Potential of Laser Scanning for Quantification of Sediment Deposits in Sewer

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ABSTRACT
There is still a long way to go in understanding the behaviour of solids in sewers due to the difficulties in obtaining sufficient monitoring data to be able to understand the dominant processes. Laser profilers have shown to be capable of measuring the pipe interior, with a high accuracy, which is sufficient to be able to detect and quantify wall losses. This paper describes the potential of laser scanning for measuring sediment volumes in sewers. In addition, the propagation of uncertainties from laser measurements to sediment volumes are discussed, with special attention to conditions that could affect the measurements. The Laser profiler has shown to be capable of measuring the pipe interior, which is sufficient to be able to detect and quantify sediment volume. Overall, this research is a first step in defining a new inspection concept that will be able to give reliable information on relevant failure mechanisms .

KEYWORDS
Inspection; laser scanning; sediments; sewer; quantification;

INTRODUCTION
Sedimentation in sewers may cause a reduction of hydraulic capacity, an increase of operational costs for frequent system cleaning, premature functioning of combined sewer overflows and increased pollution (Verbanck *et al.* 1994). There is still a long way to go in understanding the behaviour of solids in sewers due to the difficulties in obtaining sufficient monitoring data for understanding the dominant processes.

Although many studies on the sediment monitoring and quantification in sewers have been carried out in past, the results were not able to determine (with confidence) actual quantities of sediment deposits (Bertrand-Krajewski *et al.* 1993; Andrews 1998; Ashley *et al.* 2000). Further, CCTV inspection, the most common inspection technique, is used in most cases after cleaning of the sewer. Consequently, CCTV inspections don't usually record presence of deposits in the sewer. Therefore, a new method should be defined for robust and accurate estimation of deposits quantities (and their uncertainties) in sewers. Laser scanning offers a new and challenging perspective for accurate, non-invasive assessment of pipe conditions for dry sewers. Laser profilers have shown to be capable of measuring the pipe interior, with a high accuracy, which is sufficient to be able to detect and quantify wall losses (Stanić *et al.* 2013). This concept is applied in experiments to estimate deposits quantities in sewers. A forgotten issue in earlier applications of these laser profilers, is the necessity to know exactly the camera position and orientation, for which the laser profile has to be corrected. This procedure has been described in (Clemens *et al.* submitted).

This paper describes the potential of laser scanning for measuring sediment volumes in sewers. In addition, the propagation of uncertainties from laser measurements to sediment volumes will be discussed, with special attention to conditions that could affect the measurements.

MATERIALS AND METHODS

Experimental method
The study was conducted on an excavated 70 year old egg-shaped concrete sewer pipe with dimensions of 400/600 mm. The measurements were carried out in two stages: measuring the shape of the pipe interior without and later on with sediment. The results where combined in order to quantify the amount of the sediment in the pipe. In addition, the measurements were carried out first in one direction and then in the opposite direction in order to check accuracy of the measurements.

At the front of the pipe a ramp is placed to ensure a smooth entrance of the measuring set-up. A frame covering these ramps is applied to darken the setup to ensure good visibility of the laser. A pyramid-shaped object (Figure 1) was used as an artificial sediment for the laser measurement. After the initial measurements of the empty pipe, the artificial sediment was placed inside the pipe. In addition, the influence of moist environment on the measuring results was assessed. Pipe was humidified before and during the experiment.

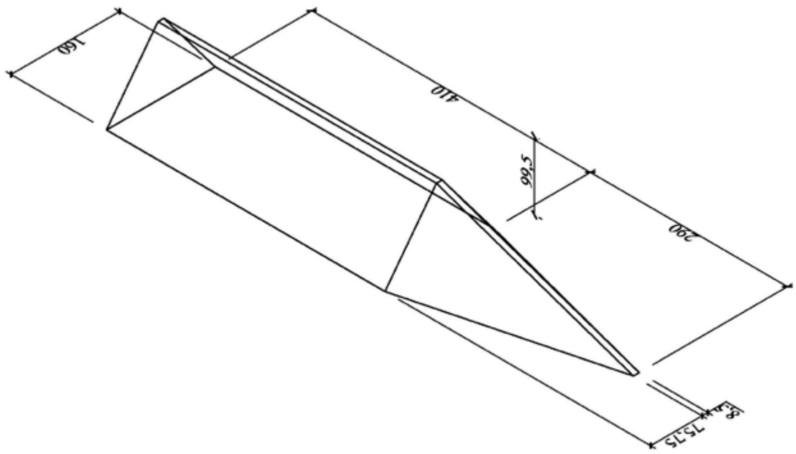

Figure 1. Artificial sediment (dimensions in cm).

