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Plihal, H., Kretschmer, F., Bin Ali, M.T. et al. (4 more authors) (2015) A novel method for rapid inspection of sewer networks: combining acoustic and optical means. Urban Water Journal, 13 (1). pp. 3-14. ISSN 1573-062X

https://doi.org/10.1080/1573062X.2015.1076857

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A novel method for rapid inspection of sewer networks: combining acoustic and optical means

H. Plihal[1], F. Kretschmer[1], M. T. Bin Ali[2], C.H. See[4], A. Romanova[5], K. V. Horoshenkov[3] and Th. Ertl[1]

1 University of Natural Resources and Life Sciences, Vienna (BOKU), Institute of Sanitary Engineering and Water Pollution Control, Muthgasse 18, A-1190 Vienna, Austria,

2 Acoustic Sensing Technology (UK) Ltd, Daresbury Innovation Centre, Keckwick Lane, Daresbury, Cheshire, WA4 4FS England

3 University of Sheffield, Department of Mechanical Engineering, Sheffield, S1 3JD England

4 University of Bolton, Deane Road, Bolton, BL3 5AB England

5 Greenwich University, School of Engineering, Old Royal Naval College, Park Row, Greenwich, London, SE10 9LS England

Corresponding author: Hanns Plihal; Postal address: University of Natural Resources and Life Sciences, Vienna (BOKU); Institute of Sanitary Engineering and Water Pollution Control, Austria, 1190 Vienna, Muthgasse 18; Phone number: +43 (0) 1 47 654 5813; Email: hanns.plihal@boku.ac.at

Abstract

Operation and maintenance of the public sewer system represent key tasks for an operator. Condition assessment is usually conducted by conventional closed circuit television (CCTV) inspection. However, alternative tools such as manhole-zoom cameras (MZCs) and the acoustic technology SewerBatt® are available today.

The INNOKANIS project investigates structural and operational condition assessment in the sewer system by means of 3 MZC models and SewerBatt® to develop a combined optical and acoustic device as cost-effective alternative to conventional CCTV inspection.

The first field trials of the ongoing project were conducted in Austria in 2011. 640 conditions according to EN 13508-2/A1 were investigated and compared against conventional CCTV reports. Individual and combined detection rates for both devices were calculated.

Based on the current findings, both MZC and SewerBatt® are effective alternatives to conventional CCTV inspection. In addition, performance is significantly enhanced when both devices are used in combination.

Keywords: acoustic inspection, CCTV, INNOKANIS, manhole-zoom camera, SewerBatt®

1. Introduction

With the development of the sewer system in Austria largely completed, the focus is shifting towards maintenance. Sustainable operation and maintenance of sewers require regular information about the structural, operational, hydraulic and environmentally relevant conditions of the underground network. Many defects in the sewer system are only detected during routine CCTV inspections, often conducted in 10 or 15 year intervals, or once they have already caused problems such as blockages or pipe collapses. However, sewer operators can detect many defects at an early stage, e.g.

within the framework of annual maintenance measures, if using innovative inspection methods.

The current research project INNOKANIS (2014) explores innovative methods for sewer inspection by means of three different types of manhole-zoom camera (MZC) and SewerBatt® (Horoshenkov *et al.* 2010), a device for acoustic inspection. So far 640 conditions according to EN 13508-2/A1 (2010) were investigated in field trials and compared against reports based on conventional CCTV inspection.

The objective of this research is to develop a combination of MZC and SewerBatt® as innovative and cost-effective alternative to conventional CCTV inspection.

2. State-of-the-Art

At present the condition assessment of sewer systems is conducted either directly through operational staff or indirectly, e.g. by use of CCTV inspection. Conventional CCTV inspection provides structural and some operational information about the sewer system. Operational details regarding deposits are usually not considered since the sewer system has to be cleaned prior to CCTV inspection. The resulting CCTV reports form the basis for a sewer register and rehabilitation or renovation work.

Current improvements to CCTV inspection include 2- or 3-D ”scan” technologies such as DigiSewer®, Panoramo® and Spherix®. This technology enables the recording of digital images of the entire sewer wall (Chae *et al.* 2008) which are then processed offline so that the sewer can be inspected off-site (i.e. in the office). The next step of development is digital image processing for automatic recognition of defects (Mueller and Fischer 2007, Guo *et al.* 2009).

In addition to CCTV inspection, there are special methods like laser profilers combining a laser projection with a camera that captures the images. This method is mainly used for cross-section analysis and the detection of cracks or obstacles (e.g. Gooch *et al.* 1996, Duran *et al.* 2003, Arsénio *et al.* 2013).

Another special method is ground penetrating radar (Deserno *et al.* 2009) to obtain background information, based on an antenna emitting high-frequency electromagnetic impulses into the soil layer. The resulting measurements are translated into “radargrams” and subsequently evaluated by geologists. This method enables the detection of ground anomalies around the sewer, which might imply the risk of future collapse.

Until recently, CCTV inspection has been considered the only method to obtain a comprehensive overview regarding the structural and operational conditions in the sewer system. However, this represents a considerable financial burden for smaller municipalities, particularly in rural areas. Thus, other more cost-effective inspection methods are worth exploiting, such as the use of a MZC (Rinner *et al.* 2008, Wang *et al.* 2013) or SewerBatt® technologies, an acoustic device.

2.1 Manhole-Zoom Camera (MZC)

This is a camera system with integrated illumination attached to a pole which is lowered into the manhole (see Figure 1). Thus, the camera can be used without the staff entering the sewer system. In sewer pipes of circular cross-section the MZC is positioned in the centre of the pipe, in pipes of egg-shaped profile, it is positioned in the lower third of the pipe. The camera zooms into the pipe section to be investigated, generating either photographs or videos. According to Busnello (2011) the average inspection range of a MZC is 20 to 30 m, depending on various structural and operational factors such as angular displacements, invert specifics, spider webs etc. (see Section 3.5). Thus, with an average pipe section length of 50 m, the inspection of the sewer system needs to be conducted both up- and downstream for a full survey. Pipe sections exceeding 50 m in length cannot be fully illuminated by a MZC which reduces the detection rate of conditions in the pipe.

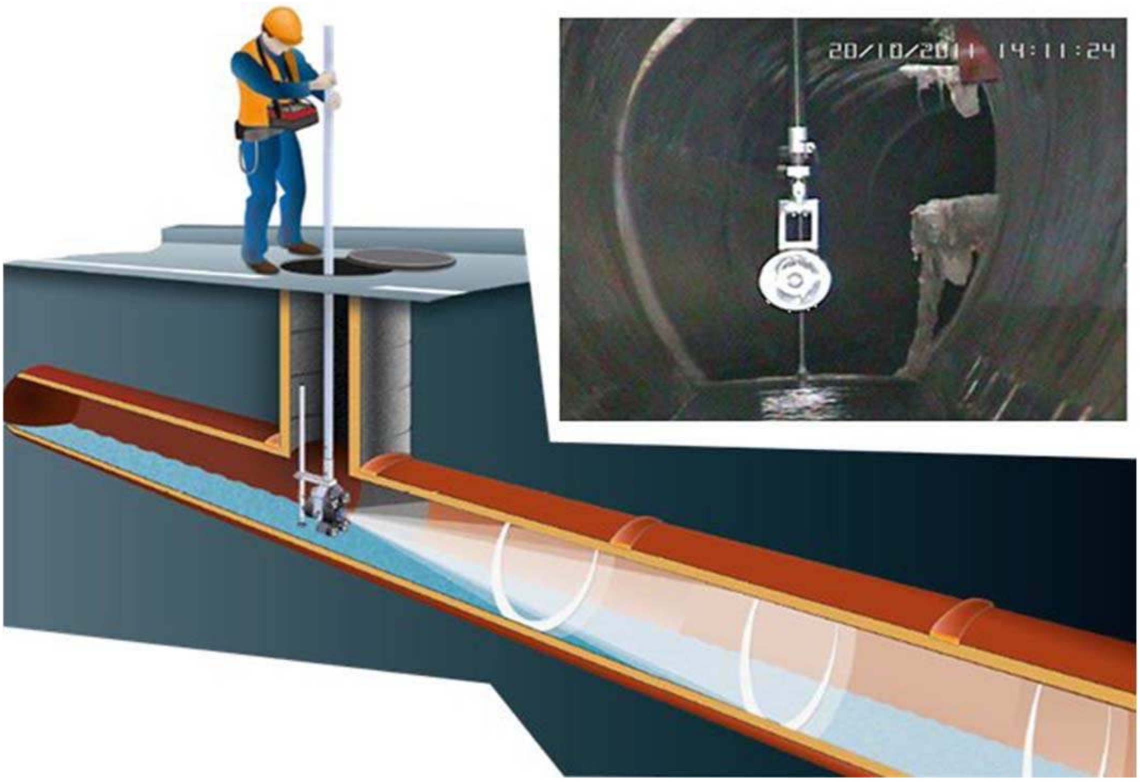


Figure 1. The operation principle of a MZC (based on MesSen Nord 2013)

