APPLICATION OF A BRIGHTNESS-ADAPTED EDGE DETECTOR FOR REAL-TIME RAILROAD TIE DETECTION IN VIDEO IMAGES

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ABSTRACT

Due to the increasing calculation power of dedicated hardware, real-time image processing becomes practicable at reasonable expenses. Nevertheless the algorithms concerned have to be adapted to real-time requirements. The subject treated in this paper is tie detection for automated railway inspection. An edge detector is proposed in which the sensitivity is adaptable to the local brightness of the processed image. The required effort is the performance of a convolution operation with subsequent decision concerning the sign of the values obtained.

1. INTRODUCTION

Image data are collected by a gray-scale high speed line camera mounted on an inspection vehicle (cf. figure 1). By
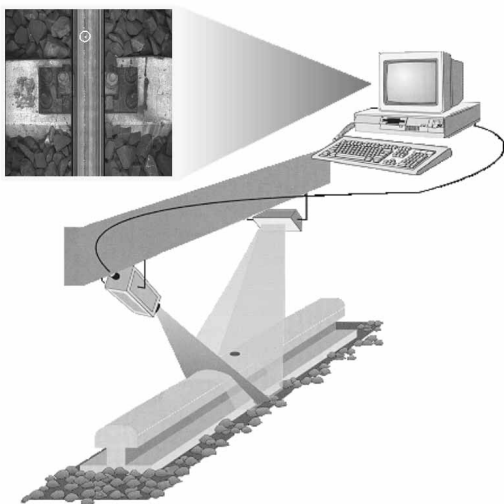

Figure 1: Video device (cf. [7])

the movement of the vehicle, image lines are combined to an image of the railway track. Furthermore the acquisition speed of this camera is adjusted to the vehicle speed to ensure equally spaced sampling. These images of the railway track are then evaluated by a subsequent calculating device in real time. Detection of faults on the rail and verification of fastenings have been dealt with in earlier investigations (cf. [1] [2]).

Faults may also appear on railroad ties. Automated fault detection will here be limited to the detection of splits or full breaks which look like wider splits. This is achievable by the application of an edge detection algorithm. Difficulties arise in connection with the recognition of the exact tie boundaries since these are supposed to be of unknown shape and material for the purpose of universal practicability. Ballast stones lying on or nearby the tie must not lead to the detection of splits. As the textures of the tie material and the ballast stones are not discernible locally, the commonly used method, calculating whether a pixel belongs to one of the groups "tie" or "ballast" by evaluation of its neighborhood, is not applicable here because of the large number of pixels to consider.

The process presented in this paper permits to detect ties independent of their shape and material. The concept behind that approach consists in an incomplete segmentation of the image by using an edge detection algorithm followed by connecting the resulting edge segments in a suitable manner. The ties are then be identified by their large surface, i.e. the segment size. This requires of course, that other large-surface objects have to be excluded or detected by other processes.

2. IMAGE ENHANCEMENT

Due to difficult illumination conditions, the images have at first to be quality-improved after their acquisition. Figure 2 shows a typical input image. In the first step, the contrast

Figure 2: Raw image data

of the image is enlarged by equalization of the histogram. The second step consists in illumination homogenization, making the image look as if it had been homogeneously illuminated. This is done by estimation of the illumination function and subsequent elimination of its influences. The improved image of figure 2 is shown in figure 3.

Figure 3: Image after histogram equalization and illumination homogenization

3. EDGE DETECTION

For incomplete segmentation of an image, edge detection algorithms are sufficient. These often treat the image as discretized function of two variables (x and y) and mark steep transitions in this function as edges. One of these algorithms is the Sobel operator where some kind of absolute value of the gradient is calculated. Positions where this value exceeds a threshold are marked as edge.

