DIGIDRAIN: City-scale digital twins for urban drainage systems

Abstract: Urban drainage infrastructure faces major challenges to keep desired performance levels due to aging systems, worsened by both natural and anthropogenic factors. To address these challenges and enhance the sustainability, safety, and resilience of urban drainage systems (UDSs), innovative management solutions and strategies are a must. Ongoing digital transformation represents an opportunity for water utilities to solve some of the urgent issues they are facing. Digital Twins (virtual replicas) could be a viable decision support tool for water utilities. DIGIDRAIN project aims at contributing to the creation of such a next-gen Digital Twin (DT) framework for UDSs.

Keywords: water utilities, digital transformation, aging systems, decision support

1. Motivation

As our cities grow bigger and older, the pressure on urban drainage infrastructure keeps increasing as we expect it to deliver the same level of services without major investments. Ageing infrastructure combined with a lack of integrated asset management and often insufficient maintenance, makes it difficult to keep the urban drainage systems (UDS) operable even in "regular" conditions. However, with more extreme flood and drought events caused by climate change, our underground water infrastructure is struggling to cope.

Traditionally, this issue would be solved by reconstruction and/or renovation of the system and/or building new infrastructure elements (e.g. retention/detention basins), which are expensive. These challenges are even more pronounced in the low- and mid-income countries (such as Serbia). Therefore, it is now critical to provide innovative solutions that can help decision makers better plan urban drainage system reconstruction and prioritize repairs of existing assets, before the infrastructure fails and causes catastrophic consequences.

Digital technologies, such as Digital Twins - DTs (virtual replicas of the real-world systems and facilities), can create a pathway for solving some of the urgent issues water utilities face. Integrating the significant amount of real-world data (gathered from a network of sensors) and simulation models of the real-world system into the Digital Twin provides a decision support tool that can help water utilities to: (1) enable efficiency and help prioritization in resources allocation through real-time monitoring and modelling of the UDS, (2) create safe virtual environment to assess various "what-if" scenarios and inform contingency planning and operation decisions, and (3) creating virtual environment for analyzing UDS upgrade using both structural and non-structural solutions to increase UDS resilience.

2. Research questions

To create such a multipurpose Digital Twin for UDS management, where real-time monitoring, resources allocations and future planning will be supported the following tasks must be considered: (i) UDS sensor coverage, (ii) simulation tools for assessing real-time system dynamics, and (iii) reliable scenario generators for future planning.

3. Methodology

Overview

To complete all the tasks necessary for designing a Digital Twin for UDSs, DIGIDRAIN project aims to develop comprehensive framework which includes (i) novel, low-cost monitoring techniques to increase UDS sensor coverage, (ii) Machine Learning (ML)-assisted algorithms for processing the sensor data, novel simulation algorithms for Digital Twin continuous update by utilizing machine learning support and (iii) algorithms for implementing and analyzing the effects of various real-time control (RTC) strategies and sustainable drainage systems (SuDS) on UDS performance.

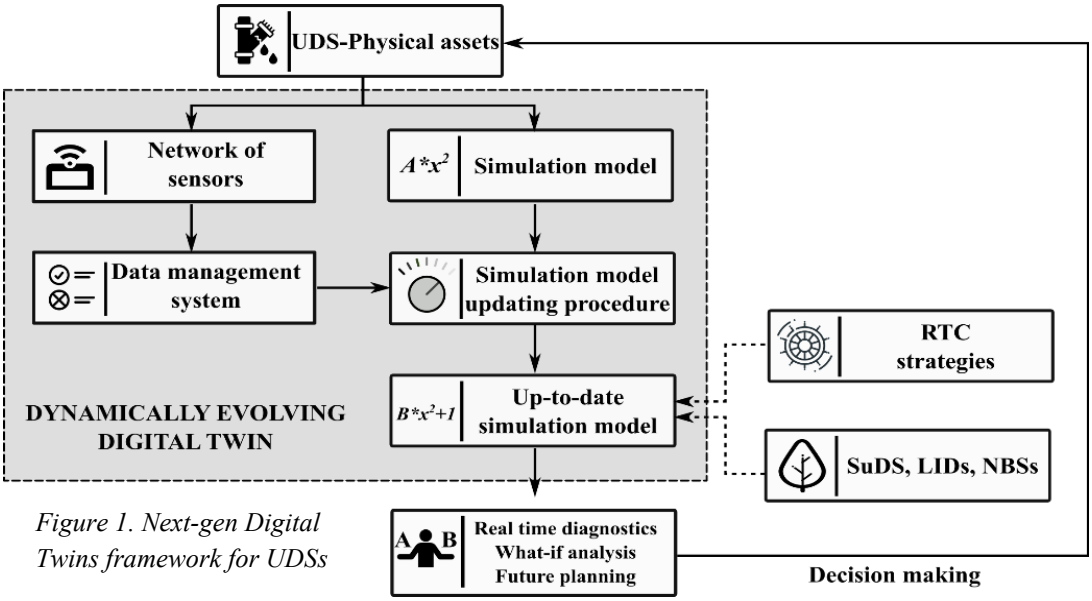

Figure 1. Next-gen Digital Twins framework for UDSs

Sensors

Establishing a sensors network is a backbone of a Digital Twin. Considering city-scale and complexity of UDSs, placing and using sensors to collect data is a challenging task. First of all, the number of sensors have to be sufficient to detect most of the changes in such a dynamic system. On the other hand, the number of sensors must be limited due to economic reasons. Therefore, this project will try to develop innovative, low-cost, monitoring solutions, coupled with industrial grade monitoring equipment. This hybrid monitoring solution will be combined with an optimal sensor placement algorithm to provide abundant and yet affordable sensors network.