Measuring set-up
Figure 2 shows the measuring set-up applied. Two D-link DCS 2310 L day/night cameras are mounted in line on a mobile platform, in front of camera 1 a laser is mounted that, using a reflecting cone, produces a laser sheet which projects a line perpendicular to the main axis of the platform on the inner pipe wall that is recorded by camera 1. Perpendicular to the camera’s axis (parallel to the plane of the laser sheet) a reflection board is positioned on which 3 parallel Fluke 414D lasers for distance measuring project 3 distinct points, that are recorded with camera 2.

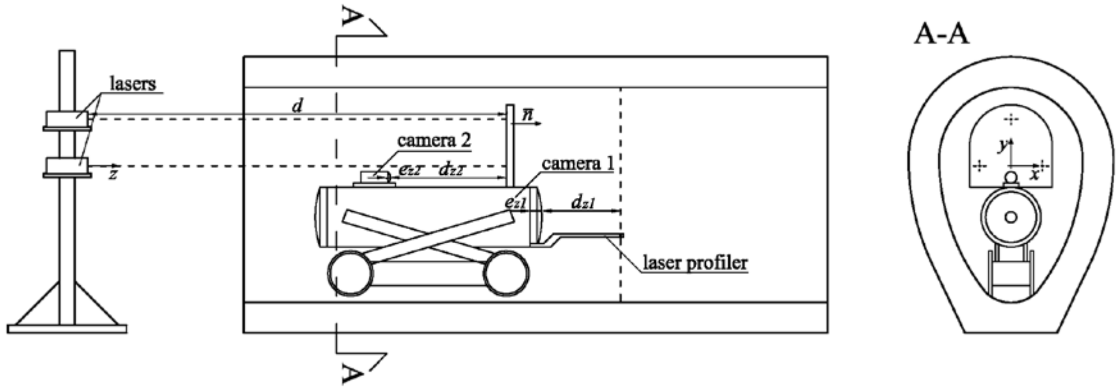

Figure 2. Measuring set-up (Clemens *et al.* submitted).

The 3 parallel lasers have a fixed position and define a reference coordinate system, with the z-axis parallel to the main axis of the pipe. The images recorded by the two cameras and the readings from the laser distance meters are stored on a computer for further processing. The mobile platform moves at a, not necessarily constant, speed of approximately 1.7 cm/s through the pipe. With a recording frequency of 25 frames/s, this implies that each frame is less than 1 mm apart along the length of the pipe. The laser distance meters and both cameras are connected to data acquisition software installed on a computer. This set-up is able to measure all 6 degrees of freedom thus determining the actual position of the 2-D image (Clemens *et al.* submitted).

Data processing

The raw data need to be processed to obtain the information sought after. The data processing encompasses the following steps:

- Determine the x, y, z position of the 3 laser points projected on the reflection board.
- Determine the position and orientation of the mobile platform.
- Correct the recorded image from camera 1 for misalignment and orientation
- Calculate the inaccuracy interval for each recorded point in x, y, and z direction.
- Generate images

These steps have been incorporated in Matlab® code that is applied as a post-process on the raw data.

The volume of sediment was quantified by overlapping the measurements with and without artificial sediment placed in the pipe. This was done using trapezoidal numerical integration. In addition, an attempt was made to determine the volume of sediment based solely on the measurements with sediment present.

Uncertainties analysis

Specifications and their standard uncertainties (obtained by repeated measurement) of the instrumentation are given in Table 1.

Table 1. Specifications and their standard uncertainties of the instrumentation.

	Brand / Model	Standard uncertainty σ (in mm)
Cameras	D link / DCS 2310 L	0.0056
Laser distance meters	Fluke/ 414D	0.5
Circular projected laser	Ibak / ILP	-
Dimensions of the measuring setup	-	0.25

The overall uncertainty of the position of a point projected on the pipe wall is determined:

- The uncertainty of the recorded images in camera 1 and camera 2.
- The uncertainty of the measured distances.
- The uncertainty of the alignment of the lasers.
- The uncertainty of the fixed distances in the measuring setup.

Assuming that the measuring errors in the parameters mentioned are mutually independent, hence neglecting covariance terms, the law of propagation of uncertainties (JCGM 104, 2009) applies for the measured points:

$$\sigma^2_{p_{corrected}} = \sum_{i=1}^{i=19} \sigma^2_{v_c(i)} \left[\frac{\partial p_{corrected}}{\partial v_c(i)} \right]^2 \qquad 1)$$

RESULTS AND DISCUSSION

The contour (Figure 3) indicates the difference between the profile measured following the procedures as described before minus the theoretical profile. Clemens *et al.* (submitted) showed that using, relatively simple instruments, statistically significant differences between corrected and uncorrected profile in x, y and z directions are obtained. As can be seen are the differences between measurement and theoretical profile vary in length and scope. The fat, oil and grease (FOG) deposits in the figure show clearly the normal DWF water level in the pipe.

