Real-Time Sensor Data Integration for BIM-Based Hydraulic Structure Monitoring

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Project BIMxD Building Monitoring

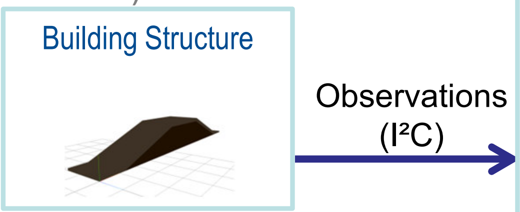
BIMxD

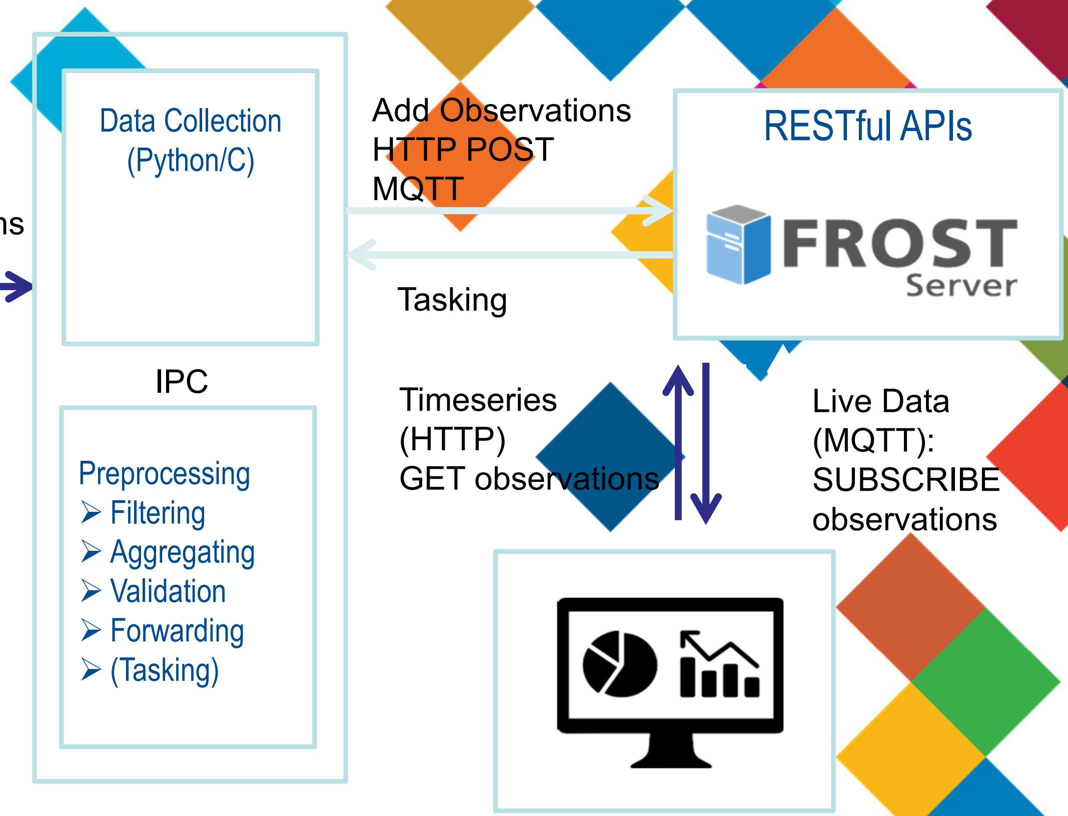
ZIM Zentrales Innovationsprogramm Mittelstand

