Generation of Synthetic SCADA Signals using cGANs for Enhanced Wind Turbine Fault Detection and Prognosis

Ali Eftekhari Milani

Donatella Zappalá

Francesco Castellani

Simon J. Watson

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Outline

- Context
- Fault detection
- Problem
- Proposed solution
- Methodology
- Results
- Conclusions and future work

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Context of the study

O&M costs are significant!
Esp. offshore (up to 30% of total cost)

Reactive Maintenance
- Fix when it breaks

Preventive Maintenance
- Maintain at regular intervals so it does not break

Predictive Maintenance
- Predict when it will break and maintain accordingly

Faults need to be predicted well before a failure happens

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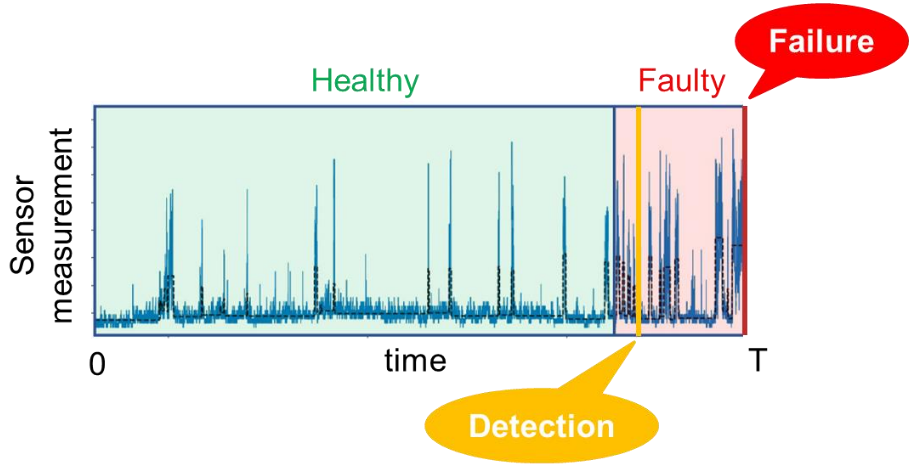
Fault detection: Two main approaches

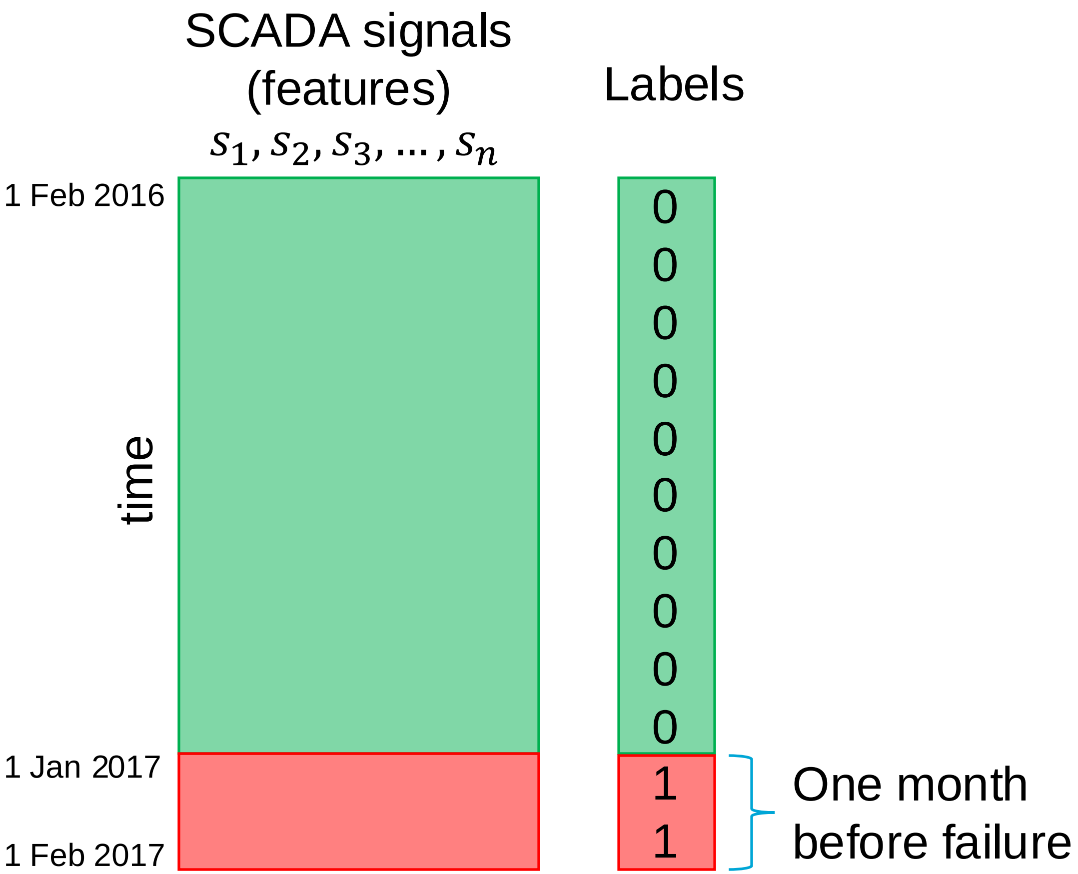
- Based on Normal Behaviour Modelling (NBM)
  - \+ Only healthy data needed for training
  - – Cannot distinguish between different failure types