2.2 Acoustic equipment

SewerBatt® is a new acoustic technology for rapid sewer inspection which was developed by the University of Bradford (www.acousticsensing.co.uk). It consists of a small acoustic sensor which comprises a microphone array, speaker and electronic block. The instrument also includes a data acquisition module and ruggedized laptop. It can operate with a long cable or via Bluetooth. Similar to MZC, a SewerBatt® sensor is inserted through the manhole and its operation does not require man entry or traversing the instrument through the sewer pipe as it is shown in Figure 2. The SewerBatt® sensor emits a sound wave and detects the reflections from parts of the pipe where a change in the pipe cross-section has occurred or where the pipe wall material properties are no longer uniform. In this way blockages, damaged pipe connections, wall cracks and incrustation can be acoustically detected. The exact location of these conditions is determined through the time of flight by estimating accurately the sound speed in the pipe from the temperature measurements. Each of these conditions is characterised by a unique type of sound reflection pattern which is stored in a database on the PC. This database can then be used to train software to recognise individual sewer conditions when the device is taken to the field for a sewer condition survey. The SewerBatt® is a ruggedized instrument. The MEMS microphones in the microphone array are very robust and their sensitivity does not drift in time. The signal processing system is robust enough to tolerate some deviation in the level of the signal which can be caused by possible contamination of the microphone with moisture or debris. Any deviations in the microphone sensitivity which exceed the set threshold results in an error message which suggests replacing the microphone array. The microphones can be calibrated manually, by saving their acoustic performance in a file for future use (see Bin Ali 2010 for details).

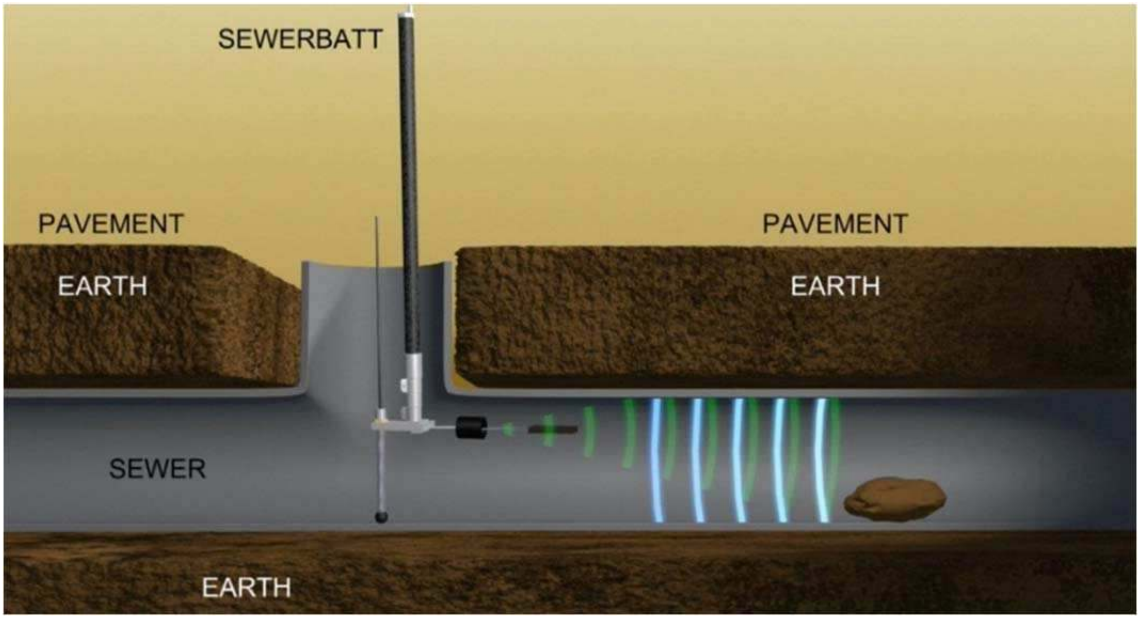


Figure 2. The operation principle of SewerBatt® instrument (Horoshenkov 2013)

2.3 Comparison SewerBatt® vs. MZC

Table 1 compares the main parameters of SewerBatt® and MZC.

The inspection direction of both devices can be up- or downstream. Depending on the number of conditions and their sizes, SewerBatt® usually requires only one direction for inspection. In contrast, the authors recommend an inspection in both directions for optimal structural and operational condition assessment by means of a MZC. However, this might not fully eliminate the presence of blind spots in the investigated pipe section.

Acoustic measurements conducted by SewerBatt® provide a probability estimate regarding the presence of a certain condition, while MZC produce photos or videos of the conditions investigated in the pipe.

The inspection speed of both MZC and SewerBatt® is very high compared to the conventional CCTV crawler inspection. According to Rinner *et al.* (2008) 2 to 3 km of sewer can be inspected per day if a MZC is used. Similar results have been obtained for SewerBatt®. In contrast, conventional CCTV inspection is limited to approximately 700 m of sewer per day (EPA 2010).

Due to the considerably increased inspection speed and output both MZC and SewerBatt® are more cost-effective than conventional CCTV inspection. Whereas the expenses for conventional CCTV inspection amount to EUR 1.30 per m, inspection costs decrease to EUR 0.30 per m if a MZC is used instead, as discussed by Pamperl *et al.* (2010). This is supported by similar findings published by EPA (2010). The cost of SewerBatt® is estimated to be similar to the cost of MZC in terms of equipment costs (EUR 10-15k) and survey costs (EUR 0.30 per m). However, both MZC and SewerBatt® only generate a basic overview of the conditions in the sewer system.

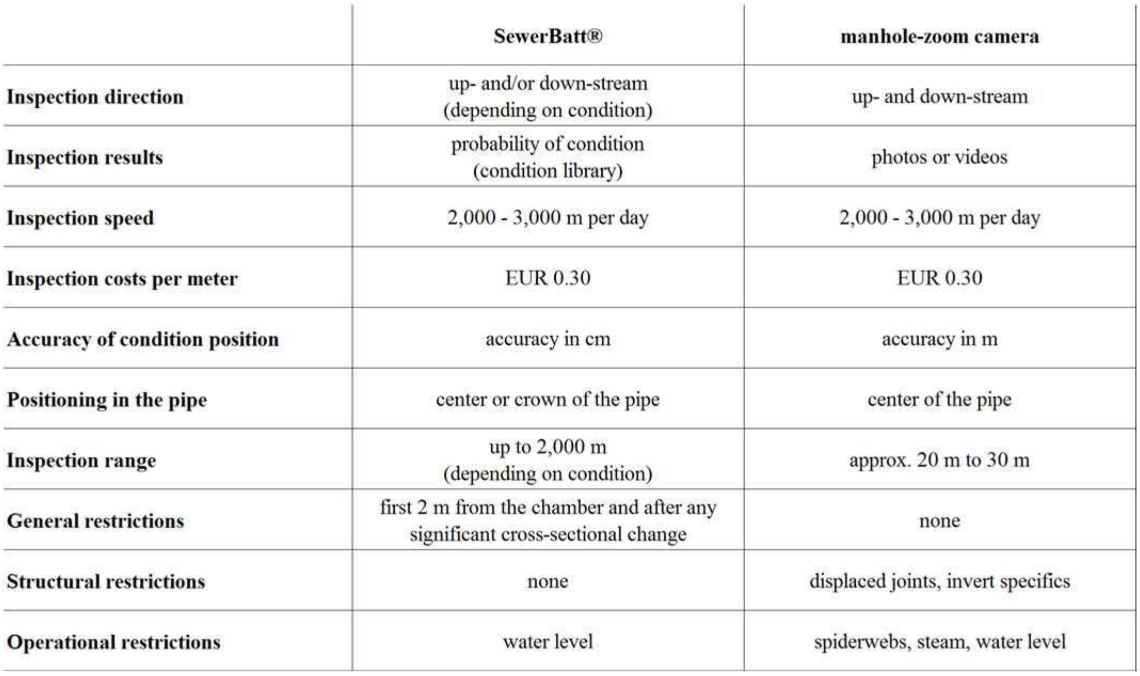
Therefore they cannot fully replace conventional CCTV inspection, but are used to identify pipes that require cleaning or a more detailed inspection by CCTV (EPA 2010).

