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Automated detection of cracks in buried concrete pipe images

Sunil K. Sinha [a,*], Paul W. Fieguth [b]

[a] Department of Civil and Environmental Engineering, Pennsylvania State University, University Park, PA 16802, USA
[b] Department of Systems Design Engineering, University of Waterloo, Ontario, Canada N2L3G1

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Abstract

The detection of cracks in concrete infrastructure is a problem of great interest. In particular, the detection of cracks in buried pipes is a crucial step in assessing the degree of pipe deterioration for municipal and utility operators. The key challenge is that whereas joints and laterals have a predictable appearance, the randomness and irregularity of cracks make them difficult to model. Our previous work has led to a segmented pipe image (with holes, joints, and laterals eliminated) obtained by a morphological approach. This paper presents the development of a statistical filter for the detection of cracks in the pipes. We propose a two-step approach. The first step is local and is used to extract crack features from the buried pipe images; we present two such detectors as well as a method for fusing them. The second step is global and defines the cracks among the segment candidates by processes of cleaning and linking. The influences of the parameters on crack detection are studied and results are presented for various pipe images.

Keywords: Pipeline Infrastructure; Automated inspection; Pipeline assessment; Image processing; Segmentation; Crack detection; Statistical properties

1. Introduction

Segmentation of pipe images aims at the separation of distresses (if any) from the image background. Thus, as a result of the segmentation process, each image pixel is classified into two categories: healthy (background) and distress (other). We have previously developed a morphological approach to the segmentation problem [1], as shown in Fig. 1. Experimental results have demonstrated that the proposed approach is effective in segmenting holes, joints, laterals and pipe collapse. However, the segmentation and classification of cracks in a pipe surface (the focus of this paper) is particularly difficult because of the irregularities in crack shape and size, the background camouflage of corroded areas, debris, patches of repair work, and areas of poorly illuminated conditions.

Crack detection is of broad interest and has been studied extensively because a wide variety of civil structures can crack (roads, bridges, pipes, pillars, columns, beams, etc.), and an assessment of cracking may be crucial for reasons of safety and cost-effective maintenance. Indeed, many researchers have paid a great deal of attention to automated cracking detection/classification. Li et al. [2] proposed an algorithm for pavement cracking detection based on certain histogram assumptions. A standard model was proposed to represent pavement surface images toward a unified and automated acquisition of key characteristics for improving data quality [3]. However, this model did not discuss how to employ such a mode in crack detection/classification system. An approach to the recognition of segmented pavement distress images was studied in Mohajeri and Manning [4]. It uses directional filters to classify the cracks. The crack is longitudinal if there is a high concentration of object pixels in a narrow interval of x (transverse) coordinates, and it is transverse if there is a high count of object pixels in a narrow interval of y (longitudinal) coordinates. However, it is difficult to get a segmented crack image, and it is also not clear how to identify other crack types by analyzing these counts. Another statistical approach [5] recognized the imperfec-

* Corresponding author. Tel.: +1 814 865 9433; fax: +1 814 863 7304.
E-mail addresses: sunil@engr.psu.edu (S.K. Sinha), pfieguth@uwaterloo.ca (P.W. Fieguth).

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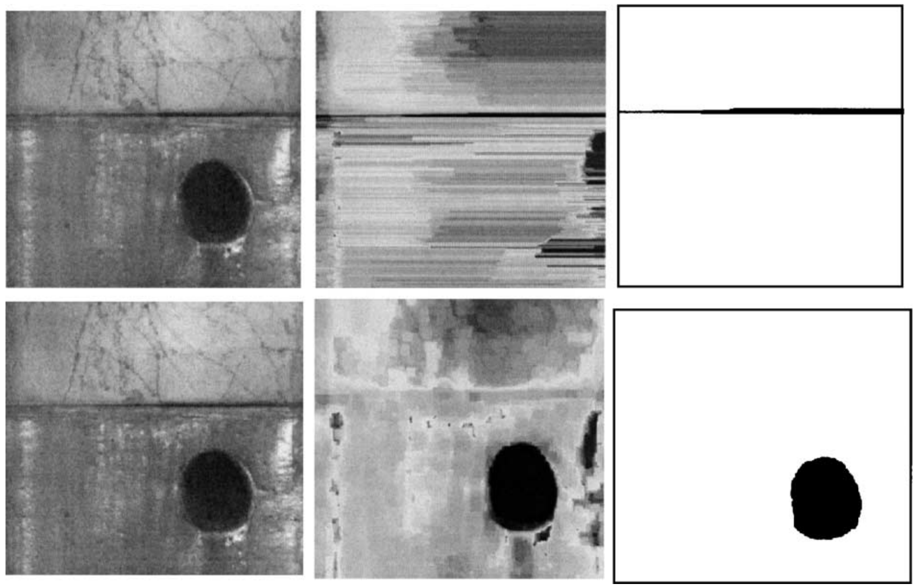

Fig. 1. A morphological approach [1] to joint/lateral discrimination using different structuring elements: a horizontal element (top) of length 285 mm, consistent with the geometry of a joint, as opposed to a circular element (bottom) of radius 57 mm, tuned to the shape of a lateral.

tions of segmentation that cause difficulty in distinguishing pavement-cracking types, particularly between multiple and mushroom cracks. In this method, the original image is enhanced by subtracting an average of a few plain (non-distress) images from the same series to compensate for the lighting variations. A crack is detected by assigning one out of four values to each pixel, based on its probability of being an object pixel. Regazzoni [12] defines a cooperative process between three levels of a Bayesian network [21], allowing the introduction of local contextual knowledge as well as more global information concerning straight line. Hellwich [13] uses Bayesian a priori information concerning line continuity expressed as neighborhood relations between pixels.

Interest in crack-like features is far broader than civil infrastructure, and many approaches have been developed to deal with the detection of linear features such as road networks in satellite images, arteries in retinal images, bone structures, cell boundaries, etc. [5–11]. Nearly all of these methods approach crack/line detection similarly, as a local spatial operator, seeking narrow regions (cracks) whose statistics are at odds with the surroundings (background). By adjusting this detector over position, size and orientation, cracks of different sizes and angles may be found. The approach proposed in this paper builds on these methods, and the experimental performance is found to be in good agreement with the manual detection of cracks.

2. Proposed statistical filters for crack detection

We propose a two-step algorithm for the detection of crack features in the segmented underground pipe images. The first step is local and uses statistical properties to extract crack features from the segmented image, which are treated as crack segment candidates. In the second step, global cleaning and linking operations merge segments to form cracks.

The algorithm begins by performing a local detection of cracks, based on the fusion of the results from two crack detection filters, both taking the statistical properties of image into account. The first crack detector D_1 is based on a ratio edge detector: An in-depth statistical study of its behavior is given in Lopes et al. [9]. The second crack detector D_2, which has emerged from this research, uses the operators of Yakimovsky [10]. Responses from both the first and second detectors are merged to obtain a unique response as well as an associated direction in each pixel. The detection results are post-processed to provide candidate segments. Fig. 2 shows the different steps of the proposed crack detection algorithms.

Both detectors are based on the same basic model, considering the relative statistics of those adjacent regions R_1, R_2, and R_3 as shown in Fig. 3. We denote by $|R_i|$, μ_i, σ_i^2 the number of pixels, sample mean, and sample variance over R_i.

2.1. Crack detector D_1

The ratio crack detector is defined as the ratio of the average of pixel values of two non-overlapping adjacent neighborhoods. The response of the detector between region i and j is defined as

$$r_{ij} : r_{ij} = 1 - \min\left(\mu_i/\mu_j, \mu_j/\mu_i\right) \quad (1)$$