Thinking Robots? A tale for the future of drainage systems?

Des robots intelligents ? Une vision d'avenir pour les réseaux d’assainissement ?

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RÉSUMÉ

Les systèmes de drainage urbain reposent largement sur des inspections visuelles pour la gestion patrimoniale, mais les pratiques actuelles utilisant des robots CCTV filaires restent limitées en portée et en flexibilité. Les robots autonomes d’inspection des égouts promettent un changement de paradigme en permettant la collecte de données à haute résolution spatiale et temporelle, améliorant ainsi la précision de l’évaluation de la topologie du réseau, des conditions hydrauliques et du suivi des défauts. Cet article explore les impacts potentiels de ces technologies à travers deux ateliers organisés dans le cadre du projet européen PIPEON. Le premier atelier a réuni des chercheurs pour imaginer les besoins futurs en données pour la modélisation, tandis que le second a aligné les attentes des développeurs de capteurs et des services d’assainissement sur les exigences pratiques et les formats de données. Les résultats révèlent des priorités contrastées : les chercheurs mettent l’accent sur les capacités de modélisation transformatrices, tandis que les services privilégient la fiabilité opérationnelle, la détection des défauts et l’intégration aux systèmes SIG existants. L’étude souligne les opportunités et les défis pour concilier ces perspectives et assurer une adoption efficace des technologies d’inspection autonome pour une gestion durable des réseaux d’assainissement urbains.

ABSTRACT

Urban drainage systems rely heavily on visual inspections for asset management, but current practices using tethered CCTV robots are limited in range and flexibility. Autonomous sewer inspection robots promise a paradigm shift by enabling high-resolution spatial and temporal data collection, improving accuracy in network topology assessment, hydraulic conditions, and defect monitoring. This paper explores the potential impacts of such technologies through two stakeholder workshops conducted under the EU-funded PIPEON project. The first workshop gathered researchers to envision future data needs for modeling, while the second aligned the expectations of sensor developers and utilities on practical requirements and data formats. Findings reveal contrasting priorities: researchers emphasize transformative modeling capabilities, whereas utilities focus on operational reliability, defect detection, and integration with existing GIS systems. The study highlights opportunities and challenges in bridging these perspectives to ensure effective adoption of autonomous inspection technologies for sustainable urban drainage management.

KEYWORDS

Asset management, autonomous robots, condition assessment, stakeholders, sewer inspection

Gestion patrimoniale, robots autonomes, évaluation de l'état, acteurs de la gestion de l’eau, inspection des égouts

1 INTRODUCTION

Monitoring the functional state of an urban drainage (UD) system is at the core of asset management, the deployment of visual inspection technology (either using direct visual access for inspection of applying photo and/or video cameras) was and has remained the main method of gathering information for several decades (Cherqui et al., 2024). Current commercially available sewer inspection robots are tethered and remotely controlled platforms (by humans) with a practical operational range around 100-150m, equipped with Closed-circuit television (CCTV). Autonomous inspection robots working in sewer environments will change the type and way information about the state of our wastewater collection and drainage systems is collected, both in spatial and temporal resolution, and could start a new information paradigm. This will lead to change into how we envision models could be used by utilities to manage their urban drainage systems, ranging from more focussed, responsive operational maintenance, better informed deterioration models for contemporaneous sewer condition and responsive repair, to better calibrated hydrodynamic performance models for sewer systems. These changes can be fourfold:

- The first is one mainly about accuracy, as more accurate geometrical data (collected by robots with better mapping capabilities and more appropriate and accurate sensors). This will reduce network model uncertainty considerably.
- The second is the ability to pick up intermittent or unexpected changes, for example blockages, damages, or other physio-chemical changes that can be registered by sensors equipped on robots.
- The third is that a moving robot can be the sensor collecting hydraulic data as it moves within a changing system (e.g., registering flows) resulting in a Lagrangian (e.g., Seyoum et al., 2025) rather than a more traditional Eulerian calibration data set (e.g., Tscheikner-Gratl et al., 2016).
- The fourth is that the use of autonomous robots can allow operational teams to better plan their work, eliminate the need to enter systems, avoid traffic hazards but selecting low risk system entry points and develop a better work-life balance, with fewer emergency callouts and the need only to work during sociable hours.

