Use of numbered and coloured 3d printed pills as a new, low-cost, robust and easy method to inspect mis-, cross- and illicit connections in separate sewers

Utilisation de pilules numérotées, colorées et imprimées en 3d pour l'inspection des erreurs de branchements et connections illicites en réseaux séparatifs

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RÉSUMÉ

Les réseaux d'assainissement séparatifs sont de plus en plus préférés aux réseaux unitaires mais ils sont sensibles aux erreurs (in)volontaires de branchements entre les bâtiments et le réseau. Il existe quelques techniques d'inspections spécifiques à ce type de recherche : les tests à la fumée et aux colorants sont les plus utilisés. Ces techniques restent chères et chronophages. Cette étude présente une nouvelle méthode, simple et bon marché, basée sur des pilules imprimées en 3d. Ces pilules, numérotées (avec un code unique) et colorées (bleu ou rouge), sont envoyées par courrier aux habitants, jetées à différents points (toilettes, gouttières, *etc.*) puis collectées dans les réseaux. Après une analyse automatique des pilules récupérées, une comparaison entre les bases de données des pilules jetées et collectées permet l'identification et la localisation des erreurs de branchements (à l 'intérieur même des bâtiments). Les conceptions de pilules et de l'analyseur, les méthodes d'analyses et les outils en ligne sont décrits dans ce résumé. L'acceptabilité sociale de la méthode est brièvement discutée. Des tests *in situ* sont prévus aux Pays-Bas et en France d'ici la conférence.

ABSTRACT

Separate sewers are more and more preferred than combined ones but are sensitive to (in)voluntary mistakes in the connections between buildings and the network. There are only a few inspection techniques specifically devoted to such investigations: smoking test and dye tracing are the most popular. Those techniques are time consuming and expensive. This paper presents a new, low-cost and easy method based on 3D printed pills. Numbered (with a unique code) and coloured (blue or red) pills are sent by mail to inhabitants, thrown in different locations (toilets, downpipes, *etc.*) and then collected in sewers. After an automatic treatment of the collected pills, the comparison between the sent and collected pill databases allows the identification and the location (inside the building itself) of the misconnections. Pill and pill analyser designs, analysis methods and on-line tools are described on this paper. Social acceptability is briefly discussed. Some *in situ* tests will take place in France and in the Netherlands before the conference.

MOTS CLÉS

3d printing, illicit connections, inspection technique, low-cost, separate sewers

1 INTRODUCTION

Sewer systems have been developed for centuries and seem to become more and more separate. On one hand, construction of new areas require new sewer systems; and on the other hand, aging of existing structures (buildings and sewer itself) require maintenance operations as the creation of new connections to the sewer or changes in the plumbing of buildings. An assumption can be issued: misconnections can differ inside one apartment or one house. Misconnections lead to several problems. Domestic water connected to the storm water part of the sewer induces contamination of surface waters, which may lead to nutriment pollutions, increasing risks for public heath, *etc*. Rain water connected to the domestic water induces more frequent overflows, a lower efficiency in waste water treatment plants, higher pumping cost and pollution linked to supply and maintenance, *etc*. In such cases, separate sewers are usually considered as less efficient than combined ones if the rate of misconnection is higher than 5 %. In order to identify potential misconnections after the construction of a new sewer or for diagnostic of an existing one, there are several inspection techniques (Panasiuk *et al.*, 2015) and highlight the need of low-cost and simple technique. Recently, 3d printing techniques have been developed and the creativity of researchers seems to be the most important of potential further uses of such technologies. Several materials can be used: metal, ceramic, carbon, … and plastic, the latter being the most popular. Plastic pollution is the most important marine pollution in terms of proportions; it varies between 60% and 80% of the total marine debris (Derraik, 2002). Environment friendly plastics are available for 3d printing: Poly Lactic Acid (PLA) is an entirely biodegradable polymer (Garlotta, 2001). This paper present an application of 3D printing techniques for sewer inspection. The main idea is unsophisticated and obvious and can be summarized as the four following steps: *i)* send randomly 3D printed, coloured (for the type of water) and numbered pills by mail to every house, apartment, office in one catchment, *ii)* after updating a database, inhabitants throw the pills in each of water outlets (sink, toilet, downpipe) they receive, *iii)* pills are collected downstream in both systems (wastewater and storm water) and *iv)* with colour and text recognition software, misconnections can be identified by comparison with the data of the database. This paper briefly described al the materials and software required for subsequent applications. All technical details and tutorials can be found on this website, devoted to recent techniques in sewer inspections. Presented materials and hardware are published under the CC BY-NC-SA 3.0 license and the software are available in OpenSource.

