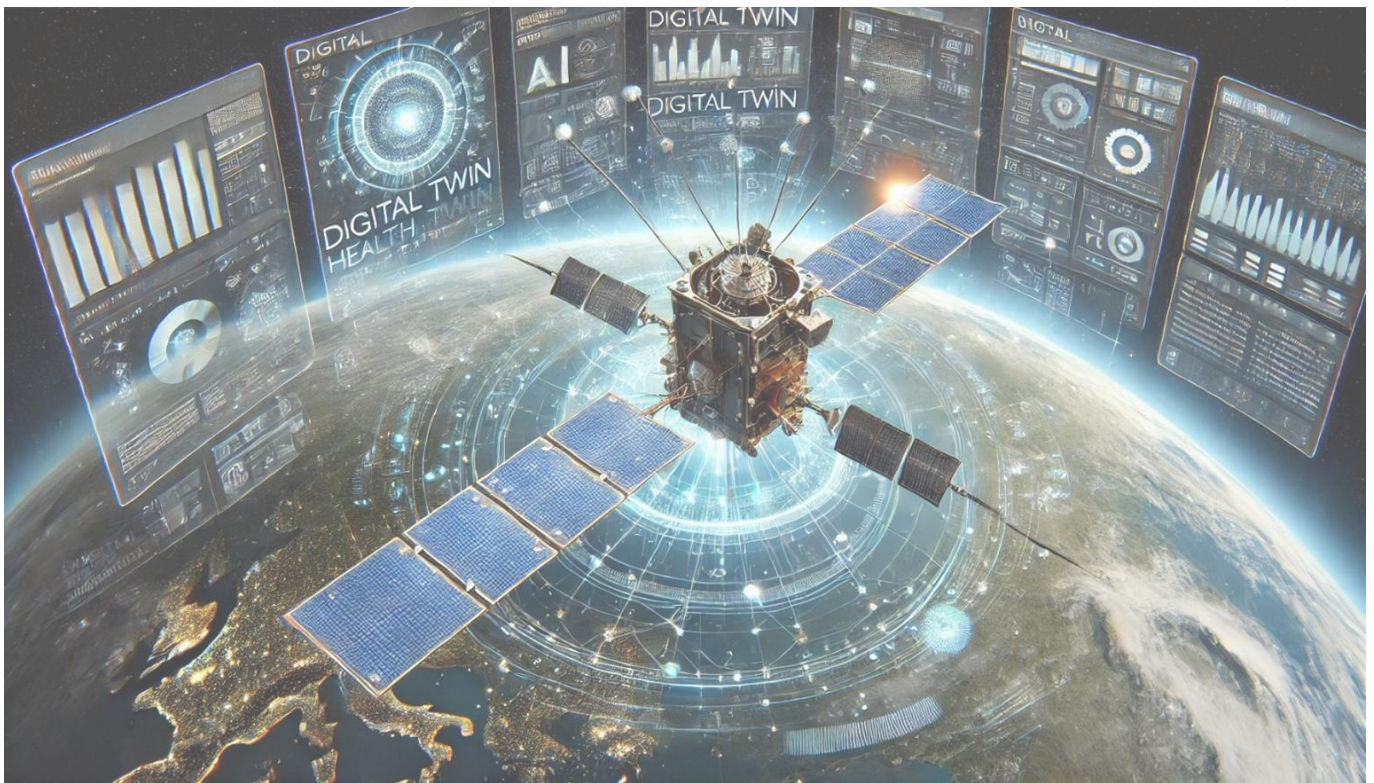


# AI-POWERED DIGITAL TWIN PROTOTYPE FOR SATELLITE HEALTH MONITORING



- Prepared by

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# AI-POWERED DIGITAL TWIN PROTOTYPE FOR SATELLITE HEALTH MONITORING

## Project Overview:

This task involves developing a prototype of an AI-powered digital twin for satellite health monitoring. The digital twin will simulate real-time satellite conditions and predict potential issues using AI models trained on simulated satellite telemetry data.

