Digital Twin Workflow Development Framework in the Context of Fluid Structure Interaction

WESC2021 "Emerging Technologies and Special Sessions"
Digital Twin Technology

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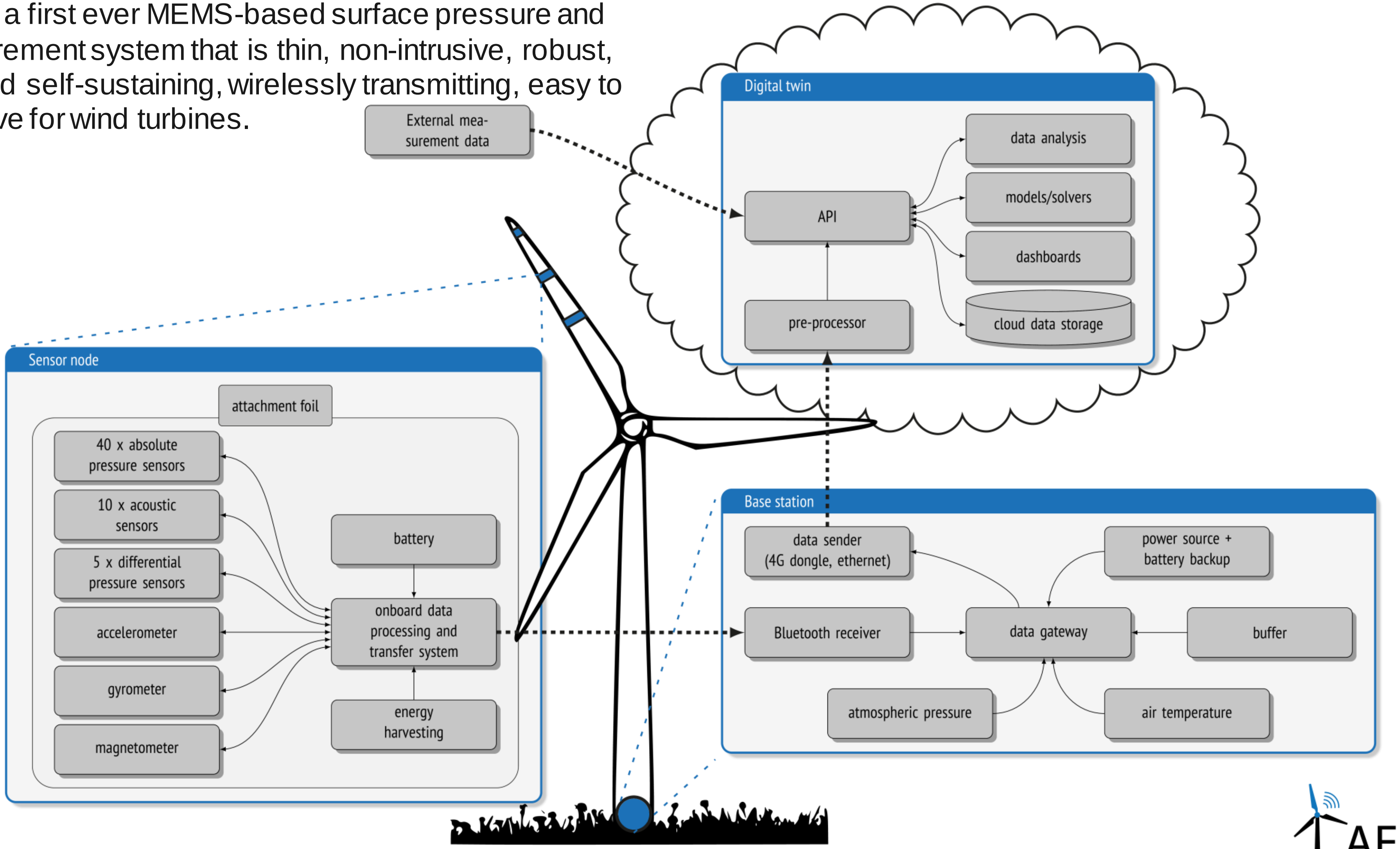
OST Ostschweizer Fachhochschule
ETH zürich
BRIDGE
FNSNF Swiss National Science Foundation
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Innosuisse – Swiss Innovation Agency
AEROSENSE

25th May 2021

Contents

The Aerosense project

- **Project goal:** develop a first ever MEMS-based surface pressure and acoustic smart measurement system that is thin, non-intrusive, robust, modular, low power and self-sustaining, wirelessly transmitting, easy to install and cost-effective for wind turbines.



