SewerBall: A new concept to inspect sewers using mobile wastewater quality sensors

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Highlights

- Service based on high technology and artificial intelligence
- Sewer disorder detection: Inflows and Infiltrations, industrial discharges, seawater intrusion,

Introduction

Sewer inspection is a critical task for wastewater operators aiming at preventing or replacing asset showing wear of infrastructure or even wrong connections. Such disorders can lead for instance to: 1/ stormwater pipes polluted by wastewater entrances due to wrong connection or 2/ wastewater pipes diluted due to the reversed connection, or 3/ pollution of any type of water resulting from an industrial or accidental discharge, or 4/ increasing salinity composition due to seawater infiltration (Cahoon and Hanke, 2019). Consequences can be various: Inflows and Infiltrations (I&I) can lead to increase Combined Sewer Overflows (CSOs) frequency and annual volume and thus, increase the environmental impact. The treatment process performances at Wastewater Resources Recovery Facilities (WRRFs) can be also reduced due to hydraulics shocks or pollution/toxicity events to finally have negative environmental impacts. Finally, in the context of Climate Change, the asset degradation rate will be increased necessitating from stakeholders to better address these issues.

Development of sewer inspection technologies have accelerated within the last decades, boosted by the need for it but also the recent technology improvement in the areas of sensors miniaturization, computation rapidity, robotic autonomy… Most of the time, the existing technologies are composed on three main pillars: 1/ a vehicle to transport the sensors (trolley, boat, flying drone), 2/ sensors (camera, sonar, laser...) and 3/ algorithms including artificial intelligence in order to automatise the data treatment. Moradi et al. (2019) identified four types of technology and compared pros and cons: Vision-based such as Close Circuit TeleVision (CCTV); structural and bedding with Ground Penetrating Radar (GPR) or sonar; hybrid technologies that combines laser or acoustic and camera and; defect specific like electric-based inspection. They also reviewed existing and innovative algorithms automating sewer inspection. The authors compared all technologies regarding data collection quality and analysis, their performance, complexity, and cost, highlighting that there is no perfect technology. They conclude that to cover all sewer inspection requirements, one would need to couple various technologies.

The present paper introduces a new methodology for sewer inspection based on a completely innovative concept named the SewerBall. The principle of this innovation is to use a mobile device with quality sensors on board, collecting data at high frequency, for monitoring wastewater quality along a pipe. An abnormal change in the monitored signals is the result of the mixing of two water volume with different quality nature. A dedicated algorithm based on a multi-variate mathematical analysis of the quality signals has been developed to automatically identify sewer disorders.

Methodology

The device

The solution is based on the SQUID (Sewage Quality Instrumented Device) floating sensor developed by EAWAG (Koller et al., 2017). The device is a 10 cm spherical shape embarking four small water quality sensors (Figure 1):

T°C, conductive electro-conductivity, pH and Oxydo-Reduction Potential (ORP). The Printed Circuit Boards (PCBs) manage the signal conversion, the data storage, the Bluetooth module, the LEDs and buzzer and energy supply thanks to a 1,000 mAh polymer lithium-ion battery. Eventually, the device is protected by a waterproof housing.

Figure 1. SQUID opened

The inspection methodology

The floating device is injected in the sewer through a manhole from the surface reducing operator damage risk. The sensor drifts along the pipe collecting wastewater quality data every second. The sensor is finally recovered downstream thanks to a dedicated screener. At each step (launching, intermediate checkpoints and recovering), the GPS locations and datetime are reported by the operator. This information is further used for disorder geolocation.

A data analysis algorithm

Data are analysed thanks to a multi-variate approach based on clustering methodologies. The algorithm uses two non-supervised methods. First, the Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) developed by (Campello et al., 2013) and implemented in Python by McInnes et al. (2017). Then, the well-known K-means clustering method (MacQueen, 1967) is also used in case the first method fails, it appeared that both methods are very complementary which can be explained by the differences of the clustering methods nature. The k-means algorithm used is included in the scikit-Learn Python package (https://scikit-learn.org/stable/modules/generated/sklearn.cluster.KMeans.html).

Results and discussion

More than thirty field sewer inspections were performed with the SewerBall since 2019 in France, focusing on I&I. The inspections distances ranged between 80 m to 1,500 m for run duration between 3 and 30 minutes. The smaller pipe diameter inspected was 200 mm spherical shape and the higher pipe diameter was 2,000 mm. Among those inspections, various experiments were set to:

- ✓ **Assess the method potential** to identify I&I by reproducing an artificial disorder injecting clean water in the inspected trunk sewer at an intermediary manhole.
- ✓ **Assess the replication and reproducibility** by running two different inspections on the same trunk with two different devices and by running twice the same inspection with the same device.
- ✓ **Assess the disorder detection performance** by comparing SewerBall inspection results with CCTV inspection results on the same trunk sewer.
- ✓ **Assess the sewer pipe repair** by running an inspection before the repair that shows a disorder and running another inspection after the repair occurred.

The Figure 2 presents an example of replication test results where two SewerBalls are run on the same 161 m trunk sewer at few minutes delay. Both average SewerBall velocities were reported at 0.48 m/s. The clustering-based algorithm analysis of the two SewerBall inspections shows two coloured zones that refers to the identification of the initial wastewater quality properties before having been mixed with an extraneous water. The disorders are represented by the split between the blue and the red zones. The red coloured zone refers to a different wastewater quality property resulting from the quality after the I&I.