- Real-time Satellite Health Monitoring
- Predictive Analytics for anomaly detection
- Interactive Dashboard (built with Streamlit)
- Automated Alert System
- Visualization of Satellite Metrics

## Usage

- Launch the dashboard using Streamlit.
- View real-time telemetry data and health status of satellites.
- Receive alerts if anomalies are detected.
- Access the Digital Twin simulation for in-depth analysis.

## Phase 1: Data Collection & Digital Twin setup

- Identify key satellite parameters to simulate (e.g., battery voltage, solar panel efficiency, thruster health, etc.).
- Generate or use **pre-existing satellite telemetry datasets** for training & simulation.
- Set up a basic **database** (MySQL) to store simulated satellite data.

Dataset: [Sample satellite telemetry data.csv](#)

## Satellite Telemetry Parameters:

- |                          |                      |                         |
|--------------------------|----------------------|-------------------------|
| • timestamp              | • thermal_gradient   | • data_quality          |
| • battery_voltage        | • position           | • error_flags           |
| • battery_current        | • velocity           | • latency               |
| • state_of_charge        | • gyroscope          | • bit_error_rate        |
| • solar_panel_voltage    | • magnetometer_rpm   | • sensor_discrepancies  |
| • solar_panel_current    | • reaction_wheel_rpm | • thruster_malfunctions |
| • solar_panel_efficiency | • thruster_status    | • thruster_efficiency   |
| • power_consumption      | • signal_strength    | • orientation           |
| • internal_temp          | • data_rate          | • throughput            |
| • battery_temp           | • packet_loss        | • power_anomalies       |
| • solar_panel_temp       | • payload_power      | • thermal_anomalies     |
| • radiator_temp          | • sensor_data_rate   | • aocs_faults           |
| • radiator_efficiency    | • camera_temp        | • payload_failures      |

## Phase 2: AI Model Development:

- Train an anomaly detection model (Isolation Forest) using historical telemetry data.
- Test AI predictions against simulated satellite failures.

### Phase 3: Real-Time Dashboard & Alerts

- Create an MYSQL to fetch Dataset and store the Predicted values.
- Implement an alert system (email) for detecting critical failures.
- Develop a dashboard (Streamlit) to visualize satellite status.

### Screenshots:

#### 1. Connect with MYSQL for get Real-Time dataset:

The screenshot shows a MySQL IDE window titled 'Project satellite sql'. The SQL editor contains the following code:

```

196     thruster_malfunctions INT,
197     thruster_efficiency FLOAT,
198     orientation FLOAT,
199     throughput FLOAT,
200     power_anomalies INT,
201     thermal_anomalies INT,
202     aocs_faults INT,
203     payload_failures INT
204 );
205 • select * from real_time_data_3;
206

```

Below the editor, the 'Result Grid' displays a table with 10 columns: timestamp, battery\_voltage, battery\_current, state\_of\_charge, solar\_panel\_voltage, solar\_panel\_current, solar\_panel\_efficiency, power\_consumption, internal\_temp, and bat. The table contains 7 rows of data for the date 2025-03-06.

timestamp	battery_voltage	battery_current	state_of_charge	solar_panel_voltage	solar_panel_current	solar_panel_efficiency	power_consumption	internal_temp	bat
2025-03-06 23:06:41	27.651	4.60087	81.3662	97.3841	8.47009	21.7515	145.415	25.7599	31.2
2025-03-06 23:07:41	29.8218	4.54591	72.9178	110	8.15457	20.2435	149.177	21.8025	31.6
2025-03-06 23:08:25	29.5646	5.01342	82.4146	96.8145	8.82541	22.4537	141.147	28.1705	30.1
2025-03-06 23:08:28	29.8533	4.97046	80.6782	102.353	8.10011	20.7566	137.094	22.589	27.5
2025-03-06 23:08:30	27.9647	5.31004	85.7183	99.2032	7.9743	18.1414	161.597	26.7473	31.7
2025-03-06 23:08:33	29.2738	5.80144	86.8977	102.491	8.20741	23.4507	160.451	20.6349	28.4
2025-03-06 23:08:36	29.8673	5.28896	83.5308	90	7.26492	19.5511	159.972	26.1396	28.6

