CITYWIDE SMOKE SPREAD PREDICTION AND AIR QUALITY IMPACT ASSESSMENT USING DIGITAL TWIN TECHNOLOGY

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Introduction:

Digital twin technology is transforming urban management by creating virtual replicas of physical environments. It enables real-time monitoring, predictive analysis, and scenario simulation using data from IoT sensors, weather systems, and more. Originally developed by NASA, digital twins are now used across industries to tackle complex challenges like smoke spread prediction and air quality management, enhancing urban resilience and decision-making.

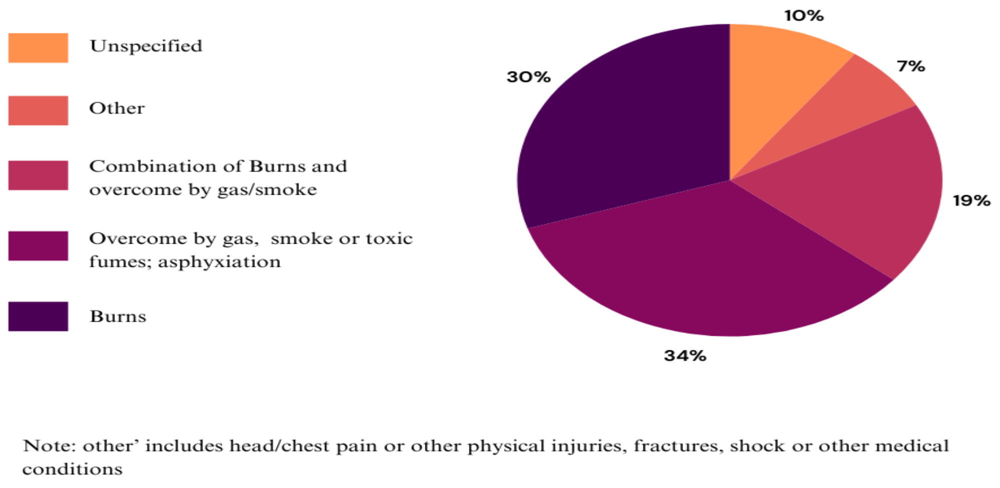

Figure 1: A pie chart showing the distribution of domestic death causes, with the largest segment representing deaths due to smoke, indicating it as the leading cause.

Objectives:

1. Develop a digital twin system for urban environments to simulate smoke dispersion and assess impacts.
2. Enable real-time air quality and smoke spread monitoring using IoT sensors.
3. Provide real-time decision support for emergency response and public safety.

Methodology:

This section outlines the systematic approach and tools used to develop and visualize the digital twin and its integration with Grafana.

1. Sensor Setup
   - Deployed dust sensor, smoke detector, and rotary encoder (to simulate wind direction) inside a room-scale model with two doors.
   - Sensors continuously monitor air quality, wind direction and smoke presence.
2. Data Ingestion
   - Sensor data sent to AWS IoT Core, enabling real-time, secure communication between the room setup and AWS cloud.
3. Data Processing
   - AWS Lambda functions triggered by IoT messages to process incoming data.
   - Data is structured and prepared for storage and visualization.
4. Data Storage
   - Processed sensor data stored in AWS Timestream for time-series analysis and historical tracking.
5. Digital Twin Modeling
   - Built a digital twin of a single room with two doors using AWS TwinMaker.
   - Integrated sensor data with room entities (e.g., doors, air zones) for real-time behavior reflection.
6. Visualization
   - Grafana dashboard to display graphs and connected with TwinMaker for real-time display.
   - Tag colors change based on sensor values to indicate severity inside the room.
7. Asset Storage
   - 3D model assets and configurations hosted on AWS S3 for scalability and centralized access.

Result and Conclusion:

Visualization of IoT Sensor readings like dust density, wind direction and smoke detection are successfully reflected in the AWS Grafana dashboard in real time. Tag colours in Digital Twin vary according to sensor values to represent severity of dust and smoke. Alert is sent to the user via SMS.

