DIGITALLY ENHANCED WATER TREATMENT

Outline

Digitalization is dramatically transforming even traditional industries, driving performance and competitiveness:[1] for instance, by embedding sensors to manufacturing equipment, manufacturers are capturing valuable data that helps them monitor the health and efficiency of those machines;[2] or, in agriculture and farming, several data-enabled services are emerging that let farmers benefit from crowd sourced, real-time monitoring of data collected from its thousands of users.[3]

[1] https://www.bernardmarr.com/default.asp?contentID=767
[2] https://tulip.co/blog/big-data/big-data-manufacturing/
[3] https://www.talend.com/resources/big-data-agriculture/

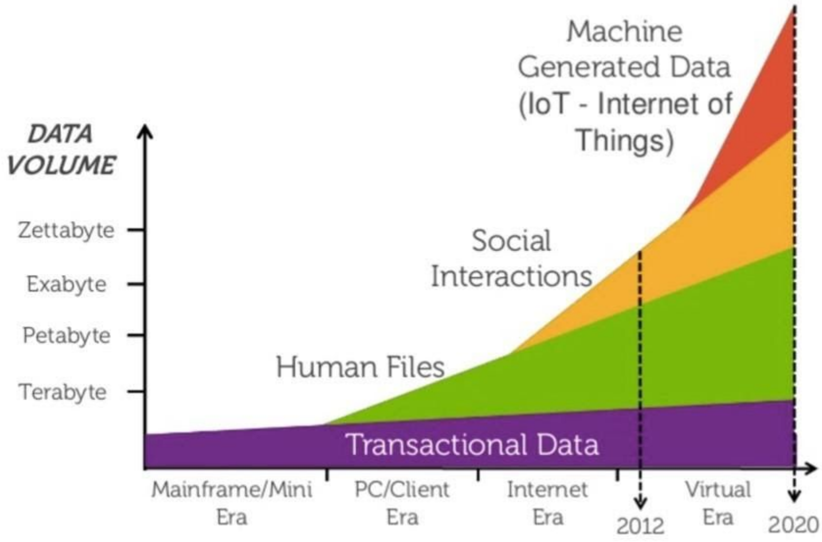

Figure 1 – The explosion of data.[4]

In the water sector, there are huge quantities of information in computer systems that are not frequently connected to each other, let alone integrated with information from external sources, such as open databases of GIS (geographic information system) data.[5,6] And, with the rise of the Internet of Things (IoT), depicted in **Figure 1**, the amount of data will continuously grow over time in the next years, opening further opportunities for integration.

If all relevant data sources were integrated, processed with advanced analytics, and connected to a system of actuators, an unlimited number of opportunities to treat water would arise with increased safety and lower energy and environmental impact.

However, value creation may be hindered by the quality of the available data and the way information is connected. This is summarized by the quote "data is the new oil", since raw data is not valuable in and of itself, but, rather, the value is created when it is gathered completely and accurately, connected to other relevant data, and done so in a timely manner. When properly refined, usable data quickly becomes a decision-making tool – information – allowing companies to be proactive and intentional in their decision-making.[7] Basically, a smart use of data and modeling can be powerful way to deal with the various forms of uncertainty which affect the water industry.[8]

To this end, digital solutions should not be designed to tackle a single technical hurdle with a piece of technology but need to follow an **end-to-end approach**, that is eliminating many middle layers or steps as possible, in order to deliver real value. In fact, digital technologies shall be seen not only as a mean to do in a smarter way a specific task, but as an occasion to re-think a process or even the whole business, as introduced within Challenge 2 on Business Model Innovation. This means that one should always consider how technical

[4] https://medium.com/@melodyucros/ladyboss-heres-why-you-should-study-big-data-721b04b8a0ca

[5] https://www.researchgate.net/publication/322901249_Applying_Big_Data_in_Water_Treatment_Industry_A_New_Era_of_Advance

[6] https://www.usgs.gov/products/data-and-tools/gis-data

[7] https://www.kenwayconsulting.com/blog/data-is-the-new-oil/

[8] https://iwa-network.org/wp-content/uploads/2020/11/IWA_2020_Digital-Water_Uncertainty.pdf

solutions are included into a wider picture, looking at the problem holistically, not limiting to a narrow part of it.

In the following, the main challenges to be tackled towards the enhancement of water treatment using digital technologies are listed.