Investigating all these aspects of this emerging area of monitoring and inspection technology, and how it could interact with current and emerging operational and modelling capabilities, is important if the community is to benefit from both new monitoring and modelling advances and respond to changes in public attitudes to work.

While expectations are high for new technologies and often a so-called paradigm shift is expected in the way we inspect, model and manage our urban drainage system, those expectations are also often diffuse and differ between stakeholder groups. The goal of this work is therefore to highlight differences between stakeholder groups ranging from scientists in the urban drainage modelling community, over sensor developers to utilities, of different size and location and their operational workers and inspection contractors.

2 METHOD

Two workshops were conducted with different stakeholder groups and different setups, both linked to the PIPEON project (https://pipeon.eu/the-project/). The first one was conducted at UDM2025, using the inspiration of Pimiento et al. (2025) following a ‘world café’ model. This was a dynamic and participatory discussion format that encouraged collaborative dialogue through rotating small-group conversations on focused questions:

(i) Looking into the future, make a wish on what data autonomous robots should deliver for our hydrodynamic and deterioration models,
(ii) How do you think the new asset and monitoring data opportunities offered by robotic inspection and sensing will change the ways we model our systems?
(iii) How do you see the feedback loop from modelling back to the robots?

This workshop received twenty participants representing ten different countries, mostly from Europe, but also from America, Africa and Asia, forming an extensively varied group within the scientific community. The workshop included two presentations as an introduction to the topics, as well as about the PIPEON project, followed by the presentation of the three discussion topics. After which, the individual reflection on the three subjects began, where the participants were provided with post it notes and pens to write down their individual reflections for fifteen minutes. Subsequently, the participants were assigned to four groups: one group with seniors/experts and the other three groups with early career/juniors. These groups discussed the three topics for one hour, wherein the participants wrote their responses as a consensus response within the group on blank papers. At the end of that session, the notes taken by each group were gathered, and a wrap-up of the discussion was presented.

The second workshop was conducted as collaborative work session with a clearly defined goal, facilitated by a neutral expert (Wróbel et al., 2021). The idea of this workshop was to bring together sensor developers (scientists) and sewer utilities (managers/operators) to devise a concrete plan of what to measure, how, in which precision, and how (data formats and reporting) to deliver the data needed to provide more responsive system management to optimise performance. The technical possibilities of existing and emerging sensor technologies were compared and aligned with the data aspirations of the sewer utilities. The envisioned result was an agreed upon priority list of what will (and could) be measured, and in which format it is delivered (e.g. to modellers, inspection companies and utilities). The participants consisted of three different sensor developers and representatives from three sewer utilities with a variety of settings (rural, urban, peri-urban) and climate zones (continental, temperate marine, boreal) to keep a manageable size for working.

