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A fast and effective ellipse detector for embedded vision applications

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ABSTRACT

Several papers addressed ellipse detection as a first step for several computer vision applications, but most of the proposed solutions are too slow to be applied in real time on large images or with limited hardware resources. This paper presents a novel algorithm for fast and effective ellipse detection and demonstrates its superior speed performance on large and challenging datasets. The proposed algorithm relies on an innovative selection strategy of arcs which are candidate to form ellipses and on the use of Hough transform to estimate parameters in a decomposed space. The final aim of this solution is to represent a building block for new generation of smart-phone applications which need fast and accurate ellipse detection also with limited computational resources.

1. Introduction

The recognition of geometrical shapes formally described by a mathematical model has a long tradition in pattern recognition. The attempts of finding new efficient solutions for detecting parametric shapes in noisy and cluttered images resulted in successful algorithms for lines and circles. They are based on accumulations/voting procedures (e.g. Hough–based methods), interpolation, curve fitting, and so on.

Similarly, the detection of ellipses has been often addressed in the past, although ellipses are more complex parametric curves due to the larger number of parameters. Ellipse detection is the starting point for many computer vision applications, since elliptical shapes are very common in nature and in hand-made objects. For instance, ellipse detection can be used in wheels detection [1], road sign detection and classification [2], object segmentation for industrial applications [3], automatic segmentation of cells from microscope imagery [3], pupil/eye tracking [4], and many more. With the advent of powerful mobile technologies for everyone and the spreading of new generations of smart-phones, the request of new applications running on these devices increased enormously. Despite their limitations, mobile devices are now powerful enough to enable on-board processing of complex data, including images and videos, allowing unprecedented capabilities in terms of applications. As a consequence, the scientific community has recently found large interest to image/video processing on smart-phones, often called *embedded* or *mobile vision* [5]. Possible applications range from real time object/person tracking [6], content-based retrieval of framed scene with markerless object recognition [7], face detection [8] (and possibly recognition), blind people aid for movement [9], etc.. As such, even though the advances in technology and multi-core processors will allow ever faster computation, keeping ellipse detection fast has the merit of allowing ever more complex computer vision applications.

Consequently, in this paper we present a new solution for very fast ellipse detection in real images. We choose arcs belonging to the same ellipse very quickly and very reliably by working at arc-level, instead of pixel-level, and by relying an innovative selection strategy. The ellipse center is then estimated exploiting the property of the midpoints of parallel chords, and remaining parameters are estimated accumulating votes in a decomposed parameter space. The good trade-off between efficiency (in the order of 10 ms per image) and accuracy makes this approach a proper candidate for implementation on mobile devices.

The rest of the paper describes the state-of-the-art in ellipse detection (Section 2), focusing mainly on fast algorithms. Section 3 describes in full details the proposed method which resulted to outperform all the existing fast methods Section 4 analyzes the novelties and the influence of the different parameters, also in comparison with other possible approaches. To prove the performance, Section 5 reports several experiments, both on synthetic and real images, including a dataset captured with mobile devices. Both efficiency and effectiveness are evaluated. Section 6 then summarizes the contributions of the paper.

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2. Related works

The importance of ellipse detection in image processing is witnessed by the large amount of works present in the literature.

Most of the methods for ellipse detection rely on the Hough Transform – HT (or its variants) to estimate the parameters. Since an ellipse is analytically defined by five parameters, these methods try to overcome the main problem of a direct application of standard HT, which is a 5D accumulator. McLaughlin [10] rely on the randomized version of HT (RHT) and aim at reducing the memory usage using proper data structures. Lu and Tan [11] iteratively focus only on the points with higher probability to belong to the a single ellipse, thus reducing the parameter space to five 1D accumulators. A very common and memory efficient approach has been proposed by Xie and Ji [12] and Chia et al. [13], where four parameters are geometrically computed, estimating in a 1D accumulator the last one. Basca et al. [14] speeded up the method of Xie et al. using RHT, thus considering only a small random subset of the initial pairs of points. HT-based methods greatly suffer from noise (which includes both background noise and points belonging to different ellipses) which "dirties" the accumulator. Also, they are computationally intense and rather slow because of the voting procedure on a huge number of edge points combinations.

Instead of reducing the space dimensionality by means of strong assumptions, Aguado et al. [15] propose a decomposition of the parameter space: parameters are estimated in consecutive steps, leveraging previous results. Zhang and Liu [16] avoid unnecessary computations for those combinations of points that cannot lie to the same ellipse boundary by carefully selecting starting edge points.

