Objective Condition Assessment of Sewer Systems

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Abstract Apart from guaranteeing the proper function of sewer systems in day to day operation, sewer system operators also must ensure that the substance of this valuable public asset is preserved for the future. This requires an all-encompassing, periodical or demand-oriented, high-accuracy condition assessment to issue respective maintenance procedures in time. The quality of condition assessment relies on the technical limits set by the TV systems used. Further, the qualification and motivation of the camera operator on the one hand, and the subjective perception on the other hand lead to considerable inaccuracies in condition rating. As a result, neither the classification and evaluation of defects nor the scheduling of repairs can be implemented with the desired degree of accuracy.

The OZEK research project therefore pursues the aim of significantly reducing these system-inherent sources of error. The intention is to improve the condition assessment making it more objective and reliable by digital image processing and classification methods. Extensive test and training condition data has been acquired by Stadtentwässerung Braunschweig, Germany, in its daily routine with the PANORAMO® inspection method. At current, 99.6% sockets and 84.4% connections are detected in 13km of pipe.

1 Introduction

Surveys and studies have shown that approx. 20% of public sewers in Germany have defects requiring short or medium term rehabilitation (Berger et al., 2004). Sewer system operators are faced, not only for the reliable disposal of wastewater but also for economical and ecological reasons, with the task of developing strategies with which the proper condition of sewer systems can be first established and then effectively preserved. The basis for the development of such sewer system strategies and specific sewer rehabilitation scheduling procedures are the condition descriptions of sewer reaches, which in turn are based essentially on TV inspections.

1.1 Sources of Error in Condition Assessment with TV Cameras

The quality of the inspection depends essentially on the qualification and the momentary motivation of the camera operator (Gangl et al. 2006, Ottenhoff et al., 2006). In this conjunction, the following basic sources of error are inevitable:

- Condition-related defects or other conspicuous points that affect the proper functioning of the sewer are overlooked.
- The sewer section is not completely scanned.
- Defects or their dimensions are described in inconsistent or non-standard terms.

The great frequency with which these types of errors occur has been demonstrated by extensive studies comparing the results of parallel inspections of the same sewers by different operators (Hüben, 2002; Müller, 2006).

This showed that only in 16 % of the 307 inspected reaches an identical number of defects were detected. A defect description was made with an identical condition classification (ZK) and condition report. Figure 1.1 shows the spread of differences in the condition classifications of each sewer reach according to the first and second inspection or report respectively, which ideally should be near to zero. Assuming that the apparent spread is normal distributed yields a standard deviation of σ = 1.34 ZK for the differences in condition classification. Thus, the differences in the condition classes determined from two inspections of one sewer section with a five-stage classification model is in a confidence interval of approx. $-2{,}6 \leq \Delta ZK \leq +2{,}6$ with a probability of 95 %. (ATV, 1999)

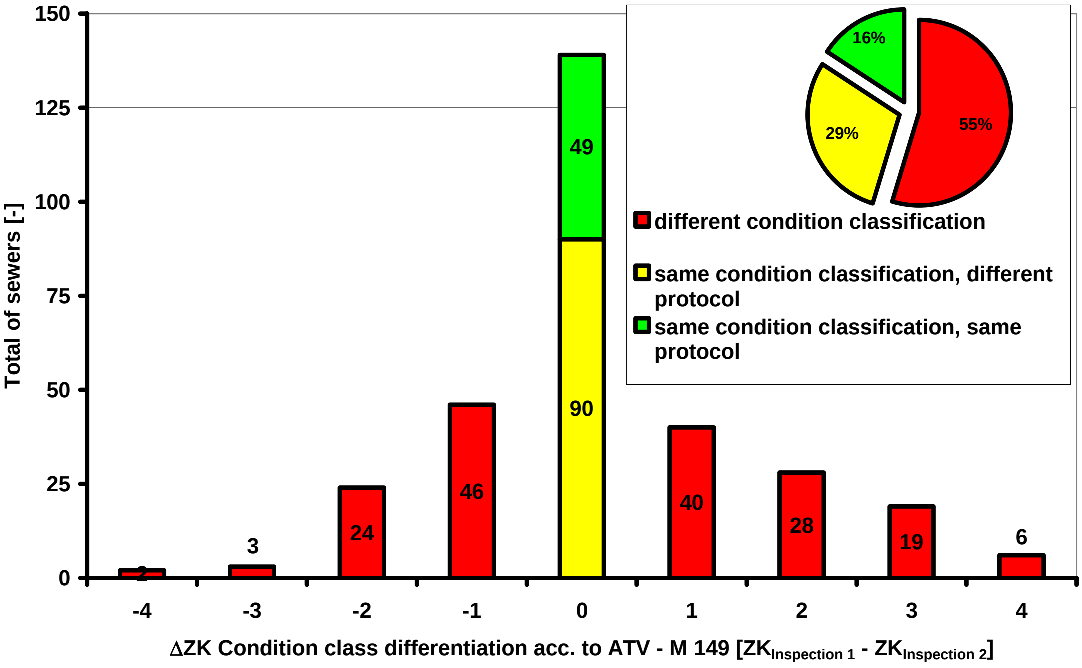


Figure 1.1 Differences in condition classification of 307 sewer reaches after parallel inspections (Müller, 2006)

All in all, this clearly shows that conventional inspections depend considerably on the operating personnel, and as a general rule, it can be assumed that the condition of sewers is not established objectively and therefore not clearly and reliably enough.

