An Efficient and Robust Local Boundary Operator

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Abstract

We present the Curved Iterative Boundary Locator (CIBL), which is a new algorithm for determining the position and local radius of curvature of a boundary which is based upon the IBL algorithm [1]. Both the IBL and CIBL use the grey level image directly, rather than an edge image, and this distinguishes them from conventional robust model fitting techniques. The performance of the CIBL is evaluated for a realistic image domain and the results are compared with data obtained from robust Least Squares ellipse fitting. We conclude that the CIBL and its variants provide a powerful technique for robust analysis, particularly in the area of industrial inspection where dimension measurement to high precision is often required.

1 Introduction

The accuracy and consistency of curve fitting algorithms is limited by the quality and quantity of edge data available. The IBL operator [1] combines the functions of edge detection and local model fitting by using a derivative of Gaussian filter with a high aspect ratio and variable orientation. This type of operator is inherently robust and uses more information from the image than conventional line fitting procedures. However, a curved boundary limits the size of filter which can be applied and this in turn limits the accuracy available.

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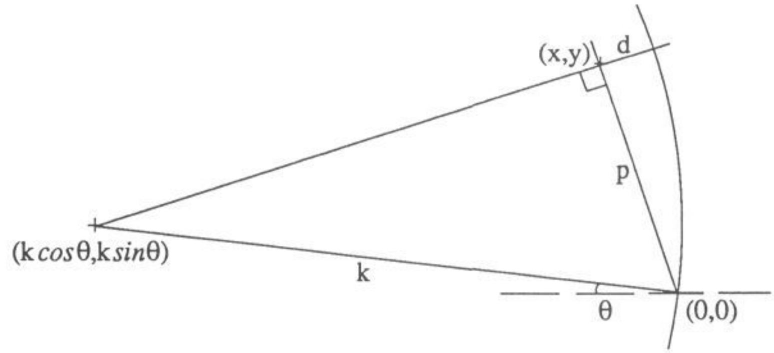

Figure 1: The geometry of the CIBL filter

2 The Curved IBL

The CIBL is a new version of the IBL which allows more accurate detection of sharply curved boundaries by using a locally adaptive radial operator. It also eliminates the need for geometric correction and can be used to determine both the position and the radius of curvature of a noisy boundary.

The filter is defined by the expression

$$\exp\left(-\frac{d^2}{2\sigma_\alpha^2}-\frac{p^2}{2\sigma_\beta^2}\right)$$

where d is the distance of a point (x, y) from a defining circular arc, p is the distance of (x, y) from the filter origin, σ_α is the standard deviation of the detector function and σ_β is the standard deviation of the projector function (figure 1).

The filter is defined here in terms of a coordinate system whose origin is at the centre of the filter. The distance p is then given by:

$$p=\sqrt{x^2+y^2}$$

We estimate the radial distance using the approximation

$$d\approx\frac{k^2-(x-k\cos\theta)^2-(y-k\sin\theta)^2}{2k}$$

where θ is the orientation of the operator and k is its radius of curvature.

An exact expression for d would include a square root term which is inconvenient when forming partial derivatives. The above approximation holds when $d \ll k$, which is usually the case.

There are three variable parameters x_0, y_0 and k, where x_0 and y_0 represent the origin of the filter in a global coordinate system and k is the radius of curvature. Three additional fixed parameters, σ_α, σ_β and θ are used to specify the orientation and spatial extent of the filter. The overall shape of this filter for a typical parameter set is shown in figure 2.

