**Crack detection on concrete surfaces using Tubularity Flow Field with Local Directional Evidence**

Concrete bridge decks are a critical structural component in bridges and the characterization of their deteriorating condition remains an ongoing challenge for the Department of Transportation. Inspectors must identify and quantify deficiencies such as cracks, delamination, and spalls. The most common non-destructive evaluation technique used is visual inspection, which can produce subjective and unreliable results. Recently there has been an increased interest in enhancing or even replacing this manual practice with digital image processing techniques, which can produce reliable and repeatable results.

Segmentation and identification of vascular structures have been well studied in the medical image processing literature. In this proposal, we identify a solution for robust identification of cracks on concrete surfaces by using tools for filamentous structure detection. The proposed methodology can be decomposed into two stages. Initially, a robust vessel indicator function is computed to suggest the presence of a crack at each location in the digital image. This indicator function, along with the crack orientation direction is then used to iteratively propagate a geometric active contour to segment the filamentous structure. The methodologies and details of the segmentation algorithm are furnished in the following sections.

**Tubularity Flow Field**

An effective method to segment filamentous structures in digital images is discussed by Mukherjee and Acton [1]. This technique, called tubularity flow field (TuFF) performs segmentation via propagation of a geometric active contour, which is implemented using level sets. In this formulation, a contour propagates under the influence of two vector fields, called tubularity flow field (see Fig. 1). The mathematics governing the contour propagation can be written in terms of a pde as follows:

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|  | (1) |

Where  is a unit normal vector at each position on the contour C(x,y). and are the axial and normal components of the tubularity flow field which signifies the vessel orientation and the direction orthogonal to it (Fig. 1). With this formulation, the contour C(x,y) undergoes motion such that it propagates both along the vessel axis (due to ) and the vessel thickness (due to ), the propagating speed being governed by the coefficients . Traditionally, a contour length regularization factor is incorporated in the solution to obtain smooth segmentation.

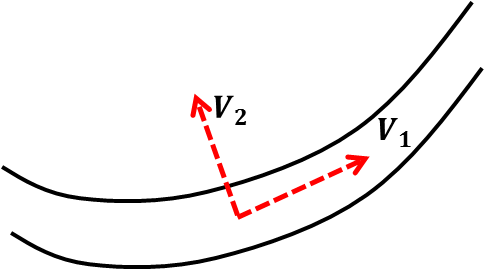


Figure 1: Tubularity flow field

In [1], the authors have illustrated the effects on curve evolution. A popular choice for the directional coefficients is . is a vessel indicator function which assumes a high scalar value () at locations where a tubular structure is present, and a low value () when such a structure is absent. Such a choice ensures that propagating active contour comes to a halt when the vessel indicator function magnitude diminishes. The vesselness measure developed by Frangi [2] is a popular choice for engineering this vessel indicator function. However, as we will show shortly, segmentation performance can be significantly improved by using a local directional filters for vessel detection [3].

**Robust vessel detection using local directional filtering**

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| (a) | (b) | (c) |

Figure 2: Examples of a backward evidence filter, local evidence filter and forward evidence filter

The principle of detecting vascular structures from digital images can be interpreted from a template matching perspective [4]. An oriented vessel template can be obtained by steering a second order Gaussian derivative filter to produce a filter bank of oriented local vessel templates. An example of such a template is shown in Fig. 2(b). Detecting the presence of a filamentous structure is then carried out by filtering the image with this local vessel template.

However, such local vessel detection methods are less proficient in detecting complex vascular geometries such as junctions and filament bends. To combat these issues, a local directional filtering approach is proposed in [4].

The impotency of traditional vessel detection methods such as [2] and [4] stems from the fact that vascular structures are modelled as piecewise rigid templates. This makes it impossible to identify junctions or sharp turns, where the rigid vessel template is not adequate to identify the structural complexity.

A solution is proposed in terms of additional evidence filters. This local evidence filters (see Fig. 2(a) and 2(c)), also called forward and backward evidence filters and respectively, in conjunction with the local vessel detector (Fig. 2(b)) provides evidence for the presence of a filamentous structure in a local neighborhood of the detection kernel. Note that we use a set of oriented evidence filters for each orientation of the detector kernel, thus being able to incorporate vessel evidence at multiple orientations. The vessel indicator function in (1) is calculated by superimposing the filter response of the detector and evidence kernels at multiple scales. This technique is extremely powerful in detecting junction points and vessel bends, thus providing a robust methodology for computing the vessel indicator function (Fig. 3(c)).

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| (a) | (b) | (c) |

Figure 3: (a) original image, (b) vessel indicator function via [2] and (c) vessel indicator function via LDE[3]

Having defined the vessel indicator function, segmentation of the cracks can be performed using level set methods [5]. Level sets are a popular choice for implementing geometric curve motion and it has the advantage that the evolving contour can change its topology naturally. An embedding function is used such that the contour C(x,y) is represented by the zero level sets of . The pde in (1) reduces to the following expression which is solved using numerical techniques.

|  |  |
| --- | --- |
|  | (1) |

The detected crack is represented by the region inside the zero level sets of . The segmented crack is smoothed to regularize the boundaries and small regions are removed using binary morphological operators. The skeleton of the segmented object is then computed, which is represented as a graph structure with the nodes representing the skeletal points and the edges indicating the connectivity between them. Results on crack detection using the proposed method are shown in Fig. 4. The morphology of the cracks is thus embedded in a graph, which provides an effective way to perform further analysis such as shape analysis and similarity studies.

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Figure 4: Crack detection results on four representative images

**References**

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