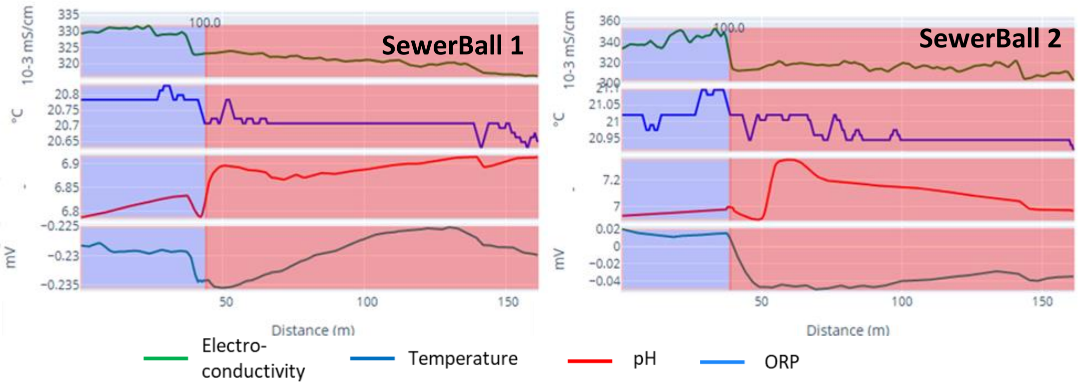

Figure 2. Raw inspection data perform on the same trunk sewer with SewerBall 1 on the left and SewerBall 2 on the right.

One can observe on Figure 2, that for each inspection runs, the sensor signals behave in similar ways even if the sensors where not properly calibrated. The absolute value of the signal is not used in this approach, only the relative dynamics of the signal is of interest for the disorder detection. The electro-conductivity of the SewerBall 1 inspection drops around 10 µS.cm^{-1} at around 45 m after the departure point and 20 µS.cm^{-1} for SewerBall 2.

Data are plot on a 3D scatter plot (Figure 3) where ORP was removed for visualization issues even if all four variables were kept obtaining results from Figure 2. One can observe that for both SewerBall inspections, two important clusters can be found in the same spaces. They both represents the two zones displayed on Figure 2. The colors only refer to clustered label number. Furthermore, based on the labelled experiments and the expert knowledge on the interpretation of the quality signals variations, we were able to classify the disorder type (industrial pollution or clear water infiltration).

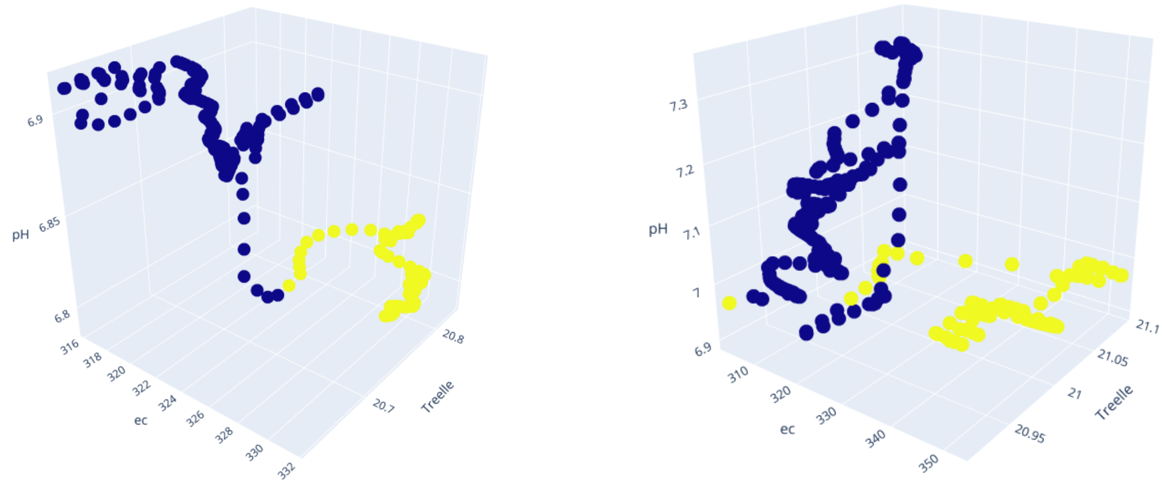

Figure 3. Clustering algorithm results for the same inspection as in Figure 2, for SewerBall 1 on the left and SewerBall 2 on the right.

Conclusion & future work

A very promising new concept for sewer inspection has been developed coupling a mobile multi-variate wastewater quality monitoring with an advanced mathematical method that allows to identify and locate disorders in sewers. These disorders can be Inflows and Infiltrations, industrial spillages, seawater intrusions or wrong pipe connections. Thanks to the development performed, this solution allows for:

- Fast and safe sewer inspection since no man descent is needed
- Cheap solution since no specific skills are required to perform it (no driving skills or else)
- High-performance disorder detection level compared to other previously cited advanced solutions

Additional inspections must be carried out to extend the disorder types list that the SewerBall solution can address. Onboard GPS- free geolocation system should be developed to enable long distances inspection.

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References

Campello R. J., Moulavi D. and J. Sander (2013) Density-based clustering based on hierarchical density estimates. In Pacific-Asia Conference on Knowledge Discovery and Data Mining (pp. 160-172). Springer Berlin Heidelberg. April.

Koller A., Ort C. and C. Ebi (2017) Mapping spatio-temporal distribution of waste-water parameters in sewers International Conference on Urban Drainage (IWA). September 10-15, Prague, Czech Republic.

McInnes L., Healy J. and S. Astels (2017) hdbscan: Hierarchical density-based clustering. Journal of Open Source Software, The Open Journal. 2(11).

MacQueen, J. B. (1967) Some methods for classification and analysis of multivariate observations. In: *Proceedings of the fifth Berkeley symposium on mathematical statistics and probability.* California: University of California Press (1), 281–297.