Scalable IoT Smart Factory Monitoring

A Cloud-Native Architecture for Real-Time Industrial Telemetry and Predictive Analytics

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Project Overview & Mission

The Mission

To engineer a scalable, cloud-native IoT monitoring platform that provides real-time visibility into machine health, minimizing industrial downtime.

The Evolution

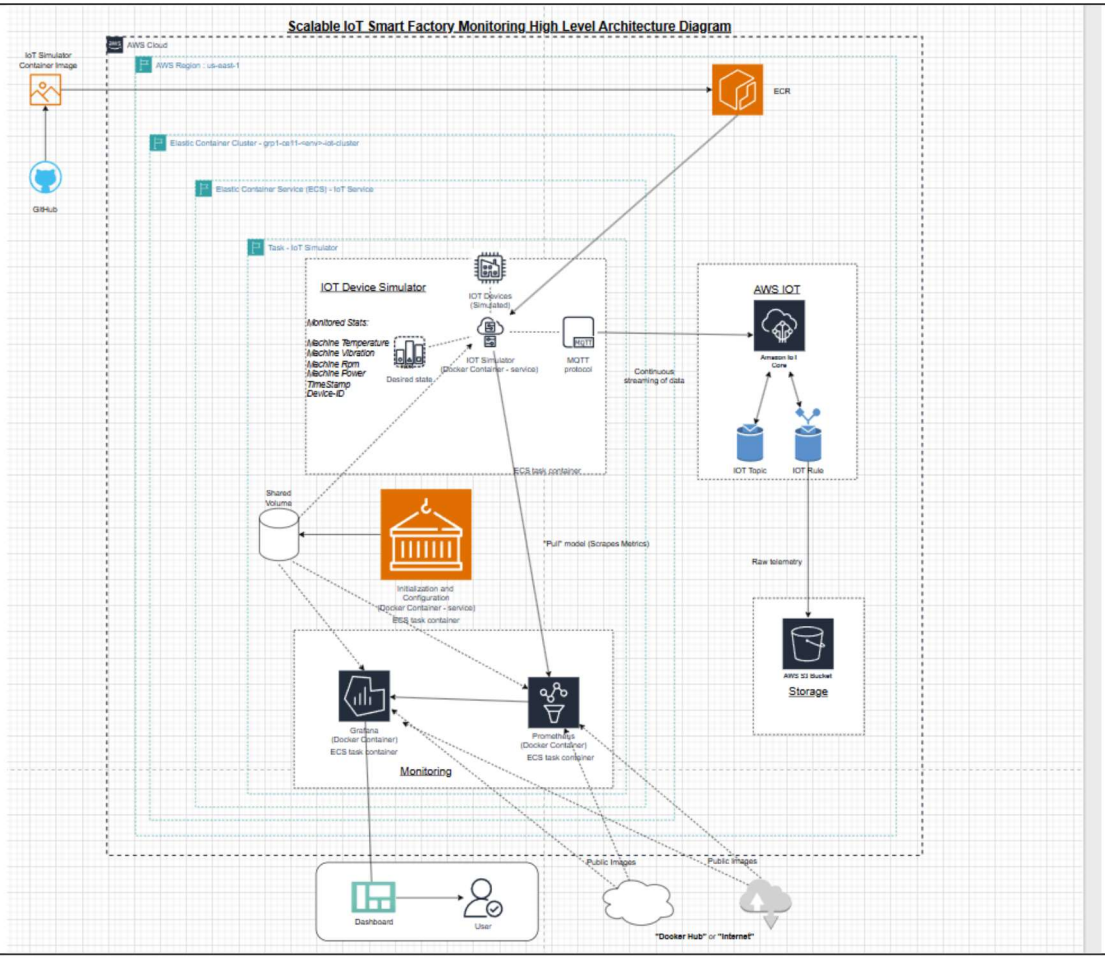
Transformed a functional prototype into an "Industrialized" solution by shifting from manual configuration to fully automated **Infrastructure as Code (IaC)**.

Core Value

Delivers a secure, **"self-healing" pipeline** capable of simulating an entire factory floor with zero-downtime deployments.

High-Level System Architecture

A macro view of the system showing the flow from the **Init Container** and **Simulation Engine** on ECS, through the **Application Load Balancer**, to the final visualization layers.