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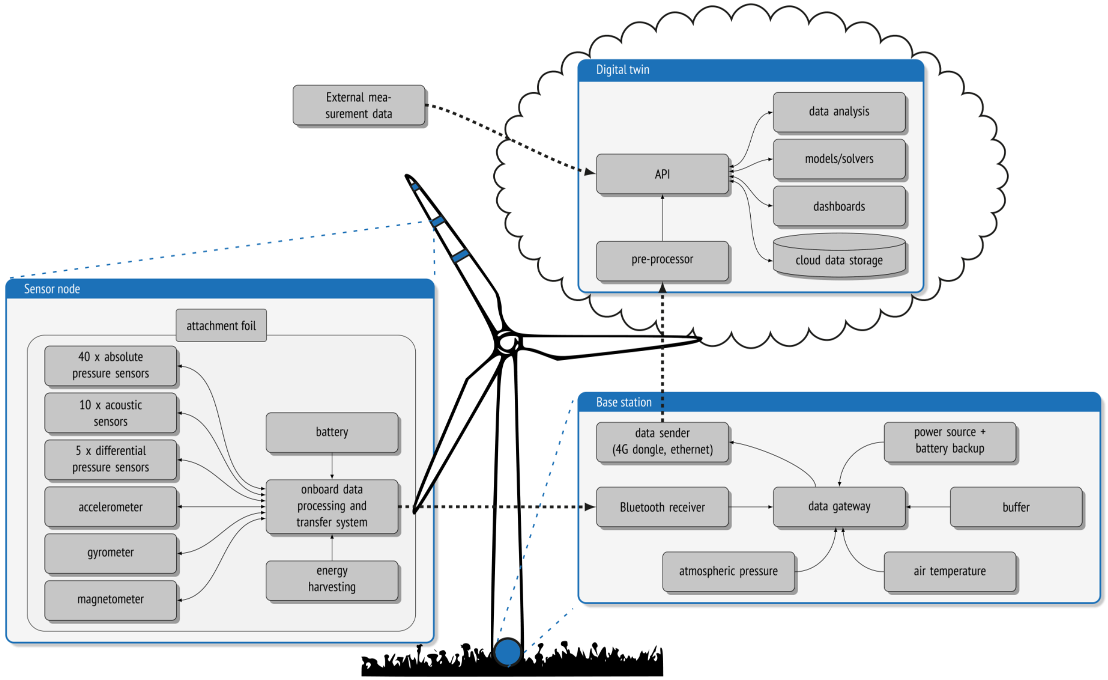
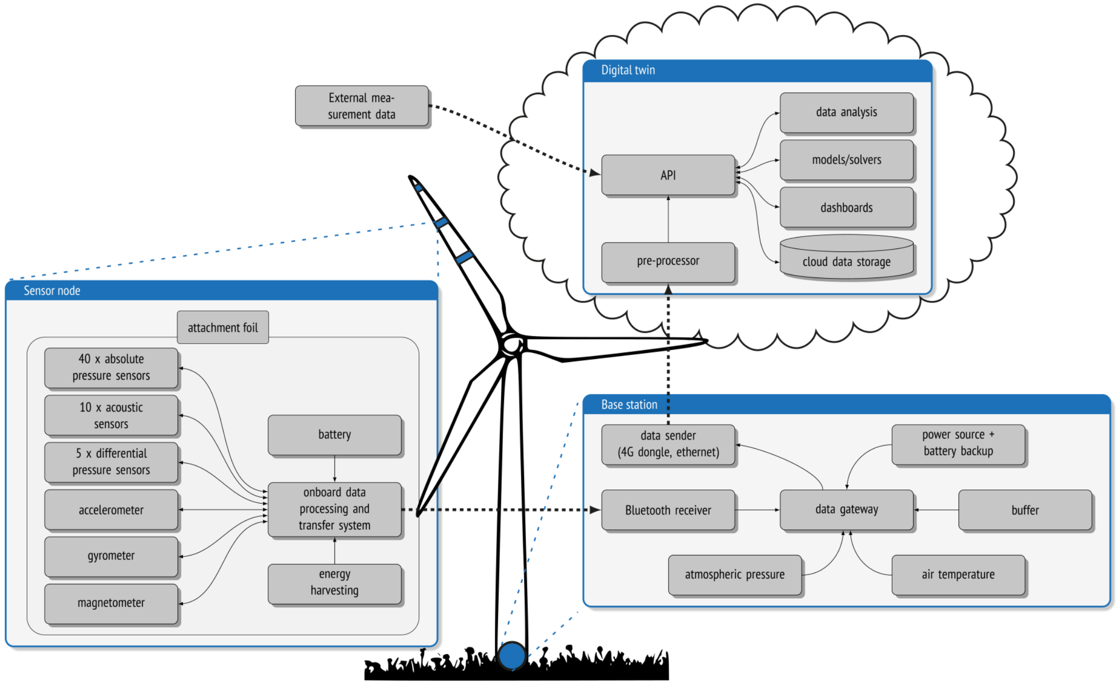


- **Use cases:**
  - **Operators**: blade surface and structural damage detection, performance optimisation, amplitude modulation detection
  - **OEMs:** optimisation of aeroacoustic design tools and wind turbine designs, understanding 3D field aerodynamics.
- **Scope:**
  - 3 years May 2020 – April 2023
  - Funding from SNF/Innouisse BRIDGE programme: CHF 2.3 m
- **Partners:**
  - Eastern Switzerland University of Applied Sciences (OST)
  - ETH Zurich Chair of Structural Mechanics and Monitoring
  - ETH Zurich Center for Project-Based Learning
  - Octue (UK)
- **Advisory Board:**
  - RES, EKZ Renewables, Enercon, GE (LM), Brüel&Kjaer
  - Fraunhofer IWES, ECN, DTU, TU Delft, NREL.