Other algorithms are based on the search for zero crossings of some kind of second order derivative of the image function which represent changes in its bending direction and hence the position of the most pronounced slopes locally. In this way the edges can be detected by application of the Laplace operator

$$\Delta f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2} \ .$$

Its sensitivity to high frequency noise makes it unusable for most applications (cf. [4] for more information on edge detection). An operator derived from this detection with the Laplace operator is the Marr-Hildreth operator. Prior to the application of the Laplace operator, the image is low-pass filtered to reduce high-frequency noise. An appropriate low-pass must provide for a narrow shaped impulse response and frequency response simultaneously in order to achieve exact boundary contours with a small-size operator. These requirements are met best by the Gaussian low-pass. These two operations are moreover fused to a Laplacian of Gaussian or shorter LoG filter. Impulse response and frequency response of a discrete LoG filter are shown in figure 4. The resulting operator is a band-pass which ideally suppresses the DC component of the image. After LoG filtering, the zero crossings e.g. the boundaries between positive and negative regions have to be marked.

D.Marr and E. Hildreth did not invent this operator with the purpose and intentions outlined in the foregoing, but in connection with investigations of the human visual system. It seems that, in the human retina, receptive cells are connected in a way that results in a LoG filtering operation(cf. [5]).
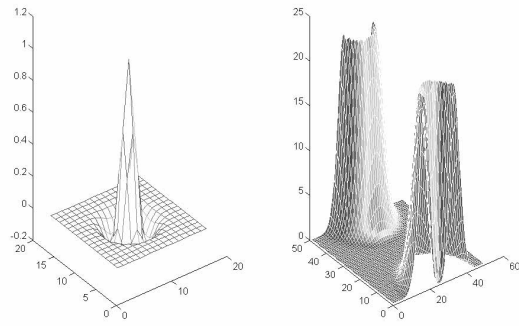

Figure 4: Impulse and frequency response of a 2-D 17x17 LoG filter (The frequency response is shifted for better visualization.)

4. PECULIARITIES OF EDGE DETECTORS

A closer look into the presented edge detection algorithms reveals some insufficiencies. The Sobel operator is unable to separate light and dark regions when the transition is not steep enough. The bending direction of the image function detected by the Laplacian leads to correct results only if the partial second order derivatives (in x and y direction) have the same sign. Partial second order derivatives with the same amount but with different signs could lead to a zero crossing. Another source of additional edges is depicted in figure 5. The test image is a gray-level image
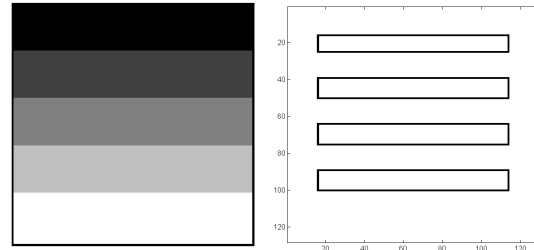

Figure 5: Test image and zero crossings resulting from LoG filtering (only valid pixels were calculated)

with levels rising in 4 steps, shown on the left. On the right, the edges detected by a Marr-Hildreth operator are shown (only valid pixels were evaluated). Obviously some of the detected edges do not exist in the image. These are the locations of saddle points in the low-pass filtered image, which lead to zero crossings too. Upon application of this operator thresholds are often introduced with the purpose of suppressing these edges. Only if the result of the LoG filter crosses the 0-plane with a sufficient slope, the zero crossing is marked as edge. Of course this method is not able to decide properly between slow-changing transitions and saddle points.

Another problem of the Marr-Hildreth operator arises when the infinitely extended LoG filter function has to be windowed in order to implement the operator. In this windowing, the LoG filter loses its property to completely suppress the DC component of the image signal, low-frequency components of the original image are added to the usual LoG filter result.