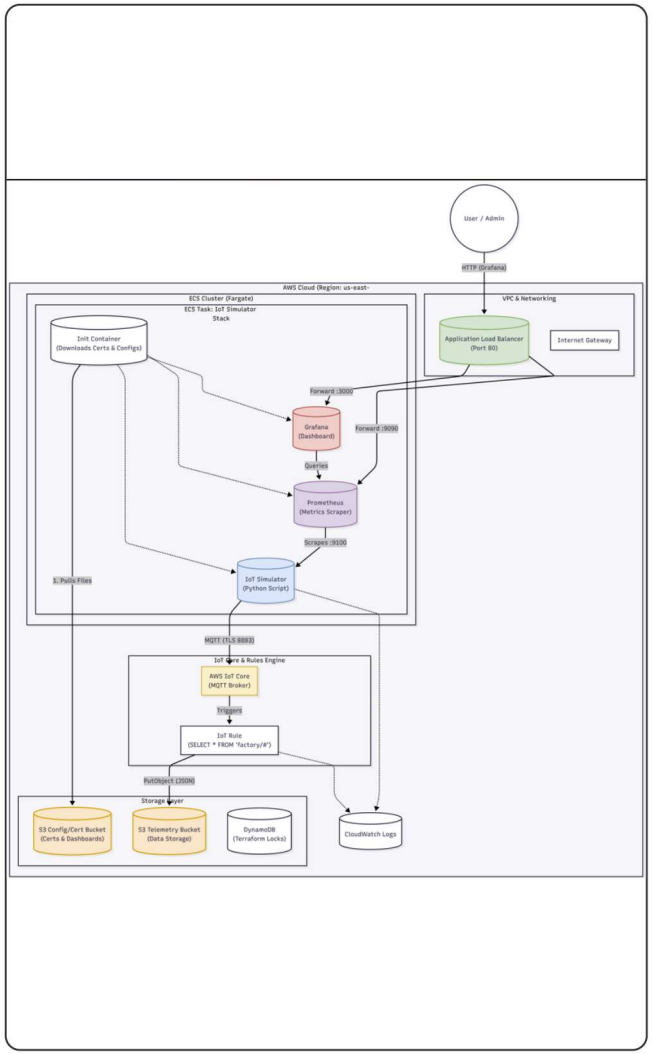
The 9-Layer Industrial Architecture

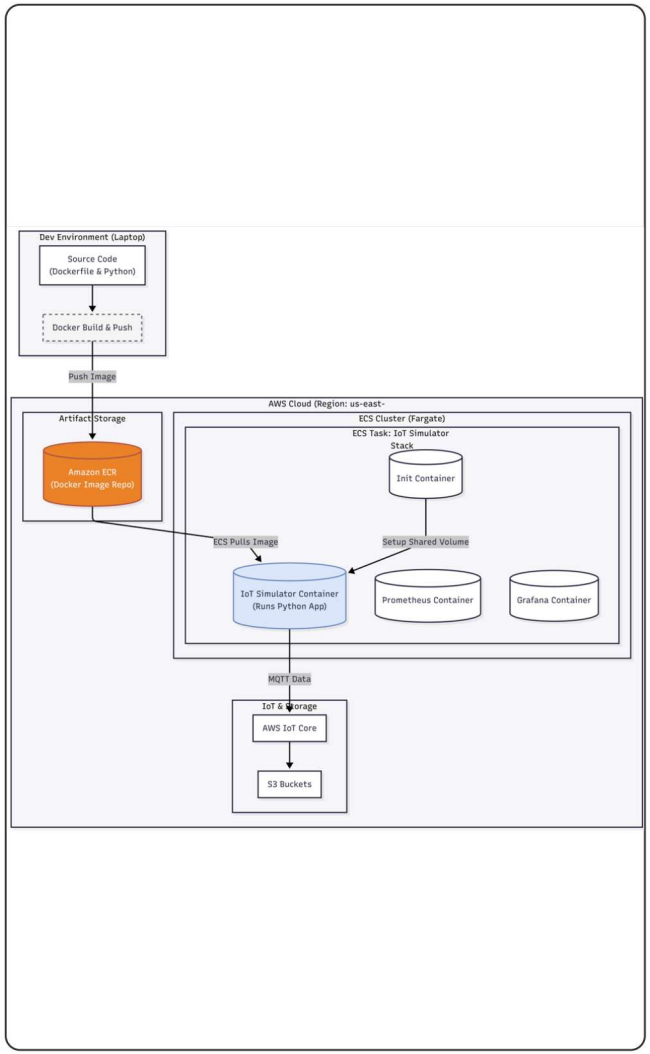
A modular stack designed for scalability and security.