2 MATERIALS AND METHODS

2.1 Pills

The specifications of the pills are listed hereafter: *i)* the pills must be cheap to be used by the everyone, *ii)* the pills must be eco-friendly because they might be lost during the exchange between the staff in charge of the diagnostic and the inhabitants, *iii)* the pills must float to be easily caught downstream, and *iv)* the pills must pass most the siphons in order to have an easy throwing process (no need to dismount the facilities). In order to reduce as much as possible the impact of potential lost pills in sewers, surface waters and later in seas, the PLA has been chosen for the design. The density of PLA is 1.29 (Garlotta, 2001). For the floatability criteria, the apparent density has to be close to 0.95. Thus explains that there is an empty volume inside the pill (Figure 1).

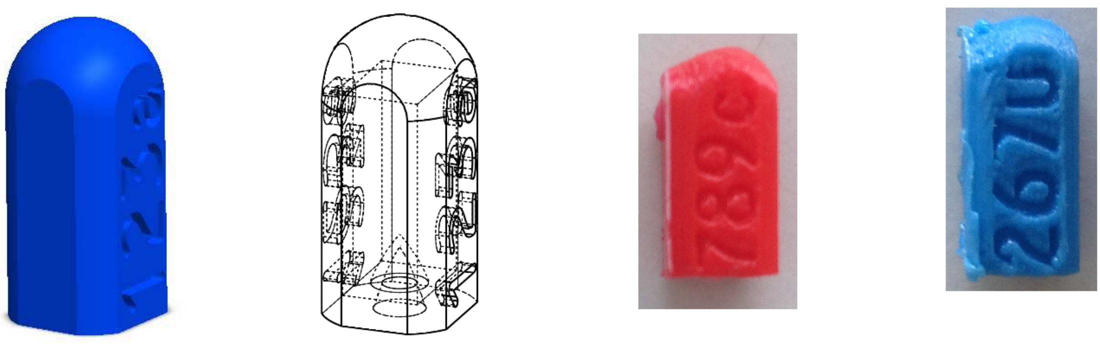

Figure 1. From left to right: 3d drawings (solid and line representations); red and blue pills.

The size has been determined to pass most of siphons. The external shape is a cylinder of 11.5 mm height and 6 mm diameter and has been designed to reduce the hydrodynamic resistance and to facilitate the printing process. Characters have been written by extrusion of 0.55 mm in OCR-B font, 10 pt to increase the readability for subsequent Optical Character Recognition (OCR). The printed code is four characters code, including numbers, lower and uppercase letters. In order to reduce fails in the OCR, graphically similar characters have been avoided. Finally, 53 characters can be used for the code: 0, 2, 3, 4, 5, 6, 7, 8, 9, a, A, B, c, C, d, D, e, E, f, F, G, h, H, i, I, J, k, K, l, L, M, n, N, o, P, Q, r, R, s, S, t, T, u, U, v, V, w, W, x, X, Y, z, Z. A character can be repeated inside a code: the total amount of available combinations is 53^4 = 7 890 481. If one envelop contains 15 pills of both colours, this combination number may be enough to investigate catchment of about 500 000 apartment/house units, *i.e.* up to 1-1.5 millions inhabitants.

2.2 Pill analyser

After the collection of pills in sewer of surface water, pills can be analysed manually or automatically with the proposed following set up (Figure 2). The collected pills are put in a cleaning bucket, set up above one home made magnetic stirrer and then guided to two results buckets (one per colour) and sent back to the cleaning bucket in case of a fail during the colour and character recognitions Transparent pipes of 10 mm (internal diameter) ensure the connection between those buckets. A smartphone connected to a laptop is in charge of the image acquisition and processing. A reading zone device has been designed and build in acrylate to ensure the correct positioning of the pill in front of the camera. Acrylate has been chosen because it has almost the same optical properties as water and thus minimises the risk of distortion that may bias the OCR. Seven solenoid valves manage the flow orientation and the recirculation. The system is controlled by Matlab©, a chassis (National Instrument, NI cDAQ-9171) and a control card (National Instrument, NI 9485) for the valve and the stirrer.