In case of an image representation by a matrix containing gray-level values from 0 for black to 255 for white, these additional components are weak in dark and strong in light regions where they lead to considerable consequences. This is illustrated in figure 6. The test image shown in the up-
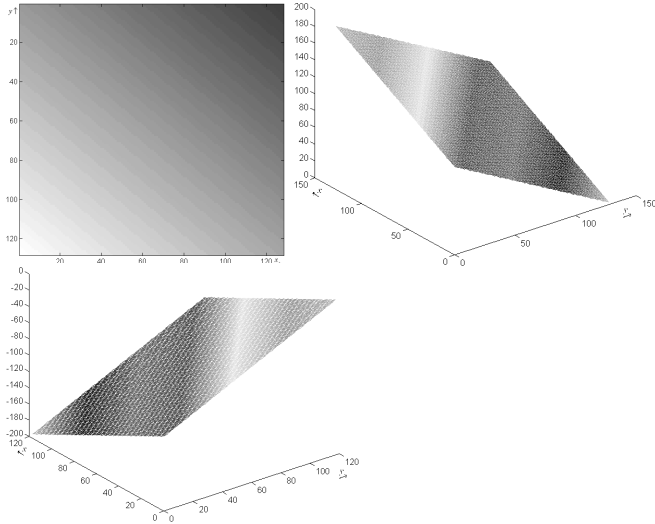
Figure 6: Test image with increasing gray level, three-dimensional representations of the image (top right) and windowed LoG filter result (lower left)

per left-hand corner is an increasing gray level in diagonal direction. Values range from 0 for black to 255 for white. In the top right-hand corner, its three-dimensional representation is given, a plane in three-dimensional space. As the LoG filter calculates second order derivatives, its result in filtering this image should be the 0-plane. The result obtained with a windowed LoG filter is shown at left, below. It is another plane but, this time, upside down. This is due to the negative sign of the windowed LoG filter applied, leading to a qualitative result which is the same plane as the input image, scaled by a factor.

This effect can be almost suppressed by cutting off fewer filter coefficients during the windowing process or by choosing a wider frequency pass band of the Gaussian to obtain a narrow LoG filter function.

The main advantage of the Sobel operator is its adjustability with respect to the steepness of detected edges via the threshold. The Marr-Hildreth operator leads to closed segments which simplifies the completion of the resulting edge segments even if one object is cut into several segments, same as with the saddle points. The effect of the added lower frequency components described above must be taken into account.

5. TIE BOUNDARY DETECTION

A favorable edge image for the boundary detection is one, where edges are few in the tie region and exist mainly in the ballast region. This is particularly difficult in images of wooden ties. As the wood grain leads to small but steep transitions in the image function, the edges in the resulting images are spread over the whole image.

The threshold of the Sobel operator can not be adjusted to suppress these disturbing edges on the tie. Too many edges in the ballast region are suppressed in order to obtain a nearly edge-free tie region.

The Marr-Hildreth operators Gaussian low-pass can be adjusted to suppress small perturbations but it is unable to suppress these steep transitions brought about by the wood grain. Hence none of these edge detectors is applicable in its usual form.

Further examinations show that the ballast region is often darker than the tie region. This originates in small shadows resulting from small spaces between the ballast stones. These shadows are even darker than the wood ties. With this knowledge, an algorithm can be applied which is more sensitive to edges in dark regions than in lighter ones. This kind of algorithm could be implemented by a Sobel operator with a threshold adapted to the brightness of the operators neighborhood. Exactly this kind of operator can be designed by application of a Marr-Hildreth operator with the described windowed LoG filter.

6. BRIGHTNESS ADAPTED EDGE DETECTION

The implementation of a brightness adapted edge detector exploiting the windowed LoG filter effect is illustrated in figure 7. The test image is depicted in the top left-hand
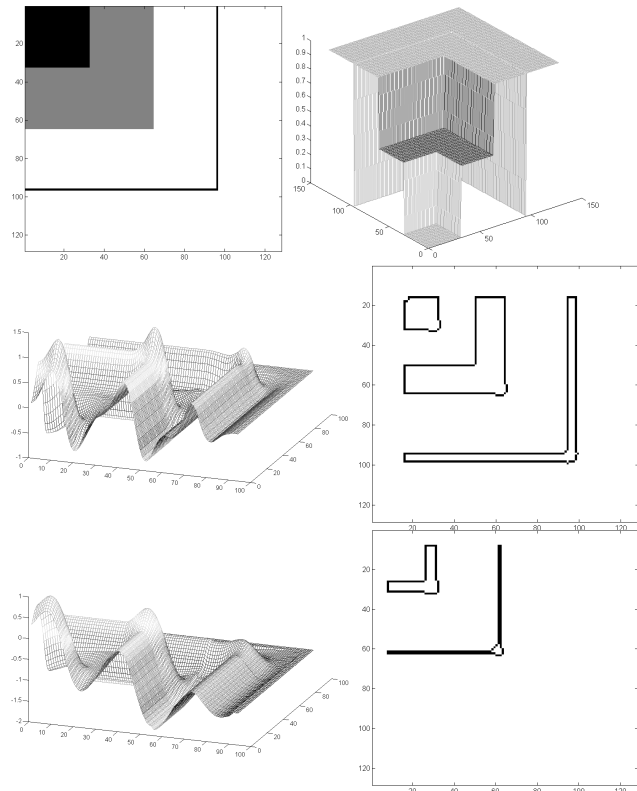
Figure 7: Comparison of usual (middle row) and windowed LoG filter (bottom row).