The Aerosense Digital Twin

- **Project subgoal:** develop a digital twin platform, that is cloud based, rapidly deployable and scalable.



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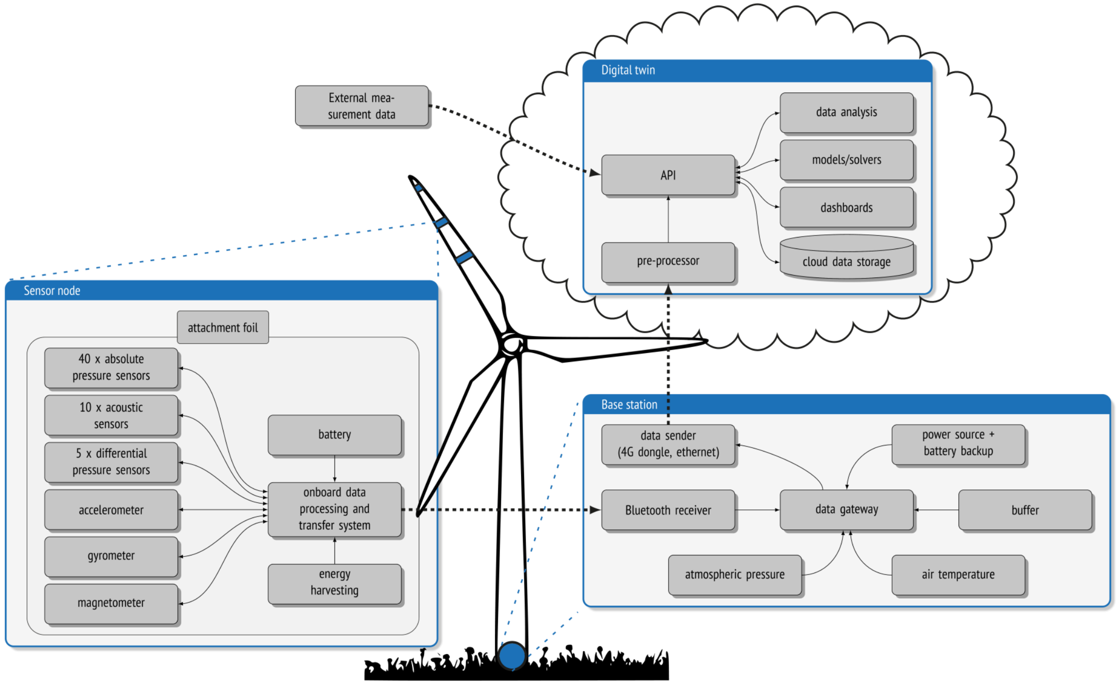

- **Digital Twins Development:**
  - **Multidisciplinary**
    - Measurement hardware
    - Calibration
    - Modeling
    - Statistics
    - IT/Software
  - **Multiscale**

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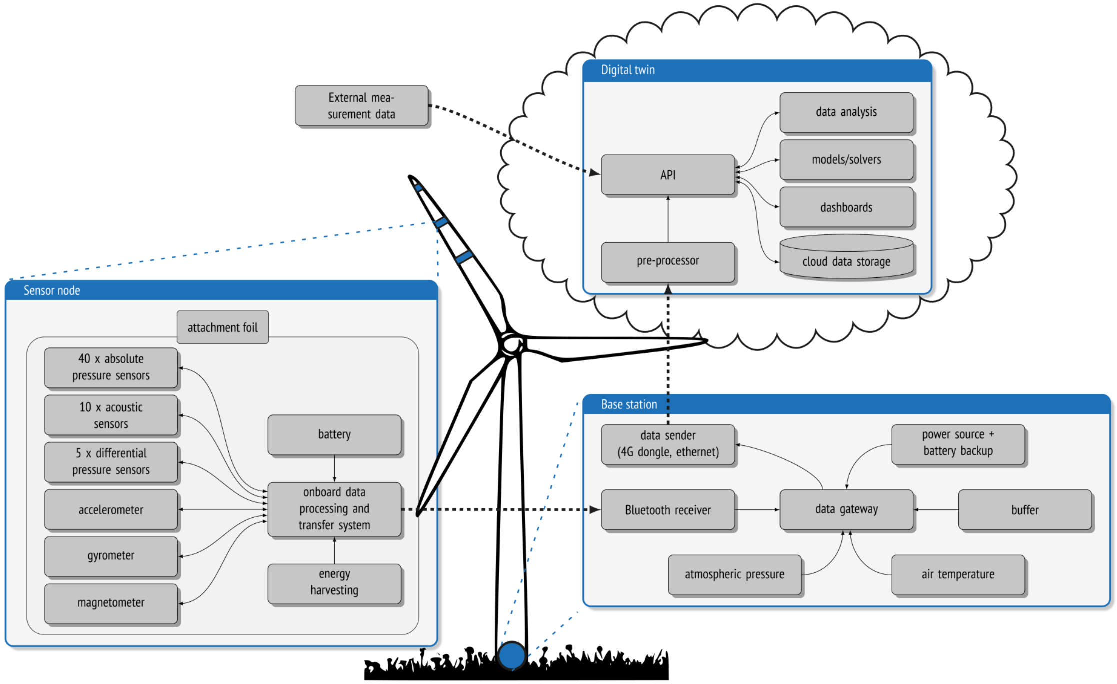

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- **Aerosense Digital Twin Requirement:**

  An **open** framework that enables scientists from different fields to contribute to the wind energy research and digital twin development by providing easy **data access** and possibility for **testing and validation** of their models.