- Development of an advanced, BIM-based monitoring system for hydraulic structures
- Combines real-time sensor data with BIM models, forming a Digital Twin for predictive maintenance and proactive infrastructure management
- Development parts of gia
  - Sensor data acquisition, preprocessing, and transmission
  - Sensor data storage structure based on web services
  - Linked data model for coupling the sensor and BIM data model
  - Processing web services for connecting the evaluation module
- Project partners: GEWECKE UND PARTNER BERATENDE INGENIEURE GMBH; WTM ENGINEERS; gia Geodätisches Institut und Lehrstuhl für Bauinformatik & Geoinformationssysteme; IWW Lehrstuhl und Institut für Wasserbau und Wasserwirtschaft; RWTH AACHEN UNIVERSITY

Sensor data system architecture

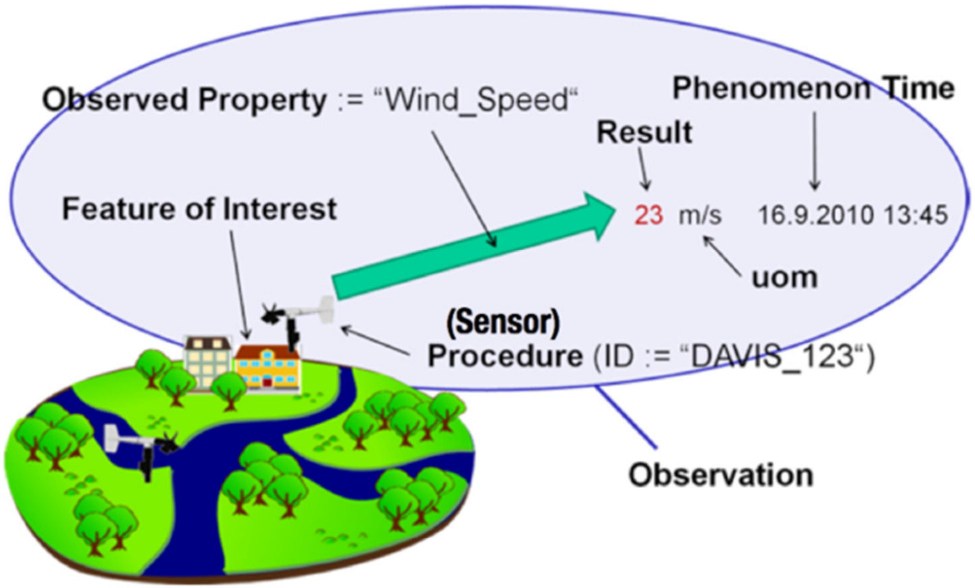
- Sensor data capturing (obeservations)
  - At building structure
- Prepressing
  - Data Filtering
  - Data Aggregating
  - Validation
  - Forwarding
- Data Transmission →Message Queuing Telemetry Transport (MQTT)
- Data storage and providing → OGC SensorThings API
- Data Visualization → Desite MD pro





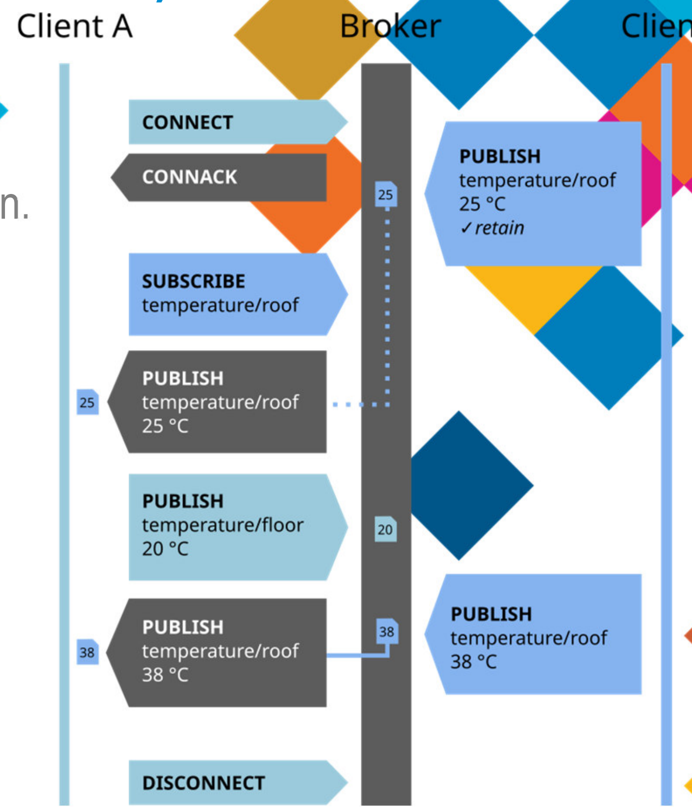
OGC SensorThings API – designed and tailored for internet of things (IoT)