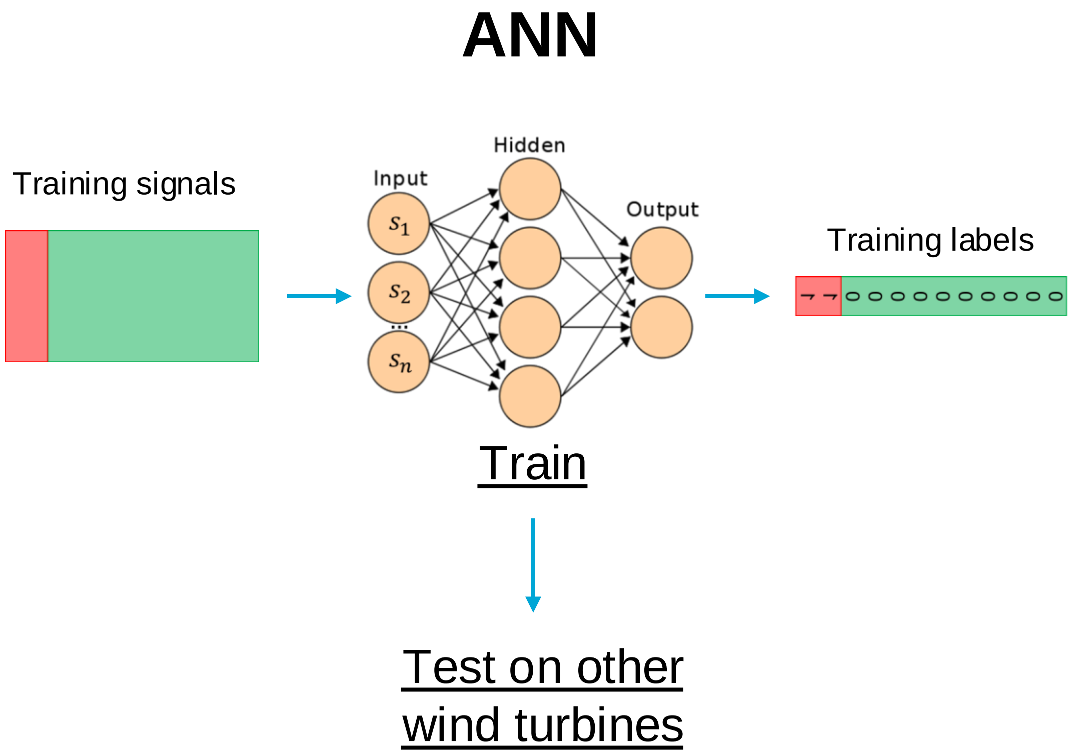
- Based on Classification
  - \+ Different failure types can be distinguished
  - – Both healthy and faulty data needed for training



When detection of <u>a certain fault type</u>, e.g., Gearbox fault, is required → Classification ~~Normal Behaviour Modelling~~

Classification





Problem

Failures are rare events!

