Boston University
Electrical & Computer Engineering

EC463 Capstone Senior Design Project

Problem Definition and Requirements Review

Smart Home Control System

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Client Sign-Off ______________________________

Smart Home Control System (Domus)

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Project Summary

The Smart Home Control and Security System with industrial IoT and LLM integration focuses on designing and implementing an innovative smart home system. The product ensures real-time security and privacy through edge-computing, also preventing potential data loss. Raspberry Pi allows us to have a basic platform to test the initial functionality of the sensors; however, this will be enhanced via mobile app development where we plan on using either Swift or Android Studio to create a personalized UI. The Raspberry Pi will act as the central unit, with Coral AI boards supporting the LLM-driven processing. Overall, this project provides a comprehensive management over everyday home devices in addition to smart features such as theft detection, energy consumption suggestions, and greater privacy via edge-computing.

1 Need for this Project

Modern homes suffer from the trouble of distributed automation systems such as one for security, one for energy management, etc. As many solutions currently in the market operate independently from one another, such as Google Nest for smart home devices and ADT service for security, leading to an efficient user experience. In addition, almost all products in the market rely heavily on cloud-based services, which tend to increase service disruptions and could cause data loss, making the home management cumbersome and complex for most users.

As the world is moving towards a more convenient route and focus on streamline processes is now more than ever, customers tend to demand seamless control without complex setup and expect real-time insights regarding energy consumption in order to make informed decisions. Privacy is also a major concern in today's world and users are becoming more skeptical of sharing their data with systems on the market.

This project addresses these challenges by developing a unified smart home platform using Raspberry Pi and Coral AI boards, integrating automation, security, and energy management. It leverages edge computing for fast, reliable control without cloud reliance, enhancing efficiency and privacy. With industrial IoT integration, the system offers advanced automation and real-time monitoring of energy use and air quality, while also ensuring data integrity. This solution empowers users to manage their homes efficiently while promoting a more sustainable future.

2 Problem Statement and Deliverables

Problem Statement

This project solves the need for a smart home system offering real-time control and security with enhanced privacy by integrating edge-computing, offering a one-stop solution.

Deliverables:

Hardware:

- A Raspberry Pi-based central unit integrated with sensors (for security, environmental monitoring, and automation) and connectivity modules (Wi-Fi, Bluetooth, Zigbee).
- Actuators and devices (e.g., smart locks, lights) connected to the system to demonstrate home automation capabilities.

Software

- A control application with a user-friendly interface for managing devices, security alerts, and energy monitoring.
- A locally deployed LLM to process voice commands, ensuring privacy and seamless operation without cloud dependency.
- Automated routines for air quality, energy tracking, and real-time alerts for security events.

Data and Simulation

- **SystemC simulation results** demonstrate the system's performance, including the interaction between hardware and software components.
- Predictive models for energy tracking and security scenarios tested through simulations to validate system behavior under different conditions.
- Logs and metrics for data-driven insights, showcasing the efficiency of edge computing and offline functionality.

