary users who receive emergency alert notifications via email. Their access is limited to alerts and occupancy updates in the event of emergencies.

– Users shall log in with verified credentials, ensuring that only authorized users created by the Security Admin can access the system.

– Admins shall be able to assign Campus Security Officers (CSOs) as secondary users responsible for receiving emergency alert notifications via email.

- **Security & Crowd Management Module:**

  – **Crowd Monitoring & Digital Twin Visualization:**

    * The system will represent both the laboratories as spatially accurate 3D digital twins.
    * The system will detect and track individuals through CCTV camera feeds using computer vision algorithms (YOLOv8 and Byte Tracking).
    * Detected individuals shall be mapped in real time onto the 3D digital twin as anonymous avatars, reflecting their movement and location while preserving privacy.
    * The digital twin will compute and update occupancy counts for both labs in near real time and generate heatmaps to visualize crowd density.

  – **Emergency Detection & Alerts:**

    * On declaration of an emergency, the system shall detect and identify occupied spaces that have not been fully evacuated.
    * The system will send alert notifications to designated security personnel (CSOs) to report these occupied spaces, including real-time location and occupancy details to support efficient response.

- **Energy Management Module:**

  - **Sensor Data Monitoring:**
    * The system will continuously access and update simulated IoT sensor data such as temperature and lighting status for both labs.
  - **Energy Correlation & Anomaly Detection:**
    * The system will correlate occupancy data with temperature and lighting data, flagging rooms exceeding a threshold unoccupancy time of 25 minutes.
    * The system will also detect anomalies when the temperature in a room exceeds or falls below defined threshold limits, ensuring proper temperature regulation and energy efficiency.
  - **Energy Management Dashboard:**
    * The dashboard will be a dedicated tabular interface displaying only flagged rooms or laboratories where energy inefficiencies are detected.
    * Each row in the table will display the current temperature and lighting values, and occupancy count.
    * Each flagged state shall persist until the next cycle of sensor data verifies that conditions have returned to normal.

- **Security Admin Module:**
  - The system shall provide the Security Admin with full access to all modules, including crowd monitoring via the digital twin and the energy management dashboard.
  - The admin shall be able to declare or end emergencies, triggering automatic detection of occupied spaces and alert notifications to designated Security Officers.
  - The admin shall be able to edit notification recipient lists, including adding or removing Security Officers' email addresses.
  - The admin will be able to manage access of all the users of the system (e.g., Facilities Managers).

- **Facilities Manager Module:**
  - The Facilities Manager will have access only to the Energy Management dashboard of the application.

- Upon login, the Facilities Manager shall be directed to a personalized dashboard summarizing current energy-related anomalies and showing the flagged labs currently violating configured thresholds.
- The Facilities Manager shall be able to filter flagged rooms by specific room or location.

2.1 Use Case Diagrams

2.1.1 User Authentication and Role Management Module (Figure 1)

This use case enables the Facilities Manager and Security Admin to manage and authenticate users within the system. The Log In process includes Verifying Credentials, which checks the authenticity of user credentials. If there is an issue during login, the system handles the errors through Error Handling for Login. Once logged in, the system Retrieves Role Data to assign the correct permissions and roles to users.

One key feature is the Manage Users and Roles functionality, allowing the Security Admin to organize user access levels and roles, so that only authorized personnel have specific system privileges. Specifically, the Facilities Manager can only access the Energy Dashboard. Additionally, the Manage Email Recipients List allows the admin to grant certain CSOs the ability to receive notifications particularly in the event of a triggered Emergency. The Store User Data and Roles functionality stores the user's credentials and role-specific data for seamless access and operation.

