Machine Learning in Wastewater Treatment Plants

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Our Profile

Luca Pucci:
Senior Process Engineer, currently working at Nocera Superiore WWTP managed by Consorzio Nocera Ambiente. Member of the Scientific Board of Legambiente, italian most widespread environmental NGO. He does research in Wastewater Engineering,Ecology and Citizen Science.

Dario Torregrossa:
Born in Palermo in 1984. Master in Enviromental Engineering (3+2), bachelor in Management Engineer (3 years) at University of Palermo. PhD at University of Luxembourg. Author of several publications concerning big data and machine learning applied to WWTPs.

Introduction to WWTP domain

Wastewater Treatment Plant history

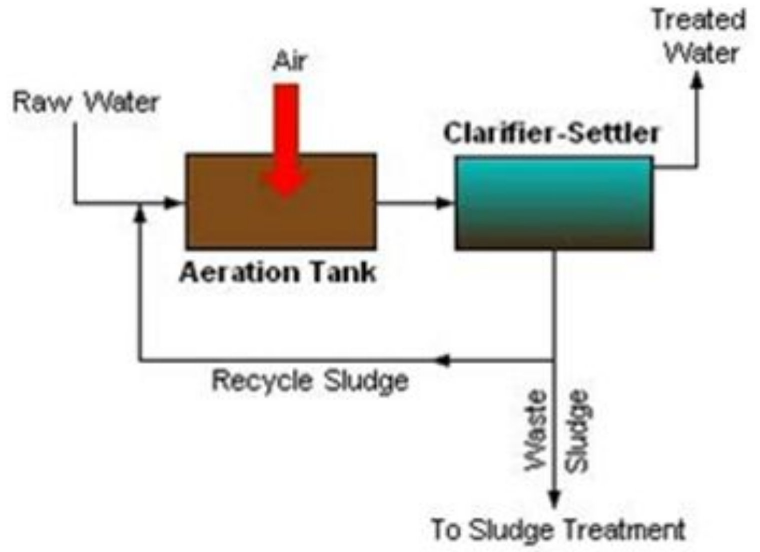
The activated sludge process was discovered in 1913 in the UK by two engineers, Edward Arden and W.T. Lockett, conducting research for the Manchester Corporation Rivers Department at Davyhulme Sewage Works.

Activated Sludge Process. https://www.iwapublishing.com/news/activated-sludge-process

Wastewater Treatment Plants - an overwiew

Urban Wastewater Treatment Plants (WWTP) remove contaminants from municipal wastewater, household sewage plus some industrial wastewater. Physical, chemical, and biological processes are used to remove contaminants and produce treated effluent.

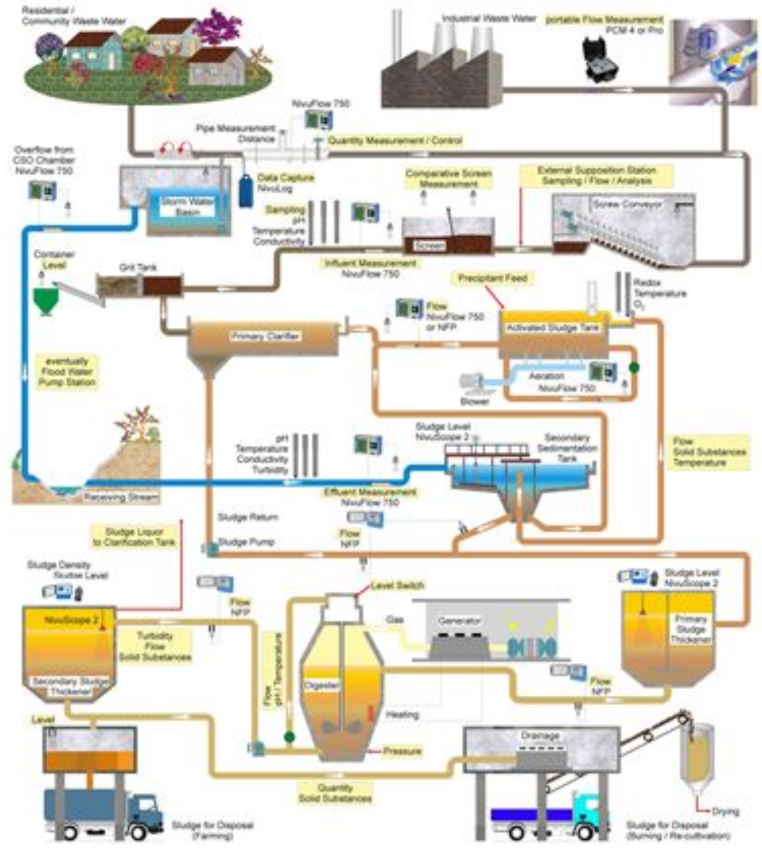
The most common biological process is Activated Sludge Process (AS). AS consist of three main components: an aeration tank, which serves as bioreactor; a settling tank ("final clarifier") for separation of AS solids and treated wastewater; a return activated sludge (RAS) equipment to transfer settled AS from the clarifier to the influent of the aeration tank.