Digital Twins: Hierarchy

Supervisory (Digital Shadow)	Measurement Stored Data/ Visual Data	Measurement System
Hierarchy	**Workflow**	**Usage**

Digital Twins: Hierarchy

Hierarchy	Workflow	Usage
Operational (Digital Shadow)	Measurement Data Analysis Stored Data/Visual Data Operator Decision	Operational Analysis
Supervisory (Digital Shadow)	Measurement Stored Data/ Visual Data	Measurement System

Digital Twins: Hierarchy

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Modelling (Digital Shadow/ Digital Twin e.g. Ansys Twin Builder)	Measurement Data Analysis Modelling (Simulations / Surrogate Models) Predicted States/Visual Data Operator Decision	Asset management
Operational (Digital Shadow)	Measurement Data Analysis Stored Data/Visual Data Operator Decision	Operational Analysis
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Digital Twins: Hierarchy

Hierarchy	Workflow	Usage
Self-Improving (Digital Shadow/ Digital Twin)	Measurements Data Analysis Evaluation of uncertainties on the state variables of the system Multi-Fidelity Simulation / Surrogate Model Uncertainty propagation/Datafusion/ Statistical Inference Predicted state with quantified uncertainty Operator Decision	Uncertainty Quantification
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Digital Twins: Hierarchy

Hierarchy	Workflow	Usage
Self-Managing (Digital Twin)	Same as below, with the system actively controlling/changing physical object	Asset Control
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[1] Wagg, D. J., Worden, K., Barthorpe, R. J., and Gardner, P.: Digital Twins: State-of-the-Art and Future Directions for Modeling and Simulation in Engineering Dynamics Applications, ASCE-ASME J Risk and Uncert in Engrg Sys Part B Mech Engrg, 6,https://doi.org/10.1115/1.4046739

Digital Twins

Physical Object (Asset)

Past states of the Physical object:

$Z_1(x,y,z,t)$, associated with prob distribution $p_1(\mu, \sigma)$

.....

$Zk(x,y,z,t)$ and $p_k(\mu, \sigma)$

Present state of the Physical object:

$Z_1(x,y,z,t_i)$ realization of $p_1(\mu, \sigma)$

.....

$Z_n(x,y,z,t_i)$, $p_n(\mu, \sigma)$

Future state of the Physical object:

$Z_1(x,y,z,t+dt)$, $P(Z_1)$

.....

$Z_n(x,y,z,t+dt)$, $P(Z_n)$

Digital Twins

Environment

Physical Object (Asset)

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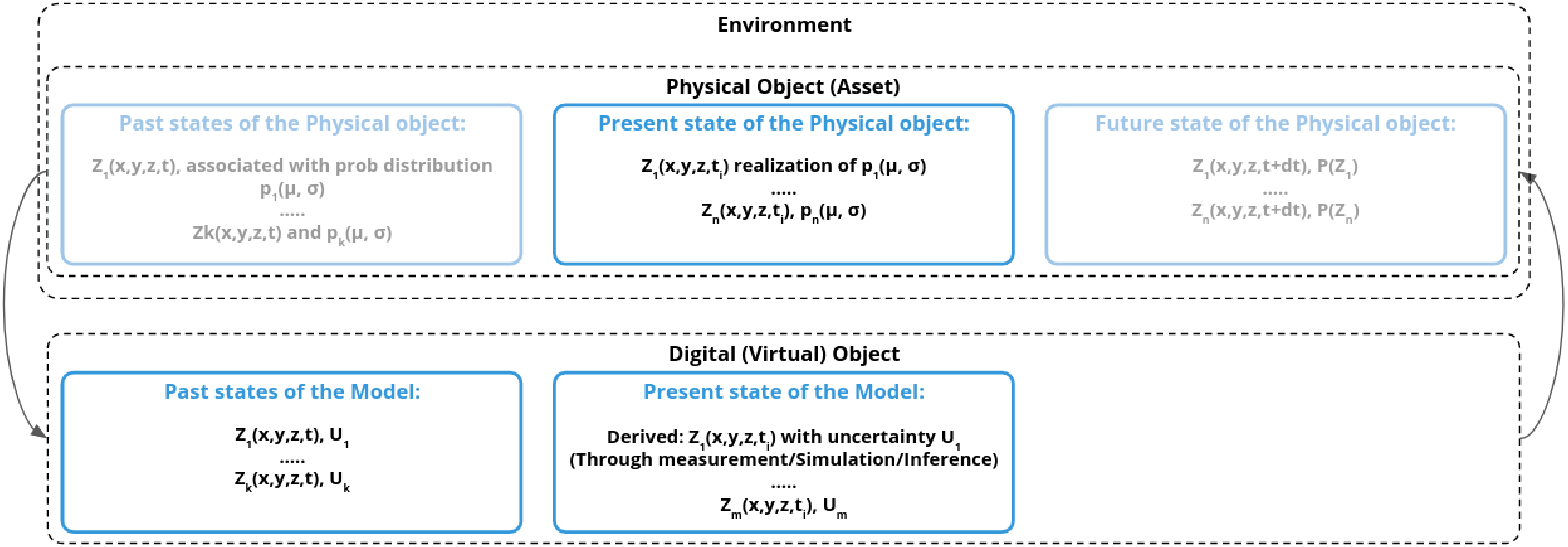
Digital (Virtual) Object