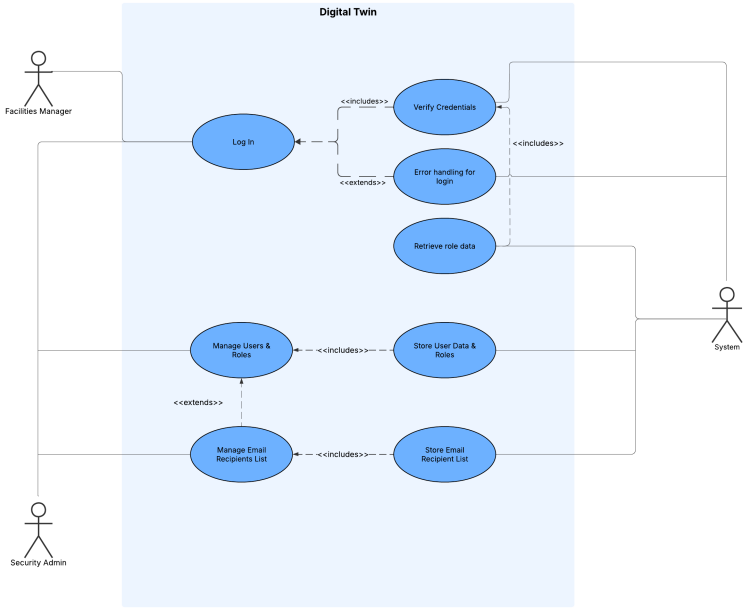

Figure 1: Use case 1: User Authentication and Role Management

2.1.2 Facilities Monitoring Module (Figure 2)

This use case enables the Facilities Manager to effectively monitor and manage energy efficiency across campus facilities. The primary function, Monitor Flagged Rooms, allows the Facilities Manager to view flagged rooms. This process includes Display IoT Data, where the system presents real-time temperature, lighting, and occupancy readings, and Detect and Flag Rooms with Energy Anomalies, which identifies spaces exceeding the defined thresholds. Additionally, the Filter Metrics Based on Different Rooms use case enables the Facilities Manager to apply a room type filter to the flagged rooms table. The Display Filtered Table functionality ensures that only filtered information is presented.

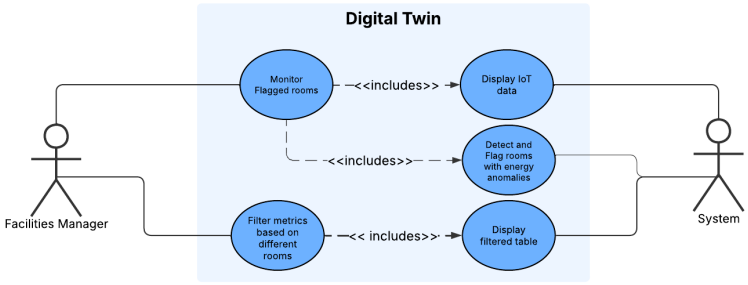

Figure 2: Use case 2: Monitoring Facilities

2.1.3 Crowd Monitoring and Emergency Handling Module (Figure 3)

This use case provides the Security Admin with comprehensive tools for monitoring crowds and managing emergencies within the system. The View Avatars on Digital Twin allows real-time visualization of crowd movements on a 3D digital replica of the monitored area, integrating with Crowd Detection (YOLOv8 + ByteTrack) for accurate monitoring.

Key features include the ability to View Occupancy Count, which displays the number of people present in a particular area, and the View Crowd Heatmap, a visual representation that shows the density and flow of individuals across the space.

In case of emergency situations, the system allows the Security Admin to Declare Emergency, triggering necessary alerts and protocols. The system can Detect Un-Evacuated Spaces, ensuring the safety of all individuals in the monitored area. Alerts are sent via Send Alert Emails to Designated Security Officers to ensure swift action. Once the situation is under control, the End Emergency function deactivates the emergency protocols.