- Developed by the OGC (Open Geospatial Consortium) → international voluntary consensus standards organization
- RESTful Architecture: SensorThings API adheres to REST principles
- Resource-Oriented: The API defines a set of resources, which can be accessed via standard URIs
- JSON Format: Data is typically exchanged in JSON format
- Scalability and Interoperability: SensorThings API is designed to be scalable and interoperable.
- Geospatial Data Support: Strong support for geospatial data



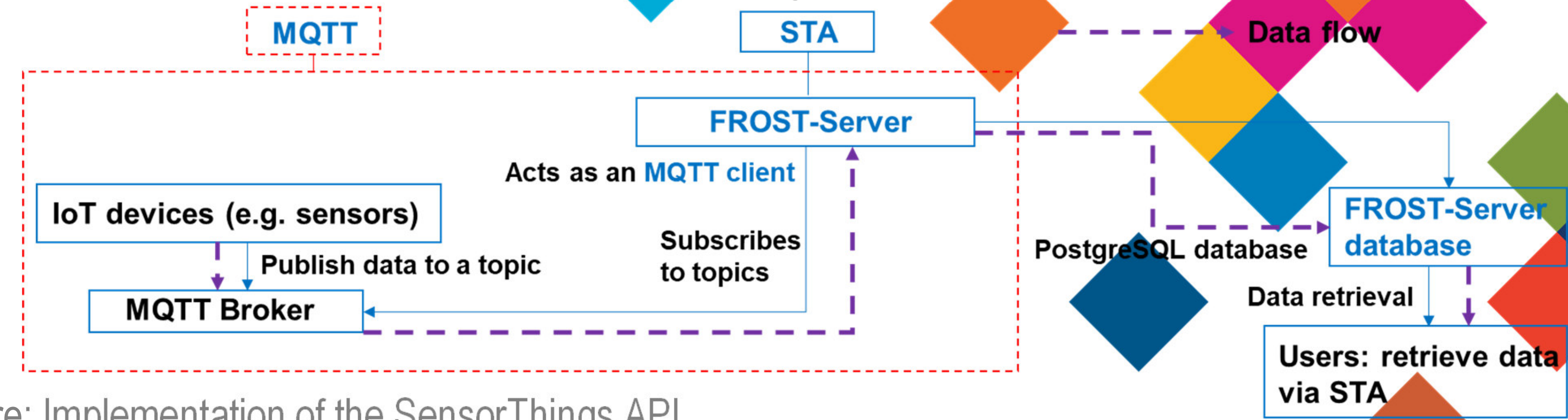
Message Queue Telemetry Transport Protocol (MQTT)

- Lightweight, publish-subscribe network protocol.
- Designed specifically for machine-to-machine (M2M) communication.
- Suitable for devices with limited resources and bandwidth (e.g., IoT applications).
- Uses a broker-based messaging model (Publish/Subscribe).
- Requires a reliable, lossless, ordered transport protocol (typically TCP/IP).
- Enables efficient real-time data exchange with remote locations/devices.
- Ideal for constrained environments (low battery, limited network connectivity)