3 Visualization

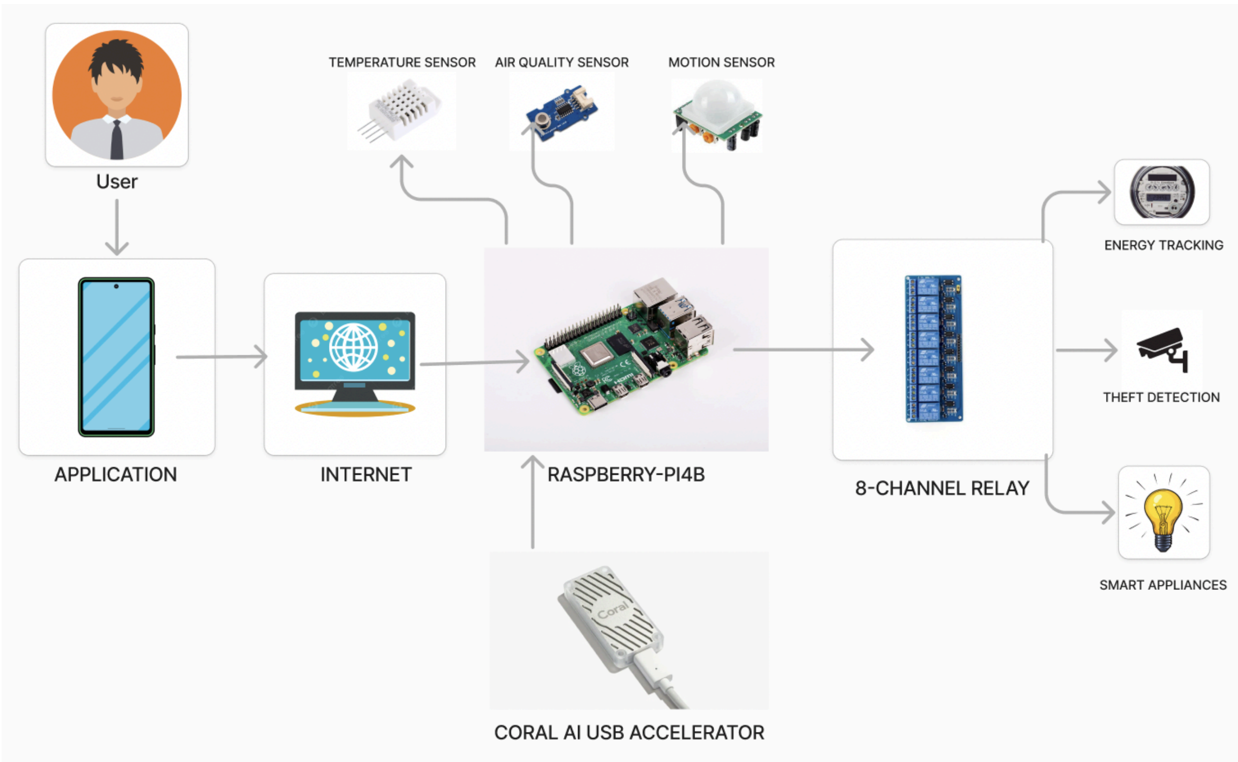

Figure 1: Hardware and Communication Flow

This figure illustrates the interactions between the user, application, and hardware components in the Smart Home Control and Security System. It demonstrates how the Raspberry Pi 5 serves as the central hub, integrating sensors (temperature, air quality, and motion), and controlling smart appliances and security features through an 8-channel relay. The Coral AI USB Accelerator enhances processing efficiency, supporting LLM-based automation. Communication flows through the internet and application interface, enabling real-time monitoring, energy tracking, and theft detection.