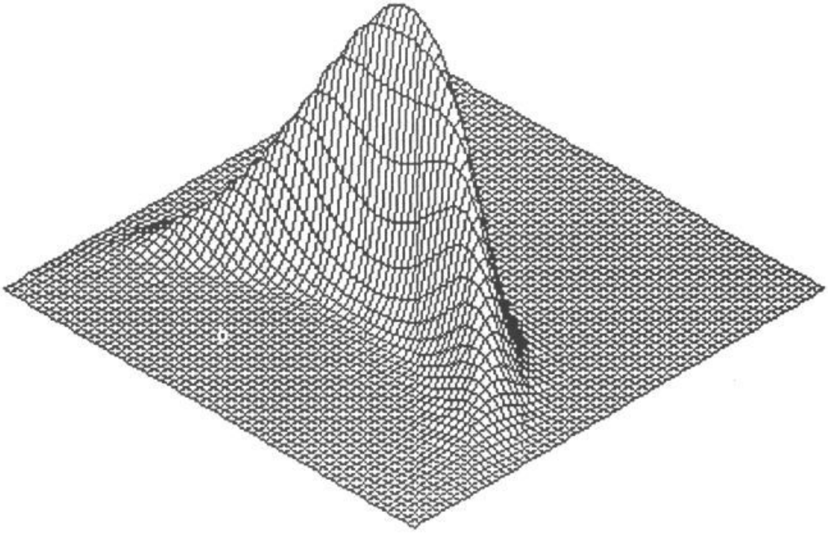

Figure 2: A typical operator shape

The CIBL finds values of x_0, y_0 and k which maximise the directional derivative of this filter in the radial direction. The program uses the NAG Fortran routine E04LBF to perform the optimisation, with the directional derivatives calculated using Reduce, in a similar manner to the IBL implementation.

3 Evaluating the Performance of the CIBL

The accuracy and sensitivity to noise of the CIBL were evaluated using a number of images of a precision ground ball-bearing of known diameter, which were degraded using photographs of a rough texture at various magnifications as a background. The image acquisition system was calibrated against the corners of a square object of known size. A common approach used for the extraction of shape information is to fit a parametric model using a robust Least Squares algorithm [2], and this was used as a reference method in order to perform a comparative evaluation of the new algorithm. Due to the aspect ratio of the framestore, the ball-bearing appeared elliptical in the image and it was necessary to use a conic model of the form:

$$ax^2 + by^2 + fx + gy + 1 = 0$$

Values of a, b, f and g were found by applying a Least Squares algorithm, made robust using a repeatedly applied binary template, to edge data returned from a standard Canny edge detector.

The diameter of the ball-bearing was measured in each image, and graphs of the measurement error against noise were plotted (figure 3). The noise was quantified by the ratio of an average size of background features to the ball-bearing diameter.

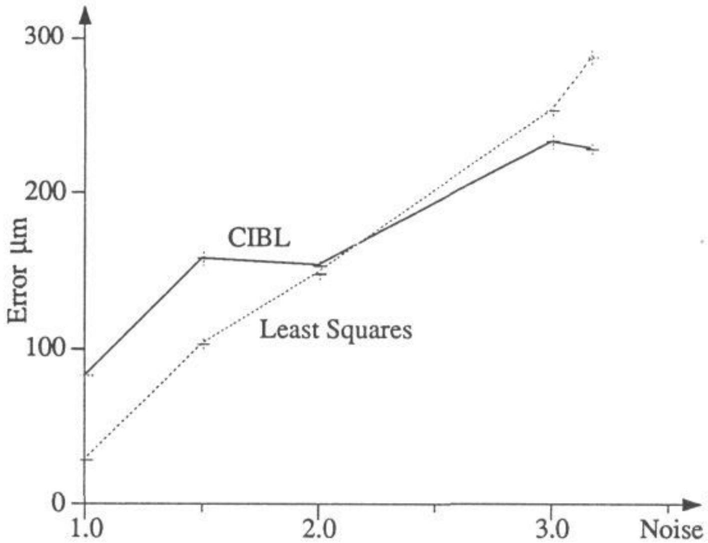

Figure 3: Measurement error plotted against noise

4 Conclusion and Discussion

It can be seen from figure 3 that the CIBL offers similar performance to the robust Least Squares fit for the test images. This is surprising since the the operator was localised to approximately one tenth of the boundary whereas the Least Squares fit encompassed the whole boundary. It is reasonable to assume that the performance of the Least Squares fit would degrade significantly if it were only presented with edgels from part of the boundary.

The ultimate limit to the accuracy of the CIBL is determined by how well the local boundary can be approximated by a circular arc. In our experiments the test object was strongly elliptical and this placed a limit on the maximum useful spatial extent of the filter.

The CIBL is likely to find applications where curved boundaries have to be accurately measured but where it is difficult to set up a parametric model, and particularly for cases where only a small boundary length is available such as when measuring partially occluded objects. One application under consideration is the measurement of gear teeth.

References

[1] Oakley J P, Shann R T. *An efficient method of finding the position of object boundaries to sub-pixel precision.* IVC (to appear October 1991).

[2] Jones G A, Princen J, Illingworth J,Kittler J. *Robust Estimation of Shape Parameters.* BMVC 1990 pp 43-47.