Data transmission: MQTT protocol + SensorThings API

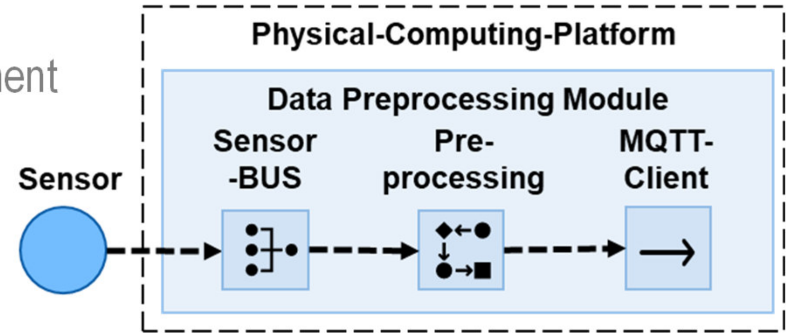
- MQTT for Real-Time Transmission of the sensor data to the SensorThings API



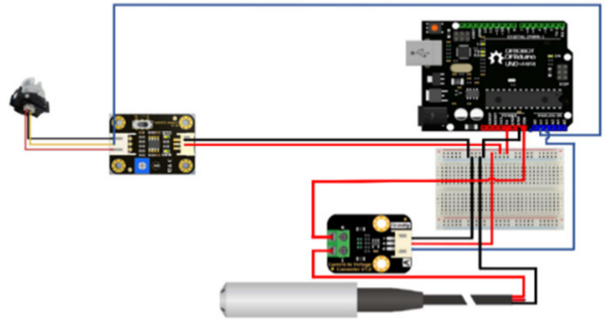
- FROST Server as Core: Implementation of the SensorThings API,
  - which serves as the main database and processing hub for sensor data,
  - which is a standardized framework for managing and accessing sensor observations and metadata
  - Which acts as an intermediary supporting both live data streaming and historical data queries in the database

Data acquisition and data stream transmission optimization

- By transitioning from a Python application on a measuring computer to an application on a physical computing platform
  - **Sensors** used can be directly connected to the physical computing platform and integrated into the data preprocessing module
  - **Physical computing platform** is significantly smaller and consumes much less energy compared to the measuring computer
  - No Need to transfer measurement data to a separate preprocessing module