MZC and SewerBatt® differ in accuracy regarding the position of a condition in the pipe. Whereas SewerBatt® provides a positioning accuracy in the centimeter range (Romanova 2009), the accuracy range of a MZC is in meters (INNOKANIS 2014). Based on the zoom factor used, the MZC estimates the distance of the condition and adds this information to the photo/video record, but not all camera models support this feature.

A MZC has to be positioned in the centre of the pipe, whereas SewerBatt® can be positioned either in the centre or in the crown of the pipe.

According to Romanova *et al*. (2013) the inspection range of SewerBatt® can be up to 2,000 m, depending on limiting factors such as the presence of manholes, number and size of conditions in the pipe and the presence of dry sediment. In contrast, the inspection range of a MZC constitutes 20 m to 30 m (Busnello 2011).

The following restrictions have to be considered when using SewerBatt®: In the first 2 m from the chamber and 1.5 m after a significant cross-sectional change such as an intruding house connection or large blockage a blind zone exists within which the detection of other conditions is compromised. In addition, SewerBatt® cannot be used below water level. According to Plihal *et al*. (2014) structural restrictions such as displaced joints and invert specifics as well as operational restrictions, e.g. spider webs, steam or high water level, have to be considered when using a MZC.



	SewerBatt®	manhole-zoom camera
Inspection direction	up- and/or down-stream (depending on condition)	up- and down-stream
Inspection results	probability of condition (condition library)	photos or videos
Inspection speed	2,000 - 3,000 m per day	2,000 - 3,000 m per day
Inspection costs per meter	EUR 0.30	EUR 0.30
Accuracy of condition position	accuracy in cm	accuracy in m
Positioning in the pipe	center or crown of the pipe	center of the pipe
Inspection range	up to 2,000 m (depending on condition)	approx. 20 m to 30 m
General restrictions	first 2 m from the chamber and after any significant cross-sectional change	none
Structural restrictions	none	displaced joints, invert specifics
Operational restrictions	water level	spiderwebs, steam, water level

Table 1. Comparison SewerBatt® vs. manhole-zoom camera (INNOKANIS 2014)

3. Methodology

The investigations discussed in this paper were conducted within the framework of the current INNOKANIS (2014) project by means of three different MZC models and one model of SewerBatt® instrument.

3.1 Manhole-zoom camera models

The following camera models (operated by the same person) were used for the current investigation:

MZC-Model 1:

- Company name: Envirosight LLC (www.envirosight.com), distributed by iPEK International GmbH (www.ipek.at)
- Camera model: QuickView®
- Illumination (lamp rating) 1,800 lumens (selective light)

- Zoom 36:1 optical and 12:1 digital
- Focus auto
- Image resolution 442 x 368 Pixel

MZC-Model 2:

- Company name: MesSen Nord GmbH (www.messen-nord.de)
- Camera model: STV 3
- Illumination 4x3 LED Lamps - 4x500 lumens (diffused light)
- Zoom 22:1 optical, 10:1 digital
- Min. sensitivity 0.07 Lux
- Focus auto and manual
- Image resolution 795 x 596 Pixel

MZC-Model 3:

- Company name: Ritec GmbH (www.ritec-tv.de)
- Camera model: Manhole Camera
- Illumination 12 x 5 LED Lamps with 8 x far reflector (diffused light)
- Min. sensitivity 1.4 Lux
- Zoom 36:1 optical and 12:1 digital
- Automatic and manual aperture control
- Focus auto and manual
- Image resolution 795 x 596 Pixel

As standard practice, these MZC models are tested and calibrated by the manufacturing companies. There is no possibility for further in situ calibration prior to the inspection of the sewer system.

3.2 SewerBatt®

- Water resistant speaker
- Data acquisition module
- Ruggedized laptop
- Excitation signal - sine chirp
- Physical process described with a hidden Markov model (Baum 1972)

3.3 Trial runs at the European Pipeline Center (EPC)

The EPC test hall is located in the Austrian federal state of Carinthia and comprises 21 sewer sections differing in pipe material, diameter and length (see Table 2 for details). In total, these pipe sections include 337 artificial structural and operational defects according to EN 13508-2/A1 (2010) (see Figure 3). Due to its invariable test conditions, the EPC represents the ideal location for a first comparison of various devices for sewer inspection.

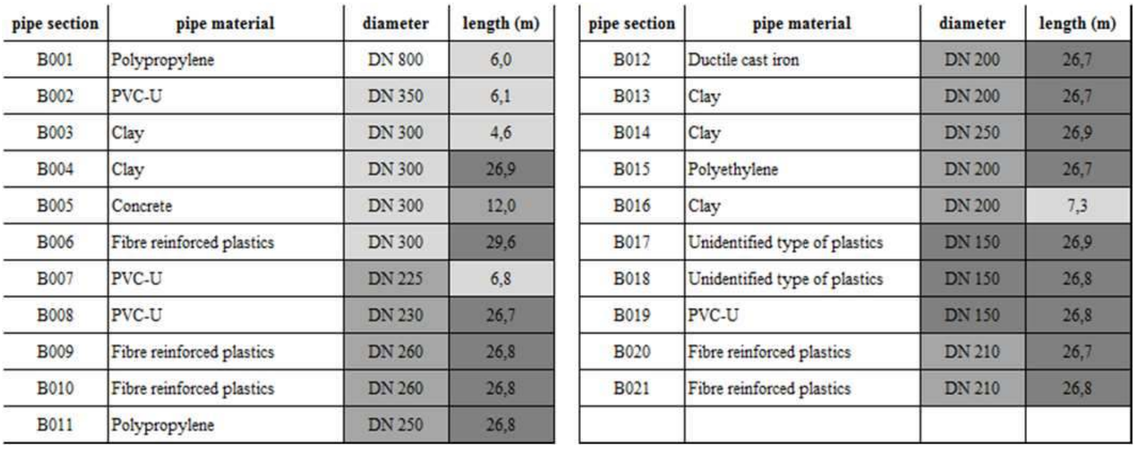
Prior to the trial runs, the defects in the EPC test hall were verified by conventional CCTV inspection based on

- 1 push camera (Gejos)
- 2 crawler cameras (IBAK Orion and IBAK Pegasus HDTV)
- 2 scan systems (Panoramo® and SideScan®)

and

- 1 laser profiler (IBAK ILP) for deformation measurements.

The resulting CCTV documentation served as reference for the subsequent MZC and SewerBatt® trial runs at the EPC. The first trial run was conducted with two cameras and SewerBatt® in 2011, followed by another trial run with a third camera model in 2013.



pipe section	pipe material	diameter	length (m)	pipe section	pipe material	diameter	length (m)
B001	Polypropylene	DN 800	6,0	B012	Ductile cast iron	DN 200	26,7
B002	PVC-U	DN 350	6,1	B013	Clay	DN 200	26,7
B003	Clay	DN 300	4,6	B014	Clay	DN 250	26,9
B004	Clay	DN 300	26,9	B015	Polyethylene	DN 200	26,7
B005	Concrete	DN 300	12,0	B016	Clay	DN 200	7,3
B006	Fibre reinforced plastics	DN 300	29,6	B017	Unidentified type of plastics	DN 150	26,9
B007	PVC-U	DN 225	6,8	B018	Unidentified type of plastics	DN 150	26,8
B008	PVC-U	DN 230	26,7	B019	PVC-U	DN 150	26,8
B009	Fibre reinforced plastics	DN 260	26,8	B020	Fibre reinforced plastics	DN 210	26,7
B010	Fibre reinforced plastics	DN 260	26,8	B021	Fibre reinforced plastics	DN 210	26,8
B011	Polypropylene	DN 250	26,8				

Table 2. EPC – pipe material, diameter and length (INNOKANIS 2014)