Data availability in WWTPs

WWTPs are dynamic and complex systems, due to continuous variations of wastewater characteristics and the intrinsic complexity of biological processes.

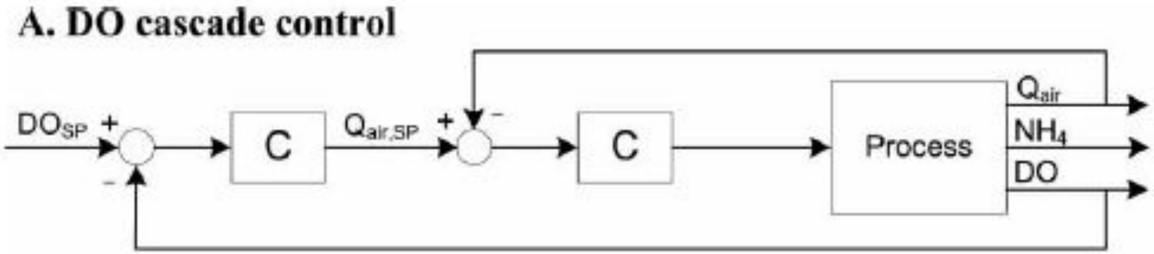
WWTPs deal today with extremely large volumes of heterogeneous, redundant, incorrect and sometimes incoherent data that come from very different sources (online sensors and analysers, laboratory, manually collected, etc.), which makes it difficult for operators to know the plant status, and to close the loop with advanced controllers.



https://www.nivus.de/fileadmin/user_upload/Anwendungen/Klaeranlagen/WWTP-NIVUS-Infographic.jpg

Data and operation management

Sensors are a critical issue because they have failures, delays, drift and noise. Dissolved Oxygen (DO) Sensors are essential to aeration control. Inaccurate measurements used in a feedback control loop may result in an undesired DO concentration and potentially reduced treatment efficiency or unnecessary aeration (with associated increasing costs).

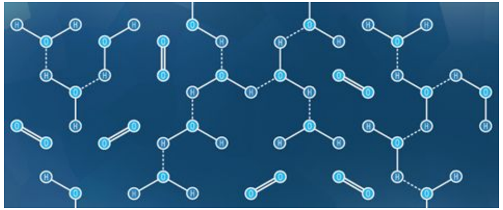


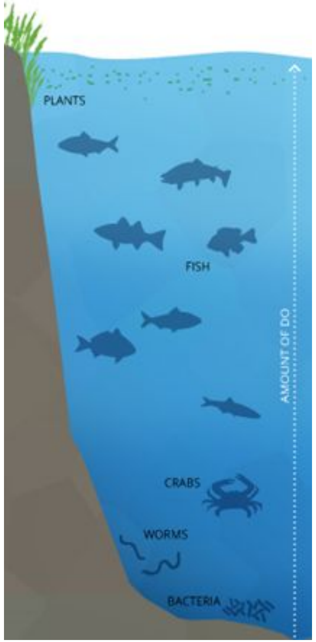
SP = set-point, C = controller

DETAILS IN: Amand et al. (2012) Aeration Control- a review. Water Science&Technology: 2374–2398

An introduction to Dissolved Oxygen DO

Dissolved oxygen refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water.