Present state of the Model:

Derived: $Z_1(x,y,z,t_i)$ with uncertainty U_1
(Through measurement/Simulation/Inference)
.....
$Z_m(x,y,z,t_i)$, U_m

Digital Twins



Digital Twins

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Past states of the Model:

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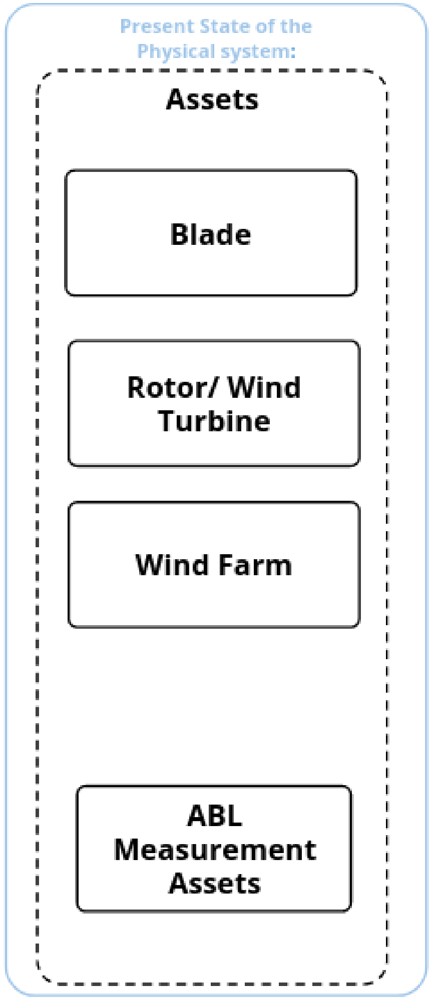
Present state of the Model:

Derived: $Z_1(x,y,z,t_i)$ with uncertainty U_1
(Through measurement/Simulation/Inference)
.....
$Z_m(x,y,z,t_i)$, U_m

Predicted state of the Model:

$Z_1(x,y,z,t+dt)$, U_1
.....
$Z_m(x,y,z,t+dt)$, U_m

Digital Twins: FSI context



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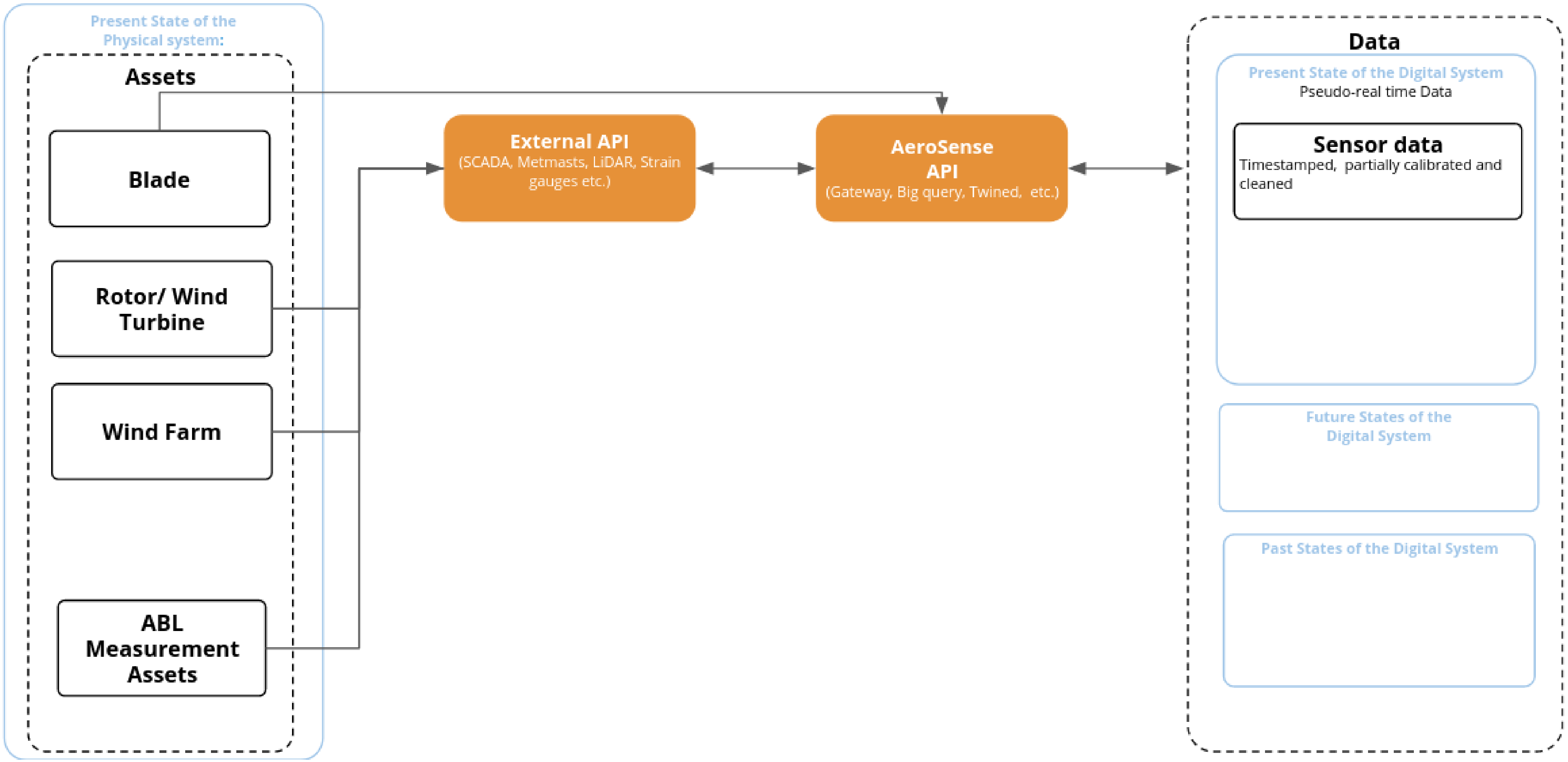