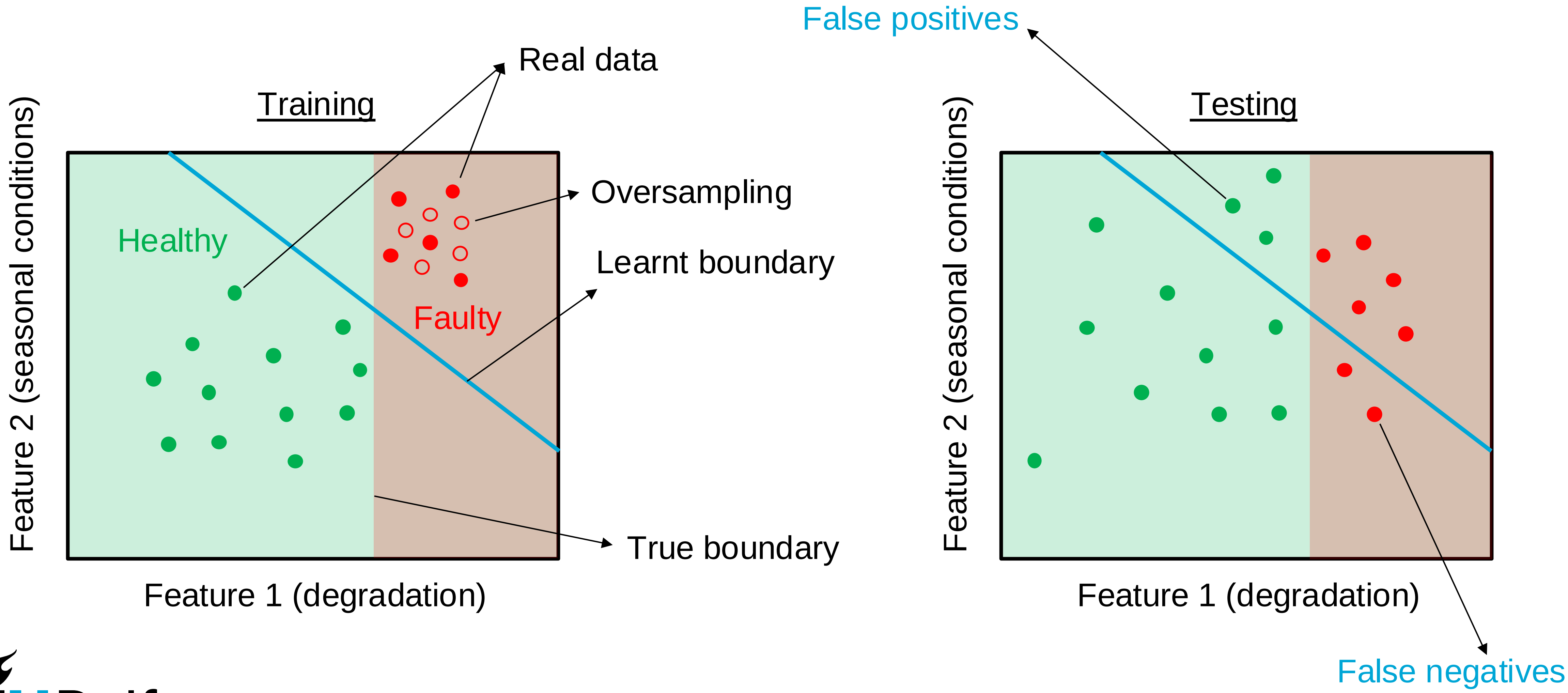
Available datasets:

Usually a handful of turbines
during a few years of operation

Very few failures events in the data

→ This leads to problems when using classification methods

A simple example



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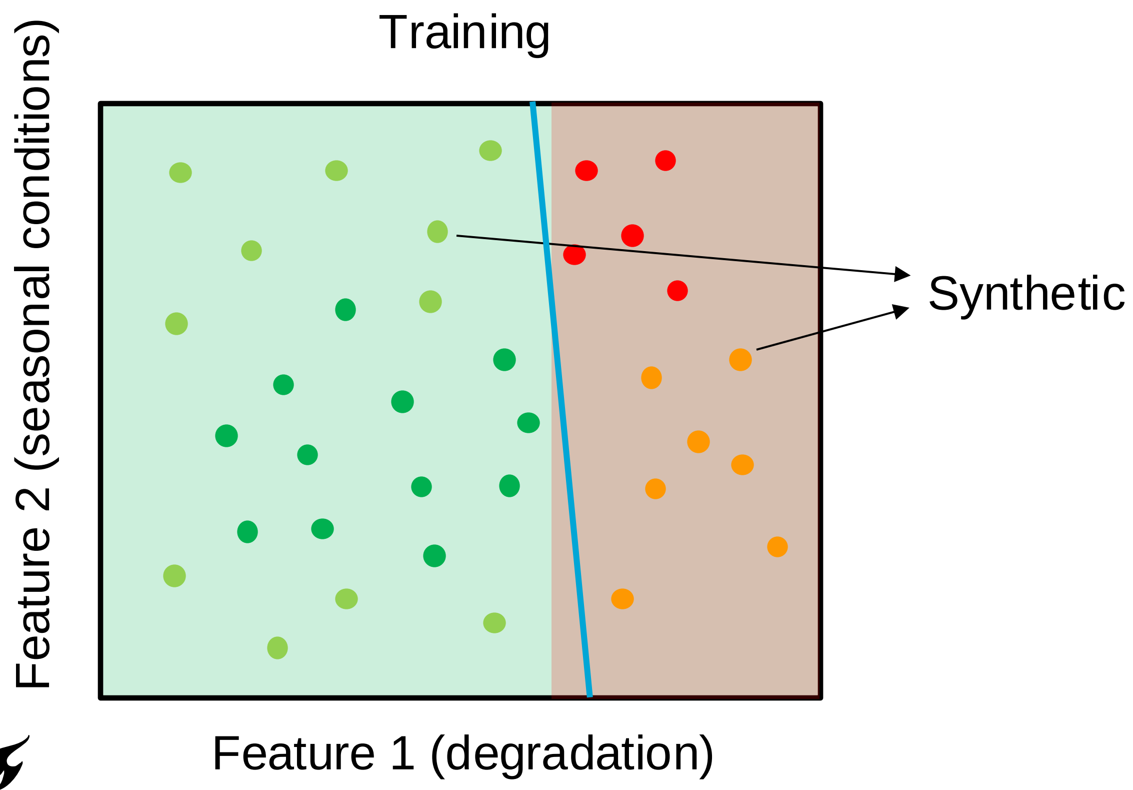
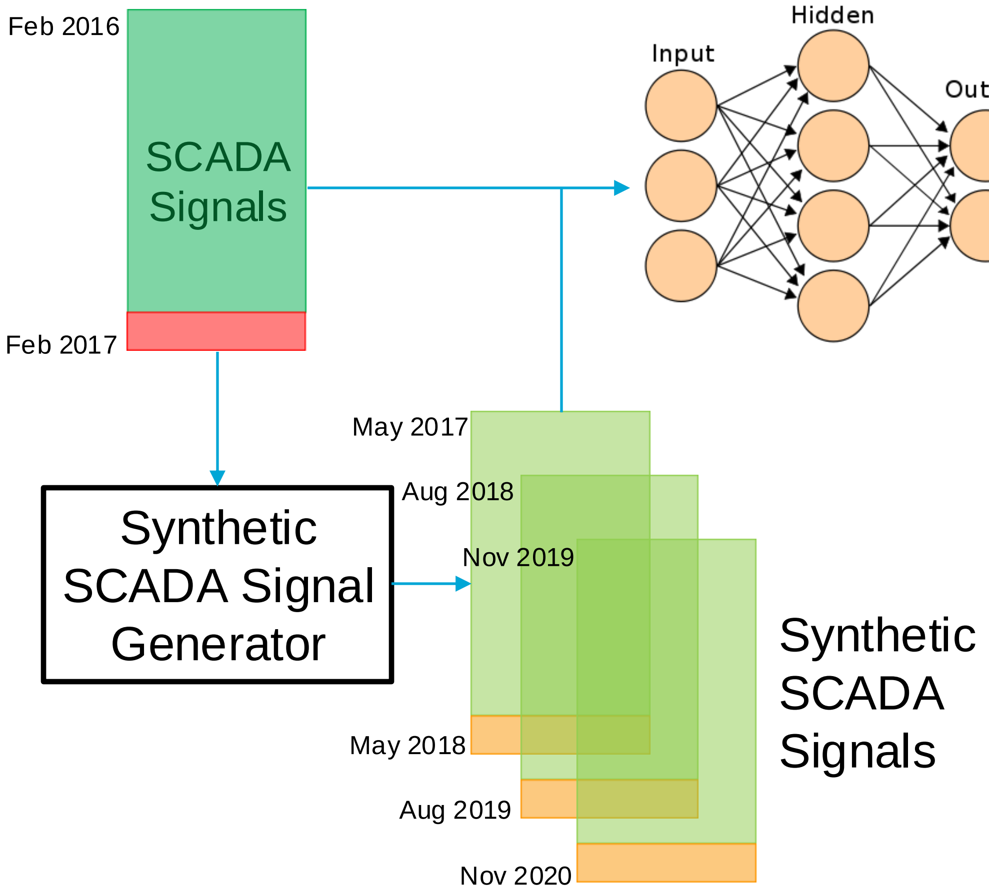
Proposed solution: Synthetic signal generation

