LINEAR FEATURE DETECTORS AND THEIR APPLICATION TO CEREAL INSPECTION

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ABSTRACT

This paper extends the vectorial strategy for designing line segment detection masks to large windows, thereby permitting line segments to be detected and orientated efficiently with just two masks in a far greater number of applications than the original formulation [1]. Our own application exemplifies the value of these linear feature detectors for the purpose of locating insects in grain, and 7×7 masks seem well suited to this task. This work is expected to be useful in many applications where linear features have to be located, and also those where thin lines have to be tracked – as in fingerprint recognition and document interpretation.

1 INTRODUCTION

Over the past decade or two, the emphasis of machine vision research has gradually shifted from low level to high level. This is unfortunate, as the quality of high level decisions is limited by the availability and accuracy of low level knowledge in any scene [1]. Furthermore, in inspection applications, accuracy is often crucial, while sensitivity of detection in the presence of noise and background clutter remains of supreme importance. This is especially true when objects have low contrast. In addition, there are occasions when the objects to be detected are small, fuzzy and ill-defined, or present other practical difficulties, and the consequence of not locating them against their background is serious and has to be minimised. Finally, there are issues of how to design optimal algorithms capable of working in real time in these practical situations. In all these cases, it is not true that everything that ought to be known can actually be found in the literature.

In this paper we consider the detection of line segments. Like edge segments and corners, these are important features which provide basic information to intermediate level analysis schemes so that the presence of complex objects can be inferred [1]. The conventional method for detecting such features is the application of small template masks – a number of template masks being required to cope with the range of possible orientations of the object and the features it contains. When template matching is attempted within a 3×3 window, eight possible orientations can normally be identified and a separate mask has to be applied for each of them – though only four are required for line and edge segment detection. In the latter case the result is low accuracy of orientation. However, the well known Sobel operator is able to estimate edge orientation to within 0.7°, but only by adopting the 'trick' of applying two masks to provide the two vector components of intensity gradient [2, 3]. As edges are characterised by magnitudes and directions only, and other features do not appear to fall into this category, it appears that this trick cannot be applied in other cases: in particular, in the line detection case there would appear to be no obvious route to accurate orientation or to further savings in computation.

These considerations recently led to the development of a vectorial approach to line segment detection mimicking the situation for the Sobel operator, and limiting the requirement to just two masks for line segment detection [4]. While this approach proved successful for 3×3 windows, it was not known how to extend it to the larger windows which might be needed in real practical applications. The work described here has tackled this problem and has produced successful masks of 7×7 and larger. It has also applied them to inspection problems – in particular the task of locating insects in images of grain.

In the following sections we outline the theory of line segment detectors operating within 3×3 windows, and then show how it can be extended to larger windows. Then we describe the results we have obtained using these detectors.

2 THE VECTORIAL STRATEGY FOR LINEAR FEATURE DETECTION

In this section we outline the recently developed vectorial strategy for linear feature detection [4]. The first task is to consider a sinewave function $G \cos(\xi - \theta)$, and to convolve it with two basis functions $P_0 = \cos \xi$ and $P_{45} = \sin \xi$, obtaining respective averages over period 2π of:

$$g_0 = \frac{1}{2} G \cos\theta \quad (1)$$

$$g_{45} = \frac{1}{2} G \sin\theta \quad (2)$$

We can now deduce the phase angle θ of the sinewave function:

$$\theta = \arctan(g_{45}/g_0) \quad (3)$$

Similarly, the amplitude G of the sinewave function can be deduced from the relation:

$$G = 2g = 2(g_0^2 + g_{45}^2)^{1/2} \quad (4)$$

This mathematical model is applied to line segment detection by taking the local intensity variation of any line segment as being approximately sinusoidal at a carefully chosen distance R from the centre of the window (e.g. R will be ~1 pixel for a line of width 1 pixel viewed in a 3 × 3 window), and taking masks such as the following to approximate the sinusoidal basis vectors:

$$L_0 = A\begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix} \qquad L_{45} = B\begin{bmatrix} -1 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & -1 \end{bmatrix} \quad (5)$$