Data collection and integration

Most water and wastewater networks are currently not digitized. They use analog or slow systems to collect samples, analyze data, and provide data for companies to use. These results are used to meet pollution requirements, policy limits, and ensure that the treatment of both water and wastewater plants is running correctly. [9]
The rapid expansion of Internet of Things (IoT) technologies, cloud computing and big data, promotes unprecedented advances in signal processing and information system. Such advances support the development of sensing technologies, as well as software-defined networks, which allow effective monitoring and modeling for water issues.

Concerning water quality measurements for supply water and wastewater, the typical properties measured are pH, chlorine, pressure, temperature, flow, level measurement, chemical properties, and microbiological contamination.

However, traditional methods for water monitoring are heavily dependent on instant point-in-space measurements, laboratory analysis, and physical and computing infrastructure. These methods are not only expensive, but also are unable to timely provide many of the required spatiotemporal features. Thus, there is a clear need for continuous on-line monitoring water quality and hydrologic conditions using advanced sensors technologies across spatiotemporal resolutions.

For instance, **smartphone-based mobile water monitoring** is a growing area of research and innovation. Low-cost smartphone-based system have been developed to measure pH, total dissolved solids (TDS) and temperature of the water using off-the-shelf detection tests, and then derive other water quality parameters using standard mathematical relationships such as salinity, oxygen reduction potential and conductivity.[10] Also, smartphones can be used to make objective colorimetric tests, enabling the measurement of low-concentration contaminants in water, such as nitrite, chromium (VI)[11] and Escherichia Coli.[12] This latter method can be improved using artificial intelligence, as recently demonstrated with the Mobile Water Kit (MWK).[13]

[9] https://www.iot-now.com/2020/09/10/104603-sensors-in-the-water-industry-the-next-step-to-iot-cities/

[10] https://link.springer.com/article/10.1007/s13201-018-0780-0
[11] https://docs.lib.purdue.edu/dissertations/AAI10272741/
[12] https://pubs.rsc.org/en/content/articlelanding/2014/AY/C4AY01245C#!divAbstract
[13] Journal of The Electrochemical Society, 166 (9) B3031-B3035 (2019)

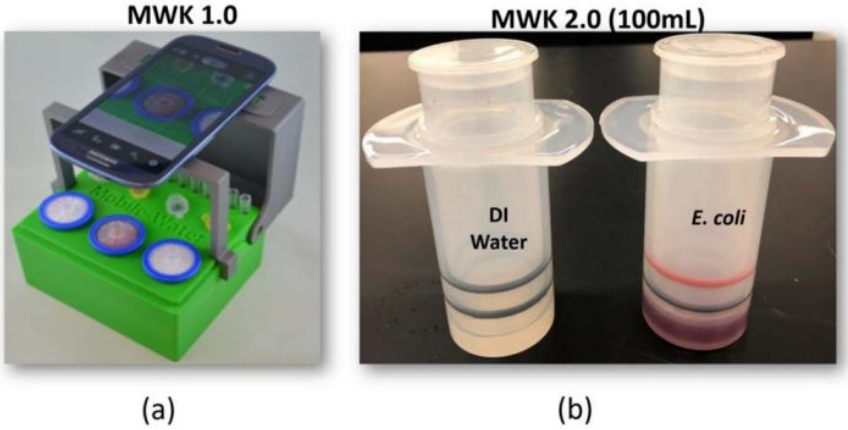

Figure 2 – The Mobile Water Kit.

Innovation may come from **soft sensors**, which combine multiple signals to calculate new quantities that don't need to be measured. In other words, the soft-sensing technique can predict hard-to-measure variables by measuring easy-to-measure variables.

This technology may be suitable to simplify the measurement of total chlorine, a key parameter to verify the correct addition of disinfectant, with respect to current techniques which rely on off-line laboratories analysis or addition of a reactant.[14]

Water quality parameters of waterbodies can be determined through **remote sensing** techniques, which use satellite and airplane images. By measuring the amount of radiation at different wavelengths reflected from the water's surface is it possible to evaluate several quantities, such as chlorophyll-a, total suspended solids (TSS), water temperature, total phosphorus, sea surface salinity, dissolved oxygen, biochemical oxygen demand (BOD) and chemical oxygen demand (COD).[15]

However, water quality data in waterbodies or at the point of use (POU) are not the only variables to be collected. In order to drive improvements, there is the need to integrate them with performance data from water treatment equipment: power consumption, chemicals dosing, pressure, temperature, flow rates, etc. These production data are included into the PLC of the equipment or, at a higher level, within the supervisory control and data acquisition (SCADA), but these sources should be connected to the cloud, i.e. entering the **Internet of Things**, in order to have broader accessibility for all the stakeholders.

