An edge-cloud IIoT framework for predictive maintenance in manufacturing systems

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UNDERSTANDING THE PAPER

- What is IntelliPdM?
- A scalable, AI-powered predictive maintenance system built on edge-cloud architecture to monitor industrial machinery in real time.
- IntelliPdM is an edge-cloud IIoT-based predictive maintenance framework designed for real-time fault detection and maintenance in manufacturing systems.
- It addresses challenges like real-time data unavailability, sensor heterogeneity, and resource-constrained deployments
- Tech stack includes Python, Apache Kafka, Spark, MongoDB, Amazon S3, Docker, Kubernetes (AWS EKS & Fargate).
- Achieved 93–95% accuracy, 75% breakdown reduction, and 10× ROI over 12 months in a large-scale Singapore deployment

PROBLEMS ADDRESSED

- Lack of real-time machine health data.
- Handling heterogeneous sensor inputs.
- High downtime and maintenance costs.
- Need for deployment in resource-constrained environments.

WHY IT IS AN EDGE COMPUTING PROBLEM

- The Challenge in Modern Industry

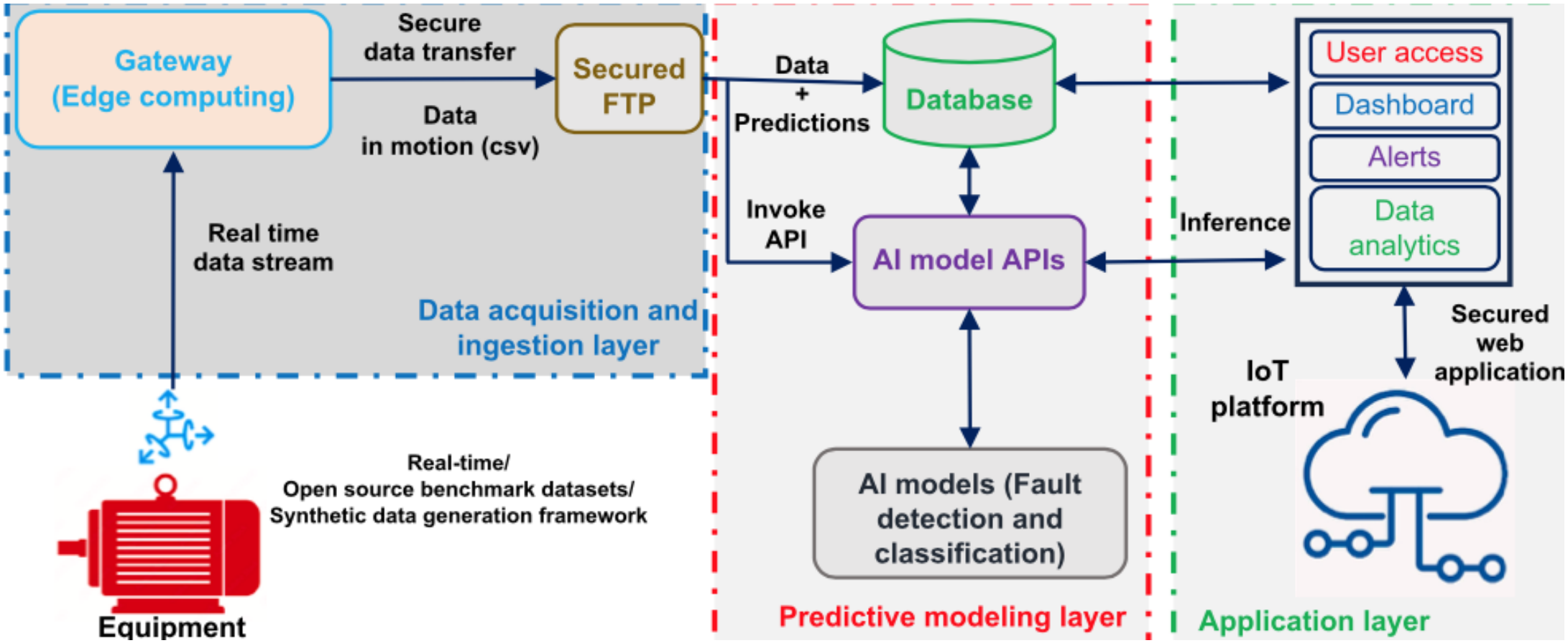
  Manufacturing machines are complex, high-value assets prone to unplanned failures, causing:

  - High downtime
  - Maintenance inefficiencies
  - Severe production losses

The Challenge in Modern Industry

- Early fault detection is key → requires low-latency analytics
- PdM systems must process sensor & video data from assets like motors, belts, fans, etc.
- Edge computing enables:
- Local data processing near machines
- Faster anomaly detection & alerting
- Lower bandwidth usage
- Enhanced privacy & security

ARCHITECTURE DIAGRAM



Node Connectivity in IntelliPdM Architecture

1. Sensor Nodes (IoT + Cameras)

Sensors (vibration, temperature, pressure, acoustic) and cameras (thermal, IR) are installed on/near industrial equipment.

These devices send raw data to Edge Nodes (Gateways) using local wired or wireless protocols (e.g., MQTT, Zigbee, Wi-Fi, or Ethernet).

Node Connectivity in IntelliPdM Architecture

2. Edge Nodes (Gateways)

Collect, preprocess, and analyze data locally to reduce latency.

Connected to:

- Sensor nodes for data intake
- Secure FTP Server for sending preprocessed data to cloud
- Kafka Message Broker for publishing operational data to topics

Runs lightweight ML models and sends intermediate decisions

Node Connectivity in IntelliPdM Architecture

3. Apache Kafka (Messaging Layer)

- Acts as a communication bus between edge devices and processing layer
- Each equipment type/data stream gets a Kafka topic
- Kafka publishes data to consumers (like Spark jobs)

Node Connectivity in IntelliPdM Architecture

4. Apache Spark (Streaming + Processing Layer)

   Consumes Kafka topics

   Performs streaming analytics, e.g., data cleaning, transformation

   Sends structured data to MongoDB

   Sends unstructured (image/audio) data to Amazon S3

Node Connectivity in IntelliPdM Architecture

5. Data Stores

MongoDB: Structured sensor data

Amazon S3: Unstructured camera/audio files

6. Predictive Modeling Layer

Models trained using real-time + synthetic data (from SMARTHome)

Deployed via REST APIs to either:

- Edge nodes (if lightweight and latency-sensitive)
- Cloud (for heavier models like CNNs)

Node Connectivity in IntelliPdM Architecture

7. Application Layer (Dashboard)

Built with Django + React

Connects to:

- REST APIs for fetching prediction results
- MongoDB for live sensor status
- S3 for visual data analysis

Visualizes alerts, faults, equipment status, and scheduling