This system-inherent, error-prone condition assessment contains a considerable potential for making wrong decisions on rehabilitation scheduling and the development of rehabilitation strategies.

1.2 Demands and Tasks

Because of the state of affairs described above, the co-operation partners in the OZEK project have set themselves the task of developing a new assessment method interdisciplinarily to permit a complete, objective and reproducible description of the condition of sewers using the PANORAMO® inspection method and digital image-processing techniques. A computer-aided methodology for using image-detection algorithms as already deployed successfully in the medical field is to be established and field-tested. In detail, these techniques must enable to determine automatically:

- the precise axial and radial position of the components of sewer structures (start of reach, end of reach, sockets, junctions and connections) and the beginning and end of defects,
- defects (e.g. cracks, fragmentation or displacement) described by defect codes, e.g. after (ATV, 1991) or (DIN, 1999), and
- the severity of these defects (e.g. width of cracks).

2 Methods

2.2 Inspection System

To develop the software modules, the original data, i.e. the scanning of the sewer reach, must already be standardized, complete and with high picture quality. At present, these three criteria are only fulfilled by the PANORAMO® inspection system. In addition, this system generates the original data in digital form, thus avoiding the costs and loss of quality caused by digitizing analogue video tapes.

Contrary to conventional TV inspection systems using video cameras, the PANORAMO® system (Figure 2.1) integrates two high-resolution digital photo cameras that are installed at the front and back of the housing. Each lens system uses special fisheye optics with a hemispherical image of 185°.

Figure 2.1 Inspection system with two symmetrically arranged scan units, each consisting of a digital photo camera and flashlighting

With this scanning system, each point in the sewer section is photographed from various angles of view at fixed intervals of 5cm and no part of the pipe wall escapes scanning (Figure 2.2).

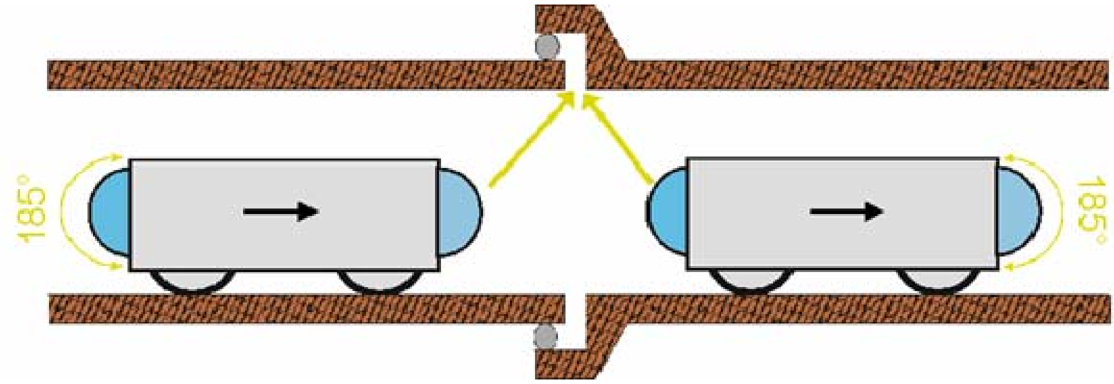


Figure 2.2 Scanning of a socket by the PANORAMO® inspection method, shown at two different positions in the sewer

In contrast to the analogue TV technology, flash lighting with an exposure time of only approx. 0.5ms is used. This avoids any motion blur that is usually a prominent source of quality impairment in conventional TV inspections. Furthermore, as the scanned data can be reproduced at any time, complete condition assessment and evaluation can be carried out in the office (Stein, Brauer and Broziewski, 2005).

In order to generate continuous motion and an angle of view like that of a conventional TV camera with the discrete spherical images generated by this system, the images are further processed using mathematical computing procedures. As a result, the sewer can be reproduced on the computer monitor in its entirety in two different ways:

A perspective view with full (2 x 360°) pan/rotate capability, always with right-side-up picture. This enables joints, laterals or defects to be assessed from various directions of view (Figure 2.3).