corner. It consists of three gray-level regions, white represented by 1, gray by 0.5 and black by 0. The white region

is intersected by a thin black line. This line represents the wood grain which is to be suppressed. The other edges have to be detected. In the top right-hand corner the test images three-dimensional representation is shown. The middle row shows the filter result of an (approximately) ideal LoG while the bottom row shows the result of a windowed LoG filter. The figure shows at left, the three-dimensional representation and, at right, the resulting zero crossings as boundary between positive and negative regions. Since only valid values of the convolution were considered, a frame of zeroes was added around the resulting edge matrix in order to keep the original image size.

Comparing the two three-dimensional filter results, the difference caused by the additional low-frequency components becomes clear. The result of the windowed LoG filter is "torn away" from the zero plane (into negative direction because of negative sign of the applied LoG filter). With this filter, the edges caused by the small line in the white region can be suppressed without suppressing any of the other edges.

This effect can be controlled by either the filter length or the passband of the Gaussian low pass since the relationship between these values influences the intensity of the cut-off effect. The Gaussian passband coefficient is the more handy one as it can be set up continuously.

The effect is dependent on image representation so that other values of brightness can be suppressed. By simple addition of a DC component, an unsuppressed brightness value can be adjusted. Other brightness values are influenced in dependence of their distance from the unsuppressed one. Further transformations than the simple addition of a constant value are conceivable.

With only one convolution operation, it is possible to implement an edge detector which is adaptable in its sensitivity to the brightness of the images pixel neighborhood.

With this operator, also wood ties become detectable.

Since the bending direction of the image function does not change inside the tie boundary (after the low-pass filtering), the whole regions instead of only their boundaries can be evaluated. In this way, the search for zero crossings can be replaced by a distinction between positive and negative regions. This is easily achievable by application of the sign of the pixel values. That leads to a further simplification of the algorithm. An image of a wooden tie filtered by a windowed LoG filter and subsequently binarized by application of the sign is shown in figure 8.
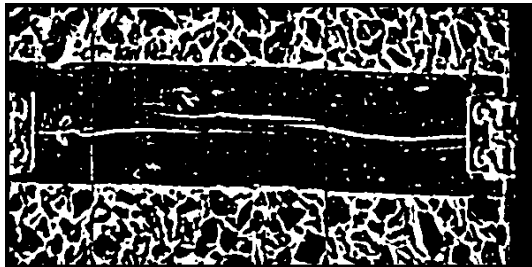

Figure 8: Edge segments resulting from a windowed LoG filter

7. EDGE CONNECTION

The tie region is still connected to other regions in the ballast. To cut these connections, morphological operations are used. This cut can be implemented by a dilation (cf. [6]) of the boundary segments (white in fig. 8) where an operation such as "let region grow" is applied. With this dilation the boundaries move exactly by the same amount of pixels which has served for region growth. Subsequently an erosion, preventing the cutting of regions is used. This kind of erosion is often called "thinning" (cf. [3]). This method permits the connection of most of the boundary segments. Figure 9 shows an image with detected boundary contour.

Figure 9: A detected boundary contour of a wooden tie

8. CONCLUSION

The presented algorithm permits the detection of edges with a sensitivity adaptable to brightness in only two steps. The first step is a convolution, the second one a simple distinction between positive and negative regions. For application for tie boundary detection purposes, this operator permits the real-time detection with a reasonable effort in terms of hardware.

9. REFERENCES

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