Figure 4 shows an empirical cumulative distribution function of the differences between the measurement results in both directions, assuming that the data are independent. 95% of measured differences falls within the scope of ±6.35 mm. These differences are present due to the inaccuracy of measurement apparatus (relatively simple and cheap instruments). In addition, Clemens *et al.* (submitted) showed that there are three main contributing sources of uncertainties, in descending order: the misalignment of the lasers, the image quality of the two cameras and the distance measurement. The obtainable uncertainty in the result is quantified. The calculated maximum standard uncertanties in x, y and z direction are σ_x = 2.8 mm, σ_y = 5.8 mm and σ_z = 4.8 mm. Furthemore, the cross-sections that were compared are not on exact same position. In conclusion, using high-end instrumentation potentially will result in a far better accuracy.

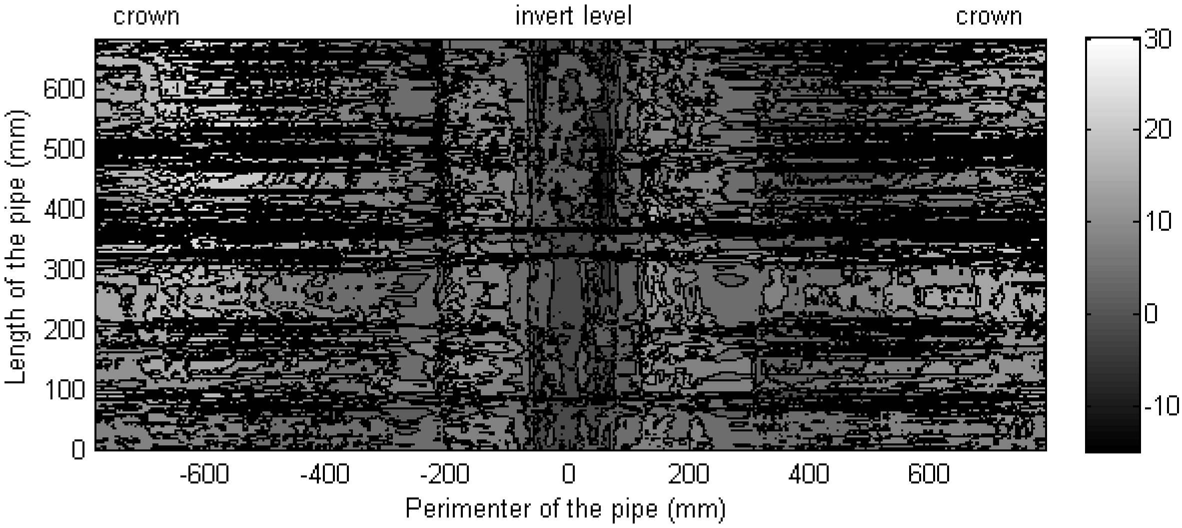

Figure 3. Difference between theoretical and measured geometry for the old pipe after correction for position and orientation of the measuring platform.

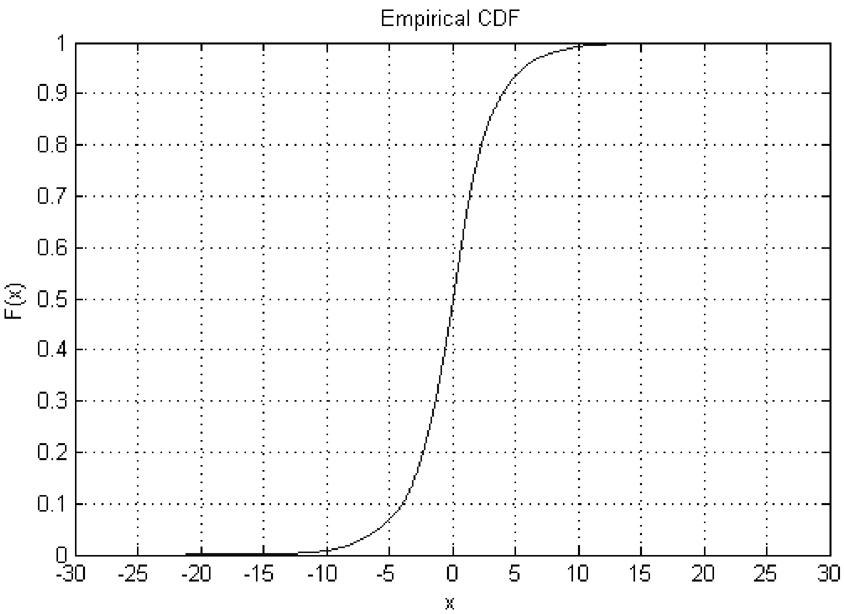

Figure 4. Empirical cumulative distribution function of the differences between the repeated measurements.