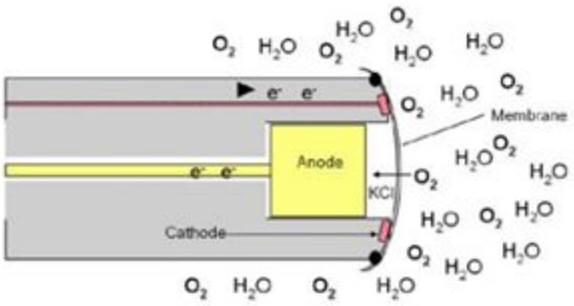


Activated Sludge Aeration Tank

An introduction to DO sensors

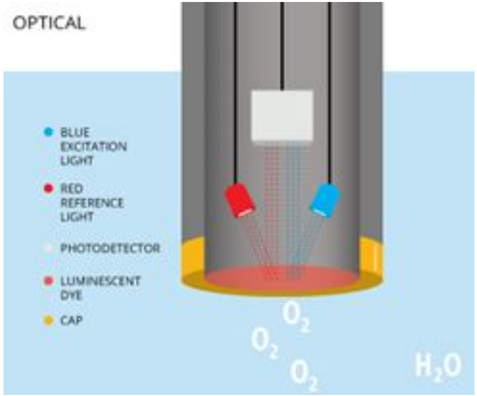
Electrochemical

They use electrodes where the dissolved oxygen reacts with the cathode to produce a current. The electrode has a semi-permeable membrane which allows O_2 to pass through.



Optical

Optical DO sensors work by measuring the changes in luminescence of a luminescent molecule which gets excited by a blue LED source and then release light in the red wavelength



Fundamentals of environmental measurement. https://www.fondriest.com/

DO sensors fouling and maintenance

DO Sensor Fouling sources:

solids deposition (biofilm formation, chemical precipitation, sludge, and plastic products), hair and fibres, and grease

DO Sensor maintenance:

Visual inspection of the sensor, Manual cleaning, Reading verifications on a regular basis (12/24 times/year)

Time-consuming actions (at least 1 hour per sensor)

Many and possibly remotly located DO sensors (up to 30 DO sensors, WWTP area up to 30 hectars)

Description of sensors used in this work

HACH LANGE

LDO sc
Process Sensor for
Dissolved Oxygen

sc200™ UNIVERSAL CONTROLLER

Objective and strategy of this work

Objective:

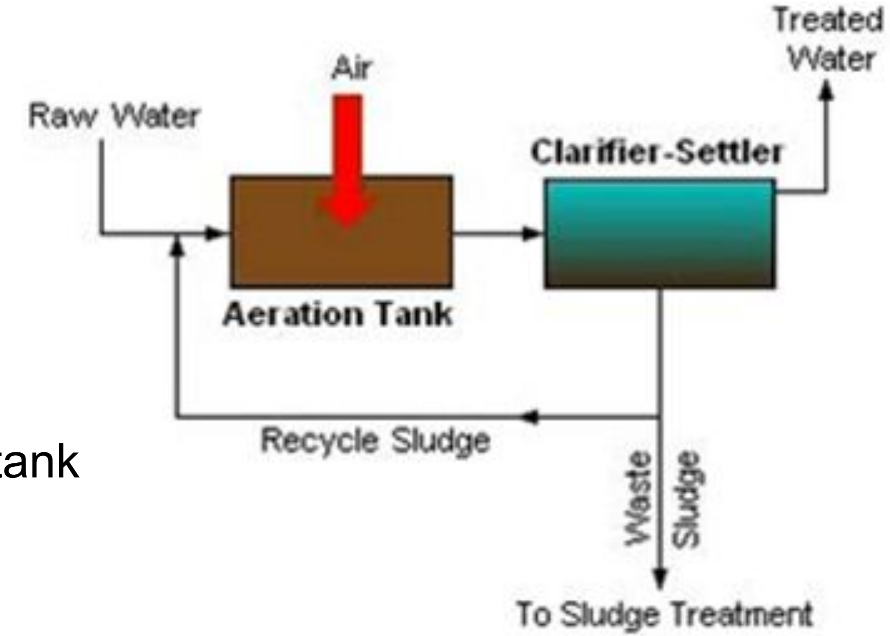
- Validate sensor data
- Replace sensor data in case of failure

Strategy:

