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Accurate detection of ellipses with false detection control at video rates using a gradient analysis

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ABSTRACT

Accurate ellipse detection in image streams at real-time execution is an open challenge. We present a novel fast and robust ellipse detection method. The method adopts arcs selection, smart grouping, and repeated utilization of gradient information to significantly reduce the computations otherwise needed without compromising the detection effectiveness. Geometric properties calculable with few computations, such as arc smoothness, relative placement of curves, and region of confidence for ellipse centres, are utilized for this purpose. An exhaustive sensitivity analysis of the method's control parameters has been performed. It reveals range of values that support consistent performance over diverse challenging datasets with complex background, multiple differently sized ellipses, and occluded, overlapping ellipses. The method's performance is compared with six state-of-the-art detectors over four diverse datasets. Among all the tested methods, the proposed method demonstrates the best balance between detection effectiveness (the best or the second best F-measure scores) and computation time (>40 Hz) across all the datasets.

1. Introduction

An ellipse (or a circle) is a common man-made nonlinear geometric shape. The ellipse detection from image streams is a common need in a variety of applications such as industrial inspection [1], medical diagnosis [2,3], recognition of traffic signs [4], security [5], face recognition [6,7], and object tracking for a robotic platform [8–10]. Thus, it is important to realize a robust ellipse detection method for real images and image streams. However, ellipse detection is a challenging task. The presence of noise substantially overwhelms edge pixels of real ellipses and breaks an ellipse's boundary into multiple disconnected arc segments. This issue, in addition to complex background, causes degradation in the performances of the existing ellipse detection methods in terms of either the detection accuracy or the execution time, often both. Moreover, efforts to improve detection accuracy often result in longer execution time, while algorithmic efforts in reducing execution time often compromise the detection accuracy. In our paper, we focus on improving the ellipse detection performance, in terms of both the detection accuracy and the execution time, even while dealing with occluded ellipses, overlapping ellipses, and incomplete ellipses in images taken in practical scenarios.

1.1. Related work

Five-dimensional Hough Transform (HT) is a classical method for detecting ellipses. Regardless of the robustness, the standard Hough transform [11] involves a large amount of computational cost. To improve the computational efficiency of HT, various HT-based approaches [12–16], such as Randomized Hough Transform (RHT) [15] and Probabilistic Hough Transform (PHT) [16], have been developed. However, these variants of HT cannot reach video rate computation speeds due to the process of voting among numerous candidates. Hybrid methods that combine Hough Transform and other geometric approaches have also been proposed to overcome the shortcomings of Hough Transform. For instance, Cakir et al. [17] combine feature-based models with HT to improve the detection accuracy. Chen et al. [18] integrate the advantages of HT and edge segment detection, described next, which allows its applications to industrial scenarios.

Another class of ellipse detection approaches is edge segment detection techniques. Methods in this class exploit the connectivity between edge pixels to detect ellipses. The main steps of these methods are to extract arcs and then group them by exploiting geometric or algebraic properties of ellipses. Specifically, edge arcs that may consist of an ellipse are found by variety of techniques such as the statistical regression method [19], curve segmentation by fitting a set of short line segments on edges [20–26], connec-

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