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The future of artificial intelligence for wastewater networks

L'avenir de l'intelligence artificielle pour les réseaux d'assainissement

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RÉSUMÉ

Le changement climatique entraîne une augmentation des précipitations extrêmes et des changements dans nos modèles de précipitation, ce qui entraîne à son tour plus d'inondations urbaines et des échecs du réseau d'égouts. De plus, l'urbanisation croissante a le potentiel de aggraver la situation en raison de l'augmentation résultante de la zone imperméable et, par conséquent, de l'écoulement. Selon les Nations Unies, il est estimé qu'environ les deux tiers de la population mondiale vivront probablement en ville d'ici 2050. Cependant, la refonte et le développement de l'infrastructure de réseau d'égouts existante pour faire face à ces défis est coûteux. D'autres défis comprennent, par exemple, la nécessité de réduire la consommation d'énergie et les émissions de carbone. Le but de cet article est donc de passer en revue les recherches récentes sur l'intelligence artificielle (IA) et de voir comment elle pourrait être utilisée pour faire face aux problèmes existants de gestion du réseau d'égouts. La limite de la recherche est située entre l'orifice de sortie du client et l'orifice d'entrée de l'usine de traitement des eaux usées (WWTP). Les principales applications de l'IA abordées dans cet article sont : la prédiction de l'échec des tuyaux, l'interprétation de l'inspection par caméra CCTV, la prédiction du niveau d'eau et du débit, le contrôle en temps réel du débit et l'économie d'énergie des pompes

ABSTRACT

Climate change is leading to increased extreme rainfall and changes in precipitation patterns, resulting in more urban floods and sewer network failures. Moreover, increasing urbanisation has the potential to worsen the situation due to the resultant increase in impervious areas and, thus, runoff. According to the United Nations, it is estimated that around two-thirds of the world's population are likely to be living in cities by 2050. However, redesigning and developing the existing sewer network infrastructure to address these challenges is costly. Further challenges include, for example, the need to reduce energy use and carbon emissions. Therefore, the purpose of this paper is to review recent research into artificial intelligence (AI) and how it could address the existing issues in sewer network management. The research boundary is between the customer outlet and the wastewater treatment plant's inlet (WWTP). The key applications of AI addressed in this paper are pipe failure prediction, CCTV inspection interpretation, water level and flow rate prediction, real-time control flow, and pump energy saving.

KEYWORDS

Artificial Intelligence (AI), Flood mitigation, real-time control (RTC), Sewer network, Smart City

1 INTRODUCTION

Climate change leads to increased extreme rainfall and changing precipitation patterns, resulting in more urban floods and sewer network failures (Masson-Delmotte et al., 2021). Moreover, increasing urbanisation has the potential to worsen the situation due to the resultant increase in impervious area and, thus, runoff. According to the United Nations, it is estimated that around two-thirds of the world's population is likely to be living in cities by 2050. However, redesigning and developing the existing sewer network infrastructure to address these challenges is costly. Further challenges include, for example, the need to reduce energy use and carbon emissions. Therefore, this paper aims to review recent research into artificial intelligence (AI) and the state of today's typical practices that implement AI and investigate how it could be used to address the existing issues in sewer network management.

This review is linked to the 12 'Big Questions' identified by UK Water Industry Research (UKWIR, 2021) as a result of consultation with stakeholders to address the challenges of today and the future in the water sector, and in particular, Question 6: "how do we achieve zero uncontrolled discharged from sewers by 2050?"

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2 STATE-OF-THE-ART

In this section, we review the current state-of-the-art AI in wastewater network management, focusing specifically on methodologies and applications related to pipe failure prediction, CCTV inspection, water level and flow rate prediction, and flow control.

2.1 Pipe Failure Prediction

Pipelines are the key components of urban sewer infrastructure. As the sewer system ages, the pipelines deteriorate, leading to system failure and, thus, a range of negative consequences, such as flooding, overflow and pollution. There is a large volume of published studies investigating the capability of machine learning in predicting pipe failure. Loganathan et al. (2021), for example, compared logistic regression (LR), k-nearest neighbours (K-NN), and random forests (RF) techniques to investigate the optimal method which could prioritise inspection and condition of sanitary sewer pipes. Robles-Velasco et al. (2021) implemented a genetic algorithm (GA) to estimate the optimal weights of an LR model, which is used to predict sewer pipe failure. Sousa et al. (2014) developed ANN and support vector machine (SVM) methods to predict future intervention, and the LR model was used to compare their results.