#### 2. Dataset:

The screenshot shows an Excel spreadsheet titled 'Anomaly Detection Prediction Results.csv'. The data is organized in columns A through M, representing various telemetry parameters over time. The columns are: timestamp, battery\_voltage, battery\_current, state\_of\_charge, solar\_panel\_voltage, solar\_panel\_current, solar\_panel\_efficiency, power\_consumption, internal\_temp, battery\_temp, solar\_panel\_temp, radiator\_temp, radiator\_efficiency, and thermal. The data spans from 06-03-2025 23:06 to 06-03-2025 23:13. The spreadsheet includes standard Excel features like the ribbon, formula bar, and status bar.

timestamp	battery_voltage	battery_current	state_of_charge	solar_panel_voltage	solar_panel_current	solar_panel_efficiency	power_consumption	internal_temp	battery_temp	solar_panel_temp	radiator_temp	radiator_efficiency	thermal
06-03-2025 23:06	27.651	4.60087	81.3662	97.3841	8.47009	21.7515	145.415	25.7599	31.2296	41.9734	19.663	87.873	
06-03-2025 23:07	29.8218	4.54591	72.9178	110	8.15457	20.2435	149.177	21.8025	31.6705	39.9526	19.7359	84.9553	
06-03-2025 23:08	29.5646	5.01342	82.4146	96.8145	8.82541	22.4537	141.147	28.1705	30.1027	43.3088	21.1316	87.9566	
06-03-2025 23:08	29.8533	4.97046	80.6782	102.353	8.10011	20.7566	137.094	22.589	27.9997	38.2863	20.1874	79.8964	
06-03-2025 23:08	27.9647	5.31004	85.7183	99.2032	7.9743	18.1414	161.597	26.7473	31.7676	43.3739	18.9022	85.3667	
06-03-2025 23:08	29.2738	5.80144	86.8977	102.491	8.20741	23.4507	160.451	20.6349	28.4847	40.4456	15.9236	82.8754	
06-03-2025 23:08	29.8673	5.28896	83.5308	90	7.26492	19.5511	159.972	26.1396	28.6112	39.6807	17.3382	90.3073	
06-03-2025 23:08	29.4392	5.84866	76.84	101.811	7.71942	21.6658	147.476	19.7357	27.3873	44.6144	20.8974	82.0046	
06-03-2025 23:08	27.2171	5.25209	81.636	100.727	8.25165	20.4214	147.851	26.609	31.6447	42.7497	24.1107	91.5772	
06-03-2025 23:08	29.6869	5.20538	80.2779	95.5712	8.00121	21.7302	152.082	34.3978	31.2691	42.3613	17.0915	87.9983	
06-03-2025 23:08	32	5.20449	82.4754	94.2433	8.3921	20.6832	164.354	20.7679	31.6002	49.8143	16.9884	83.7375	
06-03-2025 23:08	27.5732	4.50239	76.1533	90.9564	7.09375	20.5043	148.45	25.663	28.5719	41.949	20.6258	81.2766	
06-03-2025 23:08	27.2922	5.33274	79.3994	98.8745	7.59715	19.7357	134.883	24.1106	29.5867	45.2442	19.7608	87.2737	
06-03-2025 23:08	32	5.761	78.6287	99.1143	7.90038	24.3839	154.869	22.9337	26.3618	37.718	20.46	84.2986	
06-03-2025 23:09	26.7408	4.621	81.267	97.1	8.67491	22.1683	144.772	22.7491	27.6071	43.6096	23.5356	87.6307	
06-03-2025 23:09	25.272	5.18406	82.9679	96.2186	21.9145	150.895	25.773	31.3176	44.366	23.7752	84.5667		
06-03-2025 23:10	27.9992	4.36576	77.2063	101.88	8.57479	18.9793	150.444	22.9829	29.9651	44.5443	19.3081	92.0687	
06-03-2025 23:10	25.9102	5.58731	72.5552	107.562	8.10977	25.0183	142.632	24.3674	28.2396	32.3607	20.825	78.5125	
06-03-2025 23:10	27.736	4.62322	80.8341	108.391	8.12216	19.2707	147.665	24.0504	35	36.6909	23.0921	91.4795	
06-03-2025 23:10	29.4956	4.94236	80.3752	97.6015	8.59737	21.6174	147.184	25.8991	30.3805	45.8385	17.8029	83.9582	
06-03-2025 23:11	27.9132	5.01832	81.1635	100.493	7.03305	19.013	162.069	26.4346	30.9571	43.5629	20.6188	85.7487	
06-03-2025 23:12	27.2464	5.0595	79.6583	90	7.984	21.1073	151.149	29.1829	28.4662	35.2345	15.11	87.5425	
06-03-2025 23:12	28.1641	4.60888	82.0208	98.593	7.44644	19.8934	150.751	28.8525	31.2318	43.8234	19.019	84.5393	
06-03-2025 23:12	17.2516	4.75114	80.5845	103.198	7.54413	19.7854	166.067	24.3207	33.2118	36.0596	18.2826	86.3517	
06-03-2025 23:13	26.6243	5.85714	79.6865	103.289	6.98678	22.0266	132.546	25.5779	33.6569	40.2558	22.1785	85.1549	
06-03-2025 23:13	27.8517	5.52127	87.4878	101.093	8.00789	21.1158	127.277	25.5843	31.8415	41.0887	21.6425	91.6962	