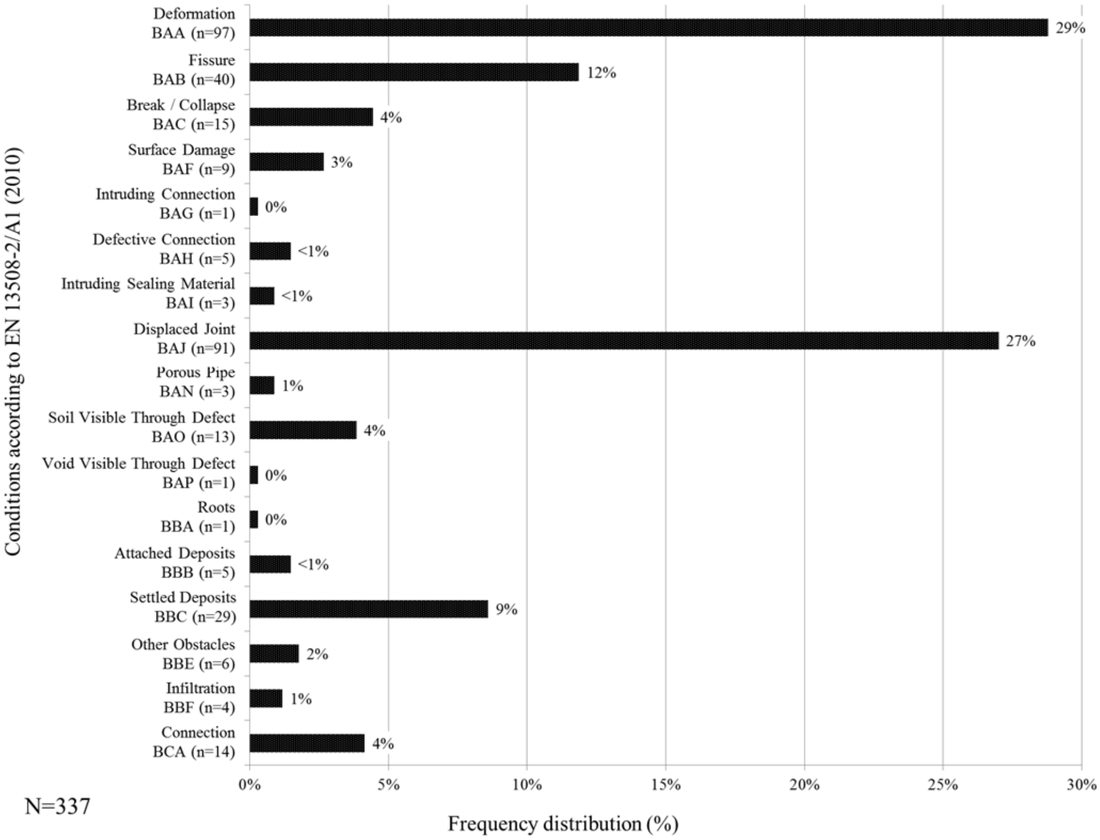


Figure 3. EPC – frequency distribution of conditions according to EN 13508-2/A1 (2010) (INNOKANIS 2014)

3.4 Field trials

The field trials were conducted with 2 camera models and SewerBatt® in 111 selected sewer sections in the Austrian federal states of Salzburg, Upper and Lower Austria in 2011. The investigated sewer sections differed in pipe length, diameter and material as illustrated in Figures 4 to 6.

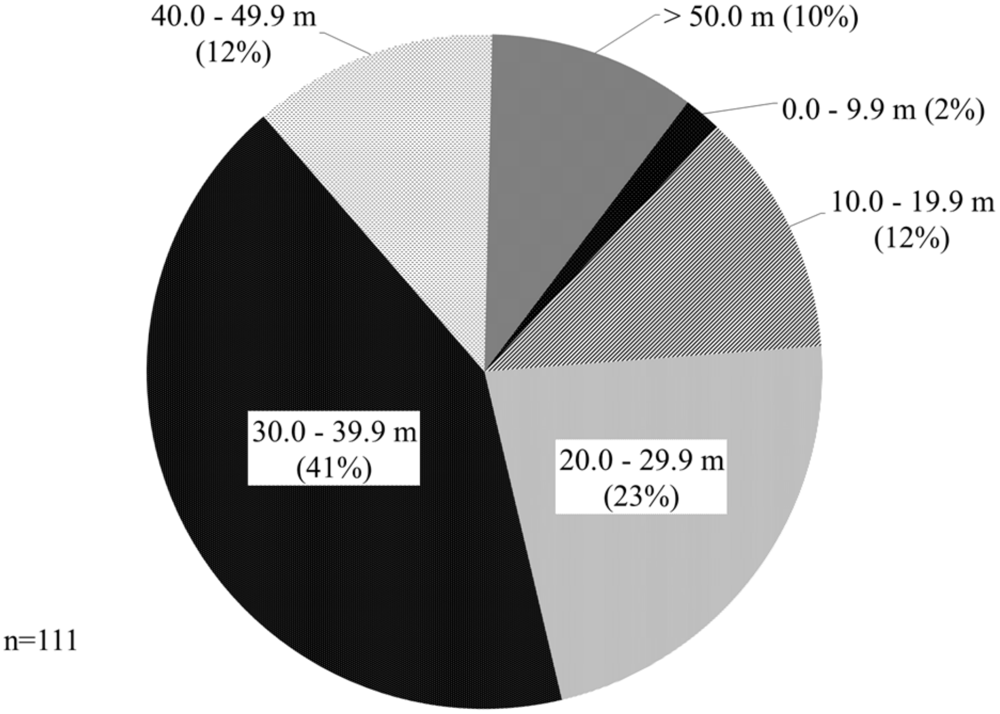


Figure 4. Field trials – pipe length (INNOKANIS 2014)

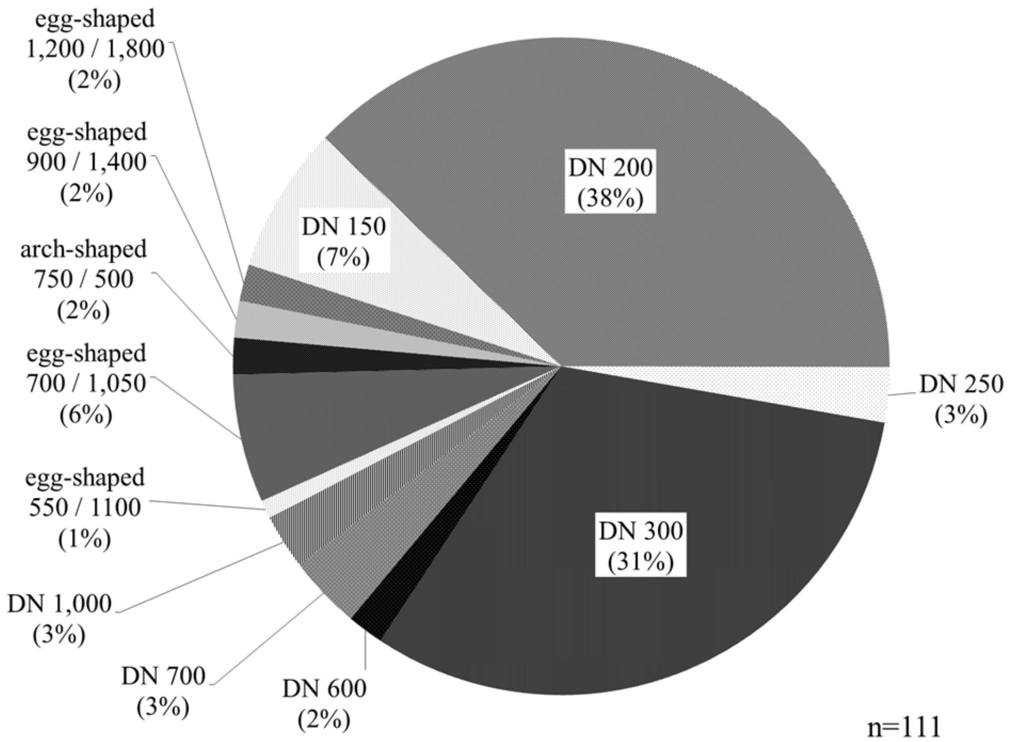


Figure 5. Field trials – pipe diameter (INNOKANIS 2014)

