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A technology for sewer pipe inspection (Part 2): Experimental assessment of a new laser profiler for sewer defect detection and quantification

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ABSTRACT

In order to test the laser-scanning device presented by Stanić, Lepot, Catieau, Langeveld and Clemens [1], laboratory experiments have been performed. Various objects, covering a wide range of sizes, shapes, materials, colours and reflectiveness, have been installed in a concrete pipe and scanned by the prototype in order to identify potential object characteristics that may affect measurement uncertainty and/or create bias. By taking into account both uncertainties (on scanned and measured sizes), scanned dimensions have been compared to measurements performed with a calliper or a ruler: overall the values are mutually consistent. The proposed prototype is suitable for sewer inspections: displaced joints, cracks, deposits can be accurately measured without any bias by comparison to CCTV. Uncertainty in the measurement appears to be unaffected by humidity or fat deposits.

1. Introduction

Sewers are aging underground structures that are often used beyond their expected life duration and their actual functionality is hard to quantify *in situ*. The management of such system requires accurate and detailed data on their functioning and constructive strength and stability in order to optimize the trade-off between the repair/replacement costs and an acceptable level of various risks: urban flooding, pipe collapse and/or pollution of water bodies caused by sewer overflows (environmental and public health risks). Various techniques already exist to inspect such linear infrastructure: *i)* CCTV inspection is the most commonly applied in practise but has shown to be inaccurate [2,3], *ii)* laser profiling techniques [1,4], *iii)* acoustic techniques (*e.g.* in [5,6]), or *iv)* a combination of them [7]. Previous studies highlight the relative inaccuracy and the subjectivity of CCTV reports, due to: *i)* the absence of measuring devices and/or software, *ii)* the quantification classes of some standard methods [8,9], and *iii)* the human interpretation of the videos. CCTV inspections have been compared to acoustic techniques [10] but not to laser scanning techniques: this is the main goal of this study. Since laser inspection devices deliver 3D scans of a sewer reach, they appear to be the most promising emerging technology for accurate measurements [11]. Several industrial laser-scanning devices are available on the market, based on two different approaches. The first one consists of a rotating laser distance meter, sometimes mounted on a CCTV tractor (by example, the Rauschusa system [12]): by construction, such a system just delivers a 3D image of the reach only along a helical curve. The second approach, similar to the one used in this study [1], is based on a ring laser light (a laser projected simultaneously at 360 degrees, *e.g.* the maverick Inspection system [13]). In order to avoid bias in the data, both approaches require knowledge on the exact position and spatial orientation of the device [4]: to the authors' knowledge, no correction system is proposed by the commercial systems so far.

The companion paper [1] describes in detail the design of the new laser profiler used in this study and provides important feedback and suggestions for further developments: device accuracy, importance of the laser alignment and a perfect synchronisation inter- and intra-acquisition systems. Since the prototype has been built and calibrated, a standard uncertainty of the air-solid interface position has been estimated: from 1,1 mm to 1,8 mm, from invert level to the top of the pipe, respectively. The prototype has to be exhaustively tested to ensure its robustness and suitability for *in situ* measurements and applications. Is the prototype able to measure fully the size of various objects in the

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pipe and to detect usual defects in sewer pipe? Under which conditions does bias occur in the measurements? Does this technology present disadvantages when compared to CCTV inspections? In a more general way, is the laser profiler technique a potential candidate for replacing CCTV?

In order to answer these questions and after a short introduction into the presently applied inspection techniques and defect classification (Section 2), the design of the prototype is briefly described (Section 3.1), all the laboratory tests (performed on real pipes) are described in Section 3.2. Data validation and analysis (comparison between measured - by a calliper or a ruler - and scanned - by the prototype - object dimensions) methods are briefly described in Section 3.3. Results of the comparison between the scanned and measured sizes are presented and discussed in the fourth section of this article.

2. Defects recorded by CCTV and their quantifications

Sewer inspections are mainly done based on CCTV footage: defects are characterised and quantified according to standard methods (varying however between EU, USA and other countries). As an example, a European standard method [5] has been translated in national regulations with some tiny differences per country. In Japan, defects identified by CCTV are coded using a less detailed system of codes than in Europe.

The retained standard method for defect coding [8] records the following information (Table 1).