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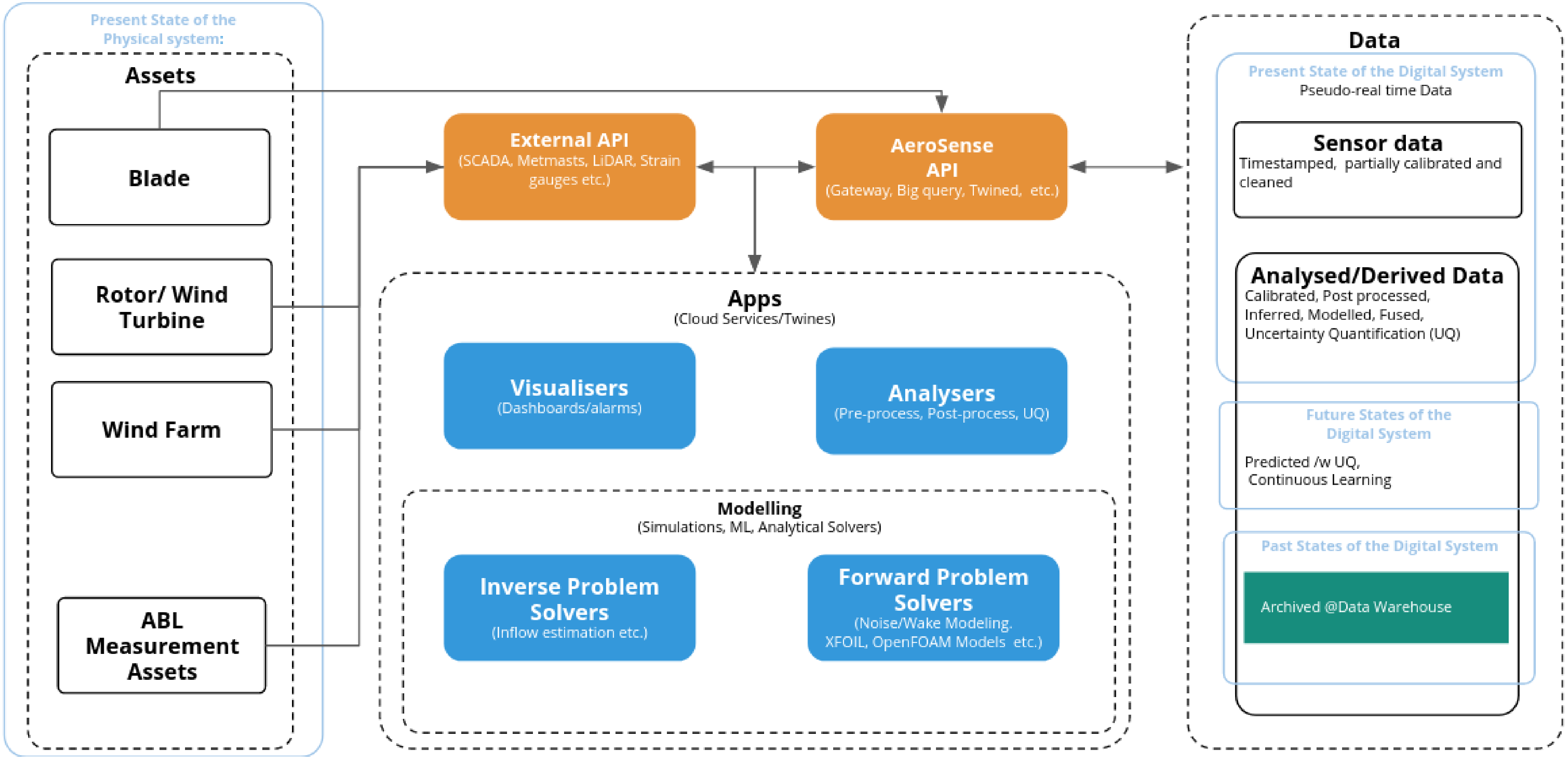
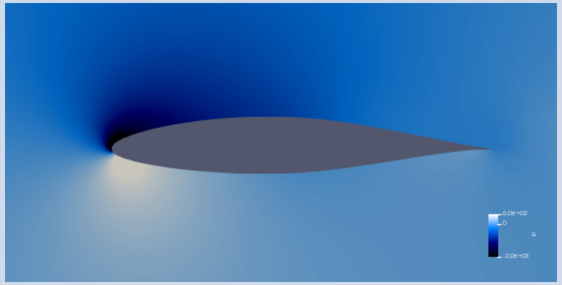
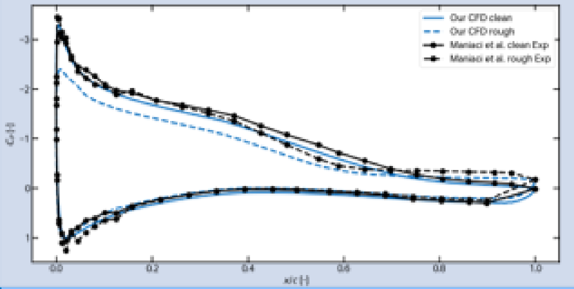