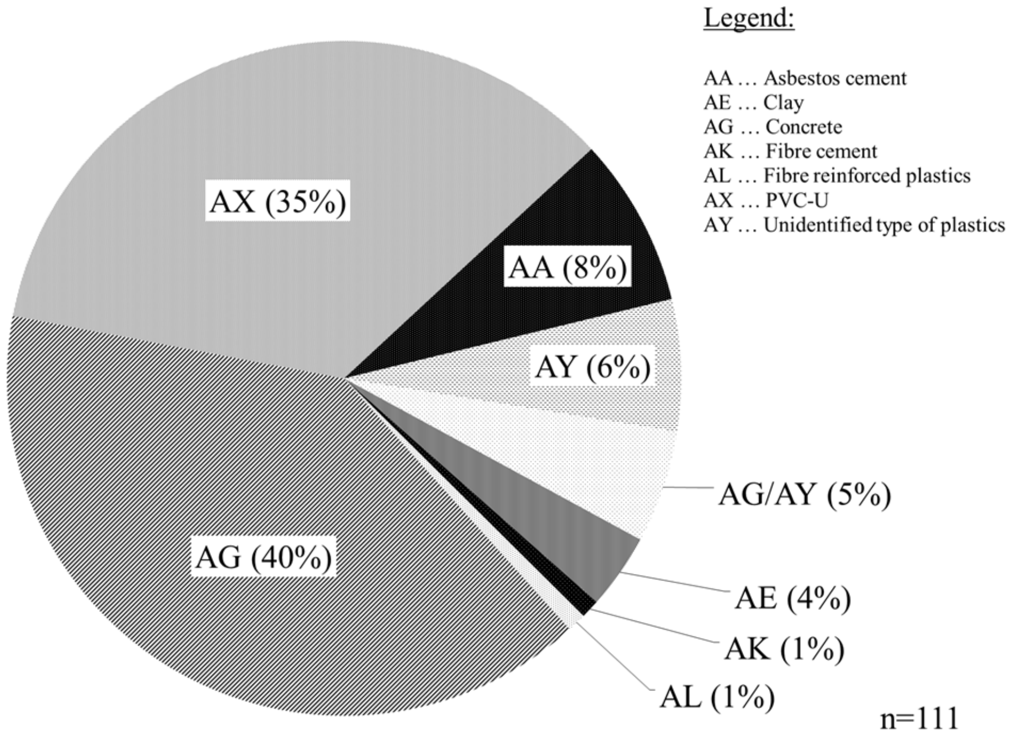


Figure 6. Field trials – pipe material (INNOKANIS 2014)

According to Dirksen *et al*. (2013) and Sousa *et al.* (2014) the reliability of CCTV reports is questionable, with false descriptions of the real conditions often amounting to 30 % or more. Thus, the CCTV documentation provided by the sewer operators for the field trials had to be verified in terms of the conditions, their locations and other quantitative information before subsequently being used as reference to assess the quality of MZC and SewerBatt® data. The pipe sections investigated in the field trials included 640 verified structural and operational conditions according to EN 13508-2/A1 (2010) as shown in Figure 7.

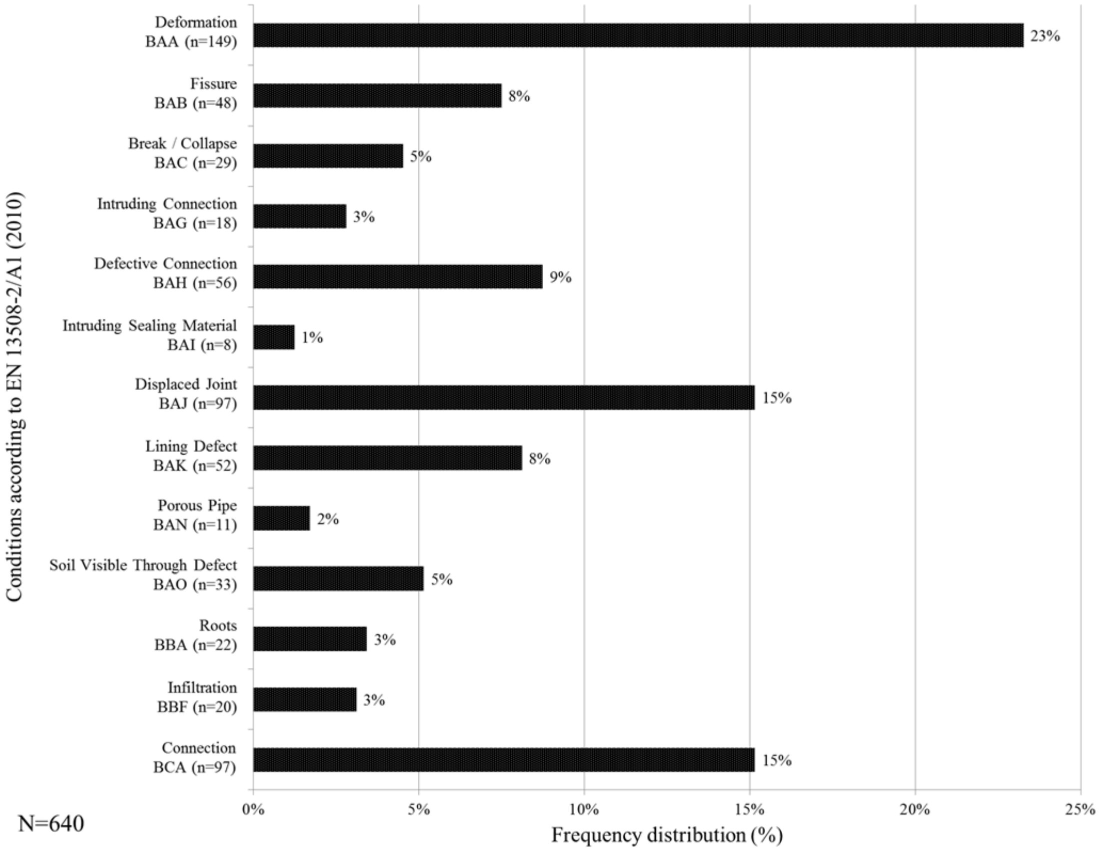


Figure 7. Field trials – frequency distribution of conditions according to EN 13508-2/A1 (2010) (INNOKANIS 2014)

3.5 Data analysis

To compare the MZC and SewerBatt® results against conventional CCTV reference data and with each other, an ACCESS database was set up.

To start with, the CCTV reference data were recoded and analysed according to EN 13508-2/A1 (2010). The adherence to this standard was necessary to ensure the comparability of data.

If a condition was clearly identified with the MZC, then it was assigned to the category "detection = OK". Conditions that were poorly recognisable were assigned to the category "detection ≈ OK". In this case true/false checkboxes were used to select the reason for the poor recognition from the following 11 categories: poor illumination, selective light, poor image resolution, no focus, manhole positioning not OK, high angular displacement, invert specifics (correct camera positioning in the manhole impossible), condition/defect too small, spider webs, steam, water level too high

If a condition could not be detected with the MZC, neither the checkbox "detection = OK" nor the checkbox "detection ≈ OK" was activated and the reason for the non-recognition was selected from the 11 categories indicated above.

The SewerBatt® data had to be analysed separately for single and multiple conditions since the device cannot discriminate between different defects if they cluster within a distance comparable to the acoustic wavelength. This is illustrated by the defective house connection in Figure 8 which according to EN 13508-2/A1 (2010) has to be coded as: connection (BCA), intruding connection (BAG), defective connection (BAH), break / collapse (BAC), and soil visible through defect (BAO). In contrast, SewerBatt® only records one reflection for these 5 conditions.