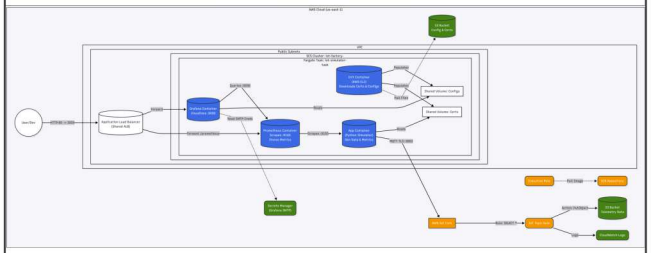
Layer	Technical Implementation
1. Simulation	Python simulators on **ECS Fargate** using **mTLS** for secure identity.
2. Ingestion	**AWS IoT Core** manages thousands of concurrent MQTT connections.
3. Processing	Dual-path: SQL-based **IoT Rules** (Event-driven) and **Prometheus** (Stateful).
4. Storage	**Amazon S3** for raw data archival and **Prometheus TSDB** for real-time metrics.
5. ML / AI	Future **Scikit-learn** models to forecast failure based on S3 history.
6. Visualization	**Grafana** dashboards with active **SMTP** alert triggers.
7. Observability	Centralized **CloudWatch Logs** track rule execution and container health.
8. Security	IAM "Least Privilege" roles and **Security Group** isolation.
9. DevOps	Automated lifecycle via **Terraform**, **GitHub Actions**, and **ECR**.

Detailed System Flow

Detailed interaction sequence covering the **Cold Path** (S3 Archival) and **Hot Path** (Real-time Metrics).







Purpose & System Capabilities

High-Fidelity Simulation

Emulates industrial IoT devices producing multi-variable telemetry (Temperature, Vibration, RPM, Power) without physical hardware.

Secure Ingestion

Establishes encrypted communication to publish sensor data securely to **AWS IoT Core** via **MQTT over TLS**.

Fault Injection

Intentionally injects controlled anomalies (e.g., sensor drift) to validate the resilience and accuracy of downstream monitoring pipelines.

Continuous Service

Engineered as a containerized, stateless, and environment-agnostic service running on **Amazon ECS Fargate**.

Data Flow & Payload Engineering

Edge Generation

Each device thread generates a high-fidelity JSON payload:

```
{
  "device_id": "M001",
  "temp": 59.2,
  "vibration": 0.42,
  "rpm": 1425
}
```

Initialization Logic

An **Init Container** securely downloads certificates and configurations from **S3** to shared volumes before the application starts.

Transport

Data is transmitted via **MQTT over TLS (Port 8883)**, ensuring full encryption from edge to cloud.

Routing Strategy

- **Cold Path:** Raw telemetry → IoT Rules → S3 Bucket (Archival).
- **Hot Path:** Metrics Endpoint → Prometheus Scraper → Grafana (Real-time).

Security & Governance Deep-Dive

Identity Management

Implements **"Least Privilege"** by decoupling the **Execution Role** (Infrastructure) from the **Task Role** (Application).

Secrets Governance

Sensitive credentials (SMTP, X.509 certs) are stored in **AWS Secrets Manager** and encrypted via **KMS**—never hardcoded.

Network Perimeter

Ingress is strictly limited via **Stateful Security Groups**. Only Port 3000 (Grafana) and Port 9090 (Prometheus) are exposed to authorized IPs.

"Self-Healing" CI/CD Pipeline

Continuous Integration

Automated **Terraform Format & Validate** runs on every code push to ensure quality.