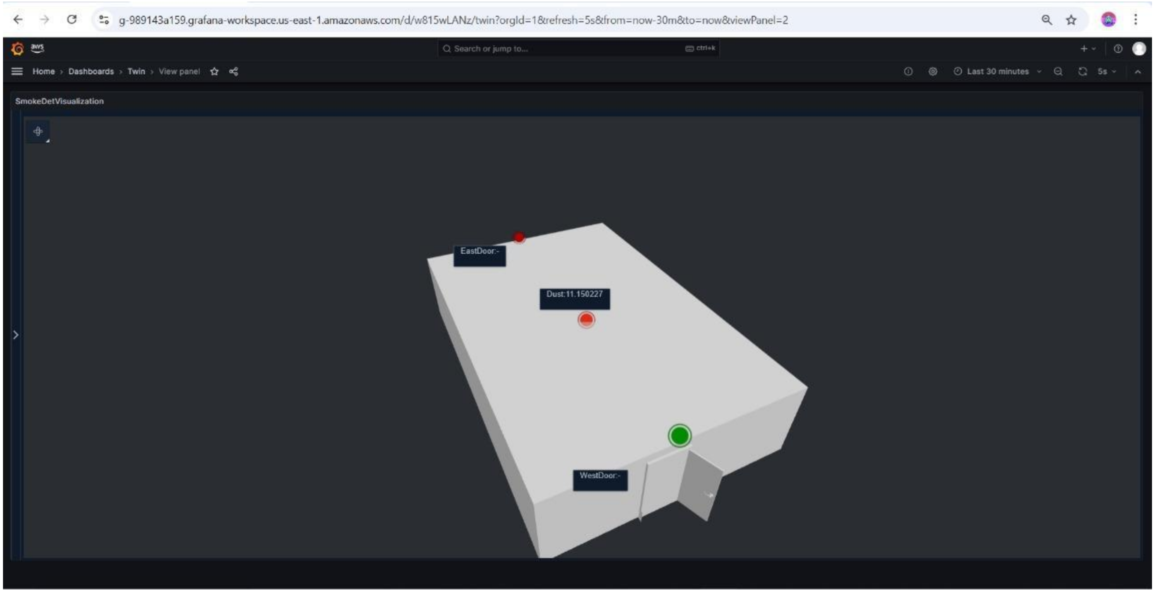

Figure 1: Red tags indicate presence of smoke and that its at severe level, Green tag indicates absence of smoke

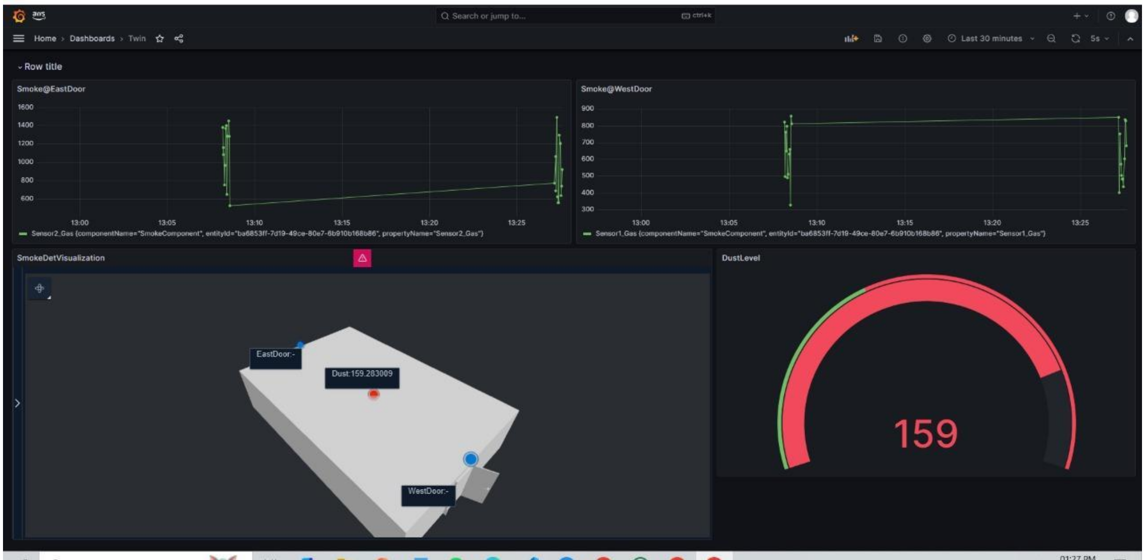

Figure 2: Grafana dashboard showing smoke detection trends at doors and dust level in room. Dust in room is severe, tags at doors are in default state hence are in blue tags.

In conclusion, this project represents a transformative step in leveraging digital twin technology to address critical urban challenges, particularly in air quality and smoke spread monitoring. By developing a comprehensive digital twin system integrated with a miniature model of a city, the project bridges the gap between physical environments and virtual simulations. The combination of real-time data integration, predictive analytics, and scenario testing offers unparalleled insights into urban dynamics, enabling smarter and more proactive decision-making.

Future Scope:

The future scope of this project includes:

1. Scalability to multi-room or building-level models
2. Integration with additional sensors
3. Automated emergency response triggers
4. Smart city integration
5. Integration with weather and external environmental APIs
6. Energy-efficient model optimization