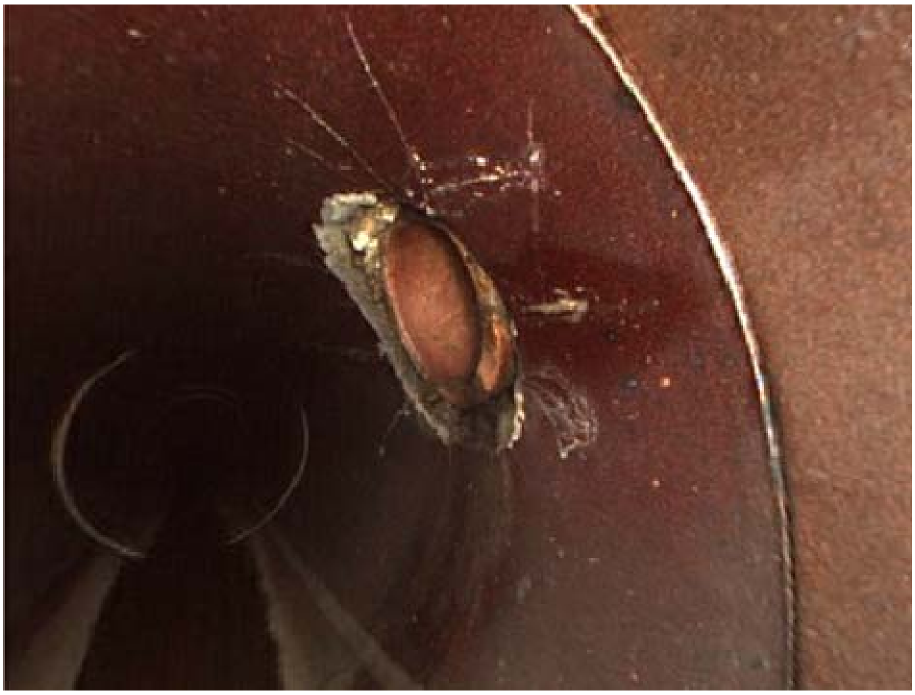


Figure 2.3 Perspective view of a defective connection

In addition, a two-dimensional (2D) unfolded view (vertical view from above with the inner surface of the pipe laid flat) can be generated from the data. This view gives e.g. a quick overview of the state of the pipe and permits easy measurement of the position and size of objects (Figure 2.4).

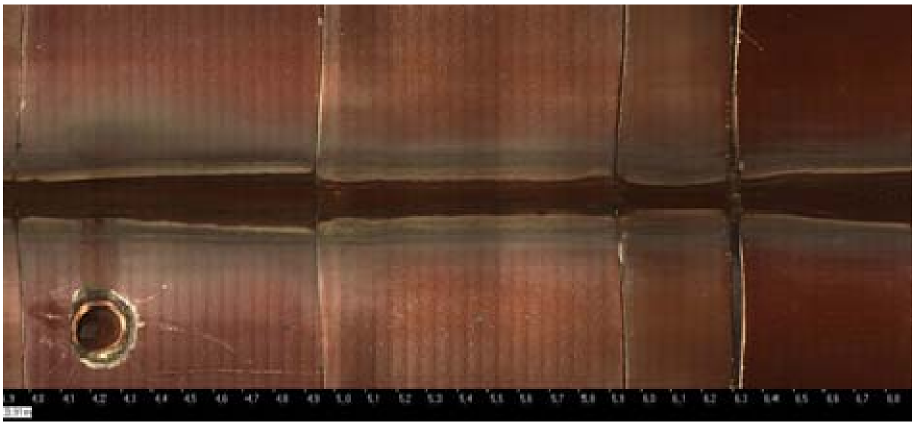


Figure 2.4 Two-dimensional unfolded view

That defects are missed during scanning does not occur as a source of error when data is scanned with the PANORAMO$^{®}$ system, due to its character, and the resulting films have high picture sharpness. However, defect detection and description is still performed manually in the every-day commercial use of this system and, as with conventional pipe scanning, is subject to individual error potential through the person carrying out the analysis.

2.2 Data Acquisition

On the basis of existing TV inspections carried out with conventional methods, extensive video data was available on the sewer system of the City of Braunschweig. After evaluation of this inspection data (defect reports and films/photos) and the sewer master data, sewer reaches in which a representative cross-section of defects, extent of damage and optical influences (e.g. material color, distance of the pipe walls from the inspection unit) occur were systematically selected by the Research Institute for Water and Waste Management, Aachen University of Technology (RWTH), Aachen, Germany (FiW).

In the project phase running in 2005/2006, the pipe materials were first limited to vitrified clay in order to show the basic practicability of the proposed methodology. In the second phase of the project, it is intended to adapt the developed algorithms for concrete pipes. As these two pipe materials constitute well over 90 % of municipal sewer systems, the computer processing methods to be developed can be considered to be generally applicable (ATV, 1996).

The data recalled from Braunschweig was reviewed by the ISA and forwarded to the Department of Medical Informatics, RWTH Aachen, Germany (MI). There, the development of the image detection algorithms described below is being carried out in close co-ordination with the FiW.

2.2.1 Image Processing

The image processing part of this project encompasses three main areas: (i) data handling, (ii) data access and pre-processing, and (iii) the classification system.