Simulating the same failure at different seasonal conditions



<u>Train with a combination of field and synthetic signals</u>



Methodology for synthetic SCADA signal generation

Selected SCADA Signals:

- Related to the operation of the component of interest (e.g., Gearbox temperature and pressure signals) — $\boldsymbol{S}$
- Related to environmental conditions (e.g., Ambient temperature) — $\boldsymbol{E}$
- Related to wind turbine operational mode (e.g., Rotor speed) — $\boldsymbol{O}$

CAE[1]

Health Indicator (HI) — D

Assumption: S is a stochastic function of O, E, and D

$$\boldsymbol{S} = F(\underbrace{\boldsymbol{O}, \boldsymbol{E}}_{\boldsymbol{C}}, D, \boldsymbol{Z})$$

- Signals ← $\boldsymbol{S}$
- Conditions ← $\boldsymbol{C}$
- $\boldsymbol{Z}$ → Unit Gaussian noise vector

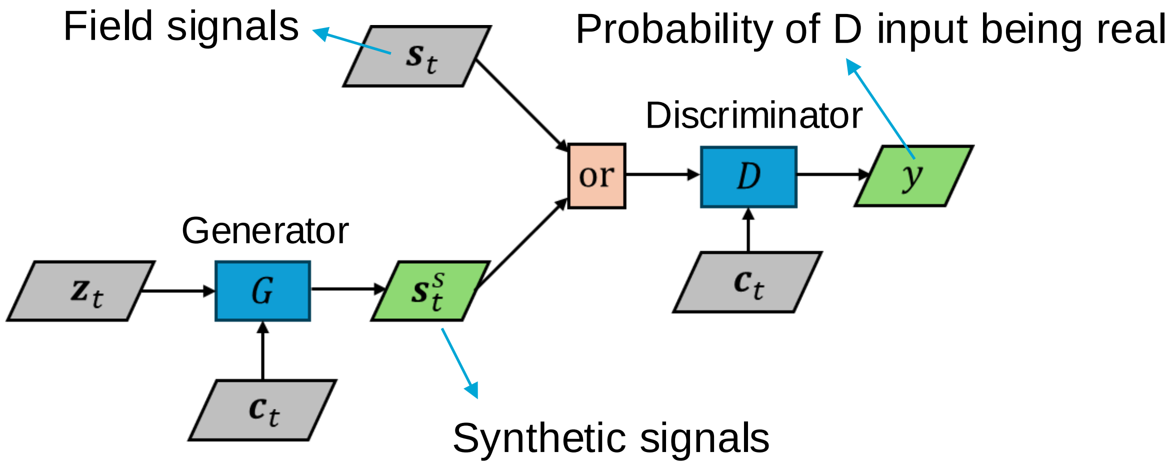
1: Eftekhari Milani, A., Zappalá, D., and Watson, S.; A hybrid Convolutional Autoencoder training algorithm for unsupervised bearing health indicator construction, Engineering Applications of Artificial Intelligence, 2024