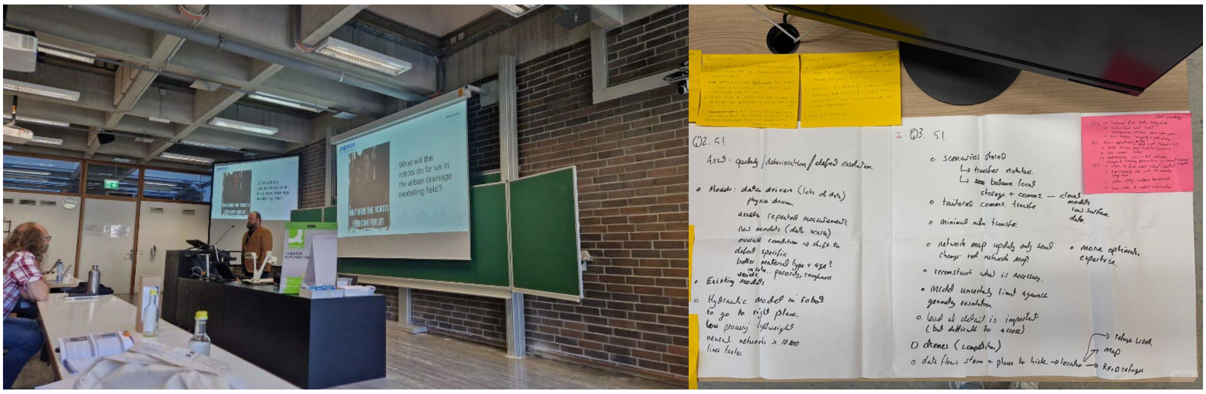

Figure 1: Workshop impressions

3 RESULTS

For this abstract we compare the answers to the first question of workshop 1 with the expectations in workshop 2, as they relate most closely in the way the questions were posed. Also, the first question was the one were the participants of workshop 1 showed the most consistency. This question includes considering what currently not available information one would want from autonomous robots, what changes in data availability and quality can be expected (e.g., spatial and temporal resolution of inspection and monitoring, accuracy of observations) and what of this is useful for model development and what for the application. As resources are always limited, answering this question also entails an implicit ranking of the priorities. For the first workshop the results for the first question can be summarized into five points:

- Topological and asset data: An increased coverage of data (from hard-to-reach areas) is expected, which will help to bridge the gap of missing information about the network features as well as increase the accuracy (e.g. location), thus enhancing the information regarding network topology, connectivity and localization. As R&D topics, longevity and path planning were mentioned, highlighting the need for more detailed and active path planning and a more rapid processing model for defect data to support path planning.
- Asset data: Regarding the assets, information anticipated from the robots includes physical features of the network, such as pipe diameter, material, wall thickness, pipe roughness (measured or estimated), and weir height, among others. Missing information, such as geometry data, can be further enhanced by collecting the data “as is” rather than “as was planned”.
- Hydraulic data: A standard data type is expected, including in pipe data of hydraulic variables at high resolution, such as flow, velocity, and water depth. However, a different approach was also discussed involving spatially dynamic datasets, consisting of multiple types of measurements, not limited to the traditional measured values or measurement techniques. Data fusion is expected, which can incorporate static, mobile data and multi-sensing data – enhancing the data reliability and quality.
- Defect data: A higher degree of expected data includes defect quantification, which involves the defect

size and its changes over time, including its evolution, deterioration, or potential to change into a more severe defect (e.g., monitoring, such as sediment accumulation). This information must be available across the whole network and should consider issues specifically impacting hydraulics. Based on the material, robots would help improve the estimation of deterioration in the pipe sections.

- Water quality: Improving water quality data collection was a mentioned topic, as well as identifying pollution sources and sampling areas of the network that present specific issues. But this topic was challenging for existing sensor technologies as many water quality parameters require complex, labour-intensive analysis.

In workshop 2 the outcome was a more detailed list of measured features and parameters which can be classified into similar groups as in workshop 1. The most important feature for the utilities was the knowledge of the robot's location at all times, as a main point of operational practice and security. This is a point that was mentioned by the researchers but more as a requirement for moving sensors and not as of interest in itself. The next important point was the accurate assessment of the asset's location, corresponding to the topological data. Then we have defect data in order of importance: Deformations, Blockages, Joints, non-radial cracks. Additional information on the assets followed including slopes and diameters. Only then hydraulic data as water level and temperature followed. The data would need to be delivered in a data format (.csv, .txt), that can be easily implemented in the existing GIS Databases (connection to unique pipe and manhole IDs) of the utilities or adapted to fit with existing .xml formats, so data on defects would need to be mapped onto existing EN defect classification systems. Reporting would be adjusted to current formats for pipe sections between manholes. The availability or need to collect video data would be decided after quality assurance in the beginning to avoid excessive data storage of redundant data.

4 DISCUSSION AND CONCLUSION

The priorities of the stakeholders diverged quite substantially, which can be mainly explained by the different objectives of the groups. The research community (especially in urban drainage modelling) focussed on a paradigm change brought by novel technology and data sources that could revolutionize the field. The utilities saw the technology provided more as a gradual improvement of existing practices (faster, cheaper, higher accessibility) and with an amount of scepticism (maybe also informed by everyday experience with the challenging environment and the restrictions in the field), that can be expected in a generally conservative field. The first concern was the possibility of the robots malfunctioning and the need to extract it from the system, which requires knowledge of its location. The focus is on trustworthy solutions to provide a level of trust with respect to uncertainties in the data and environment and there is still a need to consider how autonomous systems could impact on the working environment of the current inspection workforce.

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