Besides technical challenges of connecting such devices, the end user may not be keen to share data from the installed equipment on-site for data privacy and security issues. This opens another challenge which blends cultural and technological aspects: how to break resistances from customers and other data owners to share their data and, at the same time, ensure **cyber-security** of all the shared information.[16]

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[14] https://www.researchgate.net/publication/336779328_A_novel_method_for_total_chlorine_detection_using_machine_learning_with_electrode_arrays

[15] Sensors 2016, 16, 1298; doi:10.3390/s16081298

[16] https://smartwatermagazine.com/news/wpl-environmental-wastewater-solutions/water-utilities-urged-share-data-suppliers

Moreover, cyber-security goes beyond potential data leaks. In fact, while remote access/control of technologies used in water treatment provides benefits, it also makes these systems vulnerable to potential interruption through digital hacks (malware, ransomware, etc). These technologies need to be effectively secured against cyber-attacks and be enabled to operate off-line in the event of a successful attack.

Design for flexibility and improved performance

Water treatment capabilities are designed with the maximum requirement in mind, but energy and chemicals consumption would be dramatically reduced if the treatment equipment were designed for fluctuating water quality and quantity and the process were dynamically adapted to the actual instantaneous demand.

In fact, quality of influent water may follow periodic variations that can vary on an hourly, daily, weekly, or seasonal basis. Despite this, the treatment process is rarely modified accordingly, causing energy and material waste or even dangerous fluctuations of the quality of output water. As an example, in some cases, disinfection by-products in drinking water follow a seasonal pattern, as shown in **Figure 1**. Such periodicity is typically caused by several reasons, not always under control, yet adaptation of the treatment process or even treatment equipment design to cyclical variations can undoubtedly mitigate the issue.

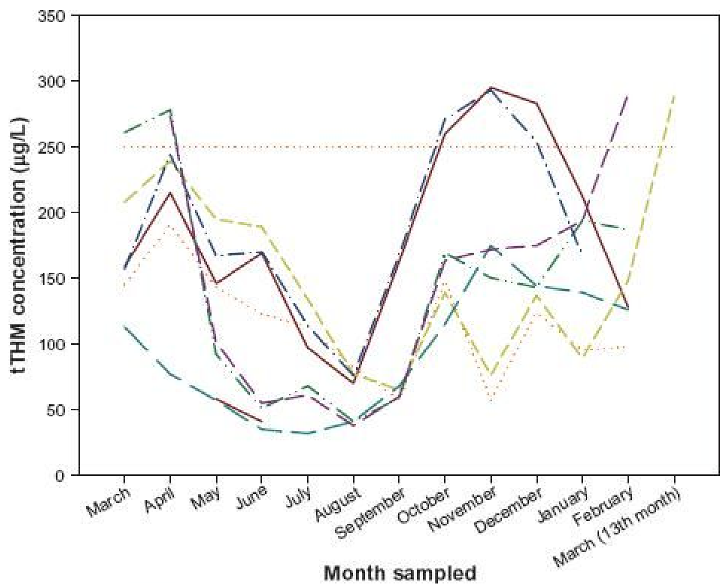

Figure 3 – Changes in total trihalomethanes concentration in drinking water over twelve months.[17]

A possible solution can be based on **Artificial Intelligence and Machine Learning (AI/ML)**. Given that process parameters and data from sensors are collected in near real-time, they can be used to understand the relationship of each process to the effluent water quality and load and create a digital twin, a digital replica of a physical system. The learnt relationship can be employed to decide the most optimal efficient set-points for treatment at any time.

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17 https://bioone.org/journals/air-soil-and-water-research/volume-4/issue-1/ASWR.S5618/Temporal-and-Spatial-Variation-of-Trihalomethanes-and-Haloacetic-Acids-Concentration/10.1177/ASWR.S5618.full

Besides process design and optimization, AI/ML technologies have been applied in the fields of source water quality, coagulation/flocculation, disinfection, and membrane filtration, including source water contaminant monitoring and identification, accurate and efficient prediction of coagulant dosage, analysis of the formation of disinfection by-products and advanced control of membrane fouling.[18]

In addition to data-driven approaches, modeling is another promising tool for designing more flexible equipment and processes. **Computational Fluid Dynamics** (CFD) can provide a better understanding of the behavior of a water treatment system for improved design and operation. In fact, process design of water and wastewater treatment process has always relied heavily on trial-and-error based physical testing and experimenting, leading to long time-to-market and sub-optimal solutions. With CFD, a powerful computer simulation provides an alternative as it allows high resolution calculation and visualization of mixing and reactions inside water and wastewater treatment systems, in 3D and at real scale. While the core of CFD relies on fluid physics equations, multiphase simulations (i.e., gases and solids in liquids) and direct integration of (bio)chemical conversions have become mature engineering frameworks.