(i) Data Handling

Image processing is based on single unfolded 2D images of the acquired inspection videos, each displaying one meter of pipe. The pipe elements, defects, obstructions, and the respective state information are stored in a database by means of reach, inspection data, distance to start of reach, and clockwise position yielding world-coordinates. At the same time, multiple images in various resolutions for the same position may be required for image processing. Therefore, a translation between the world coordinates to the image numbers and their pixel positions has been developed. Further, the single images may contain only parts of visually important objects at the borders, which are continued in the adjacent image on top, bottom, left, or right hand side (Figure 2.5). This is considered appropriate in the classification routines.

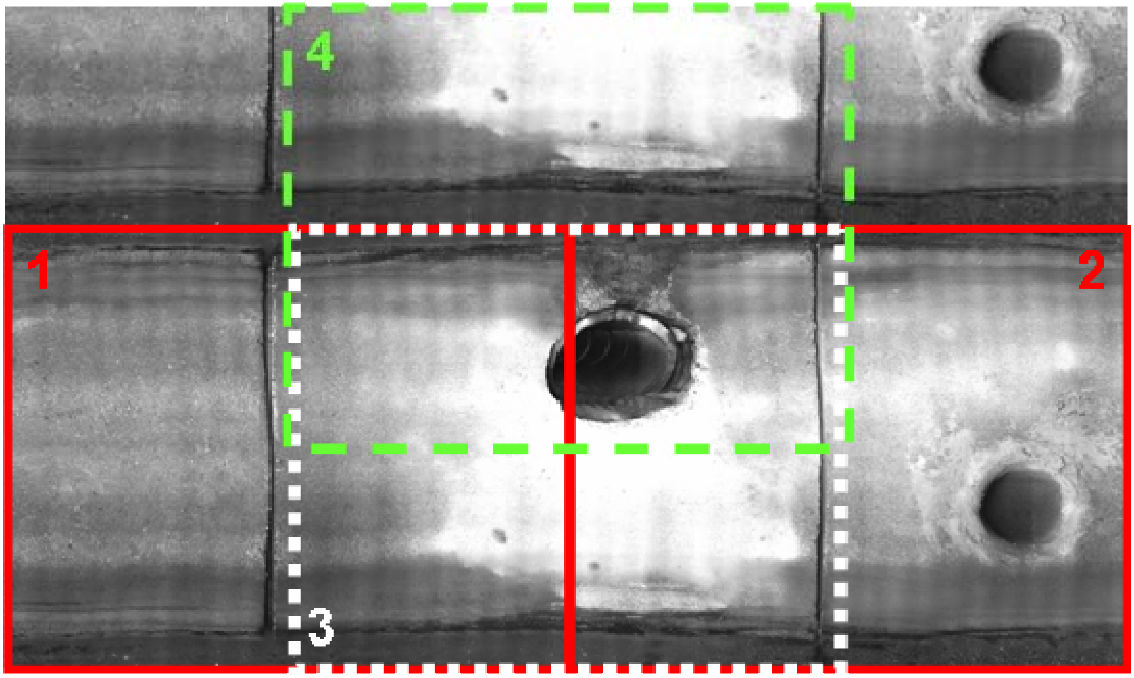
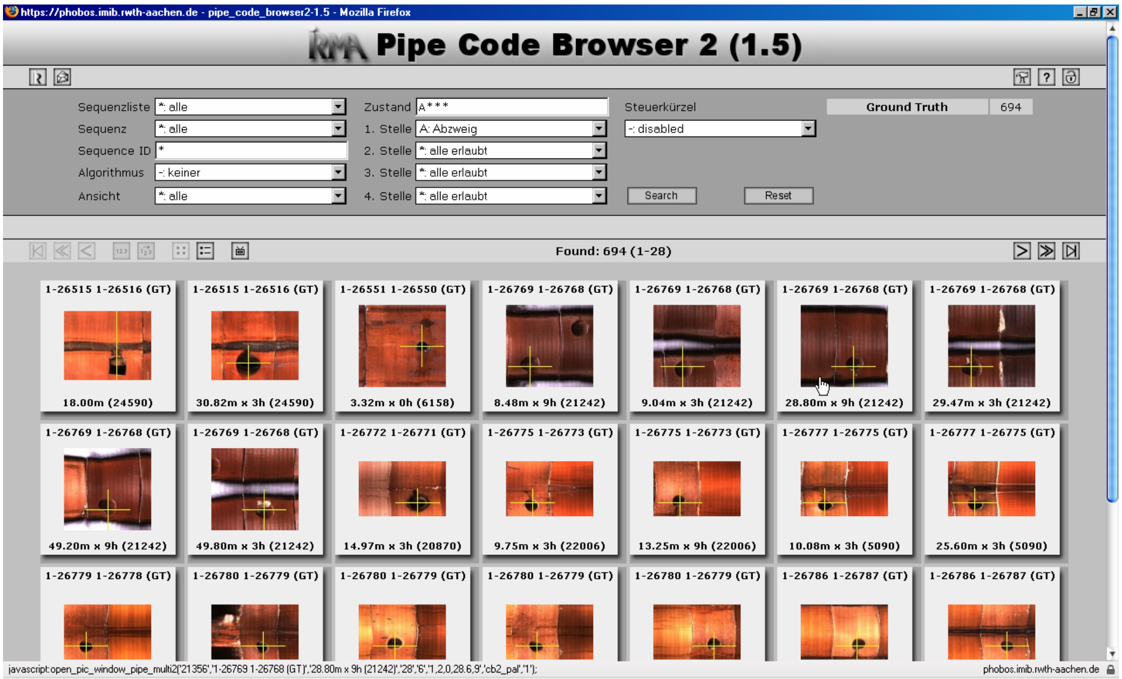


