System Requirements Specification (SRS)

Project Name: Smart Data Center Guardian (IoT & AI Monitoring System) **Version:** 2.1
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1. Introduction

1.1 Purpose

The purpose of this document is to define the functional and non-functional requirements for the "Smart Data Center Guardian." This system is designed to monitor critical server room parameters (environmental and electrical) and provide AI-driven physical security. It serves as a comprehensive solution to prevent equipment failure, fire hazards, and unauthorized access in data centers.

1.2 Scope

The system utilizes a central IoT Gateway (Raspberry Pi 4) to interface with sensors and control actuators. It features:

- **Environmental Safety:** Monitoring temperature, humidity, and smoke/gas levels.
- **Electrical Reliability:** Monitoring current draw to detect overloads or failures.
- **Physical Security:** An Edge AI model for personnel tracking (entry/exit timing).
- **Remote Observability:** A cloud-based dashboard for real-time data visualization and historical logging.

1.3 Definitions and Acronyms

- **Edge Computing:** Processing data locally on the Raspberry Pi rather than sending raw streams to the cloud.
- **MQTT (Message Queuing Telemetry Transport):** Lightweight messaging protocol for IoT.
- **PDU (Power Distribution Unit):** The device fitting multiple outputs designed to distribute electric power to racks.
- **SRS:** System Requirements Specification.

2. Overall Description

2.1 Product Perspective

This system operates as a distributed IoT network. The Raspberry Pi acts as the local controller (Edge Node), handling immediate decision-making (fan control, alarms) and AI processing. The Cloud Platform acts as the long-term storage and visualization layer.

2.2 System Architecture & Data Flow

To ensure reliability and low latency, the system architecture is defined as follows:

2.2.1 AI Model Deployment (Edge Processing)

The AI model for personnel tracking shall run locally on the Raspberry Pi 4 (Edge).
Justification:

- **Latency:** Security alerts for unauthorized access must be real-time. Cloud round-trip time is too slow for intrusion alarms.
- **Bandwidth Efficiency:** Streaming 24/7 HD video to the cloud is bandwidth-prohibitive. The Pi will process video locally and only transmit metadata (e.g., "Person detected: 12:00 PM") to the cloud.
- **Privacy:** Raw video footage of sensitive server areas remains on the local network.

2.2.2 Cloud Data Topology

The data transmission pipeline follows a Publish-Subscribe model:

1. **Acquisition:** Sensors read data; the AI model processes frames.
2. **Transmission:** The Raspberry Pi bundles data into JSON payloads and publishes them via MQTT to a Cloud Broker (e.g., AWS IoT Core or HiveMQ).
3. **Storage:** A cloud backend service subscribes to these topics and persists data into:
    - **Time-Series Database (InfluxDB):** For continuous sensor readings (Temp, Amps).
    - **Relational Database (PostgreSQL):** For event logs (Entry/Exit times, Alarms).
4. **Visualization:** The Web Dashboard fetches data from the cloud databases via REST API to display real-time gauges and historical graphs.

3. Specific Requirements

3.1 Hardware Interface & Sensor Deployment

This section defines the sensor requirements, contrasting the Prototype implementation with Production standards.

3.1.1 Sensor Placement Strategy

- **Temperature (AM2320)**

    - **Real-World Placement:** 3 per Rack: Intake (bottom), Intake (top), and Exhaust (rear) to measure "Delta T".
    - **Prototype Implementation:** 1 Unit placed near the heat source.
- **Smoke/Gas (MQ-2)**
    - **Real-World Placement:** Ceiling & Return Air: Mounted on the ceiling above hot aisles and inside AC return vents.
    - **Prototype Implementation:** 1 Unit placed centrally in the enclosure.
- **Current (ACS712)**
    - **Real-World Placement:** PDU Level: Installed inside the Rack PDU to monitor total power draw per rack.
    - **Prototype Implementation:** 1 Unit (5A) in series with the load.
- **Camera (Pi Cam)**
    - **Real-World Placement:** Man-Trap / Entry: Mounted facing the main entry door to capture faces upon entry.
    - **Prototype Implementation:** 1 Unit facing the monitored area.