Note that when using this model, we have to map the phase angle θ to 2φ, where φ is the actual line orientation in the image. We also have to find how well the approximations made in matching the mathematical model to the particular application work in practice. First, we consider how to determine the values of the coefficients A and B to be used in equation 5. Applying the above masks to a window with the intensity pattern

a	b	c
d	e	f
g	h	i

leads to:

$$g_0 = A(d + f - b - h) \quad (6)$$

$$g_{45} = B(c + g - a - i) \quad (7)$$

and hence to the following formulae for effective line contrast and estimated orientation:

$$g = (g_0^2 + g_{45}^2)^{1/2} \quad (8)$$

$$\varphi = \theta/2 = \frac{1}{2}\arctan(g_{45}/g_0) \quad (9)$$

Detailed calculations were carried out in [4] for the case of a thin line of width w passing through the centre of the 3 × 3 window, pixel responses being taken in proportion to the area of the line falling within each pixel. However, for lines of substantial width, theory proved intractable and simulations were needed to determine the outcome. What was remarkable about the results was the high orientation accuracy that occurred for w = 1.4, in the case when B/A = 0.86, which gave a maximum error of just 0.4°. In what follows we will not be concerned to obtain a high orientation accuracy, but will be content to use equation 8 to obtain an accurate estimate of line contrast using just two masks, thereby saving on computation. The reason for this is that our motivation is to attain high sensitivity in the detection of image features that correspond to contaminants, rather than to pass results on to high-level interpretation algorithms, as orientation is not an important output parameter in our application.

3 DESIGNING LINEAR FEATURE DETECTION MASKS FOR LARGER WINDOWS

When larger windows are used, it is possible to design the masks more ideally to match the image features that have to be detected, because of the greater resolution then permitted. However, there are many more degrees of freedom in the design, and there is some uncertainty as to how to proceed. The basic principle is (a) to use masks which correspond to the sinusoidal model developed in Section 2, and (b) to make their size correspond to those of the image features that have to be detected. For a given rectangular bar-shaped object of width w, the sinusoidal model will achieve the best match for a thin ring of radius R_0 for which the two arc lengths within the bar are each one quarter of the circumference $2\pi R_0$ of the ring. Simple geometry shows that this occurs when:

$$2R_0 \sin(\pi/4) = w \quad (10)$$

$$\therefore\ R_0 = w/\sqrt{2} \quad (11)$$

The width ΔR of the ring should in principle be infinitesimal, but in practice, considering noise and other variations in the data set, ΔR can validly be up to about 40% of R_0. The other relevant factor is the intensity profile of the ring, and how accurately this has to map to the intensity profile of the rectangular bars to be located in the image. In many applications, such bars will not have sharp edges, but will be slightly fuzzy, and the sides will have significant and varying intensity gradient. Thus the actual intensity profile is quite likely to correspond reasonably closely to a true sinusoidal variation. We have found that intuitive designs of masks based on the above principles have proved very close to optimal when experimental tests are made. Figure 1 shows masks that have resulted from this type of design process for one specific value of R (2.5 pixels).

4 APPLICATION TO CEREAL INSPECTION

The application of machine vision methods in determining grain quality has been investigated by various workers in recent years [5]. Efforts have concentrated mainly on the determination of varietal purity [6], but limited capability for detection of foreign material [7] and damaged grains [8] has also been demonstrated. In addition, there is the need for a cheap commercial system which can detect insect infestations and other contaminants in grain. The inspection work described in this section has paid particular attention to this latter need.

While searching for methods for reliably locating contaminants in grain, thresholding initially seemed to be the approach offering the most promise, as so many contaminants are dark relative to the light brown colour of the grain. Dark contaminants that could be sought in this way included rodent droppings, moulds and adult insects. However, early successful tests on these lines showed that a good many false alarms would result from chaff and other permitted admixture, from less serious contaminants such as rapeseeds, and even from shadows between, and discolourations on, the grains themselves. In addition, insects present an especially serious threat, because they can multiply alarmingly in a short span of time, so greater certainty of detection is vital in this case. This meant that a considerably more discriminating method was required for locating adult insects. These considerations led to use of the linear feature detection approach for detecting small adult insects (Figure 2). This proved possible because these insects appear as dark objects with a linear (essentially bar-shaped) structure; hence attempts to detect them by applying bar-shaped masks led ultimately to a linear feature detector which had good sensitivity for a reasonable range of insect sizes.