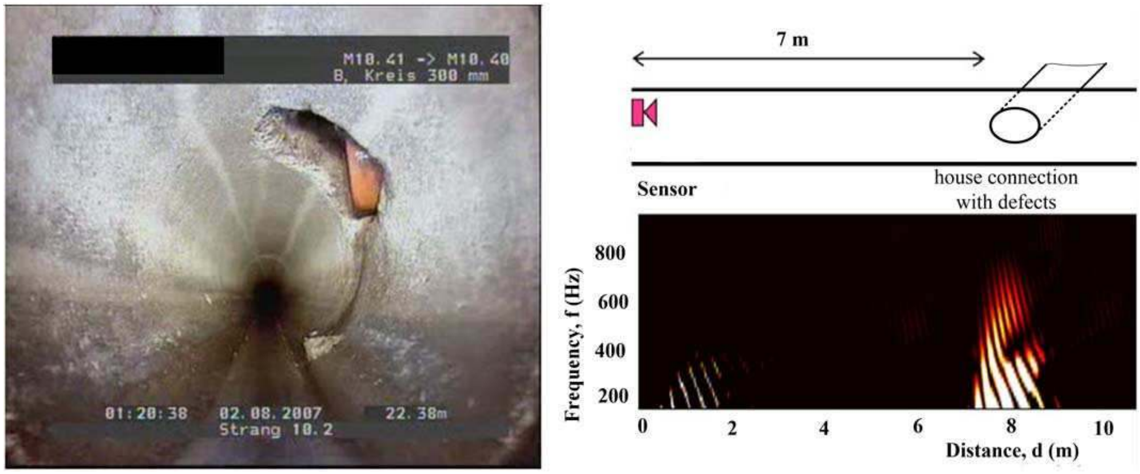


Figure 8. CCTV vs. SewerBatt® inspection results – groups of structural conditions (INNOKANIS 2014)

Based on the separate analyses of MZC and SewerBatt® data, a combined detection rate for both devices was estimated for each investigated condition.

4. Results

4.1 EPC (trial run) results

Figure 9 summarises the individual detection rates for structural and operational conditions which were attained with the 4 inspection devices (3 MZCs and 1 SewerBatt®) in the trial runs. The detection rate is defined as the proportion of defects which are recognised by the investigated method compared to that recognised by CCTV inspection.

For MZC a particularly high detection rate of approximately 70 % was found for displaced joints, compared to a rate of 31 % obtained by SewerBatt®. The MZC detection rate for settled deposits ranged from 54 % to 77 %, whereas no condition of this category was recorded by SewerBatt®. In contrast, the performance of SewerBatt® was superior with regard to identifying connections (63 % vs. 38 %).

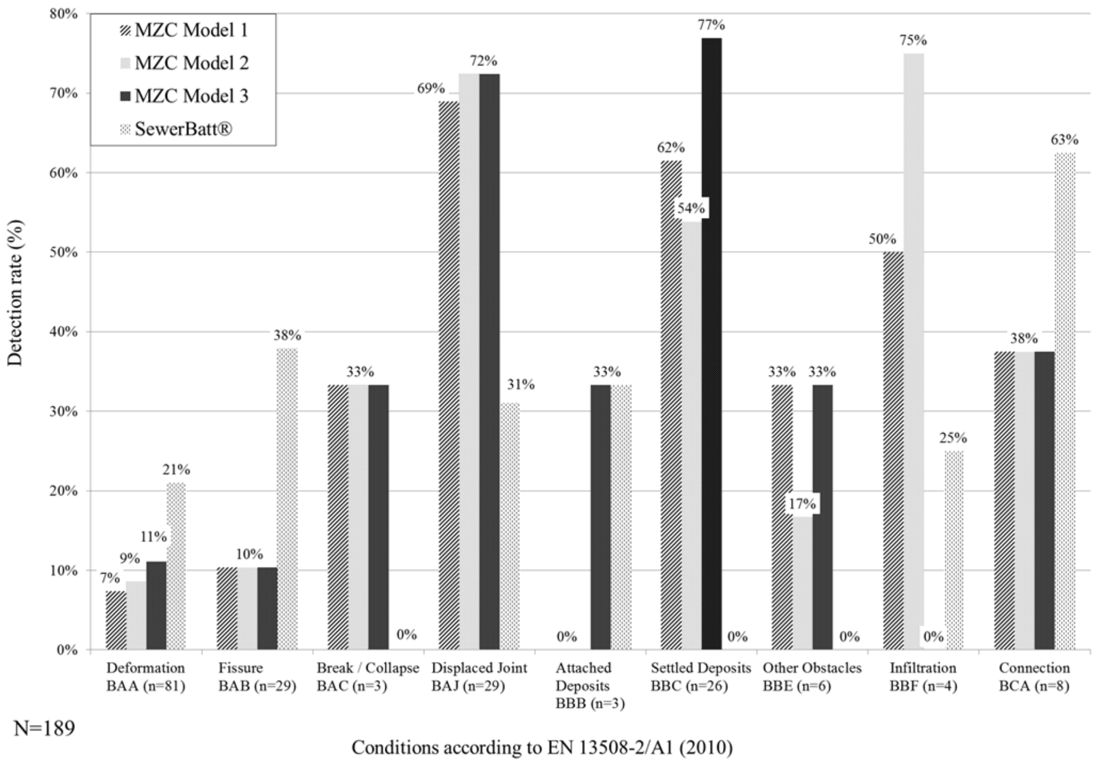


Figure 9. EPC – individual detection rates (INNOKANIS 2014)

Figure 10 shows the combined detection rates for SewerBatt® and each MZC model for single conditions. The combined detection rate is the proportion of defects recognised when SewerBatt® is combined with each MZC model compared to that recognised by CCTV inspection. Each column represents the detection rate for a combination of devices, i.e. one of the 3 MZC models and SewerBatt®, for a single condition. In addition, each column consists of 3 areas: the conditions only recognised by MZC, the conditions only recognised by SewerBatt®, and the conditions recognised by both MZC and SewerBatt®. As can be seen, in most cases the individual performances can be significantly improved when the two technologies, MZC and SewerBatt®, are combined. Thus, the detection rates for the condition "deformation" increased from less than 10 % - 20 % to 25 % - 30 %, and the detection rates for the condition "fissure" increased from only 10 % (MZC) to approximately 50 %. For displaced joints detection rates increased from a minimum value of 31 % (SewerBatt®) to 86 % - 90 %.

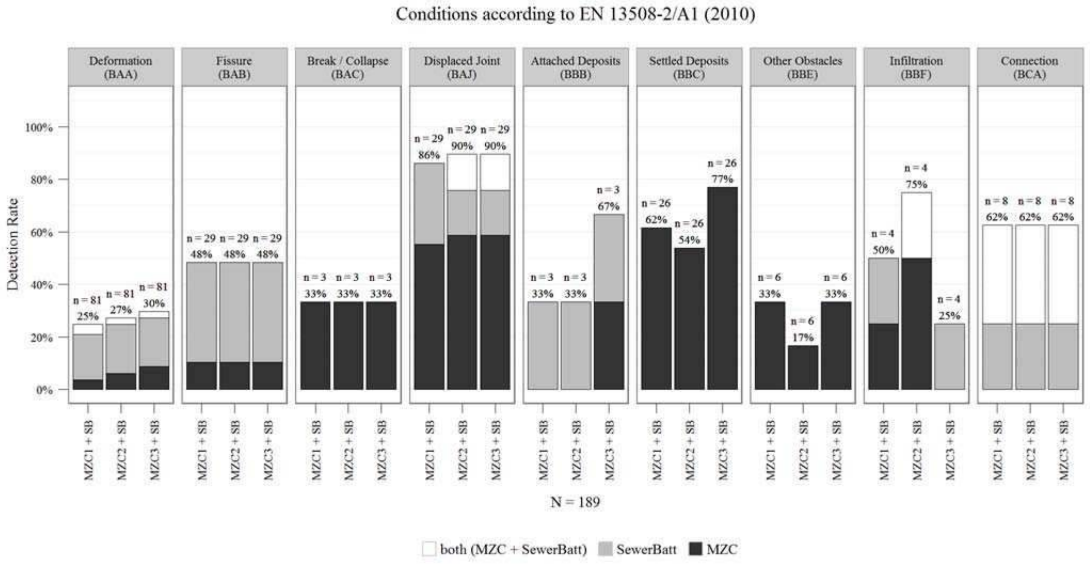


Figure 10. EPC – combined detection rates (INNOKANIS 2014)

As mentioned in section 3.5, some of the investigated conditions occurred in groups. This refers to defects which comprise several adjoining conditions according to EN 13508-2/A1 (2010). The following multiple condition categories were analysed:

- connection with defects: connection a/o fissure a/o break/collapse a/o intruding connection a/o defective connection a/o soil visible through defect (BCA a/o BAB a/o BAC a/o BAG a/o BAH a/o BAO)
- pipe deformation + fissure a/o displaced joint a/o surface damage (BAA + BAB a/o BAJ a/o BAF)
- fissure a/o break/collapse a/o soil visible through defect a/o void visible through defect (BAB a/o BAC a/o BAO a/o BAP)

- fissure + displaced joint a/o displaced joint + soil visible through defect (BAB + BAJ a/o BAJ + BAO)
- longitudinal and angular displaced joint (BAJ-A + BAJ-C)

Figure 11 shows the detection rates for these multiple conditions when combining SewerBatt® with each of the MZC models in turn. Depending on the camera model involved, the combined recognition rates for these groups of conditions ranged from 67 % to 100 %.