3.1.2 Sensitivity & Range Specifications

A. Current Sensor Requirements

- **Context:** Standard server racks typically draw between 16A (3.6kW) and 32A (7.2kW). High-density GPU racks may draw up to 60A.
- **Production Requirement:** The production sensor must utilize a Split-Core Current Transformer (CT) with a range of 0–100A and 1% accuracy.
- **Prototype Exception:** The prototype uses an ACS712 (5A) sensor suitable for measuring low-power demonstration loads (< 1A).

B. Temperature Sensor Requirements

- **Context:** The ASHRAE recommended range for server rooms is 18°C to 27°C.
- **Production Requirement:** The sensor must have a resolution of 0.1°C and a response time of < 2 seconds to detect rapid thermal runaway.
- **Prototype Exception:** The prototype uses the AM2320 sensor which communicates via I2C.

C. Smoke & Gas Sensor Requirements

- **Context:** In a production environment, "Early Warning Fire Detection" (EWFD) is critical. Systems must detect the chemical signature of overheating components (cable jacketing off-gassing) before visible smoke or flames appear.
- **Production Requirement:**
    - **Sensitivity:** The sensor must detect smoke obscuration levels as low as 0.05% to 2.0% per foot (obs/ft).
    - **Target Gases:** Must detect Carbon Monoxide (CO) and thermal decomposition particles.

    - **Latency:** Response time must be < 10 seconds from gas release to alarm trigger.
- **Prototype Exception:** The prototype utilizes an MQ-2 Gas Sensor.
    - **Range:** Detects combustible gas concentrations from 300 ppm to 10,000 ppm.
    - **Mechanism:** Uses an electrochemical sensor (SnO2) rather than optical aspiration. It is sufficient for demonstrating the logic of "threshold breach -> alarm".

D. Visual Surveillance (Camera) Requirements

- **Context:** For the AI model to accurately perform "Personnel Tracking" (Face Detection or Person Re-identification), the input image must have sufficient pixel density and clarity, even in varying lighting conditions.
- **Production Requirement:**
    - **Resolution:** Minimum 1080p (1920x1080) to ensure facial features are recognizable from a distance of 5 meters.
    - **Field of View (FOV):** Minimum 90° to 110° wide-angle lens to cover the entire server room entrance (Man-Trap) without blind spots.
    - **Low Light:** Must support IR (Infrared) Night Vision (0 Lux sensitivity with IR On) for 24/7 monitoring.
- **Prototype Exception:** The prototype utilizes the Raspberry Pi Camera Module v1.3.
    - **Specs:** 5 Megapixels, 1080p @ 30fps.
    - **Limitation:** It lacks an IR-Cut filter (No Night Vision) and has a standard FOV (~54°), which is acceptable for a controlled demo environment but would require an upgrade for a dark server room deployment.

3.2 Functional Requirements

3.2.1 Environmental & Safety Monitoring

- **FR-01:** The system shall read Temperature and Humidity data every 2 seconds via the I2C protocol.
- **FR-02:** The system shall read Smoke and Current levels via the MCP3008 ADC using the SPI protocol.
- **FR-03 (Automated Cooling):** If Temperature > Threshold, the system shall activate the cooling fan via GPIO18 (PWM).
- **FR-04 (Safety Interlock):** If Smoke > Threshold, the system must trigger the Buzzer (GPIO17) and immediately publish a "CRITICAL_FIRE" event to the cloud.

3.2.2 AI-Based Personnel Tracking

- **FR-05 (Entry Detection):** The AI model, using a lightweight YOLO model (e.g., Tiny YOLO), shall identify when a "Person" object enters the camera frame. The system shall then log the Entry_Timestamp for the detected entry.

Enhancement: The lightweight YOLO model will detect and track the presence of human figures in the video feed with optimized real-time processing on edge devices, such as a Raspberry Pi 4.