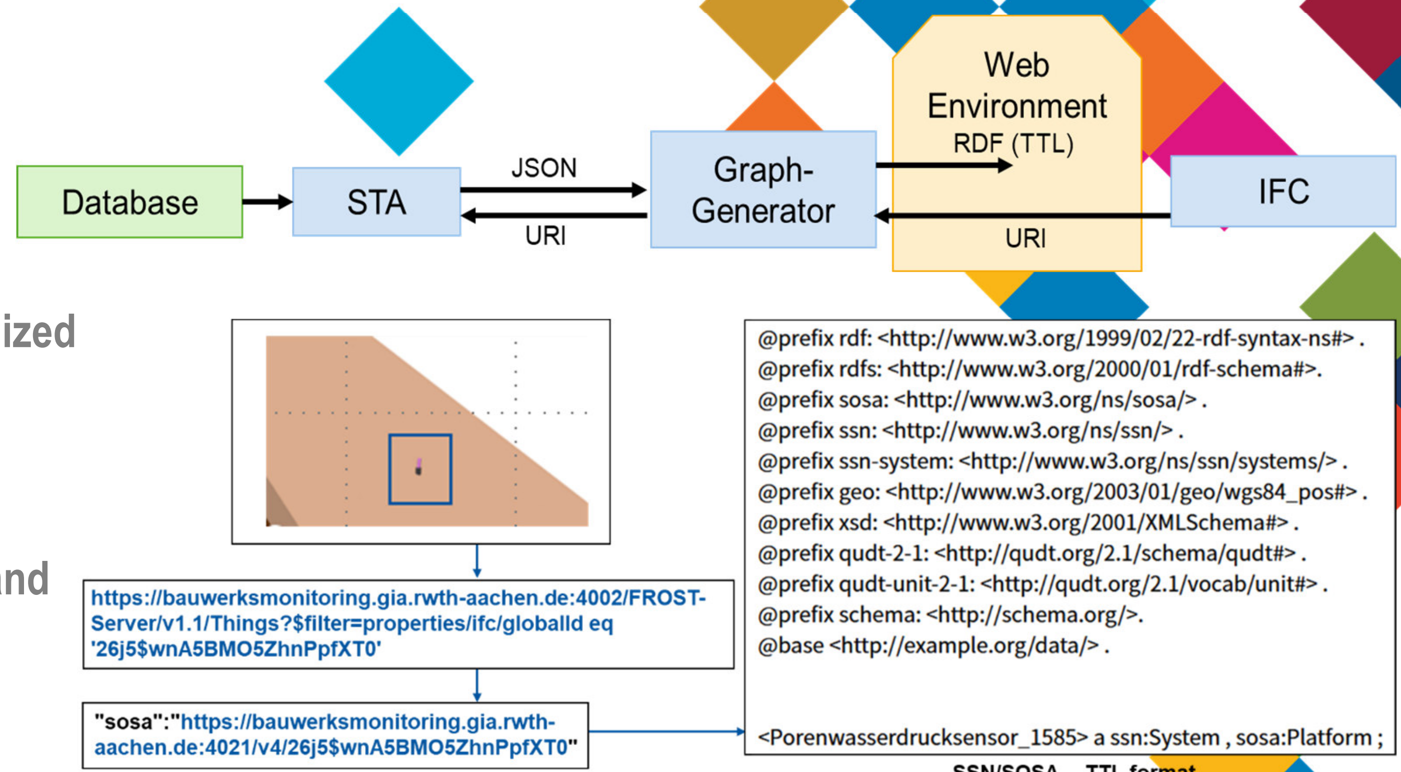
Schematic representation of the further developed data preprocessing module on a physical computing platform



Schematic representation of the connection of a pressure and a turbidity sensor to an Arduino UNO R4 WiFi

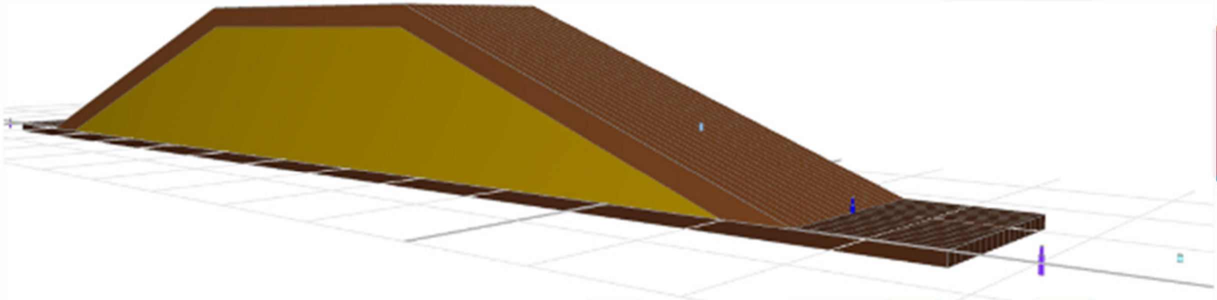
Linked Data Model – data coupling

- Establishes a **semantic connection** between sensor data and structural elements in the BIM model.
- Sensor Metadata Storage – **Metadata**.
- **Data Consistency** – Creates a **centralized single source of truth**, maintaining alignment with sensor measurements.
- Use of **Semantic Web Technologies**.
- RDF format - ensure **interoperability and scalability**.