Methodology for synthetic SCADA signal generation

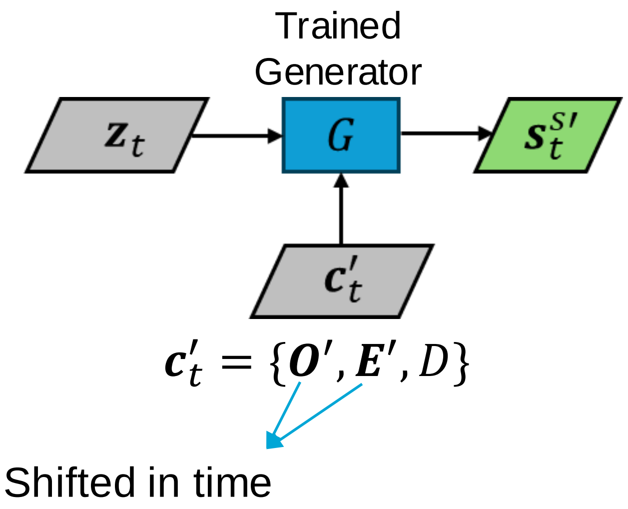
$$\boldsymbol{S} = F(\overbrace{\boldsymbol{O},\boldsymbol{E},D}^{\boldsymbol{C}},\boldsymbol{Z})$$

→ modelled through a Conditional GAN (cGAN) which is a probabilistic generative deep learning framework

Training



Generation



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Dataset

- The SCADA dataset is received from **Lucky Wind S.p.A**
- Signals available from nine wind turbines (WT 1-9) through 5 years of operation, resampled to 6-hour intervals
- WT 8 experienced a gearbox failure in Feb 2022 → WT 8 used for training
- The remaining eight WTs → used for testing

- Selected signals for analysis:

$\boldsymbol{S}$ Temperature signals: 3 gearbox bearings, gearbox oil, gearbox oil at the inlet
Pressure signals: gearbox oil before filter, and after filter