Data&Models

Generating a significant amount of sensor data creates new challenges which require novel solutions. Data anomalies (outliers, zero drifts etc) and gaps in the time series data (periods without data), are often problem due to hardware limitations and many other factors. Hence, advanced algorithms are necessary for automatic processing of sensor data. Here, ML-algorithms have been developed for imputation of the missing data and detection of outliers. This algorithm will be used to provide continuous and physically sound sensor data.

Processed sensor data will be integrated into the simulation module of a Digital Twin through a data assimilation algorithm (Figure 2). This algorithm will provide continuous update of simulation model state, parameters and configuration to provide up-to-date virtual replica of the real system. This will allow efficient detection of sudden changes in system and localization of the problems.

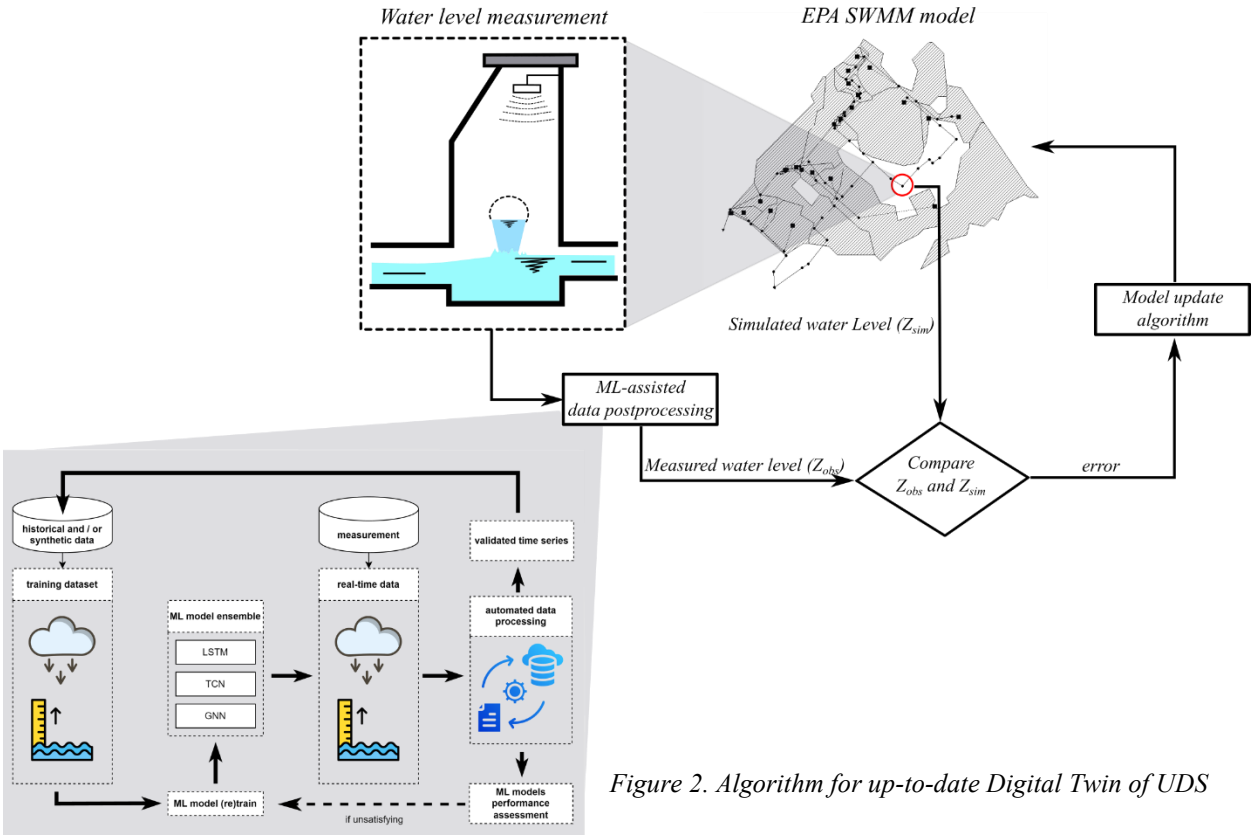

Figure 2. Algorithm for up-to-date Digital Twin of UDS

Simulation add-ins

Further utilization of Digital Twins for UDSs as a virtual platform for assessing various what-if scenarios, contingency planning and future development requires additional simulation elements (simulation add-ins). Here, simulation add-ins will provide a) realistic failure generator, b) computationally efficient simulation models (e.g. based on physics-informed neural networks) for modelling nature-based solutions (NBS), and c) module for integration and optimal placement of NBSs to improve UDS performance in extreme conditions, using Digital Twin as a basis.

4. Solution/Discussion

The urban water sector faces growing challenges, including aging infrastructure, limited financial resources, and a shortage of skilled workforce. These issues highlight the urgent need for innovative solutions, such as Digital Twins, which are poised to play a transformative role in the industry's future. Despite their potential, the application of Digital Twins in the urban water sector remains limited, underscoring the necessity for a structured framework to facilitate their implementation. The DIGIDRAIN project addresses this gap by developing a comprehensive framework, supported by a suite of technical tools, to enable the effective adoption of this technology.

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