- Develop a soft-sensor based on historical data

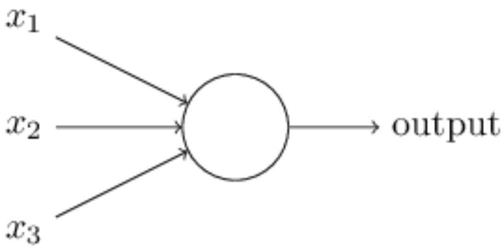
Case study

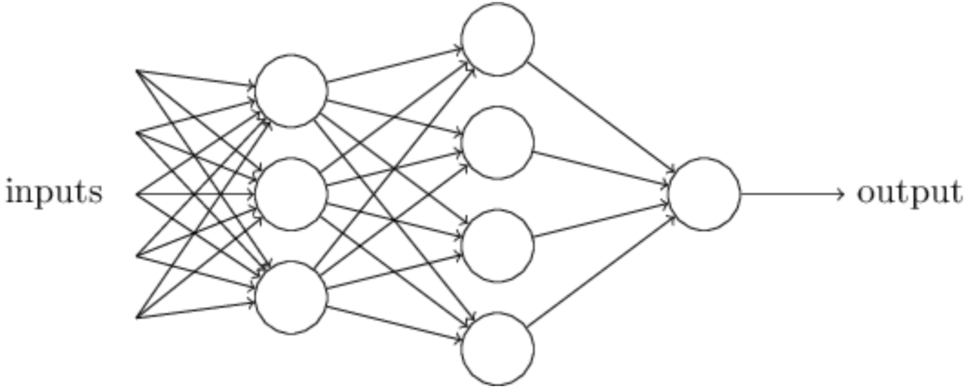
- 2 aeration tanks
- 6 DO sensors
- Flowrate to biological treatment
- Recirculated activated sludge
- Total Suspended Solids in aeration tank

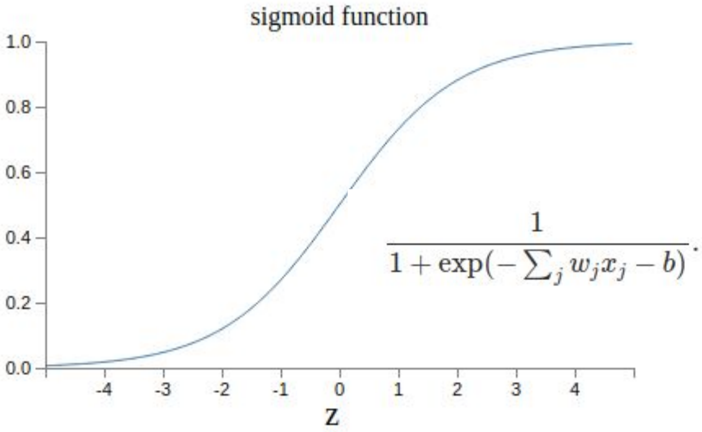


Into the methodology

A short introduction to Neural Networks

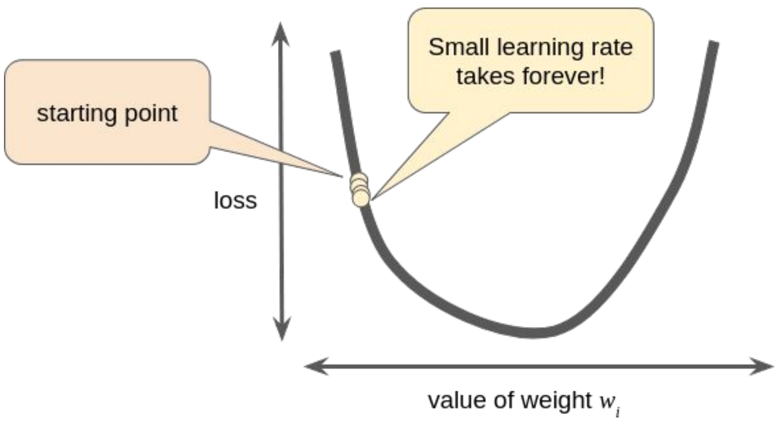


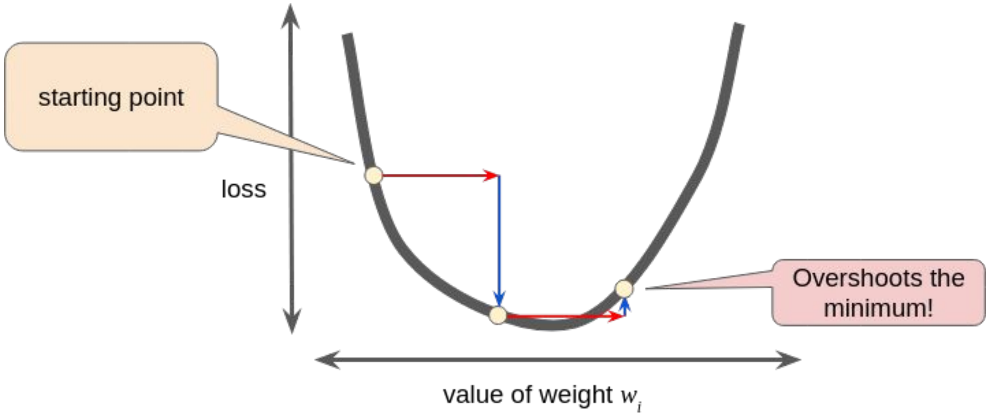




- Inputs and the outputs are provided;
- An initial random status of weights is assigned;
- The network calculates the output for given input and compare it for the desired output
- The network adjust the weights until the error is minimized