3. Alert System Output

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SAT-2023-DT-001 Anomaly Alert - 2025-03-07 12:43:30.618386

mass1441m2@gmail.com

to me

Fri, Mar 7, 12:43 PM (1 day ago)

CRITICAL ANOMALY DETECTED!

System: SAT-2023-DT-001

Timestamp: 2025-03-07 12:43:30.618386

Key Parameters:

- Battery Voltage: 29.19 V

- Internal Temperature: 21.5°C

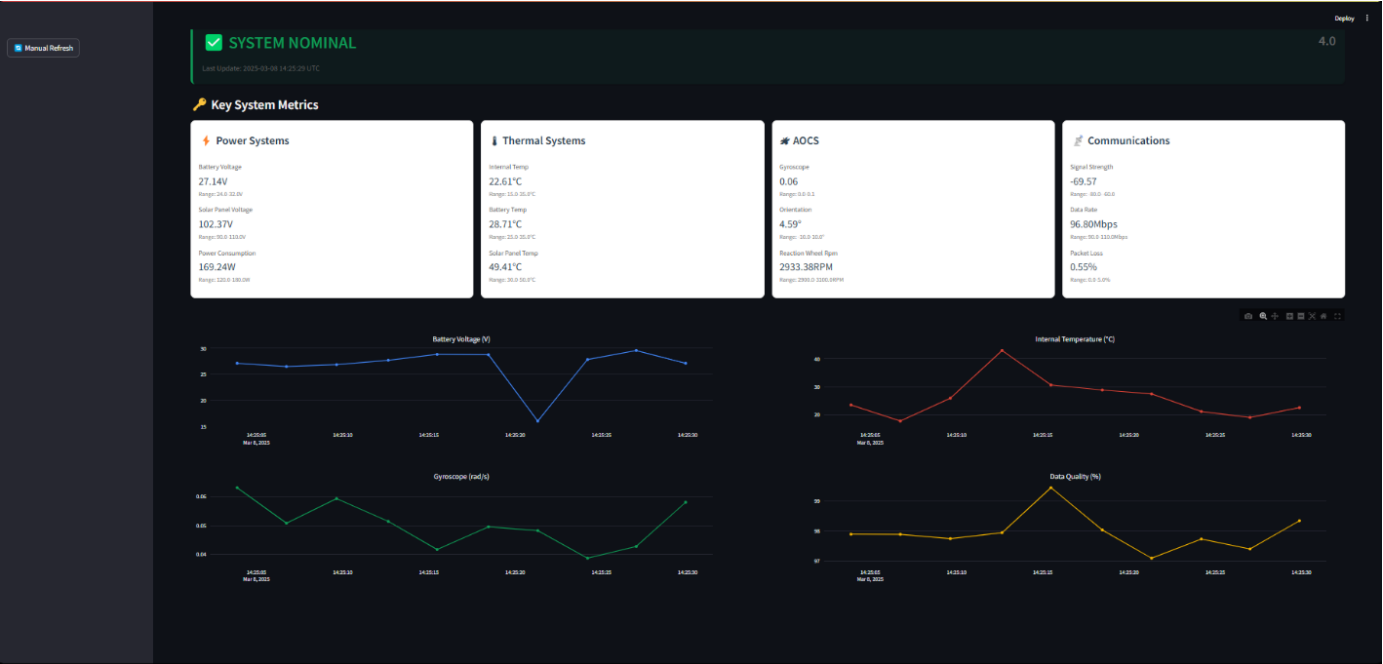
- Gyroscope: 0.0420 rad/s

- Data Quality: 97.5%

Reply

Forward

4. Streamlit Dashboard:



## Using Libraries:

### 1. Database & Data Handling

- `mysql.connector` → Connects to MySQL databases.
- `pandas` → Handles dataframes and data manipulation.
- `numpy` → Supports numerical computations.

### 2. Machine Learning & Preprocessing

- `joblib` → Loads the Isolation Forest model.
- `sklearn.preprocessing.MinMaxScaler` → Normalizes/scales data.

### 3. Web Framework

- `streamlit` → Builds the interactive web dashboard.

### 4. Email Handling

- `smtplib` → Sends emails using SMTP.
- `email.mime.multipart.MIMEMultipart` → Structures email messages.
- `email.mime.text.MIMEText` → Handles email text content.

### 5. Visualization

- `plotly.graph_objects` → Creates charts and visualizations.
- `plotly.subplots.make_subplots` → Combines multiple charts in one figure.

### 6. Miscellaneous

- `random` → Generates random numbers for simulated data.