- **FR-06 (Exit Detection):** The AI model, powered by the lightweight YOLO model, shall identify when the "Person" object leaves the camera frame and log the Exit_Timestamp for the detected exit.

  Enhancement: The YOLO model will efficiently detect when a person exits the frame, providing real-time exit event logging with minimal latency. This could be paired with motion detection algorithms to enhance accuracy for persons who move out of the frame quickly.

- **FR-07 (Duration Logic):** The system shall calculate the Duration as:

  Duration = Exit_Timestamp - Entry_Timestamp.

  Enhancement: The system calculates the duration between entry and exit times based on the logs captured by the YOLO model. This duration can be continuously updated and monitored to trigger alerts if necessary.

  FR-08 (Loitering Alert):

- If the Duration exceeds the defined authorization window (e.g., 30 minutes), the system shall trigger an "Unauthorized Loitering" alert on the dashboard.

  Enhancement: The lightweight YOLO model helps detect and monitor the movement of individuals within the restricted area. If an individual lingers beyond the authorized duration, a real-time alert will be triggered on the dashboard, notifying security or administrators of unauthorized loitering.

3.2.3 Additional Detection Capabilities

Fire Detection:

- The system will integrate an AI-based fire detection model using real-time video analytics. The system shall detect flames or smoke within the camera frame and raise an immediate fire alert.

  Enhancement: Using a lightweight YOLO model or a custom CNN model trained for fire detection, the system will analyze video frames for signs of fire, smoke, or rapid temperature changes that could indicate a fire hazard.

Gun Detection:

- The AI model shall detect if a gun-like object is present in the camera frame. Upon detection, the system shall trigger an immediate security alert.

  Enhancement: A lightweight YOLO model or a specialized object detection model trained to recognize guns or weaponry will scan the video feed for such objects. If a weapon is detected,

the system will trigger a real-time alert and log the event, allowing for immediate security intervention.

3.3 Communication Interface Requirements

3.3.1 Local (Hardware) Interfaces

- **I2C (Inter-Integrated Circuit):** Selected for the AM2320.
    - **Reason:** Supports addressing multiple sensors on a single 2-wire bus, minimizing cabling in crowded racks.
- **SPI (Serial Peripheral Interface):** Selected for the MCP3008 ADC.
    - **Reason:** Full-duplex high-speed communication is required to sample analog signals (smoke/power) rapidly enough to capture transient spikes.
- **CSI (Camera Serial Interface):** Selected for the Pi Camera.
    - **Reason:** Provides high-bandwidth direct access to the GPU for video processing, which is superior to USB cameras for latency.

3.3.2 Remote (Network) Interfaces

- **MQTT (Message Queuing Telemetry Transport):**
    - **Usage:** Pi → Cloud Communication.
    - **Reason:** Ideally suited for unstable network environments. It supports "Last Will and Testament" (LWT) to notify the dashboard immediately if the Raspberry Pi goes offline unexpectedly.
- **HTTPS / WSS (Secure WebSockets):**
    - **Usage:** Cloud → Dashboard.
    - **Reason:** Ensures secure, real-time data streaming to the user's browser (PC or Mobile).

4. Non-Functional Requirements

4.1 Reliability & Availability

- **NFR-01 (Fail-Safe):** The cooling fan must default to "ON" if the control logic fails or the temperature sensor disconnects (Hardware Fail-safe).
- **NFR-02 (Data Buffering):** In the event of an internet outage, the Raspberry Pi must store logs locally (SQLite/Text) and sync them to the cloud upon reconnection.

4.2 Security

- **NFR-03:** All MQTT payloads must be encrypted using TLS/SSL.
- **NFR-04:** The dashboard must require generic authentication (Username/Password) to prevent unauthorized viewing of server room data.

4.3 Performance

- **NFR-05:** The end-to-end latency from a sensor event (e.g., Smoke detected) to Dashboard Alert must be < 2 seconds.
- **NFR-06:** The AI inference speed (FPS) must be sufficient (at least 5 FPS) to accurately track walking speed.