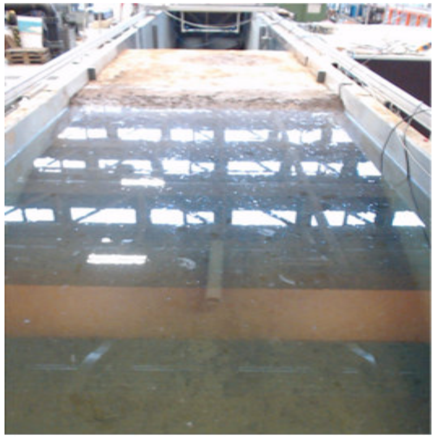


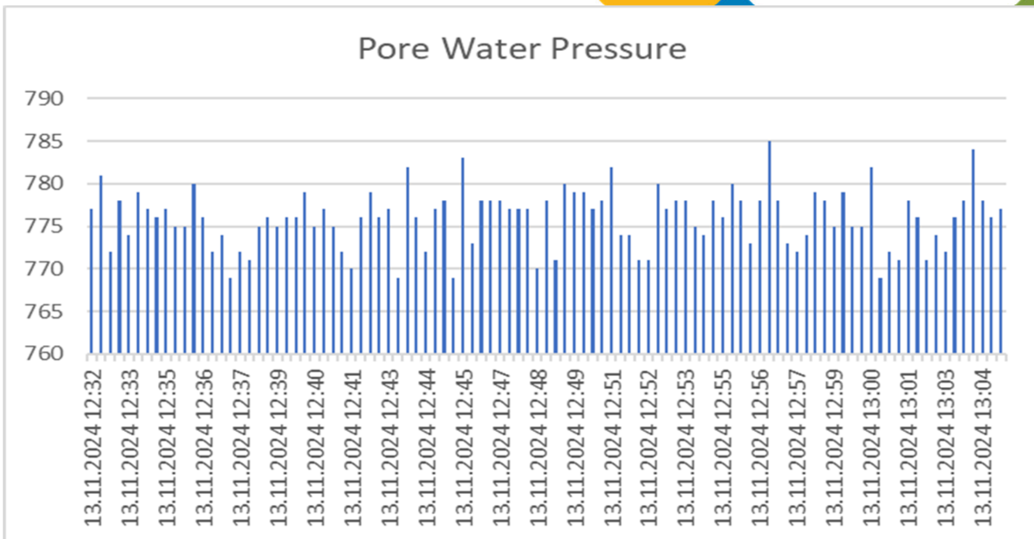
SSN/SOSA – TTL format

Test at a demonstrator dike at IWW



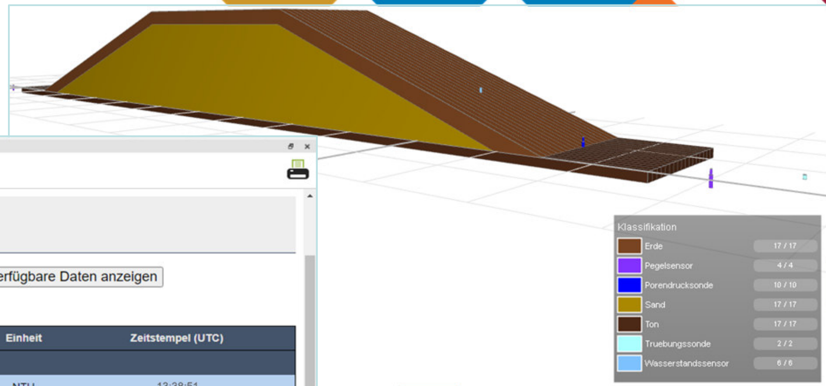
- Land side of the Scaled demonstrator dike – land side (below left) and water side (below right)
- 3D BIM model of the demonstrator dike
- Pore water pressure data (units: V/204,8)