CFD as a digital engineering tool may be beneficial to technology manufacturers like De Nora for designing, with a shorter time-to-market, equipment, and treatment processes with proactive avoidance of operational issues, optimal energy usage, smart chemical dosing and efficient and less conservative design.[19]

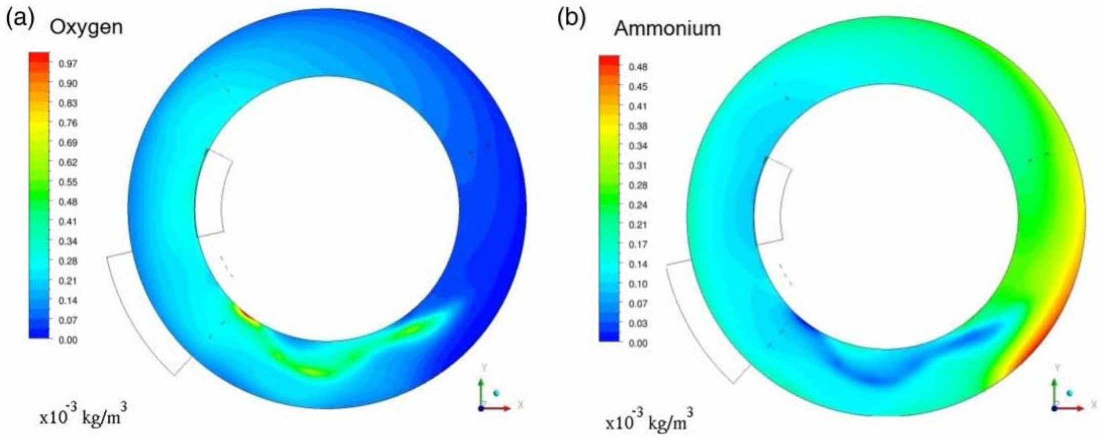

Figure 2 – Oxygen and ammonium concentration plots in a biological reactor for wastewater treatment.[20]

Reduction of energy and environmental footprint

In the water and wastewater industry, the operations usually date back to the 1970s or 80s and are costly in terms of energy and chemical consumption: many operations are still manual and often overdosing of chemicals is frequent. Process control is often performed *via* manual adjustments of parameters such as aeration pumps and chemical injection,

[18] Chemical Engineering Journal 405 (2021) 126673.
[19] https://iwa-network.org/computational-fluid-dynamics-cfd-a-revolutionary-tool-for-the-water-industry/
[20] https://api.semanticscholar.org/CorpusID:11769397

which in turn are based on manual sampling and retrospective tests realized on methodical periods.[21]

In many cases, energy consumption is one of the highest operational cost factors. With power prices set to increase over the next years, water and wastewater operators have a very practical reason to optimize their energy use in addition to more general sustainability goals.

It is estimated that the net annual electricity consumption for urban water management accounts for about 5.5% of the electricity consumed by households in one year in Europe. Traditionally, the largest energy use for drinking water suppliers is the electricity used for pumping (approximately 80%).

Waste-water treatment plants (WWTP), on the other hand, also utilize mechanisms necessitating heavy energy consumption. For instance, they use of blowers to provide oxygen in activated sludge reactors with fine bubble aeration, especially for nitrogen removal purposes. Aeration systems, pumping, propellers and mixers, as well as solids processing, usually account for most of the electricity use.[22]

The benefit of applying digital technologies to water treatment plants can be truly disruptive: a fully connected wastewater treatment plant equipped with a process control based on real-time online sensors can reduce its footprint to zero and become climate neutral.[23] Similar principles can be applied also to drinking water treatment processes. Data analysis based on machine learning can realize water quality diagnosis, autonomous decision making and operation process optimization, leading to increased efficiency, prolonged asset life and reduction of the waste of treatment equipment.

[21] Water Research 157 (2019) 498 – 513.

[22] https://www.eureau.org/resources/briefing-notes/3890-briefing-note-on-reducing-the-energy-footprint-of-water-sector/file

[23] https://iwa-network.org/how-can-more-water-treatment-cut-co2-emissions/