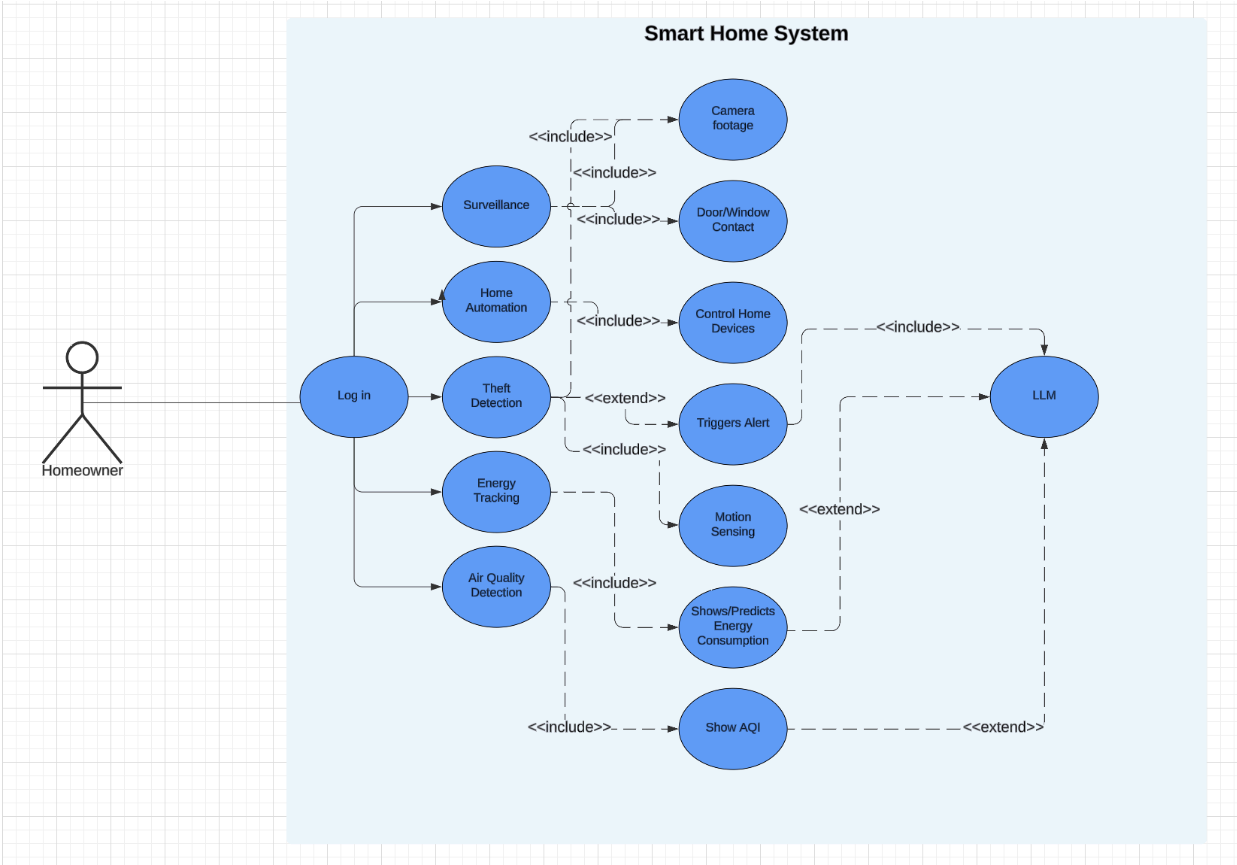

Figure 2: Use-Case UML Diagram

This diagram illustrates the interactions between the homeowner and the various components of the smart home system. Key features include surveillance, home automation, theft detection, energy tracking, and air quality monitoring, all managed through a unified platform. The Large Language Model (LLM) provides enhanced automation and control, integrating with modules such as motion sensing and device management. Edge computing ensures seamless, real-time processing with minimal cloud dependence, promoting privacy and efficiency.

4 Competing Technologies

This section highlights competing technologies addressing similar challenges to our Smart Home System, which integrates automation, security, energy tracking, and air quality monitoring with a focus on privacy. Key competitors influenced our design choices, as outlined below:

Google Nest

- **Overview:** Cloud-based smart home ecosystem with AI-driven automation.
- **Key Features:**
  - Cloud infrastructure for control and analytics
  - Smart energy management via thermostats and appliances
  - AI-based behavior learning and automation
  - Centralized control through Google Home app
- **Design Insight:** Inspired by Nest's energy tracking, we incorporated predictive energy models. To address cloud-related privacy and latency concerns, we used edge computing for offline functionality.

Amazon Alexa

- **Overview:** Voice-controlled smart home platform with extensive device support.
- **Key Features:**
  - Voice-based control
  - Broad third-party interoperability
  - Routine automation via cloud services
  - Continuous learning for better voice recognition
- **Design Insight:** Alexa's broad compatibility led us to support Wi-Fi, Bluetooth, and Zigbee. Inspired by seamless voice control, we integrated a local LLM to enhance privacy with cloud-independent operations.

Home Assistant

- **Overview:** Open-source platform offering flexible, local control with minimal cloud reliance.
- **Key Features:**
  - Community-driven customization
  - Support for multiple protocols (Wi-Fi, Zigbee, Bluetooth)
  - Local control for enhanced privacy
  - Integration with third-party services

- **Design Insight:** We adopted Home Assistant's flexibility for broad protocol support while adding advanced security features like theft detection. Our edge-computing approach aligns with its local control for privacy and offline capability.

Apple HomeKit

- **Overview:** Privacy-focused ecosystem with secure communication and limited third-party integrations.
- **Key Features:**
  - End-to-end encryption
  - Centralized control via the Home app
  - Controlled ecosystem with limited external device support
- **Design Insight:** Inspired by HomeKit's focus on privacy, we implemented secure communication while supporting broader interoperability than Apple's closed system.

Relevant Standards and Patents

- **Key Features:**
  - **IEEE IoT Standards:** Ensure interoperability across Wi-Fi, Bluetooth, and Zigbee.
  - **ISO Smart Home Standards:** Provide security and automation frameworks.
  - **Patents:** Emphasize energy management and edge computing best practices.
- **Design Insight:** Compliance with these standards ensures compatibility and security, while patents inspired our predictive energy tracking models for efficiency.

This comparison guided our system's development, ensuring it remains privacy-focused, flexible, and compliant with industry standards.

5 Engineering Requirements

Performance Objectives:

- Response time: < 200ms
- Security detection accuracy: > 95%
- LLM inference: < 500ms per command
- Compliance with Wi-Fi, Bluetooth and Zigbee devices

Constraints:

- The system must operate efficiently on a Raspberry Pi platform (core) parallel to Coral AI boards
- Local LLM model RAM usage must not exceed 500MB
- The system should handle up to 30 connected devices at maximum capacity
- Must comply with data privacy regulations, limiting external data transmission as the system is mainly based on edge computing

Functions:

- Automation: Real-time control of multiple parallel devices
- Surveillance: Real-time monitoring through cameras and motion sensors
- Energy Management: Analyze trends and suggest optimizations for energy use
- Air Quality Monitoring: Alert users when AQI exceeds safe thresholds

Means:

- Raspberry Pi 5B: Serves as the core between all home automation activities, theft detection and energy tracking
- Coral AI USB accelerator: Supports computational demands to run locally on raspberry pi for reduced response time
- Zigbee Devices: Used for collecting energy consumption data from home appliances
- Sensors and Camera: Real time data collection by object detection and motion recognition

6 Appendix

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