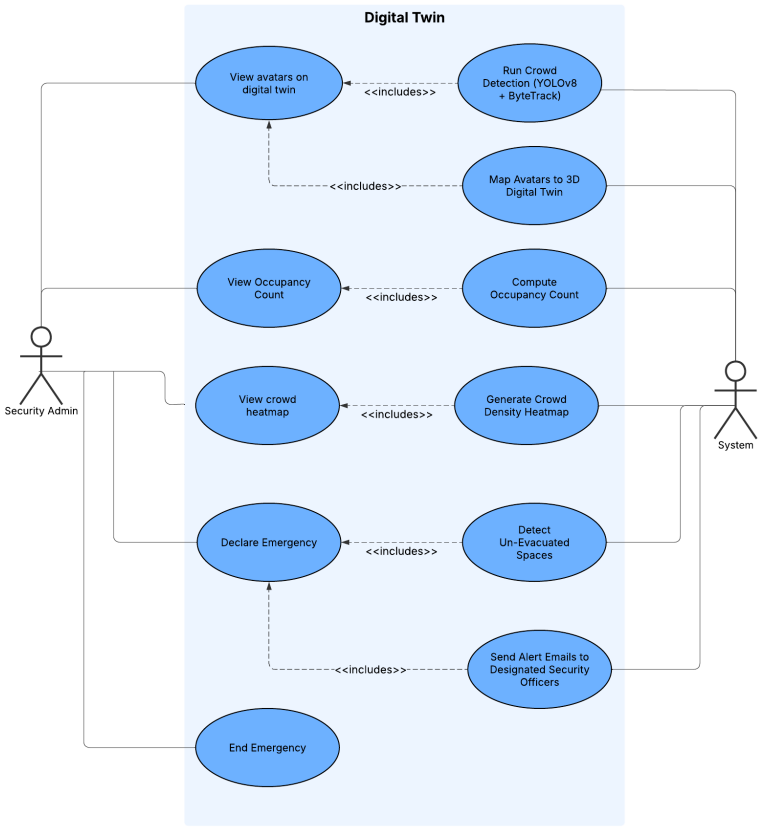

Figure 3: Use case 3: Crowd Monitoring and Emergency Handling

3 Non Functional Requirements

This section specifies the non-functional requirements of our system, specifically addressing performance, reliability, security, usability, accuracy, and compliance.

- **Performance:**
  - **Real-Time Responsiveness:** The system should process and update crowd monitoring and sensor data on the dashboard in real-time with a latency of no more than 2–3 seconds.
  - **Efficient Data Processing:** The model shall process video frames at a minimum of 10–15 FPS in normal operating conditions.

  - **Scalable Data Throughput:** The system shall handle simultaneous data streams from 6 CCTVs and 1 hour of simulated IoT sensor data without too much degradation in performance.

- **Reliability:**
  - **System Uptime:** The system should have a minimum uptime of 99% during operational hours.
  - **Data Integrity:** The system should ensure that all transmitted sensor and crowd data are accurately recorded without duplication or loss.

- **Security:**
  - **Authentication and Access Control:** Only authorized users (admins, facility managers) shall access respective dashboard sections. All logins shall be password-protected.
  - **Secure Communication:** All data communication between cameras, simulated IoT devices, and servers shall use encrypted channels (HTTPS).

- **Usability:**
  - **Intuitive Interface:** The dashboard shall have a clean, user-friendly design, easily understandable by non-technical staff (security and facility personnel).
  - **Interactive Visualization:** The 3D digital twin view shall allow zooming, rotating, and panning interactively.
  - **Alert Accessibility:** Alerts and notifications shall be visually highlighted in the notifications panel for admins in the event an individual(s) is detected in a room during an emergency.

- **Accuracy & Precision:**
  - **Counting Accuracy:** The people detection system shall achieve at least 85% accuracy under normal lighting and camera angles.

- **Compliance:**
  - **Data Privacy:** Camera feeds and crowd data shall not store or display personally identifiable information (PII). Individuals will be represented with anonymous avatars, thus conforming with ethical AI and data privacy guidelines (particularly GDPR).