A short introduction to Neural Networks - 2





Back-propagation: 1 learning rate for all the parameters

RPROP each weight and bias has a different, variable, implied learning rate

- each weight has a LR that increases when the gradient doesn't change sign (weight move to right direction)
- decreases when the gradient does change sign

Balance between performance and over-fitting

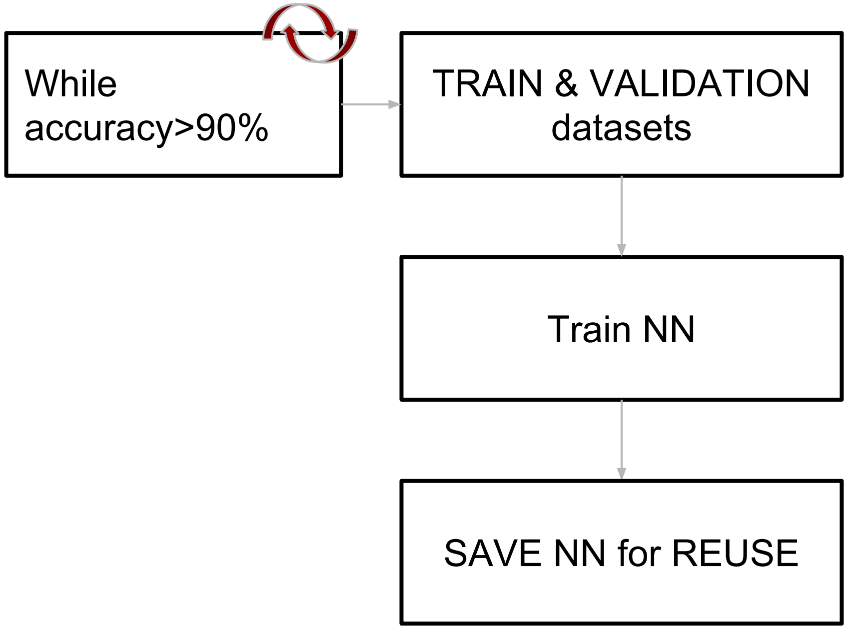
Structure and number of neurons:

- 1 hidden layer is expected to work
- The number of neurons is to be chosen

Low number
Low performance

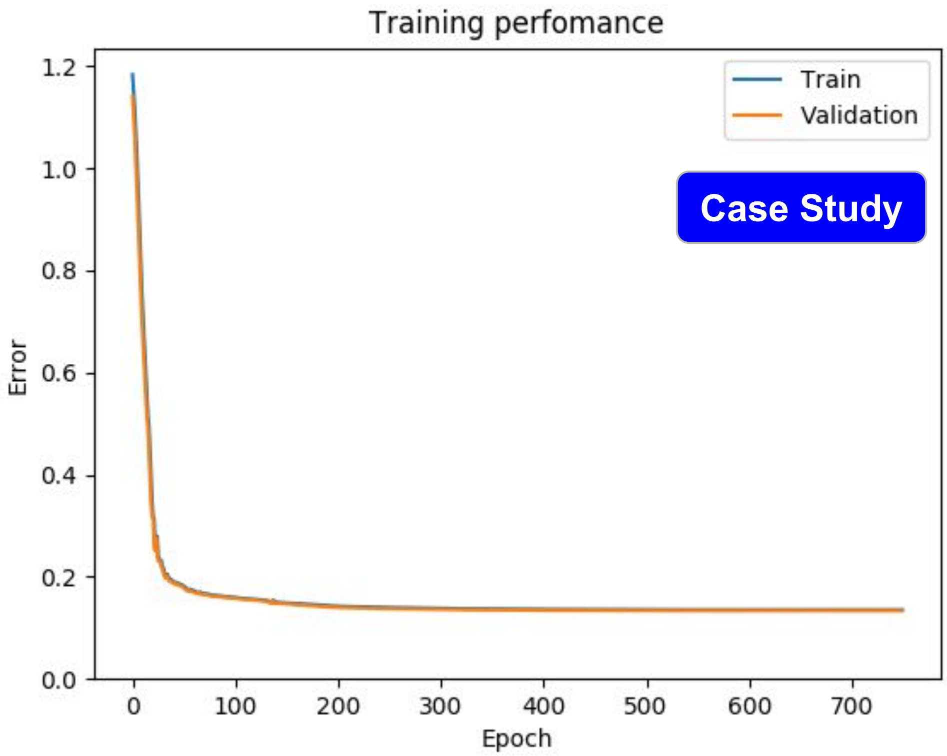
High number
Over-fitting = iper-specialization