Smart Import Innovation

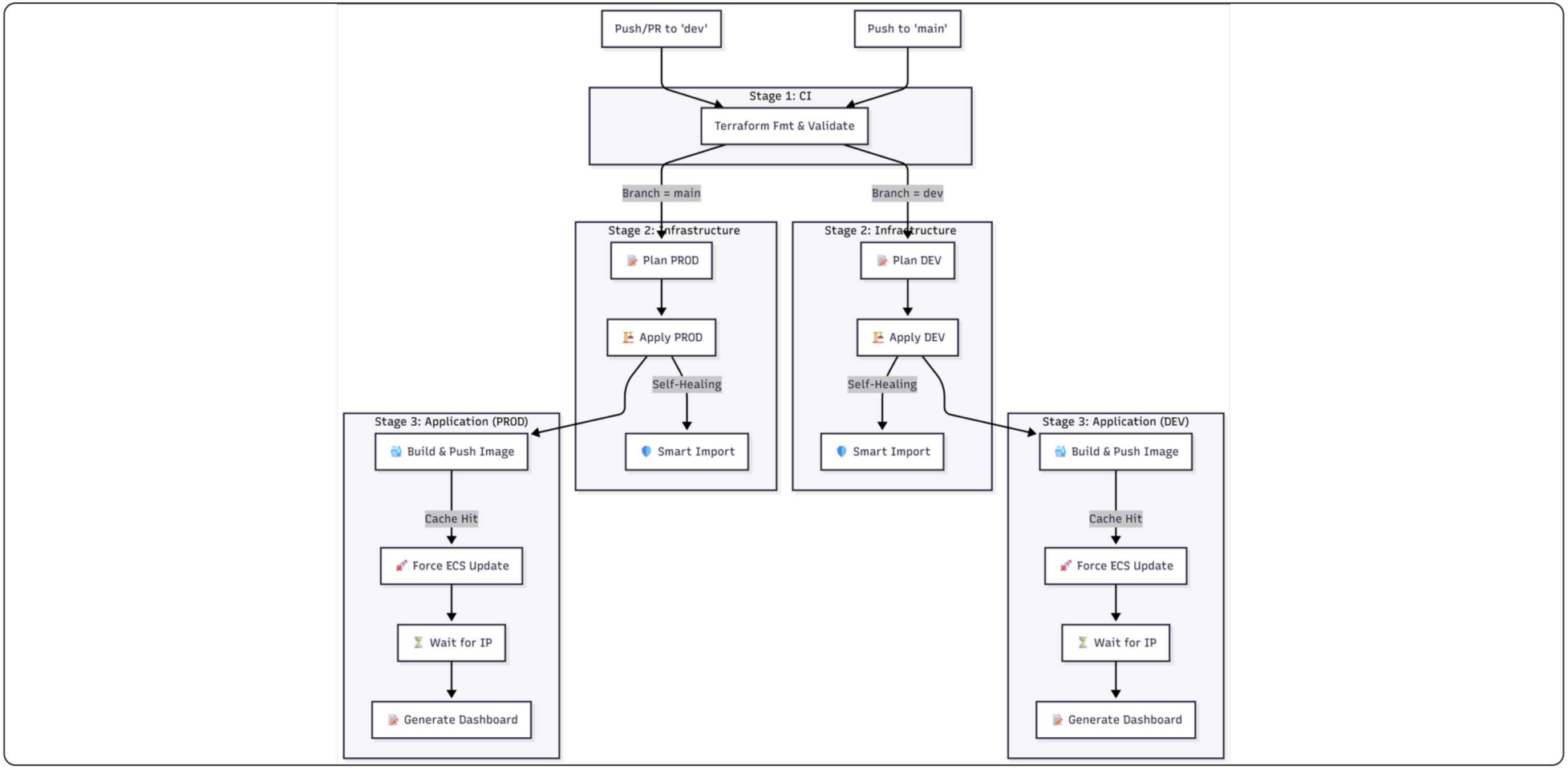
A custom `tf-smart-import.sh` utility dynamically adopts existing AWS resources into the state file, preventing deployment failures due to conflicts like "BucketAlreadyExists".

Zero-Downtime Delivery

The pipeline builds versioned images to **Amazon ECR**, followed by a **Force ECS Update** to refresh the live application without service interruption.

CI/CD Pipeline Architecture

Visualizing the automated build and deployment flow from **GitHub Actions** to **Amazon ECS**.



Key Technical Achievements

Multi-Device Scaling

Refactored the core logic to support **concurrent device handling**, allowing a single container to simulate an entire "Plant Floor".

Unified Access

Configured an **Application Load Balancer (ALB)** with path-based routing to serve the Simulator, Prometheus, and Grafana through a single endpoint.

Active Response

Shifted from passive monitoring to active alerting; the system now triggers **SMTP emails** immediately when "Sensor Drift" is detected.

Future Roadmap

AI-Driven Predictive Maintenance

Utilizing the **S3 Data Lake** to train **Scikit-learn** models for anomaly detection and Remaining Useful Life (RUL) prediction.

Dynamic Identity Scaling

Enhancing the simulator to support dynamic device registration and automated scaling policies based on load.

Thank You

We have delivered a robust, secure, and industrialized IoT platform that transforms raw data into proactive industrial insights.

Q & A Session

Open floor for questions regarding architecture, security implementation, or future ML integration.

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