Other approaches rely more heavily on the symmetry between the points on the boundary. Some methods [17–19] first find and analyze symmetry axes, estimating parameters using the HT, others [20] instead rely on symmetric relationships among boundary points and then adopt a least square fitting method.

All aforementioned methods start the estimation from sets of points, eventually selected according to some kind of geometric constraints. However, when considered unrelated to its neighbors, an edge pixel does not contribute significantly to a correct ellipse detection. A better characterization could be achieved using sets of connected edge pixels, i.e. *arcs*, which can be generated by linking short straight lines [1,21–24], splitting the edge contour [25–28], or validating connected edge pixels [29]. The ellipses parameters are obtained using ellipse fitting methods [30,31] on a reduced set of arcs, which are obtained grouping arcs according to their relative position and constraints on the curvature [1,21,22,25,26], or ellipse fitting error [23,24,27–29].

Most of the works present in the literature claim high detection accuracy. However, these results are validated mostly on a few synthetic images, and rarely on more than 10 real images, except [1,25]. The execution time for methods that claim to be fast or real-time [1,16,18,21–23,26] has been computed on few images as well, and may increase significantly on different kind of images. In this paper we present a novel method (preliminary works can be found in [32,33] for ellipse detection that results to be much faster than other state-of-the-art methods, while achieving similar or even better detection performance. We also present two annotated datasets (available on-line) of real images on which we tested both fast and effective methods for a fair evaluation.

3. Method description

We present a novel algorithm for fast ellipse detection designed for real-time performance on real world images. It first selects combination of arcs belonging to the same ellipse and then estimates its parameters via the Hough Transform in a decomposed parameter space. Let us first describe the overall procedure, as outlined in Fig. 1.

As first step arcs are extracted from the edge mask and classified in four classes according to their convexity. We classify edge pixels in two main directions according to their gradient phase and group 8-connected edge pixels in the same direction class to form *arcs*. Their quality is also improved removing short or straight arcs. Arcs are then classified according to their convexity, computed in a robust and efficient way. By combining the two classifications it is possible to assign each arc to a quadrant, in analogy with the final configuration in a Cartesian plane as depicted in Fig. 2(c). The method is tailored for the detection of visible ellipses, defined as having the boundary partially visible in at least three quadrants. Consequently we search for combinations of three arcs, called *triplets*, each belonging to a different quadrant. To avoid the combinatorial explosion, we select only triplets formed by arcs that satisfy three criteria based on convexity, mutual position and same pairwise estimated center. A selected triplet forms a *candidate* ellipse and, already knowing its center, we estimate the remaining three parameters in a decomposed Hough space requiring three 1D accumulators. Candidate ellipses are then validated according to the fitness of the estimation with the actual edge pixels. Since an ellipse may be supported by different triplets, multiple detections with slightly different parameters can be generated. We deal with multiple detections using a fast clustering procedure in the parameter space.

The following subsections will describe the different phases of the algorithm in detail.

3.1. Arc extraction

In this phase we extract arcs from the input image, first by detecting edge points, then grouping them in arcs, and finally classifying arcs based on edge direction and convexity.

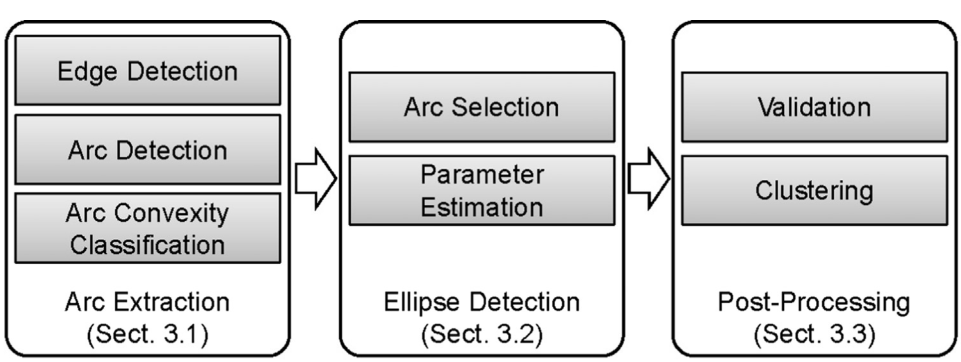

Fig. 1. Flowchart of the algorithm.