Train the NN - Algorithm



DETAILS IN: Torregrossa D, Leopold U, Hernández-Sancho F, Hansen J (2018) Machine learning for energy cost modelling in wastewater treatment plants. J Environ Manage 223:1061–1067

Train the NN - Algorithm



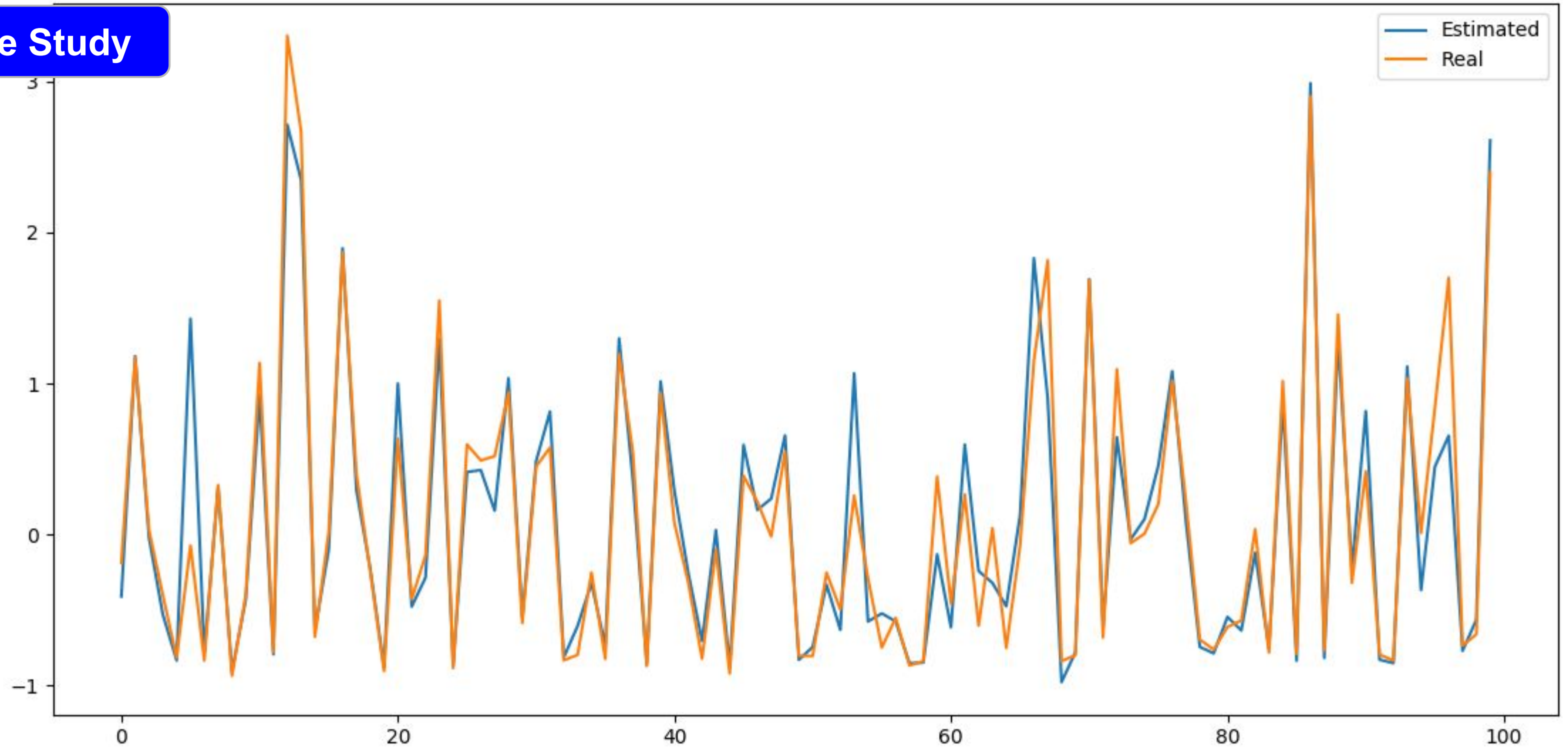
Accuracy on train dataset= 92%
Accuracy on test dataset=91%