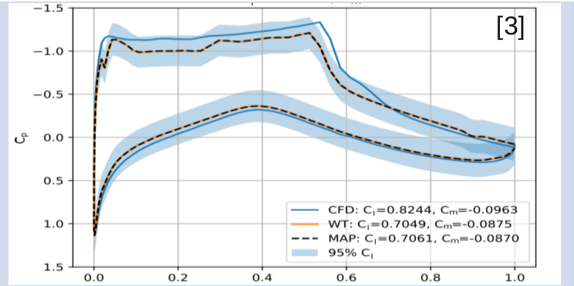
Digital Twins: App Layer Development



Physics-based modelling

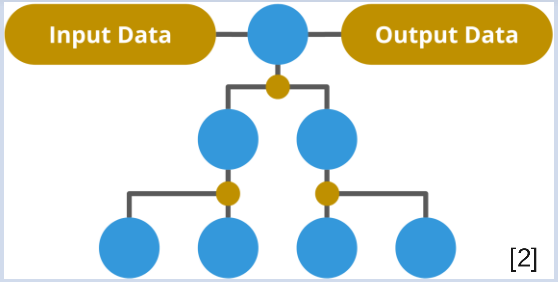


Verification and validation

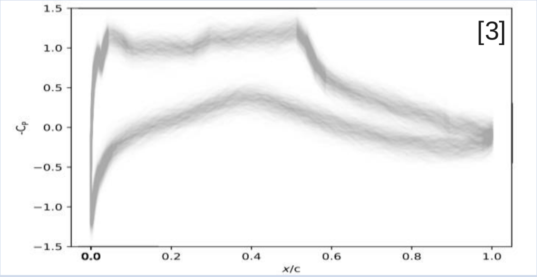


Data-augmented modelling

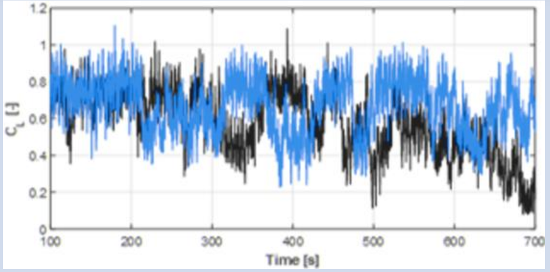
Software integration and management



Uncertainty quantification



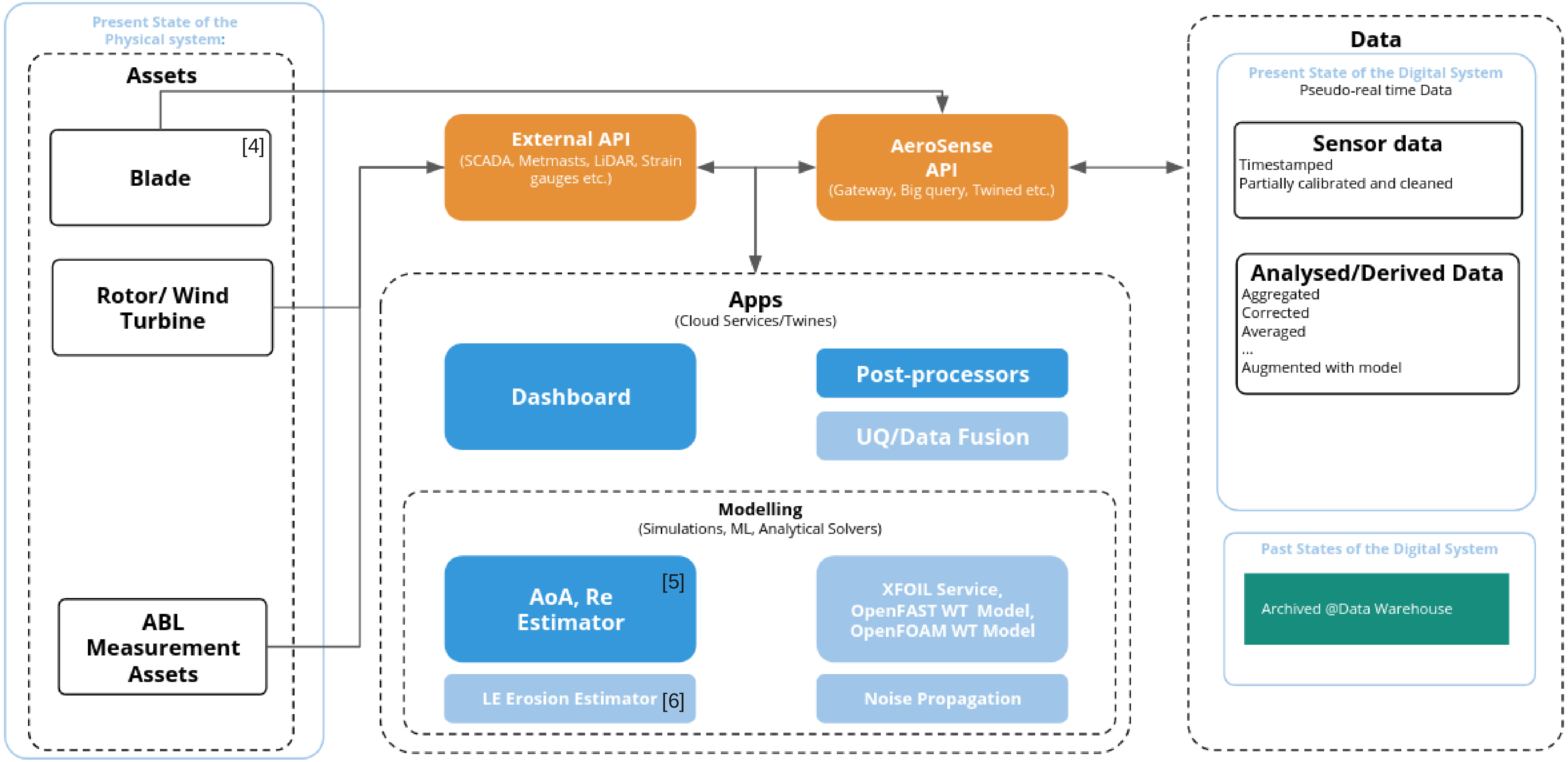
Output visualization



[2] Octue - https://tw ined.readthedocs.io
[3] Renganathan, S. A., Harada, K., and Mavris, D. N.: Aerodynamic Data Fusion Tow ard the Digital Tw in Paradigm, AIAA Journal, 58,3902–3918, https://doi.org/10.2514/1.J059203, 2020.

AEROSENSE

Digital Twins: AEROSENSE - AVENTA Test Wind Turbine



[4] Tommaso Polonelli et al - Towards A Self-sustaining Wireless Smart Sensor Node for Continuous Monitoring of Wind Turbines , WESC 2021
[5] Julien Deparday et al - Development of a method for obtaining local inflow angle from pressure gradient at leading edge on operating wind turbine blades, WESC 2021
[6] Gregory Duthé et al - Learning to diagnose leading edge erosion degradation on an airfoil via aerodynamic pressure coefficients, WESC 2021

Conclusions

Software integration and management

- Bottleneck for implementation of research advances in industry.
- Common open-source framework will significantly accelerate DT developments, especially UQ and Data Augmented Modelling research

High-level DT Abstractions and Open-Source Libraries

- IT/Cloud infrustucture (Twined, Octue SDK)
- Python Libraries (OpenOA, Aerosense)
- Published Wrappers (Aerosense)
- Common metadata definitions

Thank you for your attention!

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Aerosense at WESC:

- Tommaso Polonelli - Towards A Self-sustaining Wireless Smart Sensor Node for Continuous Monitoring of Wind Turbines
- Gregory Duthé - Le arning to diagnose leading edge erosion degradation on an airfoil via aerodynamic pressure coefficients
- Julien Deparday - Development of a method for obtaining local inflow angle from pressure gradient at leading edge on operating wind turbine blades

Find out more here:

https://www.iet.hsr.ch/index.php?id=19191&L=4

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