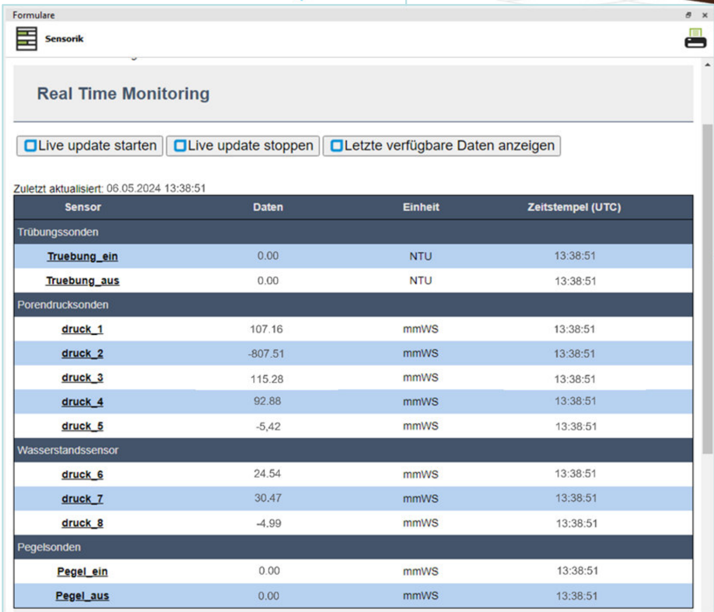




Integration of sensor data into the software environment of the digital twin

- Use of BIM software DESITE md pro
  - Storage and visualization of 3D model
  - Real-time sensor data access and visualization
  - Use of software API + JavaScript
- Access of sensor data from FROST server
  - Communication between server and software via HTTP protocol and SensorThings API
- Visualization of current and historic sensor data as time series



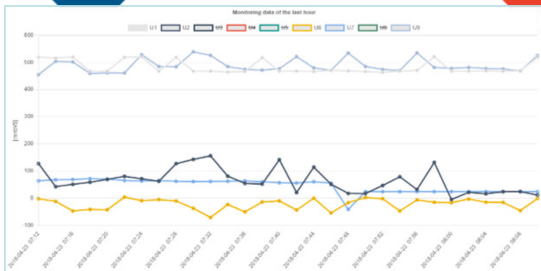

Formulare
Sensorik

Real Time Monitoring

Live update starten | Live update stoppen | Letzte verfügbare Daten anzeigen

Zuletzt aktualisiert: 06.05.2024 13:38:51

Sensor	Daten	Einheit	Zeitstempel (UTC)
Trübungssonden			
Truebung_ein	0.00	NTU	13:38:51
Truebung_aus	0.00	NTU	13:38:51
Porendrucksonden			
druck_1	107.16	mmWS	13:38:51
druck_2	-807.51	mmWS	13:38:51
druck_3	115.28	mmWS	13:38:51
druck_4	92.88	mmWS	13:38:51
druck_5	-5.42	mmWS	13:38:51
Wasserstandssensor			
druck_6	24.54	mmWS	13:38:51
druck_7	30.47	mmWS	13:38:51
druck_8	-4.99	mmWS	13:38:51
Pegelsonden			
Pegel_ein	0.00	mmWS	13:38:51
Pegel_aus	0.00	mmWS	13:38:51



Conclusion and Future Work

- **Key Takeaways:**
  - OGC SensorThings API + MQTT + Sensor Data Fusion enables **real-time data transmission.**
  - Linked-data Model supports **real-time visualization.**
- **Future Work:**
  - **Ensuring MQTT Message Order:** Implement mechanisms to maintain correct message sequence in high-frequency data streams.
  - **GeoMQTT Implementation:** Enable geospatial and temporal filtering for more efficient data distribution.
  - **Edge Computing Integration:** Introduce additional MQTT layers for on-site data filtering, aggregation, and compression.
  - **System Optimization:** Enhance robustness, efficiency, and adaptability for structural health monitoring.

The most relevant SDGs related to the presentation and theme of this session

1st relevant SDG: 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

2nd relevant SDG: 15 LIFE ON LAND

3rd relevant SDG: 13 CLIMATE ACTION

SUSTAINABLE DEVELOPMENT GOALS | International Federation of Surveyors supports the Sustainable Development Goals