Train size=5982 records
Test size= 3989 records

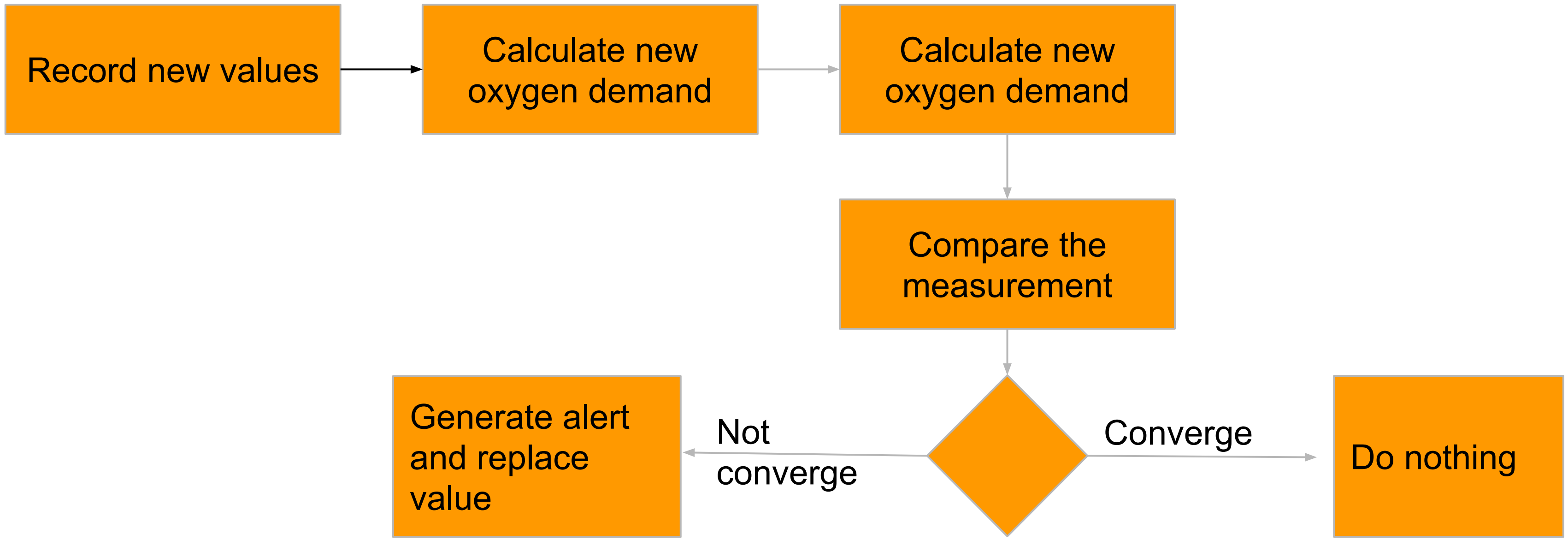
The model performance is robust

Validation of the results

Case Study

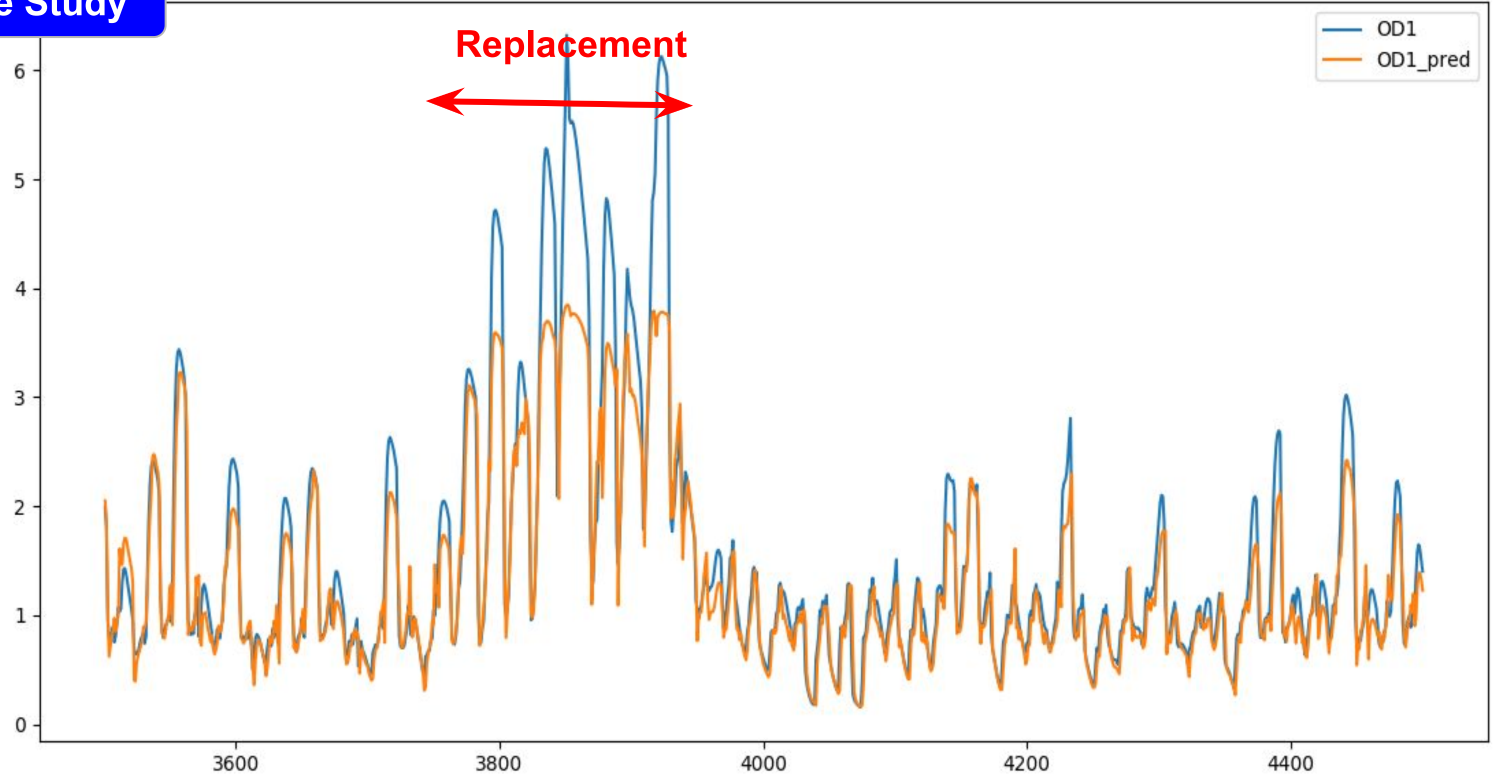


Use the NN


Record new values
Calculate new oxygen demand
Calculate new oxygen demand
Compare the measurement
Generate alert and replace value
Not converge
Converge
Do nothing

Results

Case Study



Pro/Cons of the approach

PRO

- Useful to identify sensor issues
- Fast & cost free
- Uncertainty can be managed
- Really useful to manage long shot-down of a real sensor while waiting for maintenance

CONS

- Even soft-sensors need periodic maintenance and updates