The main class of insect which we targeted in our study was *Oryzaephilus surinamensis* (saw-toothed grain beetle): insects in this class approximated to rectangular bars of about 10×3 pixels, and masks of size 7×7 proved to be appropriate for identifying the pixels on the centrelines of these insects. In addition, the insects could appear in any orientation, so potentially quite a large number of template masks might be required: this would have the disadvantage that their sequential implementation would be highly computation intensive and not conducive to real-time operation. In view of this, it was decided to employ the vectorial approach to template matching, in which two orthogonal masks would be used as outlined in Sections 2 and 3 instead of the much larger number (typically four or eight) by a more conventional approach.

The output of the linear feature detector was taken to give the definitive insect signal and was thresholded to make decisions on the presence of any insects. This approach proved adequate for the location of small adult insects. Although it resulted in a small false negative rate of around 1 percent, all the cases observed (from a total set of 300 insects) corresponded to specific identifable problems, such as insects being viewed end on or being partly obscured by grains, or (in one instance) another species of insect, a grain weevil, emerging from a grain!

The procedure also led to a small proportion of false alarms in the proximity of dark grain boundaries, and especially in the region of shadow between two touching grain boundaries. Thus a specific detector was required to post-process the object field and eliminate such cases. There remained a much smaller number of false alarms due to chaff and other artefacts which simulated the appearance of insects: clearly any method of pattern recognition is unable to distinguish such artefacts from the intended type of object if the visual resemblance is too close. In this case, the only way of improving the recognition rate would have been to increase resolution by a factor of at least two, in which case the speed of recognition would have been reduced by a factor of about four (or equivalently the cost of any fast hardware accelerator would have been increased by a similar factor). Such system optimisation issues are beyond the scope of this paper. We merely remark that the linear feature detector procedures we have developed seem to meet the needs for a highly effective preliminary screening of the input images. Finally, we note that, unlike the case of edge detection, a suitable line detection strategy is to concentrate on the negative-going line-enhanced image: light lines do not correspond to any relevant types of contaminant.

5 CONCLUDING REMARKS

This paper has extended the vectorial strategy for designing line segment detection masks to larger windows, thereby permitting line segments to be detected and orientated efficiently with just two masks in a far greater number of applications than the original formulation. This work uses a theoretically based strategy which is backed up by experimental tests to ensure that it operates well in practical cases. Specifically, the masks have to be adapted to detect particular linear features (a) by adjusting their radii to match the widths of the linear features which are modelled as rectangular bars of constant width w; (b) by increasing sensitivity without seriously affecting discriminability by employing ring masks of greater than infinitesimal width. As for the earlier 3×3 masks described in [4], a full theoretical analysis is difficult, but this paper has shown that the situation is well understood, and experimental tests verify the effectiveness of this type of linear feature detector.

This work is expected to be useful in many applications where linear features have to be located, and those where thin lines have to be tracked: such applications range from fingerprint analysis to document interpretation, and cover many cases of industrial inspection including crack, scratch and fiducial line detection. Our own application has exemplified the value of these linear feature detectors for the purpose of insect location in grain: in that case 7×7 masks seemed well suited to the task.

Acknowledgement

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·	·	-1	-2	-1	·	·
·	·	-1	-2	-1	·	·
1	1	·	·	·	1	1
2	2	·	•	·	2	2
1	1	·	·	·	1	1
·	·	-1	-2	-1	·	·
·	·	-1	-2	-1	·	·

·	·	-1	·	1	·	·
·	-2	-2	·	2	2	·
-1	-2	·	·	·	2	1
·	·	·	•	·	·	·
1	2	·	·	·	-2	-1
·	2	2	·	-2	-2	·
·	·	1	·	-1	·	·