- `time` → Handles time-related operations.
- `datetime` → Deals with timestamps.
- `timedelta` → Manipulates date and time intervals.

Project GitHub link - <https://github.com/madesh6554/AI-Powered-Digital-Twin-Prototype-for-Satellite-Health-Monitoring.git>

### Next Improvements

- Tune the dataset to improve the accuracy and reliability of telemetry data.
- Incorporate more realistic data to better simulate real satellite conditions.
- Enhance the dashboard for improved visualization and usability.
- Deploy the digital twin prototype on free-tier cloud hosting (Render/Supabase/Vercel).
- Conduct final testing & bug fixes.



### **Supporting Researches websites link:**

- [A Digital Twin-Based Approach for the Fault Diagnosis and Health Monitoring of a Complex Satellite System](#)
- [dasjaydeep2001/AI-Driven-Digital-Twin-for-Structural-Health-Monitoring-: This project aims to revolutionize structural health monitoring by leveraging Artificial Intelligence \(AI\), specifically Artificial Neural Networks \(ANN\), combined with Digital Twin technology. Our goal is to develop a fast-response surrogate model capable of providing real-time safety insights for critical infrastructure, such as bridges.](#)
- [data.nasa.gov/browse?sortBy=newest&pageSize=20&limitTo=datasets](#)