Figure 2.5 Image encoding by overlapping images. Each pixel is contained in four images. This ensures quick presentation and most of all avoids the separation of objects into neighbouring images which would make detection more difficult. Shown are two original images (1 and 2) as well as the horizontal (3) and vertical (4) overlapping images.

(ii) Data Access and Pre-Processing

In order to communicate between the wide-spread project partners, several browser-based solutions have been developed using modules from a system for content-based image retrieval (Lehmann et al., 2004). Besides access to the database tables, the extensive visualizations of the manual or automatically achieved classifications as well as statistical information have been developed. Visualizations are supported either based on the reach or on the state/classification information. If, for example, all connections in all reaches are selected by code “A***” (conforming to ATV code, where the wildcard allows any entry), the high diversity of connections is illustrated (Figure 2.6). This has not only proven valuable for the development of an automated detection system, but can also be useful for training of inspection personnel.



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Pipe Code Browser 2 (1.5)

Sequenzliste: *: alle
Sequenz: *: alle
Sequence ID: *
Algorithmus: -: keiner
Ansicht: *: alle
Zustand: A***
1. Stelle: A: Abzweig
2. Stelle: *: alle erlaubt
3. Stelle: *: alle erlaubt
4. Stelle: *: alle erlaubt
Steuerkürzel: -: disabled
Ground Truth: 694

Found: 694 (1-28)

javascript:open_pic_window_pipe_multi2('21356','1-26769 1-26768 (GT)','28.80m x 9h (21242)','28','6','1,2,0,28.6,9','cb2_pal','1');

phobos.imib.rwth-aachen.de

Figure 2.6 Pipe Code Browser
Example for displaying connections in all reaches. The number of columns and rows is freely configurable.

During the process of unwinding the fisheye-perspective videos, a periodic fluctuation of the lighting is introduced to the images. Since this noise can cause severe difficulties in the detection process, a filter for its removal has been successfully developed by means of amplitude modification in the Fourier spectrum of the images.

(iii) Classification System

As 20 percent of the pipe defects are related to connections, and 11 percent to leaky sockets, with another 12 percent due to shifts in position (Berger and Lohaus, 2004), the first two main goals of the classifying process were the development of robust algorithms for the detection of connections and sockets. While connections could be erroneously assumed to display as single, round or oval, clearly delineated and contrasted to the environment, homogeneous, and dark regions and sockets to be represented by single, clearly delineated, thin, dark, vertical straight lines, from top to bottom of the image, Figure 2.7 illustrates that in real world applications rarely any of these assumptions hold. This forbids out-of-the-box image processing solutions for the detection. Instead, specifically tailored approaches needed to be developed.

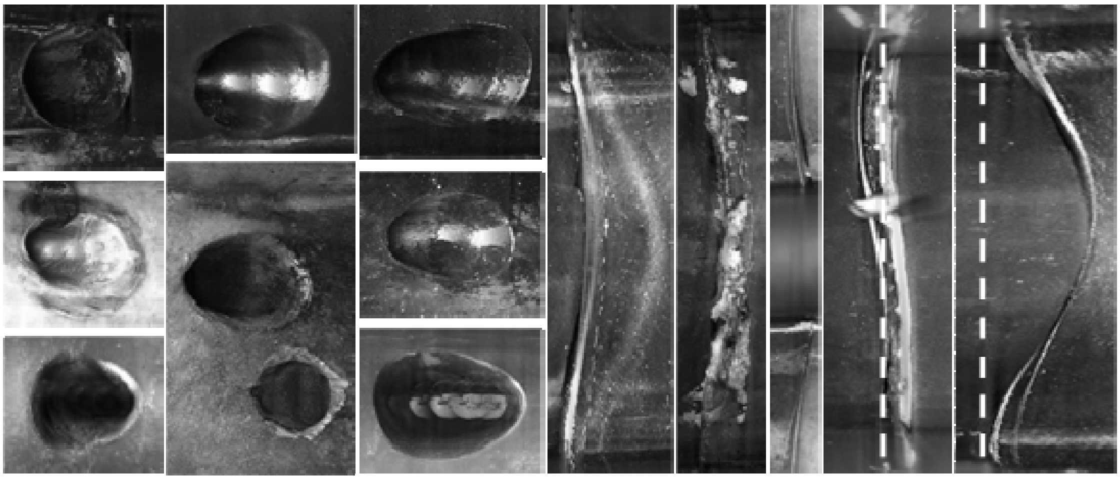

Figure 2.7 Example of variability of connections (left) and sockets (right). The dotted lines in the two rightmost images indicate the desired straightness.