Afterwards measurements were carried out artificial sediment placed inside the pipe. The volume of the sediment was known to be 5.75 dm^3. Figure 5 shows two cross-sections models of sewer pipe with and without sediment present in the pipe. The filling degree per cross-section varies from 0.11% (0.02 dm^2) to 6.15% (1.23 dm^2). Also, closed circuit television (CCTV) inspection can recognize settled deposit in the sewer and assess the degree of filling with ranges (Nederlands Normalisatie-instituut 2004). Consequently, laser scanning is better able to quantify the amount of the settled deposit. The sediment volume, after data processing, was calculated to be 6.2 dm^3, which is about 8% more than the actual volume. This deviation from the actual value of the volume is due to imperfect profile overlapping. As mentioned earlier, the key issue is the instrumentation inaccuracy and alignment.

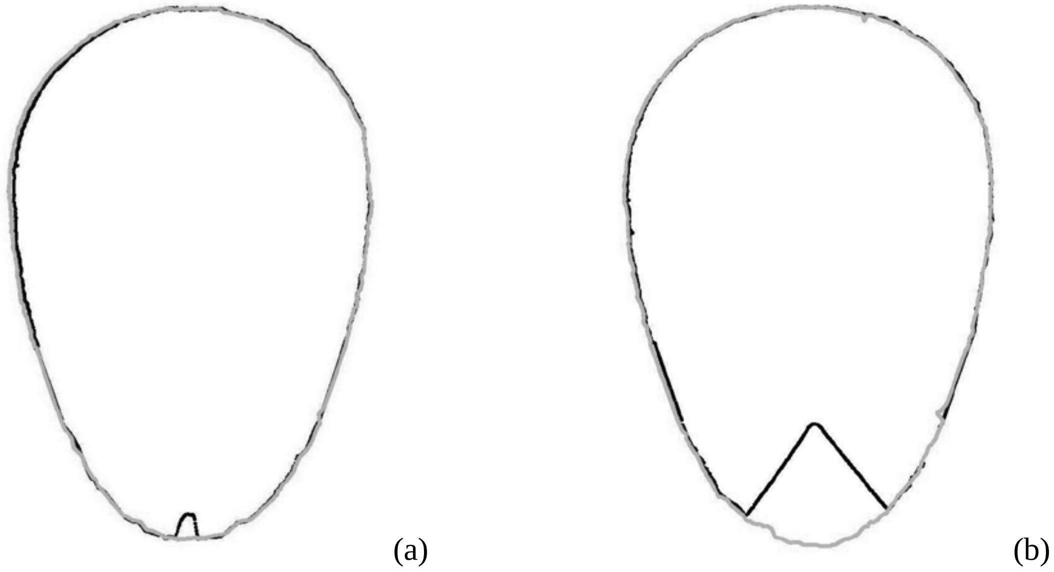

Figure 5. Overlapped cross-section models of sewer pipe with and without sediment present in the pipe: (a) at a distance of 30 mm (b) at a distance of 530 mm

Furthermore, calculated volume based solely on measurements when the sediment was present in the pipe is 6 dm^3, which is about 4.5% more than the actual volume. This implies that with a good selection of the profile position we can get a good estimation of the sediment volume (figure 6). The position of the profile was determined based on the known geometry of the theoretical profile (top part of the pipe is semicircle) and assumption that the pipe deteriorated uniformly in the crown region. In addition, when the pipe's environment is humidified it was observed that the intensity of the laser beam is somewhat lower in comparison with a dry environment. Attention should be paid to this during the actual inspection.

Figure 5. Overlapped cross-section models of sewer pipe and theoretical profile at a distance of 345 mm.

CONCLUSIONS

The Laser profiler has shown to be capable of measuring the pipe interior, which is sufficient to be able to detect and quantify sediment volume. The advantage of laser profilers is speed. The accuracy of measurements is mainly dependent on the accuar of the instrumetation and laser alingment. However, with using high-end instrumentation and better laser alingment a far better accuracy can be obtained. Results showed that with good selection fo the profile poition we can get a good estimation of the settled deposit volume. Laser scanning is a more accurate method of settled deposit quantification than visual inspection based on Standard NEN 3399 – condition assesment (Nederlands Normalisatie-instituut 2004). Overall, this research is a first step in defining a new inspection concept based on the application of a laser profiler.

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