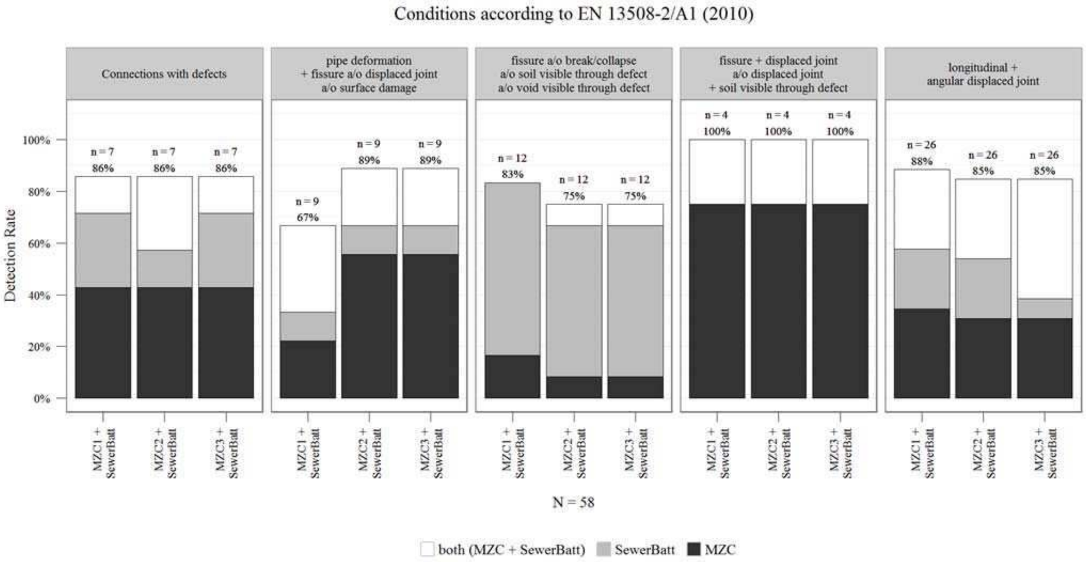


Figure 11. EPC – detection rates for grouped (multiple) conditions and combined devices (INNOKANIS 2014)

4.2 Field trial results

Figure 12 illustrates the combined detection rates for each of the 2 MZC models and SewerBatt®. Again, the performance can be significantly improved when both technologies are combined. Thus, depending on the camera model involved, detection rates between 70 % and 90 % were obtained for the conditions “displaced joint” and “connection”. However, the sample sizes for the conditions “fissure”, “break/collapse”, "intruding sealing material" and "roots" were too small for their detection rates to be representative.

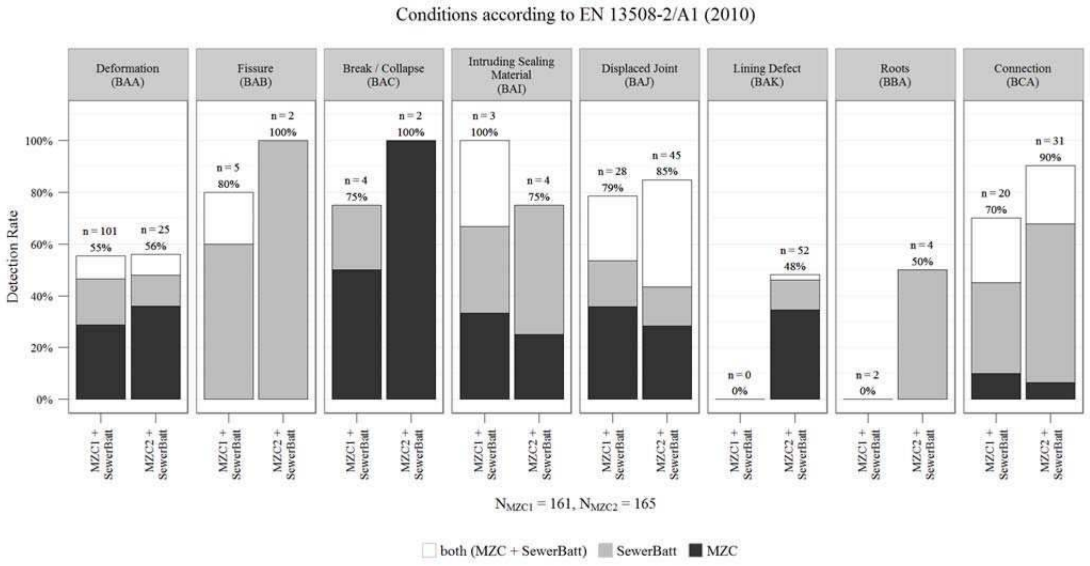


Figure 12. Field trials – combined detection rates for MZC Model 1 + SewerBatt® and MZC Model 2 + SewerBatt® (INNOKANIS 2014)

Similar to the trial runs, some of the conditions investigated in the field occurred in groups. The following multiple condition categories were analysed:

- connection with defects: connection a/o fissure a/o break/collapse a/o surface damage a/o intruding connection a/o defective connection a/o soil visible through defect a/o roots (BCA a/o BAB a/o BAC a/o BAF a/o BAG a/o BAH a/o BAO a/o BBA)
- porous pipe with infiltration (BAN + BBF)
- multiple (vertical and horizontal) deformations (BAA-A + BAA-B)
- pipe deformation with fissure a/o break/collapse (BAA + BAB a/o BAC)

- pipe deformation with fissure a/o break/collapse with displaced joint (BAA + BAB a/o BAC + BAJ)
- deformation with soil visible through defect a/o settled deposits (BAA + BAO a/o BCC)
- multiple fissures or breaks (BAB or BAC)
- multiple displaced joints (BAJ)
- other special chambers ("blind chambers" in a pipe section without direct access from the surface) and connection (BCD-Z + BCA)

Figure 13 shows the detection rates for these multiple conditions when SewerBatt® is combined with each of the MZC models. Depending on the camera model involved, recognition rates of up to 100 % were obtained for some of the categories.