For detection of connections, six classes of frequent appearances of connections were identified (Figure 2.8). The detection of these classes of connections is achieved from multi-scale analysis (Thies, 2003), as shown in Figure 2.9, where the regional attributes in each scale are compared to the class prototype's attributes. The prototype attributes selected in a training process are subsets of 51 attributes covering shape, texture, and structural features. The final decision on the presence of connections is obtained combining interval and distance classifiers.

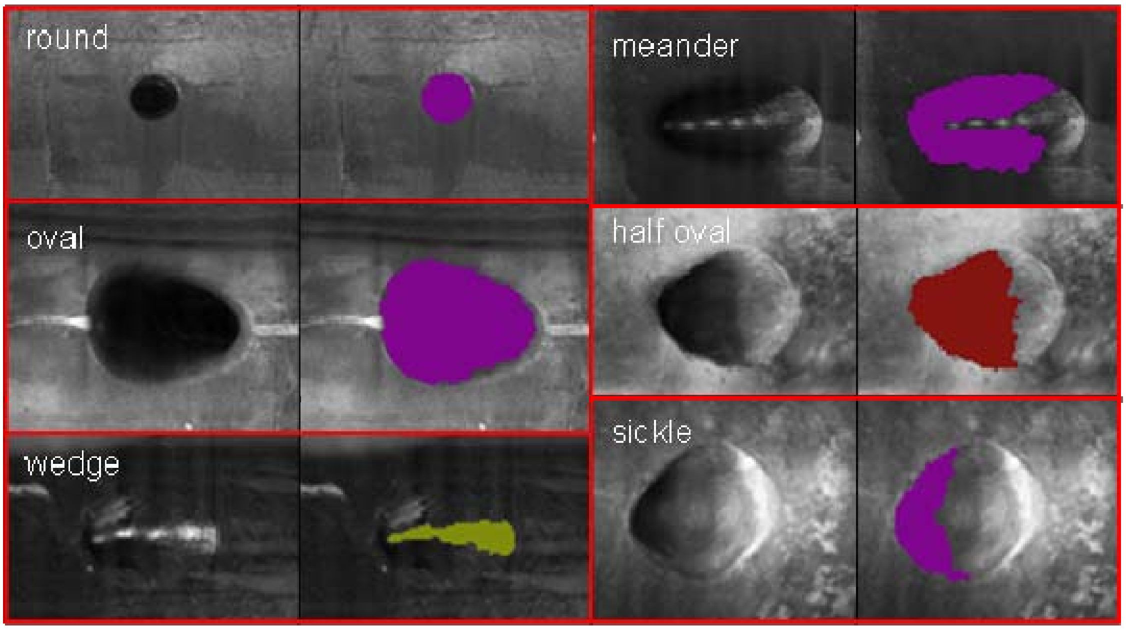

Figure 2.8 Examples for the six identified connection-prototypes. For each prototype, the original connection is shown on the left, its corresponding region of interest is indicated as an overlay on the right.

