Available online at www.sciencedirect.com
SCIENCE DIRECT®

Pattern Recognition 38 (2005) 1087 – 1098

PATTERN RECOGNITION
THE JOURNAL OF THE PATTERN RECOGNITION SOCIETY
www.elsevier.com/locate/patcog

Morphological corner detector using paired triangular structuring elements

Alina Sobania, J. Paul O. Evans*

Vision Systems Group, School of Computing and Informatics, Nottingham Trent University, Newton Building, Burton Street, Nottingham NG1 4BU, UK

Received 1 May 2003; received in revised form 30 September 2004; accepted 18 October 2004

Abstract

This paper describes corner detection from segmented areas using mathematical morphology employing paired triangular structuring elements. The algorithm identified as TriSE02 detects the inner corners of a segmented area and stores information regarding each corner's angular orientation and position. The theoretical development of this detector together with its empirical performance is established in a test utilising standard template images. Seven other established corner detectors were also tested to provide comparative performance information. This work was originally developed to identify conjugate corners in stereoscopic dual-energy X-ray images produced by an experimental system for aviation security screening. The oversensitivity exhibited by the established detectors when applied to the dual-energy X-ray images has been significantly improved upon by the new detector. Also, the careful development of the default parameterisation has resulted in a flexible approach, which is suitable for different image types and formats.

Keywords: Corner detection; Mathematical morphology; Feature extraction; Stereoscopic; Dual-energy X-ray

1. Introduction

This paper presents a corner detector developed as part of a programme of research into object recognition for security X-ray screening of luggage at airport checkpoints. The detector is utilised for the identification of conjugate or corresponding corners in stereoscopic images produced by a dual-energy (or materials discriminating) X-ray scanner [1–4] designed by the University team. However, object identification using stereoscopic images is beyond the scope of this report which concentrates on the performance of the corner detector when operating on individual images. The dual-energy X-ray technique for medium energy X-rays ($E\gamma < 140$ keV) provides material discrimination information and involves obtaining simultaneously two spatially equivalent images at a high X-ray energy (~ 140 keV) and at a low X-ray energy (~ 80 keV) [5–8]. The materials information is made available to the human observer by colour encoding the resultant images, i.e. blue indicates a metallic material, orange an organic material, and green a 'mixed' material. The development of the new detector was precipitated by the oversensitive results produced by other well-established algorithms when applied to the X-ray images. A comparative corner detection study utilising seven other algorithms operating on a 'standard' set of images provides significant evidence for the improved performance of the new detector.

Corner detectors can be generally divided into two categories [9], namely geometry based or template based. The geometric approach is the most popular and identifies

* Corresponding author. Tel.: +44 (0) 115 848 2723; fax: +44 (0) 115 848 6567.

E-mail address: paul.evans@ntu.ac.uk (J.P.O. Evans).

0031-3203/$30.00
doi:10.1016/j.patcog.2004.10.009

corners by analysing their geometric features. This can be accomplished by extracting edges and locating points of local maximum curvature using appropriate thresholds [10–16,32]. The disadvantage of such techniques is that they are generally not capable of registering corner attributes such as angular orientation. Alternatively, the template-based methods [13,17,18] employ image templates to detect corners by measuring their similarity or fit between the stored templates and the imaged object shape. However, a disadvantage of this approach is that it can be slow in terms of its processing speed due to its highly computational nature. The new corner detector may be characterised as belonging to the latter technique. The templates or structuring elements used are of triangular shape. The use of morphological operators together with using just two structuring elements has significantly reduced the computational cost disadvantage. Also, a significant advantage of the technique is that various corner attributes can be identified and stored.

The following section discusses the appearance of corners in X-ray images. Section 3 presents a short review of existing morphological corner detectors. Section 4 describes the detection concept, mathematical implementation and segmentation techniques for the proposed corner detector. Section 5 discusses the result of the corner detection, and influence of parameter alteration. Section 6 presents a comparative study utilising seven common corner detectors. The conclusions and future work are discussed in Section 7.

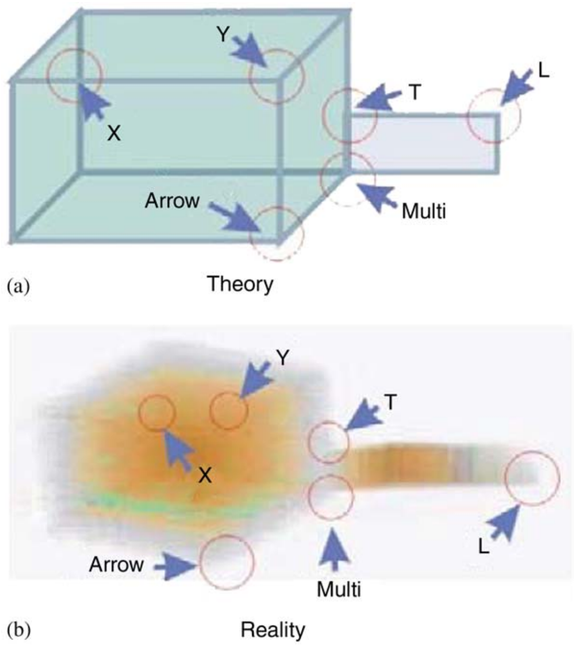

Fig. 1. Assorted corner types produced by (a) drawing of a cube and rectangle (i.e. ground truth) and (b) a dual-energy X-ray image of a cube and a wedge made of solid wood.

2. Corners in X-ray images

A mathematical corner model is an elusive concept. While humans know what the notion ‘corner’ implies, a singular generally accepted mathematical definition of a corner for a digital, optical or X-ray image does not exist. Corners are usually detectable at the T-, Y- or X-junctions of an edge (see Fig. 1).

Edge junctions occur where two or more segments meet, overlap, or intersect. Theoretically a computer can locate T, Y and X junctions, as well as less rigidly defined structures, such as saddle points in the intensity surface. These can be detected by identifying locally maximum curvature from a chain of edge points by using appropriate thresholds or by segmenting the image into blobs and searching for typical structures. However, it is clear that even junctions that can be easily distinguished by the human eye still pose demanding problems for low-level processes by computer. This situation can be exacerbated in transmission X-ray images because of a fundamental property of such images called material or structural unsharpness. This effect refers to the typically soft or blurred edges (see Fig. 1b) routinely encountered in transmission X-ray images produced by the correspondingly short ray paths through the imaged object near its physical boundaries. Thus, whilst in theory many more corners are made available by revealing the internal structure of an object, they will often be difficult or impossible to detect in a practical X-ray image. This can be appreciated by examining Fig. 1 where easily identifiable corners are generally L junctions located at the object boundaries. This general observation was an important consideration in the development of the new corner detector and resulted in the decision to concentrate on corner detection at object boundaries. It was concluded that this approach would avoid the worst effects of structural unsharpness at the cost of reducing the overall number of corners detectable per object. However, the trade-off between the detection of a large number of potential corners (including many false corners) and a reduced set of robustly detected corners would improve the correlation of conjugate corners in the stereoscopic images being considered. Therefore, the corners are detected at the boundaries of object segments as an alternative to the preparatory use of edge detection. By this method, the corners are measured by the shape of the extracted corner segments instead of by measuring the curvature of a detected edge.

3. Morphology in corner detection

The use of morphology in corner detection is not a new idea although it remains attractive in the context of its implicit reliance on geometric structure in images [19]. The general concept of morphological implementation in corner detection presented by L. Haralick and R. Shapiro [20] implies the use of a structuring element in the hit-and-miss