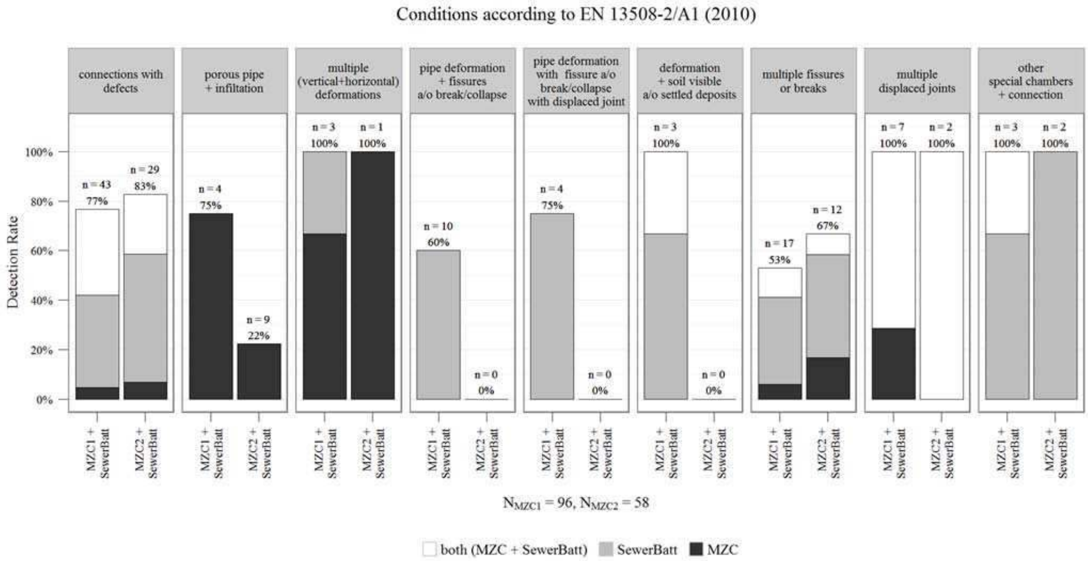
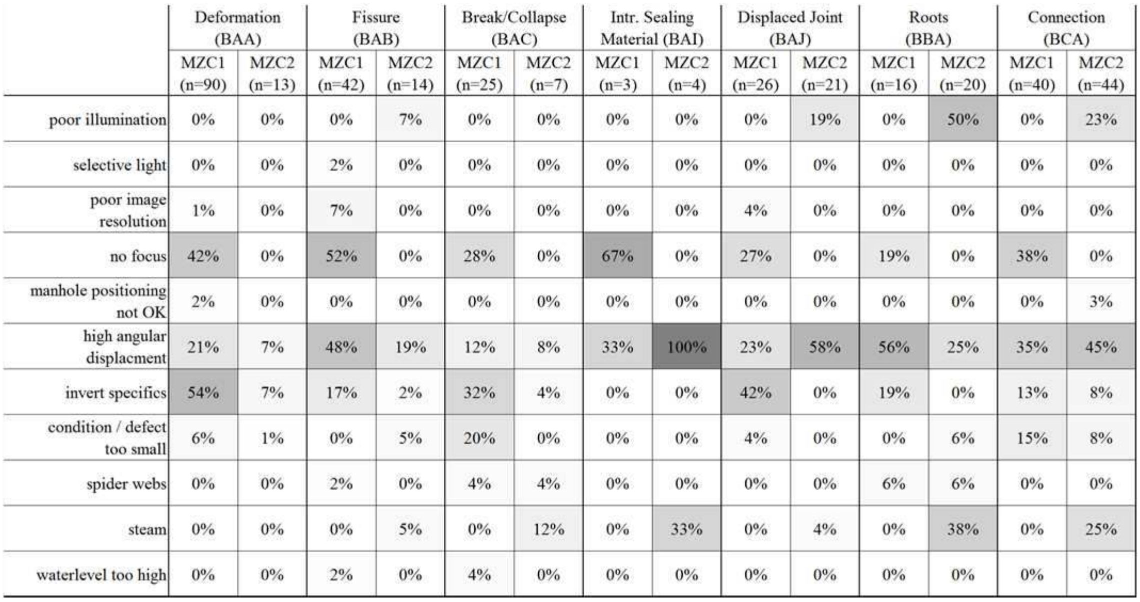


Figure 13. Field trials – detection rates for grouped (multiple) conditions and combined devices (INNOKANIS 2014)

4.3 Factors limiting the detection of conditions in the field trials

If a condition could not be detected, the cause of this non-recognition was documented (see section 3.5). Table 3 illustrates the significance of these causes for MZC Model 1 and 2.



	Deformation (BAA)		Fissure (BAB)		Break/Collapse (BAC)		Intr. Sealing Material (BAI)		Displaced Joint (BAJ)		Roots (BBA)		Connection (BCA)	
	MZC1 (n=90)	MZC2 (n=13)	MZC1 (n=42)	MZC2 (n=14)	MZC1 (n=25)	MZC2 (n=7)	MZC1 (n=3)	MZC2 (n=4)	MZC1 (n=26)	MZC2 (n=21)	MZC1 (n=16)	MZC2 (n=20)	MZC1 (n=40)	MZC2 (n=44)
poor illumination	0%	0%	0%	7%	0%	0%	0%	0%	0%	19%	0%	50%	0%	23%
selective light	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
poor image resolution	1%	0%	7%	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%
no focus	42%	0%	52%	0%	28%	0%	67%	0%	27%	0%	19%	0%	38%	0%
manhole positioning not OK	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%
high angular displacment	21%	7%	48%	19%	12%	8%	33%	100%	23%	58%	56%	25%	35%	45%
invert specifics	54%	7%	17%	2%	32%	4%	0%	0%	42%	0%	19%	0%	13%	8%
condition / defect too small	6%	1%	0%	5%	20%	0%	0%	0%	4%	0%	0%	6%	15%	8%
spider webs	0%	0%	2%	0%	4%	4%	0%	0%	0%	0%	6%	6%	0%	0%
steam	0%	0%	0%	5%	0%	12%	0%	33%	0%	4%	0%	38%	0%	25%
waterlevel too high	0%	0%	2%	0%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 3. Field trials – limiting factors affecting the recognition rates of MZC Model 1 and 2 (INNOKANIS 2014)

As can be seen, angular displacements represented significant constraints for both MZC models. In addition, for MZC Model 1 invert specifics (rendering the correct positioning of the camera in the manhole impossible) and the absence of a manual focus seemed to play a further important role. In contrast, steam and poor camera light turned out to be particularly limiting factors for MZC Model 2.

For SewerBatt® the main factors limiting the detection rate are:

- a low acoustic reflection strength of a defect in the pipe
- clustering of defects which results in inability of the acoustical system to resolve individual defects

- reliance of the SewerBatt® technology on the provision of an extensive database of defects
- the presence of a blind zone within the first 2 - 4 meters from the sensor

5. Discussion and Conclusion

In summary, both MZC models obtained particularly high detection rates for the condition “displaced joint”. Usually the detection of operational conditions reducing the pipe diameter (e.g. roots, attached deposits etc.) is one of the strengths of a MZC. However, both in the trial runs and the field trials the sample sizes for these conditions were very small which explains the low detection rates currently obtained.

In contrast, MZC cannot detect defects in pipes with angular displacements and the provided information regarding the position of a condition in the pipe is not very accurate. As demonstrated, the performance also depends on the specifics of the MZC model used. For camera model 1 the absence of a manual focus[1] seemed to play a particularly significant role, while poor illumination represented an issue for camera model 2.

SewerBatt® achieved a particularly high detection rate for the condition “connection”. In addition, this technology is not affected by the design of the pipe and its alignment such as angular displacements. Another major strength is its accuracy in determining the position of the condition in the pipe section.

However, in contrast to MZC technology, single conditions cannot be discriminated within a group of conditions unless the database contains a record of signatures for this group. In addition, SewerBatt® has a blind zone the length of which depends on the pipe size and the conditions present.

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[1] manual focus has been added in the meantime

As has been shown, the limitations of the two technologies can be significantly reduced when both are used in combination, resulting in largely improved detection rates. Although the current project represents only a very first attempt to analyse multiple conditions, particularly high detection rates were obtained for this category, e.g. for connections with defects.

However, not all structural and operational defects listed in the EN 13508-2/A1 (2010) standard could be investigated with these new technologies so far and for some conditions the sample sizes were too small to be representative.

In addition, the data generated during the trial runs are not as representative as the performance in the field. Nevertheless the standardised environment and the wide range of pipe materials, diameters and conditions provided an important basis to investigate the possibility of a future combination of devices.

Moreover, the MZC and SewerBatt® data were currently analysed with prior knowledge of the conditions present in the inspected pipe sections. It is suggested to repeat this analysis with “blind data” whereby the conventional CCTV documentation only becomes available once the coding for the MZC and SewerBatt® data is completed.

Finally, since condition assessment by means of MZC or SewerBatt® is very different to conventional CCTV inspection and generates different results in terms of detail and accuracy, a simplified version of the coding system is required. The difficulty of translating the MZC and SewerBatt® results into the current version of EN 13508-2/A1 (2010) is illustrated by the example of a defective house connection discussed in Section 3.5.

In conclusion, both MZC and SewerBatt® allow for a simple, quick and cost-effective inspection of the sewer system. Despite certain limitations these two technologies provide modern alternatives to conventional CCTV inspection and performance can be significantly improved when both devices are used in combination.

6. Outlook

The data in this paper represents a promising basis for further exploration. With investigations continuing until December 2014, the final cycle of the INNOKANIS (2014) project will generate additional data for analysis and further explore a future combination of the two devices. Another focus will be on multiple condition assessment by means of a combined device. In addition, it will be sought to integrate the inspection results in operational management software and in a further step in a sewer register.

7. Acknowledgement

The current paper is based on investigations within the framework of the research project INNOKANIS (2014), funded by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. The authors are grateful for this support. In addition, the authors would like to thank the MZC companies iPEK International GmbH, MesSen Nord GmbH and Ritec GmbH as well as the sewer operators RHV Trumerseen, RHV Wolfgangsee-Ischl and AWV Anzbach-Laabental for their support and assistance with the project. Further thanks go to IBAK Helmut Hunger GmbH & Co. KG and MTA Messtechnik GmbH (European Pipeline Center).

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