Figure 1 Typical (7×7) linear feature detection masks

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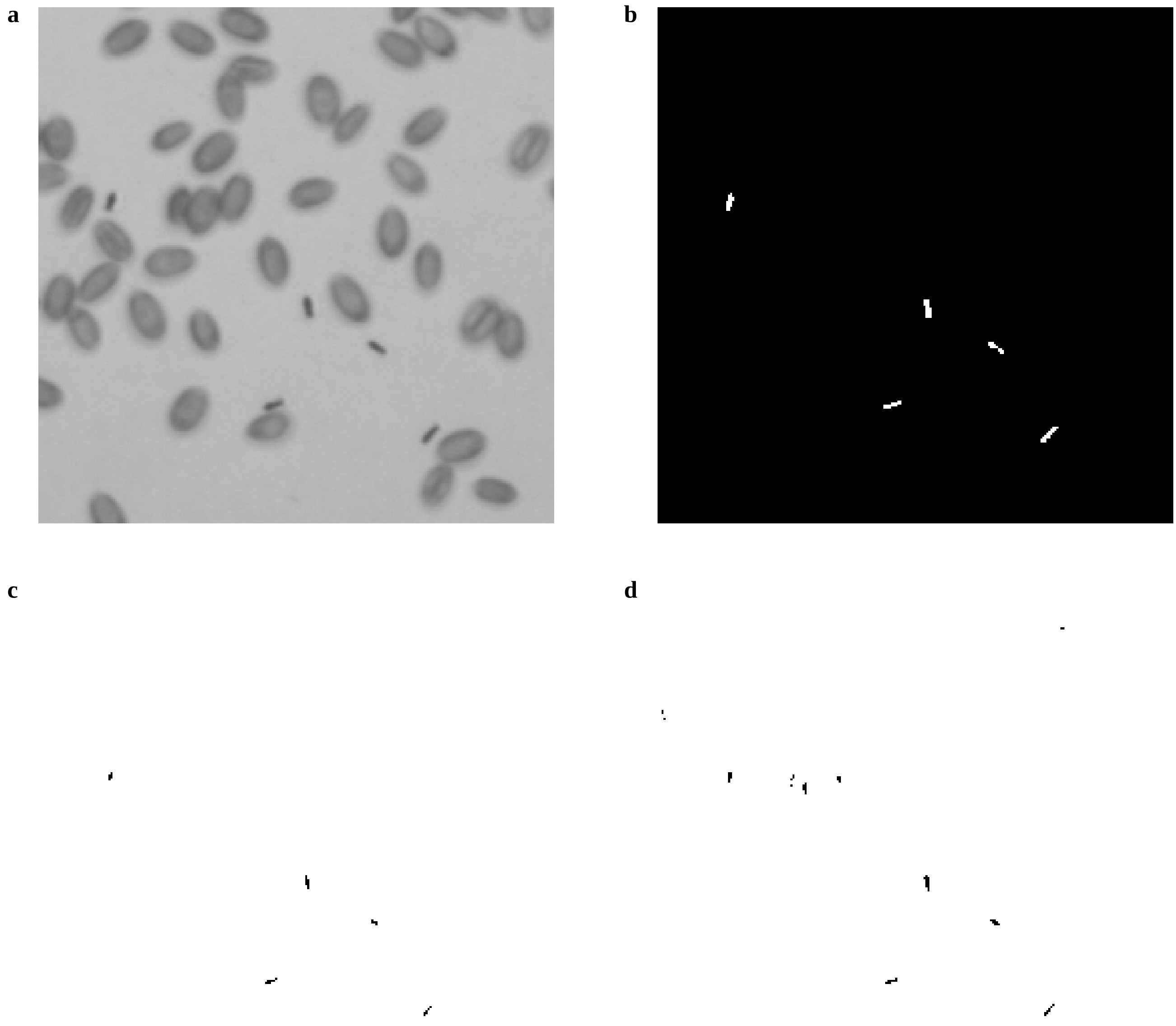

Figure 2 Insects located by linear feature detector. (a) Original image. (b) Result of applying linear feature detection algorithm. (c) Result of selecting optimum (minimum error) threshold level on (a). (d) Effect of small increase in threshold.