- The training of the software needs competencies in programming, machine learning and in the specific domain

Potential for the future

Transitioning from Water Treatment to Resource Recovery

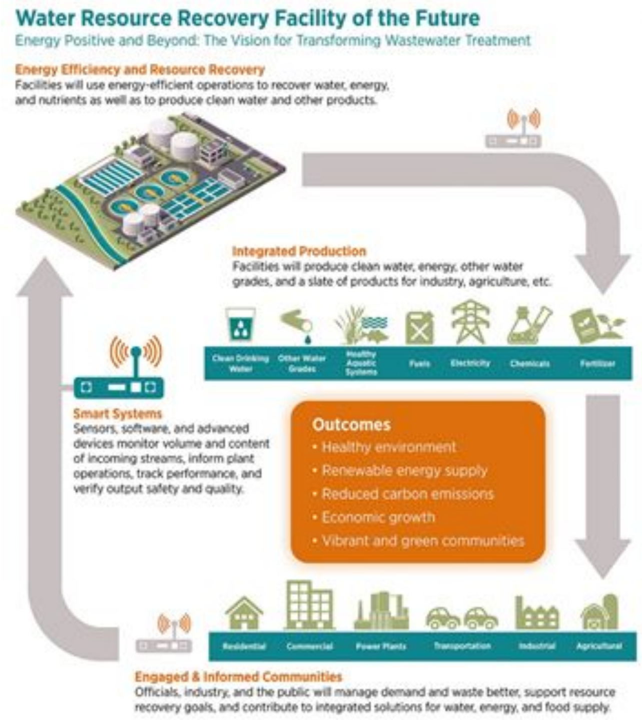
In 2012 the Water Environment Federation formally began using the term, water resource recovery facility (WRRF), in place of WWTP.

(1)efficiently recover the resources in wastewater

(2) integrate production with other utilities

(3) engage and inform stakeholders

(4) run smart systems.



https://www.energy.gov/eere/bioenergy/energy-positive-water-resource-recovery-workshop-report

Our contact

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