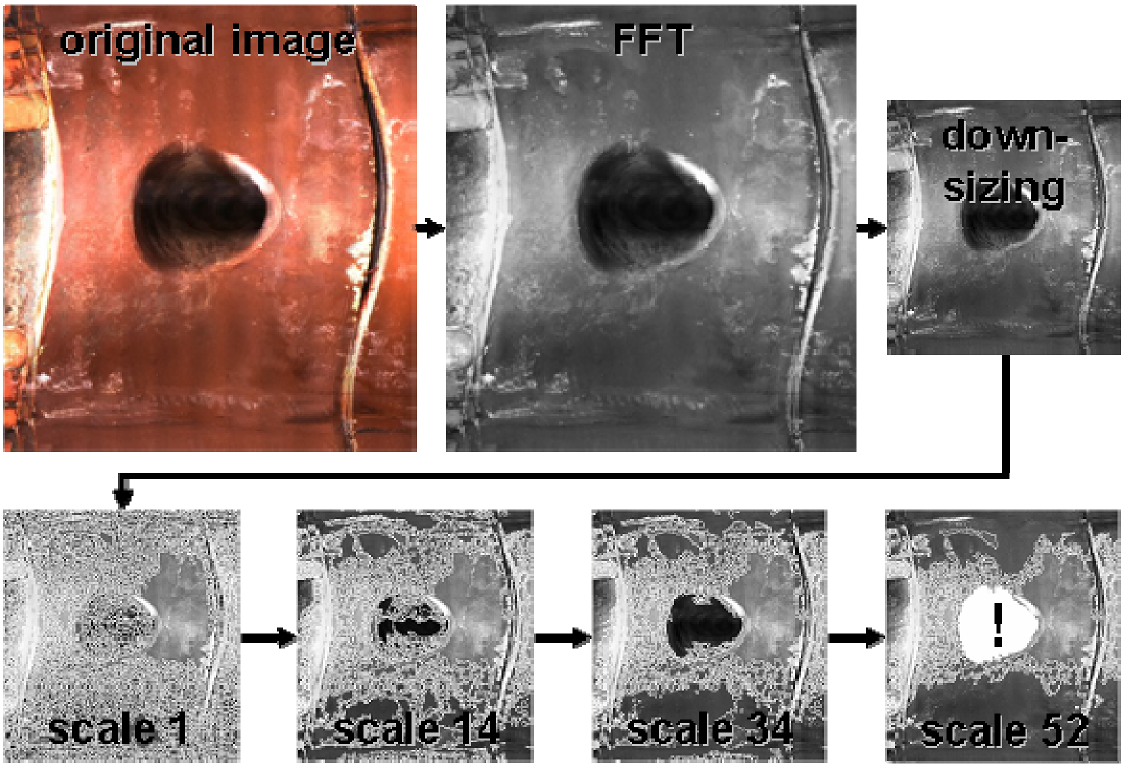

Figure 2.9 Identification of connections by multi-scale analysis. After noise removal by Fourier-filtering and down-sizing multiple scales are calculated and the resulting regions are matched to trained prototypes. In this example a connection has been identified in scale 52.

The detection of sockets can also be achieved from multi-scale analysis, but a sliding window approach has proven to be also very successful. The denoised grayscale images are subjected to a Canny filter (Canny, 1986), i.e. the image is smoothed, a gradient is derived, and in combination with a non-maxima suppression, the image is binarized to an edge image. As the sockets lead to vertical edges, only the gradient in horizontal direction is computed. In the binarized edge image, short edges are removed as they are assumed to result from noise, leaving only long, vertical edges in the image. A sliding window approach observes the height percentage which is covered by long vertical edges in the current slice. Figure 2.10 illustrates the graphical outcome of each processing step for the socket detection.