$\boldsymbol{E}$ ambient temperature, ambient wind speed

$\boldsymbol{O}$ rotor RPM

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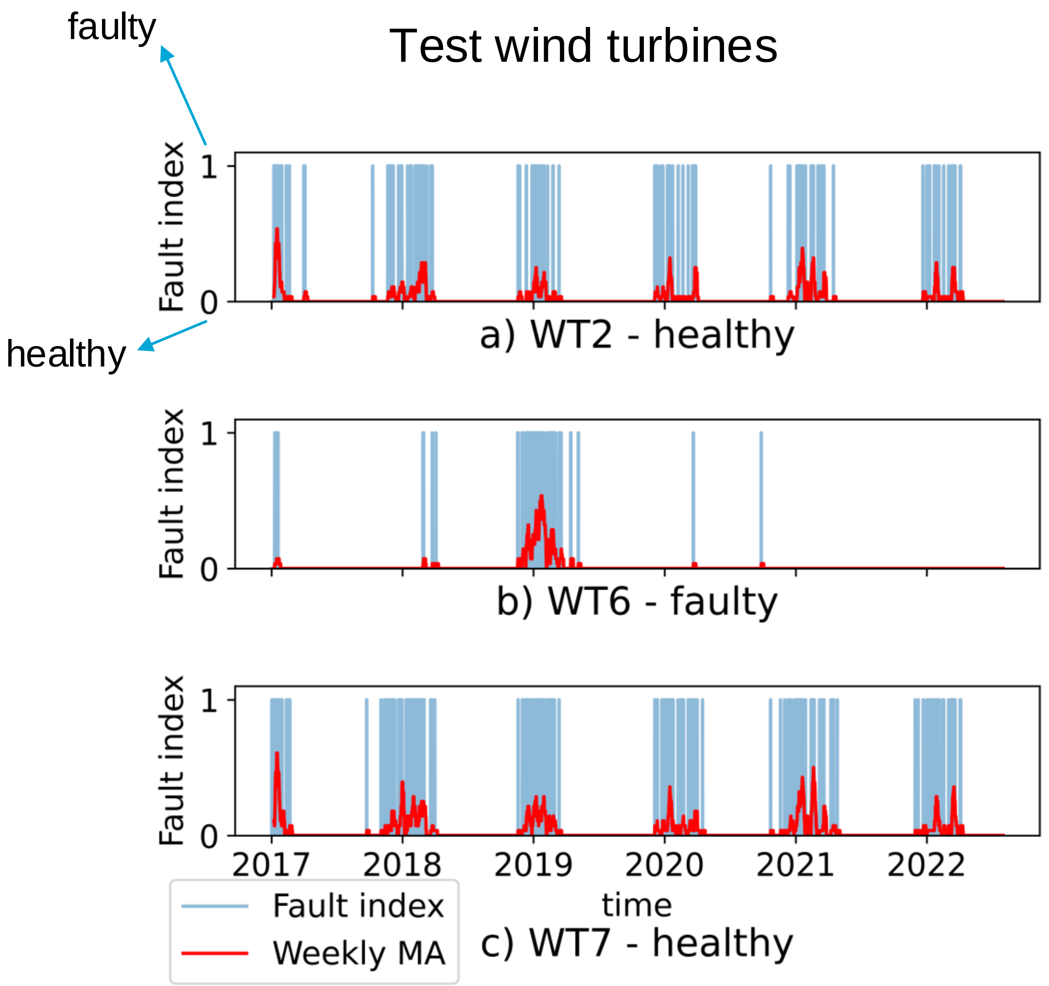
Results – Without synthetic signals

ANN trained with data related to only one failure event (WT 8 – one year leading to failure)

- A lot of false positives around the date of the training set failure (February)
- Not clear whether the detection in WT 6 is, in fact, a fault or a false positive



The model cannot distinguish between the features specific to seasonal conditions at the time of failure and those specific to component degradation!

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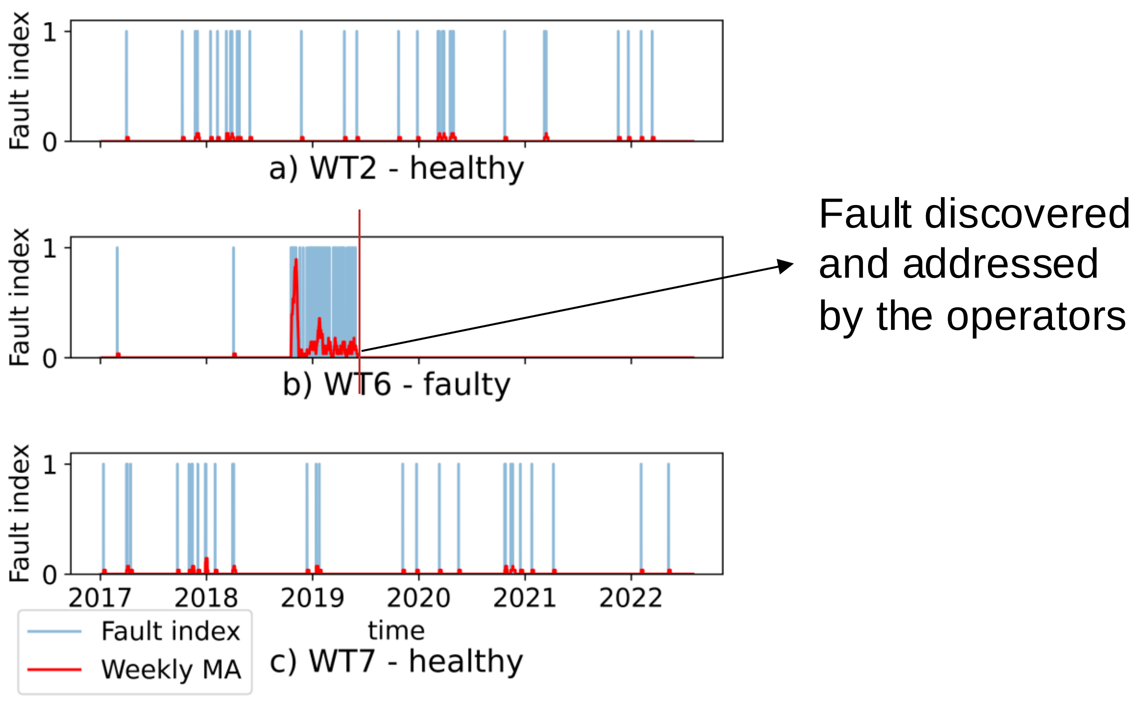
Results – With synthetic signals