2.2 CCTV Inspection

CCTV inspection systems are commonly used to assess sewer pipe structural conditions; however, manual interpretation of CCTV images is time-consuming, tedious, and costly. Thus, a large and growing body of literature has investigated the capability of computer vision in identifying pipe defects based on CCTV footage. For example, Kumar et al. (2018) developed a convolutional neural network (CNN) to classify defective pipes with an average precision of 90.6% during testing. Likewise, Hassan et al. (2019) implemented CNN to classify pipe defects into six classes with an average accuracy of 96.3% during testing. Moreover, Cheng and Wang (2018) used faster region-based CNN (R-CNN) as an object detector to identify defects automatically. Similarly, Yin et al. (2020) executed a CNN model based on an object detector named YOLOv3 to label CCTV video frames based on seven classes of defects. This study proposed a new method without extracting defected frames from CCTV video, and it could identify defect frames based on the video footage with a mean precision of 85.4%.

2.3 Water Level and Flow Rate Prediction

A number of studies have found artificial neural networks (ANNs) to be an appropriate technique to predict water level and flow rate in one or several locations in a sewer network. Mounce et al. (2014), for example, implemented a shallow neural network; Zhang et al. (2018b, 2018c) developed long short-term memory (LSTM), gated recurrent unit (GRU), support vector regression (SVR), recurrent neural network (RNN) and multilayer perceptron (MLP) techniques; Kilsdonk et al. (2022), Palmitessa et al. (2021), and Yin et al. (2022) implemented the LSTM method; and Shishegar et al. (2021) developed an octonion-valued neural network (OVNN) to predict flow rate.

2.4 Flow control

A number of studies have investigated the ability of fuzzy logic algorithms to mitigate combined sewer overflows with real-time control (RTC) systems (Li, 2020; Ostojin et al., 2017; Shepherd et al., 2016). Recently, a brand new RTC method based on deep reinforcement learning (RL) has been investigated for flood control in multiple studies (Bowes et al., 2021; Mullapudi et al., 2020; Saliba et al., 2020).

3 CONCLUSIONS

The current study aimed to determine the capability of AI applications in addressing sewer system network issues. This study found that whilst AI has been shown to offer help with a range of sewer network management challenges, the main focus to date has been on reducing flooding and sewer overflow. It was found that ANNs have the highest performance in pipe failure prediction and could help asset management to shift from reactive to proactive intervention. Also, implementing a CNN model could improve the accuracy of CCTV inspection interpretation while reducing costs. It was found that LSTM has better performance than other ML techniques in water level and flow rate prediction, and it is faster than deterministic models; also, the model could be used as a soft sensor to reduce the cost of sensor instalment and maintenance. The results of this study indicate that reinforcement learning has high capability in real-time control of flow whilst handling uncertainty better than rule-based control strategies. However, whilst AI could benefit sewer network management, some significant limitations and gaps are discussed in the following section.

3.1 Gaps and Recommendations

Most AI techniques are black box in nature, which leads to a lack of insight about the process and the system's reliability. Since, in sewer network management, public safety is critical, more research is needed to address this issue. For example, several false alarms could lead to a lack of confidence in AI-based systems and warnings to be ignored. An issue that has been less widely addressed in the existing literature is whether AI is able to reduce pump energy consumption or not. Also, most of the literature reviewed analysed AI tools in a virtual environment, with the performance of proposed methods not tested in real-world applications.

Further research needs to be done to identify the ability of RL agents in flow control. RL-based control strategies need to be examined first in a laboratory and afterwards in the real world. Also, it would be interesting to assess the performance of an integrated system which uses the same data to predict pipe failure, water level, and flow rates and uses predicted outputs as control flow model inputs. Also, using unmanned aerial vehicles (UAVs), which AI controls for remote sensing of urban areas during pluvial flood events, is an interesting topic which needs more investigation. Moreover, existing research typically focuses on predicting flood events in a 1D network; however, it would be interesting to investigate the ability of AI to predict surface runoff during floods. A future status wherein wastewater networks can be better managed by an overarching AI tool remains on the horizon. However, progress is being made in developing a silver basket of solutions that can be brought together as water service providers continue their digitalisation activities.

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