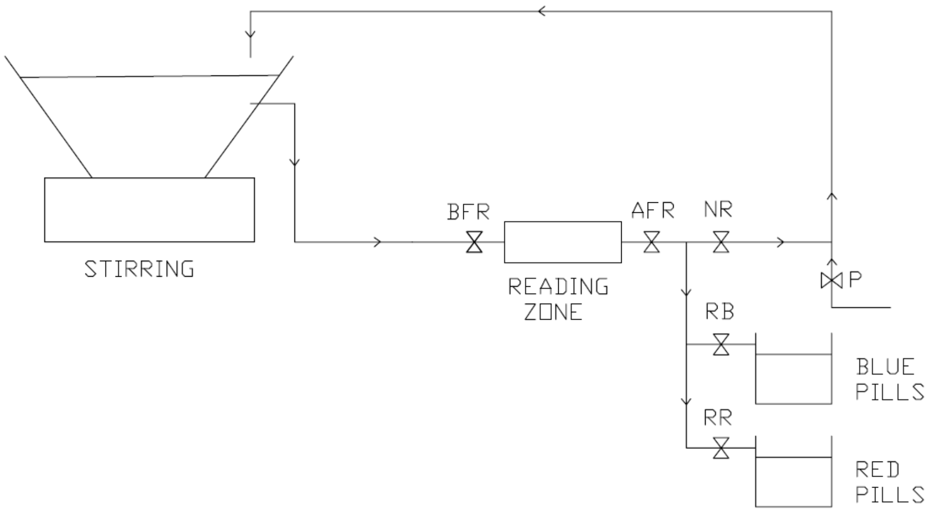

Figure 2. Scheme of pill analyser.

2.3 Method

The method is divided in four steps:

- Step 1: Distributio of the pills. Due to the lightweights of the pills (0.2 gram per pill), some dozens of pills can be easily send by mail to every postal address (house, apartment, office, *etc.*) connected to the sewer to inspect. An explicative letter (available in several languages on the website previously cited) can be sent in the same envelop to explain the project, the principle, where and how to throw the pills and how to fill in the paper form or the data base with an on-line tool or app described hereafter.
- Step 2: On-line tool and app to validate the expected database. A database needs to be constructed in order to know which pill has been thrown where. Inhabitants can choose two tools: *i)* a paper form, sent by mail with the pills and *ii)* a on-line tool accessible with Internet.

- Step 3: Collection of the pills. One or more filet(s), previously described, have to be placed at strategic locations (every possible outlets of the sewer): pumping stations, overflow structures, tank inlets, the downstream point of the catchment, connecting points to surface waters, etc. The identification of these locations requires detailed knowledge of the catchment to inspect.
- Step 4: Colour and number recognition to identify misconnections. A Matlab© code has been written to process the image acquired by the smartphone or the camera. In order to increase the recognition rate, the text read by the code is compare to a temporary data base: the database built during step 2 where the codes of each already recognized pill have been removed.

3 RESULTS AND DISCUSSION

Two tests have been performed to ensure the reliability of the project. For the first one, pills have been spread to volunteers in our department to test the flush through siphons. The pills have been able to pass all the tested siphons, requiring sometime to preliminary cleaning when the presence of long hair is suspected (in sink, shower, bath of bathroom). A second one has confirmed the robustness of the colour and text recognition code: the efficiency has been improved by a Graphical User Interface (GUI) and the comparison to the temporary database (in case of partial recognition).

There are still two important questions liked to this new method. The first one is dealing with the collection of the pills in sewer of surface water: some appropriate nets, ideally positioned in sewers, still need to be tested *in situ*. The second one is linked to the social acceptability: inhabitants are supposed to fill in the database, while giving some personal details. We think that an encrypted database, the diffusion of the tools in a total transparency and the automatic suppression of all the database after a delay will be enough to convince people to take part of this new inspection method. Only feedbacks at mid- and long-term will confirm or invalidate the social acceptability.

4 CONCLUSIONS AND PERSPECTIVES

The technique presented in this paper seems promising and technically feasible. Some work still needs to be done before conducting full tests: this will be finished by the end of spring 2016. Those first tests *in* situ will provide evidence for the applicability of the proposed method. The materials cost for one pill is circa 0.01 euros, they can be home printed (2000 euros for a 3d printer) or printed by a supplier. The pill analyser cost about 2500 euros in terms of materials and about a day of staff cost to be built. With 20 to 30 pills per habitation, including furniture and printing (paper) cost, the price of a mailing to one adress is circa 3 euros. The pills can be collected by sewer maintenance workers and be automatically analysed and sorted with the pill analyser. A low-cost solution for this analyser can be developed using the following equipment: a Raspberry Pi 2 Model instead of the laptop, a Raspberry Pi camera instead of the smartphone and a cheap control kit (National Instrument, NI USB-6008 or 6009) instead of the chassis and the control card. This method will allow for an accurate a cheap identification of the misconnections, detect the scale of the misconnection (a full building or more local errors) in order to draw an accurate diagnostic of the sewer and to list and prioritize the repair work to decrease the misconnection rates.

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