ANN trained with both WT 8 data and four synthetically generated data

- Most of the false positives have been resolved
- A fault is detected at the end of Oct 2018 and continues until the end of May 2019
- The operating company confirmed that a gearbox fault was discovered and repaired around the end of May 2019

ANN (Classifier) trained with the field and synthetic datasets



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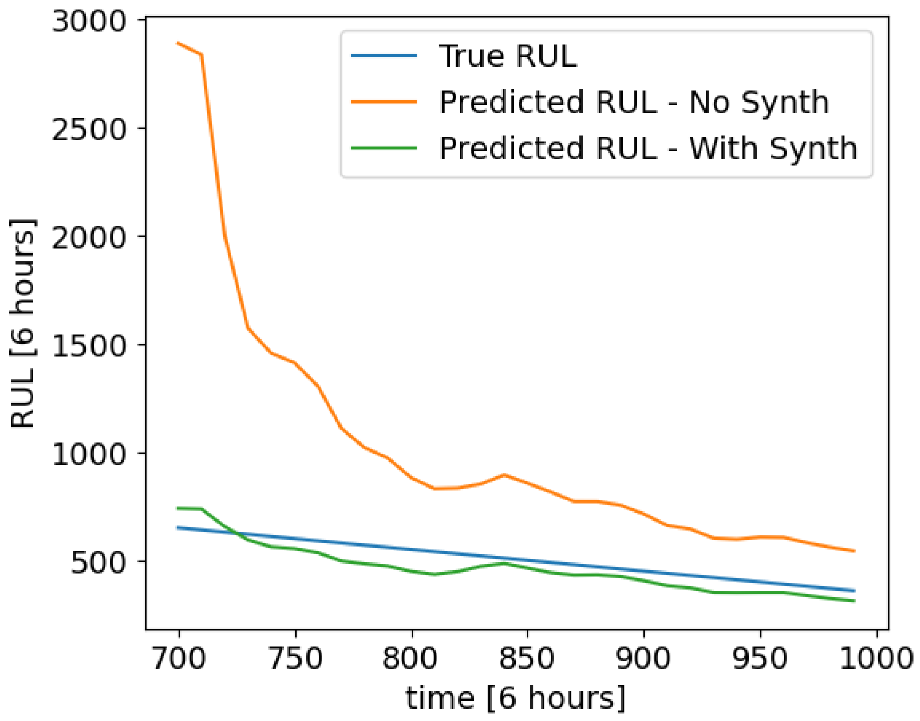
Conclusions

- Classification methods are useful when the detection of a certain type of fault is required. However, their application is hindered by the limited availability of failure events in SCADA datasets
- In this work, a method based on cGANs is proposed to generate synthetic signals and address this limitation
- The generated synthetic signals improve the training of a classifier to learn fault features, leading to significantly fewer false positives.
- This leads to the blind detection of a fault in the gearbox of another wind turbine seven months before its discovery and maintenance by the wind farm operators.

Ongoing work

- Application to Remaining Useful Life (RUL) prediction



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Thank you for your attention!