Based on the visual inspection and the position of the CCTV tractor, the defects are positioned (longitudinal location - in m - from a reference point) and coded with different letters or numbers to:

- define the defect and its origin with the main code: deformation, fissure, break/collapse, defective brickwork or masonry, missing mortar, surface damage, intruding connection, defective connection, intruding sealing material, displaced joint, lining observation, defective repair, weld failure, porous pipe, soil visible through defect, void visible through defect, roots, attached deposit, settled deposits, ingress of soil, other obstacles, infiltration, exfiltration, vermin, other connection (pipe), point repair, curvature of sewer, start node type, finish node, general photograph, general remark, inspection terminated before finish node, water level, flow from incoming pipe, atmosphere within the pipeline and loss of vision;
- characterise the defect, with specific sub-codes (1 and 2) depending on the main code. For example, for a fissure (main code BAB), characterisation 1 can be A for a surface crack, B for a crack or C for a fracture and the characterisation 2 can be A for longitudinal, B for circumferential, C for complex, D for helical or E for starting from a point;
- quantify the defect with a specific sub-codes (1 and 2) depending on the main code. For example, a connection is quantified by Quantification 1 (in mm, the height of the connecting pipe) and Quantification 2 (in mm, the width only if it differs from the heights). Most of the defects only have one quantification;
- locate the beginning and the end of the defects according to the clock face references (from 1 to 12);
- indicate if the defect is located at a joint (transition) in the structure.

The previously listed defects highlight several advantages and disadvantages of the CCTV method. CCTV is only fit for identifying defects that can be visually detected by an operator. The quantification is done by human interpretation of images and, sometimes, with the position of the tractor: subjectivity can lead to some bias in the data [2]. Measurement by a laser profiler seems to result in more objective results relating more directly to the actual status of the sewer. However, some of the defects can be detected only with colour camera and under good light conditions such as lining observations, exfiltration or atmosphere-related issues (*i.e.* presence of potentially hazardous atmosphere due to fog, the occurrence oxygen deficiency, hydrogen sulphide, methane or other gasses).

3. Material and methods

3.1. The laser-profiling prototype

The prototype consists of two main parts (Fig. 1): a stationary part where three laser distance meters (Dimetix, FLS C10) and a pulsing laser (Osela, Streamlaser – 660 nm) have been set up and a moving part where two cameras and a laser profiler (Ibak, ILP) have been installed.

The data stemming from the image processing of the front camera (Allied Vision Technology, Prosilica GT3400C) frames (records of projection of the laser profiler) are corrected with the exact position of the moving part. The position is obtained from the three recorded distances and the image processing of the back camera (Allied Vision Technology, Manta G-282C) that records the projections of the four lasers set up on the fixed part. A detailed description on this design has been presented in [1]. The fourth laser has been used for an optical synchronisation between data acquisition system of both parts.

3.2. Object and material set

Based on the defects identified by [8], several add-ins have been set up in an egg-shaped pipe (400/600 mm) to cover the wide range of defects or solid materials, which can be found in sewer systems. Various objects and materials (Table 2) have been used to study: *i)* the defects detectable and quantifiable by the prototype, and *ii)* effect of size, shapes, colours, roughness or the kind of deposits on the measurement. Pictures of the material set are available in the electronic appendix. Each object has been scanned with the prototype: the moving part has been manually moved into the pipe.

Water {1} and Vaseline {2} (Table 2) have been applied inside the pipe, on the wall, in order to create conditions that may occur in sewers: water saturated atmosphere (temperature, humidity, diffuse infiltration through the wall) and fat deposits. Other experiments have been done to reproduce the most common sewer conditions: deposits of various materials (as sludge {6}, sand {5}, gravels {7}, *etc.*), displaced joints {3}, intrusive connections {12}, roots {13} and cracks {4}. Other objects, more unusual but that can still be found in CCTV reports (like brick {16} or a beer bottle {21}.), have been placed in the sewer pipe to test the measuring capacities of the prototype.

3.3. Methods

3.3.1. Raw-data treatment

Previous studies [1,11,14] have presented the methods applied in post-processing of the raw data (images and distances); these details are not presented in this paper. Fig. 2 summarizes all the steps of the data processing: from the raw data and sensors (left part) to the construction of the 3D model by integration, from frame 1 to frame N, of corrected (calibration), unbiased (correction of the position) and

Table 1
Coding system of the European standard method of defect coding [5].

Longitudinal location	Continuous defect code	Main code	Characterisation		Quantification		Circumferential location		Joint	Photo ref.	Video ref.	Remarks
			1	2	1	2	1	2				