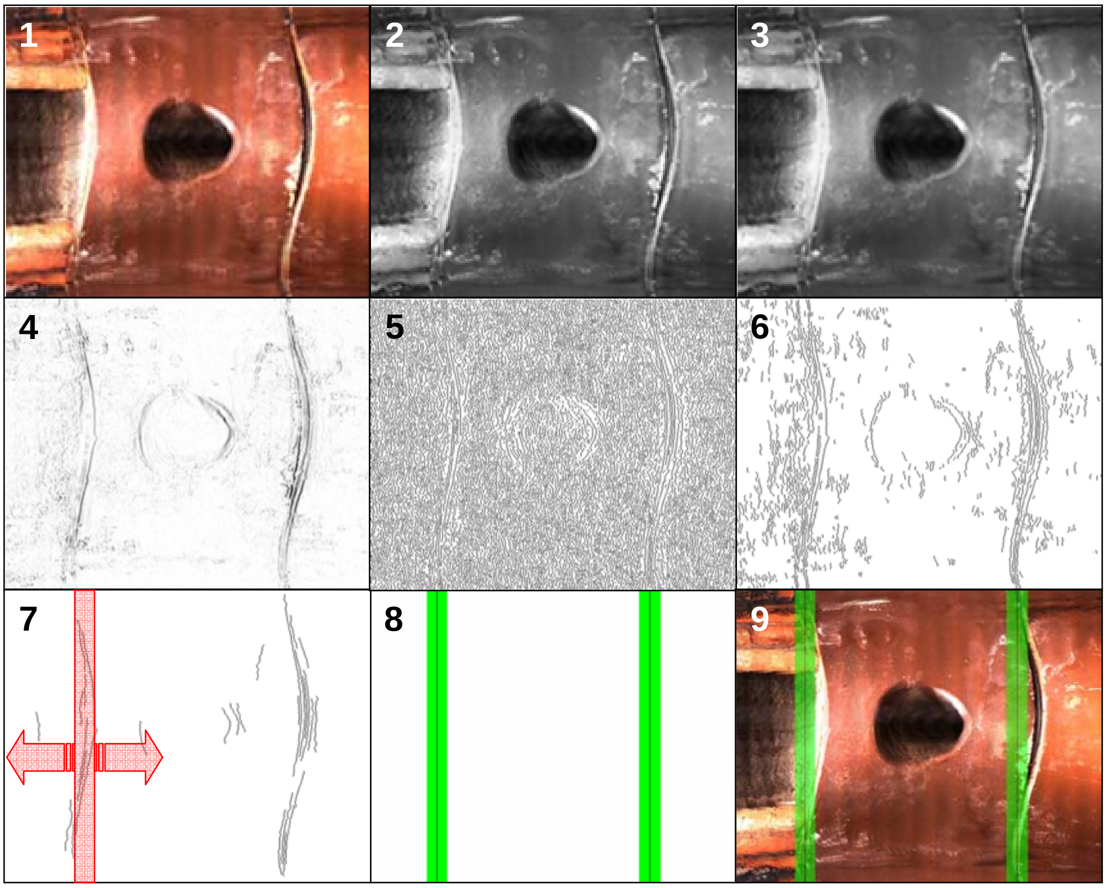

Figure 2.10 Process of socket detection: Original image (1), gray-scaled image (2), smoothed image (3), gradient image (4), binarized edge image (5), non-maxima suppressed image (6), long edge image used for sliding window (7), detected sockets (8), overlay of detections on original image (9).

In order to detect pipes without optical findings, i.e. damage- and connection-free pipes, the images are analyzed for connections, sockets and the flow line as well. All remaining areas within the image are then further analyzed by entropy and edge criteria for optical conspicuity. The flow line is excluded in this analysis as no severe damages requiring interaction are limited solely to the region below the flow line yet this region frequently causes false alerts in automatic analysis. The flow line is detected analogue to the detection of the sockets. While the sockets are detected by analyzing long vertical edges, the flow line is defined by long horizontal edges. For the computation of the edge image a larger Gauß filter can be applied, smoothing away everything besides the most prominent structures in the image. As an additional information the symmetry of the flow line on the left and right side of the pipe is used to verify the detection. Figure 2.11 illustrates flow line detections in six arbitrarily chosen reaches.

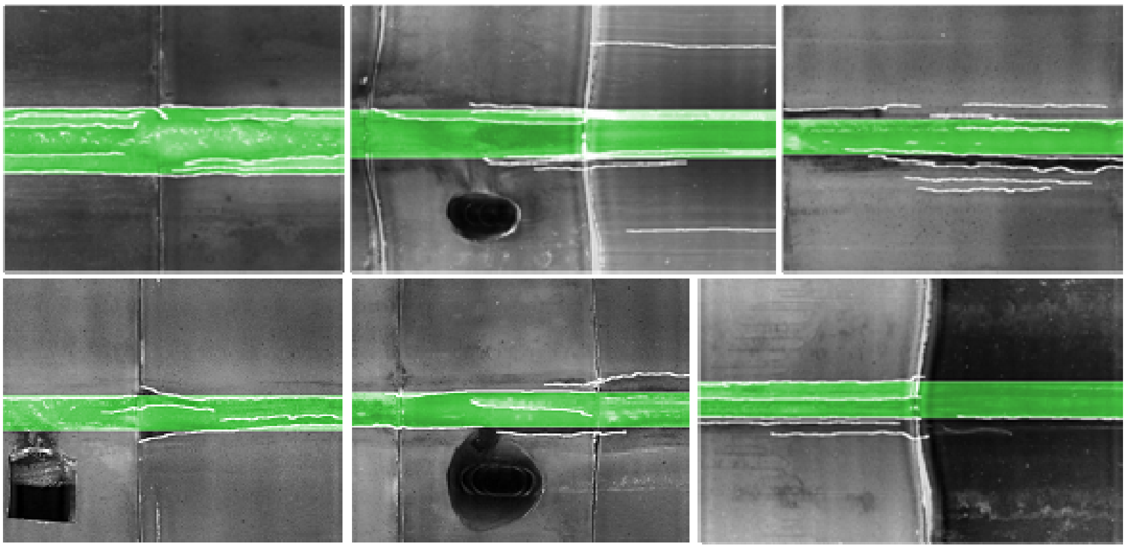

Figure 2.11 Results of the flow line detection for example sections of six arbitrarily chosen reaches. Binarized edges are shown in white, the flow lines are shown as green overlays.

3 Results

Nearly all sockets and connections could be identified. In case of the sockets 322 reaches were analysed containing 9,234 sockets. Of these, 9,179 were correctly identified, 37 were missed, while 26 positions were falsely identified as sockets. This yields a detection rate of 99.6 percent.

For the detection of connections, 200 reaches depicting 591 connections were subjected to automatic analysis. Of these, 535 were correctly identified, 56 were missed. This constitutes a detection rate of 90.52 percent.

3 Outlook

After the developed algorithms are now able to determine sockets, connections and the flow line with high quality, a selection of pipes without optical findings (damage- and connection-free pipes) is possible and can be indicated to the inspector to further diagnosis. This first step is already a substantial work relief for the examining engineer: Instead of concentrating on the damage search, he is able to concentrate on the damage diagnosis. As further algorithms are developed for the recognition of the different apparent damages (e.g. cracks, obstacles or position deviations) and so gradually an additional support of the examining engineer is provided.

In the intended second project phase the implementation of the algorithms takes place in the application environment of the PANORAMO® system as well as the evaluation of the algorithms on the basis of inspections in the Braunschweig sewer system.

Acknowledgement

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